# Writing Device Drivers

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Part No: 816–4854–10
January 2005


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# Preface

*Writing Device Drivers* provides information on developing device drivers for character-oriented devices, block-oriented devices, and small computer system interface (SCSI) target devices. This book describes development of dynamically loadable and unloadable, multithreaded re-entrant device drivers that conform to the Solaris™ 10 Device Driver Interface and the Driver-Kernel Interface (DDI/DKI). A common driver development approach is taken to avoid platform-specific issues, such as *endianness* and data ordering.

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**Note –** This Solaris release supports systems that use the SPARC® and x86 families of processor architectures: UltraSPARC®, SPARC64, AMD64, Pentium, and Xeon EM64T. The supported systems appear in the *Solaris 10 Hardware Compatibility List* at `http://www.sun.com/bigadmin/hcl`. This document cites any implementation differences between the platform types.

In this document the term "x86" refers to 64-bit and 32-bit systems manufactured using processors compatible with the AMD64 or Intel Xeon/Pentium product families. For supported systems, see the *Solaris 10 Hardware Compatibility List*.

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## Who Should Use This Book

This book is written for UNIX® programmers who are familiar with UNIX device drivers. Overview information is provided, but the book is not intended to serve as a general tutorial on device drivers.

**Note –** The Solaris Operating System (Solaris OS) runs on two types of hardware, or platforms—SPARC and x86. The Solaris operating system also runs on both 64–bit and 32–bit address spaces. The information in this document pertains to both platforms and address spaces unless specifically noted.

# How This Book Is Organized

This book is organized into the following chapters.

- Chapter 1 provides an introduction to device drivers and associated entry points on the Solaris platform. The entry points for each device driver type are presented in tables.
- Chapter 2 provides an overview of the Solaris kernel with an explanation of how devices are represented as nodes in a device tree.
- Chapter 3 describes the aspects of the Solaris multithreaded kernel that are relevant for device driver developers.
- Chapter 4 describes the set of interfaces for using device properties.
- Chapter 5 describes how device drivers log events.
- Chapter 6 explains the support that a driver must provide for autoconfiguration.
- Chapter 7 describes the interfaces and methodologies for drivers to read or write to device memory.
- Chapter 8 describes the mechanisms for handling interrupts. These mechanisms include registering, servicing, and removing interrupts.
- Chapter 9 describes direct memory access (DMA) and the DMA interfaces.
- Chapter 10 describes interfaces for managing device and kernel memory.
- Chapter 11 describes the set of interfaces that enable device drivers to manage user access to devices.
- Chapter 12 explains the interfaces for Power Management™, a framework for managing power consumption.
- Chapter 13 describes the LDI, which enables kernel modules to access other devices in the system.
- Chapter 14 describes drivers for character-oriented devices.
- Chapter 15 describes drivers for a block-oriented devices.
- Chapter 16 outlines the Sun Common SCSI Architecture (SCSA) and the requirements for SCSI target drivers.
- Chapter 17 explains how to apply SCSA to SCSI Host Bus Adapter (HBA) drivers.

- Chapter 18 describes the Generic LAN driver (GLD), a Solaris network driver that uses STREAMS technology and the Data Link Provider Interface (DLPI).
- Chapter 19 describes how to write a client USB device driver using the USBA 2.0 framework.
- Chapter 20 provides information on compiling, linking, and installing a driver.
- Chapter 21 describes techniques for debugging, testing, and testing drivers.
- Chapter 22 describes the recommended coding practices for writing drivers.
- Appendix A discusses multi-platform hardware issues for device drivers.
- Appendix B provides tables of kernel functions for device drivers. Deprecated functions are indicated as well.
- Appendix C provides guidelines for updating a device driver to run in a 64-bit environment.

# Related Books and Papers

For detailed reference information about the device driver interfaces, see the man page sections 9, 9E, which handle entry points, 9F for functions, and 9S for structures.

For information on hardware and other driver-related issues, see these books from Sun Microsystems:

- The *Device Driver Tutorial* provides detailed explanations of working device driver examples.
- *Application Packaging Developer's Guide*, Sun Microsystems, Inc., 2004.
- *Open Boot PROM Toolkit User's Guide*, Sun Microsystems, Inc., 1996.
- *STREAMS Programming Guide*. Sun Microsystems, Inc., 2005.
- *Multithreaded Programming Guide*. Sun Microsystems, Inc., 2005.
- *Solaris 64-bit Developer's Guide*. Sun Microsystems, Inc., 2005.
- *Solaris Modular Debugger Guide*, Sun Microsystems, Inc., 2005.
- *Solaris Dynamic Tracing Guide*, Sun Microsystems, Inc., 2005.

The following books from other sources may also be useful.

- *The SPARC Architecture Manual, Version 9*. Prentice Hall, 1998. ISBN 0–13–099227–5.
- *The SPARC Architecture Manual, Version 8*. Prentice Hall, 1994. ISBN 0-13-825001-4.
- *Pentium Pro Family Developer's Manual, Volumes 1-3*. Intel Corporation, 1996. Volume 1, ISBN 1-55512-259-0; Volume 2, ISBN 1-55512-260-4; Volume 3, ISBN 1-55512-261-2.

## Related Third-Party Web Site References

Third-party URLs are referenced in this document and provide additional, related information.

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## Typographic Conventions

The following table describes the typographic changes that are used in this book.

**TABLE P–1** Typographic Conventions

| Typeface or Symbol | Meaning | Example |
|---|---|---|
| `AaBbCc123` | The names of commands, files, and directories, and onscreen computer output | Edit your `.login` file.<br>Use `ls -a` to list all files.<br>`machine_name% you have mail.` |
| **`AaBbCc123`** | What you type, contrasted with onscreen computer output | `machine_name%` **`su`**<br>`Password:` |
| *AaBbCc123* | Command-line placeholder: replace with a real name or value | The command to remove a file is `rm filename`. |
| *AaBbCc123* | Book titles, new terms or terms to be emphasized | Read Chapter 6 in the *User's Guide*.<br>Do *not* save the file. |

# Shell Prompts in Command Examples

The following table shows the default system prompt and superuser prompt for the C shell, Bourne shell, and Korn shell.

**TABLE P–2** Shell Prompts

| Shell | Prompt |
|---|---|
| C shell prompt | `machine_name%` |
| C shell superuser prompt | `machine_name#` |
| Bourne shell and Korn shell prompt | `$` |
| Bourne shell and Korn shell superuser prompt | `#` |

PART I

# Designing Device Drivers for the Solaris Platform

The first part of this manual provides general information for developing device drivers on the Solaris platform. This part includes the following chapters:

- Chapter 1 provides an introduction to device drivers and associated entry points on the Solaris platform. The entry points for each device driver type are presented in tables.
- Chapter 2 provides an overview of the Solaris kernel with an explanation of how devices are represented as nodes in a device tree.
- Chapter 3 describes the aspects of the Solaris multithreaded kernel that are relevant for device driver developers.
- Chapter 4 describes the set of interfaces for using device properties.
- Chapter 5 describes how device drivers log events.
- Chapter 6 explains the support that a driver must provide for autoconfiguration.
- Chapter 7 describes the interfaces and methodologies for drivers to read or write to device memory.
- Chapter 8 describes the mechanisms for handling interrupts. These mechanisms include registering, servicing, and removing interrupts.
- Chapter 9 describes direct memory access (DMA) and the DMA interfaces.
- Chapter 10 describes interfaces for managing device and kernel memory.
- Chapter 11 describes the set of interfaces that enable device drivers to manage user access to devices.
- Chapter 12 explains the interfaces for the Power Management™ feature, a framework for managing power consumption.
- Chapter 13 describes the LDI, which enables kernel modules to access other devices in the system.

CHAPTER 1

# Overview of Solaris Device Drivers

This chapter gives an overview of Solaris device drivers. The chapter provides information on the following subjects:



## Device Driver Basics

This section introduces you to device drivers and their entry points on the Solaris platform.

### What Is a Device Driver?

A *device driver* is a kernel module that is responsible for managing the low-level I/O operations of a hardware device. Device drivers are written with standard interfaces that the kernel can call to interface with a device. Device drivers can also be software-only, emulating a device that exists only in software, such as RAM disks, buses, and pseudo-terminals.

A device driver contains all the device-specific code necessary to communicate with a device. This code includes a standard set of interfaces to the rest of the system. This interface shields the kernel from device specifics just as the system call interface protects application programs from platform specifics. Application programs and the rest of the kernel need little, if any, device-specific code to address the device. In this way, device drivers make the system more portable and easier to maintain.

When the Solaris operating system (OS) is initialized, devices identify themselves and are organized into the *device tree*, a hierarchy of devices. In effect, the device tree is a hardware model for the kernel. An individual device driver is represented as a node in the tree with no children. This type of node is referred to as a *leaf driver*. A driver that provides services to other drivers is called a *bus nexus driver* and is shown as a node with children. As part of the boot process, physical devices are mapped to drivers in the tree so that the drivers can be located when needed. For more information on how the Solaris OS accommodates devices, see Chapter 2.

Device drivers are classified by how they handle I/O. Device drivers fall into three broad categories:

- **Block device drivers** – For cases where handling I/O data as asynchronous chunks is appropriate. Typically, block drivers are used to manage devices with physically addressable storage media, such as disks.
- **Character device drivers** – For devices that perform I/O on a continuous flow of bytes.

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  **Note –** A driver can be both block and character at the same time if you set up two different interfaces to the file system. See "Devices as Special Files" on page 53.

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  Included in the character category are drivers that use the STREAMS model (see below), programmed I/O, direct memory access, SCSI buses, USB, and other network I/O.
- **STREAMS device drivers** – Subset of character drivers that uses the `streamio`(7I) set of routines for character I/O within the kernel.

# What Is a Device Driver Entry Point?

An *entry point* is a function within a device driver that can be called by an external entity to get access to some driver functionality or to operate a device. Each device driver provides a standard set of functions as entry points. For the complete list of entry points for all driver types, see the `Intro`(9E) man page. The Solaris kernel uses entry points for these general task areas:

- **Loading and unloading the driver**
- **Autoconfiguring the device** – Autoconfiguration is the process of loading a device driver's code and static data into memory so that the driver is registered with the system.
- **Providing I/O services for the driver**

Drivers for different types of devices have different sets of entry points according to the kinds of operations the devices perform. A driver for a memory-mapped character-oriented device, for example, supports a `devmap`(9E) entry point, while a block driver does not support this entry.

By convention, all driver function and variable names have a prefix. Typically, this prefix is the name of the driver, such as `xxopen()` for the `open`(9E) routine of driver `xx`. In subsequent examples, `xx` is used as the driver prefix.

# Device Driver Entry Points

This section provides lists of entry points for the following categories:



## Entry Points Common to All Drivers

Some operations can be performed by any type of driver, such as the functions that are required for module loading and for the required autoconfiguration entry points. This section discusses types of entry points that are common to all drivers. The common entry points are listed in "Summary of Common Entry Points" on page 36 with links to man pages and other relevant discussions.

### Device Access Entry Points

Drivers for character and block devices export the `cb_ops`(9S) structure, which defines the driver entry points for block device access and character device access. Both types of drivers are required to support the `open`(9E) and `close`(9E) entry points. Block drivers are required to support `strategy`(9E), while character drivers can choose to implement whatever mix of `read`(9E), `write`(9E), `ioctl`(9E), `mmap`(9E), or `devmap`(9E) entry points is appropriate for the type of device. Character drivers can also support a polling interface through `chpoll`(9E). Asynchronous I/O is supported through `aread`(9E) and `awrite`(9E) for block drivers and those drivers that can use both block and character file systems.

### Loadable Module Entry Points

All drivers are required to implement the loadable module entry points `_init`(9E), `_fini`(9E), and `_info`(9E) to load, unload, and report information about the driver module.

Drivers should allocate and initialize any global resources in `_init`(9E). Drivers should release their resources in `_fini`(9E).

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**Note –** In the Solaris 10 operating system, only the loadable module routines must be visible outside the driver object module. Other routines can have the storage class `static`.

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## Autoconfiguration Entry Points

Drivers are required to implement the `attach`(9E), `detach`(9E), and `getinfo`(9E) entry points for device autoconfiguration. Drivers can also implement the optional entry point `probe`(9E) in cases where devices do not identify themselves during boot-up, such as SCSI target devices. See Chapter 6 for more information on these routines.

## Kernel Statistics Entry Points

The Solaris platform provides a rich set of interfaces to maintain and export kernel-level statistics, also known as *kstats*. Drivers are free to use these interfaces to export driver and device statistics that can be used by user applications to observe the internal state of the driver. Two entry points are provided for working with kernel statistics:

- `ks_snapshot`(9E) captures `kstats` at a specific time.
- `ks_update`(9E) can be used to update kstat data at will. `ks_update()` is useful in situations where a device is set up to track kernel data but extracting that data is time-consuming.

For further information, see the `kstat_create`(9F) and `kstat`(9S) man pages. See also "Kernel Statistics" on page 457.

## Power Management Entry Point

Drivers for hardware devices that provide Power Management functionality can support the optional `power`(9E) entry point. See Chapter 12 for details about this entry point.

## Summary of Common Entry Points

The following table lists entry points that can be used by all types of drivers.

**TABLE 1–1** Entry Points for All Driver Types

| Category / Entry Point | Usage | Description |
|---|---|---|
| `cb_ops` **Entry Points** | | |
| `open`(9E) | Required | Gets access to a device. Additional information:<br>■ "`open()` Entry Point (Character Drivers)" on page 230<br>■ "`open()` Entry Point (Block Drivers)" on page 259 |
| `close`(9E) | Required | Gives up access to a device. The version of `close()` for STREAMS drivers has a different signature than character and block drivers. Additional information:<br>■ "`close()` Entry Point (Character Drivers)" on page 232<br>■ "`close()` Entry Point (Block Drivers)" on page 260 |
| **Loadable Module Entry Points** | | |
| `_init`(9E) | Required | Initializes a loadable module. Additional information:<br>■ "Loadable Driver Interfaces" on page 91 |
| `_fini`(9E) | Required | Prepares a loadable module for unloading. Required for all driver types. Additional information:<br>■ "Loadable Driver Interfaces" on page 91 |
| `_info`(9E) | Required | Returns information about a loadable module. Additional information:<br>■ "Loadable Driver Interfaces" on page 91 |
| **Autoconfiguration Entry Points** | | |
| `attach`(9E) | Required | Adds a device to the system as part of initialization. Also used to resume a system that has been suspended. Additional information:<br>■ "`attach()` Entry Point" on page 99 |
| `detach`(9E) | Required | Detaches a device from the system. Also, used to suspend a device temporarily. Additional information:<br>■ "`detach()` Entry Point" on page 104 |
| `getinfo`(9E) | Required | Gets device information that is specific to the driver, such as the mapping between a device number and the corresponding instance. Additional information:<br>■ "`getinfo()` Entry Point" on page 106<br>■ "`getinfo()` Entry Point (SCSI Target Drivers)" on page 288. |
| `probe`(9E) | See Description | Determines if a non-self-identifying device is present. Required for a device that cannot identify itself. Additional information:<br>■ "`probe()` Entry Point" on page 96<br>■ "`probe()` Entry Point (SCSI Target Drivers)" on page 283 |
| **Kernel StatisticsEntry Points** | | |

**TABLE 1–1** Entry Points for All Driver Types *(Continued)*

| Category / Entry Point | Usage | Description |
|---|---|---|
| `ks_snapshot`(9E) | Optional | Takes a snapshot of `kstat`(9S) data. Additional information:<br>■ "Kernel Statistics" on page 457 |
| `ks_update`(9E) | Optional | Updates `kstat`(9S) data dynamically. Additional information:<br>■ "Kernel Statistics" on page 457 |
| **Power Management Entry Points** | | |
| `power`(9E) | Required | Sets the power level of a device. If not used, set to NULL. Additional information:<br>■ "`power()` Entry Point" on page 185 |
| **Miscellaneous Entry Points** | | |
| `prop_op`(9E) | See Description | Reports driver property information. Required unless `ddi_prop_op`(9F) is substituted. Additional information:<br>■ "Creating and Updating Properties" on page 74<br>■ "`prop_op()` Entry Point" on page 76 |
| `dump`(9E) | See Description | Dumps memory to a device during system failure. Required for any device that is to be used as the dump device during a panic. Additional information:<br>■ "`dump()` Entry Point (Block Drivers)" on page 272<br>■ "Dump Handling" on page 297 |
| `identify`(9E) | Deprecated | Determines whether a driver is associated with a specific device. This function should no longer be used. `nulldev`(9F) should be assigned to this entry point in the `dev_ops` structure. |

# Entry Points for Block Device Drivers

Devices that support a file system are known as *block devices*. Drivers written for these devices are known as block device drivers. Block device drivers take a file system request, in the form of a `buf`(9S) structure, and issue the I/O operations to the disk to transfer the specified block. The main interface to the file system is the `strategy`(9E) routine. See Chapter 15 for more information.

A block device driver can also provide a character driver interface to allow utility programs to bypass the file system and to access the device directly. This device access is commonly referred to as the *raw* interface to a block device.

The following table lists additional entry points that can be used by block device drivers. See also "Entry Points Common to All Drivers" on page 35.

**TABLE 1–2** Additional Entry Points for Block Drivers

| Entry Point | Usage | Description |
|---|---|---|
| `aread`(9E) | Optional | Performs an asynchronous read. Drivers that do not support an `aread()` entry point should use the `nodev`(9F) error return function. Additional information:<br>■ "Differences Between Synchronous and Asynchronous I/O" on page 235<br>■ "DMA Transfers (Asynchronous)" on page 238 |
| `awrite`(9E) | Optional | Performs an asynchronous write. Drivers that do not support an `awrite()` entry point should use the `nodev`(9F) error return function. Additional information:<br>■ "Differences Between Synchronous and Asynchronous I/O" on page 235<br>■ "DMA Transfers (Asynchronous)" on page 238 |
| `print`(9E) | Required | Displays a driver message on the system console. Additional information:<br>■ "`print()` Entry Point (Block Drivers)" on page 272 |
| `strategy`(9E) | Required | Perform block I/O. Additional information:<br>■ "Canceling DMA Callbacks" on page 146<br>■ "DMA Transfers (Synchronous)" on page 237<br>■ "`strategy()` Entry Point" on page 240<br>■ "DMA Transfers (Asynchronous)" on page 238<br>■ "General Flow of Control" on page 277<br>■ "x86 Target Driver Configuration Properties" on page 352 |

# Entry Points for Character Device Drivers

Character device drivers normally perform I/O in a byte stream. Examples of devices that use character drivers include tape drives and serial ports. Character device drivers can also provide additional interfaces not present in block drivers, such as I/O control (`ioctl`) commands, memory mapping, and device polling. See Chapter 14 for more information.

The main task of any device driver is to perform I/O, and many character device drivers do what is called *byte-stream* or *character* I/O. The driver transfers data to and from the device without using a specific device address. This type of transfer is in contrast to block device drivers, where part of the file system request identifies a specific location on the device.

The `read`(9E) and `write`(9E) entry points handle byte-stream I/O for standard character drivers. See "I/O Request Handling" on page 232 for more information.

The following table lists additional entry points that can be used by character device drivers. For other entry points, see "Entry Points Common to All Drivers" on page 35.

**TABLE 1–3** Additional Entry Points for Character Drivers

| Entry Point | Usage | Description |
|---|---|---|
| `chpoll`(9E) | Optional | Polls events for a non-STREAMS character driver. Additional information:<br>■ "Multiplexing I/O on File Descriptors" on page 243 |
| `ioctl`(9E) | Optional | Performs a range of I/O commands for character drivers. `ioctl()` routines must make sure that user data is copied into or out of the kernel address space explicitly using `copyin`(9F), `copyout`(9F), `ddi_copyin`(9F), and `ddi_copyout`(9F), as appropriate. Additional information:<br>■ "`ioctl()` Entry Point (Character Drivers)" on page 246<br>■ "Implemented `ioctl` Functions" on page 360<br>■ "Well-known `ioctl` Interfaces" on page 530 |
| `read`(9E) | Required | Reads data from a device. Additional information:<br>■ "Vectored I/O" on page 233<br>■ "Differences Between Synchronous and Asynchronous I/O" on page 235<br>■ "Programmed I/O Transfers" on page 236<br>■ "DMA Transfers (Synchronous)" on page 237<br>■ "General Flow of Control" on page 277 |
| `segmap`(9E) | Optional | Maps device memory into user space. Additional information:<br>■ "`segmap()` Entry Point" on page 242<br>■ "Allocating Kernel Memory for User Access" on page 157<br>■ "Associating User Mappings With Driver Notifications" on page 174 |
| `write`(9E) | Required | Writes data to a device. Additional information:<br>■ "Device Access Functions" on page 115<br>■ "Vectored I/O" on page 233<br>■ "Differences Between Synchronous and Asynchronous I/O" on page 235<br>■ "Programmed I/O Transfers" on page 236<br>■ "DMA Transfers (Synchronous)" on page 237<br>■ "General Flow of Control" on page 277 |

# Entry Points for STREAMS Device Drivers

STREAMS is a separate programming model for writing a character driver. Devices that receive data asynchronously, such as terminal and network devices, are suited to a STREAMS implementation. STREAMS device drivers must provide the loading and autoconfiguration support described in Chapter 6. See the *STREAMS Programming Guide* for additional information on how to write STREAMS drivers.

The following table lists additional entry points that can be used by STREAMS device drivers. For other entry points, see "Entry Points Common to All Drivers" on page 35 and "Entry Points for Character Device Drivers" on page 39.

**TABLE 1–4** Entry Points for STREAMS Drivers

| Entry Point | Usage | Description |
|---|---|---|
| `put`(9E) | See Description | Coordinates the passing of messages from one queue to the next queue in a stream. Required, except for the side of the driver that reads data. Additional information:<br>■ *STREAMS Programming Guide* |
| `srv`(9E) | Required | Manipulate messages in a queue. Additional information:<br>■ *STREAMS Programming Guide* |

# Entry Points for Memory Mapped Devices

For certain devices, such as frame buffers, providing application programs with direct access to device memory is more efficient than byte-stream I/O. Applications can map device memory into their address spaces using the `mmap`(2) system call. To support memory mapping, device drivers implement `segmap`(9E) and `devmap`(9E) entry points. For information on `devmap`(9E), see Chapter 10. For information on `segmap`(9E), see Chapter 14.

Drivers that define the `devmap`(9E) entry point usually do not define `read`(9E) and `write`(9E) entry points, because application programs perform I/O directly to the devices after calling `mmap`(2).

The following table lists additional entry points that can be used by character device drivers that use the `devmap` framework to perform memory mapping. For other entry points, see "Entry Points Common to All Drivers" on page 35 and "Entry Points for Character Device Drivers" on page 39.

**TABLE 1–5** Entry Points for Character Drivers That Use `devmap` for Memory Mapping

| Entry Point | Usage | Description |
|---|---|---|
| `devmap`(9E) | Required | Validates and translates virtual mapping for a memory-mapped device. Additional information:<br>■ "Exporting the Mapping" on page 153 |
| `devmap_access`(9E) | Optional | Notifies drivers when an access is made to a mapping with validation or protection problems. Additional information:<br>■ "`devmap_access()` Entry Point" on page 168 |

**TABLE 1–5** Entry Points for Character Drivers That Use `devmap` for Memory Mapping *(Continued)*

| Entry Point | Usage | Description |
|---|---|---|
| `devmap_contextmgt`(9E) | Required | Performs device context switching on a mapping. Additional information:<br>■ "`devmap_contextmgt()` Entry Point" on page 169 |
| `devmap_dup`(9E) | Optional | Duplicates a device mapping. Additional information:<br>■ "`devmap_dup()` Entry Point" on page 171 |
| `devmap_map`(9E) | Optional | Creates a device mapping. Additional information:<br>■ "`devmap_map()` Entry Point" on page 166 |
| `devmap_unmap`(9E) | Optional | Cancels a device mapping. Additional information:<br>■ "`devmap_unmap()` Entry Point" on page 172 |

# Entry Points for the Generic LAN Device (GLD) Driver

The following table lists additional entry points that can be used by the general LAN driver (GLD). For more information on GLD drivers, see the `gld`(9E), `gld`(7D), and `gld_mac_info`(9S) man pages. For other entry points, see "Entry Points Common to All Drivers" on page 35 and "Entry Points for Character Device Drivers" on page 39.

**TABLE 1–6** Additional Entry Points for the Generic LAN Driver

| Entry Point | Usage | Description |
|---|---|---|
| `gldm_get_stats`(9E) | Optional | Gathers statistics from private counters in a generic LAN driver. Updates the `gld_stats`(9S) structure. Additional information:<br>■ "`gldm_get_stats()` Entry Point" on page 375 |
| `gldm_intr`(9E) | See Description | Receives calls for potential interrupts to a generic LAN driver (GLD). Required if `gld_intr`(9F) is used as interrupt handler. Additional information:<br>■ "`gldm_intr()` Entry Point" on page 374 |
| `gldm_ioctl`(9E) | Optional | Implements device-specific commands for a generic LAN driver (GLD). Additional information:<br>■ "`gldm_ioctl()` Entry Point" on page 375 |
| `gldm_reset`(9E) | Required | Resets a generic LAN driver (GLD) to the initial state. Additional information:<br>■ "`gldm_reset()` Entry Point" on page 372 |
| `gldm_send`(9E) | Required | Queues a packet to a generic LAN driver (GLD) for transmission. Additional information:<br>■ "`gldm_send()` Entry Point" on page 374 |

**TABLE 1–6** Additional Entry Points for the Generic LAN Driver *(Continued)*

| Entry Point | Usage | Description |
|---|---|---|
| `gldm_set_mac_addr`(9E) | Required | Sets the physical address that the generic LAN driver (GLD) uses to receive data. Additional information:<br>■ "`gldm_set_mac_addr()` Entry Point" on page 372 |
| `gldm_set_multicast`(9E) | Optional | Enables and disables device-level reception of specific multicast addresses for generic LAN driver (GLD). Additional information:<br>■ "`gldm_set_multicast()` Entry Point" on page 372 |
| `gldm_set_promiscuous`(9E) | Required | Enables and disables promiscuous mode for a generic LAN driver (GLD) to receive packets on the medium. Additional information:<br>■ "`gldm_set_promiscuous()` Entry Point" on page 373 |
| `gldm_start`(9E) | Required | Enables a generic LAN driver (GLD) to generate interrupts. Prepares the driver to call `gld_recv`(9F) to deliver received data packets. Additional information:<br>■ "`gldm_start()` Entry Point" on page 372 |
| `gldm_stop`(9E) | Required | Disables a generic LAN driver (GLD) from generating interrupts and from calling `gld_recv`(9F). Additional information:<br>■ "`gldm_stop()` Entry Point" on page 372 |

# Entry Points for SCSI HBA Drivers

The following table lists additional entry points that can be used by SCSI HBA device drivers. For information on the SCSI HBA transport structure, see `scsi_hba_tran`(9S). For other entry points, see "Entry Points Common to All Drivers" on page 35 and "Entry Points for Character Device Drivers" on page 39.

**TABLE 1–7** Additional Entry Points for SCSI HBA Drivers

| Entry Point | Usage | Description |
|---|---|---|
| `tran_abort`(9E) | Required | Aborts a specified SCSI command that has been transported to a SCSI Host Bus Adapter (HBA) driver. Additional information:<br>■ "`tran_abort()` Entry Point" on page 347 |
| `tran_bus_reset`(9e) | Optional | Resets a SCSI bus. Additional information:<br>■ "`tran_bus_reset()` Entry Point" on page 347 |
| `tran_destroy_pkt`(9E) | Required | Frees resources that are allocated for a SCSI packet. Additional information:<br>■ "`tran_destroy_pkt()` Entry Point" on page 333 |
| `tran_dmafree`(9E) | Required | Frees DMA resources that have been allocated for a SCSI packet. Additional information:<br>■ "`tran_dmafree()` Entry Point" on page 334 |

**TABLE 1–7** Additional Entry Points for SCSI HBA Drivers *(Continued)*

| Entry Point | Usage | Description |
|---|---|---|
| `tran_getcap`(9E) | Required | Gets the current value of a specific capability that is provided by the HBA driver. Additional information:<br>■ "`tran_getcap()` Entry Point" on page 341 |
| `tran_init_pkt`(9E) | Required | Allocate and initialize resources for a SCSI packet. Additional information:<br>■ "Resource Allocation" on page 325 |
| `tran_quiesce`(9e) | Optional | Stop all activity on a SCSI bus, typically for dynamic reconfiguration. Additional information:<br>■ "Dynamic Reconfiguration" on page 349 |
| `tran_reset`(9E) | Required | Resets a SCSI bus or target device. Additional information:<br>■ "`tran_reset()` Entry Point" on page 347 |
| `tran_reset_notify`(9E) | Optional | Requests notification of a SCSI target device for a bus reset. Additional information:<br>■ "`tran_reset_notify()` Entry Point" on page 348 |
| `tran_setcap`(9E) | Required | Sets the value of a specific capability that is provided by the SCSI HBA driver. Additional information:<br>■ "`tran_setcap()` Entry Point" on page 344 |
| `tran_start`(9E) | Required | Requests the transport of a SCSI command. Additional information:<br>■ "`tran_start()` Entry Point" on page 335 |
| `tran_sync_pkt`(9E) | Required | Synchronizes the view of data by an HBA driver or device. Additional information:<br>■ "`tran_sync_pkt()` Entry Point" on page 333 |
| `tran_tgt_free`(9E) | Optional | Requests allocated SCSI HBA resources to be freed on behalf of a target device. Additional information:<br>■ "`tran_tgt_free()` Entry Point" on page 324<br>■ "Transport Structure Cloning" on page 312 |
| `tran_tgt_init`(9E) | Optional | Requests SCSI HBA resources to be initialized on behalf of a target device. Additional information:<br>■ "`tran_tgt_init()` Entry Point" on page 323<br>■ "`scsi_device` Structure" on page 308 |
| `tran_tgt_probe`(9E) | Optional | Probes a specified target on a SCSI bus. Additional information:<br>■ "`tran_tgt_probe()` Entry Point" on page 324 |
| `tran_unquiesce`(9e) | Optional | Resumes I/O activity on a SCSI bus after `tran_quiesce`(9e) has been called, typically for dynamic reconfiguration. Additional information:<br>■ "Dynamic Reconfiguration" on page 349 |

## Entry Points for PC Card Drivers

The following table lists additional entry points that can be used by PC Card device drivers. For other entry points, see "Entry Points Common to All Drivers" on page 35 and "Entry Points for Character Device Drivers" on page 39.

**TABLE 1–8** Entry Points for PC Card Drivers Only

| Entry Point | Usage | Description |
|---|---|---|
| `csx_event_handler`(9E) | Required | Handles events for a PC Card driver. The driver must call the `csx_RegisterClient`(9F) function explicitly to set the entry point instead of using a structure field like `cb_ops`. |

# Considerations in Device Driver Design

Device driver must be compatible with the Solaris Operating System, both as a consumer and provider of services. This section discusses the following issues, which should be considered in device driver design:



## DDI/DKI Facilities

The DDI/DKI interfaces are provided for driver portability. With DDI/DKI, developers can write driver code in a standard fashion without having to worry about hardware or platform differences. This section describes aspects of the DDI/DKI interfaces.

### Device IDs

The Solaris DDI interfaces enable drivers to provide a persistent, unique identifier for a device. The device ID can be used to identify or locate a device. The ID is independent of the device's name or number (`dev_t`). Applications can use the functions defined in `libdevid`(3LIB) to read and manipulate the device IDs registered by the drivers.

## Device Properties

The attributes of a device or device driver are specified by *properties*. A property is a name-value pair. The name is a string that identifies the property with an associated value. Properties can be defined by the FCode of a self-identifying device, by a hardware configuration file (see the `driver.conf`(4) man page), or by the driver itself using the `ddi_prop_update`(9F) family of routines.

## Interrupt Handling

The Solaris 10 DDI/DKI addresses these aspects of device interrupt handling:

- Registering device interrupts with the system
- Removing device interrupts
- Dispatching interrupts to interrupt handlers

Device interrupt sources are contained in a property called *interrupt*, which is either provided by the PROM of a self-identifying device, in a hardware configuration file, or by the booting system on the x86 platform.

## Callback Functions

Certain DDI mechanisms provide a *callback* mechanism. DDI functions provide a mechanism for scheduling a callback when a condition is met. Callback functions can be used for the following typical conditions:

- A transfer has completed
- A resource has become available
- A time-out period has expired

Callback functions are somewhat similar to entry points, for example, interrupt handlers. DDI functions that allow callbacks expect the callback function to perform certain tasks. In the case of DMA routines, a callback function must return a value indicating whether the callback function needs to be rescheduled in case of a failure.

Callback functions execute as a separate interrupt thread. Callbacks must handle all the usual multithreading issues.

---

**Note –** A driver must cancel all scheduled callback functions before detaching a device.

---

## Software State Management

To assist device driver writers in allocating state structures, the Solaris 10 DDI/DKI provides a set of memory management routines called the *software state management routines*, also known as the *soft-state routines*. These routines dynamically allocate,

retrieve, and destroy memory items of a specified size, and hide the details of list management. An *instance number* is used to identify the desired memory item. This number is typically the instance number assigned by the system.

Routines are provided for the following tasks:

- Initialize a driver's soft-state list
- Allocate space for an instance of a driver's soft state
- Retrieve a pointer to an instance of a driver's soft state
- Free the memory for an instance of a driver's soft state
- Finish using a driver's soft-state list

See "Loadable Driver Interfaces" on page 91 for an example of how to use these routines.

## Programmed I/O Device Access

Programmed I/O device access is the act of reading and writing of device registers or device memory by the host CPU. The Solaris DDI provides interfaces for mapping a device's registers or memory by the kernel as well as interfaces for reading and writing to device memory from the driver. These interfaces enable drivers to be developed that are platform and bus independent, by automatically managing any difference in device and host endianness as well as by enforcing any memory-store sequence requirements imposed by the device.

## Direct Memory Access (DMA)

The Solaris platform defines a high-level, architecture-independent model for supporting DMA-capable devices. The Solaris DDI shields drivers from platform-specific details. This concept enables a common driver to run on multiple platforms and architectures.

## Layered Driver Interfaces

The DDI/DKI provides a group of interfaces referred to as layered device interfaces (LDI). These interfaces enable a device to be accessed from within the Solaris kernel. This capability enables developers to write applications that observe kernel device usage. For example, both the `prtconf`(1M) and `fuser`(1M) commands use LDI to enable system administrators to track aspects of device usage. The LDI is covered in more detail in Chapter 13.

# Driver Context

The driver context refers to the condition under which a driver is currently operating. The context limits the operations that a driver can perform. The driver context depends on the executing code that is invoked. Driver code executes in four contexts:

- **User context**. A driver entry point has *user context* when invoked by a user thread in a synchronous fashion. That is, the user thread waits for the system to return from the entry point that was invoked. For example, the `read`(9E) entry point of the driver has user context when invoked by a `read`(2) system call. In this case, the driver has access to the user area for copying data into and out of the user thread.
- **Kernel context**. A driver function has *kernel context* when invoked by some part of the kernel. In a block device driver, the `strategy`(9E) entry point can be called by the `pageout` daemon to write pages to the device. Because the page daemon has no relation to the current user thread, `strategy`(9E) has kernel context in this case.
- **Interrupt context**.*Interrupt context* is a more restrictive form of kernel context. Interrupt context is invoked as a result of the servicing of an interrupt. Driver interrupt routines operate in interrupt context with an associated interrupt level. Callback routines also operate in an interrupt context. See Chapter 8 for more information.
- **High—level interrupt context**.*High-level interrupt context* is a more restricted form of interrupt context. If `ddi_intr_hilevel`(9F) indicates that an interrupt is high level, the driver interrupt handler runs in high-level interrupt context. See Chapter 8 for more information.

The manual pages in section 9F document the allowable contexts for each function. For example, in kernel context the driver must not call `copyin`(9F).

# Returning Errors

Device drivers do not usually print message, except for unexpected errors such as data corruption. Instead, the driver entry points should return error codes so that the application can determine how to handle the error. The driver should use `cmn_err`(9F) to print any messages. The `cmn_err()` function is similar to the C function `printf`(3C), which prints to the console, to the message buffer, or both.

The `format` string specifier interpreted by `cmn_err`(9F) is similar to the `printf`(3C) format string, with the addition of the format `%b`, which prints bit fields. The first character of the format string can have a special meaning. Callers to `cmn_err`(9F) also specify the `level`, which indicates the label to be printed. See the `cmn_err`(9F) man page for more details.

The level `CE_PANIC` has the side effect of crashing the system. This level should be used only if the system is in such an unstable state that to continue would cause more problems. The level can also be used to get a system core dump when debugging. `CE_PANIC` should not be used in production device drivers.

# Dynamic Memory Allocation

Device drivers must be prepared to simultaneously handle all attached devices that the drivers claim to drive. The number of devices that the driver handles should not be limited. All per-device information must be dynamically allocated.

```
void *kmem_alloc(size_t size, int flag);
```

The standard kernel memory allocation routine is `kmem_alloc`(9F). `kmem_alloc()` is similar to the C library routine `malloc`(3C), with the addition of the `flag` argument. The `flag` argument can be either `KM_SLEEP` or `KM_NOSLEEP`, indicating whether the caller is willing to block if the requested size is not available. If `KM_NOSLEEP` is set and memory is not available, `kmem_alloc`(9F) returns `NULL`.

`kmem_zalloc`(9F) is similar to `kmem_alloc`(9F), but also clears the contents of the allocated memory.

---

**Note –** Kernel memory is a limited resource, not pageable, and competes with user applications and the rest of the kernel for physical memory. Drivers that allocate a large amount of kernel memory can cause system performance to degrade.

---

```
void kmem_free(void *cp, size_t size);
```

Memory allocated by `kmem_alloc`(9F) or by `kmem_zalloc`(9F) is returned to the system with `kmem_free`(9F). `kmem_free()` is similar to the C library routine `free`(3C), with the addition of the `size` argument. Drivers *must* keep track of the size of each allocated object in order to call `kmem_free`(9F) later.

# Hotplugging

This manual does not highlight hotplugging information. If you follow the rules and suggestions for writing device drivers given in this book, your driver should be able to handle hotplugging. In particular, make sure that both autoconfiguration (see Chapter 6) and `detach`(9E) work correctly in your driver. In addition, if you are designing a driver that uses power management, you should follow the information given in Chapter 12. SCSI HBA drivers may need to add a `cb_ops` structure to their `dev_ops` structure (see Chapter 17) to take advantage of hotplugging capabilities.

Previous versions of the Solaris Operating System required hotpluggable drivers to include a `DT_HOTPLUG` property, but this property is no longer required. Driver writers are free, however, to include and use the `DT_HOTPLUG` property as they see fit.

For more information, visit `http://developers.sun.com/prodtech/solaris/driverdev/reference/docs/index.htm` which contains links to hotplugging white papers.

CHAPTER 2

# Solaris Kernel and Device Tree

A device driver needs to work transparently as an integral part of the operating system. Understanding how the kernel works is a prerequisite for learning about device drivers. This chapter provides an overview of the Solaris kernel and device tree. For an overview of how device drivers work, see Chapter 1.

This chapter provides information on the following subjects:



## What Is the Kernel?

The Solaris kernel is a program that manages system resources. The kernel insulates applications from the system hardware and provides them with essential system services such as input/output (I/O) management, virtual memory, and scheduling. The kernel consists of object modules that are dynamically loaded into memory when needed.

The Solaris kernel can be divided logically into two parts: the first part, referred to as the *kernel*, manages file systems, scheduling, and virtual memory. The second part, referred to as the *I/O subsystem*, manages the physical components.

The kernel provides a set of interfaces for applications to use that are accessible through *system calls*. System calls are documented in the *Solaris 9 Reference Manual Collection* (see `Intro`(2)). Some system calls are used to invoke device drivers to

perform I/O. *Device drivers* are loadable kernel modules that manage data transfers while insulating the rest of the kernel from the device hardware. To be compatible with the operating system, device drivers need to be able to accommodate such features as multithreading, virtual memory addressing, and both 32–bit and 64–bit operation.

The following figure illustrates the kernel. The kernel modules handle system calls from application programs. The I/O modules communicate with hardware.

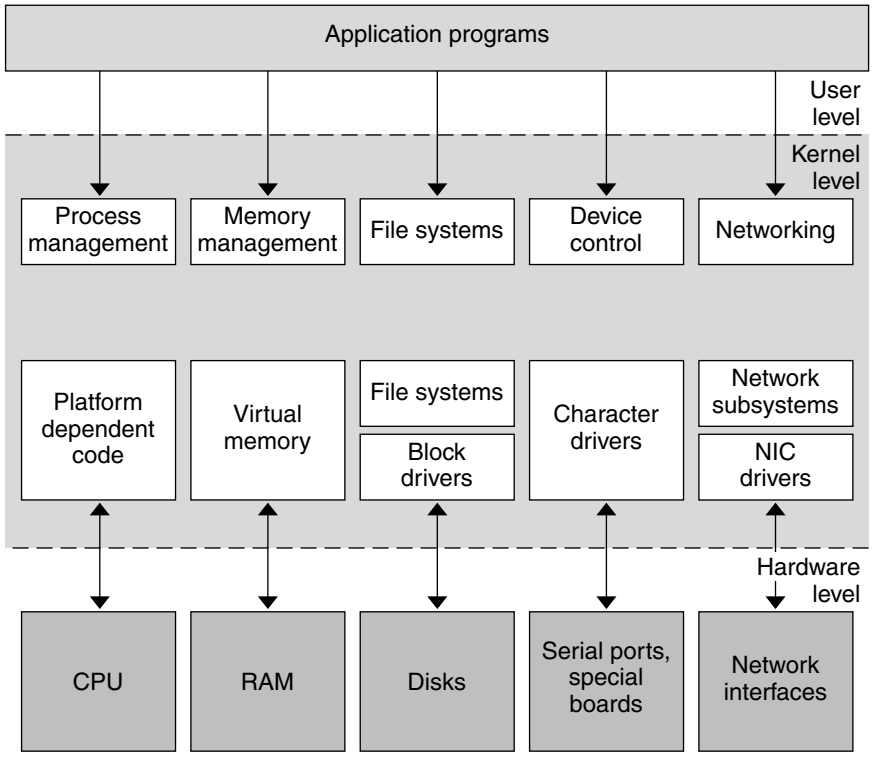



**FIGURE 2–1** Solaris Kernel

The kernel provides access to device drivers through the following features:

- **Device-to-driver mapping**. The kernel maintains the *device tree*. Each node in the tree represents a virtual or a physical device. The kernel binds each node to a driver by matching the device node name with the set of drivers installed in the system. The device is made accessible to applications only if there is a driver binding.
- **DDI/DKI interfaces**. DDI/DKI (Device Driver Interface/Driver-Kernel Interface) interfaces standardize interactions between the driver and the kernel, the device hardware, and the boot/configuration software. These interfaces keep the driver independent from the kernel and improve the driver's portability across successive

releases of the operating system on a particular machine.

- **LDI**. The LDI (Layered Driver Interface) is an extension of the DDI/DKI. The LDI enables a kernel module to access other devices in the system. The LDI also enables you to determine which devices are currently being used by the kernel. See Chapter 13.

## Multithreaded Execution Environment

The Solaris kernel is multithreaded. On a multiprocessor machine, multiple kernel threads can be running kernel code, and can do so concurrently. Kernel threads can also be pre-empted by other kernel threads at any time.

The multithreading of the kernel imposes some additional restrictions on device drivers. For more information on multithreading considerations, see Chapter 3. Device drivers must be coded to run as needed at the request of many different threads. For each thread, a driver must handle contention problems from overlapping I/O requests.

## Virtual Memory

A complete overview of the Solaris virtual memory system is beyond the scope of this book, but two virtual memory terms of special importance are used when discussing device drivers: virtual address and address space.

- **Virtual address**. A *virtual address* is an address that is mapped by the memory management unit (MMU) to a physical hardware address. All addresses directly accessible by the driver are kernel virtual addresses. Kernel virtual addresses refer to the *kernel address space*.
- **Address space**. An *address space* is a set of *virtual address segments*. Each segment is a contiguous range of virtual addresses. Each user process has an address space called the *user address space*. The kernel has its own address space, called the *kernel address space*.

## Devices as Special Files

Devices are represented in the file system by *special files*. In the Solaris Operating System (Solaris OS), these files reside in the `/devices` directory hierarchy.

Special files can be of type *block* or *character*. The type indicates which kind of device driver operates the device. Drivers can be implemented to operate on both types. For example, disk drivers export a character interface for use by the `fsck(1)` and `mkfs(1)` utilities, and a block interface for use by the file system.

Associated with each special file is a *device number* (`dev_t`). A device number consists of a *major number* and a *minor number*. The *major* number identifies the device driver associated with the special file. The *minor* number is created and used by the device

driver to further identify the special file. Usually, the minor number is an encoding that is used to identify which device instance the driver should access and which type of access should be performed. For example, the minor number can identify a tape device used for backup and can specify that the tape needs to be rewound when the backup operation is complete.

## DDI/DKI Interfaces

In System V Release 4 (SVR4), the interface between device drivers and the rest of the UNIX kernel was standardized as the DDI/DKI. The Solaris 10 DDI/DKI is documented in Section 9 of the *Solaris 9 Reference Manual Collection*. This section documents driver entry points, driver-callable functions, and kernel data structures used by device drivers.

The Solaris 10 DDI/DKI, like its SVR4 counterpart, is intended to standardize and document all interfaces between device drivers and the rest of the kernel. In addition, the Solaris 10 DDI/DKI allows source compatibility for drivers on any machine that runs the Solaris 10 Operating System, regardless of the processor architecture, whether SPARC or x86. The Solaris 10 DDI/DKI provides binary compatibility for drivers used on any Solaris 10 based processor regardless of the specific platform architecture. Drivers using only kernel facilities that are part of the Solaris 10 DDI/DKI are known as *Solaris 10 DDI/DKI-compliant device drivers*.

The Solaris 10 DDI/DKI enables platform-independent device drivers to be written for Solaris 10 based machines. These *shrink-wrapped*, that is, binary-compatible, drivers enable third-party hardware and software to be more easily integrated into Solaris 10 based machines. The Solaris 10 DDI/DKI is architecture independent, which enables the same driver to work across a diverse set of machine architectures.

Platform independence is accomplished by the design of DDI in Solaris 10 DDI/DKI. The following main areas are addressed:

- Dynamic loading and unloading of modules
- Power management
- Interrupt handling
- Accessing the device space from the kernel or a user process, that is, register mapping and memory mapping
- Accessing kernel or user process space from the device using DMA services
- Managing device properties

# Overview of the Device Tree

Devices in the Solaris OS are represented as a tree of interconnected device information nodes. The device tree describes the configuration of loaded devices for a particular machine.

## Device Tree Components

The system builds a tree structure that contains information about the devices connected to the machine at boot time. The device tree can also be modified by dynamic reconfiguration operations while the system is in normal operation. The tree begins at the root device node, which represents the platform.

Below the root node are the branches of the device tree. A branch consists of one or more bus nexus devices and a terminating leaf device.

A *bus nexus device* provides bus mapping and translation services to subordinate devices in the device tree. PCI - PCI bridges, PCMCIA adapters, and SCSI HBAs are all examples of nexus devices. The discussion of writing drivers for nexus devices is limited to the development of SCSI HBA drivers (see Chapter 17).

*Leaf devices* are typically peripheral devices such as disks, tapes, network adapters, frame buffers, and so forth. Leaf device drivers export the traditional character driver interfaces and block driver interfaces. The interfaces enable user processes to read data from and write data to either storage or communication devices.

The system goes through the following steps to build the tree:

1. The CPU is initialized and searches for firmware.
2. The main firmware (OpenBoot, Basic Input/Output System (BIOS), or `Bootconf`) initializes and creates the device tree with known or self-identifying hardware.
3. When the main firmware finds compatible firmware on a device, the main firmware initializes the device and retrieves the device's properties.
4. The firmware locates and boots the operating system.
5. The kernel starts at the root node of the tree, searches for a matching device driver, and binds that driver to the device.
6. If the device is a nexus, the kernel looks for child devices that have not been detected by the firmware. The kernel adds any child devices to the tree below the nexus node.
7. The kernel repeats the process from Step 5 until no further device nodes need to be created.

Each driver exports a device operations structure `dev_ops`(9S) to define the operations that the device driver can perform. The device operations structure contains function pointers for generic operations such as `attach`(9E), `detach`(9E), and `getinfo`(9E). The structure also contains a pointer to a set of operations specific to bus nexus drivers and a pointer to a set of operations specific to leaf drivers.

The tree structure creates a parent-child relationship between nodes. This parent-child relationship is the key to architectural independence. When a leaf or bus nexus driver requires a service that is architecturally dependent in nature, that driver requests its parent to provide the service. This approach enables drivers to function regardless of the architecture of the machine or the processor. A typical device tree is shown in the following figure.

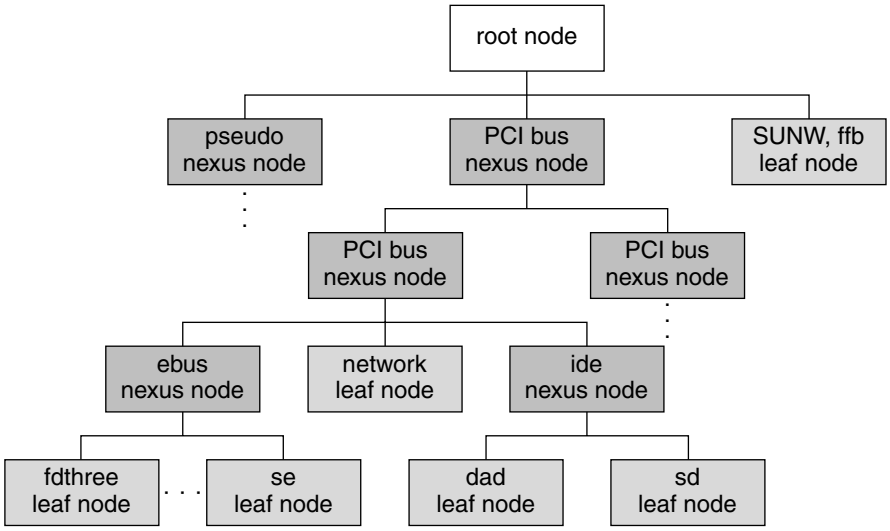



**FIGURE 2–2** Example Device Tree

The nexus nodes may have one or more children. The leaf nodes represent individual devices.

# Displaying the Device Tree

The device tree can be displayed in three ways:

- The `libdevinfo` library provides interfaces to access the contents of the device tree programmatically.
- The `prtconf`(1M) command displays the complete contents of the device tree.
- The `/devices` hierarchy is a representation of the device tree. Use the `ls`(1) command to view the hierarchy.

**Note –** `/devices` displays only devices that have drivers configured into the system. The `prtconf`(1M) command shows all device nodes regardless of whether a driver for the device exists on the system.

## `libdevinfo` Library

The `libdevinfo` library provides interfaces for accessing all public device configuration data. See the `libdevinfo`(3LIB) man page for a list of interfaces.

## `prtconf` Command

The following excerpted `prtconf`(1M) command example displays all the devices in the system.

```
System Configuration:  Sun Microsystems  sun4u
Memory size: 128 Megabytes
System Peripherals (Software Nodes):

SUNW,Ultra-5_10
    packages (driver not attached)
        terminal-emulator (driver not attached)
        deblocker (driver not attached)
        obp-tftp (driver not attached)
        disk-label (driver not attached)
        SUNW,builtin-drivers (driver not attached)
        sun-keyboard (driver not attached)
        ufs-file-system (driver not attached)
    chosen (driver not attached)
    openprom (driver not attached)
        client-services (driver not attached)
    options, instance #0
    aliases (driver not attached)
    memory (driver not attached)
    virtual-memory (driver not attached)
    pci, instance #0
        pci, instance #0
            ebus, instance #0
                auxio (driver not attached)
                power, instance #0
                SUNW,pll (driver not attached)
                se, instance #0
                su, instance #0
                su, instance #1
                ecpp (driver not attached)
                fdthree, instance #0
                eeprom (driver not attached)
                flashprom (driver not attached)
                SUNW,CS4231 (driver not attached)
```

```
            network, instance #0
            SUNW,m64B (driver not attached)
            ide, instance #0
                disk (driver not attached)
                cdrom (driver not attached)
                dad, instance #0
                sd, instance #15
        pci, instance #1
            pci, instance #0
                pci108e,1000 (driver not attached)
                SUNW,hme, instance #1
                SUNW,isptwo, instance #0
                    sd (driver not attached)
                    st (driver not attached)
                    sd, instance #0 (driver not attached)
                    sd, instance #1 (driver not attached)
                    sd, instance #2 (driver not attached)
                    [...]
    SUNW,UltraSPARC-IIi (driver not attached)
    SUNW,ffb, instance #0
    pseudo, instance #0
```

## /devices Directory

The /devices hierarchy provides a namespace that represents the device tree. Following is an abbreviated listing of the /devices namespace. The sample output corresponds to the example device tree and prtconf(1M) output shown previously.

```
/devices
/devices/pseudo
/devices/pci@1f,0:devctl
/devices/SUNW,ffb@1e,0:ffb0
/devices/pci@1f,0
/devices/pci@1f,0/pci@1,1
/devices/pci@1f,0/pci@1,1/SUNW,m64B@2:m640
/devices/pci@1f,0/pci@1,1/ide@3:devctl
/devices/pci@1f,0/pci@1,1/ide@3:scsi
/devices/pci@1f,0/pci@1,1/ebus@1
/devices/pci@1f,0/pci@1,1/ebus@1/power@14,724000:power_button
/devices/pci@1f,0/pci@1,1/ebus@1/se@14,400000:a
/devices/pci@1f,0/pci@1,1/ebus@1/se@14,400000:b
/devices/pci@1f,0/pci@1,1/ebus@1/se@14,400000:0,hdlc
/devices/pci@1f,0/pci@1,1/ebus@1/se@14,400000:1,hdlc
/devices/pci@1f,0/pci@1,1/ebus@1/se@14,400000:a,cu
/devices/pci@1f,0/pci@1,1/ebus@1/se@14,400000:b,cu
/devices/pci@1f,0/pci@1,1/ebus@1/ecpp@14,3043bc:ecpp0
/devices/pci@1f,0/pci@1,1/ebus@1/fdthree@14,3023f0:a
/devices/pci@1f,0/pci@1,1/ebus@1/fdthree@14,3023f0:a,raw
/devices/pci@1f,0/pci@1,1/ebus@1/SUNW,CS4231@14,200000:sound,audio
/devices/pci@1f,0/pci@1,1/ebus@1/SUNW,CS4231@14,200000:sound,audioctl
/devices/pci@1f,0/pci@1,1/ide@3
/devices/pci@1f,0/pci@1,1/ide@3/sd@2,0:a
/devices/pci@1f,0/pci@1,1/ide@3/sd@2,0:a,raw
```

```
/devices/pci@1f,0/pci@1,1/ide@3/dad@0,0:a
/devices/pci@1f,0/pci@1,1/ide@3/dad@0,0:a,raw
/devices/pci@1f,0/pci@1
/devices/pci@1f,0/pci@1/pci@2
/devices/pci@1f,0/pci@1/pci@2/SUNW,isptwo@4:devctl
/devices/pci@1f,0/pci@1/pci@2/SUNW,isptwo@4:scsi
```

# Binding a Driver to a Device

In addition to constructing the device tree, the kernel determines the drivers that are used to manage the devices.

Binding a driver to a device refers to the process by which the system selects a driver to manage a particular device. The binding name is the name that links a driver to a unique device node in the device information tree. For each device in the device tree, the system attempts to choose a driver from a list of installed drivers.

Each device node has an associated *name* property. This property can be assigned either from an external agent, such as the PROM, during system boot or from a `driver.conf` configuration file. In any case, the `name` property represents the `node name` assigned to a device in the device tree. The `node name` is the name visible in `/devices` and listed in the `prtconf`(1M) output.

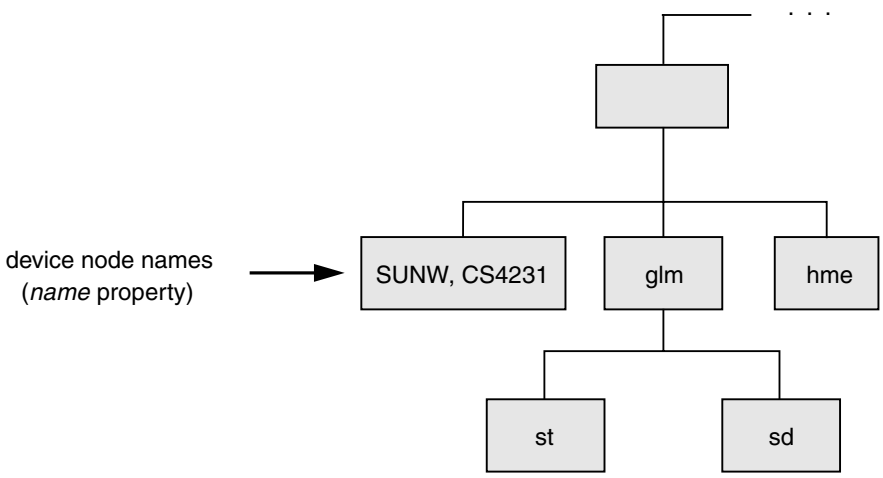



**FIGURE 2–3** Device Node Names

A device node may have an associated *compatible* property as well. The *compatible* property contains an ordered list of one or more possible driver names or driver aliases for the device.

The system uses both the *compatible* and the *name* properties to select a driver for the device. The system first attempts to match the contents of the *compatible* property, if the *compatible* property exists, to a driver on the system. Beginning with the first driver name on the *compatible* property list, the system attempts to match the driver name to a known driver on the system. Each entry on the list is processed until the system either finds a match or reaches the end of the list.

If the contents of either the *name* property or the *compatible* property match a driver on the system, then that driver is bound to the device node. If no match is found, no driver is bound to the device node.

## Generic Device Names

Some devices specify a *generic* device name as the value for the *name* property. Generic device names describe the function of a device without actually identifying a specific driver for the device. For example, a SCSI host bus adapter might have a generic device name of `scsi`. An Ethernet device might have a generic device name of `ethernet`.

The *compatible* property enables the system to determine alternate driver names for devices with a generic device name, for example, `glm` for `scsi` HBA device drivers or `hme` for `ethernet` device drivers.

Devices with generic device names are required to supply a *compatible* property.

---

**Note –** For a complete description of *generic device names*, see the IEEE 1275 Open Firmware Boot Standard.

---

The following figure shows a device node with a specific device name. The driver binding name `SUNW,ffb` is the same name as the device node name.

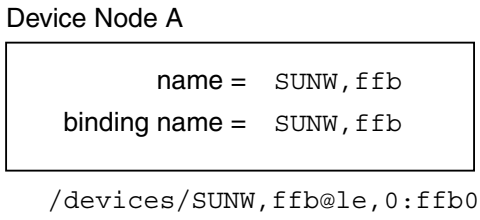



**FIGURE 2–4** Specific Driver Node Binding

The following figure shows a device node with the generic device name `display`. The driver binding name `SUNW,ffb` is the first name on the *compatible* property driver list that matches a driver on the system driver list. In this case, `display` is a generic device name for frame buffers.

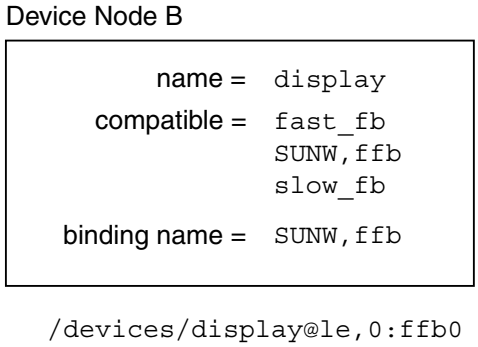



**FIGURE 2–5** Generic Driver Node Binding

CHAPTER 3

# Multithreading

This chapter describes the locking primitives and thread synchronization mechanisms of the Solaris multithreaded kernel. You should design device drivers to take advantage of multithreading. This chapter provides information on the following subjects:



## Locking Primitives

In traditional UNIX systems, every section of kernel code terminates either through an explicit call to `sleep`(1) to give up the processor or through a hardware interrupt. The Solaris Operating System operates differently. A kernel thread can be preempted at any time to run another thread. Because all kernel threads share kernel address space and often need to read and modify the same data, the kernel provides a number of locking primitives to prevent threads from corrupting shared data. These mechanisms include mutual exclusion locks, which are also known as *mutexes*, readers/writer locks, and semaphores.

### Storage Classes of Driver Data

The storage class of data is a guide to whether the driver might need to take explicit steps to control access to the data. The three data storage classes are:

- **Automatic (stack) data**. Every thread has a private stack, so drivers never need to lock automatic variables.
- **Global static data**. Global static data can be shared by any number of threads in the driver. The driver might need to lock this type of data at times.

- **Kernel heap data**. Any number of threads in the driver can share kernel heap data, such as data allocated by `kmem_alloc`(9F). The driver needs to protect shared data at all times.

# Mutual-Exclusion Locks

A mutual-exclusion lock, or *mutex*, is usually associated with a set of data and regulates access to that data. Mutexes provide a way to allow only one thread at a time access to that data. The mutex functions are:

| | |
|---|---|
| `mutex_destroy`(9F) | Releases any associated storage. |
| `mutex_enter`(9F) | Acquires a mutex. |
| `mutex_exit`(9F) | Releases a mutex. |
| `mutex_init`(9F) | Initializes a mutex. |
| `mutex_owned`(9F) | Tests to determine whether the mutex is held by the current thread. To be used in `assert`(9F) only. |
| `mutex_tryenter`(9F) | Acquires a mutex if available, but does not block. |

## Setting Up Mutexes

Device drivers usually allocate a mutex for each driver data structure. The mutex is typically a field in the structure of type `kmutex_t`. `mutex_init`(9F) is called to prepare the mutex for use. This call is usually made at `attach`(9E) time for per-device mutexes and `_init`(9E) time for global driver mutexes.

For example,

```
struct xxstate *xsp;
...
mutex_init(&xsp->mu, NULL, MUTEX_DRIVER, NULL);
...
```

For a more complete example of mutex initialization, see Chapter 6.

The driver must destroy the mutex with `mutex_destroy`(9F) before being unloaded. Destroying the mutex is usually done at `detach`(9E) time for per-device mutexes and `_fini`(9E) time for global driver mutexes.

## Using Mutexes

Every section of the driver code that needs to read or write the shared data structure must do the following tasks:

- Acquire the mutex

- Access the data
- Release the mutex

The scope of a mutex, that is, the data the mutex protects, is entirely up to the programmer. A mutex protects a data structure only if every code path that accesses the data structure does so while holding the mutex.

## Readers/Writer Locks

A *readers/writer lock* regulates access to a set of data. The readers/writer lock is so called because many threads can hold the lock simultaneously for reading, but only one thread can hold the lock for writing.

Most device drivers do not use readers/writer locks. These locks are slower than mutexes. The locks provide a performance gain only when they protect commonly read data that is not frequently written. In this case, contention for a mutex could become a bottleneck, so using a readers/writer lock might be more efficient. The readers/writer functions are summarized in the following table. See the `rwlock`(9F) man page for detailed information. The readers/writer lock functions are:

| | |
|---|---|
| `rw_destroy`(9F) | Destroys a readers/writer lock |
| `rw_downgrade`(9F) | Downgrades a readers/writer lock holder from writer to reader |
| `rw_enter`(9F) | Acquires a readers/writer lock |
| `rw_exit`(9F) | Releases a readers/writer lock |
| `rw_init`(9F) | Initializes a readers/writer lock |
| `rw_read_locked`(9F) | Determines whether a readers/writer lock is held for read or write |
| `rw_tryenter`(9F) | Attempts to acquire a readers/writer lock without waiting |
| `rw_tryupgrade`(9F) | Attempts to upgrade readers/writer lock holder from reader to writer |

## Semaphores

Counting semaphores are available as an alternative primitive for managing threads within device drivers. See the `semaphore`(9F) man page for more information. The semaphore functions are:

| | |
|---|---|
| `sema_destroy`(9F) | Destroys a semaphore. |
| `sema_init`(9F) | Initialize a semaphore. |

| | |
|---|---|
| `sema_p`(9F) | Decrement semaphore and possibly block. |
| `sema_p_sig`(9F) | Decrement semaphore but do not block if signal is pending. See "Threads Unable to Receive Signals" on page 71. |
| `sema_tryp`(9F) | Attempt to decrement semaphore, but do not block. |
| `sema_v`(9F) | Increment semaphore and possibly unblock waiter. |

# Thread Synchronization

In addition to protecting shared data, drivers often need to synchronize execution among multiple threads.

## Condition Variables in Thread Synchronization

Condition variables are a standard form of thread synchronization. They are designed to be used with mutexes. The associated mutex is used to ensure that a condition can be checked atomically, and that the thread can block on the associated condition variable without missing either a change to the condition or a signal that the condition has changed.

The `condvar`(9F) functions are:

| | |
|---|---|
| `cv_broadcast`(9F) | Signals all threads waiting on the condition variable. |
| `cv_destroy`(9F) | Destroys a condition variable. |
| `cv_init`(9F) | Initializes a condition variable. |
| `cv_signal`(9F) | Signals one thread waiting on the condition variable. |
| `cv_timedwait`(9F) | Waits for condition, time-out, or signal. See "Threads Unable to Receive Signals" on page 71. |
| `cv_timedwait_sig`(9F) | Waits for condition or time-out. |
| `cv_wait`(9F) | Waits for condition. |
| `cv_wait_sig`(9F) | Waits for condition or return zero on receipt of a signal. See "Threads Unable to Receive Signals" on page 71. |

## Initializing Condition Variables

Declare a condition variable of type `kcondvar_t` for each condition. Usually, the condition variables are declared in the driver's soft-state structure. Use `cv_init`(9F) to initialize each condition variable. Similar to mutexes, condition variables are usually initialized at `attach`(9E) time. A typical example of initializing a condition variable is:

```
cv_init(&xsp->cv, NULL, CV_DRIVER, NULL);
```

For a more complete example of condition variable initialization, see Chapter 6.

## Waiting for the Condition

To use condition variables, follow these steps in the code path waiting for the condition:

1. Acquire the mutex guarding the condition.
2. Test the condition.
3. If the test results do not allow the thread to continue, use `cv_wait`(9F) to block the current thread on the condition. `cv_wait`(9F) releases the mutex before blocking the thread and reacquires the mutex before returning. On return from `cv_wait`(9F), repeat the test.
4. After the test allows the thread to continue, set the condition to its new value. For example, set a device flag to busy.
5. Release the mutex.

## Signaling the Condition

Follow these steps in the code path to signal the condition:

1. Acquire the mutex guarding the condition.
2. Set the condition.
3. Signal the blocked thread with `cv_broadcast`(9F).
4. Release the mutex.

The following example uses a busy flag along with mutex and condition variables to force the `read`(9E) routine to wait until the device is no longer busy before starting a transfer.

**EXAMPLE 3–1** Using Mutexes and Condition Variables

```
static int
xxread(dev_t dev, struct uio *uiop, cred_t *credp)
{
        struct xxstate *xsp;
```

**EXAMPLE 3–1** Using Mutexes and Condition Variables *(Continued)*

```
        [...]
        mutex_enter(&xsp->mu);
        while (xsp->busy)
                cv_wait(&xsp->cv, &xsp->mu);
        xsp->busy = 1;
        mutex_exit(&xsp->mu);
        /* perform the data access */
}

static uint_t
xxintr(caddr_t arg)
{
        struct xxstate *xsp = (struct xxstate *)arg;
        mutex_enter(&xsp->mu);
        xsp->busy = 0;
        cv_broadcast(&xsp->cv);
        mutex_exit(&xsp->mu);
}
```

## `cv_wait()` and `cv_timedwait()` Functions

If a thread is blocked on a condition with `cv_wait`(9F) and that condition does not occur, the thread would wait forever. To avoid that situation, use `cv_timedwait`(9F), which depends upon another thread to perform a wakeup. `cv_timedwait()` takes an absolute wait time as an argument. `cv_timedwait()` returns `-1` if the time is reached and the event has not occurred. `cv_timedwait()` returns a positive value if the condition is met.

`cv_timedwait`(9F) requires an absolute wait time expressed in clock ticks since the system was last rebooted. The wait time can be determined by retrieving the current value with `ddi_get_lbolt`(9F). The driver usually has a maximum number of seconds or microseconds to wait, so this value is converted to clock ticks with `drv_usectohz`(9F) and added to the value from `ddi_get_lbolt`(9F).

The following example shows how to use `cv_timedwait`(9F) to wait up to five seconds to access the device before returning `EIO` to the caller.

**EXAMPLE 3–2** Using `cv_timedwait()`

```
clock_t            cur_ticks, to;
mutex_enter(&xsp->mu);
while (xsp->busy) {
        cur_ticks = ddi_get_lbolt();
        to = cur_ticks + drv_usectohz(5000000); /* 5 seconds from now */
        if (cv_timedwait(&xsp->cv, &xsp->mu, to) == -1) {
                /*
                 * The timeout time 'to' was reached without the
```

**EXAMPLE 3–2** Using `cv_timedwait()` *(Continued)*

```
                 * condition being signalled.
                 */
                /* tidy up and exit */
                mutex_exit(&xsp->mu);
                return (EIO);
        }
}
xsp->busy = 1;
mutex_exit(&xsp->mu);
```

Although device driver writers generally prefer to use `cv_timedwait`(9F) over `cv_wait`(9F), sometimes `cv_wait`(9F) is a better choice. For example, `cv_wait`(9F) is better if a driver is waiting on the following conditions:

- Internal driver state changes, where such a state change might require some command to be executed, or a set amount of time to pass
- Something the driver needs to single-thread
- Some situation that is already managing a possible timeout, as when "A" depends on "B," and "B" is using `cv_timedwait`(9F)

## `cv_wait_sig()` Function

A driver might be waiting for a condition that cannot occur or will not happen for a long time. In such cases, the user can send a signal to abort the thread. Depending on the driver design, the signal might not cause the driver to wake up.

`cv_wait_sig`(9F) allows a signal to unblock the thread. This capability enables the user to break out of potentially long waits by sending a signal to the thread with `kill`(1) or by typing the interrupt character. `cv_wait_sig`(9F) returns zero if it is returning because of a signal, or nonzero if the condition occurred. However, see "Threads Unable to Receive Signals" on page 71 for cases in which signals might not be received.

The following example shows how to use `cv_wait_sig`(9F) to allow a signal to unblock the thread.

**EXAMPLE 3–3** Using `cv_wait_sig()`

```
mutex_enter(&xsp->mu);
while (xsp->busy) {
        if (cv_wait_sig(&xsp->cv, &xsp->mu) == 0) {
        /* Signalled while waiting for the condition */
                /* tidy up and exit */
                mutex_exit(&xsp->mu);
                return (EINTR);
```

**EXAMPLE 3–3** Using `cv_wait_sig()` *(Continued)*

```
        }
}
xsp->busy = 1;
mutex_exit(&xsp->mu);
```

## `cv_timedwait_sig()` Function

`cv_timedwait_sig`(9F) is similar to `cv_timedwait`(9F) and `cv_wait_sig`(9F), except that `cv_timedwait_sig()` returns `-1` without the condition being signaled after a timeout has been reached, or `0` if a signal (for example, `kill`(2)) is sent to the thread.

For both `cv_timedwait`(9F) and `cv_timedwait_sig`(9F), time is measured in absolute clock ticks since the last system reboot.

# Choosing a Locking Scheme

The locking scheme for most device drivers should be kept straightforward. Using additional locks allows more concurrency but increases overhead. Using fewer locks is less time consuming but allows less concurrency. Generally, use one mutex per data structure, a condition variable for each event or condition the driver must wait for, and a mutex for each major set of data global to the driver. Avoid holding mutexes for long periods of time. Use the following guidelines when choosing a locking scheme:

- Use the multithreading semantics of the entry point to your advantage.
- Make all entry points re-entrant. You can reduce the amount of shared data by changing a static variable to automatic.
- If your driver acquires multiple mutexes, acquire and release the mutexes in the same order in all code paths.
- Hold and release locks within the same functional space.
- Avoid holding driver mutexes when calling DDI interfaces that can block, for example, `kmem_alloc`(9F) with `KM_SLEEP`.

To look at lock usage, use `lockstat`(1M). `lockstat`(1M) monitors all kernel lock events, gathers frequency and timing data about the events, and displays the data.

See the *Multithreaded Programming Guide* for more details on multithreaded operations.

## Potential Locking Pitfalls

Mutexes are not re-entrant by the same thread. If you already own the mutex, attempting to claim this mutex a second time leads to the following panic:

```
panic: recursive mutex_enter. mutex %x caller %x
```

Releasing a mutex that the current thread does not hold causes this panic:

```
panic: mutex_adaptive_exit: mutex not held by thread
```

The following panic occurs only on uniprocessors:

```
panic: lock_set: lock held and only one CPU
```

The `lock_set` panic indicates that a spin mutex is held and will spin forever, because no other CPU can release this mutex. This situation can happen if the driver forgets to release the mutex on one code path or becomes blocked while holding the mutex.

A common cause of the `lock_set` panic occurs when a device with a high-level interrupt calls a routine that blocks, such as `cv_wait`(9F). Another typical cause is a high-level handler grabbing an adaptive mutex by calling `mutex_enter`(9F).

## Threads Unable to Receive Signals

The `sema_p_sig()`, `cv_wait_sig()`, and `cv_timedwait_sig()` functions can be awakened when the thread receives a signal. A problem can arise because some threads are unable to receive signals. For example, when `close`(9E) is called as a result of the application calling `close`(2), signals can be received. However, when `close`(9E) is called from within the `exit`(2) processing that closes all open file descriptors, the thread cannot receive signals. When the thread cannot receive signals, `sema_p_sig()` behaves as `sema_p()`, `cv_wait_sig()` behaves as `cv_wait()`, and `cv_timedwait_sig()` behaves as `cv_timedwait()`.

Use caution to avoid sleeping forever on events that might never occur. Events that never occur create unkillable (`defunct`) threads and make the device unusable until the system is rebooted. Signals cannot be received by defunct processes.

To detect whether the current thread is able to receive a signal, use the `ddi_can_receive_sig`(9F) function. If the `ddi_can_receive_sig()` function returns `B_TRUE`, then the above functions can wake up on a received signal. If the `ddi_can_receive_sig()` function returns `B_FALSE`, then the above functions cannot wake up on a received signal. If the `ddi_can_receive_sig()` function returns `B_FALSE`, then the driver should use an alternate means, such as the `timeout`(9F) function, to reawaken.

One important case where this problem occurs is with serial ports. If the remote system asserts flow control and the `close`(9E) function blocks while attempting to drain the output data, a port can be stuck until the flow control condition is resolved or the system is rebooted. Such drivers should detect this case and set up a timer to abort the drain operation when the flow control condition persists for an excessive period of time.

This issue also affects the `qwait_sig`(9F) function, which is described in Chapter 7, "STREAMS Framework – Kernel Level," in *STREAMS Programming Guide*.

CHAPTER 4

# Properties

Properties are user-defined, name-value pair structures that are managed using the DDI/DKI interfaces. This chapter provides information on the following subjects:



## Device Properties

Device attribute information can be represented by a *name-value* pair notation called a *property*.

For example, device registers and onboard memory can be represented by the *reg* property. The *reg* property is a software abstraction that describes device hardware registers. The value of the *reg* property encodes the device register address location and size. Drivers use the *reg* property to access device registers.

Another example is the *interrupt* property. An *interrupt* property represents the device interrupt. The value of the *interrupt* property encodes the device-interrupt PIN.

Five types of values can be assigned to properties:

- **Byte array** – Series of bytes of an arbitrary length
- **Integer property** – An integer value
- **Integer array property** – An array of integers
- **String property** – A NULL-terminated string
- **String array property** – A list of NULL-terminated strings

A property that has no value is considered to be a Boolean property. A Boolean property that exists is true. A Boolean value that does not exist is false.

# Device Property Names

Strictly speaking, DDI/DKI software property names have no restrictions. Certain uses are recommended, however. The IEEE 1275-1994 Standard for Boot Firmware defines properties as follows:

> A property is a human readable text string consisting of from 1 to 31 printable characters. Property names *shall* not contain upper case characters or the characters "/", "\", ":", "[", "]" and "@". Property names beginning with the character "+" are reserved for use by future revisions of IEEE 1275-1994.

By convention, underscores are not used in property names. Use a hyphen (-) instead. By convention, property names ending with the question mark character (`?`) contain values that are strings, typically TRUE or FALSE, for example `auto-boot?`.

Predefined property names are listed in publications of the IEEE 1275 Working Group. See `http://playground.sun.com/1275` for information about how to obtain these publications. For a discussion of adding properties in driver configuration files, see the `driver.conf`(4) man page. The `pm`(9P) and `pm-components`(9P) man pages show how properties are used in power management. Read the `sd`(7D) man page as an example of how properties should be documented in device driver man pages.

# Creating and Updating Properties

To create a property for a driver, or to update an existing property, use an interface from the DDI driver update interfaces such as `ddi_prop_update_int`(9F) or `ddi_prop_update_string`(9F) with the appropriate property type. See Table 4–1 for a list of available property interfaces. These interfaces are typically called from the driver's `attach`(9E) entry point. In the following example, `ddi_prop_update_string()` creates a string property called `pm-hardware-state` with a value of `needs-suspend-resume`.

```
/* The following code is to tell cpr that this device
* needs to be suspended and resumed.
*/
(void) ddi_prop_update_string(device, dip,
     "pm-hardware-state", "needs-suspend-resume");
```

In most cases, using a `ddi_prop_update()` routine is sufficient for updating a property. Sometimes, however, the overhead of updating a property value that is subject to frequent change can cause performance problems. See "`prop_op()` Entry Point" on page 76 for a description of using a local instance of a property value to avoid using `ddi_prop_update()`.

# Looking Up Properties

A driver can request a property from its parent, which in turn can ask its parent. The driver can control whether the request can go higher than its parent.

For example, the `esp` driver in the following example maintains an integer property called `targetx-sync-speed` for each target. The `x` in `targetx-sync-speed` represents the target number. The `prtconf`(1M) command displays driver properties in verbose mode. The following example shows a partial listing for the `esp` driver.

```
% prtconf -v
[...]
       esp, instance #0
            Driver software properties:
                name <target2-sync-speed> length <4>
                    value <0x00000fa0>.
[...]
```

The following table provides a summary of the property interfaces.

**TABLE 4–1** Property Interface Uses

| Family | Property Interfaces | Description |
|---|---|---|
| `ddi_prop_lookup` | `ddi_prop_exists`(9F) | Looks up a property and returns successfully if the property exists. Fails if the property does not exist |
| | `ddi_prop_get_int`(9F) | Looks up and returns an integer property |
| | `ddi_prop_get_int64`(9F) | Looks up and returns a 64–bit integer property |
| | `ddi_prop_lookup_int_array`(9F) | Looks up and returns an integer array property |
| | `ddi_prop_lookup_int64_array`(9F) | Looks up and returns a 64–bit integer array property |
| | `ddi_prop_lookup_string`(9F) | Looks up and returns a string property |
| | `ddi_prop_lookup_string_array`(9F) | Looks up and returns a string array property |
| | `ddi_prop_lookup_byte_array`(9F) | Looks up and returns a byte array property |
| `ddi_prop_update` | `ddi_prop_update_int`(9F) | Updates or creates an integer property |
| | `ddi_prop_update_int64`(9F) | Updates or creates a single 64–bit integer property |
| | `ddi_prop_update_int_array`(9F) | Updates or creates an integer array property |
| | `ddi_prop_update_string`(9F) | Updates or creates a string property |
| | `ddi_prop_update_string_array`(9F) | Updates or creates a string array property |

**TABLE 4–1** Property Interface Uses *(Continued)*

| Family | Property Interfaces | Description |
|---|---|---|
| | ddi_prop_update_int64_array(9F) | Updates or creates a 64–bit integer array property |
| | ddi_prop_update_byte_array(9F) | Updates or creates a byte array property |
| ddi_prop_remove | ddi_prop_remove(9F) | Removes a property |
| | ddi_prop_remove_all(9F) | Removes all properties that are associated with a device |

Whenever possible, use 64–bit versions of `int` property interfaces such as `ddi_prop_update_int64`(9F) instead of 32–bit versions such as `ddi_prop_update_int`(9F)).

# `prop_op()` Entry Point

The `prop_op`(9E) entry point is generally required for reporting device properties or driver properties to the system. If the driver does not need to create or manage its own properties, then the `ddi_prop_op`(9F) function can be used for this entry point.

`ddi_prop_op`(9F) can be used as the `prop_op`(9E) entry point for a device driver when `ddi_prop_op()` is defined in the driver's `cb_ops`(9S) structure. `ddi_prop_op()` enables a leaf device to search for and obtain property values from the device's property list.

If the driver has to maintain a property whose value changes frequently, you should define a driver-specific `prop_op()` routine within the `cb_ops` structure instead of calling `ddi_prop_op()`. This technique avoids the inefficiency of using `ddi_prop_update()` repeatedly. The driver should then maintain a copy of the property value either within its soft-state structure or in a driver variable.

The `prop_op`(9E) entry point reports the values of specific driver properties and device properties to the system. In many cases, the `ddi_prop_op`(9F) routine can be used as the driver's `prop_op()` entry point in the `cb_ops`(9S) structure. `ddi_prop_op()` performs all of the required processing. `ddi_prop_op()` is sufficient for drivers that do not require special processing when handling device property requests.

However, sometimes the driver must provide a `prop_op()` entry point. For example, if a driver maintains a property whose value changes frequently, updating the property with `ddi_prop_update`(9F) for each change is not efficient. Instead, the driver should maintain a shadow copy of the property in the instance's soft state. The driver would then update the shadow copy when the value changes without using any of the `ddi_prop_update()` routines. The `prop_op()` entry point must intercept requests for this property and use one of the `ddi_prop_update()` routines to update the value of the property before passing the request to `ddi_prop_op()` to process the property request.

In the following example, `prop_op()` intercepts requests for the `temperature` property. The driver updates a variable in the state structure whenever the property changes. However, the property is updated only when a request is made. The driver then uses `ddi_prop_op()` to process the property request. If the property request is not specific to a device, the driver does not intercept the request. This situation is indicated when the value of the `dev` parameter is equal to `DDI_DEV_T_ANY`, the wildcard device number.

**EXAMPLE 4–1** `prop_op()` Routine

```
static int
xx_prop_op(dev_t dev, dev_info_t *dip, ddi_prop_op_t prop_op,
    int flags, char *name, caddr_t valuep, int *lengthp)
{
        minor_t instance;
        struct xxstate *xsp;
        if (dev != DDI_DEV_T_ANY) {
                return (ddi_prop_op(dev, dip, prop_op, flags, name,
                    valuep, lengthp));
        }

        instance = getminor(dev);
        xsp = ddi_get_soft_state(statep, instance);
        if (xsp == NULL)
                return (DDI_PROP_NOTFOUND);
        if (strcmp(name, "temperature") == 0) {
                ddi_prop_update_int(dev, dip, name, temperature);
        }

        /* other cases */
}
```

CHAPTER 5

# Events

A system often needs to respond to a condition change such as a user action or system request. For example, a device might issue a warning when a component begins to overheat, or might start a movie player when a DVD is inserted into a drive. Device drivers can use a special message called an *event* to inform the system that a change in state has taken place. This chapter provides the following information on events:



## Introduction to Events

An *event* is a message that a device driver sends to interested entities to indicate that a change of state has taken place. Events are implemented in the Solaris OS as user-defined, name-value pair structures that are managed using the `nvlist*` functions. (See the `nvlist_alloc`(9F) man page. Events are organized by vendor, class, and subclass. For example, you could define a class for monitoring environmental conditions. An environmental class could have subclasses to indicate changes in temperature, fan status, and power.

When a change in state occurs, the device notifies the driver. The driver then uses the `ddi_log_sysevent`(9F) function to log this event in a queue called `sysevent`. The `sysevent` queue passes events to the user level for handling by either the `syseventd` daemon or `syseventconfd` daemon. These daemons send notifications to any applications that have subscribed for notification of the specified event.

Two methods for designers of user–level applications deal with events:

- An application can use the routines in `libsysevent`(3LIB) to subscribe with the `syseventd` daemon for notification when a specific event occurs.

- A developer can write a separate user-level application to respond to an event. This type of application needs to be registered with `syseventadm`(1M). When `syseventconfd` encounters the specified event, the application is run and deals with the event accordingly.

This process is illustrated in the following figure.

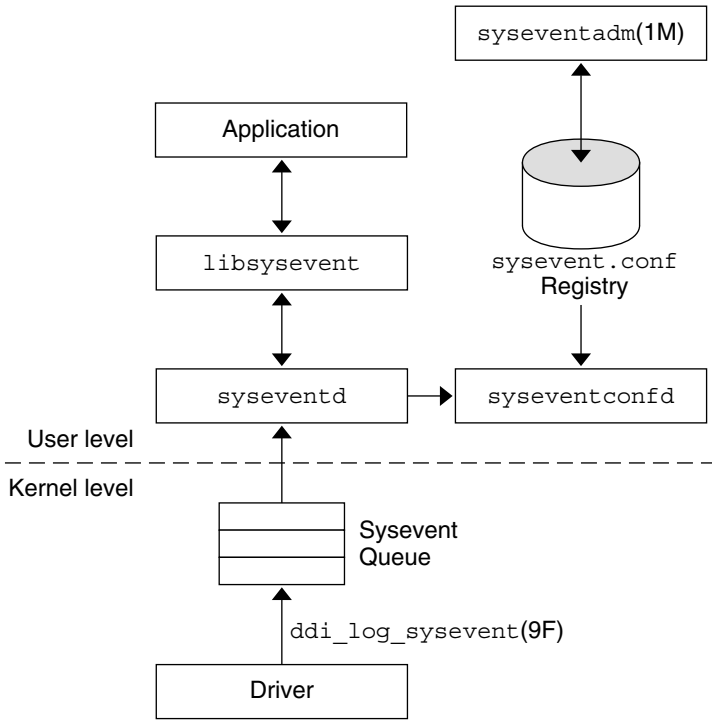



**FIGURE 5–1** Event Plumbing

# Using `ddi_log_sysevent()` to Log Events

Device drivers use the `ddi_log_sysevent`(9F) interface to generate and log events with the system.

## ddi_log_sysevent() Syntax

ddi_log_sysevent() uses the following syntax:

```
int ddi_log_sysevent(dev_info_t *dip, char *vendor, char *class,
    char *subclass, nvlist_t *attr-list, sysevent_id_t *eidp, int sleep-flag);
```

where:

*dip* A pointer to the *dev_info* node for this driver.

*vendor* A pointer to a string that defines the driver's vendor. Third-party drivers should use their company's stock symbol or a similarly enduring identifier. Sun-supplied drivers use DDI_VENDOR_SUNW.

*class* A pointer to a string defining the event's class. *class* is a driver-specific value. An example of a class might be a string that represents a set of environmental conditions that affect a device. This value must be understood by the event consumer.

*subclass* A driver-specific string that represents a subset of the *class* argument. For example, within a class that represents environmental conditions, an event subclass might refer to the device's temperature. This value must be intelligible to the event consumer.

*attr-list* A pointer to an nvlist_t structure that lists name-value attributes associated with the event. Name-value attributes are driver-defined and can refer to a specific attribute or condition of the device.

For example, consider a device that reads both CD-ROMs and DVDs. That device could have an attribute with the name disc_type and the value equal to either cd_rom or dvd.

As with *class* and *subclass*, an event consumer must be able to interpret the name–value pairs.

For more information on name-value pairs and the nvlist_t structure, see "Defining Event Attributes" on page 82, as well as the nvlist_alloc(9F) man page.

If the event has no attributes, then this argument should be set to NULL.

*eidp* The address of a sysevent_id_t structure. The sysevent_id_t structure is used to provide a unique identification for the event. ddi_log_sysevent(9F) returns this structure with a system-provided event sequence number and time stamp. See the ddi_log_sysevent(9F) man page for more information on the sysevent_id_t structure.

*sleep-flag* A flag that indicates how a caller responds when resources are not available. If *sleep-flag* is set to DDI_SLEEP, the driver blocks until the resources become available. With DDI_NOSLEEP, allocations may sleep

but are guaranteed to succeed. DDI_NOSLEEP allocations are guaranteed not to sleep but may return NULL if no memory is currently available.

## Sample Code for Logging Events

A device driver performs the following tasks to log events:

- Allocate memory for the attribute list using nvlist_alloc(9F)
- Add name-value pairs to the attribute list
- Use the ddi_log_sysevent(9F) function to log the event in the sysevent queue
- Call nvlist_free(9F) when the attribute list is no longer needed

The following example demonstrates how to use ddi_log_sysevent().

**EXAMPLE 5–1** Calling ddi_log_sysevent()

```
char *vendor_name = "DDI_VENDOR_JGJG"
char *my_class = "JGJG_event";
char *my_subclass = "JGJG_alert";
nvlist_t *nvl;
...
nvlist_alloc(&nvl, nvflag, kmflag);
...
(void) nvlist_add_byte_array(nvl, propname, (uchar_t *)propval, proplen + 1);
...
if (ddi_log_sysevent(dip, vendor_name, my_class,
    my_subclass, nvl, NULL, DDI_SLEEP)!= DDI_SUCCESS)
    cmn_err(CE_WARN, "error logging system event");
nvlist_free(nvl);
```

# Defining Event Attributes

Event attributes are defined as a list of name-value pairs. The Solaris DDI provides routines and structures for storing information in name-value pairs. Name-value pairs are retained in an nvlist_t structure, which is opaque to the driver. The value for a name-value pair may be a Boolean, an int, a byte, a string, an nvlist, or an array of these data types. An int may be defined as 16 bits, 32 bits, or 64 bits and can be signed or unsigned.

The steps in creating a list of name-value pairs are as follows.

1. Create an nvlist_t structure with nvlist_alloc(9F).

   The nvlist_alloc() interface takes three arguments:

- *nvlp* – Pointer to a pointer to an `nvlist_t` structure
- *nvflag* – Flag to indicate the uniqueness of the names of the pairs. If this flag is set to `NV_UNIQUE_NAME_TYPE`, any existing pair that matches the name and type of a new pair is removed from the list. If the flag is set to `NV_UNIQUE_NAME`, then any existing pair with a duplicate name is removed, regardless of its type. Specifying `NV_UNIQUE_NAME_TYPE` allows a list to contain two or more pairs with the same name as long as their types are different, whereas with `NV_UNIQUE_NAME` only one instance of a pair name can be in the list. If the flag is not set, then no uniqueness checking is done and the consumer of the list is responsible for dealing with duplicates.
- *kmflag* – Flag to indicate the allocation policy for kernel memory. If this argument is set to `KM_SLEEP`, then the driver blocks until the requested memory is available for allocation. `KM_SLEEP` allocations may sleep but are guaranteed to succeed. `KM_NOSLEEP` allocations are guaranteed not to sleep but may return NULL if no memory is currently available.

2. Populate the `nvlist` with name-value pairs. For example, to add a string, use `nvlist_add_string`(9F). To add an array of 32-bit integers, use `nvlist_add_int32_array`(9F). The `nvlist_add_boolean`(9F) man page contains a complete list of interfaces for adding pairs.

To deallocate a list, use `nvlist_free`(9F).

The following code sample illustrates the creation of a name-value list.

**EXAMPLE 5–2** Creating and Populating a Name-Value Pair List

```
nvlist_t*
create_nvlist()
    {
    int err;
    char *str = "child";
    int32_t ints[] = {0, 1, 2};
    nvlist_t *nvl;

    err = nvlist_alloc(&nvl, NV_UNIQUE_NAME, 0);    /* allocate list */
    if (err)
        return (NULL);
    if ((nvlist_add_string(nvl, "name", str) != 0) ||
        (nvlist_add_int32_array(nvl, "prop", ints, 3) != 0)) {
        nvlist_free(nvl);
        return (NULL);
    }
    return (nvl);
}
```

Drivers can retrieve the elements of an `nvlist` by using a lookup function for that type, such as `nvlist_lookup_int32_array`(9F), which takes as an argument the name of the pair to be searched for.

**Note –** These interfaces work only if either `NV_UNIQUE_NAME` or `NV_UNIQUE_NAME_TYPE` is specified when `nvlist_alloc`(9F) is called. Otherwise, ENOTSUP is returned, because the list cannot contain multiple pairs with the same name.

A list of name-value list pairs can be placed in contiguous memory. This approach is useful for passing the list to an entity that has subscribed for notification. The first step is to get the size of the memory block that is needed for the list with `nvlist_size`(9F). The next step is to pack the list into the buffer with `nvlist_pack`(9F). The consumer receiving the buffer's content can unpack the buffer with `nvlist_unpack`(9F).

The functions for manipulating name-value pairs are available to both user-level and kernel-level developers. You can find identical man pages for these functions in both *man pages section 3: Library Interfaces and Headers* and in *man pages section 9: DDI and DKI Kernel Functions*. For a list of functions that operate on name-value pairs, see the following table.

**TABLE 5–1** Functions for Using Name-Value Pairs

| Man Page | Purpose / Functions |
|---|---|
| `nvlist_add_boolean`(9F) | Add name-value pairs to the list. Functions include:<br>`nvlist_add_boolean(),nvlist_add_boolean_value(), nvlist_add_byte(),nvlist_add_int8(),nvlist_add_uint8(), nvlist_add_int16(),nvlist_add_uint16(),nvlist_add_int32(), nvlist_add_uint32(),nvlist_add_int64(),nvlist_add_uint64 (),nvlist_add_string(),nvlist_add_nvlist(), nvlist_add_nvpair(),nvlist_add_boolean_array(), nvlist_add_int8_array, nvlist_add_uint8_array(), nvlist_add_nvlist_array(),nvlist_add_byte_array(), nvlist_add_int16_array(),nvlist_add_uint16_array(), nvlist_add_int32_array(),nvlist_add_uint32_array(), nvlist_add_int64_array(),nvlist_add_uint64_array(), nvlist_add_string_array()` |
| `nvlist_alloc`(9F) | Manipulate the name-value list buffer. Functions include:<br>`nvlist_alloc(),nvlist_free(),nvlist_size(),nvlist_pack(), nvlist_unpack(),nvlist_dup(),nvlist_merge()` |

**TABLE 5–1** Functions for Using Name-Value Pairs *(Continued)*

| Man Page | Purpose / Functions |
|---|---|
| nvlist_lookup_boolean(9F) | Search for name-value pairs. Functions include:<br>nvlist_lookup_boolean(),nvlist_lookup_boolean_value(), nvlist_lookup_byte(),nvlist_lookup_int8(), nvlist_lookup_int16(),nvlist_lookup_int32(), nvlist_lookup_int64(),nvlist_lookup_uint8(), nvlist_lookup_uint16(),nvlist_lookup_uint32(), nvlist_lookup_uint64(),nvlist_lookup_string(), nvlist_lookup_nvlist(),nvlist_lookup_boolean_array, nvlist_lookup_byte_array(),nvlist_lookup_int8_array(), nvlist_lookup_int16_array(),nvlist_lookup_int32_array(), nvlist_lookup_int64_array(),nvlist_lookup_uint8_array(), nvlist_lookup_uint16_array(),nvlist_lookup_uint32_array(), nvlist_lookup_uint64_array(),nvlist_lookup_string_array(), nvlist_lookup_nvlist_array(),nvlist_lookup_pairs() |
| nvlist_next_nvpair(9F) | Get name–value pair data. Functions include:<br>nvlist_next_nvpair(),nvpair_name(),nvpair_type() |
| nvlist_remove(9F) | Remove name-value pairs. Functions include:<br>nv_remove(),nv_remove_all() |

CHAPTER 6

# Driver Autoconfiguration

In autoconfiguration, the driver loads code and static data into memory. This information is then registered with the system. Autoconfiguration also involves attaching individual device instances that are controlled by the driver.

This chapter provides information on the following subjects:



## Driver Loading and Unloading

The system loads driver binary modules from the `drv` subdirectory of the kernel module directory for autoconfiguration. See "Copying the Driver to a Module Directory" on page 422.

After a module is read into memory with all symbols resolved, the system calls the `_init`(9E) entry point for that module. The `_init()` function calls `mod_install`(9F), which actually loads the module.

---

**Note –** During the call to `mod_install()`, other threads are able to call `attach`(9E) as soon as `mod_install()` is called. From a programming standpoint, all `_init()` initialization must occur before `mod_install()` is called. If `mod_install()` fails (that is a nonzero value is returned), then the initialization must be backed out.

---

Upon successful completion of `_init()`, the driver is properly registered with the system. At this point, the driver is not actively managing any device. Device management happens as part of device configuration.

The system unloads driver binary modules either to conserve system memory or at the explicit request of a user. Before deleting the driver code and data from memory, the `_fini`(9E) entry point of the driver is invoked. The driver is unloaded, if and only if `_fini()` returns success.

The following figure provides a structural overview of a device driver. The shaded area highlights the driver data structures and entry points. The upper half of the shaded area contains data structures and entry points that support driver loading and unloading. The lower half is concerned with driver configuration.

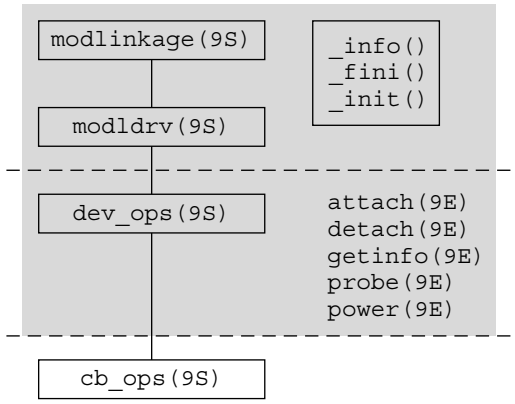



**FIGURE 6–1** Module Loading and Autoconfiguration Entry Points

# Data Structures Required for Drivers

To support autoconfiguration, drivers are required to statically initialize the following data structures:

- `modlinkage`(9S)
- `modldrv`(9S)
- `dev_ops`(9S)
- `cb_ops`(9S)

The data structures in Figure 5-1 are relied on by the driver. These structures must be provided and be initialized correctly. Without these data structures, the driver might not load properly. As a result, the necessary routines might not be loaded. If an operation is not supported by the driver, the address of the `nodev`(9F) routine can be used as a placeholder. In some instances, the driver supports the entry point and only needs to return success or failure. In such cases, the address of the routine `nulldev`(9F) can be used.

---

**Note –** These structures should be initialized at compile-time. The driver should not access or change the structures at any other time.

---

## `modlinkage` Structure

```
static struct modlinkage xxmodlinkage = {
    MODREV_1,       /* ml_rev */
    &xxmodldrv,     /* ml_linkage[] */
    NULL            /* NULL termination */
};
```

The first field is the version number of the module that loads the subsystem. This field should be `MODREV_1`. The second field points to driver's `modldrv` structure defined next. The last element of the structure should always be NULL.

## `modldrv` Structure

```
static struct modldrv xxmodldrv = {
    &mod_driverops,         /* drv_modops */
    "generic driver v1.1",  /* drv_linkinfo */
    &xx_dev_ops             /* drv_dev_ops */
};
```

This structure describes the module in more detail. The first field provides information regarding installation of the module. This field should be set to `&mod_driverops` for driver modules. The second field is a string to be displayed by `modinfo`(1M). The second field should contain sufficient information for identifying the version of source code that generated the driver binary. The last field points to the driver's `dev_ops` structure defined in the following section.

## `dev_ops` Structure

```
static struct dev_ops xx_dev_ops = {
    DEVO_REV,       /* devo_rev, */
    0,              /* devo_refcnt  */
```

```
    xxgetinfo,      /* getinfo(9E) */
    nulldev,        /* identify(9E) */
    xxprobe,        /* probe(9E) */
    xxattach,       /* attach(9E) */
    xxdetach,       /* detach(9E) */
    nodev,          /* devo_reset */
    &xx_cb_ops,     /* devo_cb_ops */
    NULL,           /* devo_bus_ops */
    &xxpower        /* power(9E) */
};
```

The dev_ops(9S) structure enables the kernel to find the autoconfiguration entry points of the device driver. The devo_rev field identifies the revision number of the structure. This field must be set to DEVO_REV. The devo_refcnt field must be initialized to zero. The function address fields should be filled in with the address of the appropriate driver entry point, except in the following cases:

- Set the devo_probe field to nulldev(9F) if a probe(9E) routine is not needed.
- Set the identify(9E) field to nulldev(9F). The identify() function is obsolete and no longer required.
- Set the devo_reset field to nodev(9F).
- Set the power(9E) field to NULL if a power() routine is not needed. Drivers for devices that provide Power Management functionality must have a power() entry point.

The devo_cb_ops member should include the address of the cb_ops(9S) structure. The devo_bus_ops field must be set to NULL.

## cb_ops Structure

```
static struct cb_ops xx_cb_ops = {
    xxopen,         /* open(9E) */
    xxclose,        /* close(9E) */
    xxstrategy,     /* strategy(9E) */
    xxprint,        /* print(9E) */
    xxdump,         /* dump(9E) */
    xxread,         /* read(9E) */
    xxwrite,        /* write(9E) */
    xxioctl,        /* ioctl(9E) */
    xxdevmap,       /* devmap(9E) */
    nodev,          /* mmap(9E) */
    xxsegmap,       /* segmap(9E) */
    xxchpoll,       /* chpoll(9E) */
    xxprop_op,      /* prop_op(9E) */
    NULL,           /* streamtab(9S) */
    D_MP | D_64BIT, /* cb_flag */
    CB_REV,         /* cb_rev */
    xxaread,        /* aread(9E) */
    xxawrite        /* awrite(9E) */
};
```

The cb_ops(9S) structure contains the entry points for the character operations and block operations of the device driver. Any entry points that the driver does not support should be initialized to nodev(9F). For example, character device drivers should set all the block-only fields, such as cb_stategy, to nodev(9F). Note that the mmap(9E) entry point is maintained for compatibility with previous releases. Drivers should use the devmap(9E) entry point for device memory mapping. If devmap(9E) is supported, set mmap(9E) to nodev(9F).

The streamtab field indicates whether the driver is STREAMS-based. Only the network device drivers that are discussed in Chapter 18 are STREAMS-based. All non-STREAMS-based drivers *must* set the streamtab field to NULL.

The cb_flag member contains the following flags:

- The D_MP flag indicates that the driver is safe for multithreading. The Solaris 10 Operating System supports only thread-safe drivers so D_MP must be set.
- The D_64BIT flag causes the driver to use the uio_loffset field of the uio(9S) structure. The driver should set the D_64BIT flag in the cb_flag field to handle 64-bit offsets properly.
- The D_DEVMAP flag supports the devmap(9E) entry point. For information on devmap(9E), see Chapter 10.

cb_rev is the cb_ops structure revision number. This field must be set to CB_REV.

# Loadable Driver Interfaces

Device drivers must be dynamically loadable. Drivers should also be unloadable to help conserve memory resources. Drivers that can be unloaded are also easier to test, debug, and patch.

Each device driver is required to implement _init(9E), _fini(9E), and _info(9E) entry points to support driver loading and unloading. The following example shows a typical implementation of loadable driver interfaces.

**EXAMPLE 6–1** Loadable Interface Section

```
static void *statep;                /* for soft state routines */
static struct cb_ops xx_cb_ops;                 /* forward reference */
static struct dev_ops xx_ops = {
    DEVO_REV,
    0,
    xxgetinfo,
    nulldev,
    xxprobe,
    xxattach,
    xxdetach,
```

**EXAMPLE 6–1** Loadable Interface Section *(Continued)*

```
    xxreset,
    nodev,
    &xx_cb_ops,
    NULL,
    xxpower
};

static struct modldrv modldrv = {
    &mod_driverops,
    "xx driver v1.0",
    &xx_ops
};

static struct modlinkage modlinkage = {
    MODREV_1,
    &modldrv,
    NULL
};

int
_init(void)
{
    int error;
    ddi_soft_state_init(&statep, sizeof (struct xxstate),
            estimated number of instances);
      further per-module initialization if necessary
    error = mod_install(&modlinkage);
    if (error != 0) {
            undo any per-module initialization done earlier
        ddi_soft_state_fini(&statep);
    }
    return (error);
}

int
_fini(void)
{
    int error;
    error = mod_remove(&modlinkage);
    if (error == 0) {
            release per-module resources if any were allocated
        ddi_soft_state_fini(&statep);
    }
    return (error);
}

int
_info(struct modinfo *modinfop)
{
    return (mod_info(&modlinkage, modinfop));
}
```

## _init() Example

The following example shows a typical _init(9E) interface.

**EXAMPLE 6–2** _init() Function

```
static void *xxstatep;
int
_init(void)
{
    int error;
    const int max_instance = 20;    /* estimated max device instances */

    ddi_soft_state_init(&xxstatep, sizeof (struct xxstate), max_instance);
    error = mod_install(&xxmodlinkage);
    if (error != 0) {
        /*
         * Cleanup after a failure
         */
        ddi_soft_state_fini(&xxstatep);
    }
    return (error);
}
```

The driver should perform any one-time resource allocation or data initialization during driver loading in _init(). For example, the driver should initialize any mutexes global to the driver in this routine. The driver should not, however, use _init(9E) to allocate or initialize anything that has to do with a particular instance of the device. Per-instance initialization must be done in attach(9E). For example, if a driver for a printer can handle more than one printer at the same time, that driver should allocate resources specific to each printer instance in attach().

---

**Note –** Once _init(9E) has called mod_install(9F), the driver should not change any of the data structures attached to the modlinkage(9S) structure because the system might make copies or change the data structures.

---

## _fini() Example

The following example demonstrates the _fini() routine.

```
int
_fini(void)
{
        int error;
    error = mod_remove(&modlinkage);
    if (error != 0) {
        return (error);
    }
```

```
    /*
     * Cleanup resources allocated in _init()
     */
    ddi_soft_state_fini(&xxstatep);
    return (0);
}
```

Similarly, in `_fini()`, the driver should release any resources that were allocated in `_init()`. The driver must remove itself from the system module list.

---

**Note –** `_fini()` might be called when the driver is attached to hardware instances. In this case, `mod_remove`(9F) returns failure. Therefore, driver resources should not be released until `mod_remove()` returns success.

---

## `_info()` Example

The following example demonstrates the `_info`(9E) routine.

```
int
_info(struct modinfo *modinfop)
{
    return (mod_info(&xxmodlinkage, modinfop));
}
```

The driver is called to return module information. The entry point should be implemented as shown above.

# Device Configuration Concepts

For each node in the kernel device tree, the system selects a driver for the node based on the node name and the `compatible` property (see "Binding a Driver to a Device" on page 59). The same driver may bind to multiple device nodes. The driver can differentiate different nodes by instance numbers assigned by the system.

After a driver is selected for a device node, the driver's `probe`(9E) entry point is called to determine the presence of the device on the system. If `probe()` is successful, the driver's `attach`(9E) entry point is invoked to set up and manage the device. The device can be opened if and only if `attach()` returns success (see "`attach()` Entry Point" on page 99).

A device may be unconfigured to conserve system memory resources or to allow device to be removed while the system is still running. To allow the device to be unconfigured, the system first checks if the device instance is referenced. This check

involves calling the driver's `getinfo`(9E) entry point to obtain information known only to the driver (see "`getinfo()` Entry Point" on page 106). If the device instance is not referenced, the driver's `detach`(9E) routine is invoked to unconfigure the device (see "`detach()` Entry Point" on page 104).

To recap, each driver must define the following entry points that are used by the kernel for device configuration:

- `probe`(9E)
- `attach`(9E)
- `detach`(9E)
- `getinfo`(9E)

Note that `attach()`, `detach()`, and `getinfo()` are required. `probe()` is only required for devices that cannot identify themselves. For self-identifying devices, an explicit `probe()` routine can be provided, or `nulldev`(9F) can be specified in the `dev_ops` structure for the `probe()` entry point.

## Device Instances and Instance Numbers

The system assigns an instance number to each device. The driver might not reliably predict the value of the instance number assigned to a particular device. The driver should retrieve the particular instance number that has been assigned by calling `ddi_get_instance`(9F).

Instance numbers represent the system's notion of devices. Each `dev_info`, that is, each node in the device tree, for a particular driver is assigned an instance number by the kernel. Furthermore, instance numbers provide a convenient mechanism for indexing data specific to a particular physical device. The most common use of instance numbers is `ddi_get_soft_state`(9F), which uses instance numbers to retrieve soft state data for specific physical devices.

**Caution –** For pseudo devices, that is, the children of pseudo nexuses, the instance numbers are defined in the `driver.conf`(4) file using the `instance` property. If the `driver.conf` file does not contain the `instance` property, the behavior is undefined. For hardware device nodes, the system assigns instance numbers when the device is first seen by the OS. The instance numbers persist across system reboots and OS upgrades.

## Minor Nodes and Minor Numbers

Drivers are responsible for managing their minor number namespace. For example, the `sd` driver needs to export eight character minor nodes and eight block minor nodes to the file system for each disk. Each minor node represents either a block interface or a character interface to a portion of the disk. The `getinfo`(9E) entry point informs the system about the mapping from minor number to device instance (see "`getinfo()` Entry Point" on page 106).

## `probe()` Entry Point

For non-self-identifying devices, the `probe`(9E) entry point should determine whether the hardware device is present on the system.

For `probe()` to determine whether the instance of the device is present, `probe()` needs to perform many tasks that are also commonly done by `attach`(9E). In particular, `probe()` might need to map the device registers.

Probing the device registers is device-specific. The driver often has to perform a series of tests of the hardware to assure that the hardware is really present. The test criteria must be rigorous enough to avoid misidentifying devices. For example, a device might appear to be present when in fact that device is not available, because a different device seems to behave like the expected device.

The test returns the following flags:

- `DDI_PROBE_SUCCESS` if the probe was successful
- `DDI_PROBE_FAILURE` if the probe failed
- `DDI_PROBE_DONTCARE` if the probe was unsuccessful yet `attach`(9E) still needs to be called
- `DDI_PROBE_PARTIAL` if the instance is not present now, but might be present in the future

For a given device instance, `attach`(9E) will not be called until `probe`(9E) has succeeded at least once on that device.

`probe`(9E) must free all the resources that `probe()` has allocated, because `probe()` may be called multiple times. However, `attach`(9E) is not necessarily called even if `probe`(9E) has succeeded

`ddi_dev_is_sid`(9F) may be used in a driver's `probe`(9E) routine to determine whether the device is self-identifying. `ddi_dev_is_sid()` is useful in drivers written for self-identifying and non-self-identifying versions of the same device.

The following example is a sample `probe()` routine.

**EXAMPLE 6–3** `probe`(9E) Routine

```
static int
xxprobe(dev_info_t *dip)
```

**EXAMPLE 6–3** probe(9E) Routine *(Continued)*

```
{

    ddi_acc_handle_t dev_hdl;
    ddi_device_acc_attr_t dev_attr;
    Pio_csr *csrp;
    uint8_t csrval;

    /*
     * if the device is self identifying, no need to probe
     */
    if (ddi_dev_is_sid(dip) == DDI_SUCCESS)
    return (DDI_PROBE_DONTCARE);

    /*
     * Initalize the device access attributes and map in
     * the devices CSR register (register 0)
     */
    dev_attr.devacc_attr_version = DDI_DEVICE_ATTR_V0;
    dev_attr.devacc_attr_endian_flags = DDI_STRUCTURE_LE_ACC;
    dev_attr.devacc_attr_dataorder = DDI_STRICTORDER_ACC;

    if (ddi_regs_map_setup(dip, 0, (caddr_t *)&csrp, 0, sizeof (Pio_csr),
    &dev_attr, &dev_hdl) != DDI_SUCCESS)
    return (DDI_PROBE_FAILURE);

    /*
     * Reset the device
     * Once the reset completes the CSR should read back
     * (PIO_DEV_READY | PIO_IDLE_INTR)
     */
    ddi_put8(dev_hdl, csrp, PIO_RESET);
    csrval = ddi_get8(dev_hdl, csrp);


    /*
     * tear down the mappings and return probe success/failure
     */
    ddi_regs_map_free(&dev_hdl);
    if ((csrval & 0xff) == (PIO_DEV_READY | PIO_IDLE_INTR))
    return (DDI_PROBE_SUCCESS);
    else
    return (DDI_PROBE_FAILURE);
}
```

When the driver's probe(9E) routine is called, the driver does not know whether the device being probed exists on the bus. Therefore, the driver might attempt to access device registers for a nonexistent device. A bus fault might be generated on some buses as a result.

The following example shows a probe(9E) routine that uses ddi_poke8(9F) to check for the existence of the device. ddi_poke8() cautiously attempts to write a value to a specified virtual address, using the parent nexus driver to assist in the process where necessary. If the address is not valid or the value cannot be written without an error occurring, an error code is returned. See also ddi_peek(9F).

In this example, ddi_regs_map_setup(9F) is used to map the device registers.

**EXAMPLE 6–4** probe(9E) Routine Using ddi_poke8(9F)

```
static int
xxprobe(dev_info_t *dip)
{

    ddi_acc_handle_t dev_hdl;
    ddi_device_acc_attr_t dev_attr;
    Pio_csr *csrp;
    uint8_t csrval;

    /*
     * if the device is self-identifying, no need to probe
     */
    if (ddi_dev_is_sid(dip) == DDI_SUCCESS)
    return (DDI_PROBE_DONTCARE);

    /*
     * Initialize the device access attrributes and map in
     * the device's CSR register (register 0)
     */
    dev_attr.devacc_attr_version - DDI_DEVICE_ATTR_V0;
    dev_attr.devacc_attr_endian_flags = DDI_STRUCTURE_LE_ACC;
    dev_attr.devacc_attr_dataorder = DDI_STRICTORDER_ACC;

    if (ddi_regs_map_setup(dip, 0, (caddr_t *)&csrp, 0, sizeof (Pio_csr),
    &dev_attr, &dev_hdl) != DDI_SUCCESS)
    return (DDI_PROBE_FAILURE);

    /*
     * The bus can generate a fault when probing for devices which
     * do not exist.  Use ddi_poke8(9f) to handle any faults which
     * may occur.
     *
     * Reset the device.  Once the reset completes the CSR should read
     * back (PIO_DEV_READY | PIO_IDLE_INTR)
     */
    if (ddi_poke8(dip, csrp, PIO_RESET) != DDI_SUCCESS) {
    ddi_regs_map_free(&dev_hdl);
    return (DDI_FAILURE);


    csrval = ddi_get8(dev_hdl, csrp);
    /*
     * tear down the mappings and return probe success/failure
     */
```

**EXAMPLE 6–4** probe(9E) Routine Using ddi_poke8(9F) *(Continued)*

```
    ddi_regs_map_free(&dev_hdl);
    if ((csrval & 0xff) == (PIO_DEV_READY | PIO_IDLE_INTR))
    return (DDI_PROBE_SUCCESS);
    else
    return (DDI_PROBE_FAILURE);
}
```

# attach() Entry Point

The kernel calls a driver's attach(9E) entry point to attach an instance of a device or to resume operation for an instance of a device that has been suspended or has been shut down by the power management framework. This section discusses only the operation of attaching device instances. Power management is discussed in Chapter 12.

A driver's attach(9E) entry point is called to attach each instance of a device that is bound to the driver. The entry point is called with the instance of the device node to attach, with DDI_ATTACH specified as the cmd argument to attach(9E). The attach entry point typically includes the following types of processing:

- Allocating a soft-state structure for the device instance
- Initializing per-instance mutexes
- Initializing condition variables
- Registering the device's interrupts
- Mapping the registers and memory of the device instance
- Creating minor device nodes for the device instance
- Reporting that the device instance has attached

## Driver Soft–State Management

To assist device driver writers in allocating state structures, the Solaris 10 DDI/DKI provides a set of memory management routines called *software state management routines*, which are also known as the *soft-state routines*. These routines dynamically allocate, retrieve, and destroy memory items of a specified size, and hide the details of list management. An *instance number* identifies the desired memory item. This number is typically the instance number assigned by the system.

Drivers typically allocate a soft-state structure for each device instance that attaches to the driver by calling ddi_soft_state_zalloc(9F), passing the instance number of the device. Because no two device nodes can have the same instance number, ddi_soft_state_zalloc(9F) fails if an allocation already exists for a given instance number.

A driver's character or block entry point (cb_ops(9S)) references a particular soft state structure by first decoding the device's instance number from the dev_t argument that is passed to the entry point function. The driver then calls

ddi_get_soft_state(9F), passing the per-driver soft-state list and the instance number that was derived. A NULL return value indicates that effectively the device does not exist and the appropriate code should be returned by the driver.

See "Creating Minor Device Nodes" on page 100 for additional information on how instance numbers and device numbers, or dev_t's, are related.

## Lock Variable and Conditional Variable Initialization

Drivers should initialize any per-instance locks and condition variables during attach. The initialization of any locks that are acquired by the driver's interrupt handler *must* be initialized prior to adding any interrupt handlers. See Chapter 3 for a description of lock initialization and usage. See Chapter 8 for a discussion of interrupt handler and lock issues.

## Creating Minor Device Nodes

An important part of the attach process is the creation of *minor nodes* for the device instance. A minor node contains the information exported by the device and the DDI framework. The system uses this information to create a *special file* for the minor node under /devices.

Minor nodes are created when the driver calls ddi_create_minor_node(9F). The driver supplies a *minor number*, a *minor name*, a *minor node type*, and whether the minor node represents a block or character device.

Drivers can create any number of minor nodes for a device. The Solaris DDI/DKI expects certain classes of devices to have minor nodes created in a particular format. For example, disk drivers are expected to create 16 minor nodes for each physical disk instance attached. Eight minor nodes are created, representing the a - h block device interfaces, with an additional eight minor nodes for the a,raw - h,raw character device interfaces.

The *minor number* passed to ddi_create_minor_node(9F) is defined wholly by the driver. The minor number is usually an encoding of the device's instance number with a minor node identifier. Taking the above example, the driver creates minor numbers for each of the minor nodes by taking the device's instance number, shifting that number left by three bits, and OR'ing in the minor node index whose values range from 0 to 7. Note that minor nodes a and a,raw share the same minor number. These minor nodes are distinguished by the *spec_type* argument passed to ddi_create_minor_node().

The *minor node type* passed to ddi_create_minor_node(9F) classifies the type of device, such as disks, tapes, network interfaces, frame buffers, and so forth.

The following table lists the types of possible nodes that may be created.

**TABLE 6–1** Possible Node Types

| Constant | Description |
|---|---|
| DDI_NT_SERIAL | Serial port |
| DDI_NT_SERIAL_DO | Dialout ports |
| DDI_NT_BLOCK | Hard disks |
| DDI_NT_BLOCK_CHAN | Hard disks with channel or target numbers |
| DDI_NT_CD | ROM drives (CD-ROM) |
| DDI_NT_CD_CHAN | ROM drives with channel or target numbers |
| DDI_NT_FD | Floppy disks |
| DDI_NT_TAPE | Tape drives |
| DDI_NT_NET | Network devices |
| DDI_NT_DISPLAY | Display devices |
| DDI_NT_MOUSE | Mouse |
| DDI_NT_KEYBOARD | Keyboard |
| DDI_NT_AUDIO | Audio Device |
| DDI_PSEUDO | General pseudo devices |

The node types DDI_NT_BLOCK, DDI_NT_BLOCK_CHAN, DDI_NT_CD, and DDI_NT_CD_CHAN cause devfsadm(1M) to identify the device instance as a disk and to create names in the /dev/dsk or /dev/rdsk directory.

The node type DDI_NT_TAPE causes devfsadm(1M) to identify the device instance as a tape and to create names in the /dev/rmt directory.

The node types DDI_NT_SERIAL and DDI_NT_SERIAL_DO cause devfsadm(1M) to perform these actions:

- Identify the device instance as a serial port
- Create names in the /dev/term directory
- Add entries to the /etc/inittab file

Vendor-supplied strings should include an identifying value such as a name or stock symbol to make the strings unique. The string can be used in conjunction with devfsadm(1M) and the devlinks.tab file (see the devlinks(1M) man page) to create logical names in /dev.

## Deferred Attach

open(9E) might be called on a minor device before attach(9E) has succeeded on the corresponding instance. open() must then return ENXIO, which causes the system to attempt to attach the device. If the attach() succeeds, the open() is retried automatically.

**EXAMPLE 6–5** Typical attach() Entry Point

```
/*
 * Attach an instance of the driver.  We take all the knowledge we
 * have about our board and check it against what has been filled in for
 * us from our FCode or from our driver.conf(4) file.
 */
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
    int instance;
    Pio *pio_p;
    ddi_device_acc_attr_t   da_attr;
    static int pio_validate_device(dev_info_t *);

    switch (cmd) {
    case DDI_ATTACH:

    /*
     * first validate the device conforms to a configuration this driver
     * supports
     */
    if (pio_validate_device(dip) == 0)
        return (DDI_FAILURE);

    /*
     * Allocate a soft state structure for this device instance
     * Store a pointer to the device node in our soft state structure
     * and a reference to the soft state structure in the device
     * node.
     */
    instance = ddi_get_instance(dip);
    if (ddi_soft_state_zalloc(pio_softstate, instance) != 0)
        return (DDI_FAILURE);
    pio_p = ddi_get_soft_state(pio_softstate, instance);
    ddi_set_driver_private(dip, (caddr_t)pio_p);
    pio_p->dip = dip;

    /*
     * Before adding the interrupt, get the interrupt block
     * cookie associated with the interrupt specification to
     * initialize the mutex used by the interrupt handler.
     */
    if (ddi_get_iblock_cookie(dip, 0, &pio_p->iblock_cookie) !=
      DDI_SUCCESS) {
        ddi_soft_state_free(pio_softstate, instance);
        return (DDI_FAILURE);
```

**EXAMPLE 6–5** Typical `attach()` Entry Point *(Continued)*

```
}

mutex_init(&pio_p->mutex, NULL, MUTEX_DRIVER, pio_p->iblock_cookie);

/*
 * Now that the mutex is initialized, add the interrupt itself.
 */
if (ddi_add_intr(dip, 0, NULL, NULL, pio_intr, (caddr_t)instance) !=
  DDI_SUCCESS) {
    mutex_destroy(&pio_p>mutex);
    ddi_soft_state_free(pio_softstate, instance);
    return (DDI_FAILURE);
}


/*
 * Initialize the device access attributes for the register
 * mapping
 */
dev_acc_attr.devacc_attr_version = DDI_DEVICE_ATTR_V0;
dev_acc_attr.devacc_attr_endian_flags = DDI_STRUCTURE_LE_ACC;
dev_acc_attr.devacc_attr_dataorder = DDI_STRICTORDER_ACC;

/*
 * Map in the csr register (register 0)
 */
if (ddi_regs_map_setup(dip, 0, (caddr_t *)&(pio_p->csr), 0,
    sizeof (Pio_csr), &dev_acc_attr, &pio_p->csr_handle) !=
    DDI_SUCCESS) {
    ddi_remove_intr(pio_p->dip, 0, pio_p->iblock_cookie);
    mutex_destroy(&pio_p->mutex);
    ddi_soft_state_free(pio_softstate, instance);
    return (DDI_FAILURE);
}

/*
 * Map in the data register (register 1)
 */
if (ddi_regs_map_setup(dip, 1, (caddr_t *)&(pio_p->data), 0,
    sizeof (uchar_t), &dev_acc_attr, &pio_p->data_handle) !=
    DDI_SUCCESS) {
    ddi_remove_intr(pio_p->dip, 0, pio_p->iblock_cookie);
    ddi_regs_map_free(&pio_p->csr_handle);
    mutex_destroy(&pio_p->mutex);
    ddi_soft_state_free(pio_softstate, instance);
    return (DDI_FAILURE);
}

/*
 * Create an entry in /devices for user processes to open(2)
 * This driver will create a minor node entry in /devices
 * of the form:  /devices/..../pio@X,Y:pio
 */
```

**EXAMPLE 6–5** Typical `attach()` Entry Point *(Continued)*

```
    if (ddi_create_minor_node(dip, ddi_get_name(dip), S_IFCHR,
        instance, DDI_PSEUDO, 0) == DDI_FAILURE) {
        ddi_remove_intr(pio_p->dip, 0, pio_p->iblock_cookie);
        ddi_regs_map_free(&pio_p->csr_handle);
        ddi_regs_map_free(&pio_p->data_handle);
        mutex_destroy(&pio_p->mutex);
        ddi_soft_state_free(pio_softstate, instance);
        return (DDI_FAILURE);
    }

    /*
     * reset device (including disabling interrupts)
     */
    ddi_put8(pio_p->csr_handle, pio_p->csr, PIO_RESET);

    /*
     * report the name of the device instance which has attached
     */
    ddi_report_dev(dip);
    return (DDI_SUCCESS);

    case DDI_RESUME:
    return (DDI_SUCCESS);

    default:
    return (DDI_FAILURE);
    }

}
```

---

**Note –** The `attach()` routine must not make any assumptions about the order of invocations on different device instances. The system may invoke `attach()` concurrently on different device instances. The system may also invoke `attach()` and `detach()` concurrently on different device instances.

---

## `detach()` Entry Point

The kernel calls a driver's `detach`(9E) entry point to detach an instance of a device or to suspend operation for an instance of a device by power management. This section discusses the operation of detaching device instances. Refer to Chapter 12 for a discussion of power management issues.

A driver's `detach()` entry point is called to detach an instance of a device that is bound to the driver. The entry point is called with the instance of the device node to be detached and with `DDI_DETACH`, which is specified as the *cmd* argument to the entry point.

A driver is required to cancel or wait for any time outs or callbacks to complete, then release any resources that are allocated to the device instance before returning. If for some reason a driver cannot cancel outstanding callbacks for free resources, the driver is required to return the device to its original state and return `DDI_FAILURE` from the entry point, leaving the device instance in the attached state.

There are two types of callback routines: those callbacks that can be canceled and those that cannot be canceled. `timeout`(9F) and `bufcall`(9F) callbacks can be atomically cancelled by the driver during `detach`(9E). Other types of callbacks such as `scsi_init_pkt`(9F) and `ddi_dma_buf_bind_handle`(9F) cannot be canceled. The driver must either block in `detach()` until the callback completes or else fail the request to detach.

**EXAMPLE 6–6** Typical `detach()` Entry Point

```
/*
 * detach(9e)
 * free the resources that were allocated in attach(9e)
 */
static int
xxdetach(dev_info_t *dip, ddi_detach_cmd_t cmd)
{
    Pio     *pio_p;
    int     instance;

    switch (cmd) {
    case DDI_DETACH:

    instance = ddi_get_instance(dip);
    pio_p = ddi_get_soft_state(pio_softstate, instance);

    /*
     * turn off the device
     * free any resources allocated in attach
     */
    ddi_put8(pio_p->csr_handle, pio_p->csr, PIO_RESET);
    ddi_remove_minor_node(dip, NULL);
    ddi_regs_map_free(&pio_p->csr_handle);
    ddi_regs_map_free(&pio_p->data_handle);
    ddi_remove_intr(pio_p->dip, 0, pio_p->iblock_cookie);
    mutex_destroy(&pio_p->mutex);
    ddi_soft_state_free(pio_softstate, instance);
    return (DDI_SUCCESS);

    case DDI_SUSPEND:
    default:
    return (DDI_FAILURE);
    }
}
```

# getinfo() Entry Point

The system calls getinfo(9E) to obtain configuration information that only the driver knows. The mapping of minor numbers to device instances is entirely under the control of the driver. The system sometimes needs to ask the driver which device a particular dev_t represents.

getinfo() can take either DDI_INFO_DEVT2INSTANCE or DDI_INFO_DEVT2DEVINFO as its *infocmd* argument. DDI_INFO_DEVT2INSTANCE asks for a device's instance number. DDI_INFO_DEVT2DEVINFO asks for a pointer to the device's dev_info structure.

In the DDI_INFO_DEVT2INSTANCE case, *arg* is a dev_t, and getinfo() must translate the minor number in dev_t to an instance number. In the following example, the minor number *is* the instance number, so getinfo() simply passes back the minor number. In this case, the driver must not assume that a state structure is available, since getinfo() may be called before attach(). The mapping defined by the driver between the minor device number and the instance number does not necessarily follow the mapping shown in the example. In all cases, however, the mapping must be static.

In the DDI_INFO_DEVT2DEVINFO case, *arg* is again a dev_t, so getinfo() first decodes the instance number for the device. getinfo() then passes back the dev_info pointer saved in the driver's soft state structure for the appropriate device, as shown in the following example.

**EXAMPLE 6–7** Typical getinfo() Entry Point

```
/*
 * getinfo(9e)
 * Return the instance number or device node given a dev_t
 */
static int
xxgetinfo(dev_info_t *dip, ddi_info_cmd_t infocmd, void *arg, void **result)
{
    int error;
    Pio *pio_p;
    int instance = getminor((dev_t)arg);

    switch (infocmd) {

    /*
     * return the device node if the driver has attached the
     * device instance identified by the dev_t value which was passed
     */
    case DDI_INFO_DEVT2DEVINFO:
    pio_p = ddi_get_soft_state(pio_softstate, instance);
    if (pio_p == NULL) {
        *result = NULL;
        error = DDI_FAILURE;
    } else {
        mutex_enter(&pio_p->mutex);
```

**EXAMPLE 6–7** Typical `getinfo()` Entry Point *(Continued)*

```
        *result = pio_p->dip;
        mutex_exit(&pio_p->mutex);
        error = DDI_SUCCESS;
    }
    break;

    /*
     * the driver can always return the instance number given a dev_t
     * value, even if the instance is not attached.
     */
    case DDI_INFO_DEVT2INSTANCE:
    *result = (void *)instance;
    error = DDI_SUCCESS;
    break;
    default:
    *result = NULL;
    error = DDI_FAILURE;
    }

    return (error);
}
```

**Note –** The `getinfo()` routine must be kept in sync with the minor nodes that the driver creates. If the minor nodes get out of sync, any hotplug operations might fail and cause a system panic.

# Using Device IDs

The Solaris DDI interfaces enable drivers to provide the *device ID*, a persistent unique identifier for a device. The *device ID* can be used to identify or locate a device. The *device ID* is independent of the `/devices` name or device number (`dev_t`). Applications can use the functions defined in `libdevid`(3LIB) to read and manipulate the device IDs registered by the drivers.

Before a driver can export a *device ID*, the driver needs to verify the device is capable of either providing a unique ID or of storing a host-generated unique ID in a not normally accessible area. WWN (world-wide number) is an example of a unique ID that is provided by the device. Device NVRAM and reserved sectors are examples of non-accessible areas where host-generated unique IDs can be safely stored.

# Registering Device IDs

Drivers typically initialize and register device IDs in the driver's `attach`(9E) handler. As mentioned above, the driver is responsible for registering a *device ID* that is persistent. As such, the driver might be required to handle both devices that can provide a unique ID directly (WWN) and devices where fabricated IDs are written to and read from stable storage.

## Registering a Device-Supplied ID

If the device can supply the driver with an identifier that is unique, the driver can simply initialize the *device ID* with this identifier and register the ID with the Solaris DDI.

```
/*
 * The device provides a guaranteed unique identifier,
 * in this case a SCSI3-WWN.  The WWN for the device has been
 * stored in the device's soft state.
 */
if (ddi_devid_init(dip, DEVID_SCSI3_WWN, un->un_wwn_len, un->un_wwn,
    &un->un_devid) != DDI_SUCCESS)
    return (DDI_FAILURE);

(void) ddi_devid_register(dip, un->un_devid);
```

## Registering a Fabricated ID

A driver may also register device IDs for devices that do not directly supply a unique ID. Registering these IDs requires the device to be capable of storing and retrieving a small amount of data in a reserved area. The driver can then create a fabricated device ID and write it to the reserved area.

```
/*
 * the device doesn't supply a unique ID, attempt to read
 * a fabricated ID from the device's reserved data.
 */

if (xxx_read_deviceid(un, &devid_buf) == XXX_OK) {
    if (ddi_devid_valid(devid_buf) == DDI_SUCCESS) {
        devid_sz = ddi_devi_sizeof(devid_buf);
        un->un_devid = kmem_alloc(devid_sz, KM_SLEEP);
        bcopy(devid_buf, un->un_devid, devid_sz);
        ddi_devid_register(dip, un->un_devid);
        return (XXX_OK);
    }
}

/*
 * we failed to read a valid device ID from the device
 * fabricate an ID, store it on the device, and register
```

```
 * it with the DDI
 */

if (ddi_devid_init(dip, DEVID_FAB, 0, NULL, &un->un_devid)
    == DDI_FAILURE) {
    return (XXX_FAILURE);
}

if (xxx_write_deviceid(un) != XXX_OK) {
    ddi_devid_free(un->un_devid);
    un->un_devid = NULL;
    return (XXX_FAILURE);
}

ddi_devid_register(dip, un->un_devid);
return (XXX_OK);
```

# Unregistering Device IDs

Drivers typically unregister and free any *device IDs* that are allocated as part of the `detach`(9E) handling. The driver first calls `ddi_devid_unregister`(9F) to unregister the *device ID* for the device instance. The driver must then free the *device ID* handle itself by calling `ddi_devid_free`(9F), and then passing the handle that had been returned by `ddi_devid_init`(9F). The driver is responsible for managing any space allocated for WWN or Serial Number data.

CHAPTER 7

# Device Access: Programmed I/O

The Solaris Operating System provides driver developers with a comprehensive set of interfaces for accessing device memory. These interfaces are designed to shield the driver from platform-specific dependencies by handling mismatches between processor and device endianness as well as enforcing any data order dependencies the device might have. By using these interfaces, you can develop a single-source driver that runs on both the SPARC and x86 processor architectures as well as the various platforms from each respective processor family.

This chapter provides information on the following subjects:



## Device Memory

Devices that support programmed I/O are assigned one or more regions of bus address space that map to addressable regions of the device. These mappings are described as pairs of values in the `reg` property associated with the device. Each value pair describes a segment of a bus address.

Drivers identify a particular bus address mapping by specifying the register number, or `regspec`, which is an index into the devices' `reg` property. The `reg` property identifies the `busaddr` and `size` for the device. Drivers pass the register number when making calls to DDI functions such as `ddi_regs_map_setup`(9F). Drivers can determine how many mappable regions have been assigned to the device by calling `ddi_dev_nregs`(9F).

## Managing Differences in Device and Host Endianness

The data format of the host can have different endian characteristics than the data format of the device. In such a case, data transferred between the host and device would need to be byte-swapped to conform to the data format requirements of the destination location. Devices with the same endian characteristics of the host require no byte-swapping of the data.

Drivers specify the endian characteristics of the device by setting the appropriate flag in the `ddi_device_acc_attr`(9S) structure that is passed to `ddi_regs_map_setup`(9F). The DDI framework then performs any required byte-swapping when the driver calls a `ddi_get`*X* routine like `ddi_get8`(9F) or a `ddi_put`*X* routine like `ddi_put16`(9F) to read or write to device memory.

## Managing Data Ordering Requirements

Platforms can reorder loads and stores of data to optimize performance of the platform. Because reordering might not be allowed by certain devices, the driver is required to specify the device's ordering requirements when setting up mappings to the device.

## `ddi_device_acc_attr` Structure

This structure describes the endian and data order requirements of the device. The driver is required to initialize and pass this structure as an argument to `ddi_regs_map_setup`(9F).

```
typedef struct ddi_device_acc_attr {
    ushort_t       devacc_attr_version;
    uchar_t    devacc_attr_endian_flags;
    uchar_t    devacc_attr_dataorder;
} ddi_device_acc_attr_t;
```

`devacc_attr_version` — Specifies `DDI_DEVICE_ATTR_V0`

`devacc_attr_endian_flags` — Describes the endian characteristics of the device. Specified as a bit value whose possible values are:

- `DDI_NEVERSWAP_ACC` – Never swap data
- `DDI_STRUCTURE_BE_ACC` – The device data format is big-endian
- `DDI_STRUCTURE_LE_ACC` – The device data format is little-endian

`devacc_attr_dataorder`

Describes the order in which the CPU must reference data as required by the device. Specified as an enumerated value, where data access restrictions are ordered from most strict to least strict.

- `DDI_STRICTORDER_ACC` – The host must issue the references in order, as specified by the programmer. This flag is the default behavior.
- `DDI_UNORDERED_OK_ACC` – The host is allowed to reorder loads and stores to device memory.
- `DDI_MERGING_OK_ACC` – The host is allowed to merge individual stores to consecutive locations. This setting also implies reordering.
- `DDI_LOADCACHING_OK_ACC` – The host is allowed to read data from the device until a store occurs.
- `DDI_STORECACHING_OK_ACC` – The host is allowed to cache data written to the device. The host can then defer writing the data to the device until a future time.

---

**Note –** The system can access data more strictly than the driver specifies in `devacc_attr_dataorder`. The restriction to the host diminishes while moving from strict data ordering to cache storing in terms of data accesses by the driver.

---

# Mapping Device Memory

Drivers typically map all regions of a device during `attach`(9E). The driver maps a region of device memory by calling `ddi_regs_map_setup`(9F), specifying the register number of the region to map, the device access attributes for the region, an offset, and size. The DDI framework sets up the mappings for the device region and returns an opaque handle to the driver. This data access handle is passed as an argument to the `ddi_get8`(9F) or `ddi_put8`(9F) family of routines when reading data from or writing data to that region of the device.

The driver verifies that the shape of the device mappings match what the driver is expecting by checking the number of mappings exported by the device. The driver calls `ddi_dev_nregs`(9F) and then verifies the size of each mapping by calling `ddi_dev_regsize`(9F).

# Mapping Setup Example

The following simple example demonstrates the DDI data access interfaces. This driver is for a fictional little endian device that accepts one character at a time and generates an interrupt when ready for another character. This device implements two register sets: the first is an 8-bit CSR register, and the second is an 8-bit data register.

**EXAMPLE 7–1** Mapping Setup

```
#define CSR_REG 0
#define DATA_REG 1

/*
 * Initialize the device access attributes for the register
 * mapping
 */
dev_acc_attr.devacc_attr_version = DDI_DEVICE_ATTR_V0;
dev_acc_attr.devacc_attr_endian_flags = DDI_STRUCTURE_LE_ACC;
dev_acc_attr.devacc_attr_dataorder = DDI_STRICTORDER_ACC;

/*
 * Map in the csr register (register 0)
 */
if (ddi_regs_map_setup(dip, CSR_REG, (caddr_t *)&(pio_p->csr), 0,
  sizeof (Pio_csr), &dev_acc_attr, &pio_p->csr_handle) != DDI_SUCCESS) {
mutex_destroy(&pio_p->mutex);
ddi_soft_state_free(pio_softstate, instance);
return (DDI_FAILURE);
}

/*
 * Map in the data register (register 1)
 */
if (ddi_regs_map_setup(dip, DATA_REG, (caddr_t *)&(pio_p->data), 0,
  sizeof (uchar_t), &dev_acc_attr, &pio_p->data_handle) \
        != DDI_SUCCESS) {
mutex_destroy(&pio_p->mutex);
ddi_regs_map_free(&pio_p->csr_handle);
ddi_soft_state_free(pio_softstate, instance);
return (DDI_FAILURE);
}
```

# Device Access Functions

Drivers use the `ddi_get8`(9F) and `ddi_put8`(9F) family of routines in conjunction with the handle returned by `ddi_regs_map_setup`(9F) to transfer data to and from a device. The DDI framework automatically handles any byte-swapping that is required to meet the endian format for the host or device, and enforces any store-ordering constraints the device might have.

The DDI provides interfaces for transferring data in 8-bit, 16-bit, 32–bit, and 64–bit quantities, as well as interfaces for transferring multiple values repeatedly. See the man pages for the `ddi_get8`(9F), `ddi_put8`(9F), `ddi_rep_get8`(9F) and `ddi_rep_put8`(9F) families of routines for a complete listing and description of these interfaces.

The following example builds on Example 7–1 where the driver mapped the device's CSR and data registers. Here, the driver's `write`(9E) entry point, when called, writes a buffer of data to the device one byte at a time.

**EXAMPLE 7–2** Mapping Setup: Buffer

```
static  int
pio_write(dev_t dev, struct uio *uiop, cred_t *credp)
{
    int  retval;
    int  error = OK;
    Pio *pio_p = ddi_get_soft_state(pio_softstate, getminor(dev));

    if (pio_p == NULL)
    return (ENXIO);
    mutex_enter(&pio_p->mutex);
    /*
     * enable interrupts from the device by setting the Interrupt
     * Enable bit in the devices CSR register
     */
    ddi_put8(pio_p->csr_handle, pio_p->csr,
      (ddi_get8(pio_p->csr_handle, pio_p->csr) | PIO_INTR_ENABLE));

    while (uiop->uio_resid > 0) {
    /*
     * This device issues an IDLE interrupt when it is ready
     * to accept a character; the interrupt can be cleared
     * by setting PIO_INTR_CLEAR.  The interrupt is reasserted
     * after the next character is written or the next time
     * PIO_INTR_ENABLE is toggled on.
     *
     * wait for interrupt (see pio_intr)
     */
     cv_wait(&pio_p->cv, &pio_p->mutex);
```

**EXAMPLE 7–2** Mapping Setup: Buffer *(Continued)*

```
     /*
      * get a character from the user's write request
      * fail the write request if any errors are encountered
      */
     if ((retval = uwritec(uiop)) == -1) {
         error = retval;
         break;
     }

     /*
      * pass the character to the device by writing it to
      * the device's data register
      */
     ddi_put8(pio_p->data_handle, pio_p->data, (uchar_t)retval);
    }

    /*
     * disable interrupts by clearing the Interrupt Enable bit
     * in the CSR
     */
    ddi_put8(pio_p->csr_handle, pio_p->csr,
      (ddi_get8(pio_p->csr_handle, pio_p->csr) & ~PIO_INTR_ENABLE));

    mutex_exit(&pio_p->mutex);
    return (error);
}
```

# Alternate Device Access Interfaces

In addition to implementing all device accesses through the `ddi_get8`(9F) and `ddi_put8`(9F) families of interfaces, the Solaris OS provides interfaces that are specific to particular bus implementations. While these functions can be more efficient on some platforms, use of these routines can limit the ability of the driver to remain portable across different bus versions of the device.

## Memory Space Access

With memory mapped access, device registers appear in memory address space. The `ddi_get`*X* family of routines and the `ddi_put`*X* family are available for use by drivers as an alternative to the standard device access interfaces.

## I/O Space Access

With I/O space access, the device registers appear in I/O space, where each addressable element is called an I/O port. The `ddi_io_get8`(9F) and `ddi_io_put8`(9F) routines are available for use by drivers as an alternative to the standard device access interfaces.

## PCI Configuration Space Access

To access PCI configuration space without using the normal device access interfaces, a driver is required to map PCI configuration space by calling `pci_config_setup`(9F) in place of `ddi_regs_map_setup`(9F). The driver can then call the `pci_config_get8`(9F) and `pci_config_put8`(9F) families of interfaces to access PCI configuration space.

CHAPTER 8

# Interrupt Handlers

This chapter describes mechanisms for handling interrupts, such as registering, servicing, and removing interrupts. This chapter provides information on the following subjects:



## Interrupt Handler Overview

An interrupt is a hardware signal from a device to a CPU. An interrupt tells the CPU that the device needs attention and that the CPU should stop any current activity and respond to the device. If a CPU is available, that is, not performing a task with higher priority, the CPU suspends the current thread. The CPU then invokes the interrupt handler for that device. The job of the interrupt handler is to service the device and stop the device from interrupting. Once the handler returns, the CPU resumes the activity from before the interrupt occurred.

The DDI/DKI provides interfaces for registering and servicing interrupts.

### Interrupt Specification

The *interrupt specification* is information the system uses to bind a device interrupt source with a specific device interrupt handler. The specification describes the information provided by the hardware to the system when making an interrupt request. The information in an interrupt specification varies from bus to bus.

Interrupt specifications typically include a bus-interrupt level. For vectored interrupts, the specifications include an interrupt vector. On x86 platforms, the interrupt specification defines the relative interrupt priority of the device. Interrupt specifications are bus specific. See the man pages for `isa`(4), `sbus`(4), and `pci`(4) for information on interrupt specifications for these buses.

## Interrupt Number

The driver must provide the system with an interrupt number to register an interrupt. This interrupt number identifies the interrupt specification for which the driver is registering a handler. Most devices have one interrupt: interrupt number 0. However, some devices have different interrupts for different events. A communications controller might have one interrupt for receive ready and another interrupt for transmit ready. If a driver has to support several variations of a controller, the driver can call `ddi_dev_nintrs`(9F) to find out the number of device interrupts. Normally, the device driver knows how many interrupts the device has.

## Interrupt Block Cookies

An `iblock` cookie is an opaque data structure that represents the information the system needs to block interrupts. This cookie is returned from `ddi_get_iblock_cookie`(9F) or `ddi_get_soft_iblock_cookie`(9F). This interface uses an interrupt number to return the `iblock` cookie associated with a specific interrupt source. The value of the `iblock` cookie must be passed to `mutex_init`(9F) to initialize driver mutexes to be used in the interrupt routine. The value of the `iblock` cookie is obtained by passing the address of the cookie to `ddi_get_iblock_cookie()` or `ddi_get_soft_iblock_cookie()`, as shown in the following example:

```
ddi_get_soft_iblock_cookie(dip, DDI_SOFTINT_HI,
    &xsp->low_iblock_cookie)
mutex_init(&xsp->low_mu, NULL, MUTEX_DRIVER,
    (void *)xsp->low_iblock_cookie);
```

# Device Interrupts

Buses implement interrupts in two common ways: *vectored* and *polled*. Both methods commonly supply a bus-interrupt priority level. Vectored devices also supply an interrupt vector. Polled devices do not supply interrupt vectors.

# High-Level Interrupts

A bus prioritizes a device interrupt at a *bus-interrupt level*. The bus interrupt level is then mapped to a processor-interrupt level. A bus interrupt level that maps to a CPU interrupt priority above the scheduler priority level is called a *high-level interrupt*. High-level interrupt handlers are restricted to calling the following DDI interfaces:

- `mutex_enter`(9F) and `mutex_exit`(9F) on a mutex that is initialized with an `iblock` cookie associated with the high-level interrupt
- `ddi_trigger_softintr`(9F)
- The `ddi_get`*X*/`ddi_put`*X* families of routines

A bus-interrupt level by itself does not determine whether a device interrupts at a high level: a given bus-interrupt level can map to a high-level interrupt on one platform, but map to an ordinary interrupt on another platform.

Although the driver can choose whether to support devices that have high-level interrupts, the driver is always required to check the interrupt level. The function `ddi_intr_hilevel`(9F) when given an interrupt number returns a value indicating whether the interrupt is high level.

# Normal Interrupts

The only information the system has about a device interrupt is either the priority level for the bus interrupt, for example, the IPL on an SBus in a SPARC machine, or the interrupt request number, for example, the IRQ on an ISA bus in an x86 machine.

When an interrupt handler is registered, the system adds the handler to a list of potential interrupt handlers for each IPL or IRQ. When the interrupt occurs, the system must determine which device, of all the devices associated with a given IPL or IRQ, actually interrupted. The system calls all the interrupt handlers for the designated IPL or IRQ until one handler *claims* the interrupt.

The following buses are capable of supporting polled interrupts:

- SBus
- ISA
- PCI

# Software Interrupts

The Solaris 10 DDI/DKI supports software interrupts, also known as *soft interrupts*. Soft interrupts are initiated by software rather than by a hardware device. Handlers for these interrupts must also be added to and removed from the system. Soft interrupt handlers run in interrupt context and therefore can be used to do many of the tasks that belong to an interrupt handler.

Hardware interrupt handlers must perform their tasks quickly, because the handlers may have to suspend other system activity while doing these tasks. This requirement is particularly true for high-level interrupt handlers, which operate at priority levels greater than the priority level of the system scheduler. High-level interrupt handlers mask the operations of all lower-priority interrupts, including the interrupt operations of the system clock. Consequently, the interrupt handler must avoid involvement in activities that might cause it to sleep, such as acquiring a mutex.

If the handler sleeps, then the system might hang because the clock is masked and incapable of scheduling the sleeping thread. For this reason, high-level interrupt handlers normally perform a minimum amount of work at high-priority levels and delegate other tasks to software interrupts, which run below the priority level of the high-level interrupt handler. Because software interrupt handlers run below the priority level of the system scheduler, software interrupt handlers can do the work that the high-level interrupt handler was incapable of doing.

# Registering Interrupts

Before a device driver can receive and service interrupts, the driver must register an interrupt handler with the system by calling `ddi_add_intr`(9F). Registering interrupts provides the system with a way to associate an interrupt handler with an interrupt specification. The interrupt handler is called when the device might have been responsible for the interrupt. The handler has the responsibility of determining whether it should handle the interrupt and, if so, of claiming that interrupt.

**Caution –** A potential race condition exists between the time that an interrupt handler is added and the time that the mutexes are initialized. The interrupt routine is eligible to be called as soon as `ddi_add_intr`(9F) returns. Another device could potentially interrupt and cause the handler to be invoked. Such a situation would result in the interrupt routine being called before any mutexes have been initialized with the returned interrupt block cookie. If the interrupt routine acquires a mutex before the mutex has been initialized, undefined behavior can result. To ensure that this race condition does not occur, always initialize mutexes and any other data used in the interrupt handler before adding the interrupt.

To register a driver's interrupt handler, the driver usually performs the following steps in `attach`(9E).

1. Test for high-level interrupts by calling `ddi_intr_hilevel`(9F) to find out whether the interrupt specification maps to a high-level interrupt. If the specification maps accordingly, one possibility is to post a message to that effect and return `DDI_FAILURE`. See Example 8–1.

2. Get the `iblock` cookie by calling `ddi_get_iblock_cookie`(9F).
3. Initialize any associated mutexes with the `iblock` cookie by calling `mutex_init`(9F).
4. Register the interrupt handler by calling `ddi_add_intr`(9F).

The following example shows how to install an interrupt handler.

**EXAMPLE 8–1** Routine Installation of an Interrupt Handler With `attach()`

```
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
    struct xxstate *xsp;
    switch (cmd) {
    case DDI_ATTACH:
        [...]
        if (ddi_intr_hilevel(dip, inumber) != 0){
            cmn_err(CE_CONT,
            "xx: high-level interrupts are not supported\n");
            return (DDI_FAILURE);
        }
        ddi_get_iblock_cookie(dip, inumber, &xsp->iblock_cookie);
        mutex_init(&xsp->mu, NULL, MUTEX_DRIVER,
        (void *)xsp->iblock_cookie);
        cv_init(&xsp->cv, NULL, CV_DRIVER, NULL);
        if (ddi_add_intr(dip, inumber, NULL, NULL, xxintr,
            (caddr_t)xsp) != DDI_SUCCESS){
            cmn_err(CE_WARN, "xx: cannot add interrupt handler.");
            goto failed;
        }
        return (DDI_SUCCESS);
    case DDI_RESUME:
          For information, see Chapter 12, "Power Management."
    default:
    return (DDI_FAILURE);
    }
    failed:
       remove interrupt handler if necessary, destroy mutex and condition variable
    return (DDI_FAILURE);
}
```

# Interrupt Handler Responsibilities

The interrupt handler has a set of responsibilities to perform. Some responsibilities are required by the framework, and some responsibilities are required by the device. All interrupt handlers are required to do the following tasks:

- **Determine whether the device is interrupting and possibly reject the interrupt.**

The interrupt handler must first examine the device to determine whether this device has issued the interrupt. If the device has not issued the interrupt, the handler must return `DDI_INTR_UNCLAIMED`. This step allows the implementation of *device polling*. Device polling tells the system whether this device, among a number of devices at the given interrupt priority level, has issued the interrupt.

- **Inform the device that the device is being serviced.**

  Informing a device about servicing is a device-specific operation that is required for the majority of devices. For example, SBus devices are required to interrupt until the driver tells the SBus devices to stop. This approach guarantees that all SBus devices that interrupt at the same priority level are serviced.

- **Perform any I/O request-related processing.**

  Devices interrupt for different reasons, such as *transfer done* or *transfer error*. This step can involve using data access functions to read the device's data buffer, examine the device's error register, and set the status field in a data structure accordingly. Interrupt dispatching and processing are relatively time consuming.

- **Do any additional processing that could prevent another interrupt.**

  For example, read the next item of data from the device.

- **Return** `DDI_INTR_CLAIMED`.

The following example shows an interrupt routine.

**EXAMPLE 8–2** Interrupt Example

```
static uint_t
xxintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    uint8_t     status;
    volatile  uint8_t  temp;

    /*
     * Claim or reject the interrupt.This example assumes
     * that the device's CSR includes this information.
     */
    mutex_enter(&xsp->high_mu);
    /* use data access routines to read status */
    status = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
    if (!(status & INTERRUPTING)) {
        mutex_exit(&xsp->high_mu);
        return (DDI_INTR_UNCLAIMED); /* dev not interrupting */
    }
    /*
     * Inform the device that it is being serviced, and re-enable
     * interrupts. The example assumes that writing to the
     * CSR accomplishes this. The driver must ensure that this data
     * access operation makes it to the device before the interrupt
     * service routine returns. For example, using the data access
     * functions to read the CSR, if it does not result in unwanted
     * effects, can ensure this.
     */
```

**EXAMPLE 8–2** Interrupt Example *(Continued)*

```
    ddi_put8(xsp->data_access_handle, &xsp->regp->csr,
        CLEAR_INTERRUPT | ENABLE_INTERRUPTS);
    /* flush store buffers */
    temp = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);

    mutex_exit(&xsp->mu);
    return (DDI_INTR_CLAIMED);
}
```

Most of the steps performed by the interrupt routine depend on the specifics of the device itself. Consult the hardware manual for the device to determine the cause of the interrupt, detect error conditions, and access the device data registers.

# Handling High-Level Interrupts

High-level interrupts are those interrupts that interrupt at the level of the scheduler and above. This level does not allow the scheduler to run. Therefore, high-level interrupt handlers cannot be pre-empted by the scheduler. High-level interrupts cannot rely on the scheduler, that is, they cannot block because of the scheduler. High-level interrupts can only use mutual exclusion locks for locking.

Because of this situation, the driver must use `ddi_intr_hilevel`(9F) to determine whether the driver is using high-level interrupts. If `ddi_intr_hilevel`(9F) returns true, the driver can fail to attach, or the driver can use a two-level scheme to handle interrupts.

The suggested method is to add a high-level interrupt handler, which simply triggers a lower-priority software interrupt to handle the device. The driver should allow more concurrency by using a separate mutex for protecting data from the high-level handler.

## High-level Mutexes

A mutex initialized with the interrupt block cookie that represents a high-level interrupt is known as a*high-level mutex*. While holding a high-level mutex, the driver is subject to the same restrictions as a high-level interrupt handler.

# High-Level Interrupt Handling Example

In the following example, the high-level mutex (`xsp->high_mu`) is used only to protect data shared between the high-level interrupt handler and the soft interrupt handler. The protected data includes a queue used by both the high-level interrupt handler and the low-level handler, and a flag that indicates that the low-level handler is running. A separate low-level mutex (`xsp->low_mu`) protects the rest of the driver from the soft interrupt handler.

**EXAMPLE 8–3** Handling High-Level Interrupts With `attach()`

```
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
    struct xxstate *xsp;
    [...]
    if (ddi_intr_hilevel(dip, inumber)) {
        ddi_get_iblock_cookie(dip, inumber,
        &xsp->high_iblock_cookie);
        mutex_init(&xsp->high_mu, NULL, MUTEX_DRIVER,
        (void *)xsp->high_iblock_cookie);
        if (ddi_add_intr(dip, inumber, &xsp->high_iblock_cookie,
        &xsp->high_idevice_cookie, xxhighintr, (caddr_t)xsp)
        != DDI_SUCCESS)
        goto failed;
        ddi_get_soft_iblock_cookie(dip, DDI_SOFTINT_HI,
        &xsp->low_iblock_cookie)
        mutex_init(&xsp->low_mu, NULL, MUTEX_DRIVER,
        (void *)xsp->low_iblock_cookie);
        if (ddi_add_softintr(dip, DDI_SOFTINT_HI, &xsp->id,
        &xsp->low_iblock_cookie, NULL,
        xxlowintr, (caddr_t)xsp) != DDI_SUCCESS)
        goto failed;
    } else {
        add normal interrupt handler
    }
    cv_init(&xsp->cv, NULL, CV_DRIVER, NULL);
    [...]
    return (DDI_SUCCESS);
    failed:
        free allocated resources, remove interrupt handlers
    return (DDI_FAILURE);
}
```

The high-level interrupt routine services the device and queues the data. The high-level routine triggers a software interrupt if the low-level routine is not running, as the following example demonstrates.

**EXAMPLE 8–4** High-level Interrupt Routine

```
static uint_t
xxhighintr(caddr_t arg)
{
```

**EXAMPLE 8–4** High-level Interrupt Routine *(Continued)*

```
    struct xxstate    *xsp = (struct xxstate *)arg;
    uint8_t    status;
    volatile  uint8_t  temp;
    int    need_softint;

    mutex_enter(&xsp->high_mu);
    /* read status */
    status = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
    if (!(status & INTERRUPTING)) {
    mutex_exit(&xsp->high_mu);
    return (DDI_INTR_UNCLAIMED); /* dev not interrupting */
    }

    ddi_put8(xsp->data_access_handle,&xsp->regp->csr,
    CLEAR_INTERRUPT | ENABLE_INTERRUPTS);
    /* flush store buffers */
    temp = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
         read data from device and queue the data for the low-level interrupt handler;
    if (xsp->softint_running)
    need_softint = 0;
    else {
    xsp->softint_count++;
    need_softint = 1;
    }
    mutex_exit(&xsp->high_mu);
    /* read-only access to xsp->id, no mutex needed */
    if (need_softint)
    ddi_trigger_softintr(xsp->id);
    return (DDI_INTR_CLAIMED);
}
```

The low-level interrupt routine is started by the high-level interrupt routine, which triggers a software interrupt. The low-level interrupt routine runs until there is nothing left to process, as the following example shows.

**EXAMPLE 8–5** Low-Level Interrupt Routine

```
static uint_t
xxlowintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    [...]
    mutex_enter(&xsp->low_mu);
    mutex_enter(&xsp->high_mu);
    if (xsp->softint_count > 1) {
    xsp->softint_count--;
    mutex_exit(&xsp->high_mu);
    mutex_exit(&xsp->low_mu);
    return (DDI_INTR_CLAIMED);
    }
    if (    queue empty) {
```

**EXAMPLE 8–5** Low-Level Interrupt Routine *(Continued)*

```
    mutex_exit(&xsp->high_mu);
    mutex_exit(&xsp->low_mu);
    return (DDI_INTR_UNCLAIMED);
    }
    xsp->softint_running = 1;
    while (    data on queue) {
    ASSERT(mutex_owned(&xsp->high_mu);
        dequeue data from high-level queue;
    mutex_exit(&xsp->high_mu);
        normal interrupt processing
    mutex_enter(&xsp->high_mu);
    }
    xsp->softint_running = 0;
    xsp->softint_count = 0;
    mutex_exit(&xsp->high_mu);
    mutex_exit(&xsp->low_mu);
    return (DDI_INTR_CLAIMED);
}
```

CHAPTER 9

# Direct Memory Access (DMA)

Many devices can temporarily take control of the bus. These devices can perform data transfers that involve main memory and other devices. Because the device is doing the work without the help of the CPU, this type of data transfer is known as *direct memory access* (DMA). The following types of DMA transfers can be performed:

- Between two devices
- Between a device and memory
- Between memory and memory

This chapter explains transfers between a device and memory only. The chapter provides information on the following subjects:



## DMA Model

The Solaris Device Driver Interface/Driver-Kernel Interface (DDI/DKI) provides a high-level, architecture-independent model for DMA. This model enables the framework, that is, the DMA routines, to hide such architecture-specific details, for instance:

- Setting up DMA mappings
- Building scatter-gather lists
- Ensuring that I/O and CPU caches are consistent

Several abstractions are used in the DDI/DKI to describe aspects of a DMA transaction:

- **DMA object** – Memory that is the source or destination of a DMA transfer.
- **DMA handle** – An opaque object returned from a successful `ddi_dma_alloc_handle`(9F) call. The DMA handle can be used in subsequent DMA subroutine calls to refer to such DMA objects.
- **DMA cookie** – A `ddi_dma_cookie`(9S) structure (`ddi_dma_cookie_t`) describes a contiguous portion of a DMA object that is entirely addressable by the device. The cookie contains DMA addressing information that is required to program the DMA engine.

Rather than map an object directly into memory, device drivers allocate DMA *resources* for a memory object. The DMA routines then perform any platform-specific operations that are needed to set up the object for DMA access. The driver receives a DMA *handle* to identify the DMA resources that are allocated for the object. This handle is opaque to the device driver. The driver must save the handle and pass the handle in subsequent calls to DMA routines. The driver should not interpret the handle in any way.

Operations are defined on a DMA handle that provide the following services:

- Manipulating DMA resources
- Synchronizing DMA objects
- Retrieving attributes of the allocated resources

# Types of Device DMA

Devices perform one of the following three types of DMA:

- Bus-master DMA
- Third-party DMA
- First-party DMA

## Bus-Master DMA

The driver should program the device's DMA registers directly in cases where the device acts like a true *bus master*. For example, a device acts like a bus master when the DMA engine resides on the device board. The transfer address and count are obtained from the DMA cookie to be passed on to the device.

## Third-Party DMA

Third-party DMA utilizes a system DMA engine resident on the main system board, which has several DMA channels that are available for use by devices. The device relies on the system's DMA engine to perform the data transfers between the device and memory. The driver uses DMA engine routines (see `ddi_dmae`(9F)) to initialize and program the DMA engine. For each DMA data transfer, the driver programs the DMA engine and then gives the device a command to initiate the transfer in cooperation with that engine.

## First-Party DMA

Under first-party DMA, the device uses a channel from the system's DMA engine to drive that device's DMA bus cycles. The `ddi_dmae_1stparty`(9F) function is used to configure this channel in a cascade mode so that the DMA engine does not interfere with the transfer.

# Types of Host Platform DMA

The platform on which the device operates provides either direct memory access (DMA) or direct virtual memory access (DVMA).

On platforms that support DMA, the system provides the device with a physical address in order to perform transfers. In this case, the transfer of a DMA object can actually consist of a number of physically discontiguous transfers. An example is when an application transfers a buffer that spans several contiguous virtual pages that map to physically discontiguous pages. To deal with the discontiguous memory, devices for these platforms usually have some kind of scatter-gather DMA capability. Typically, x86 systems provide physical addresses for direct memory transfers.

On platforms that support DVMA, the system provides the device with a virtual address to perform transfers. In this case, memory management units (MMU) provided by the underlying platform translate device accesses to these virtual addresses into the proper physical addresses. The device transfers to and from a contiguous virtual image that can be mapped to discontiguous physical pages. Devices that operate in these platforms do not need scatter-gather DMA capability. Typically, SPARC platforms provide virtual addresses for direct memory transfers.

# DMA Software Components: Handles, Windows, and Cookies

A DMA *handle* is an opaque pointer that represents an object, usually a memory buffer or address. A DMA handle enables a device to perform DMA transfers. Several different calls to DMA routines use the handle to identify the DMA resources that are allocated for the object.

An object represented by a DMA handle is completely covered by one or more *DMA cookies*. A DMA cookie represents a contiguous piece of memory that is used in data transfers by the DMA engine. The system divides objects into multiple cookies based on the following information:

- The `ddi_dma_attr(9S)` attribute structure provided by the driver
- Memory location of the target object
- Alignment of the target object

If an object is too big to fit the request within system resource limitations, that object has to be broken up into multiple *DMA windows*. You can only activate and allocate resources to one window at a time. The `ddi_dma_getwin`(9F) function is used to position between windows within an object. Each DMA window consists of one or more DMA cookies. For more information, see "DMA Windows" on page 150.

Some DMA engines can accept more than one cookie. Such engines perform scatter-gather I/O without the help of the system. In this case, the most efficient approach is to use `ddi_dma_nextcookie`(9F) to get as many cookies as the DMA engine can handle. These cookies must then be programmed into the engine. The device can then be programmed to transfer the total number of bytes covered by the aggregate of these DMA cookies.

# DMA Operations

The steps in a DMA transfer are similar among the types of DMA. The following sections present methods for performing DMA transfers.

---

**Note –** You do not have to ensure that the DMA object is locked in memory in block drivers for buffers that come from the file system. The file system has already locked the data in memory.

---

## Performing Bus-Master DMA Transfers

The driver should perform the following steps for bus-master DMA.

1. Describe the DMA attributes. This step enables the routines to ensure that the device is able to access the buffer.
2. Allocate a DMA handle.
3. Ensure that the DMA object is locked in memory (see the `physio`(9F) or `ddi_umem_lock`(9F) man page).
4. Allocate DMA resources for the object.
5. Program the DMA engine on the device. Next start the engine. When the transfer is complete, continue the bus master operation.
6. Perform any required object synchronizations.
7. Release the DMA resources.
8. Free the DMA handle.

## Performing First-Party DMA Transfers

The driver should perform the following steps for first-party DMA.

1. Allocate a DMA channel.
2. Configure the channel with `ddi_dmae_1stparty`(9F).
3. Ensure that the DMA object is locked in memory (see the `physio`(9F) or `ddi_umem_lock`(9F) man page).
4. Allocate DMA resources for the object.
5. Program the DMA engine on the device.
6. Start the engine.
7. When the transfer is complete, continue the bus-master operation.
8. Perform any required object synchronizations.
9. Release the DMA resources.
10. Deallocate the DMA channel.

## Performing Third-Party DMA Transfers

The driver should perform these steps for third-party DMA.

1. Allocate a DMA channel.
2. Retrieve the system's DMA engine attributes with `ddi_dmae_getattr`(9F).
3. Lock the DMA object in memory (see the man page`physio`(9F) or `ddi_umem_lock`(9F)).

4. Allocate DMA resources for the object.
5. Program the system DMA engine to perform the transfer with `ddi_dmae_prog`(9F).
6. Perform any required object synchronizations.
7. Stop the DMA engine with `ddi_dmae_stop`(9F).
8. Release the DMA resources.
9. Deallocate the DMA channel.

Certain hardware platforms restrict DMA capabilities in a bus-specific way. Drivers should use `ddi_slaveonly`(9F) to determine whether the device is in a slot in which DMA is possible.

# DMA Attributes

DMA attributes describe the attributes and limits of a DMA engine, which include:

- Limits on addresses that the device can access
- Maximum transfer count
- Address alignment restrictions

A device driver must inform the system about any DMA engine limitations through the `ddi_dma_attr`(9S) structure. This action ensures that DMA resources that are allocated by the system can be accessed by the device's DMA engine. The system can impose additional restrictions on the device attributes, but the system never removes any of the driver-supplied restrictions.

## `ddi_dma_attr` Structure

The DMA attribute structure has the following members:

```
typedef struct ddi_dma_attr {
    uint_t      dma_attr_version;       /* version number */
    uint64_t    dma_attr_addr_lo;       /* low DMA address range */
    uint64_t    dma_attr_addr_hi;       /* high DMA address range */
    uint64_t    dma_attr_count_max;     /* DMA counter register */
    uint64_t    dma_attr_align;     /* DMA address alignment */
    uint_t      dma_attr_burstsizes;    /* DMA burstsizes */
    uint32_t    dma_attr_minxfer;       /* min effective DMA size */
    uint64_t    dma_attr_maxxfer;       /* max DMA xfer size */
    uint64_t    dma_attr_seg;       /* segment boundary */
    int         dma_attr_sgllen;    /* s/g length */
    uint32_t    dma_attr_granular;      /* granularity of device */
    uint_t      dma_attr_flags;     /* Bus specific DMA flags */
} ddi_dma_attr_t;
```

where:

`dma_attr_version` Version number of the attribute structure. `dma_attr_version` should be set to DMA_ATTR_V0.

| | |
|---|---|
| `dma_attr_addr_lo` | Lowest bus address that the DMA engine can access. |
| `dma_attr_addr_hi` | Highest bus address that the DMA engine can access. |
| `dma_attr_count_max` | Specifies the maximum transfer count that the DMA engine can handle in one cookie. The limit is expressed as the maximum count minus one. This count is used as a bit mask, so the count must also be one less than a power of two. |
| `dma_attr_align` | Specifies additional alignment requirements for any allocated DMA resources. This field can be used to force more restrictive alignment than implicitly specified by other DMA attributes, such as alignment on a page boundary. |
| `dam_attr_burstsizes` | Specifies the *burst sizes* that the device supports. A burst size is the amount of data the device can transfer before relinquishing the bus. This member is a binary encoding of burst sizes, which are assumed to be powers of two. For example, if the device is capable of doing 1-byte, 2-byte, 4-byte, and 16-byte bursts, this field should be set to 0 x 17. The system also uses this field to determine alignment restrictions. |
| `dma_attr_minxfer` | Minimum effective transfer size that the device can perform. This size also influences restrictions on alignment and on padding. |
| `dma_attr_maxxfer` | Describes the maximum number of bytes that the DMA engine can accommodate in one I/O command. This limitation is only significant if `dma_attr_maxxfer` is less than `(dma_attr_count_max + 1) * dma_attr_sgllen`. |
| `dma_attr_seg` | Upper bound of the DMA engine's address register. `dma_attr_seg` is often used where the upper 8 bits of an address register are a latch that contains a segment number. The lower 24 bits are used to address a segment. In this case, `dma_attr_seg` would be set to 0xFFFFFF, which prevents the system from crossing a 24-bit segment boundary when allocating resources for the object. |
| `dma_attr_sgllen` | Specifies the maximum number of entries in the scatter-gather list. `dma_attr_sgllen` is the number of cookies that the DMA engine can consume in one I/O request to the device. If the DMA engine has no scatter-gather list, this field should be set to 1. |

| | |
|---|---|
| `dma_attr_granular` | This field describes the granularity of the device's DMA transfer ability, in units of bytes. This value is used to specify, for example, the sector size of a mass storage device. DMA requests are broken into multiples of this value. If the device has no scatter-gather capability, then the size of each DMA transfer is a multiple of this value. If the device has scatter-gather capability, then a single segment cannot be smaller than the minimum transfer value. A single segment can, however, be less than the granularity. However the total transfer length of the scatter-gather list must be a multiple of the granularity value. |
| `dma_attr_flags` | This field can be set to `DDI_DMA_FORCE_PHYSICAL`, which indicates that the system should return physical rather than virtual I/O addresses if the system supports both. If the system does not support physical DMA, the return value from `ddi_dma_alloc_handle(9F)` is `DDI_DMA_BADATTR`. In this case, the driver has to clear `DDI_DMA_FORCE_PHYSICAL` and retry the operation. |

## SBus Example

A DMA engine on an SBus in a SPARC machine has the following attributes:

- Access to addresses ranging from 0xFF000000 to 0xFFFFFFFF only
- 32-bit DMA counter register
- Ability to handle byte-aligned transfers
- Support for 1-byte, 2-byte, and 4-byte burst sizes
- Minimum effective transfer size of 1 byte
- 32-bit address register
- No scatter-gather list
- Operation on sectors only, for example, a disk

A DMA engine on an SBus in a SPARC machine has the following attribute structure:

```
static ddi_dma_attr_t attributes = {
    DMA_ATTR_V0,      /* Version number */
    0xFF000000,       /* low address */
    0xFFFFFFFF,       /* high address */
    0xFFFFFFFF,       /* counter register max */
    1,        /* byte alignment */
    0x7,          /* burst sizes: 0x1 | 0x2 | 0x4 */
    0x1,          /* minimum transfer size */
    0xFFFFFFFF,       /* max transfer size */
    0xFFFFFFFF,       /* address register max */
    1,        /* no scatter-gather */
    512,          /* device operates on sectors */
    0,        /* attr flag: set to 0 */
```

```
};
```

## ISA Bus Example

A DMA engine on an ISA bus in an x86 machine has the following attributes:

- Access to the first 16 megabytes of memory only
- Inability to cross a 1–megabyte boundary in a single DMA transfer
- 16-bit counter register
- Ability to handle byte-aligned transfers
- Support for 1-byte, 2-byte, and 4-byte burst sizes
- Minimum effective transfer size of 1 byte
- Ability to hold up to 17 scatter-gather transfers
- Operation on sectors only, for example, a disk

A DMA engine on an ISA bus in an x86 machine has the following attribute structure:

```
static ddi_dma_attr_t attributes = {
    DMA_ATTR_V0,      /* Version number */
    0x00000000,       /* low address */
    0x00FFFFFF,       /* high address */
    0xFFFF,       /* counter register max */
    1,        /* byte alignment */
    0x7,          /* burst sizes */
    0x1,          /* minimum transfer size */
    0xFFFFFFFF,       /* max transfer size */
    0x000FFFFF,       /* address register max */
    17,           /* scatter-gather */
    512,          /* device operates on sectors */
    0,        /* attr flag: set to 0 */
};
```

# Managing DMA Resources

This section describes how to manage DMA resources.

# Object Locking

Before allocating the DMA resources for a memory object, the object must be prevented from moving. Otherwise, the system can remove the object from memory while the device is trying to write to that object. A missing object would cause the data transfer to fail and possibly corrupt the system. The process of preventing memory objects from moving during a DMA transfer is known as *locking down the object*.

The following object types do not require explicit locking:

- Buffers coming from the file system through `strategy`(9E). These buffers are already locked by the file system.
- Kernel memory allocated within the device driver, such as that allocated by `ddi_dma_mem_alloc`(9F).

For other objects such as buffers from user space, `physio`(9F) or `ddi_umem_lock`(9F) must be used to lock down the objects. Locking down objects with these functions is usually performed in the `read`(9E) or `write`(9E) routines of a character device driver. See "Data Transfer Methods" on page 236 for an example.

# Allocating a DMA Handle

A DMA handle is an opaque object that is used as a reference to subsequently allocated DMA resources. The DMA handle is usually allocated in the driver's `attach()` entry point that uses `ddi_dma_alloc_handle`(9F). `ddi_dma_alloc_handle()` takes the device information that is referred to by `dip` and the device's DMA attributes described by a `ddi_dma_attr`(9S) structure as parameters. `ddi_dma_alloc_handle()` has the following syntax:

```
int ddi_dma_alloc_handle(dev_info_t *dip,
    ddi_dma_attr_t *attr, int (*callback)(caddr_t),
    caddr_t arg, ddi_dma_handle_t *handlep);
```

where:

*dip* Pointer to the device's `dev_info` structure.

*attr* Pointer to a `ddi_dma_attr`(9S) structure, as described in "DMA Attributes" on page 134.

*callback* Address of the callback function for handling resource allocation failures.

*arg* Argument to be passed to the callback function.

*handlep* Pointer to a DMA handle to store the returned handle.

# Allocating DMA Resources

Two interfaces allocate DMA resources:

- `ddi_dma_buf_bind_handle`(9F) – Used with `buf(9S)` structures
- `ddi_dma_addr_bind_handle`(9F) – Used with virtual addresses

DMA resources are usually allocated in the driver's `xxstart()` routine, if an `xxstart()` routine exists. See "Asynchronous Data Transfers (Block Drivers)" on page 267 for a discussion of *xxstart*. These two interfaces have the following syntax:

```
int ddi_dma_addr_bind_handle(ddi_dma_handle_t handle,
    struct as *as, caddr_t addr,
    size_t len, uint_t flags, int (*callback)(caddr_t),
    caddr_t arg, ddi_dma_cookie_t *cookiep, uint_t *ccountp);

int ddi_dma_buf_bind_handle(ddi_dma_handle_t handle,
    struct buf *bp, uint_t flags,
    int (*callback)(caddr_t), caddr_t arg,
    ddi_dma_cookie_t *cookiep, uint_t *ccountp);
```

The following arguments are common to both `ddi_dma_addr_bind_handle`(9F) and `ddi_dma_buf_bind_handle`(9F):

*handle* DMA handle and the object for allocating resources.

*flags* Set of flags that indicate the transfer direction and other attributes. `DDI_DMA_READ` indicates a data transfer from device to memory. `DDI_DMA_WRITE` indicates a data transfer from memory to device. See the `ddi_dma_addr_bind_handle`(9F) or `ddi_dma_buf_bind_handle`(9F) man page for a complete discussion of the allowed flags.

*callback* Address of callback function for handling resource allocation failures. See the `ddi_dma_alloc_handle`(9F) man page.

*arg* Argument to pass to the callback function.

*cookiep* Pointer to the first DMA cookie for this object.

*ccountp* Pointer to the number of DMA cookies for this object.

For `ddi_dma_addr_bind_handle`(9F), the object is described by an address range with the following parameters:

*as* Pointer to an address space structure. *as* must be `NULL`.

*addr* Base kernel address of the object.

*len* Length of the object in bytes.

For `ddi_dma_buf_bind_handle`(9F), the object is described by a `buf`(9S) structure pointed to by `bp`.

## Device Register Structure

DMA-capable devices require more registers than were used in the previous examples.

The following fields are used in the device register structure to support DMA-capable device with no scatter-gather support:

```
uint32_t      dma_addr;      /* starting address for DMA */
uint32_t      dma_size;      /* amount of data to transfer */
```

The following fields are used in the device register structure to support DMA-capable devices with scatter-gather support:

```
struct sglentry {
    uint32_t    dma_addr;
    uint32_t    dma_size;
} sglist[SGLLEN];

caddr_t      iopb_addr;      /* When written informs device of the next */
                /* command's parameter block address. */
                /* When read after an interrupt,contains */
                /* the address of the completed command. */
```

## DMA Callback Example

In Example 9–1, `xxstart()` is used as the callback function. The per-device state structure is used as the argument to `xxstart()`. `xxstart()` attempts to start the command. If the command cannot be started because resources are not available, `xxstart()` is scheduled to be called later when resources are available.

Because `xxstart()` is used as a DMA callback, `xxstart()` must follow the following rules, which are imposed on DMA callbacks:

- Resources cannot be assumed to be available. The callback must try to allocate resources again.
- The callback must indicate to the system whether allocation succeeded. `DDI_DMA_CALLBACK_RUNOUT` should be returned if the callback fails to allocate resources, in which case `xxstart()` needs to be called again later. `DDI_DMA_CALLBACK_DONE` indicates success, so that no further callback is necessary.

**EXAMPLE 9–1** DMA Callback Example

```
static int
xxstart(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    struct device_reg *regp;
    int flags;
    mutex_enter(&xsp->mu);
    if (xsp->busy) {
```

**EXAMPLE 9–1** DMA Callback Example *(Continued)*

```
        /* transfer in progress */
        mutex_exit(&xsp->mu);
        return (DDI_DMA_CALLBACK_RUNOUT);
    }
    xsp->busy = 1;
    regp = xsp->regp;
    if (    transfer is a read) {
        flags = DDI_DMA_READ;
    } else {
        flags = DDI_DMA_WRITE;
    }
    mutex_exit(&xsp->mu);
    if (ddi_dma_buf_bind_handle(xsp->handle,xsp->bp,flags,
xxstart,
        (caddr_t)xsp, &cookie, &ccount) != DDI_DMA_MAPPED) {
        /* really should check all return values in a switch */
        mutex_enter(&xsp->mu);
        xsp->busy=0;
        mutex_exit(&xsp->mu);
        return (DDI_DMA_CALLBACK_RUNOUT);
    }
    [...]
        program the DMA engine
    [...]
    return (DDI_DMA_CALLBACK_DONE);
}
```

# Determining Maximum Burst Sizes

Drivers specify the DMA burst sizes that their device supports in the `dma_attr_burstsizes`field of the `ddi_dma_attr`(9S) structure. This field is a bitmap of the supported burst sizes. However, when DMA resources are allocated, the system might impose further restrictions on the burst sizes that might be actually used by the device. The `ddi_dma_burstsizes`(9F) routine can be used to obtain the allowed burst sizes. This routine returns the appropriate burst size bitmap for the device. When DMA resources are allocated, a driver can ask the system for appropriate burst sizes to use for its DMA engine.

**EXAMPLE 9–2** Determining Burst Size

```
#define BEST_BURST_SIZE 0x20 /* 32 bytes */

     if (ddi_dma_buf_bind_handle(xsp->handle,xsp->bp, flags, xxstart,
     (caddr_t)xsp, &cookie, &ccount) != DDI_DMA_MAPPED) {
         /* error handling */
      }
    burst = ddi_dma_burstsizes(xsp->handle);
    /* check which bit is set and choose one burstsize to */
```

**EXAMPLE 9–2** Determining Burst Size *(Continued)*

```
/* program the DMA engine */
if (burst & BEST_BURST_SIZE) {
    program DMA engine to use this burst size      } else {
    other cases      }
```

# Allocating Private DMA Buffers

Some device drivers might need to allocate memory for DMA transfers in addition to performing transfers requested by user threads and the kernel. Some examples of allocating private DMA buffers are setting up shared memory for communication with the device and allocating intermediate transfer buffers. Use `ddi_dma_mem_alloc`(9F) to allocate memory for DMA transfers.

```
int ddi_dma_mem_alloc(ddi_dma_handle_t handle, size_t length,
    ddi_device_acc_attr_t *accattrp, uint_t flags,
    int (*waitfp)(caddr_t), caddr_t arg, caddr_t *kaddrp,
    size_t *real_length, ddi_acc_handle_t *handlep);
```

where:

| | |
|---|---|
| *handle* | DMA handle |
| *length* | Length in bytes of the desired allocation |
| *accattrp* | Pointer to a device access attribute structure |
| *flags* | Data transfer mode flags. Possible values are `DDI_DMA_CONSISTENT` and `DDI_DMA_STREAMING`. |
| *waitfp* | Address of callback function for handling resource allocation failures. See the `ddi_dma_alloc_handle`(9F) man page |
| *arg* | Argument to pass to the callback function |
| *kaddrp* | Pointer on a successful return that contains the address of the allocated storage |
| *real_length* | Length in bytes that was allocated |
| *handlep* | Pointer to a data access handle |

*flags* should be set to `DDI_DMA_CONSISTENT` if the device accesses in a nonsequential fashion. Synchronization steps that use `ddi_dma_sync`(9F) should be as lightweight as possible due to frequent application to small objects. This type of access is commonly known as *consistent* access. Consistent access is particularly useful for I/O parameter blocks that are used for communication between a device and the driver.

On the x86 platform, allocation of DMA memory that is physically contiguous has these requirements:

- The length of the scatter-gather list `dma_attr_sgllen` in the `ddi_dma_attr`(9S) structure must be set to 1.
- Do not specify `DDI_DMA_PARTIAL`. `DDI_DMA_PARTIAL` permits partial resource allocation.

The following example shows how to allocate IOPB memory and the necessary DMA resources to access this memory. DMA resources must still be allocated, and the `DDI_DMA_CONSISTENT` flag must be passed to the allocation function.

**EXAMPLE 9–3** Using `ddi_dma_mem_alloc(9F)`

```
if (ddi_dma_mem_alloc(xsp->iopb_handle, size, &accattr,
    DDI_DMA_CONSISTENT, DDI_DMA_SLEEP, NULL, &xsp->iopb_array,
    &real_length, &xsp->acchandle) != DDI_SUCCESS) {
        error handling
    goto failure;
}
if (ddi_dma_addr_bind_handle(xsp->iopb_handle, NULL,
    xsp->iopb_array, real_length,
    DDI_DMA_READ | DDI_DMA_CONSISTENT, DDI_DMA_SLEEP,
    NULL, &cookie, &count) != DDI_DMA_MAPPED) {
        error handling
    ddi_dma_mem_free(&xsp->acchandle);
    goto failure;
}
```

*flags* should be set to `DDI_DMA_STREAMING` for memory transfers that are sequential, unidirectional, block-sized, and block-aligned. This type of access is commonly known as *streaming* access.

In some cases, an I/O transfer can be sped up by using an I/O cache. I/O cache transfers one cache line at a minimum. `ddi_dma_mem_alloc`(9F) rounds `size` to a multiple of the cache line to avoid data corruption.

`ddi_dma_mem_alloc`(9F) returns the actual size of the allocated memory object. Because of padding and alignment requirements, the actual size might be larger than the requested size. `ddi_dma_addr_bind_handle`(9F) requires the actual length.

`ddi_dma_mem_free`(9F) is used to free the memory allocated by `ddi_dma_mem_alloc`(9F).

---

**Note –** If the memory is not properly aligned, the transfer might succeed. However, the system might choose a different and possibly less efficient transfer mode with fewer restrictions. For this reason, `ddi_dma_mem_alloc()` is preferred over `kmem_alloc`(9F) when allocating memory for the device to access.

---

## Handling Resource Allocation Failures

The resource-allocation routines provide the driver with several options when handling allocation failures. The *waitfp* argument indicates whether the allocation routines block, return immediately, or schedule a callback, as shown in the following table.

**TABLE 9–1** Resource Allocation Handling

| *waitfp* **value** | **Indicated Action** |
|---|---|
| `DDI_DMA_DONTWAIT` | Driver does not want to wait for resources to become available |
| `DDI_DMA_SLEEP` | Driver is willing to wait indefinitely for resources to become available |
| Other values | The address of a function to be called when resources are likely to be available |

# Programming the DMA Engine

When the resources have been successfully allocated, the device must be programmed. Although programming a DMA engine is device specific, all DMA engines require a starting address and a transfer count. Device drivers retrieve these two values from the *DMA cookie* returned by a successful call from `ddi_dma_addr_bind_handle`(9F), `ddi_dma_buf_bind_handle`(9F), or `ddi_dma_getwin`(9F). These functions all return the first DMA cookie and a cookie count indicating whether the DMA object consists of more than one cookie. If the cookie count `N` is greater than 1, `ddi_dma_nextcookie`(9F) has to be called *N*-1 times to retrieve all the remaining cookies.

A DMA cookie is of type `ddi_dma_cookie`(9S). This type of cookie has the following fields:

```
uint64_t    _dmac_ll;       /* 64-bit DMA address */
uint32_t    _dmac_la[2];    /* 2 x 32-bit address */
size_t      dmac_size;      /* DMA cookie size */
uint_t      dmac_type;      /* bus specific type bits */
```

The `dmac_laddress` specifies a 64-bit I/O address that is appropriate for programming the device's DMA engine. If a device has a 64-bit DMA address register, a driver should use this field to program the DMA engine. The `dmac_address` field specifies a 32-bit I/O address that should be used for devices that have a 32-bit DMA address register. `dmac_size` contains the transfer count. Depending on the bus architecture, the `dmac_type` field in the cookie might be required by the driver. The driver should not perform any manipulations, such as logical or arithmetic, on the cookie.

**EXAMPLE 9–4** ddi_dma_cookie(9S) Example

```
ddi_dma_cookie_t            cookie;

     if (ddi_dma_buf_bind_handle(xsp->handle,xsp->bp, flags, xxstart,
     (caddr_t)xsp, &cookie, &xsp->ccount) != DDI_DMA_MAPPED) {
         /* error handling */
      }
     sglp = regp->sglist;
     for (cnt = 1; cnt <= SGLLEN; cnt++, sglp++) {
     /* store the cookie parms into the S/G list */
     ddi_put32(xsp->access_hdl, &sglp->dma_size,
         (uint32_t)cookie.dmac_size);
     ddi_put32(xsp->access_hdl, &sglp->dma_addr,
         cookie.dmac_address);
     /* Check for end of cookie list */
     if (cnt == xsp->ccount)
         break;
     /* Get next DMA cookie */
     (void) ddi_dma_nextcookie(xsp->handle, &cookie);
     }
    /* start DMA transfer */
     ddi_put8(xsp->access_hdl, &regp->csr,
     ENABLE_INTERRUPTS | START_TRANSFER);
```

---

**Note –** ddi_dma_addr_bind_handle() and ddi_dma_buf_bind_handle() can return more DMA cookies than fit into the scatter-gather list. In this case, the driver must continue the transfer in the interrupt routine. The driver must also reprogram the scatter-gather list with the remaining DMA cookies. sgllen cookies must be handled one at a time.

---

# Freeing the DMA Resources

After a DMA transfer is completed, usually in the interrupt routine, the driver can release DMA resources by calling ddi_dma_unbind_handle(9F).

As described in "Synchronizing Memory Objects" on page 148, ddi_dma_unbind_handle(9F) calls ddi_dma_sync(9F), eliminating the need for any explicit synchronization. After calling ddi_dma_unbind_handle(9F), the DMA resources become invalid, and further references to the resources have undefined results. The following example shows how to use ddi_dma_unbind_handle(9F).

**EXAMPLE 9–5** Freeing DMA Resources

```
static uint_t
xxintr(caddr_t arg)
{
     struct xxstate *xsp = (struct xxstate *)arg;
```

**EXAMPLE 9–5** Freeing DMA Resources *(Continued)*

```
     uint8_t    status;
    volatile   uint8_t   temp;
     mutex_enter(&xsp->mu);
     /* read status */
     status = ddi_get8(xsp->access_hdl, &xsp->regp->csr);
     if (!(status & INTERRUPTING)) {
        mutex_exit(&xsp->mu);
        return (DDI_INTR_UNCLAIMED);
     }
     ddi_put8(xsp->access_hdl, &xsp->regp->csr, CLEAR_INTERRUPT);
      /* for store buffers */
     temp = ddi_get8(xsp->access_hdl, &xsp->regp->csr);
     ddi_dma_unbind_handle(xsp->handle);
     [...]
     /* check for errors */
     [...]
     xsp->busy = 0;
     mutex_exit(&xsp->mu);
     if (    pending transfers) {
        (void) xxstart((caddr_t)xsp);
     }
     return (DDI_INTR_CLAIMED);
}
```

The DMA resources should be released. The DMA resources should be reallocated if a different object is to be used in the next transfer. However, if the same object is always used, the resources can be allocated once. The resources can then be reused as long as intervening calls to `ddi_dma_sync`(9F) remain.

# Freeing the DMA Handle

When the driver is detached, the DMA handle must be freed. `ddi_dma_free_handle`(9F) destroys the DMA handle and destroys any residual resources that the system is caching on the handle. Any further references of the DMA handle will have undefined results.

# Canceling DMA Callbacks

DMA callbacks cannot be canceled. Cancelling a DMA callback requires some additional code in the drivers `detach`(9E) routine. `detach()` must not return `DDI_SUCCESS` if any outstanding callbacks exist. (See Example 9–6.) When DMA callbacks occur, the `detach()` routine must wait for the callback to run. When the callback has finished, `detach()` must prevent the callback from rescheduling itself. Callbacks can be prevented from rescheduling through additional fields in the state structure, as shown in the following example.

**EXAMPLE 9–6** Canceling DMA Callbacks

```
static int
xxdetach(dev_info_t *dip, ddi_detach_cmd_t cmd)
{
     [...]
     mutex_enter(&xsp->callback_mutex);
     xsp->cancel_callbacks = 1;
     while (xsp->callback_count > 0) {
        cv_wait(&xsp->callback_cv, &xsp->callback_mutex);
     }
     mutex_exit(&xsp->callback_mutex);
     [...]
 }

static int
xxstrategy(struct buf *bp)
{
     [...]
     mutex_enter(&xsp->callback_mutex);
       xsp->bp = bp;
     error = ddi_dma_buf_bind_handle(xsp->handle, xsp->bp, flags,
         xxdmacallback, (caddr_t)xsp, &cookie, &ccount);
     if (error == DDI_DMA_NORESOURCES)
       xsp->callback_count++;
     mutex_exit(&xsp->callback_mutex);
     [...]
}

static int
xxdmacallback(caddr_t callbackarg)
{
     struct xxstate *xsp = (struct xxstate *)callbackarg;
     [...]
     mutex_enter(&xsp->callback_mutex);
     if (xsp->cancel_callbacks) {
        /* do not reschedule, in process of detaching */
        xsp->callback_count--;
        if (xsp->callback_count == 0)
           cv_signal(&xsp->callback_cv);
        mutex_exit(&xsp->callback_mutex);
        return (DDI_DMA_CALLBACK_DONE);    /* don't reschedule it */
     }
     /*
    * Presumably at this point the device is still active
    * and will not be detached until the DMA has completed.
    * A return of 0 means try again later
    */
     error = ddi_dma_buf_bind_handle(xsp->handle, xsp->bp, flags,
         DDI_DMA_DONTWAIT, NULL, &cookie, &ccount);
     if (error == DDI_DMA_MAPPED) {
        [...]
        /* program the DMA engine */
         [...]
        xsp->callback_count--;
```

**EXAMPLE 9–6** Canceling DMA Callbacks *(Continued)*

```
            mutex_exit(&xsp->callback_mutex);
            return (DDI_DMA_CALLBACK_DONE);
        }
        if (error != DDI_DMA_NORESOURCES) {
            xsp->callback_count--;
            mutex_exit(&xsp->callback_mutex);
            return (DDI_DMA_CALLBACK_DONE);
        }
        mutex_exit(&xsp->callback_mutex);
        return (DDI_DMA_CALLBACK_RUNOUT);
}
```

# Synchronizing Memory Objects

In the process of accessing the memory object, the driver might need to synchronize the memory object with respect to various caches. This section provides guidelines on when and how to synchronize memory objects.

## Cache

CPU cache is a very high-speed memory that sits between the CPU and the system's main memory. I/O cache sits between the device and the system's main memory, as shown in the following figure.

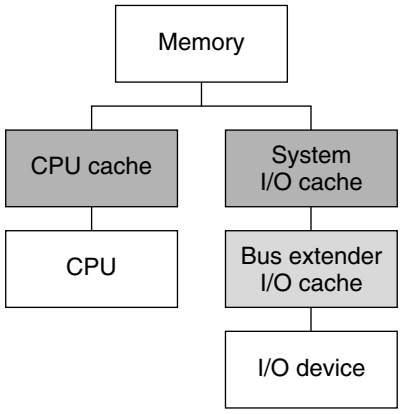



**FIGURE 9–1** CPU and System I/O Caches

When an attempt is made to read data from main memory, the associated cache checks for the requested data. If so, the cache supplies the data quickly. If the cache does not have the data, the cache retrieves the data from main memory. The cache then passes the data on to the requestor and saves the data in case of a subsequent request.

Similarly, on a write cycle, the data is stored in the cache quickly. The CPU or device is allowed to continue executing, that is, transferring data. Storing data in a cache takes much less time than waiting for the data to be written to memory.

With this model, after a device transfer is complete, the data can still be in the I/O cache with no data in main memory. If the CPU accesses the memory, the CPU might read the wrong data from the CPU cache. The driver must call a synchronization routine to flush the data from the I/O cache and update the CPU cache with the new data. This action ensures a consistent view of the memory for the CPU. Similarly, a synchronization step is required if data modified by the CPU is to be accessed by a device.

You can create additional caches and buffers between the device and memory, such as bus extenders and bridges. Use `ddi_dma_sync(9F)` to synchronize *all* applicable caches.

## `ddi_dma_sync()` Function

A memory object might have multiple mappings, such as for the CPU and for a device, by means of a DMA handle. A driver with multiple mappings needs to call `ddi_dma_sync`(9F) if any mappings are used to modify the memory object. Calling `ddi_dma_sync()` ensures that the modification of the memory object is complete before the object is accessed through a different mapping. `ddi_dma_sync()` can also inform other mappings of the object if any cached references to the object are now stale. Additionally, `ddi_dma_sync()` flushes or invalidates stale cache references as necessary.

Generally, the driver has to call `ddi_dma_sync()` when a DMA transfer completes. The exception to this rule is if deallocating the DMA resources with `ddi_dma_unbind_handle`(9F) does an implicit `ddi_dma_sync()` on behalf of the driver. The syntax for `ddi_dma_sync()` is as follows:

```
int ddi_dma_sync(ddi_dma_handle_t handle, off_t off,
size_t length, uint_t type);
```

If the object is going to be read by the DMA engine of the device, the device's view of the object must be synchronized by setting *type* to `DDI_DMA_SYNC_FORDEV`. If the DMA engine of the device has written to the memory object and the object is going to be read by the CPU, the CPU's view of the object must be synchronized by setting *type* to `DDI_DMA_SYNC_FORCPU`.

The following example demonstrates synchronizing a DMA object for the CPU:

```
if (ddi_dma_sync(xsp->handle, 0, length, DDI_DMA_SYNC_FORCPU)
    == DDI_SUCCESS) {
    /* the CPU can now access the transferred data */
    [...]
} else {
        error handling
}
```

Use the flag DDI_DMA_SYNC_FORKERNEL if the only mapping is for the kernel, as in the case of memory that is allocated by ddi_dma_mem_alloc(9F). The system tries to synchronize the kernel's view more quickly than the CPU's view. If the system cannot synchronize the kernel view faster, the system acts as if the DDI_DMA_SYNC_FORCPU flag were set.

# DMA Windows

If the system cannot allocate resources for a large object, the transfer must be broken into a series of smaller transfers. The driver can break up the transfer itself. Alternatively, the driver can let the system allocate resources for only part of the object, thereby creating a series of DMA *windows*. Allowing the system to allocate resources is the preferred solution, as the system can manage the resources more effectively than the driver.

A DMA window has two attributes. The *offset* attribute is measured from the beginning of the object. The *length* attribute is the number of bytes of memory to be allocated. After a partial allocation, only a range of *length* bytes that starts at *offset* has allocated resources.

A DMA window is requested by specifying the DDI_DMA_PARTIAL flag as a parameter to ddi_dma_buf_bind_handle(9F) or ddi_dma_addr_bind_handle(9F). Both functions return DDI_DMA_PARTIAL_MAP if a window can be established. However, the system might allocate resources for the entire object, in which case DDI_DMA_MAPPED is returned. The driver should check the return value to determine whether DMA windows are in use. See the following example.

**EXAMPLE 9–7** Setting Up DMA Windows

```
static int
xxstart (caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    struct device_reg *regp = xsp->reg;
    ddi_dma_cookie_t cookie;
    int    status;
    mutex_enter(&xsp->mu);
    if (xsp->busy) {
        /* transfer in progress */
        mutex_exit(&xsp->mu);
        return (DDI_DMA_CALLBACK_RUNOUT);
    }
    xsp->busy = 1;
    mutex_exit(&xsp->mu);
    if (    transfer is a read) {
        flags = DDI_DMA_READ;
```

**EXAMPLE 9–7** Setting Up DMA Windows *(Continued)*

```
    } else {
        flags = DDI_DMA_WRITE;
    }
    flags |= DDI_DMA_PARTIAL;
    status = ddi_dma_buf_bind_handle(xsp->handle, xsp->bp,
        flags, xxstart, (caddr_t)xsp, &cookie, &ccount);
    if (status != DDI_DMA_MAPPED &&
        status != DDI_DMA_PARTIAL_MAP)
        return (DDI_DMA_CALLBACK_RUNOUT);
    if (status == DDI_DMA_PARTIAL_MAP) {
        ddi_dma_numwin(xsp->handle, &xsp->nwin);
        xsp->partial = 1;
        xsp->windex = 0;
    } else {
        xsp->partial = 0;
    }
    [...]
        program the DMA engine
    [...]
    return (DDI_DMA_CALLBACK_DONE);
}
```

Two functions operate with DMA windows. The first, `ddi_dma_numwin`(9F), returns the number of DMA windows for a particular DMA object. The other function, `ddi_dma_getwin`(9F), allows repositioning within the object, that is, reallocation of system resources. `ddi_dma_getwin()` shifts the current window to a new window within the object. Because `ddi_dma_getwin()` reallocates system resources to the new window, the previous window becomes invalid.

**Caution –** Do not move the DMA windows with a call to `ddi_dma_getwin()` before transfers into the current window are complete. Wait until the transfer to the current window is complete, which is when the interrupt arrives. Then call `ddi_dma_getwin()` to avoid data corruption.

`ddi_dma_getwin()` is normally called from an interrupt routine, as shown in Example 9–8. The first DMA transfer is initiated as a result of a call to the driver. Subsequent transfers are started from the interrupt routine.

The interrupt routine examines the status of the device to determine whether the device completes the transfer successfully. If not, normal error recovery occurs. If the transfer is successful, the routine must determine whether the logical transfer is complete. A complete transfer includes the entire object as specified by the `buf`(9S) structure. In a partial transfer, only one DMA window is moved. In a partial transfer, the interrupt routine moves the window with `ddi_dma_getwin`(9F), retrieves a new cookie, and starts another DMA transfer.

If the logical request has been completed, the interrupt routine checks for pending requests. If necessary, the interrupt routine starts a transfer. Otherwise, the routine returns without invoking another DMA transfer. The following example illustrates the usual flow control.

**EXAMPLE 9–8** Interrupt Handler Using DMA Windows

```
static uint_t
xxintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    uint8_t    status;
    volatile   uint8_t   temp;
    mutex_enter(&xsp->mu);
    /* read status */
    status = ddi_get8(xsp->access_hdl, &xsp->regp->csr);
    if (!(status & INTERRUPTING)) {
        mutex_exit(&xsp->mu);
        return (DDI_INTR_UNCLAIMED);
    }
    ddi_put8(xsp->access_hdl,&xsp->regp->csr, CLEAR_INTERRUPT);
    /* for store buffers */
    temp = ddi_get8(xsp->access_hdl, &xsp->regp->csr);
    if (    an error occurred during transfer) {
        bioerror(xsp->bp, EIO);
        xsp->partial = 0;
    } else {
        xsp->bp->b_resid -=     amount transferred;
    }

    if (xsp->partial && (++xsp->windex < xsp->nwin)) {
        /* device still marked busy to protect state */
        mutex_exit(&xsp->mu);
        (void) ddi_dma_getwin(xsp->handle, xsp->windex,
            &offset, &len, &cookie, &ccount);
         program the DMA engine with the new cookie(s)
        [...]
        return (DDI_INTR_CLAIMED);
    }
    ddi_dma_unbind_handle(xsp->handle);
    biodone(xsp->bp);
    xsp->busy = 0;
    xsp->partial = 0;
    mutex_exit(&xsp->mu);
    if (    pending transfers) {
        (void) xxstart((caddr_t)xsp);
    }
    return (DDI_INTR_CLAIMED);
}
```

CHAPTER 10

# Mapping Device and Kernel Memory

Some device drivers allow applications to access device or kernel memory through `mmap`(2). Frame buffer drivers, for example, allow the frame buffer to be mapped into a user thread. Another example would be a pseudo driver that uses a shared kernel memory pool to communicate with an application. This chapter provides information on the following subjects:



## Memory Mapping Overview

The steps that a driver must take to export device or kernel memory are as follows:

1. Set the `D_DEVMAP` flag in the `cb_flag` flag of the `cb_ops`(9S) structure.
2. Define a `devmap`(9E) driver entry point to export the mapping.
3. Use `devmap_devmem_setup`(9F) to set up user mappings to a device. To set up user mappings to kernel memory, use `devmap_umem_setup`(9F).

## Exporting the Mapping

The `devmap`(9E) entry point is called as a result of the `mmap`(2) system call. `devmap`(9E) is used for the following operations:

- Validate the user mapping to the device or kernel memory

- Translate the logical offset within the application mapping to the corresponding offset within the device or kernel memory
- Pass the mapping information to the system for setting up the mapping

`devmap()` has the following syntax:

```
int devmap(dev_t dev, devmap_cookie_t handle, offset_t off,
     size_t len, size_t *maplen, uint_t model);
```

where:

*dev* Device whose memory is to be mapped.

*handle* Device-mapping handle that the system creates and uses to describe a mapping to contiguous memory in the device or kernel.

*off* Logical offset within the application mapping that has to be translated by the driver to the corresponding offset within the device or kernel memory.

*len* Length (in bytes) of the memory being mapped.

*maplen* Enables driver to associate different kernel memory regions or multiple physically discontiguous memory regions with one contiguous user application mapping.

*model* Data model type of the current thread.

The system creates multiple mapping handles in one `mmap`(2) system call. For example, the mapping might contain multiple physically discontiguous memory regions.

Initially, `devmap`(9E) is called with the parameters *off* and *len*. These parameters are passed by the application to `mmap`(2). `devmap`(9E) sets **maplen* to the length from *off* to the end of a contiguous memory region. **maplen* must be rounded up to a multiple of a page size. **maplen* can be set to less than the original mapping length `len`. If so, the system uses a new mapping handle with adjusted *off* and *len* parameters to call `devmap`(9E) repeatedly until the initial mapping length is satisfied.

If a driver supports multiple application data models, *model* has to be passed to `ddi_model_convert_from`(9F). The `ddi_model_convert_from()` function determines whether a data model mismatch exists between the current thread and the device driver. The device driver might have to adjust the shape of data structures before exporting the structures to a user thread that supports a different data model. See Appendix C page for more details.

`devmap`(9E) must return `-1` if the logical offset, *off*, is out of the range of memory exported by the driver.

# Associating Device Memory With User Mappings

Use devmap_devmem_setup(9F) to export device memory to user applications.

---

**Note –** devmap_devmem_setup() has to be called from the driver's devmap(9E) entry point.

---

devmap_devmem_setup() has the following syntax:

```
int devmap_devmem_setup(devmap_cookie_t handle, dev_info_t *dip,
    struct devmap_callback_ctl *callbackops, uint_t rnumber,
    offset_t roff, size_t len, uint_t maxprot, uint_t flags,
    ddi_device_acc_attr_t *accattrp);
```

where:

| | |
|---|---|
| *handle* | Opaque device-mapping handle that the system uses to identify the mapping. |
| *dip* | Pointer to the device's dev_info structure. |
| *callbackops* | Pointer to a devmap_callback_ctl(9S) structure that enables the driver to be notified of user events on the mapping. |
| *rnumber* | Index number to the register address space set. |
| *roff* | Offset into the device memory. |
| *len* | Length in bytes that is exported. |
| *maxprot* | Allows the driver to specify different protections for different regions within the exported device memory. |
| *flags* | Must be set to DEVMAP_DEFAULTS. |
| *accattrp* | Pointer to a ddi_device_acc_attr(9S) structure. |

*roff* and *len* describe a range within the device memory specified by the register set *rnumber*. The register specifications that are referred to by *rnumber* are described by the reg property. For devices with only one register set, pass zero for rnumber. The range is defined by *roff* and *len*. The range is made accessible to the user's application mapping at the *offset* that is passed in by the devmap(9E) entry point. Usually the driver passes the devmap(9E) offset directly to devmap_devmem_setup(9F). The return address of mmap(2) then maps to the beginning address of the register set.

*maxprot* enables the driver to specify different protections for different regions within the exported device memory. For example, one region might not allow write access by setting only `PROT_READ` and `PROT_USER`.

The following example shows how to export device memory to an application. The driver first determines whether the requested mapping falls within the device memory region. The size of the device memory is determined using `ddi_dev_regsize`(9F). The length of the mapping is rounded up to a multiple of a page size using `ptob`(9F) and `btopr`(9F). `devmap_devmem_setup`(9F) is called to export the device memory to the application.

**EXAMPLE 10–1** Using the `devmap_devmem_setup()` Routine

```
static int
xxdevmap(dev_t dev, devmap_cookie_t handle, offset_t off, size_t len,
    size_t *maplen, uint_t model)
{
    struct xxstate *xsp;
    int    error, rnumber;
    off_t regsize;

    /* Set up data access attribute structure */
    struct ddi_device_acc_attr xx_acc_attr = {
        DDI_DEVICE_ATTR_V0,
        DDI_NEVERSWAP_ACC,
        DDI_STRICTORDER_ACC
    };
    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL)
        return (-1);
    /* use register set 0 */
    rnumber = 0;
    /* get size of register set */
    if (ddi_dev_regsize(xsp->dip, rnumber, &regsize) != DDI_SUCCESS)
        return (-1);
    /* round up len to a multiple of a page size */
       len = ptob(btopr(len));
    if (off + len > regsize)
        return (-1);
    /* Set up the device mapping */
    error = devmap_devmem_setup(handle, xsp->dip, NULL, rnumber,
    off, len, PROT_ALL, DEVMAP_DEFAULTS, &xx_acc_attr);
    /* acknowledge the entire range */
    *maplen = len;
    return (error);
}
```

# Associating Kernel Memory With User Mappings

Some device drivers might need to allocate kernel memory that is made accessible to user programs through `mmap`(2). One example is setting up shared memory for communication between two applications. Another example is sharing memory between a driver and an application.

When exporting kernel memory to user applications, follow these steps:

1. Use `ddi_umem_alloc`(9F) to allocate kernel memory.
2. Use `devmap_umem_setup`(9F) to export the memory.
3. Use `ddi_umem_free`(9F) to free the memory when the memory is no longer needed.

## Allocating Kernel Memory for User Access

Use `ddi_umem_alloc`(9F) to allocate kernel memory that is exported to applications. `ddi_umem_alloc()` uses the following syntax:

```
void *ddi_umem_alloc(size_t size, int flag, ddi_umem_cookie_t
*cookiep);
```

where:

*size* Number of bytes to allocate.

*flag* Used to determine the sleep conditions and the memory type.

*cookiep* Pointer to a kernel memory cookie.

`ddi_umem_alloc`(9F) allocates page-aligned kernel memory. `ddi_umem_alloc()` returns a pointer to the allocated memory. Initially, the memory is filled with zeroes. The number of bytes that are allocated is a multiple of the system page size, which is rounded up from the *size* parameter. The allocated memory can be used in the kernel. This memory can be exported to applications as well. *cookiep* is a pointer to the kernel memory cookie that describes the kernel memory being allocated. *cookiep* is used in `devmap_umem_setup`(9F) when the driver exports the kernel memory to a user application.

The *flag* argument indicates whether `ddi_umem_alloc`(9F) blocks or returns immediately, and whether the allocated kernel memory is pageable. The values for the `flag` argument as follows:

| | |
|---|---|
| DDI_UMEM_NOSLEEP | Driver does not need to wait for memory to become available. Return NULL if memory unavailable. |
| DDI_UMEM_SLEEP | Driver can wait indefinitely for memory to become available. |
| DDI_UMEM_PAGEABLE | Driver allows memory to be paged out. If not set, the memory is locked down. |

The ddi_umem_lock() can perform device-locked-memory checks. The function checks against the limit value that is specified in the project.max-device-locked-memory. If the current project locked-memory usage is below the limit, the project's locked-memory byte count is increased. After the limit check, the memory is locked. ddi_umem_unlock() unlocks the memory and the project's locked-memory byte count is decremented.

The account method that is used is an imprecise full price model. For example, two callers of umem_lockmemory() within the same project with overlapping memory regions are charged twice. For details of project.max-device-locked-memory adjustment, see prctl(1).

The following example shows how to allocate kernel memory for application access. The driver exports one page of kernel memory, which is used by multiple applications as a shared memory area. The memory is allocated in segmap(9E) when an application maps the shared page the first time. An additional page is allocated if the driver has to support multiple application data models. For example, a 64-bit driver might export memory both to 64-bit applications and to 32-bit applications. 64-bit applications share the first page, and 32-bit applications share the second page.

**EXAMPLE 10–2** Using the ddi_umem_alloc() Routine

```
static int
xxsegmap(dev_t dev, off_t off, struct as *asp, caddr_t *addrp, off_t len,
    unsigned int prot, unsigned int maxprot, unsigned int flags,
    cred_t *credp)
{
    int error;
    minor_t instance = getminor(dev);
    struct xxstate *xsp = ddi_get_soft_state(statep, instance);

    size_t mem_size;
        /* 64-bit driver supports 64-bit and 32-bit applications */
    switch (ddi_mmap_get_model()) {
        case DDI_MODEL_LP64:
             mem_size = ptob(2);
             break;
        case DDI_MODEL_ILP32:
             mem_size = ptob(1);
             break;
    }

    mutex_enter(&xsp->mu);
```

**EXAMPLE 10–2** Using the `ddi_umem_alloc()` Routine *(Continued)*

```
    if (xsp->umem == NULL) {

        /* allocate the shared area as kernel pageable memory */
        xsp->umem = ddi_umem_alloc(mem_size,
            DDI_UMEM_SLEEP | DDI_UMEM_PAGEABLE, &xsp->ucookie);
    }
    mutex_exit(&xsp->mu);
    /* Set up the user mapping */
    error = devmap_setup(dev, (offset_t)off, asp, addrp, len,
        prot, maxprot, flags, credp);

    return (error);
}
```

# Exporting Kernel Memory to Applications

Use `devmap_umem_setup`(9F) to export kernel memory to user applications. `devmap_umem_setup()` must be called from the driver's `devmap`(9E) entry point. The syntax for `devmap_umem_setup()` is as follows:

```
int devmap_umem_setup(devmap_cookie_t handle, dev_info_t *dip,
    struct devmap_callback_ctl *callbackops, ddi_umem_cookie_t cookie,
    offset_t koff, size_t len, uint_t maxprot, uint_t flags,
    ddi_device_acc_attr_t *accattrp);
```

where:

| | |
|---|---|
| *handle* | Opaque structure used to describe the mapping. |
| *dip* | Pointer to the device's `dev_info` structure. |
| *callbackops* | Pointer to a `devmap_callback_ctl`(9S) structure. |
| *cookie* | Kernel memory cookie returned by `ddi_umem_alloc`(9F). |
| *koff* | Offset into the kernel memory specified by cookie. |
| *len* | Length in bytes that is exported. |
| *maxprot* | Specifies the maximum protection possible for the exported mapping. |
| *flags* | Must be set to `DEVMAP_DEFAULTS`. |
| *accattrp* | Pointer to a `ddi_device_acc_attr`(9S) structure. |

*handle* is a device-mapping handle that the system uses to identify the mapping. *handle* is passed in by the `devmap`(9E) entry point. *dip* is a pointer to the device's `dev_info` structure. *callbackops* allows the driver to be notified of user events on the mapping. Most drivers set *callbackops* to NULL when kernel memory is exported.

*koff* and *len* specify a range within the kernel memory allocated by `ddi_umem_alloc`(9F). This range is made accessible to the user's application mapping at the offset that is passed in by the `devmap`(9E) entry point. Usually, the driver passes the `devmap`(9E) offset directly to `devmap_umem_setup`(9F). The return address of `mmap`(2) then maps to the kernel address returned by `ddi_umem_alloc`(9F). *koff* and *len* must be page-aligned.

*maxprot* enables the driver to specify different protections for different regions within the exported kernel memory. For example, one region might not allow write access by only setting `PROT_READ` and `PROT_USER`.

The following example shows how to export kernel memory to an application. The driver first checks whether the requested mapping falls within the allocated kernel memory region. If a 64-bit driver receives a mapping request from a 32-bit application, the request is redirected to the second page of the kernel memory area. This redirection ensures that only applications compiled to the same data model share the same page.

**EXAMPLE 10–3** `devmap_umem_setup`(9F) Routine

```
static int
xxdevmap(dev_t dev, devmap_cookie_t handle, offset_t off, size_t len,
    size_t *maplen, uint_t model)
{
    struct xxstate *xsp;
    int    error;

    /* round up len to a multiple of a page size */
    len = ptob(btopr(len));
    /* check if the requested range is ok */
    if (off + len > ptob(1))
        return (ENXIO);
    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL)
        return (ENXIO);

    if (ddi_model_convert_from(model) == DDI_MODEL_ILP32)
        /* request from 32-bit application. Skip first page */
        off += ptob(1);

    /* export the memory to the application */
    error = devmap_umem_setup(handle, xsp->dip, NULL, xsp->ucookie,
        off, len, PROT_ALL, DEVMAP_DEFAULTS, NULL);
    *maplen = len;
    return (error);
}
```

## Freeing Kernel Memory Exported for User Access

When the driver is unloaded, the memory that was allocated by `ddi_umem_alloc`(9F) must be freed by calling `ddi_umem_free`(9F).

```
void ddi_umem_free(ddi_umem_cookie_t cookie);
```

*cookie* is the kernel memory cookie returned by `ddi_umem_alloc`(9F).

CHAPTER 11

# Device Context Management

Some device drivers, such as drivers for graphics hardware, provide user processes with direct access to the device. These devices often require that only one process at a time accesses the device.

This chapter describes the set of interfaces that enable device drivers to manage access to such devices. The chapter provides information on the following subjects:



## Introduction to Device Context

This section introduces device context and the context management model.

### What Is a Device Context?

The *context* of a device is the current state of the device hardware. The device driver manages the device context for a process on behalf of the process. The driver must maintain a separate device context for each process that accesses the device. The device driver has the responsibility to restore the correct device context when a process accesses the device.

### Context Management Model

Frame buffers provide a good example of device context management. An accelerated frame buffer enables user processes to directly manipulate the control registers of the device through memory-mapped access. Because these processes do not use

traditional system calls, a process that accesses the device need not call the device driver. However, the device driver must be notified when a process is about to access a device. The driver needs to restore the correct device context and needs to provide any necessary synchronization.

To resolve this problem, the device context management interfaces enable a device driver to be notified when a user process accesses memory-mapped regions of the device, and to control accesses to the device's hardware. Synchronization and management of the various device contexts are the responsibility of the device driver. When a user process accesses a mapping, the device driver must restore the correct device context for that process.

A device driver is notified whenever a user process performs any of the following actions:

- Accesses a mapping
- Duplicates a mapping
- Frees a mapping
- Creates a mapping

The following figure shows multiple user processes that have memory-mapped a device. The driver has granted process B access to the device, and process B no longer notifies the driver of accesses. However, the driver *is* still notified if either process A or process C accesses the device.

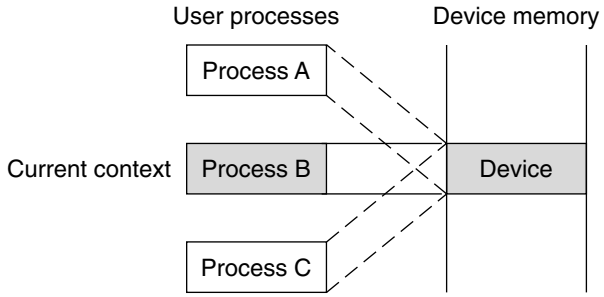



**FIGURE 11–1** Device Context Management

At some point in the future, process A accesses the device. The device driver is notified and blocks future access to the device by process B. The driver then saves the device context for process B. The driver restores the device context of process A. The driver then grants access to process A, as illustrated in the following figure. At this point, the device driver is notified if either process B or process C accesses the device.

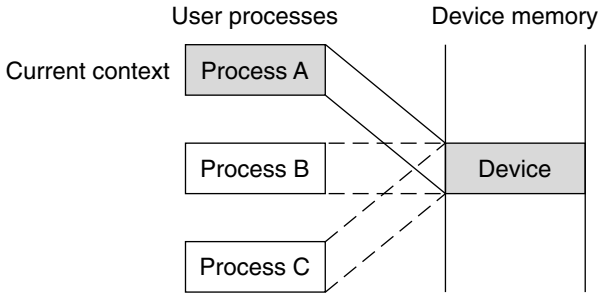



**FIGURE 11–2** Device Context Switched to User Process A

On a multiprocessor machine, multiple processes could attempt to access the device at the same time. This situation can cause thrashing. Some devices require a longer time to restore a device context. To prevent more CPU time from being used to restore a device context than to actually use that device context, the minimum time that a process needs to have access to the device can be set using `devmap_set_ctx_timeout`(9F).

The kernel guarantees that once a device driver has granted access to a process, no other process is allowed to request access to the same device for the time interval specified by `devmap_set_ctx_timeout`(9F).

# Context Management Operation

The general steps for performing device context management are as follows:

1. Define a `devmap_callback_ctl`(9S) structure.
2. Allocate space to save device context if necessary.
3. Set up user mappings to the device and driver notifications with `devmap_devmem_setup`(9F).
4. Manage user access to the device with `devmap_load`(9F) and `devmap_unload`(9F).
5. Free the device context structure, if needed.

## `devmap_callback_ctl` Structure

The device driver must allocate and initialize a `devmap_callback_ctl`(9S) structure to inform the system about the entry point routines for device context management.

This structure uses the following syntax:

```
struct devmap_callback_ctl {
    int devmap_rev;
    int (*devmap_map)(devmap_cookie_t dhp, dev_t dev,
    uint_t flags, offset_t off, size_t len, void **pvtp);
    int (*devmap_access)(devmap_cookie_t dhp, void *pvtp,
    offset_t off, size_t len, uint_t type, uint_t rw);
    int (*devmap_dup)(devmap_cookie_t dhp, void *pvtp,
    devmap_cookie_t new_dhp, void **new_pvtp);
    void (*devmap_unmap)(devmap_cookie_t dhp, void *pvtp,
    offset_t off, size_t len, devmap_cookie_t new_dhp1,
    void **new_pvtp1, devmap_cookie_t new_dhp2,
    void **new_pvtp2);
};
```

| | |
|---|---|
| `devmap_rev` | The version number of the `devmap_callback_ctl` structure. The version number must be set to `DEVMAP_OPS_REV`. |
| `devmap_map` | Must be set to the address of the driver's `devmap_map`(9E) entry point. |
| `devmap_access` | Must be set to the address of the driver's `devmap_access`(9E) entry point. |
| `devmap_dup` | Must be set to the address of the driver's `devmap_dup`(9E) entry point. |
| `devmap_unmap` | Must be set to the address of the driver's `devmap_unmap`(9E) entry point. |

# Entry Points for Device Context Management

The following entry points are used to manage device context:

- `devmap`(9E)
- `devmap_access`(9E)
- `devmap_contextmgt`(9E)
- `devmap_dup`(9E)
- `devmap_unmap`(9E)

## `devmap_map()` Entry Point

The syntax for `devmap`(9E) is as follows:

```
int xxdevmap_map(devmap_cookie_t handle, dev_t dev, uint_t flags,
    offset_t offset, size_t len, void **new-devprivate);
```

The `devmap_map()` entry point is called after the driver returns from its `devmap()` entry point and the system has established the user mapping to the device memory. The `devmap()` entry point enables a driver to perform additional processing or to allocate mapping specific private data. For example, in order to support context switching, the driver has to allocate a context structure. The driver must then associate the context structure with the mapping.

The system expects the driver to return a pointer to the allocated private data in **new-devprivate*. The driver must store *offset* and *len*, which define the range of the mapping, in its private data. Later, when the system calls `devmap_unmap`(9E), the driver uses this information to determine how much of the mapping is being unmapped.

*flags* indicates whether the driver should allocate a private context for the mapping. For example, a driver can allocate a memory region to store the device context if *flags* is set to `MAP_PRIVATE`. If `MAP_SHARED` is set, the driver returns a pointer to a shared region.

The following example shows a `devmap()` entry point. The driver allocates a new context structure. The driver then saves relevant parameters passed in by the entry point. Next, the mapping is assigned a new context either through allocation or by attaching the mapping to an already existing shared context. The minimum time interval that the mapping should have access to the device is set to one millisecond.

**EXAMPLE 11–1** Using the `devmap()` Routine

```
static int
int xxdevmap_map(devmap_cookie_t handle, dev_t dev, uint_t flags,
    offset_t offset, size_t len, void **new_devprivate)
{
    struct xxstate *xsp = ddi_get_soft_state(statep,
                  getminor(dev));
    struct xxctx *newctx;

    /* create a new context structure */
    newctx = kmem_alloc(sizeof (struct xxctx), KM_SLEEP);
    newctx->xsp = xsp;
    newctx->handle = handle;
    newctx->offset = offset;
    newctx->flags = flags;
    newctx->len = len;
    mutex_enter(&xsp->ctx_lock);
    if (flags & MAP_PRIVATE) {
        /* allocate a private context and initialize it */
        newctx->context = kmem_alloc(XXCTX_SIZE, KM_SLEEP);
        xxctxinit(newctx);
    } else {
        /* set a pointer to the shared context */
        newctx->context = xsp->ctx_shared;
    }
    mutex_exit(&xsp->ctx_lock);
    /* give at least 1 ms access before context switching */
```

**EXAMPLE 11–1** Using the `devmap()` Routine *(Continued)*

```
    devmap_set_ctx_timeout(handle, drv_usectohz(1000));
    /* return the context structure */
    *new_devprivate = newctx;
    return(0);
}
```

## `devmap_access()` Entry Point

The `devmap_access`(9E) entry point is called when an access is made to a mapping whose translations are invalid. Mapping translations are invalidated when the mapping is created with `devmap_devmem_setup`(9F) in response to `mmap`(2), duplicated by `fork`(2), or explicitly invalidated by a call to `devmap_unload`(9F).

The syntax for `devmap_access()` is as follows:

```
int xxdevmap_access(devmap_cookie_t handle, void *devprivate,
    offset_t offset, size_t len, uint_t type, uint_t rw);
```

where:

| | |
|---|---|
| *handle* | Mapping handle of the mapping that was accessed by a user process. |
| *devprivate* | Pointer to the driver private data associated with the mapping. |
| *offset* | Offset within the mapping that was accessed. |
| *len* | Length in bytes of the memory being accessed. |
| *type* | Type of access operation. |
| *rw* | Specifies the direction of access. |

The system expects `devmap_access`(9E) to call either `devmap_do_ctxmgt`(9F) or `devmap_default_access`(9F) to load the memory address translations before `devmap_access()` returns. For mappings that support context switching, the device driver should call `devmap_do_ctxmgt()`. This routine is passed all parameters from `devmap_access`(9E), as well as a pointer to the driver entry point `devmap_contextmgt`(9E), which handles the context switching. For mappings that do not support context switching, the driver should call `devmap_default_access`(9F). The purpose of `devmap_default_access()` is to call `devmap_load`(9F) to load the user translation.

The following example shows a `devmap_access`(9E) entry point. The mapping is divided into two regions. The region that starts at offset `OFF_CTXMG` with a length of `CTXMGT_SIZE` bytes supports context management. The rest of the mapping supports default access.

**EXAMPLE 11–2** Using the `devmap_access()` Routine

```
#define OFF_CTXMG      0
#define CTXMGT_SIZE    0x20000
static int
xxdevmap_access(devmap_cookie_t handle, void *devprivate,
    offset_t off, size_t len, uint_t type, uint_t rw)
{
    offset_t diff;
    int    error;

    if ((diff = off - OFF_CTXMG) >= 0 && diff < CTXMGT_SIZE) {
        error = devmap_do_ctxmgt(handle, devprivate, off,
            len, type, rw, xxdevmap_contextmgt);
    } else {
        error = devmap_default_access(handle, devprivate,
            off, len, type, rw);
    }
    return (error);
}
```

## `devmap_contextmgt()` Entry Point

The syntax for `devmap_contextmgt`(9E) is as follows:

```
int xxdevmap_contextmgt(devmap_cookie_t handle, void *devprivate,
    offset_t offset, size_t len, uint_t type, uint_t rw);
```

`devmap_contextmgt()` should call `devmap_unload`(9F) with the handle of the mapping that currently has access to the device. This approach invalidates the translations for that mapping. The approach ensures that a call to `devmap_access`(9E) occurs for the current mapping the next time the mapping is accessed. The mapping translations for the mapping that caused the access event to occur need to be validated. Accordingly, the driver must restore the device context for the process requesting access. Furthermore, the driver must call `devmap_load`(9F) on the *handle* of the mapping that generated the call to this entry point.

Accesses to portions of mappings that have had their mapping translations validated by a call to `devmap_load()` do not generate a call to `devmap_access()`. A subsequent call to `devmap_unload()` invalidates the mapping translations. This call allows `devmap_access()` to be called again.

If either `devmap_load()` or `devmap_unload()` returns an error, `devmap_contextmgt()` should immediately return that error. If the device driver encounters a hardware failure while restoring a device context, a `-1` should be returned. Otherwise, after successfully handling the access request, `devmap_contextmgt()` should return zero. A return of other than zero from `devmap_contextmgt()` causes a `SIGBUS` or `SIGSEGV` to be sent to the process.

The following example shows how to manage a one-page device context.

**Note –** `xxctxsave()` and `xxctxrestore()` are device-dependent context save and restore functions. `xxctxsave()` reads data from the registers and saves the data in the soft state structure. `xxctxrestore()` takes data that is saved in the soft state structure and writes the data to device registers. Note that the read, write, and save are all performed with the DDI/DKI data access routines.

**EXAMPLE 11–3** Using the `devmap_contextmgt()` Routine

```
static int
xxdevmap_contextmgt(devmap_cookie_t handle, void *devprivate,
    offset_t off, size_t len, uint_t type, uint_t rw)
{
    int    error;
    struct xxctx *ctxp = devprivate;
    struct xxstate *xsp = ctxp->xsp;
    mutex_enter(&xsp->ctx_lock);
    /* unload mapping for current context */
    if (xsp->current_ctx != NULL) {
        if ((error = devmap_unload(xsp->current_ctx->handle,
            off, len)) != 0) {
            xsp->current_ctx = NULL;
            mutex_exit(&xsp->ctx_lock);
            return (error);
        }
    }
    /* Switch device context - device dependent */
    if (xxctxsave(xsp->current_ctx, off, len) < 0) {
        xsp->current_ctx = NULL;
        mutex_exit(&xsp->ctx_lock);
        return (-1);
    }
    if (xxctxrestore(ctxp, off, len) < 0){
        xsp->current_ctx = NULL;
        mutex_exit(&xsp->ctx_lock);
        return (-1);
    }
    xsp->current_ctx = ctxp;
    /* establish mapping for new context and return */
    error = devmap_load(handle, off, len, type, rw);
    if (error)
        xsp->current_ctx = NULL;
    mutex_exit(&xsp->ctx_lock);
    return (error);
}
```

## devmap_dup() Entry Point

The devmap_dup(9E) entry point is called when a device mapping is duplicated, for example, by a user process that calls fork(2). The driver is expected to generate new driver private data for the new mapping.

The syntax fordevmap_dup() is as follows:

```
int xxdevmap_dup(devmap_cookie_t handle, void *devprivate,
    devmap_cookie_t new-handle, void **new-devprivate);
```

where:

| | |
|---|---|
| *handle* | Mapping handle of the mapping being duplicated. |
| *new-handle* | Mapping handle of the mapping that was duplicated. |
| *devprivate* | Pointer to the driver private data associated with the mapping being duplicated. |
| **new-devprivate* | Should be set to point to the new driver private data for the new mapping. |

Mappings that have been created with devmap_dup() by default have their mapping translations invalidated. Invalid mapping translations force a call to the devmap_access(9E) entry point the first time the mapping is accessed.

The following example shows a typical devmap_dup() routine.

**EXAMPLE 11–4** Using the devmap_dup() Routine

```
static int
xxdevmap_dup(devmap_cookie_t handle, void *devprivate,
    devmap_cookie_t new_handle, void **new_devprivate)
{
    struct xxctx *ctxp = devprivate;
    struct xxstate *xsp = ctxp->xsp;
    struct xxctx *newctx;
    /* Create a new context for the duplicated mapping */
    newctx = kmem_alloc(sizeof (struct xxctx), KM_SLEEP);
    newctx->xsp = xsp;
    newctx->handle = new_handle;
    newctx->offset = ctxp->offset;
    newctx->flags = ctxp->flags;
    newctx->len = ctxp->len;
    mutex_enter(&xsp->ctx_lock);
    if (ctxp->flags & MAP_PRIVATE) {
        newctx->context = kmem_alloc(XXCTX_SIZE, KM_SLEEP);
        bcopy(ctxp->context, newctx->context, XXCTX_SIZE);
    } else {
        newctx->context = xsp->ctx_shared;
    }
    mutex_exit(&xsp->ctx_lock);
    *new_devprivate = newctx;
```

**EXAMPLE 11–4** Using the `devmap_dup()` Routine *(Continued)*

```
    return(0);
}
```

## `devmap_unmap()` Entry Point

The `devmap_unmap`(9E) entry point is called when a mapping is unmapped. Unmapping can be caused by a user process exiting or by calling the `munmap(2)` system call.

The syntax for `devmap_unmap()` is as follows:

```
void xxdevmap_unmap(devmap_cookie_t handle, void *devprivate,
    offset_t off, size_t len, devmap_cookie_t new-handle1,
    void **new-devprivate1, devmap_cookie_t new-handle2,
    void **new-devprivate2);
```

where:

| | |
|---|---|
| *handle* | Mapping handle of the mapping being freed. |
| *devprivate* | Pointer to the driver private data associated with the mapping. |
| *off* | Offset within the logical device memory at which the unmapping begins. |
| *len* | Length in bytes of the memory being unmapped. |
| *new-handle1* | Handle that the system uses to describe the new region that ends at *off* - 1. *new-handle1* can be NULL. |
| *new-devprivate1* | Pointer to be filled in by the driver with the private driver mapping data for the new region that ends at *off* -1. *new-devprivate1* is ignored if *new-handle1* is NULL. |
| *new-handle2* | Handle that the system uses to describe the new region that begins at *off* + *len*. *new-handle2* can be NULL. |
| *new-devprivate2* | Pointer to be filled in by the driver with the driver private mapping data for the new region that begins at *off* + *len*. *new-devprivate2* is ignored if *new-handle2* is NULL. |

The `devmap_unmap()` routine is expected to free any driver private resources that were allocated when this mapping was created, either by `devmap_map`(9E) or by `devmap_dup`(9E). If the mapping is only partially unmapped, the driver must allocate new private data for the remaining mapping before freeing the old private data. Calling `devmap_unload`(9F) on the handle of the freed mapping is not necessary, even if this handle points to the mapping with the valid translations. However, to prevent future `devmap_access`(9E) problems, the device driver should make sure the current mapping representation is set to “no current mapping”.

The following example shows a typical `devmap_unmap()` routine.

**EXAMPLE 11–5** Using the `devmap_unmap()` Routine

```
static void
xxdevmap_unmap(devmap_cookie_t handle, void *devprivate,
    offset_t off, size_t len, devmap_cookie_t new_handle1,
    void **new_devprivate1, devmap_cookie_t new_handle2,
    void **new_devprivate2)
{
    struct xxctx *ctxp = devprivate;
    struct xxstate *xsp = ctxp->xsp;
    mutex_enter(&xsp->ctx_lock);

    /*
     * If new_handle1 is not NULL, we are unmapping
     * at the end of the mapping.
     */
    if (new_handle1 != NULL) {
        /* Create a new context structure for the mapping */
        newctx = kmem_alloc(sizeof (struct xxctx), KM_SLEEP);
        newctx->xsp = xsp;
           if (ctxp->flags & MAP_PRIVATE) {
               /* allocate memory for the private context
               /* and copy it */
            newctx->context = kmem_alloc(XXCTX_SIZE, KM_SLEEP);
            bcopy(ctxp->context, newctx->context, XXCTX_SIZE);
        } else {
            /* point to the shared context */
            newctx->context = xsp->ctx_shared;
        }
        newctx->handle = new_handle1;
        newctx->offset = ctxp->offset;
        newctx->len = off - ctxp->offset;
        *new_devprivate1 = newctx;
    }
    /*
     * If new_handle2 is not NULL, we are unmapping
     * at the beginning of the mapping.
     */
    if (new_handle2 != NULL) {
        /* Create a new context for the mapping */
        newctx = kmem_alloc(sizeof (struct xxctx), KM_SLEEP);
        newctx->xsp = xsp;
        if (ctxp->flags & MAP_PRIVATE) {
            newctx->context = kmem_alloc(XXCTX_SIZE, KM_SLEEP);
            bcopy(ctxp->context, newctx->context, XXCTX_SIZE);
        } else {
            newctx->context = xsp->ctx_shared;
        }
        newctx->handle = new_handle2;
        newctx->offset = off + len;
        newctx->flags = ctxp->flags;
        newctx->len = ctxp->len - (off + len - ctxp->off);
```

**EXAMPLE 11–5** Using the `devmap_unmap()` Routine *(Continued)*

```
        *new_devprivate2 = newctx;
    }
    if (xsp->current_ctx == ctxp)
        xsp->current_ctx = NULL;
    mutex_exit(&xsp->ctx_lock);
    if (ctxp->flags & MAP_PRIVATE)
        kmem_free(ctxp->context, XXCTX_SIZE);
    kmem_free(ctxp, sizeof (struct xxctx));
}
```

# Associating User Mappings With Driver Notifications

When a user process requests a mapping to a device with `mmap`(2), the driver's `segmap`(9E) entry point is called. The driver must use `ddi_devmap_segmap`(9F) or `devmap_setup`(9F) when setting up the memory mapping if the driver needs to manage device contexts. Both functions call the driver's `devmap`(9E) entry point, which uses `devmap_devmem_setup`(9F) to associate the device memory with the user mapping. See Chapter 10 for details on how to map device memory.

The driver must inform the system of the `devmap_callback_ctl`(9S) entry points to get notifications of accesses to the user mapping. The driver informs the system by providing a pointer to a `devmap_callback_ctl`(9S) structure to `devmap_devmem_setup(9F)`. A `devmap_callback_ctl`(9S) structure describes a set of entry points for context management. These entry points are called by the system to notify a device driver to manage events on the device mappings.

The system associates each mapping with a mapping handle. This handle is passed to each of the entry points for context management. The mapping handle can be used to invalidate and validate the mapping translations. If the driver *invalidates* the mapping translations, the driver will be notified of any future access to the mapping. If the driver *validates* the mapping translations, the driver will no longer be notified of accesses to the mapping. Mappings are always created with the mapping translations invalidated so that the driver will be notified on first access to the mapping.

The following example shows how to set up a mapping using the device context management interfaces.

**EXAMPLE 11–6** `devmap`(9E) Entry Point With Context Management Support

```
static struct devmap_callback_ctl xx_callback_ctl = {
    DEVMAP_OPS_REV, xxdevmap_map, xxdevmap_access,
    xxdevmap_dup, xxdevmap_unmap
};
```

**EXAMPLE 11–6** devmap(9E) Entry Point With Context Management Support *(Continued)*

```
static int
xxdevmap(dev_t dev, devmap_cookie_t handle, offset_t off,
    size_t len, size_t *maplen, uint_t model)
{
    struct xxstate *xsp;
    uint_t rnumber;
    int    error;

    /* Setup data access attribute structure */
    struct ddi_device_acc_attr xx_acc_attr = {
        DDI_DEVICE_ATTR_V0,
        DDI_NEVERSWAP_ACC,
        DDI_STRICTORDER_ACC
    };
    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL)
        return (ENXIO);
    len = ptob(btopr(len));
    rnumber = 0;
    /* Set up the device mapping */
    error = devmap_devmem_setup(handle, xsp->dip, &xx_callback_ctl,
        rnumber, off, len, PROT_ALL, 0, &xx_acc_attr);
    *maplen = len;
    return (error);
}
```

# Managing Mapping Accesses

The device driver is notified when a user process accesses an address in the memory-mapped region that does not have valid mapping translations. When the access event occurs, the mapping translations of the process that currently has access to the device must be invalidated. The device context of the process that requested access to the device must be restored. Furthermore, the translations of the mapping of the process requesting access must be validated.

The functions devmap_load(9F) and devmap_unload(9F) are used to validate and invalidate mapping translations.

## devmap_load() Entry Point

The syntax for devmap_load(9F) is as follows:

```
int devmap_load(devmap_cookie_t handle, offset_t offset,
    size_t len, uint_t type, uint_t rw);
```

`devmap_load()` validates the mapping translations for the pages of the mapping specified by `handle`, `offset`, and `len`. By validating the mapping translations for these pages, the driver is telling the system not to intercept accesses to these pages of the mapping. Furthermore, the system must not allow accesses to proceed without notifying the device driver.

`devmap_load()` must be called with the offset and the handle of the mapping that generated the access event for the access to complete. If `devmap_load`(9F) is not called on this handle, the mapping translations are not validated, and the process receives a `SIGBUS`.

## `devmap_unload()` Entry Point

The syntax for `devmap_unload`(9F) is as follows:

```
int devmap_unload(devmap_cookie_t handle, offset_t offset,
 size_t len);
```

`devmap_unload()` invalidates the mapping translations for the pages of the mapping specified by *handle*, *offset*, and *len*. By invalidating the mapping translations for these pages, the device driver is telling the system to intercept accesses to these pages of the mapping. Furthermore, the system must notify the device driver the next time that these mapping pages are accessed by calling the `devmap_access`(9E) entry point.

For both functions, requests affect the entire page that contains the *offset* and all pages up to and including the entire page that contains the last byte, as indicated by *offset* + *len*. The device driver must ensure that for each page of device memory being mapped, only one process has valid translations at any one time.

Both functions return zero if successful. If, however, an error occurred in validating or invalidating the mapping translations, that error is returned to the device driver. The device driver must return this error to the system.

CHAPTER 12

# Power Management

Power management provides the ability to control and manage the electrical power usage of a computer system or device. Power management enables systems to conserve energy by using less power when idle and by shutting down completely when not in use. For example, desktop computer systems can use a significant amount of power and often are left idle, particularly at night. Power management software can detect that the system is not being used. Accordingly, power management can power down the system or some of its components.

This chapter provides information on the following subjects:



## Power Management Framework

The Solaris Power Management™ framework depends on device drivers to implement device-specific power management functions. The framework is implemented in two parts:

- Device power management – Automatically turns off unused devices to reduce power consumption
- System power management – Automatically turns off the computer when the entire system is idle

## Device Power Management

The framework enables devices to reduce their energy consumption after a specified idle time interval. As part of power management, system software checks for idle devices. The Power Management framework exports interfaces that enable communication between the system software and the device driver.

The Solaris Power Management framework provides the following features for device power management:

- A device-independent model for power-manageable devices.
- `dtpower`(1M), a tool for configuring workstation power management. Power management can also be implemented through the `power.conf`(4) and `/etc/default/power` files.
- A set of DDI interfaces for notifying the framework about power management compatibility and idleness state.

## System Power Management

System power management involves saving the state of the system prior to powering the system down. Thus, the system can be returned to the same state immediately when the system is turned back on.

To shut down an entire system with return to the state prior to the shutdown, take the following steps:

- Stop kernel threads and user processes. Restart these threads and processes later.
- Save the hardware state of all devices on the system to disk. Restore the state later.

---

**SPARC only –** System power management is currently implemented only on some SPARC systems supported by the Solaris 10 Operating System. See the `power.conf`(4) man page for more information.

---

The System Power Management framework in the Solaris Operating System provides the following features for system power management:

- A platform-independent model of system idleness.
- `pmconfig`(1M), a tool for configuring workstation power management. Power management can also be implemented through the `power.conf`(4) and `/etc/default/power` files.
- A set of interfaces for the device driver to override the method for determining which drivers have hardware state.
- A set of interfaces to enable the framework to call into the driver to save and restore the device state.

- A mechanism for notifying processes that a resume operation has occurred.

# Device Power Management Model

The following sections describe the details of the device power management model. This model includes the following elements:

- Components
- Idleness
- Power levels
- Dependency
- Policy
- Device power management interfaces
- Power management entry points

## Power Management Components

A device is power manageable if the power consumption of the device can be reduced when the device is idle. Conceptually, a power-manageable device consists of a number of power-manageable hardware units that are called *components*.

The device driver notifies the system about device components and their associated power levels. Accordingly, the driver creates a `pm-components`(9P) property in the driver's `attach`(9E) entry point as part of driver initialization.

Most devices that are power manageable implement only a single component. An example of a single-component, power-manageable device is a disk whose spindle motor can be stopped to save power when the disk is idle.

If a device has multiple power-manageable units that are separately controllable, the device should implement multiple components.

An example of a two-component, power-manageable device is a frame buffer card with a monitor. Frame buffer electronics is the first component [component 0]. The frame buffer's power consumption can be reduced when not in use. The monitor is the second component [component 1]. The monitor can also enter a lower power mode when the monitor is not in use. The frame buffer electronics and monitor are considered by the system as one device with two components.

### Multiple Power Management Components

To the power management framework, all components are considered equal and completely independent of each other. If the component states are not completely compatible, the device driver must ensure that undesirable state combinations do not

occur. For example, a frame buffer/monitor card has the following possible states: `D0`, `D1`, `D2`, and `D3`. The monitor attached to the card has the following potential states: `On`, `Standby`, `Suspend`, and `Off`. These states are not necessarily compatible with each other. For example, if the monitor is `On`, then the frame buffer must be at `D0`, that is, full on. If the frame buffer driver gets a request to power up the monitor to `On` while the frame buffer is at `D3`, the driver must call `pm_raise_power`(9F) to bring the frame buffer up before setting the monitor `On`. System requests to lower the power of the frame buffer while the monitor is `On` must be refused by the driver.

# Power Management States

Each component of a device can be in one of two states: *busy* or *idle*. The device driver notifies the framework of changes in the device state by calling `pm_busy_component`(9F) and `pm_idle_component`(9F). When components are initially created, the components are considered idle.

# Power Levels

From the `pm-components` property exported by the device, the Device Power Management framework knows what power levels the device supports. Power-level values must be positive integers. The interpretation of power levels is determined by the device driver writer. Power levels must be listed in monotonically increasing order in the `pm-components` property. A power level of 0 is interpreted by the framework to mean off. When the framework must power up a device due to a dependency, the framework sets each component at its highest power level.

The following example shows a `pm-components` entry from the `.conf` file of a driver that implements a single power-managed component consisting of a disk spindle motor. The disk spindle motor is component 0. The spindle motor supports two power levels. These levels represent “stopped” and “spinning at full speed.”

**EXAMPLE 12–1** Sample `pm-component` Entry

```
pm-components="NAME=Spindle Motor", "0=Stopped", "1=Full Speed";
```

The following example shows how Example 12–1 could be implemented in the `attach()` routine of the driver.

**EXAMPLE 12–2** `attach`(9E) Routine With `pm-components` Property

```
static char *pmcomps[] = {
    "NAME=Spindle Motor",
    "0=Stopped",
    "1=Full Speed"
};
```

**EXAMPLE 12–2** `attach`(9E) Routine With `pm-components` Property *(Continued)*

```
...

xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
...
    if (ddi_prop_update_string_array(DDI_DEV_T_NONE, dip,
        "pm-components", &pmcomp[0],
        sizeof (pmcomps) / sizeof (char *)) != DDI_PROP_SUCCESS)
        goto failed;
...
```

The following example shows a frame buffer that implements two components. Component 0 is the frame buffer electronics that support four different power levels. Component 1 represents the state of power management of the attached monitor.

**EXAMPLE 12–3** Multiple Component `pm-components` Entry

```
pm-components="NAME=Frame Buffer", "0=Off", "1=Suspend", \
    "2=Standby", "3=On",
    "NAME=Monitor", "0=Off", "1=Suspend", "2=Standby", "3=On";
```

When a device driver is first attached, the framework does not know the power level of the device. A power transition can occur when:

- The driver calls `pm_raise_power`(9F) or `pm_lower_power`(9F).
- The framework has lowered the power level of a component because a time threshold has been exceeded.
- Another device has changed power and a dependency exists between the two devices. See "Power Management Dependencies" on page 181.

After a power transition, the framework begins tracking the power level of each component of the device. Tracking also occurs if the driver has informed the framework of the power level. The driver informs the framework of a power level change by calling `pm_power_has_changed`(9F).

The system calculates a default threshold for each potential power transition. These thresholds are based on the system idleness threshold. The default thresholds can be overridden using `pmconfig` or `power.conf`(4). Another default threshold based on the system idleness threshold is used when the component power level is unknown.

# Power Management Dependencies

Some devices should be powered down only when other devices are also powered down. For example, if a CD-ROM drive is allowed to power down, necessary functions, such as the ability to eject a CD, might be lost.

To prevent a device from powering down independently, you can make that device dependent on another device that is likely to remain powered on. Typically, a device is made dependent upon a frame buffer, because a monitor is generally on whenever a user is utilizing a system.

The `power.conf`(4)file specifies the dependencies among devices. (A parent node in the device tree implicitly depends upon its children. This dependency is handled automatically by the power management framework.) You can specify a particular dependency with a `power.conf`(4) entry of this form:

`device-dependency` *dependent-phys-path phys-path*

Where *dependent-phys-path* is the device that is kept powered up, such as the CD-ROM drive. *phys-path* represents the device whose power state is to be depended on, such as the frame buffer.

Adding an entry to `power.conf` for every new device that is plugged into the system would be burdensome. The following syntax enables you to indicate dependency in a more general fashion:

`device-dependency-property` *property phys-path*

Such an entry mandates that any device that exports the property *property* must be dependent upon the device named by *phys-path*. Because this dependency applies especially to removable-media devices, `/etc/power.conf` includes the following line by default:

```
device_dependent-property  removable-media  /dev/fb
```

With this syntax, no device that exports the `removable-media` property can be powered down unless the console frame buffer is also powered down.

For more information, see the `power.conf`(4) and `removable-media`(9P) man pages.

# Automatic Power Management for Devices

If automatic power management is enabled by `pmconfig` or `power.conf`(4), then all devices with a `pm-components`(9P) property automatically will use power management. After a component has been idle for a default period, the component is automatically lowered to the next lowest power level. The default period is calculated by the power management framework to set the entire device to its lowest power state within the system idleness threshold.

**Note –** By default, automatic power management is enabled on all SPARC desktop systems first shipped after July 1, 1999. This feature is disabled by default for all other systems. To determine whether automatic power management is enabled on your machine, refer to the `power.conf`(4) man page for instructions.

`power.conf`(4) can be used to override the defaults calculated by the framework.

# Device Power Management Interfaces

A device driver that supports a device with power-manageable components must create a `pm-components`(9P) property. This property indicates to the system that the device has power-manageable components. `pm-components` also tells the system which power levels are available. The driver typically informs the system by calling `ddi_prop_update_string_array`(9F) from the driver's `attach`(9E) entry point. An alternative means of informing the system is from a `driver.conf`(4) file. See the `pm-components`(9P) man page for details.

## Busy-Idle State Transitions

The driver must keep the framework informed of device state transitions from idle to busy or busy to idle. Where these transitions happen is entirely device-specific. The transitions between the busy and idle states depend on the nature of the device and the abstraction represented by the specific component. For example, SCSI disk target drivers typically export a single component, which represents whether the SCSI target disk drive is spun up or not. The component is marked busy whenever an outstanding request to the drive exists. The component is marked idle when the last queued request finishes. Some components are created and never marked busy. For example, components created by `pm-components`(9P) are created in an idle state.

The `pm_busy_component`(9F) and `pm_idle_component`(9F) interfaces notify the power management framework of busy-idle state transitions. The `pm_busy_component`(9F) call has the following syntax:

```
int pm_busy_component(dev_info_t *dip, int component);
```

`pm_busy_component`(9F) marks *component* as busy. While the component is busy, that component should not be powered off. If the component is already powered off, then marking that component busy does not change the power level. The driver needs to call `ddi_dev_is_needed`(9F) for this purpose. Calls to `pm_busy_component`(9F) are cumulative and require a corresponding number of calls to `pm_idle_component` (9F) to idle the component.

The pm_idle_component(9F) routine has the following syntax:

```
int pm_idle_component(dev_info_t *dip, int component);
```

pm_idle_component(9F) marks *component* as idle. An idle component is subject to being powered off. pm_idle_component(9F) must be called once for each call to pm_busy_component(9F) in order to idle the component.

## Device Power State Transitions

A device driver can call ddi_dev_is_needed(9F) to request that a component be set to at least a given power level. Setting the power level in this manner is necessary before using a component that has been powered off. For example, a SCSI disk target driver's read(9E) routine might need to spin up the disk, if the disk has been powered off. ddi_dev_is_needed(9F) requests the power management framework to initiate a device power state transition to a higher power level. Normally, reductions in component power levels are initiated by the framework. However, a device driver should call pm_lower_power(9F) when detaching, in order to reduce the power consumption of unused devices as much as possible.

Powering down can pose risks for some devices. For example, some tape drives damage tapes when power is removed. Similarly, some disk drives have a limited tolerance for power cycles, because each cycle results in a head landing. The no-involuntary-power-cycles(9P) property should be used to notify the system that the device driver should control all power cycles for the device. This approach prevents power from being removed from a device while the device driver is detached unless the device was powered off by a driver's call to pm_raise_power(9F).

ddi_dev_is_needed(9F) is called when the driver discovers that a component needed for some operation is at an insufficient power level. This interface causes the driver to raise the current power level of the component to the needed level. All the devices that depend on this device are also brought back to full power by this call.

pm_raise_power(9F) is called when the device is detaching once access to the device is no longer needed. Call pm_lower_power() to set each component at the lowest power so that the device uses as little power as possible while not in use. The syntax for pm_raise_power(9F) is the same as the syntax for ddi_dev_is_needed(9F).

pm_power_has_changed(9F) is called to notify the framework about a power transition. The transition might be due to the device changing its own power level. The transition might also be due to an operation such as suspend-resume. The syntax for pm_power_has_changed(9F) is the same as the syntax for ddi_dev_is_needed(9F).

## `power()` Entry Point

The power management framework uses the `power`(9E) entry point.

`power()` uses the following syntax:

```
int power(dev_info_t *dip, int component, int level);
```

When a component's power level needs to be changed, the system calls the `power`(9E) entry point. The action taken by this entry point is device driver-specific. In the example of the SCSI target disk driver mentioned previously, setting the power level to 0 results in sending a SCSI command to spin down the disk, while setting the power level to the full power level results in sending a SCSI command to spin up the disk.

If a power transition can cause the device to lose state, the driver must save any necessary state in memory for later restoration. If a power transition requires that the saved state be restored before the device can be used again, then the driver must restore that state. The framework makes no assumptions about what power transactions cause the loss of or require the restoration of state for automatically power-manage devices. The following example shows a sample `power()` routine.

**EXAMPLE 12–4** Using the `power()` Routine for a Single-Component Device

```
int
xxpower(dev_info_t *dip, int component, int level)
{
    struct xxstate *xsp;
    int instance;

    instance = ddi_get_instance(dip);
    xsp = ddi_get_soft_state(statep, instance);
    /*
     * Make sure the request is valid
     */
    if (!xx_valid_power_level(component, level))
        return (DDI_FAILURE);
    mutex_enter(&xsp->mu);
    /*
     * If the device is busy, don't lower its power level
     */
    if (xsp->xx_busy[component] &&
        xsp->xx_power_level[component] > level) {
        mutex_exit(&xsp->mu);
        return (DDI_FAILURE);
    }

    if (xsp->xx_power_level[component] != level) {
        /*
         * device- and component-specific setting of power level
         * goes here
         */
        [...]
```

**EXAMPLE 12–4** Using the `power()` Routine for a Single-Component Device *(Continued)*

```
        xsp->xx_power_level[component] = level;
    }
    mutex_exit(&xsp->mu);
    return (DDI_SUCCESS);
}
```

The following example is a `power()` routine for a device with two components, where component 0 must be on when component 1 is on.

**EXAMPLE 12–5** `power`(9E) Routine for Multiple-Component Device

```
int
xxpower(dev_info_t *dip, int component, int level)
{
    struct xxstate *xsp;
    int instance;

    instance = ddi_get_instance(dip);
    xsp = ddi_get_soft_state(statep, instance);
    /*
     * Make sure the request is valid
     */
    if (!xx_valid_power_level(component, level))
        return (DDI_FAILURE);
    mutex_enter(&xsp->mu);
    /*
     * If the device is busy, don't lower its power level
     */
    if (xsp->xx_busy[component] &&
        xsp->xx_power_level[component] > level) {
        mutex_exit(&xsp->mu);
        return (DDI_FAILURE);
    }

    /*
     * This code implements inter-component dependencies:
     * If we are bringing up component 1 and component 0
     * is off, we must bring component 0 up first, and if
     * we are asked to shut down component 0 while component
     * 1 is up we must refuse
     */
    if (component == 1 && level > 0 && xsp->xx_power_level[0] == 0) {
        xsp->xx_busy[0]++;
        if (pm_busy_component(dip, 0) != DDI_SUCCESS) {
            /*
             * This can only happen if the args to
             * pm_busy_component()
             * are wrong, or pm-components property was not
             * exported by the driver.
             */
            xsp->xx_busy[0]--;
            mutex_exit(&xsp->mu);
```

**EXAMPLE 12–5** power(9E) Routine for Multiple-Component Device *(Continued)*

```
            cmn_err(CE_WARN, "xxpower pm_busy_component()
                failed");
            return (DDI_FAILURE);
        }
        mutex_exit(&xsp->mu);
        if (pm_raise_power(dip, 0, XX_FULL_POWER_0) != DDI_SUCCESS)
            return (DDI_FAILURE);
        mutex_enter(&xsp->mu);
    }
    if (component == 0 && level == 0 && xsp->xx_power_level[1] != 0) {
        mutex_exit(&xsp->mu);
        return (DDI_FAILURE);
    }
    if (xsp->xx_power_level[component] != level) {
        /*
         * device- and component-specific setting of power level
         * goes here
         */
        [...]
        xsp->xx_power_level[component] = level;
    }
    mutex_exit(&xsp->mu);
    return (DDI_SUCCESS);
}
```

# System Power Management Model

This section describes the details of the System Power Management model. The model includes the following components:

- Autoshutdown threshold
- Busy state
- Hardware state
- Policy
- Power management entry points

## Autoshutdown Threshold

The system can be shut down, that is, powered off, automatically after a configurable period of idleness. This period is known as the *autoshutdown threshold*. This behavior is enabled by default for SPARC desktop systems first shipped after October 1, 1995 and before July 1, 1999. See the power.conf(4)man page for more information. Autoshutdown can be overridden using dtpower(1M) or power.conf(4).

## Busy State

The busy state of the system can be measured in several ways. The currently supported built-in metric items are keyboard characters, mouse activity, `tty` characters, load average, disk reads, and NFS requests. Any one of these items can make the system busy. In addition to the built-in metrics, an interface is defined for running a user-specified process that can indicate that the system is busy.

## Hardware State

Devices that export a `reg` property are considered to have hardware state that must be saved prior to shutting down the system. A device without the `reg` property is considered to be stateless. However, this consideration can be overridden by the device driver.

A device with hardware state but no `reg` property, such as a SCSI driver, must be called to save and restore the state if the driver exports a `pm-hardware-state` property with the value `needs-suspend-resume`. Otherwise, the lack of a `reg` property is taken to mean that the device has no hardware state. For information on device properties, see Chapter 4.

A device with a `reg` property and no hardware state can export a `pm-hardware-state` property with the value `no-suspend-resume`. Using `no-suspend-resume` with the `pm-hardware-state` property keeps the framework from calling the driver to save and restore that state. For more information on power management properties, see the `pm-components`(9P) man page.

## Automatic Power Management for Systems

The system is shut down if the following conditions apply:

- Autoshutdown is enabled by `dtpower`(1M) or `power.conf`(4).
- The system has been idle for *autoshutdown threshold* minutes.
- All of the metrics that are specified in `power.conf` have been satisfied.

## Entry Points Used by System Power Management

System power management passes the command `DDI_SUSPEND` to the `detach`(9E) driver entry point to request the driver to save the device hardware state. System power management passes the command `DDI_RESUME` to the `attach`(9E) driver entry point to request the driver to restore the device hardware state.

### `detach()` Entry Point

The syntax for `detach`(9E) is as follows:

```
int detach(dev_info_t *dip, ddi_detach_cmd_t cmd);
```

A device with a `reg` property or a `pm-hardware-state` property set to `needs-suspend-resume` must be able to save the hardware state of the device. The framework calls into the driver's `detach`(9E) entry point to enable the driver to save the state for restoration after the system power returns. To process the `DDI_SUSPEND` command, `detach`(9E) must perform the following tasks:

- Block further operations from being initiated until the device is resumed, except for `dump`(9E) requests.
- Wait until outstanding operations have completed. If an outstanding operation can be restarted, you can abort that operation.
- Cancel any timeouts and callbacks that are pending.
- Save any volatile hardware state to memory. The state includes the contents of device registers, and can also include downloaded firmware.

If the driver is unable to suspend the device and save its state to memory, then the driver must return `DDI_FAILURE`. The framework then aborts the system power management operation.

In some cases, powering down a device involves certain risks. For example, if a tape drive is powered off with a tape inside, the tape can be damaged. In such a case, `attach`(9E) should do the following:

- Call `ddi_removing_power`(9F) to determine whether a `DDI_SUSPEND` command can cause power to be removed from the device.
- Determine whether power removal can cause problems.

If both cases are true, the `DDI_SUSPEND` request should be rejected. Example 12–6 shows an `attach`(9E) routine using `ddi_removing_power`(9F) to check whether the `DDI_SUSPEND` command causes problems.

Dump requests must be honored. The framework uses the `dump`(9E) entry point to write out the state file that contains the contents of memory. See the `dump`(9E) man page for the restrictions that are imposed on the device driver when using this entry point.

Calling the `detach`(9E) entry point of a power-manageable component with the `DDI_SUSPEND` command should save the state when the device is powered off. The driver should cancel pending timeouts. The driver should also suppress any calls to `ddi_dev_is_needed`(9F) except for `dump`(9E) requests. When the device is resumed by a call to `attach`(9E) with a command of `DDI_RESUME`, timeouts and calls to `pm_raise_power()` can be resumed. The driver must keep sufficient track of its state to be able to deal appropriately with this possibility. The following example shows a `detach`(9E) routine with the `DDI_SUSPEND` command implemented.

**EXAMPLE 12–6** `detach`(9E) Routine Implementing `DDI_SUSPEND`

```
int
xxdetach(dev_info_t *dip, ddi_detach_cmd_t cmd)
{
    struct xxstate *xsp;
```

**EXAMPLE 12–6** `detach`(9E) Routine Implementing `DDI_SUSPEND` *(Continued)*

```
    int instance;

    instance = ddi_get_instance(dip);
    xsp = ddi_get_soft_state(statep, instance);

    switch (cmd) {
    case DDI_DETACH:
      [...]

    case DDI_SUSPEND:
           /*
        * We do not allow DDI_SUSPEND if power will be removed and
        * we have a device that damages tape when power is removed
        * We do support DDI_SUSPEND for Device Reconfiguration.
.
        */
          if (ddi_removing_power(dip) && xxdamages_tape(dip))
             return (DDI_FAILURE);

        mutex_enter(&xsp->mu);
        xsp->xx_suspended = 1;  /* stop new operations */

        /*
         * Sleep waiting for all the commands to be completed
         */
        [...]

        /*
         * If a callback is outstanding which cannot be cancelled
         * then either wait for the callback to complete or fail the
         * suspend request
         */
        [...]

        /*
         * This section is only needed if the driver maintains a
         * running timeout
         */
        if (xsp->xx_timeout_id) {
            timeout_id_t temp_timeout_id = xsp->xx_timeout_id;

            xsp->xx_timeout_id = 0;
            mutex_exit(&xsp->mu);
            untimeout(temp_timeout_id);
            mutex_enter(&xsp->mu);
        }

        if (!xsp->xx_state_saved) {
            /*
             * Save device register contents into
             * xsp->xx_device_state
             */
            [...]
```

**EXAMPLE 12–6** detach(9E) Routine Implementing DDI_SUSPEND *(Continued)*

```
        }
        mutex_exit(&xsp->mu);
        return (DDI_SUCCESS);

    default:
        return (DDI_FAILURE);
}
```

## attach() Entry Point

The syntax for attach(9E) is as follows:

```
int attach(dev_info_t *dip, ddi_attach_cmd_t cmd);
```

When power is restored to the system, each device with a reg property or with a pm-hardware-state property of value needs-suspend-resume has its attach(9E) entry point called with a command value of DDI_RESUME. If the system shutdown is aborted, each suspended driver is called to resume even though the power has not been shut off. Consequently, the resume code in attach(9E) must make no assumptions about whether the system actually lost power.

The power management framework considers the power level of the components to be unknown at DDI_RESUME time. Depending on the nature of the device, the driver writer has two choices:

- If the driver can determine the actual power level of the components of the device without powering the components up, such as by reading a register, then the driver should notify the framework of the power level of each component by calling pm_power_has_changed(9F).
- If the driver cannot determine the power levels of the components, then the driver should mark each component internally as unknown and call pm_raise_power(9F) before the first access to each component.

The following example shows an attach(9E) routine with the DDI_RESUME command.

**EXAMPLE 12–7** attach(9E) Routine Implementing DDI_RESUME

```
int
xxattach(devinfo_t *dip, ddi_attach_cmd_t cmd)
{
    struct xxstate *xsp;
    int    instance;

    instance = ddi_get_instance(dip);
    xsp = ddi_get_soft_state(statep, instance);

    switch (cmd) {
    case DDI_ATTACH:
```

**EXAMPLE 12–7** attach(9E) Routine Implementing DDI_RESUME *(Continued)*

```
    [...]

    case DDI_RESUME:
        mutex_enter(&xsp->mu);
        if (xsp->xx_pm_state_saved) {
            /*
             * Restore device register contents from
             * xsp->xx_device_state
             */
            [...]
        }
        /*
         * This section is optional and only needed if the
         * driver maintains a running timeout
         */
        xsp->xx_timeout_id = timeout(...);

        xsp->xx_suspended = 0;      /* allow new operations */
        cv_broadcast(&xsp->xx_suspend_cv);

        /* If it is possible to determine in a device-specific
         * way what the power levels of components are without
         * powering the components up,
         * then the following code is recommended
         */
        for (i = 0; i < num_components; i++) {
            xsp->xx_power_level[i] = xx_get_power_level(dip, i);
            if (xsp->xx_power_level[i] != XX_LEVEL_UNKNOWN)
                (void) pm_power_has_changed(dip, i,
                    xsp->xx_power_level[i]);
        }
        mutex_exit(&xsp->mu);
        return(DDI_SUCCESS);
    default:
        return(DDI_FAILURE);
    }
}
```

---

**Note –** The detach(9E) and attach(9E) interfaces can also be used to resume a system that has been quiesced.

---

# Power Management Device Access Example

If power management is supported, and `detach`(9E) and `attach`(9E) are used as in Example 12–6 and Example 12–7, then access to the device can be made from user context, for example, from `read`(2), `write`(2), and `ioctl`(2).

The following example demonstrates this approach. The example assumes that the operation about to be performed requires a component `component` that is operating at power level `level`.

**EXAMPLE 12–8** Device Access

```
...
mutex_enter(&xsp->mu);
/*
 * Block command while device is suspended via DDI_SUSPEND
 */
while (xsp->xx_suspended)
    cv_wait(&xsp->xx_suspend_cv, &xsp->mu);

/*
 * Mark component busy so power() will reject attempt to lower power
 */
xsp->xx_busy[component]++;
if (pm_busy_component(dip, component) != DDI_SUCCESS) {
    xsp->xx_busy[component]--;
    /*
     * Log error and abort
     */
    [...]
}

if (xsp->xx_power_level[component] < level) {
    mutex_exit(&xsp->mu);
    if (pm_raise_power(dip, component, level) != DDI_SUCCESS) {
        /*
         * Log error and abort
         */
        [...]
    }
    mutex_enter(&xsp->mu);
}
...
```

The code fragment in the following example can be used when device operation completes, for example, in the device's interrupt handler.

**EXAMPLE 12–9** Device Operation Completion

```
...
/*
```

**EXAMPLE 12–9** Device Operation Completion *(Continued)*

```
 * For each command completion, decrement the busy count and unstack
 * the pm_busy_component() call by calling pm_idle_component(). This
 * will allow device power to be lowered when all commands complete
 * (all pm_busy_component() counts are unstacked)
 */
xsp->xx_busy[component]--;
if (pm_idle_component(dip, component) != DDI_SUCCESS) {
    xsp->xx_busy[component]++;
    /*
     * Log error and abort
     */
    [...]
}

/*
 * If no more outstanding commands, wake up anyone (like DDI_SUSPEND)
 * waiting for all commands to  be completed
 */
...
```

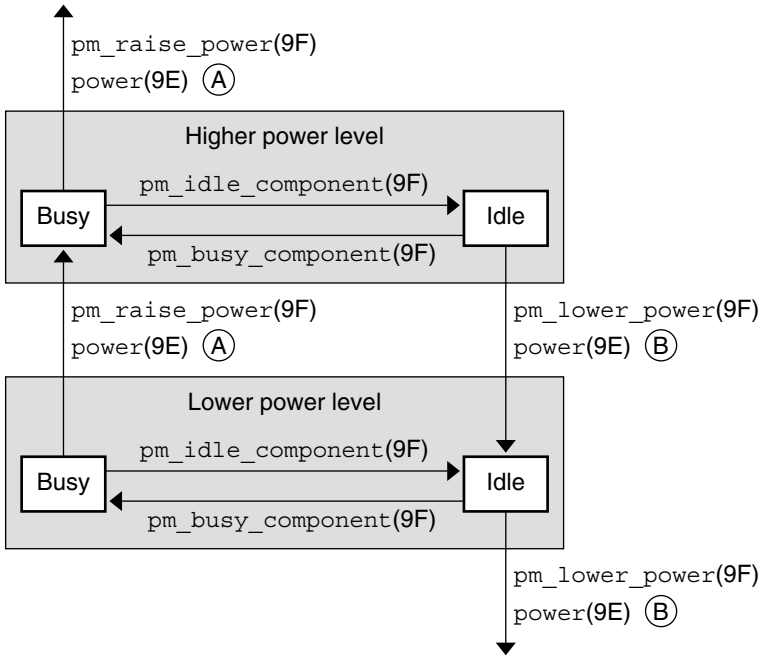
# Power Management Flow of Control

Figure 12–1 illustrates the flow of control in the power management framework.

When a component's activity is complete, a driver can call `pm_idle_component`(9F) to mark the component as idle. When the component has been idle for its threshold time, the framework can lower the power of the component to its next lower level. The framework calls the `power`(9E) function to set the component's power to the next lower supported power level, if a lower level exists. The driver's `power`(9E) function should reject any attempt to lower the power level of a component when that component is busy. The `power`(9E) function should save any state that could be lost in a transition to a lower level prior to making that transition.

When the component is needed at a higher level, the driver calls `pm_busy_component`(9F). This call keeps the framework from lowering the power still further and then calls `ddi_dev_is_needed`(9F) on the component. The framework next calls `power`(9E) to raise the power of the component before the call to `pm_raise_power`(9F) returns. The driver's `power`(9E) code must restore any state that was lost in the lower level but that is needed in the higher level.

When a driver is detaching, the driver should call `pm_lower_power`(9F) for each component to lower its power to its lowest level. The framework can then call the driver's `power`(9E) routine to lower the power of the component before the call to `pm_lower_power`(9F) returns.




(A) `power`(9E) can be called by the framework to raise the power level of a component as a result of a dependency or can be called by the framework as a result of the driver's call to `pm_raise_power`(9F).

(B) `power`(9E) can be called by the framework to lower the power level of a component as a result of a device idleness, or can be called by the framework as a result of the driver's call to `pm_lower_power`(9F) when the driver is detaching.

Note:
9E routines are always called by the framework.
9F routines are always called by the driver.

**FIGURE 12–1** Power Management Conceptual State Diagram

# Changes to Power Management Interfaces

Previous to the Solaris 8 release, power management of devices was not automatic. Developers had to add an entry to `/etc/power.conf` for each device that was to be power-managed. The framework assumed that all devices supported only two power levels: 0 and standard power.

Power assumed an implied dependency of all other components on component 0. When component 0 changed to level 0, a call was made into the driver's `detach(9E)` with the `DDI_PM_SUSPEND` command to save the hardware state. When component 0 changed from level 0, a call was made to the `attach(9E)` routine with the command `DDI_PM_RESUME` to restore hardware state.

The following interfaces and commands are obsolete, although they are still supported for binary purposes:

- `ddi_dev_is_needed`(9F)
- `pm_create_components`(9F)
- `pm_destroy_components`(9F)
- `pm_get_normal_power`(9F)
- `pm_set_normal_power`(9F)
- `DDI_PM_SUSPEND`
- `DDI_PM_RESUME`

As of the Solaris 8 release, devices that export the `pm-components` property automatically use power management, if `autopm` is enabled.

The framework now knows from the `pm-components` property which power levels are supported by each device.

The framework makes no assumptions about dependencies among the different components of a device. The device driver is responsible for saving and restoring hardware state as needed when changing power levels.

These changes enable the power management framework to deal with emerging device technology. Power management now results in greater power savings. The framework can detect automatically which devices can save power. The framework can use intermediate power states of the devices. A system can now meet energy consumption goals without powering down the entire system and without any functions.

**TABLE 12–1** Power Management Interfaces

| Removed Interfaces | Equivalent Solaris 10 Interfaces |
|---|---|
| pm_create_components(9F) | `pm-components`(9P) |
| pm_set_normal_power(9F) | `pm-components`(9P) |
| pm_destroy_components(9F) | None |
| pm_get_normal_power(9F) | None |
| ddi_dev_is_needed(9F) | `pm_raise_power`(9F) |
| None | `pm_lower_power`(9F) |
| None | `pm_power_has_changed`(9F) |
| DDI_PM_SUSPEND | None |
| DDI_PM_RESUME | None |

CHAPTER 13

# Layered Driver Interface (LDI)

The LDI is a set of DDI/DKI that enables a kernel module to access other devices in the system. The LDI also enables you to determine which devices are currently being used by kernel modules.

This chapter covers the following topics:



## LDI Overview

The LDI includes two categories of interfaces:

- **Kernel interfaces**. User applications use system calls to open, read, and write to devices that are managed by a device driver within the kernel. Kernel modules can use the LDI kernel interfaces to open, read, and write to devices that are managed by another device driver within the kernel. For example, a user application might use `read`(2) and a kernel module might use `ldi_read`(9F) to read the same device. See "Kernel Interfaces" on page 200.
- **User interfaces**. The LDI user interfaces can provide information to user processes regarding which devices are currently being used by other devices in the kernel. See "User Interfaces" on page 217.

The following terms are commonly used in discussing the LDI:

- **Target Device**. A target device is a device within the kernel that is managed by a device driver and is being accessed by a device consumer.
- **Device Consumer**. A device consumer is a user process or kernel module that opens and accesses a target device. A device consumer normally performs operations such as `open`, `read`, `write`, or `ioctl` on a target device.

- **Kernel Device Consumer**. A kernel device consumer is a particular kind of device consumer. A kernel device consumer is a kernel module that accesses a target device. The kernel device consumer usually is not the device driver that manages the target device that is being accessed. Instead, the kernel device consumer accesses the target device indirectly through the device driver that manages the target device.
- **Layered Driver**. A layered driver is a particular kind of kernel device consumer. A layered driver is a kernel driver that does not directly manage any piece of hardware. Instead, a layered driver accesses one of more target devices indirectly through the device drivers that manage those target devices. Volume managers and STREAMS multiplexers are good examples of layered drivers.

# Kernel Interfaces

Some LDI kernel interfaces enable the LDI to track and report kernel device usage information. See "Layered Identifiers – Kernel Device Consumers" on page 200.

Other LDI kernel interfaces enable kernel modules to perform access operations such as `open`, `read`, and `write` a target device. These LDI kernel interfaces also enable a kernel device consumer to query property and event information about target devices. See "Layered Driver Handles – Target Devices" on page 201.

"LDI Kernel Interfaces Example" on page 206 shows an example driver that uses many of these LDI interfaces.

## Layered Identifiers – Kernel Device Consumers

Layered identifiers enable the LDI to track and report kernel device usage information. A layered identifier (`ldi_ident_t`) identifies a kernel device consumer. Kernel device consumers must obtain a layered identifier prior to opening a target device using the LDI.

Layered drivers are the only supported types of kernel device consumers. Therefore, a layered driver must obtain a layered identifier that is associated with the device number, the device information node, or the stream of the layered driver. The layered identifier is associated with the layered driver. The layered identifier is not associated with the target device.

You can retrieve the kernel device usage information that is collected by the LDI by using the `libdevinfo`(3LIB) interfaces, the `fuser`(1M) command, or the `prtconf`(1M) command. For example, the `prtconf`(1M) command can show which target devices a layered driver is accessing or which layered drivers are accessing a particular target device. See "User Interfaces" on page 217 to learn more about how to retrieve device usage information.

The following describes the LDI layered identifier interfaces:

| | |
|---|---|
| `ldi_ident_t` | Layered identifier. An opaque type. |
| `ldi_ident_from_dev`(9F) | Allocate and retrieve a layered identifier that is associated with a `dev_t` device number. |
| `ldi_ident_from_dip`(9F) | Allocate and retrieve a layered identifier that is associated with a `dev_info_t` device information node. |
| `ldi_ident_from_stream`(9F) | Allocate and retrieve a layered identifier that is associated with a stream. |
| `ldi_ident_release`(9F) | Release a layered identifier that was allocated with `ldi_ident_from_dev`(9F), `ldi_ident_from_dip`(9F), or `ldi_ident_from_stream`(9F). |

## Layered Driver Handles – Target Devices

Kernel device consumers must use a layered driver handle (`ldi_handle_t`) to access a target device through LDI interfaces. The `ldi_handle_t` type is valid only with LDI interfaces. The LDI allocates and returns this handle when the LDI successfully opens a device. A kernel device consumer can then use this handle to access the target device through the LDI interfaces. The LDI deallocates the handle when the LDI closes the device. See "LDI Kernel Interfaces Example" on page 206 for an example.

This section discusses how kernel device consumers can access target devices and retrieve different types of information. See "Opening and Closing Target Devices" on page 202 to learn how kernel device consumers can open and close target devices. See "Accessing Target Devices" on page 202 to learn how kernel device consumers can perform operations such as `read`, `write`, `strategy`, and `ioctl` on target devices. "Retrieving Target Device Information" on page 203 describes interfaces that retrieve target device information such as device open type and device minor name. "Retrieving Target Device Property Values" on page 204 describes interfaces that retrieve values and address of target device properties. See "Receiving Asynchronous Device Event Notification" on page 205 to learn how kernel device consumers can receive event notification from target devices.

## Opening and Closing Target Devices

This section describes the LDI kernel interfaces for opening and closing target devices. The open interfaces take a pointer to a layered driver handle. The open interfaces attempt to open the target device specified by the device number, device ID, or path name. If the open operation is successful, the open interfaces allocate and return a layered driver handle that can be used to access the target device. The close interface closes the target device associated with the specified layered driver handle and then frees the layered driver handle.

| | |
|---|---|
| `ldi_handle_t` | Layered driver handle for target device access. An opaque data structure that is returned when a device is successfully opened. |
| `ldi_open_by_dev`(9F) | Open the device specified by the `dev_t` device number parameter. |
| `ldi_open_by_devid`(9F) | Open the device specified by the `ddi_devid_t` device ID parameter. You also must specify the minor node name to open. |
| `ldi_open_by_name`(9F) | Open a device by path name. The path name is a null-terminated string in the kernel address space. The path name must be an absolute path, beginning with a forward slash character (`/`). |
| `ldi_close`(9F) | Close a device that was opened with `ldi_open_by_dev`(9F), `ldi_open_by_devid`(9F), or `ldi_open_by_name`(9F). After `ldi_close`(9F) returns, the layered driver handle of the device that was closed is no longer valid. |

## Accessing Target Devices

This section describes the LDI kernel interfaces for accessing target devices. These interfaces enable a kernel device consumer to perform operations on the target device specified by the layered driver handle. Kernel device consumers can perform operations such as `read`, `write`, `strategy`, and `ioctl` on the target device.

| | |
|---|---|
| `ldi_handle_t` | Layered driver handle for target device access. An opaque data structure. |
| `ldi_read`(9F) | Pass a read request to the device entry point for the target device. This operation is supported for block, character, and STREAMS devices. |
| `ldi_aread`(9F) | Pass an asynchronous read request to the device entry point for the target device. This operation is supported for block and character devices. |

| | |
|---|---|
| `ldi_write`(9F) | Pass a write request to the device entry point for the target device. This operation is supported for block, character, and STREAMS devices. |
| `ldi_awrite`(9F) | Pass an asynchronous write request to the device entry point for the target device. This operation is supported for block and character devices. |
| `ldi_strategy`(9F) | Pass a strategy request to the device entry point for the target device. This operation is supported for block and character devices. |
| `ldi_dump`(9F) | Pass a dump request to the device entry point for the target device. This operation is supported for block and character devices. |
| `ldi_poll`(9F) | Pass a poll request to the device entry point for the target device. This operation is supported for block, character, and STREAMS devices. |
| `ldi_ioctl`(9F) | Pass an `ioctl` request to the device entry point for the target device. This operation is supported for block, character, and STREAMS devices. The LDI supports STREAMS linking and STREAMS `ioctl` commands. See the "STREAM IOCTLS" section of the `ldi_ioctl`(9F) man page. See also the `ioctl` commands in the `streamio`(7I) man page. |
| `ldi_devmap`(9F) | Pass a `devmap` request to the device entry point for the target device. This operation is supported for block and character devices. |
| `ldi_getmsg`(9F) | Get a message block from a stream. |
| `ldi_putmsg`(9F) | Put a message block on a stream. |

## Retrieving Target Device Information

This section describes LDI interfaces that kernel device consumers can use to retrieve device information about a specified target device. A target device is specified by a layered driver handle. A kernel device consumer can receive information such as device number, device open type, device ID, device minor name, and device size.

| | |
|---|---|
| `ldi_get_dev`(9F) | Get the `dev_t` device number for the target device specified by the layered driver handle. |
| `ldi_get_otyp`(9F) | Get the open flag that was used to open the target device specified by the layered driver handle. This flag tells you whether the target device is a character device or a block device. |

| | |
|---|---|
| `ldi_get_devid`(9F) | Get the `ddi_devid_t` device ID for the target device specified by the layered driver handle. Use `ddi_devid_free`(9F) to free the `ddi_devid_t` when you are finished using the device ID. |
| `ldi_get_minor_name`(9F) | Retrieve a buffer that contains the name of the minor node that was opened for the target device. Use `kmem_free`(9F) to release the buffer when you are finished using the minor node name. |
| `ldi_get_size`(9F) | Retrieve the partition size of the target device specified by the layered driver handle. |

## Retrieving Target Device Property Values

This section describes LDI interfaces that kernel device consumers can use to retrieve property information about a specified target device. A target device is specified by a layered driver handle. A kernel device consumer can receive values and addresses of properties and determine whether a property exists.

| | |
|---|---|
| `ldi_prop_exists`(9F) | Return `1` if the property exists for the target device specified by the layered driver handle. Return `0` if the property does not exist for the specified target device. |
| `ldi_prop_get_int`(9F) | Search for an `int` integer property that is associated with the target device specified by the layered driver handle. If the integer property is found, return the property value. |
| `ldi_prop_get_int64`(9F) | Search for an `int64_t` integer property that is associated with the target device specified by the layered driver handle. If the integer property is found, return the property value. |
| `ldi_prop_lookup_int_array`(9F) | Retrieve the address of an `int` integer array property value for the target device specified by the layered driver handle. |
| `ldi_prop_lookup_int64_array`(9F) | Retrieve the address of an `int64_t` integer array property value for the target device specified by the layered driver handle. |

| | |
|---|---|
| ldi_prop_lookup_string(9F) | Retrieve the address of a NULL-terminated string property value for the target device specified by the layered driver handle. |
| ldi_prop_lookup_string_array(9F) | Retrieve the address of an array of strings. The string array is an array of pointers to NULL-terminated strings of property values for the target device specified by the layered driver handle. |
| ldi_prop_lookup_byte_array(9F) | Retrieve the address of an array of bytes. The byte array is a property value of the target device specified by the layered driver handle. |

## Receiving Asynchronous Device Event Notification

The LDI enables kernel device consumers to register for event notification and to receive event notification from target devices. A kernel device consumer can register an event handler that will be called when the event occurs. The kernel device consumer must open a device and receive a layered driver handle before the kernel device consumer can register for event notification with the LDI event notification interfaces.

The LDI event notification interfaces enable a kernel device consumer to specify an event name and to retrieve an associated kernel event cookie. The kernel device consumer can then pass the layered driver handle (ldi_handle_t), the cookie (ddi_eventcookie_t), and the event handler to ldi_add_event_handler(9F) to register for event notification. When registration completes successfully, the kernel device consumer receives a unique LDI event handler identifier (ldi_callback_id_t). The LDI event handler identifier is an opaque type that can be used only with the LDI event notification interfaces.

The LDI provides a framework to register for events generated by other devices. The LDI itself does not define any event types or provide interfaces for generating events.

The following describes the LDI asynchronous event notification interfaces:

| | |
|---|---|
| ldi_callback_id_t | Event handler identifier. An opaque type. |
| ldi_get_eventcookie(9F) | Retrieve an event service cookie for the target device specified by the layered driver handle. |
| ldi_add_event_handler(9F) | Add the callback handler specified by the ldi_callback_id_t registration identifier. The callback handler is invoked when the event specified by the ddi_eventcookie_t cookie occurs. |

| | |
|---|---|
| `ldi_remove_event_handler`(9F) | Remove the callback handler specified by the `ldi_callback_id_t` registration identifier. |

# LDI Kernel Interfaces Example

This section shows an example kernel device consumer that uses some of the LDI calls discussed in the preceding sections in this chapter. This section discusses the following aspects of this example module:

- "Device Configuration File" on page 206
- "Driver Source File" on page 206
- "Test the Layered Driver" on page 216

This example kernel device consumer is named `lyr`. The `lyr` module is a layered driver that uses LDI calls to send data to a target device. In its `open`(9E) entry point, the `lyr` driver opens the device that is specified by the `lyr_targ` property in the `lyr.conf` configuration file. In its `write`(9E) entry point, the `lyr` driver writes all of its incoming data to the device specified by the `lyr_targ` property.

## Device Configuration File

In the configuration file shown below, the target device that the `lyr` driver is writing to is the console.

**EXAMPLE 13–1** Configuration File

```
#
# Copyright 2004 Sun Microsystems, Inc.  All rights reserved.
# Use is subject to license terms.
#
#pragma ident    "%Z%%M%    %I%    %E% SMI"

name="lyr" parent="pseudo" instance=1;
lyr_targ="/dev/console";
```

## Driver Source File

In the driver source file shown below, the `lyr_state_t` structure holds the soft state for the `lyr` driver. The soft state includes the layered driver handle (`lh`) for the `lyr_targ` device and the layered identifier (`li`) for the `lyr` device. For more information on soft state, see "Retrieving Driver Soft State Information" on page 455.

In the lyr_open() entry point, ddi_prop_lookup_string(9F) retrieves from the lyr_targ property the name of the target device for the lyr device to open. The ldi_ident_from_dev(9F) function gets an LDI layered identifier for the lyr device. The ldi_open_by_name(9F) function opens the lyr_targ device and gets a layered driver handle for the lyr_targ device.

Note that if any failure occurs in lyr_open(), the ldi_close(9F), ldi_ident_release(9F), and ddi_prop_free(9F) calls undo everything that was done. The ldi_close(9F) function closes the lyr_targ device. The ldi_ident_release(9F) function releases the lyr layered identifier. The ddi_prop_free(9F) function frees resources allocated when the lyr_targ device name was retrieved. If no failure occurs, the ldi_close(9F) and ldi_ident_release(9F) functions are called in the lyr_close() entry point.

In the last line of the driver module, the ldi_write(9F) function is called. The ldi_write(9F) function takes the data written to the lyr device in the lyr_write() entry point and writes that data to the lyr_targ device. The ldi_write(9F) function uses the layered driver handle for the lyr_targ device to write the data to the lyr_targ device.

**EXAMPLE 13–2** Driver Source File

```
#include <sys/types.h>
#include <sys/file.h>
#include <sys/errno.h>
#include <sys/open.h>
#include <sys/cred.h>
#include <sys/cmn_err.h>
#include <sys/modctl.h>
#include <sys/conf.h>
#include <sys/stat.h>

#include <sys/ddi.h>
#include <sys/sunddi.h>
#include <sys/sunldi.h>

typedef struct lyr_state {
    ldi_handle_t    lh;
    ldi_ident_t     li;
    dev_info_t      *dip;
    minor_t     minor;
    int         flags;
    kmutex_t    lock;
} lyr_state_t;

#define LYR_OPENED      0x1     /* lh is valid */
#define LYR_IDENTED     0x2     /* li is valid */


static int lyr_info(dev_info_t *, ddi_info_cmd_t, void *, void **);
static int lyr_attach(dev_info_t *, ddi_attach_cmd_t);
static int lyr_detach(dev_info_t *, ddi_detach_cmd_t);
```

**EXAMPLE 13–2** Driver Source File *(Continued)*

```
static int lyr_open(dev_t *, int, int, cred_t *);
static int lyr_close(dev_t, int, int, cred_t *);
static int lyr_write(dev_t, struct uio *, cred_t *);

static void *lyr_statep;

static struct cb_ops lyr_cb_ops = {
    lyr_open,       /* open */
    lyr_close,      /* close */
    nodev,      /* strategy */
    nodev,      /* print */
    nodev,      /* dump */
    nodev,      /* read */
    lyr_write,      /* write */
    nodev,      /* ioctl */
    nodev,      /* devmap */
    nodev,      /* mmap */
    nodev,      /* segmap */
    nochpoll,       /* poll */
    ddi_prop_op,    /* prop_op */
    NULL,       /* streamtab  */
    D_NEW | D_MP,   /* cb_flag */
    CB_REV,     /* cb_rev */
    nodev,      /* aread */
    nodev       /* awrite */
};

static struct dev_ops lyr_dev_ops = {
    DEVO_REV,       /* devo_rev, */
    0,          /* refcnt  */
    lyr_info,       /* getinfo */
    nulldev,    /* identify */
    nulldev,    /* probe */
    lyr_attach,     /* attach */
    lyr_detach,     /* detach */
    nodev,      /* reset */
    &lyr_cb_ops,    /* cb_ops */
    NULL,       /* bus_ops */
    NULL        /* power */
};

static struct modldrv modldrv = {
    &mod_driverops,
    "LDI example driver",
    &lyr_dev_ops
};

static struct modlinkage modlinkage = {
    MODREV_1,
    &modldrv,
    NULL
```

**EXAMPLE 13–2** Driver Source File *(Continued)*

```
};


int
_init(void)
{
    int rv;

    if ((rv = ddi_soft_state_init(&lyr_statep, sizeof (lyr_state_t),
        0)) != 0) {
        cmn_err(CE_WARN, "lyr _init: soft state init failed\n");
        return (rv);
    }

    if ((rv = mod_install(&modlinkage)) != 0) {
        cmn_err(CE_WARN, "lyr _init: mod_install failed\n");
        goto FAIL;
    }

    return (rv);
    /*NOTEREACHED*/
FAIL:
    ddi_soft_state_fini(&lyr_statep);
    return (rv);
}


int
_info(struct modinfo *modinfop)
{
    return (mod_info(&modlinkage, modinfop));
}


int
_fini(void)
{
    int rv;

    if ((rv = mod_remove(&modlinkage)) != 0) {
        return(rv);
    }

    ddi_soft_state_fini(&lyr_statep);

    return (rv);
}

/*
 * 1:1 mapping between minor number and instance
 */
static int
```

**EXAMPLE 13–2** Driver Source File *(Continued)*

```
lyr_info(dev_info_t *dip, ddi_info_cmd_t infocmd, void *arg, void **result)
{
    int inst;
    minor_t minor;
    lyr_state_t *statep;
    char *myname = "lyr_info";

    minor = getminor((dev_t)arg);
    inst = minor;
    switch (infocmd) {
    case DDI_INFO_DEVT2DEVINFO:
        statep = ddi_get_soft_state(lyr_statep, inst);
        if (statep == NULL) {
            cmn_err(CE_WARN, "%s: get soft state "
                "failed on inst %d\n", myname, inst);
            return (DDI_FAILURE);
        }
        *result = (void *)statep->dip;
        break;
    case DDI_INFO_DEVT2INSTANCE:
        *result = (void *)inst;
        break;
    default:
        break;
    }

    return (DDI_SUCCESS);
}


static int
lyr_attach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
    int inst;
    lyr_state_t *statep;
    char *myname = "lyr_attach";

    switch (cmd) {
    case DDI_ATTACH:
        inst = ddi_get_instance(dip);

        if (ddi_soft_state_zalloc(lyr_statep, inst) != DDI_SUCCESS) {
            cmn_err(CE_WARN, "%s: ddi_soft_state_zallac failed "
                "on inst %d\n", myname, inst);
            goto FAIL;
        }

        statep = (lyr_state_t *)ddi_get_soft_state(lyr_statep, inst);
        if (statep == NULL) {
            cmn_err(CE_WARN, "%s: ddi_get_soft_state failed on "
                "inst %d\n", myname, inst);
            goto FAIL;
```

**EXAMPLE 13–2** Driver Source File *(Continued)*

```
        }
        statep->dip = dip;
        statep->minor = inst;

        if (ddi_create_minor_node(dip, "node", S_IFCHR, statep->minor,
            DDI_PSEUDO, 0) != DDI_SUCCESS) {
            cmn_err(CE_WARN, "%s: ddi_create_minor_node failed on "
                "inst %d\n", myname, inst);
            goto FAIL;
        }
        mutex_init(&statep->lock, NULL, MUTEX_DRIVER, NULL);
        return (DDI_SUCCESS);

    case DDI_RESUME:
    case DDI_PM_RESUME:
    default:
        break;
    }
    return (DDI_FAILURE);
    /*NOTREACHED*/
FAIL:
    ddi_soft_state_free(lyr_statep, inst);
    ddi_remove_minor_node(dip, NULL);
    return (DDI_FAILURE);
}


static int
lyr_detach(dev_info_t *dip, ddi_detach_cmd_t cmd)
{
    int inst;
    lyr_state_t *statep;
    char *myname = "lyr_detach";

    inst = ddi_get_instance(dip);
    statep = ddi_get_soft_state(lyr_statep, inst);
    if (statep == NULL) {
        cmn_err(CE_WARN, "%s: get soft state failed on "
            "inst %d\n", myname, inst);
        return (DDI_FAILURE);
    }
    if (statep->dip != dip) {
        cmn_err(CE_WARN, "%s: soft state does not match devinfo "
            "on inst %d\n", myname, inst);
        return (DDI_FAILURE);
    }

    switch (cmd) {
    case DDI_DETACH:
        mutex_destroy(&statep->lock);
        ddi_soft_state_free(lyr_statep, inst);
        ddi_remove_minor_node(dip, NULL);
```

**EXAMPLE 13–2** Driver Source File *(Continued)*

```
        return (DDI_SUCCESS);
    case DDI_SUSPEND:
    case DDI_PM_SUSPEND:
    default:
        break;
    }
    return (DDI_FAILURE);
}

/*
 * on this driver's open, we open the target specified by a property and store
 * the layered handle and ident in our soft state.  a good target would be
 * "/dev/console" or more interestingly, a pseudo terminal as specified by the
 * tty command
 */
/*ARGSUSED*/
static int
lyr_open(dev_t *devtp, int oflag, int otyp, cred_t *credp)
{
    int rv, inst = getminor(*devtp);
    lyr_state_t *statep;
    char *myname = "lyr_open";
    dev_info_t *dip;
    char *lyr_targ = NULL;

    statep = (lyr_state_t *)ddi_get_soft_state(lyr_statep, inst);
    if (statep == NULL) {
        cmn_err(CE_WARN, "%s: ddi_get_soft_state failed on "
            "inst %d\n", myname, inst);
        return (EIO);
    }
    dip = statep->dip;

    /*
     * our target device to open should be specified by the "lyr_targ"
     * string property, which should be set in this driver's .conf file
     */
    if (ddi_prop_lookup_string(DDI_DEV_T_ANY, dip, DDI_PROP_NOTPROM,
        "lyr_targ", &lyr_targ) != DDI_PROP_SUCCESS) {
        cmn_err(CE_WARN, "%s: ddi_prop_lookup_string failed on "
            "inst %d\n", myname, inst);
        return (EIO);
    }

    /*
     * since we only have one pair of lh's and li's available, we don't
     * allow multiple on the same instance
     */
    mutex_enter(&statep->lock);
    if (statep->flags & (LYR_OPENED | LYR_IDENTED)) {
        cmn_err(CE_WARN, "%s: multiple layered opens or idents "
            "from inst %d not allowed\n", myname, inst);
```

**EXAMPLE 13–2** Driver Source File *(Continued)*

```
        mutex_exit(&statep->lock);
        ddi_prop_free(lyr_targ);
        return (EIO);
    }

    rv = ldi_ident_from_dev(*devtp, &statep->li);
    if (rv != 0) {
        cmn_err(CE_WARN, "%s: ldi_ident_from_dev failed on inst %d\n",
            myname, inst);
        goto FAIL;
    }
    statep->flags |= LYR_IDENTED;

    rv = ldi_open_by_name(lyr_targ, FREAD | FWRITE, credp, &statep->lh,
        statep->li);
    if (rv != 0) {
        cmn_err(CE_WARN, "%s: ldi_open_by_name failed on inst %d\n",
            myname, inst);
        goto FAIL;
    }
    statep->flags |= LYR_OPENED;

    cmn_err(CE_CONT, "\n%s: opened target '%s' successfully on inst %d\n",
        myname, lyr_targ, inst);
    rv = 0;

FAIL:
    /* cleanup on error */
    if (rv != 0) {
        if (statep->flags & LYR_OPENED)
            (void)ldi_close(statep->lh, FREAD | FWRITE, credp);
        if (statep->flags & LYR_IDENTED)
            ldi_ident_release(statep->li);
        statep->flags &= ~(LYR_OPENED | LYR_IDENTED);
    }
    mutex_exit(&statep->lock);

    if (lyr_targ != NULL)
        ddi_prop_free(lyr_targ);
    return (rv);
}


/*
 * on this driver's close, we close the target indicated by the lh member
 * in our soft state and release the ident, li as well.  in fact, we MUST do
 * both of these at all times even if close yields an error because the
 * device framework effectively closes the device, releasing all data
 * associated with it and simply returning whatever value the target's
 * close(9E) returned.  therefore, we must as well.
 */
/*ARGSUSED*/
```

**EXAMPLE 13–2** Driver Source File *(Continued)*

```
static int
lyr_close(dev_t devt, int oflag, int otyp, cred_t *credp)
{
    int rv, inst = getminor(devt);
    lyr_state_t *statep;
    char *myname = "lyr_close";

    statep = (lyr_state_t *)ddi_get_soft_state(lyr_statep, inst);
    if (statep == NULL) {
        cmn_err(CE_WARN, "%s: ddi_get_soft_state failed on "
            "inst %d\n", myname, inst);
        return (EIO);
    }

    mutex_enter(&statep->lock);

    rv = ldi_close(statep->lh, FREAD | FWRITE, credp);
    if (rv != 0) {
        cmn_err(CE_WARN, "%s: ldi_close failed on inst %d, but will ",
            "continue to release ident\n", myname, inst);
    }
    ldi_ident_release(statep->li);
    if (rv == 0) {
        cmn_err(CE_CONT, "\n%s: closed target successfully on "
            "inst %d\n", myname, inst);
    }
    statep->flags &= ~(LYR_OPENED | LYR_IDENTED);

    mutex_exit(&statep->lock);
    return (rv);
}


/*
 * echo the data we receive to the target
 */
/*ARGSUSED*/
static int
lyr_write(dev_t devt, struct uio *uiop, cred_t *credp)
{
    int rv, inst = getminor(devt);
    lyr_state_t *statep;
    char *myname = "lyr_write";

    statep = (lyr_state_t *)ddi_get_soft_state(lyr_statep, inst);
    if (statep == NULL) {
        cmn_err(CE_WARN, "%s: ddi_get_soft_state failed on "
            "inst %d\n", myname, inst);
        return (EIO);
    }

    return (ldi_write(statep->lh, uiop, credp));
```

**EXAMPLE 13–2** Driver Source File *(Continued)*

```
}
```

## ▼ How to Build and Load the Layered Driver

**Steps**

1. **Compile the driver.**

   Use the `-D_KERNEL` option to indicate that this is a kernel module.

   - If you are compiling for a 64–bit SPARC architecture, use the `-xarch=v9` option:

     ```
     % cc -c -D_KERNEL -xarch=v9 lyr.c
     ```

   - If you are compiling for a 32–bit SPARC or x86 architecture, use the following command:

     ```
     % cc -c -D_KERNEL lyr.c
     ```

2. **Link the driver.**

   ```
   % ld -r -o lyr lyr.o
   ```

3. **Install the configuration file.**

   As user `root`, copy the configuration file to the kernel driver area of the machine:

   ```
   # cp lyr.conf /usr/kernel/drv
   ```

4. **Install the driver binary.**

   - As user `root`, copy the driver binary to the `sparcv9` driver area on a 64–bit SPARC architecture:

     ```
     # cp lyr /usr/kernel/drv/sparcv9
     ```

   - As user `root`, copy the driver binary to the `drv` driver area on a 32–bit SPARC or x86 architecture:

     ```
     # cp lyr /usr/kernel/drv
     ```

5. **Load the driver.**

   As user `root`, use the `add_drv`(1M) command to load the driver.

   ```
   # add_drv lyr
   ```

   List the pseudo devices to confirm that the `lyr` device now exists:

   ```
   # ls /devices/pseudo | grep lyr
   lyr@1
   lyr@1:node
   ```

## Test the Layered Driver

To test the `lyr` driver, write a message to the `lyr` device and verify that the message displays on the `lyr_targ` device.

**EXAMPLE 13–3** Write a Short Message to the Layered Device

In this example, the `lyr_targ` device is the console of the system where the `lyr` device is installed.

If the display you are viewing is also the display for the console device of the system where the `lyr` device is installed, note that writing to the console will corrupt your display. The console messages will appear outside your window system. You will need to redraw or refresh your display after testing the `lyr` driver.

If the display you are viewing is not the display for the console device of the system where the `lyr` device is installed, log into or otherwise gain a view of the display of the target console device.

The following command writes a very brief message to the `lyr` device:

```
# echo "\n\n\t===> Hello World!! <===\n" > /devices/pseudo/lyr@1:node
```

You should see the following messages displayed on the target console:

```
console login:

    ===> Hello World!! <===

lyr:
lyr_open: opened target '/dev/console' successfully on inst 1
lyr:
lyr_close: closed target successfully on inst 1
```

The messages from `lyr_open()` and `lyr_close()` come from the `cmn_err`(9F) calls in the `lyr_open()` and `lyr_close()` entry points.

**EXAMPLE 13–4** Write a Longer Message to the Layered Device

The following command writes a longer message to the `lyr` device:

```
# cat lyr.conf > /devices/pseudo/lyr@1:node
```

You should see the following messages displayed on the target console:

```
lyr:
lyr_open: opened target '/dev/console' successfully on inst 1
#
# Copyright 2004 Sun Microsystems, Inc.  All rights reserved.
# Use is subject to license terms.
#
#pragma ident   "%Z%%M% %I%     %E% SMI"
```

**EXAMPLE 13–4** Write a Longer Message to the Layered Device *(Continued)*

```
name="lyr" parent="pseudo" instance=1;
lyr_targ="/dev/console";
lyr:
lyr_close: closed target successfully on inst 1
```

**EXAMPLE 13–5** Change the Target Device

To change the target device, edit `/usr/kernel/drv/lyr.conf` and change the value of the `lyr_targ` property to be a path to a different target device. For example, the target device could be the output of a `tty` command in a local terminal. An example of such a device path is `/dev/pts/4`.

Make sure the `lyr` device is not in use before you update the driver to use the new target device.

```
# modinfo -c | grep lyr
174          3 lyr                                 UNLOADED/UNINSTALLED
```

Use the `update_drv`(1M) command to reload the `lyr.conf` configuration file:

```
# update_drv lyr
```

Write a message to the `lyr` device again and verify that the message displays on the new `lyr_targ` device.

# User Interfaces

The LDI includes user-level library and command interfaces to report device layering and usage information. "Device Information Library Interfaces" on page 218 discusses the `libdevinfo`(3LIB) interfaces for reporting device layering information. "Print System Configuration Command Interfaces" on page 220 discusses the `prtconf`(1M) interfaces for reporting kernel device usage information. "Device User Command Interfaces" on page 222 discusses the `fuser`(1M) interfaces for reporting device consumer information.

# Device Information Library Interfaces

The LDI includes `libdevinfo`(3LIB) interfaces that report a snapshot of device layering information. Device layering occurs when one device in the system is a consumer of another device in the system. Device layering information is reported only if both the consumer and the target are bound to a device node that is contained within the snapshot.

Device layering information is reported by the `libdevinfo`(3LIB) interfaces as a directed graph. An *lnode* is an abstraction that represents a vertex in the graph and is bound to a device node. You can use `libdevinfo`(3LIB) interfaces to access properties of an lnode, such as the name and device number of the node.

The edges in the graph are represented by a link. A link has a source lnode that represents the device consumer. A link also has a target lnode that represents the target device.

The following describes the `libdevinfo`(3LIB) device layering information interfaces:

| | |
|---|---|
| `DINFOLYR` | Snapshot flag that enables you to capture device layering information. |
| `di_link_t` | A directed link between two endpoints. Each endpoint is a `di_lnode_t`. An opaque structure. |
| `di_lnode_t` | The endpoint of a link. An opaque structure. A `di_lnode_t` is bound to a `di_node_t`. |
| `di_node_t` | Represents a device node. An opaque structure. A `di_node_t` is not necessarily bound to a `di_lnode_t`. |
| `di_walk_link`(3DEVINFO) | Walk all links in the snapshot. |
| `di_walk_lnode`(3DEVINFO) | Walk all lnodes in the snapshot. |
| `di_link_next_by_node`(3DEVINFO) | Get a handle to the next link where the specified `di_node_t` node is either the source or the target. |
| `di_link_next_by_lnode`(3DEVINFO) | Get a handle to the next link where the specified `di_lnode_t` lnode is either the source or the target. |
| `di_link_to_lnode`(3DEVINFO) | Get the lnode that corresponds to the specified endpoint of a `di_link_t` link. |

| | |
|---|---|
| `di_link_spectype`(3DEVINFO) | Get the link spectype. The spectype indicates how the target device is being accessed. The target device is represented by the target lnode. |
| `di_lnode_next`(3DEVINFO) | Get a handle to the next occurrence of the specified `di_lnode_t` lnode associated with the specified `di_node_t` device node. |
| `di_lnode_name`(3DEVINFO) | Get the name that is associated with the specified lnode. |
| `di_lnode_devinfo`(3DEVINFO) | Get a handle to the device node that is associated with the specified lnode. |
| `di_lnode_devt`(3DEVINFO) | Get the device number of the device node that is associated with the specified lnode. |

The device layering information returned by the LDI can be quite complex. Therefore, the LDI provides interfaces to help you traverse the device tree and the device usage graph. These interfaces enable the consumer of a device tree snapshot to associate custom data pointers with different structures within the snapshot. For example, as an application traverses lnodes, the application can update the custom pointer associated with each lnode to mark which lnodes already have been seen.

The following describes the `libdevinfo`(3LIB) node and link marking interfaces:

| | |
|---|---|
| `di_lnode_private_set`(3DEVINFO) | Associate the specified data with the specified lnode. This association enables you to traverse lnodes in the snapshot. |
| `di_lnode_private_get`(3DEVINFO) | Retrieve a pointer to data that was associated with an lnode through a call to `di_lnode_private_set`(3DEVINFO). |
| `di_link_private_set`(3DEVINFO) | Associate the specified data with the specified link. This association enables you to traverse links in the snapshot. |
| `di_link_private_get`(3DEVINFO) | Retrieve a pointer to data that was associated with a link through a call to `di_link_private_set`(3DEVINFO). |

# Print System Configuration Command Interfaces

The `prtconf`(1M) command is enhanced to display kernel device usage information. The default `prtconf`(1M) output is not changed. Device usage information is displayed when you specify the verbose option (`-v`) with the `prtconf`(1M) command. Usage information about a particular device is displayed when you specify a path to that device on the `prtconf`(1M) command line.

| | |
|---|---|
| `prtconf -v` | Display device minor node and device usage information. Show kernel consumers and the minor nodes each kernel consumer currently has open. |
| `prtconf` *path* | Display device usage information for the device specified by *path*. |
| `prtconf -a` *path* | Display device usage information for the device specified by *path* and all device nodes that are ancestors of *path*. |
| `prtconf -c` *path* | Display device usage information for the device specified by *path* and all device nodes that are children of *path*. |

**EXAMPLE 13–6** Device Usage Information

When you want usage information about a particular device, the value of the *path* parameter can be any valid device path.

```
% prtconf /dev/cfg/c0
SUNW,isptwo, instance #0
```

**EXAMPLE 13–7** Ancestor Node Usage Information

To display usage information about a particular device and all device nodes that are ancestors of that particular device, specify the `-a` flag with the `prtconf`(1M) command. Ancestors include all nodes up to the root of the device tree. If you specify the `-a` flag with the `prtconf`(1M) command, then you must also specify a device *path* name.

```
% prtconf -a /dev/cfg/c0
SUNW,Sun-Fire
    ssm, instance #0
        pci, instance #0
            pci, instance #0
                SUNW,isptwo, instance #0
```

**EXAMPLE 13–8** Child Node Usage Information

To display usage information about a particular device and all device nodes that are children of that particular device, specify the `-c` flag with the `prtconf`(1M) command. If you specify the `-c` flag with the `prtconf`(1M) command, then you must also specify a device *path* name.

**EXAMPLE 13–8** Child Node Usage Information *(Continued)*

```
% prtconf -c /dev/cfg/c0
SUNW,isptwo, instance #0
    sd (driver not attached)
    st (driver not attached)
    sd, instance #1
    sd, instance #0
    sd, instance #6
    st, instance #1 (driver not attached)
    st, instance #0 (driver not attached)
    st, instance #2 (driver not attached)
    st, instance #3 (driver not attached)
    st, instance #4 (driver not attached)
    st, instance #5 (driver not attached)
    st, instance #6 (driver not attached)
    ses, instance #0 (driver not attached)
    ...
```

**EXAMPLE 13–9** Layering and Device Minor Node Information – Keyboard

To display device layering and device minor node information about a particular device, specify the `-v` flag with the `prtconf`(1M) command.

```
% prtconf -v /dev/kbd
conskbd, instance #0
    System properties:
        ...
    Device Layered Over:
        mod=kb8042 dev=(101,0)
            dev_path=/isa/i8042@1,60/keyboard@0
    Device Minor Nodes:
        dev=(103,0)
            dev_path=/pseudo/conskbd@0:kbd
                spectype=chr type=minor
                dev_link=/dev/kbd
        dev=(103,1)
            dev_path=/pseudo/conskbd@0:conskbd
                spectype=chr type=internal
            Device Minor Layered Under:
                mod=wc accesstype=chr
                    dev_path=/pseudo/wc@0
```

This example shows that the `/dev/kbd` device is layered on top of the hardware keyboard device (`/isa/i8042@1,60/keyboard@0`). This example also shows that the `/dev/kbd` device has two device minor nodes. The first minor node has a `/dev` link that can be used to access the node. The second minor node is an internal node that is not accessible through the file system. The second minor node has been opened by the `wc` driver, which is the workstation console. Compare the output from this example to the output from Example 13–12.

**EXAMPLE 13–10** Layering and Device Minor Node Information – Network Device

This example shows which devices are using the currently plumbed network device.

```
% prtconf -v /dev/iprb0
pci1028,145, instance #0
    Hardware properties:
        ...
    Interrupt Specifications:
        ...
    Device Minor Nodes:
        dev=(27,1)
            dev_path=/pci@0,0/pci8086,244e@1e/pci1028,145@c:iprb0
                spectype=chr type=minor
                alias=/dev/iprb0
        dev=(27,4098)
            dev_path=<clone>
            Device Minor Layered Under:
                mod=udp6 accesstype=chr
                    dev_path=/pseudo/udp6@0
        dev=(27,4097)
            dev_path=<clone>
            Device Minor Layered Under:
                mod=udp accesstype=chr
                    dev_path=/pseudo/udp@0
        dev=(27,4096)
            dev_path=<clone>
            Device Minor Layered Under:
                mod=udp accesstype=chr
                    dev_path=/pseudo/udp@0
```

This example shows that the `iprb0` device has been linked under `udp` and `udp6`. Notice that no paths are shown to the minor nodes that `udp` and `udp6` are using. No paths are shown in this case because the minor nodes were created through `clone` opens of the `iprb` driver, and therefore there are no file system paths by which these nodes can be accessed. Compare the output from this example to the output from Example 13–11.

# Device User Command Interfaces

The `fuser`(1M) command is enhanced to display device usage information. The `fuser`(1M) command displays device usage information only if *path* represents a device minor node. The `-d` flag is valid for the `fuser`(1M) command only if you specify a *path* that represents a device minor node.

| | |
|---|---|
| `fuser` *path* | Display information about application device consumers and kernel device consumers if *path* represents a device minor node. |
| `fuser -d` *path* | Display all users of the underlying device that is associated with the device minor node represented by *path*. |

Kernel device consumers are reported in one of the following four formats. Kernel device consumers always are surrounded by square brackets ( `[]` ).

[*kernel_module_name*]
[*kernel_module_name*,`dev_path=`*path*]
[*kernel_module_name*,`dev=(`*major*,*minor*`)`]
[*kernel_module_name*,`dev=(`*major*,*minor*`),dev_path=`*path*]

When the `fuser`(1M) command displays file or device users, the output consists of a process ID on `stdout` followed by a character on `stderr`. The character on `stderr` describes how the file or device is being used. All kernel consumer information is displayed to `stderr`. No kernel consumer information is displayed to `stdout`.

If you do not use the `-d` flag, then the `fuser`(1M) command reports consumers of only the device minor node that is specified by *path*. If you use the `-d` flag, then the `fuser`(1M) command reports consumers of the device node that underlies the minor node specified by *path*. The following example illustrates the difference in report output in these two cases.

**EXAMPLE 13–11** Consumers of Underlying Device Nodes

Most network devices clone their minor node when the device is opened. If you request device usage information for the clone minor node, the usage information might show that no process is using the device. If instead you request device usage information for the underlying device node, the usage information might show that a process is using the device. In this example, no device consumers are reported when only a device *path* is passed to the `fuser`(1M) command. When the `-d` flag is used, the output shows that the device is being accessed by `udp` and `udp6`.

```
% fuser /dev/iprb0
/dev/iprb0:
% fuser -d /dev/iprb0
/dev/iprb0:  [udp,dev_path=/pseudo/udp@0] [udp6,dev_path=/pseudo/udp6@0]
```

Compare the output from this example to the output from Example 13–10.

**EXAMPLE 13–12** Consumer of the Keyboard Device

In this example, a kernel consumer is accessing `/dev/kbd`. The kernel consumer that is accessing the `/dev/kbd` device is the workstation console driver.

```
% fuser -d /dev/kbd
/dev/kbd:  [genunix] [wc,dev_path=/pseudo/wc@0]
```

Compare the output from this example to the output from Example 13–9.

# PART II Designing Specific Kinds of Device Drivers

The second part of the book provides design information that is specific to the type of driver:

- Chapter 14 describes drivers for character-oriented devices.
- Chapter 15 describes drivers for a block-oriented devices.
- Chapter 16 outlines the Sun Common SCSI Architecture (SCSA) and the requirements for SCSI target drivers.
- Chapter 17 explains how to apply SCSA to SCSI Host Bus Adapter (HBA) drivers.
- Chapter 18 describes the Generic LAN driver (GLD), a Solaris network driver that uses STREAMS technology and the Data Link Provider Interface (DLPI).
- Chapter 19 describes how to write a client USB device driver using the USBA 2.0 framework.

CHAPTER 14

# Drivers for Character Devices

A *character device* does not have physically addressable storage media, such as tape drives or serial ports, where I/O is normally performed in a byte stream. This chapter describes the structure of a character device driver, focusing in particular on entry points for character drivers. In addition, this chapter describes the use of `physio`(9F) and `aphysio`(9F) in the context of synchronous and asynchronous I/O transfers.

This chapter provides information on the following subjects:



## Overview of the Character Driver Structure

Figure 14–1 shows data structures and routines that define the structure of a character device driver. Device drivers typically include the following elements:

- Device-loadable driver section
- Device configuration section
- Character driver entry points

The shaded device access section in the following figure illustrates character driver entry points.

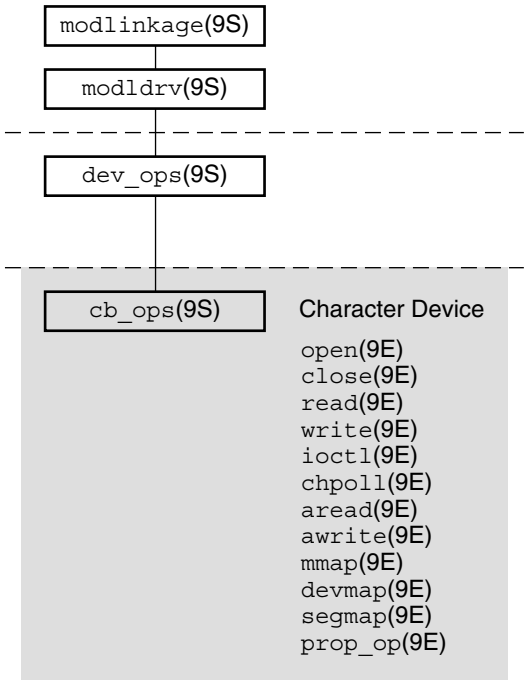



**FIGURE 14–1** Character Driver Roadmap

Associated with each device driver is a `dev_ops`(9S) structure, which in turn refers to a `cb_ops`(9S) structure. These structures contain pointers to the driver entry points:

- `open`(9E)
- `close`(9E)
- `read`(9E)
- `write`(9E)
- `ioctl`(9E)
- `chpoll`(9E)
- `aread`(9E)
- `awrite`(9E)
- `mmap`(9E)
- `devmap`(9E)
- `segmap`(9E)
- `prop_op`(9E)

---

**Note –** Some of these entry points can be replaced with `nodev`(9F) or `nulldev`(9F) as appropriate.

---

# Character Device Autoconfiguration

The `attach`(9E) routine should perform the common initialization tasks that all devices require, such as:

- Allocating per-instance state structures
- Registering device interrupts
- Mapping the device's registers
- Initializing mutex variables and condition variables
- Creating power-manageable components
- Creating minor nodes

See "`attach()` Entry Point" on page 99 for code examples of these tasks.

Character device drivers create minor nodes of type `S_IFCHR`. A minor node of `S_IFCHR` causes a character special file that represents the node to eventually appear in the `/devices` hierarchy.

The following example shows a typical `attach`(9E) routine for character drivers. Properties that are associated with the device are commonly declared in an `attach()` routine. This example uses a predefined `Size` property. `Size` is the equivalent of the `Nblocks` property for getting the size of partition in a block device. If, for example, you are doing character I/O on a disk device, you might use `Size` to get the size of a partition. Since `Size` is a 64–bit property, you must use a 64–bit property interface. In this case, you use `ddi_prop_update_int64`(9F). See "Device Properties" on page 73 for more information about properties.

**EXAMPLE 14–1** Character Driver `attach()` Routine

```
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
  int instance = ddi_get_instance(dip);
  switch (cmd) {
  case DDI_ATTACH:
    allocate a state structure and initialize it.
    map the device's registers.
    add the device driver's interrupt handler(s).
    initialize any mutexes and condition variables.
    create power manageable components.
       /*
        * Create the device's minor node. Note that the node_type
        * argument is set to DDI_NT_TAPE.
        */
        if (ddi_create_minor_node(dip, "minor_name", S_IFCHR,
            instance, DDI_NT_TAPE, 0) == DDI_FAILURE) {
    free resources allocated so far.
            /* Remove any previously allocated minor nodes */
            ddi_remove_minor_node(dip, NULL);
            return (DDI_FAILURE);
```

**EXAMPLE 14–1** Character Driver `attach()` Routine *(Continued)*

```
        }
        /*
         * Create driver properties like "Size." Use "Size"
         * instead of "size" to ensure the property works
         * for large bytecounts.
         */
         xsp->Size =      size of device in bytes;
         maj_number = ddi_driver_major(dip);
         if (ddi_prop_update_int64(makedevice(maj_number, instance),
              dip, "Size", xsp->Size) != DDI_PROP_SUCCESS) {
           cmn_err(CE_CONT, "%s: cannot create Size property\n",
                ddi_get_name(dip));
             free resources allocated so far
          return (DDI_FAILURE);
        }
        [...]
        return (DDI_SUCCESS);
case DDI_RESUME:
         For information, see Chapter 12, "Power Managerment," in this book.
default:
    return (DDI_FAILURE);
      }
}
```

# Device Access (Character Drivers)

Access to a device by one or more application programs is controlled through the `open`(9E) and `close`(9E) entry points. An `open`(2) system call to a special file representing a character device always causes a call to the `open`(9E) routine for the driver. For a particular minor device, `open`(9E) can be called many times. The `close`(9E) routine is called only when the final reference to a device is removed. If the device is accessed through file descriptors, the final call to `close`(9E) can occur as a result of a `close`(2) or `exit`(2) system call. If the device is accessed through memory mapping, the final call to `close`(9E) can occur as a result of a `munmap`(2) system call.

## `open()` Entry Point (Character Drivers)

The primary function of `open()` is to verify that the open request is allowed. The syntax for `open`(9E) is as follows:

```
int xxopen(dev_t *devp, int flag, int otyp, cred_t *credp);
```

where:

*devp* Pointer to a device number. The `open()` routine is passed a pointer so that the driver can change the minor number. With this pointer, drivers can dynamically create minor instances of the device. An example would be a pseudo terminal driver that creates a new pseudo-terminal whenever the driver is opened. A driver that dynamically chooses the minor number normally creates only one minor device node in `attach`(9E) with `ddi_create_minor_node`(9F), then changes the minor number component of `*devp` using `makedevice`(9F) and `getmajor`(9F):

```
*devp = makedevice(getmajor(*devp), new_minor);
```

You do not have to call `ddi_create_minor_node`(9F) for the new minor. A driver may not change the major number of `*devp`. The driver must keep track of available minor numbers internally.

*flag* Flag with bits to indicate whether the device is opened for reading (`FREAD`), writing (`FWRITE`), or both. User threads issuing the `open`(2) system call can also request exclusive access to the device (`FEXCL`) or specify that the open should not block for any reason (`FNDELAY`), but the driver must enforce both cases. A driver for a write-only device such as a printer might consider an `open`(9E) for reading invalid.

*otyp* Integer that indicates how `open()` was called. The driver must check that the value of *otyp* is appropriate for the device. For character drivers, *otyp* should be `OTYP_CHR` (see the `open`(9E) man page).

*credp* Pointer to a credential structure containing information about the caller, such as the user ID and group IDs. Drivers should not examine the structure directly, but should instead use `drv_priv`(9F) to check for the common case of root privileges. In this example, only `root` or a user with the PRIV_SYS_DEVICES privilege is allowed to open the device for writing.

The following example shows a character driver `open`(9E) routine.

**EXAMPLE 14–2** Character Driver `open`(9E) Routine

```
static int
xxopen(dev_t *devp, int flag, int otyp, cred_t *credp)
{
    minor_t        instance;

    if (getminor(*devp)      is invalid)
        return (EINVAL);
    instance = getminor(*devp); /* one-to-one example mapping */
    /* Is the instance attached? */
    if (ddi_get_soft_state(statep, instance) == NULL)
        return (ENXIO);
    /* verify that otyp is appropriate */
    if (otyp != OTYP_CHR)
        return (EINVAL);
    if ((flag & FWRITE) && drv_priv(credp) == EPERM)
        return (EPERM);
```

**EXAMPLE 14–2** Character Driver `open`(9E) Routine *(Continued)*

```
    return (0);
}
```

## `close()` Entry Point (Character Drivers)

The syntax for `close`(9E) is as follows:

```
int xxclose(dev_t dev, int flag, int otyp, cred_t *credp);
```

`close()` should perform any cleanup necessary to finish using the minor device, and prepare the device (and driver) to be opened again. For example, the open routine might have been invoked with the exclusive access (`FEXCL`) flag. A call to `close`(9E) would allow further open routines to continue. Other functions that `close`(9E) might perform are:

- Waiting for I/O to drain from output buffers before returning
- Rewinding a tape (tape device)
- Hanging up the phone line (modem device)

A driver that waits for I/O to drain could wait forever if draining stalls due to external conditions such as flow control. See "Threads Unable to Receive Signals" on page 71 for information about how to avoid this problem.

# I/O Request Handling

This section discusses I/O request processing in detail.

## User Addresses

When a user thread issues a `write`(2) system call, the thread passes the address of a buffer in user space:

```
char buffer[] = "python";
count = write(fd, buffer, strlen(buffer) + 1);
```

The system builds a uio(9S) structure to describe this transfer by allocating an iovec(9S) structure and setting the iov_base field to the address passed to write(2), in this case, buffer. The uio(9S) structure is passed to the driver write(9E) routine. See "Vectored I/O" on page 233 for more information about the uio(9S) structure.

The address in the iovec(9S) is in user space, not kernel space. Thus, the address is neither guaranteed to be currently in memory nor to be a valid address. In either case, accessing a user address directly from the device driver or from the kernel could crash the system. Thus, device drivers should never access user addresses directly. Instead, a data transfer routine in the Solaris 10 DDI/DKI should be used to transfer data into or out of the kernel. These routines can handle page faults. The DDI/DKI routines can bring in the proper user page to continue the copy transparently. Alternatively, the routines can return an error on an invalid access.

copyout(9F) can be used to copy data from kernel space to user space. copyin(9F) can copy data from user space to kernel space. ddi_copyout(9F) and ddi_copyin(9F) operate similarly but are to be used in the ioctl(9E) routine. copyin(9F) and copyout(9F) can be used on the buffer described by each iovec(9S) structure, or uiomove(9F) can perform the entire transfer to or from a contiguous area of driver or device memory.

# Vectored I/O

In character drivers, transfers are described by a uio(9S) structure. The uio(9S) structure contains information about the direction and size of the transfer, plus an array of buffers for one end of the transfer. The other end is the device.

The uio(9S) structure contains the following members:

```
iovec_t    *uio_iov;     /* base address of the iovec */
                 /* buffer description array */
int        uio_iovcnt;       /* the number of iovec structures */
off_t      uio_offset;       /* 32-bit offset into file where */
                 /* data is transferred from or to */
offset_t       uio_loffset;      /* 64-bit offset into file where */
                 /* data is transferred from or to */
uio_seg_t      uio_segflg;       /* identifies the type of I/O */
                 /* transfer: */
                 /*  UIO_SYSSPACE:  kernel <-> kernel */
                 /*  UIO_USERSPACE: kernel <-> user */
short      uio_fmode;    /* file mode flags (not driver setTable) */
daddr_t    uio_limit;    /* 32-bit ulimit for file (maximum */
                 /* block offset). not driver settable. */
diskaddr_t     uio_llimit;       /* 64-bit ulimit for file (maximum block */
                 /* block offset). not driver settable. */
int        uio_resid;    /* amount (in bytes) not */
                 /* transferred on completion */
```

A uio(9S) structure is passed to the driver read(9E) and write(9E) entry points. This structure is generalized to support what is called *gather-write* and *scatter-read*. When writing to a device, the data buffers to be written do not have to be contiguous in application memory. Similarly, data that is transferred from a device into memory comes off in a contiguous stream but can go into noncontiguous areas of application memory. See the readv(2), writev(2), pread(2), and pwrite(2) man pages for more information on scatter-gather I/O.

Each buffer is described by an iovec(9S) structure. This structure contains a pointer to the data area and the number of bytes to be transferred.

```
caddr_t    iov_base;    /* address of buffer */
int        iov_len;     /* amount to transfer */
```

The uio structure contains a pointer to an array of iovec(9S) structures. The base address of this array is held in uio_iov, and the number of elements is stored in uio_iovcnt.

The uio_offset field contains the 32-bit offset into the device at which the application needs to begin the transfer. uio_loffset is used for 64-bit file offsets. If the device does not support the notion of an offset, these fields can be safely ignored. The driver should interpret either uio_offset or uio_loffset, but not both. If the driver has set the D_64BIT flag in the cb_ops(9S) structure, that driver should use uio_loffset.

The uio_resid field starts out as the number of bytes to be transferred, that is, the sum of all the iov_len fields in uio_iov. This field *must* be set by the driver to the number of bytes that were *not* transferred before returning. The read(2) and write(2) system calls use the return value from the read(9E) and write(9E) entry points to determine failed transfers. If a failure occurs, these routines return -1. If the return value indicates success, the system calls return the number of bytes requested minus uio_resid. If uio_resid is not changed by the driver, the read(2) and write(2) calls return 0. A return value of 0 indicates end-of-file, even though all the data has been transferred.

The support routines uiomove(9F), physio(9F), and aphysio(9F) update the uio(9S) structure directly. These support routines update the device offset to account for the data transfer. Neither the uio_offset or uio_loffset fields need to be adjusted when the driver is used with a seekable device that uses the concept of position. I/O performed to a device in this manner is constrained by the maximum possible value of uio_offset or uio_loffset. An example of such a usage is raw I/O on a disk.

If the device has no concept of position, the driver can take the following steps:

1. Save uio_offset or uio_loffset.
2. Perform the I/O operation.
3. Restore uio_offset or uio_loffset to the field's initial value.

I/O that is performed to a device in this manner is not constrained by the maximum possible value of `uio_offset` or `uio_loffset`. An example of this type of usage is I/O on a serial line.

The following example shows one way to preserve `uio_loffset` in the `read`(9E) function.

```
static int
xxread(dev_t dev, struct uio *uio_p, cred_t *cred_p)
{
     offset_t off;
     [...]

     off = uio_p->uio_loffset;  /* save the offset */
    /* do the transfer */
    uio_p->uio_loffset = off;  /* restore it */
}
```

# Differences Between Synchronous and Asynchronous I/O

Data transfers can be *synchronous* or *asynchronous*. The determining factor is whether the entry point that schedules the transfer returns immediately or waits until the I/O has been completed.

The `read`(9E) and `write`(9E) entry points are synchronous entry points. The transfer must not return until the I/O is complete. Upon return from the routines, the process knows whether the transfer has succeeded.

The `aread`(9E) and `awrite`(9E) entry points are asynchronous entry points. Asynchronous entry points schedule the I/O and return immediately. Upon return, the process that issues the request knows that the I/O is scheduled and that the status of the I/O must be determined later. In the meantime, the process can perform other operations.

With an asynchronous I/O request to the kernel, the process is not required to wait while the I/O is in process. A process can perform multiple I/O requests and let the kernel handle the data transfer details. Asynchronous I/O requests enable applications such as transaction processing to use concurrent programming methods to increase performance or response time. Any performance boost for applications that use asynchronous I/O, however, comes at the expense of greater programming complexity.

# Data Transfer Methods

Data can be transferred using either programmed I/O or DMA. These data transfer methods can be used either by synchronous or by asynchronous entry points, depending on the capabilities of the device.

## Programmed I/O Transfers

Programmed I/O devices rely on the CPU to perform the data transfer. Programmed I/O data transfers are identical to other read and write operations for device registers. Various data access routines are used to read or store values to device memory.

`uiomove`(9F) can be used to transfer data to some programmed I/O devices. `uiomove`(9F) transfers data between the user space, as defined by the `uio(9S)` structure, and the kernel. `uiomove()` can handle page faults, so the memory to which data is transferred need not be locked down. `uiomove()` also updates the `uio_resid` field in the `uio`(9S) structure. The following example shows one way to write a ramdisk `read`(9E) routine. It uses synchronous I/O and relies on the presence of the following fields in the ramdisk state structure:

```
caddr_t    ram;        /* base address of ramdisk */
int        ramsize;    /* size of the ramdisk */
```

**EXAMPLE 14–3** Ramdisk `read`(9E) Routine Using `uiomove`(9F)

```
static int
rd_read(dev_t dev, struct uio *uiop, cred_t *credp)
{
     rd_devstate_t     *rsp;

     rsp = ddi_get_soft_state(rd_statep, getminor(dev));
     if (rsp == NULL)
       return (ENXIO);
     if (uiop->uio_offset >= rsp->ramsize)
       return (EINVAL);
     /*
      * uiomove takes the offset into the kernel buffer,
      * the data transfer count (minimum of the requested and
      * the remaining data), the UIO_READ flag, and a pointer
      * to the uio structure.
      */
     return (uiomove(rsp->ram + uiop->uio_offset,
         min(uiop->uio_resid, rsp->ramsize - uiop->uio_offset),
         UIO_READ, uiop));
}
```

Another example of programmed I/O would be a driver that writes data one byte at a time directly to the device's memory. Each byte is retrieved from the `uio`(9S) structure by using `uwritec`(9F). The byte is then sent to the device. `read`(9E) can use `ureadc`(9F) to transfer a byte from the device to the area described by the `uio`(9S) structure.

**EXAMPLE 14–4** Programmed I/O `write`(9E) Routine Using `uwritec`(9F)

```
static int
xxwrite(dev_t dev, struct uio *uiop, cred_t *credp)
{
    int    value;
    struct xxstate     *xsp;

    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL)
        return (ENXIO);
        if the device implements a power manageable component, do this:
    pm_busy_component(xsp->dip, 0);
    if (xsp->pm_suspended)
        ddi_dev_is_needed(xsp->dip, normal power);

    while (uiop->uio_resid > 0) {
        /*
         * do the programmed I/O access
         */
        value = uwritec(uiop);
        if (value == -1)
               return (EFAULT);
        ddi_put8(xsp->data_access_handle, &xsp->regp->data,
            (uint8_t)value);
        ddi_put8(xsp->data_access_handle, &xsp->regp->csr,
            START_TRANSFER);
        /*
         * this device requires a ten microsecond delay
         * between writes
         */
        drv_usecwait(10);
    }
    pm_idle_component(xsp->dip, 0);
    return (0);
}
```

## DMA Transfers (Synchronous)

Character drivers generally use `physio`(9F) to do the setup work for DMA transfers in `read`(9E) and `write`(9E), as is shown in Example 14–5.

```
int physio(int (*strat)(struct buf *), struct buf *bp,
     dev_t dev, int rw, void (*mincnt)(struct buf *),
     struct uio *uio);
```

physio(9F) requires the driver to provide the address of a strategy(9E) routine. physio(9F) ensures that memory space is locked down, that is, memory cannot be paged out, for the duration of the data transfer. This lock-down is necessary for DMA transfers because DMA transfers cannot handle page faults. physio(9F) also provides an automated way of breaking a larger transfer into a series of smaller, more manageable ones. See "minphys() Entry Point" on page 240 for more information.

**EXAMPLE 14–5** read(9E) and write(9E) Routines Using physio(9F)

```
static int
xxread(dev_t dev, struct uio *uiop, cred_t *credp)
{
     struct xxstate *xsp;
     int ret;

     xsp = ddi_get_soft_state(statep, getminor(dev));
     if (xsp == NULL)
        return (ENXIO);
     ret = physio(xxstrategy, NULL, dev, B_READ, xxminphys, uiop);
     return (ret);
}

static int
xxwrite(dev_t dev, struct uio *uiop, cred_t *credp)
{
     struct xxstate *xsp;
     int ret;

     xsp = ddi_get_soft_state(statep, getminor(dev));
     if (xsp == NULL)
        return (ENXIO);
     ret = physio(xxstrategy, NULL, dev, B_WRITE, xxminphys, uiop);
     return (ret);
}
```

In the call to physio(9F), xxstrategy() is a pointer to the driver strategy routine. Passing NULL as the buf(9S) structure pointer tells physio(9F) to allocate a buf(9S) structure. If the driver must provide physio(9F) with a buf(9S) structure, getrbuf(9F) should be used to allocate the structure. physio(9F) returns zero if the transfer completes successfully, or an error number on failure. After calling strategy(9E), physio(9F) calls biowait(9F) to block until the transfer either completes or fails. The return value of physio(9F) is determined by the error field in the buf(9S) structure set by bioerror(9F).

## DMA Transfers (Asynchronous)

Character drivers that support aread(9E) and awrite(9E) use aphysio(9F) instead of physio(9F).

```
int aphysio(int (*strat)(struct buf *), int (*cancel)(struct buf *),
     dev_t dev, int rw, void (*mincnt)(struct buf *),
     struct aio_req *aio_reqp);
```

---

**Note –** The address of `anocancel`(9F) is the only value that can currently be passed as the second argument to `aphysio`(9F).

---

`aphysio`(9F) requires the driver to pass the address of a `strategy`(9E) routine. `aphysio`(9F) ensures that memory space is locked down, that is, cannot be paged out, for the duration of the data transfer. This lock-down is necessary for DMA transfers because DMA transfers cannot handle page faults. `aphysio`(9F) also provides an automated way of breaking a larger transfer into a series of smaller, more manageable ones. See "`minphys()` Entry Point" on page 240 for more information.

Example 14–5 and Example 14–6 demonstrate that the `aread`(9E) and `awrite`(9E) entry points differ only slightly from the `read`(9E) and `write`(9E) entry points. The difference lies mainly in their use of `aphysio`(9F) instead of `physio`(9F).

**EXAMPLE 14–6** `aread`(9E) and `awrite`(9E) Routines Using `aphysio`(9F)

```
static int
xxaread(dev_t dev, struct aio_req *aiop, cred_t *cred_p)
{
     struct xxstate *xsp;

     xsp = ddi_get_soft_state(statep, getminor(dev));
     if (xsp == NULL)
         return (ENXIO);
     return (aphysio(xxstrategy, anocancel, dev, B_READ,
     xxminphys, aiop));
}

static int
xxawrite(dev_t dev, struct aio_req *aiop, cred_t *cred_p)
{
     struct xxstate *xsp;

     xsp = ddi_get_soft_state(statep, getminor(dev));
     if (xsp == NULL)
        return (ENXIO);
     return (aphysio(xxstrategy, anocancel, dev, B_WRITE,
     xxminphys,aiop));
}
```

In the call to aphysio(9F), xxstrategy() is a pointer to the driver strategy routine. *aiop* is a pointer to the aio_req(9S) structure. *aiop* is passed to aread(9E) and awrite(9E). aio_req(9S) describes where the data is to be stored in user space. aphysio(9F) returns zero if the I/O request is scheduled successfully or an error number on failure. After calling strategy(9E), aphysio(9F) returns without waiting for the I/O to complete or fail.

## minphys() Entry Point

The minphys() entry point is a pointer to a function to be called by physio(9F) or aphysio(9F). The purpose of *xxminphys* is to ensure that the size of the requested transfer does not exceed a driver-imposed limit. If the user requests a larger transfer, strategy(9E) is called repeatedly, requesting no more than the imposed limit at a time. This approach is important because DMA resources are limited. Drivers for slow devices, such as printers, should be careful not to tie up resources for a long time.

Usually, a driver passes the address of the kernel function minphys(9F), but the driver can define its own xxminphys() routine instead. The job of xxminphys() is to keep the b_bcount field of the buf(9S) structure under a driver's limit. The driver should adhere to other system limits as well. For example, the driver's xxminphys() routine should call the system minphys(9F) routine after setting the b_bcount field and before returning.

**EXAMPLE 14–7** minphys(9F) Routine

```
#define XXMINVAL (512 << 10)    /* 512 KB */
static void
xxminphys(struct buf *bp)
{
       if (bp->b_bcount > XXMINVAL)
        bp->b_bcount = XXMINVAL
      minphys(bp);
}
```

## strategy() Entry Point

The strategy(9E) routine originated in block drivers. The strategy function got its name from implementing a strategy for efficient queuing of I/O requests to a block device. A driver for a character-oriented device can also use a strategy(9E) routine. In the character I/O model presented here, strategy(9E) does not maintain a queue of requests, but rather services one request at a time.

In the following example, the strategy(9E) routine for a character-oriented DMA device allocates DMA resources for synchronous data transfer. strategy() starts the command by programming the device register. See Chapter 9 for a detailed description.

**Note –** `strategy`(9E) does not receive a device number (`dev_t`) as a parameter. Instead, the device number is retrieved from the `b_edev` field of the `buf`(9S) structure passed to `strategy`(9E).

**EXAMPLE 14–8** `strategy`(9E) Routine

```
static int
xxstrategy(struct buf *bp)
{
     minor_t            instance;
     struct xxstate         *xsp;
     ddi_dma_cookie_t       cookie;

     instance = getminor(bp->b_edev);
     xsp = ddi_get_soft_state(statep, instance);
     [...]
          if the device has power manageable components
          mark the device busy with pm_busy_components(9F),
          and then ensure that the device
          is powered up by calling ddi_dev_is_needed(9F).

          set up DMA resources with ddi_dma_alloc_handle(9F) and
          ddi_dma_buf_bind_handle(9F).
     xsp->bp = bp; /* remember bp */
          program DMA engine and start command
     return (0);
}
```

**Note –** Although `strategy()` is declared to return an `int`, `strategy()` must always return zero.

On completion of the DMA transfer, the device generates an interrupt, causing the interrupt routine to be called. In the following example, `xxintr()` receives a pointer to the state structure for the device that might have generated the interrupt.

**EXAMPLE 14–9** Interrupt Routine

```
static u_int
xxintr(caddr_t arg)
{
     struct xxstate *xsp = (struct xxstate *)arg;
     if (    device did not interrupt) {
        return (DDI_INTR_UNCLAIMED);
     }
     if (    error) {
             error handling
```

**EXAMPLE 14–9** Interrupt Routine *(Continued)*

```
        }
            release any resources used in the transfer, such as DMA resources
            ddi_dma_unbind_handle(9F) and ddi_dma_free_handle(9F)
        /* notify threads that the transfer is complete */
        biodone(xsp->bp);
        return (DDI_INTR_CLAIMED);
}
```

The driver indicates an error by calling `bioerror`(9F). The driver must call `biodone`(9F) when the transfer is complete or after indicating an error with `bioerror`(9F).

# Mapping Device Memory

Some devices, such as frame buffers, have memory that is directly accessible to user threads by way of memory mapping. Drivers for these devices typically do not support the `read`(9E) and `write`(9E) interfaces. Instead, these drivers support memory mapping with the `devmap`(9E) entry point. For example, a frame buffer driver might implement the `devmap`(9E) entry point to allow the frame buffer to be mapped in a user thread.

## `segmap()` Entry Point

```
int xxsegmap(dev_t dev, off_t off, struct as *asp, caddr_t *addrp,
     off_t len, unsigned int prot, unsigned int maxprot,
     unsigned int flags, cred_t *credp);
```

The entry point `segmap`(9E) is responsible for setting up a memory mapping requested by an `mmap`(2) system call. Drivers for many memory-mapped devices use `ddi_devmap_segmap`(9F) as the entry point rather than defining their own `segmap`(9E) routine.

By providing a `segmap`(9E) entry point, a driver can take care of general tasks before creating the mapping. For example, the driver can check mapping permissions. The driver can also allocate private mapping resources. `segmap`(9E) must call `devmap_setup`(9F) before returning.

In the following example, the driver controls a frame buffer that allows write-only mappings. The driver returns `EINVAL` if the application tries to gain read access and then calls `devmap_setup`(9F) to set up the user mapping.

**EXAMPLE 14–10** `segmap(9E)` Routine

```
static int
xxsegmap(dev_t dev, off_t off, struct as *asp, caddr_t *addrp,
    off_t len, unsigned int prot, unsigned int maxprot,
    unsigned int flags, cred_t *credp)
{
    if (prot & PROT_READ)
        return (EINVAL);
    return (devmap_setup(dev, (offset_t)off, as, addrp,
        (size_t)len, prot, maxprot, flags, cred));
}
```

## `devmap()` Entry Point

```
int xxdevmap(dev_t dev, devmap_cookie_t handle, offset_t off,
     size_t len, size_t *maplen, uint_t model);
```

The `devmap()` entry point is called to export device memory or kernel memory to user applications. `devmap`(9E) is called from `devmap_setup`(9F) inside `segmap`(9E) or on behalf of `ddi_devmap_segmap`(9F). See Chapter 10 and Chapter 11 for details.

# Multiplexing I/O on File Descriptors

A thread sometimes needs to handle I/O on more than one file descriptor. One example is an application program that needs to read the temperature from a temperature-sensing device and then report the temperature to an interactive display. A program that makes a read request with no data available should not block while waiting for the temperature before interacting with the user again.

The `poll`(2) system call provides users with a mechanism for multiplexing I/O over a set of file descriptors that reference open files. `poll`(2) identifies those file descriptors on which a program can send or receive data without blocking, or on which certain events have occurred.

To allow a program to poll a character driver, the driver must implement the `chpoll`(9E) entry point. `chpoll()` uses the following syntax:

```
int xxchpoll(dev_t dev, short events, int anyyet, short *reventsp,
     struct pollhead **php);
```

The system calls `chpoll`(9E) when a user process issues a `poll`(2) system call on a file descriptor associated with the device. The `chpoll`(9E) entry point routine is used by non-STREAMS character device drivers that need to support polling.

In chpoll(9E), the driver must follow these rules:

- Implement the following algorithm when the chpoll(9E) entry point is called:

```
if (     events are satisfied now) {
    *reventsp =      mask of satisfied events;
} else {
    *reventsp = 0;
    if (!anyyet)
        *phpp = &     local pollhead structure;
}
return (0);
```

  xxchpoll() should check to see whether certain events have occurred. See the chpoll(9E) man page. chpoll() should then return the mask of satisfied events by setting the return events in **reventsp*.

  If no events have occurred, the return field for the events is cleared. If the *anyyet* field is not set, the driver must return an instance of the pollhead structure. The pollhead structure is usually allocated in a state structure. pollhead should be treated as opaque by the driver. None of the pollhead fields should be referenced.

- Call pollwakeup(9F) whenever a device condition of type events, listed in Example 14–11, occurs. This function should be called only with one event at a time. pollwakeup(9F) might be called in the interrupt routine when the condition has occurred.

Example 14–11 and Example 14–12 show how to implement the polling discipline and how to use pollwakeup(9F).

**EXAMPLE 14–11** chpoll(9E) Routine

```
static int
xxchpoll(dev_t dev, short events, int anyyet,
    short *reventsp, struct pollhead **phpp)
{
     uint8_t status;
     short revent;
     struct xxstate *xsp;

     xsp = ddi_get_soft_state(statep, getminor(dev));
     if (xsp == NULL)
         return (ENXIO);
     revent = 0;
     /*
    * Valid events are:
    * POLLIN | POLLOUT | POLLPRI | POLLHUP | POLLERR
    * This example checks only for POLLIN and POLLERR.
    */
     status = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
     if ((events & POLLIN) &&      data available to read) {
        revent |= POLLIN;
```

**EXAMPLE 14–11** chpoll(9E) Routine *(Continued)*

```
    }
    if ((events & POLLERR) && (status & DEVICE_ERROR)) {
       revent |= POLLERR;
    }
    /* if nothing has occurred */
    if (revent == 0) {
       if (!anyyet) {
       *phpp = &xsp->pollhead;
       }
    }
      *reventsp = revent;
    return (0);
}
```

In the following example, the driver can handle the POLLIN and POLLERR events. The driver first reads the status register to determine the current state of the device. The parameter events specifies which conditions the driver should check. If the appropriate conditions have occurred, the driver sets that bit in **reventsp*. If none of the conditions have occurred and if *anyyet* is not set, the address of the pollhead structure is returned in **phpp*.

**EXAMPLE 14–12** Interrupt Routine Supporting chpoll(9E)

```
static u_int
xxintr(caddr_t arg)
{
       struct xxstate *xsp = (struct xxstate *)arg;
    uint8_t    status;
        normal interrupt processing
    [...]
    status = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
    if (status & DEVICE_ERROR) {
       pollwakeup(&xsp->pollhead, POLLERR);
    }
    if (    just completed a read) {
       pollwakeup(&xsp->pollhead, POLLIN);
    }
    [...]
    return (DDI_INTR_CLAIMED);
}
```

pollwakeup(9F) is usually called in the interrupt routine when a supported condition has occurred. The interrupt routine reads the status from the status register and checks for the conditions. The routine then calls pollwakeup(9F) for each event to possibly notify polling threads that they should check again. Note that pollwakeup(9F) should not be called with any locks held, as deadlock could result if another routine tried to enter chpoll(9E) and grab the same lock.

# Miscellaneous I/O Control

The `ioctl`(9E) routine is called when a user thread issues an `ioctl`(2) system call on a file descriptor associated with the device. The I/O control mechanism is a catchall for getting and setting device-specific parameters. This mechanism is frequently used to set a device-specific mode, either by setting internal driver software flags or by writing commands to the device. The control mechanism can also be used to return information to the user about the current device state. In short, the control mechanism can do whatever the application and driver need to have done.

## `ioctl()` Entry Point (Character Drivers)

```
int xxioctl(dev_t dev, int cmd, intptr_t arg, int mode,
     cred_t *credp, int *rvalp);
```

The *cmd* parameter indicates which command `ioctl`(9E) should perform. By convention, the driver with which an I/O control command is associated is indicated in bits 8-15 of the command. Typically, the ASCII code of a character represents the driver. The driver-specific command in bits 0-7. The creation of some I/O commands is illustrated in the following example:

```
#define XXIOC    ('x' << 8)    /* 'x' is a character representing */
                               /* device xx */

#define XX_GET_STATUS          (XXIOC | 1) /* get status register */
#define XX_SET_CMD             (XXIOC | 2) /* send command */
```

The interpretation of *arg* depends on the command. I/O control commands should be documented in the driver documentation or a man page. The command should also be defined in a public header file, so that applications can determine the name of the command, what the command does, and what the command accepts or returns as *arg*. Any data transfer of *arg* into or out of the driver must be performed by the driver.

Certain classes of devices such as frame buffers or disks must support standard sets of I/O control requests. These standard I/O control interfaces are documented in the *Solaris 8 Reference Manual Collection*. For example, `fbio`(7I) documents the I/O controls that frame buffers must support, and `dkio`(7I) documents standard disk I/O controls. See "Miscellaneous I/O Control" on page 246 for more information on I/O controls.

Drivers must use `ddi_copyin`(9F) to transfer *arg* data from the user–level application to the kernel level. Drivers must use `ddi_copyout`(9F) to transfer data from the kernel to the user level. Failure to use `ddi_copyin`(9F) or `ddi_copyout`(9F) can result in panics under two conditions. A panic occurs if the architecture separates the kernel and user address spaces, or if the user address has been swapped out.

ioctl(9E) is usually a switch statement with a case for each supported ioctl(9E) request.

**EXAMPLE 14–13** ioctl(9E) Routine

```
static int
xxioctl(dev_t dev, int cmd, intptr_t arg, int mode,
    cred_t *credp, int *rvalp)
{
     uint8_t        csr;
     struct xxstate     *xsp;

     xsp = ddi_get_soft_state(statep, getminor(dev));
     if (xsp == NULL) {
        return (ENXIO);
     }
     switch (cmd) {
     case XX_GET_STATUS:
       csr = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
       if (ddi_copyout(&csr, (void *)arg,
           sizeof (uint8_t), mode) != 0) {
           return (EFAULT);
       }
       break;
     case XX_SET_CMD:
       if (ddi_copyin((void *)arg, &csr,
         sizeof (uint8_t), mode) != 0) {
         return (EFAULT);
       }
       ddi_put8(xsp->data_access_handle, &xsp->regp->csr, csr);
       break;
     default:
       /* generic "ioctl unknown" error */
       return (ENOTTY);
     }
     return (0);
}
```

The *cmd* variable identifies a specific device control operation. A problem can occur if *arg* contains a user virtual address. ioctl(9E) must call ddi_copyin(9F) or ddi_copyout(9F) to transfer data between the data structure in the application program pointed to by *arg* and the driver. In Example 14–13, for the case of an XX_GET_STATUS request, the contents of *xsp->regp->csr* are copied to the address in *arg*. ioctl(9E) can store in **rvalp* any integer value as the return value to the ioctl(2) system call that makes a successful request. Negative return values, such as -1, should be avoided. Many application programs assume that negative values indicate failure.

The following example demonstrates an application that uses the I/O controls discussed in the previous paragraph.

**EXAMPLE 14–14** Using `ioctl`(9E)

```
#include <sys/types.h>
#include "xxio.h"     /* contains device's ioctl cmds and args */
int
main(void)
{
     uint8_t    status;
     [...]

     /*
      * read the device status
      */
     if (ioctl(fd, XX_GET_STATUS, &status) == -1) {
             error handling
     }
     printf("device status %x\n", status);
     exit(0);
}
```

# I/O Control Support for 64-Bit Capable Device Drivers

The Solaris kernel runs in 64-bit mode on suitable hardware, supporting both 32-bit applications and 64-bit applications. A 64-bit device driver is required to support I/O control commands from programs of both sizes. The difference between a 32-bit program and a 64-bit program is the C language type model. A 32-bit program is ILP32, and a 64-bit program is LP64. See Appendix C for information on C data type models.

If data that flows between programs and the kernel is not identical in format, the driver must be able to handle the model mismatch. Handling a model mismatch requires making appropriate adjustments to the data.

To determine whether a model mismatch exists, the `ioctl`(9E) mode parameter passes the data model bits to the driver. As Example 14–15 shows, the mode parameter is then passed to `ddi_model_convert_from`(9F) to determine whether any model conversion is necessary.

A flag subfield of the mode argument is used to pass the data model to the `ioctl`(9E) routine. The flag is set to one of the following:

- `DATAMODEL_ILP32`
- `DATAMODEL_LP64`

`FNATIVE` is conditionally defined to match the data model of the kernel implementation. The `FMODELS` mask should be used to extract the flag from the *mode* argument. The driver can then examine the data model explicitly to determine how to copy the application data structure.

The DDI function ddi_model_convert_from(9F) is a convenience routine that can assist some drivers with their ioctl() calls. The function takes the data type model of the user application as an argument and returns one of the following values:

- DDI_MODEL_ILP32 – Convert from ILP32 application
- DDI_MODEL_NONE – No conversion needed

DDI_MODEL_NONE is returned if no data conversion is necessary, as occurs when the application and driver have the same data model. DDI_MODEL_ILP32 is returned to a driver that is compiled to the LP64 model and that communicates with a 32-bit application.

In the following example, the driver copies a data structure that contains a user address. The data structure changes size from ILP32 to LP64. Accordingly, the 64-bit driver uses a 32-bit version of the structure when communicating with a 32-bit application.

**EXAMPLE 14–15** ioctl(9E) Routine to Support 32-bit Applications and 64-bit Applications

```
struct args32 {
    uint32_t    addr;    /* 32-bit address in LP64 */
    int     len;
}
struct args {
    caddr_t     addr;    /* 64-bit address in LP64 */
    int     len;
}

static int
xxioctl(dev_t dev, int cmd, intptr_t arg, int mode,
    cred_t *credp, int *rvalp)
{
    struct  xxstate  *xsp;
    struct  args     a;
    xsp = ddi_get_soft_state(statep, getminor(dev));
    if (xsp == NULL) {
        return (ENXIO);
    }
    switch (cmd) {
    case XX_COPYIN_DATA:
        switch(ddi_model_convert_from(mode)) {
        case DDI_MODEL_ILP32:
        {
            struct args32 a32;

            /* copy 32-bit args data shape */
            if (ddi_copyin((void *)arg, &a32,
                sizeof (struct args32), mode) != 0) {
                return (EFAULT);
            }
            /* convert 32-bit to 64-bit args data shape */
            a.addr = a32.addr;
            a.len = a32.len;
```

**EXAMPLE 14–15** `ioctl`(9E) Routine to Support 32-bit Applications and 64-bit Applications *(Continued)*

```
            break;
        }
        case DDI_MODEL_NONE:
            /* application and driver have same data model. */
            if (ddi_copyin((void *)arg, &a, sizeof (struct args),
                mode) != 0) {
                return (EFAULT);
            }
        }
        /* continue using data shape in native driver data model. */
        break;

    case XX_COPYOUT_DATA:
        /* copyout handling */
        break;
    default:
        /* generic "ioctl unknown" error */
        return (ENOTTY);
    }
    return (0);
}
```

# Handling `copyout()` Overflow

Sometimes a driver needs to copy out a native quantity that no longer fits in the 32-bit sized structure. In this case, the driver should return `EOVERFLOW` to the caller. `EOVERFLOW` serves as an indication that the data type in the interface is too small to hold the value to be returned, as shown in the following example.

**EXAMPLE 14–16** Handling `copyout`(9F) Overflow

```
int
    xxioctl(dev_t dev, int cmd, intptr_t arg, int mode,
     cred_t *cr, int *rval_p)
    {
        struct resdata res;

        [...]      body of driver code  [...]

        switch (ddi_model_convert_from(mode & FMODELS)) {
        case DDI_MODEL_ILP32: {
            struct resdata32 res32;

            if (res.size > UINT_MAX)
                    return (EOVERFLOW);
            res32.size = (size32_t)res.size;
            res32.flag = res.flag;
            if (ddi_copyout(&res32,
```

**EXAMPLE 14–16** Handling copyout(9F) Overflow *(Continued)*

```
                (void *)arg, sizeof (res32), mode))
                    return (EFAULT);
        }
        break;

        case DDI_MODEL_NONE:
            if (ddi_copyout(&res, (void *)arg, sizeof (res), mode))
                    return (EFAULT);
            break;
        }
        return (0);
    }
```

# 32–bit and 64–bit Data Structure Macros

The method in Example 14–16 works well for many drivers. An alternate scheme is to use the data structure macros that are provided in <sys/model.h>to move data between the application and the kernel. These macros make the code less cluttered and behave identically, from a functional perspective.

**EXAMPLE 14–17** Using Data Structure Macros to Move Data

```
int
    xxioctl(dev_t dev, int cmd, intptr_t arg, int mode,
        cred_t *cr, int *rval_p)
    {
        STRUCT_DECL(opdata, op);

        if (cmd != OPONE)
            return (ENOTTY);

        STRUCT_INIT(op, mode);

        if (copyin((void *)arg,
            STRUCT_BUF(op), STRUCT_SIZE(op)))
                return (EFAULT);

        if (STRUCT_FGET(op, flag) != XXACTIVE ||
            STRUCT_FGET(op, size) > XXSIZE)
                return (EINVAL);
        xxdowork(device_state, STRUCT_FGET(op, size));
        return (0);
}
```

## How Do the Structure Macros Work?

In a 64-bit device driver, structure macros enable the use of the same piece of kernel memory by data structures of both sizes. The memory buffer holds the contents of the native form of the data structure, that is, the LP64 form, and the ILP32 form. Each structure access is implemented by a conditional expression. When compiled as a 32-bit driver, only one data model, the native form, is supported. No conditional expression is used.

The 64-bit versions of the macros depend on the definition of a shadow version of the data structure. The shadow version describes the 32-bit interface with fixed-width types. The name of the shadow data structure is formed by appending "32" to the name of the native data structure. For convenience, place the definition of the shadow structure in the same file as the native structure to ease future maintenance costs.

The macros can take the following arguments:

*structname* The structure name of the native form of the data structure as entered after the `struct` keyword.

*umodel* A flag word that contains the user data model, such as `FILP32` or `FLP64`, extracted from the mode parameter of `ioctl`(9E).

*handle* The name used to refer to a particular instance of a structure that is manipulated by these macros.

*fieldname* The name of the field within the structure.

## When to Use Structure Macros

Macros enable you to make in-place references only to the fields of a data item. Macros do not provide a way to take separate code paths that are based on the data model. Macros should be avoided if the number of fields in the data structure is large. Macros should also be avoided if the frequency of references to these fields is high.

Macros hide many of the differences between data models in the implementation of the macros. As a result, code written with this interface is generally easier to read. When compiled as a 32-bit driver, the resulting code is compact without needing clumsy `#ifdefs`, but still preserves type checking.

## Declaring and Initializing Structure Handles

STRUCT_DECL(9F) and STRUCT_INIT(9F) can be used to declare and initialize a handle and space for decoding an ioctl on the stack. STRUCT_HANDLE(9F) and STRUCT_SET_HANDLE(9F) declare and initialize a handle without allocating space on the stack. The latter macros can be useful if the structure is very large, or is contained in some other data structure.

---

**Note –** Because the STRUCT_DECL(9F) and STRUCT_HANDLE(9F) macros expand to data structure declarations, these macros should be grouped with such declarations in C code.

---

The macros for declaring and initializing structures are as follows:

STRUCT_DECL(*structname*, *handle*)
: Declares a *structure handle*that is called handle for a struct *structname* data structure. STRUCT_DECL allocates space for its native form on the stack. The native form is assumed to be larger than or equal to the ILP32 form of the structure.

STRUCT_INIT(*handle*, *umodel*)
: Initializes the data model for *handle* to umodel. This macro must be invoked before any access is made to a structure handle declared with STRUCT_DECL(9F).

STRUCT_HANDLE(*structname*, *handle*)
: Declares a *structure handle* that is called handle. Contrast with STRUCT_DECL(9F).

STRUCT_SET_HANDLE(*handle*, *umodel*, *addr*)
: Initializes the data model for *handle* to *umodel*, and sets *addr* as the buffer used for subsequent manipulation. Invoke this macro before accessing a structure handle declared with STRUCT_DECL(9F).

## Operations on Structure Handles

The macros for performing operations on structures are as follows:

size_t STRUCT_SIZE(*handle*)
: Returns the size of the structure referred to by *handle*, according to its embedded data model.

*typeof fieldname* STRUCT_FGET(*handle*, *fieldname*)
: Returns the indicated field in the data structure referred to by *handle*. This field is a non-pointer type.

*typeof fieldname* STRUCT_FGETP(*handle*, *fieldname*)
: Returns the indicated field in the data structure referred to by *handle*. This field is a pointer type.

`STRUCT_FSET(`*handle*`, `*fieldname*`, `*val*`)`
Sets the indicated field in the data structure referred to by *handle* to value *val*. The type of *val* should match the type of *fieldname*. The field is a non-pointer type.

`STRUCT_FSETP(`*handle*`, `*fieldname*`, `*val*`)`
Sets the indicated field in the data structure referred to by *handle* to value *val*. The field is a pointer type.

*typeof fieldname* `*STRUCT_FADDR(`*handle*`, `*fieldname*`)`
Returns the address of the indicated field in the data structure referred to by *handle*.

`struct structname *STRUCT_BUF(`*handle*`)`
Returns a pointer to the native structure described by *handle*.

## Other Operations

Some miscellaneous structure macros follow:

`size_t SIZEOF_STRUCT(`*struct_name*`, `*datamodel*`)`
Returns the size of *struct_name,* which is based on the given data model.

`size_t SIZEOF_PTR(`*datamodel*`)`
Returns the size of a pointer based on the given data model.

CHAPTER 15

# Drivers for Block Devices

This chapter describes the structure of block device drivers. The kernel views a block device as a set of randomly accessible logical blocks. The file system uses a list of `buf`(9S) structures to buffer the data blocks between a block device and the user space. Only block devices can support a file system.

This chapter provides information on the following subjects:



## Block Driver Structure Overview

Figure 15–1 shows data structures and routines that define the structure of a block device driver. Device drivers typically include the following elements:

- Device-loadable driver section
- Device configuration section
- Device access section

The shaded device access section in the following figure illustrates entry points for block drivers.

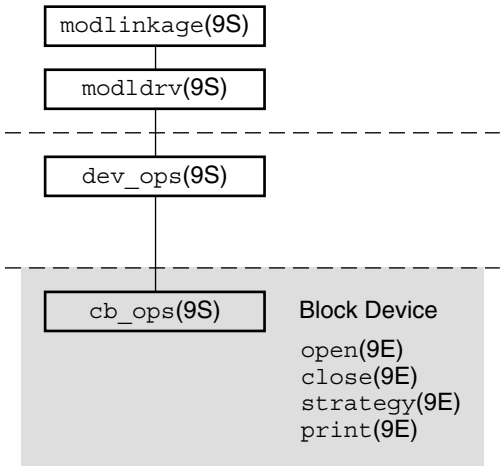



**FIGURE 15–1** Block Driver Roadmap

Associated with each device driver is a `dev_ops`(9S) structure, which in turn refers to a `cb_ops`(9S) structure. See Chapter 6 for details on driver data structures.

Block device drivers provide these entry points:

- `open`(9E)
- `close`(9E)
- `strategy`(9E)
- `print`(9E)

---

**Note –** Some of the entry points can be replaced by `nodev`(9F) or `nulldev`(9F) as appropriate.

---

# File I/O

A file system is a tree-structured hierarchy of directories and files. Some file systems, such as the UNIX File System (UFS), reside on block-oriented devices. File systems are created by `format`(1M) and `newfs`(1M).

When an application issues a `read`(2) or `write`(2) system call to an ordinary file on the UFS file system, the file system can call the device driver `strategy`(9E) entry point for the block device on which the file system resides. The file system code can call `strategy`(9E) several times for a single `read`(2) or `write`(2) system call.

The file system code determines the logical device address, or *logical block number*, for each ordinary file block. A block I/O request is then built in the form of a `buf`(9S) structure directed at the block device. The driver `strategy`(9E) entry point then interprets the `buf`(9S) structure and completes the request.

# Block Device Autoconfiguration

`attach`(9E) should perform the common initialization tasks for each instance of a device:

- Allocating per-instance state structures
- Mapping the device's registers
- Registering device interrupts
- Initializing mutex and condition variables
- Creating power manageable components
- Creating minor nodes

Block device drivers create minor nodes of type `S_IFBLK`. As a result, a block special file that represents the node appears in the `/devices` hierarchy.

Logical device names for block devices appear in the `/dev/dsk` directory, and consist of a controller number, bus-address number, disk number, and slice number. These names are created by the `devfsadm`(1M) program if the node type is set to `DDI_NT_BLOCK` or `DDI_NT_BLOCK_CHAN`. `DDI_NT_BLOCK_CHAN` should be specified if the device communicates on a channel, that is, a bus with an additional level of addressability. SCSI disks are a good example. `DDI_NT_BLOCK_CHAN` causes a bus-address field (t*N*) to appear in the logical name. `DDI_NT_BLOCK` should be used for most other devices.

A minor device refers to a partition on the disk. For each minor device, the driver must create an `nblocks` or `Nblocks` property. This integer property gives the number of blocks supported by the minor device expressed in units of `DEV_BSIZE`, that is, 512 bytes. The file system uses the `nblocks` and `Nblocks` properties to determine device limits. `Nblocks` is the 64–bit version of `nblocks`. `Nblocks` should be used with storage devices that can hold over 1 Tbyte of storage per disk. See "Device Properties" on page 73 for more information.

Example 15–1 shows a typical `attach`(9E) entry point with emphasis on creating the device's minor node and the `Nblocks` property. Note that because this example uses `Nblocks` and not `nblocks`, `ddi_prop_update_int64`(9F) is called instead of `ddi_prop_update_int`(9F).

As a side note, this example shows the use of `makedevice`(9F) to create a device number for `ddi_prop_update_int64()`. The `makedevice` function makes use of `ddi_driver_major`(9F), which generates a major number from a pointer to a `dev_info_t` structure. Using `ddi_driver_major()` is similar to using `getmajor`(9F), which gets a `dev_t` structure pointer.

**EXAMPLE 15–1** Block Driver `attach()` Routine

```
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
     int instance = ddi_get_instance(dip);
     switch (cmd) {
       case DDI_ATTACH:
         allocate a state structure and initialize it
    map the devices registers
    add the device driver's interrupt handler(s)
    initialize any mutexes and condition variables
    read label information if the device is a disk
    create power manageable components
        /*
         * Create the device minor node. Note that the node_type
         * argument is set to DDI_NT_BLOCK.
         */
        if (ddi_create_minor_node(dip, "minor_name", S_IFBLK,
            instance,  DDI_NT_BLOCK, 0) == DDI_FAILURE) {
             free resources allocated so far
           /* Remove any previously allocated minor nodes */
           ddi_remove_minor_node(dip, NULL);
           return (DDI_FAILURE);
         }
        /*
         * Create driver properties like "Nblocks". If the device
         * is a disk, the Nblocks property is usually calculated from
         * information in the disk label.  Use "Nblocks" instead of
         * "nblocks" to ensure the property works for large disks.
         */
         xsp->Nblocks =      size of device in 512 byte blocks;
         maj_number = ddi_driver_major(dip);
        if (ddi_prop_update_int64(makedevice(maj_number, instance), dip,
           "Nblocks", xsp->Nblocks) != DDI_PROP_SUCCESS) {
           cmn_err(CE_CONT, "%s: cannot create Nblocks property\n",
                ddi_get_name(dip));
             free resources allocated so far
          return (DDI_FAILURE);
        }
        xsp->open = 0;
        xsp->nlayered = 0;
        [...]
        return (DDI_SUCCESS);

    case DDI_RESUME:
            For information, see Chapter 12, "Power Management," in this book.
        default:
           return (DDI_FAILURE);
     }
}
```

# Controlling Device Access

This section describes the entry points for `open()` and `close()` functions in block device drivers. See Chapter 14 for more information on `open`(9E) and `close`(9E).

## `open()` Entry Point (Block Drivers)

The `open`(9E) entry point is used to gain access to a given device. The `open`(9E) routine of a block driver is called when a user thread issues an `open`(2) or `mount`(2) system call on a block special file associated with the minor device, or when a layered driver calls `open`(9E). See "File I/O" on page 256 for more information.

The `open()` entry point should check for the following conditions:

- The device can be opened, that is, the device is online and ready.
- The device can be opened as requested. The device supports the operation. The device's current state does not conflict with the request.
- The caller has permission to open the device.

The following example demonstrates a block driver `open`(9E) entry point.

**EXAMPLE 15–2** Block Driver `open`(9E) Routine

```
static int
xxopen(dev_t *devp, int flags, int otyp, cred_t *credp)
{
       minor_t         instance;
       struct xxstate        *xsp;

     instance = getminor(*devp);
     xsp = ddi_get_soft_state(statep, instance);
     if (xsp == NULL)
           return (ENXIO);
     mutex_enter(&xsp->mu);
     /*
    * only honor FEXCL. If a regular open or a layered open
    * is still outstanding on the device, the exclusive open
    * must fail.
    */
     if ((flags & FEXCL) && (xsp->open || xsp->nlayered)) {
       mutex_exit(&xsp->mu);
       return (EAGAIN);
     }
     switch (otyp) {
       case OTYP_LYR:
         xsp->nlayered++;
         break;
```

**EXAMPLE 15–2** Block Driver open(9E) Routine *(Continued)*

```
      case OTYP_BLK:
         xsp->open = 1;
         break;
     default:
         mutex_exit(&xsp->mu);
         return (EINVAL);
     }
   mutex_exit(&xsp->mu);
      return (0);
}
```

The otyp argument is used to specify the type of open on the device. OTYP_BLK is the typical open type for a block device. A device can be opened several times with otyp set to OTYP_BLK. close(9E) is called only once when the final close of type OTYP_BLK has occurred for the device. otyp is set to OTYP_LYR if the device is being used as a layered device. For every open of type OTYP_LYR, the layering driver issues a corresponding close of type OTYP_LYR. The example keeps track of each type of open so the driver can determine when the device is not being used in close(9E).

# close() Entry Point (Block Drivers)

The close(9E) entry point uses the same arguments as open(9E) with one exception. dev is the device number rather than a pointer to the device number.

The close() routine should verify otyp in the same way as was described for the open(9E) entry point. In the following example, close() must determine when the device can really be closed. Closing is affected by the number of block opens and layered opens.

**EXAMPLE 15–3** Block Device close(9E) Routine

```
static int
xxclose(dev_t dev, int flag, int otyp, cred_t *credp)
{
     minor_t instance;
     struct xxstate *xsp;

     instance = getminor(dev);
     xsp = ddi_get_soft_state(statep, instance);
       if (xsp == NULL)
          return (ENXIO);
     mutex_enter(&xsp->mu);
     switch (otyp) {
       case OTYP_LYR:
       xsp->nlayered--;
       break;
      case OTYP_BLK:
```

**EXAMPLE 15–3** Block Device `close`(9E) Routine *(Continued)*

```
        xsp->open = 0;
        break;
      default:
        mutex_exit(&xsp->mu);
        return (EINVAL);
        }

      if (xsp->open || xsp->nlayered) {
        /* not done yet */
        mutex_exit(&xsp->mu);
        return (0);
      }
        /* cleanup (rewind tape, free memory, etc.) */
    /* wait for I/O to drain */
      mutex_exit(&xsp->mu);

      return (0);
}
```

# `strategy()` Entry Point

The `strategy`(9E) entry point is used to read and write data buffers to and from a block device. The name *strategy* refers to the fact that this entry point might implement some optimal strategy for ordering requests to the device.

`strategy`(9E) can be written to process one request at a time, that is, a synchronous transfer. `strategy()` can also be written to queue multiple requests to the device, as in an asynchronous transfer. When choosing a method, the abilities and limitations of the device should be taken into account.

The `strategy`(9E) routine is passed a pointer to a `buf`(9S) structure. This structure describes the transfer request, and contains status information on return. `buf`(9S) and `strategy`(9E) are the focus of block device operations.

# `buf` Structure

The following `buf` structure members are important to block drivers:

```
int          b_flags;     /* Buffer Status */
struct buf       *av_forw;    /* Driver work list link */
struct buf       *av_back;    /* Driver work list link */
size_t       b_bcount;    /* # of bytes to transfer */
union {
caddr_t      b_addr;      /* Buffer's virtual address */
} b_un;
daddr_t      b_blkno;     /* Block number on device */
```

```
diskaddr_t       b_lblkno;    /* Expanded block number on device */
size_t       b_resid;     /* # of bytes not transferred */
                  /* after error */
int          b_error;     /* Expanded error field */
void         *b_private;      /* "opaque" driver private area */
dev_t        b_edev;      /* expanded dev field */
```

where:

`av_forw` and `av_back` — Pointers that the driver can use to manage a list of buffers by the driver. See "Asynchronous Data Transfers (Block Drivers)" on page 267 for a discussion of the `av_forw` and `av_back` pointers.

`b_bcount` — Specifies the number of bytes to be transferred by the device.

`b_un.b_addr` — The kernel virtual address of the data buffer. Only valid after `bp_mapin`(9F) call.

`b_blkno` — The starting 32-bit logical block number on the device for the data transfer, which is expressed in 512-byte `DEV_BSIZE` units. The driver should use either `b_blkno` or `b_lblkno` but not both.

`b_lblkno` — The starting 64-bit logical block number on the device for the data transfer, which is expressed in 512-byte `DEV_BSIZE` units. The driver should use either `b_blkno` or `b_lblkno` but not both.

`b_resid` — Set by the driver to indicate the number of bytes that were not transferred because of an error. See Example 15–7 for an example of setting `b_resid`. The `b_resid` member is overloaded. `b_resid` is also used by `disksort`(9F).

`b_error` — Set to an error number by the driver when a transfer error occurs. `b_error` is set in conjunction with the `b_flags` `B_ERROR` bit. See the `Intro`(9E) man page for details about error values. Drivers should use `bioerror`(9F) rather than setting `b_error` directly.

`b_flags` — Flags with status and transfer attributes of the `buf` structure. If `B_READ` is set, the `buf` structure indicates a transfer from the device to memory. Otherwise, this structure indicates a transfer from memory to the device. If the driver encounters an error during data transfer, the driver should set the `B_ERROR` field in the `b_flags` member. In addition, the driver should provide a more specific error value in `b_error`. Drivers should use `bioerror`(9F) rather than setting `B_ERROR`.

**Caution –** Drivers should never clear `b_flags`.

| | |
|---|---|
| `b_private` | For exclusive use by the driver to store driver-private data. |
| `b_edev` | Contains the device number of the device that was used in the transfer. |

## `bp_mapin` Structure

A `buf` structure pointer can be passed into the device driver's `strategy`(9E) routine. However, the data buffer referred to by `b_un.b_addr` is not necessarily mapped in the kernel's address space. Therefore, the driver cannot directly access the data. Most block-oriented devices have DMA capability and therefore do not need to access the data buffer directly. Instead, these devices use the DMA mapping routines to enable the device's DMA engine to do the data transfer. For details about using DMA, see Chapter 9.

If a driver needs to access the data buffer directly, that driver must first map the buffer into the kernel's address space by using `bp_mapin`(9F). `bp_mapout`(9F) should be used when the driver no longer needs to access the data directly.

**Caution –** `bp_mapout`(9F) should only be called on buffers that have been allocated and are owned by the device driver. `bp_mapout()` must not be called on buffers that are passed to the driver through the `strategy`(9E) entry point, such as a file system. `bp_mapin`(9F) does not keep a reference count. `bp_mapout`(9F) removes any kernel mapping on which a layer over the device driver might rely.

# Synchronous Data Transfers (Block Drivers)

This section presents a simple method for performing synchronous I/O transfers. This method assumes that the hardware is a simple disk device that can transfer only one data buffer at a time by using DMA. Another assumption is that the disk can be spun up and spun down by software command. The device driver's `strategy`(9E) routine waits for the current request to be completed before accepting a new request. The device interrupts when the transfer is complete. The device also interrupts if an error occurs.

The steps for performing a synchronous data transfer for a block driver are as follows:

1. Check for invalid `buf`(9S) requests.

   Check the `buf`(9S) structure that is passed to `strategy`(9E) for validity. All drivers should check the following conditions:

   - The request begins at a valid block. The driver converts the `b_blkno` field to the correct device offset and then determines whether the offset is valid for the device.
   - The request does not go beyond the last block on the device.
   - Device-specific requirements are met.

   If an error is encountered, the driver should indicate the appropriate error with `bioerror`(9F). The driver should then complete the request by calling `biodone`(9F). `biodone()` notifies the caller of `strategy`(9E) that the transfer is complete. In this case, the transfer has stopped because of an error.

2. Check whether the device is busy.

   Synchronous data transfers allow single-threaded access to the device. The device driver enforces this access in two ways:

   - The driver maintains a busy flag that is guarded by a mutex.
   - The driver waits on a condition variable with `cv_wait`(9F), when the device is busy.

   If the device is busy, the thread waits until the interrupt handler indicates that the device is not longer busy. The available status can be indicated by either the `cv_broadcast`(9F) or the `cv_signal`(9F) function. See Chapter 3 for details on condition variables.

   When the device is no longer busy, the `strategy`(9E) routine marks the device as available. `strategy()` then prepares the buffer and the device for the transfer.

3. Set up the buffer for DMA.

Prepare the data buffer for a DMA transfer by using `ddi_dma_alloc_handle`(9F) to allocate a DMA handle. Use `ddi_dma_buf_bind_handle`(9F) to bind the data buffer to the handle. For information on setting up DMA resources and related data structures, see Chapter 9.

4. Begin the transfer.

   At this point, a pointer to the `buf`(9S) structure is saved in the state structure of the device. The interrupt routine can then complete the transfer by calling `biodone`(9F).

   The device driver then accesses device registers to initiate a data transfer. In most cases, the driver should protect the device registers from other threads by using mutexes. In this case, because `strategy`(9E) is single-threaded, guarding the device registers is not necessary. See Chapter 3 for details about data locks.

   When the executing thread has started the device's DMA engine, the driver can return execution control to the calling routine, as follows:

```
static int
xxstrategy(struct buf *bp)
{
    struct xxstate *xsp;
    struct device_reg *regp;
    minor_t instance;
    ddi_dma_cookie_t cookie;
    instance = getminor(bp->b_edev);
    xsp = ddi_get_soft_state(statep, instance);
    if (xsp == NULL) {
       bioerror(bp, ENXIO);
       biodone(bp);
       return (0);
    }
    /* validate the transfer request */
    if ((bp->b_blkno >= xsp->Nblocks) || (bp->b_blkno < 0)) {
       bioerror(bp, EINVAL);
       biodone(bp);
       return (0);
    }
    /*
     * Hold off all threads until the device is not busy.
     */
    mutex_enter(&xsp->mu);
    while (xsp->busy) {
       cv_wait(&xsp->cv, &xsp->mu);
    }
    xsp->busy = 1;
    mutex_exit(&xsp->mu);
         if the device has power manageable components,
    mark the device busy with pm_busy_components(9F),
    and then ensure that the device
    is powered up by calling ddi_dev_is_needed(9F).

          Set up DMA resources with ddi_dma_alloc_handle(9F) and ddi_dma_buf_bind_handle(9F).
```

```
    xsp->bp = bp;
    regp = xsp->regp;
    ddi_put32(xsp->data_access_handle, &regp->dma_addr,
        cookie.dmac_address);
    ddi_put32(xsp->data_access_handle, &regp->dma_size,
         (uint32_t)cookie.dmac_size);
    ddi_put8(xsp->data_access_handle, &regp->csr,
         ENABLE_INTERRUPTS | START_TRANSFER);
    return (0);
}
```

5. Handle the interrupting device.

   When the device finishes the data transfer, the driver generates an interrupt, which eventually results in the driver's interrupt routine being called. Most drivers specify the state structure of the device as the argument to the interrupt routine when registering interrupts. See the `ddi_add_intr`(9F) man page and "Registering Interrupts" on page 122. The interrupt routine can then access the `buf`(9S) structure being transferred, plus any other information that is available from the state structure.

   The interrupt handler should check the device's status register to determine whether the transfer completed without error. If an error occurred, the handler should indicate the appropriate error with `bioerror`(9F). The handler should also clear the pending interrupt for the device and then complete the transfer by calling `biodone`(9F).

   As the final task, the handler clears the busy flag. The handler then calls `cv_signal`(9F) or `cv_broadcast`(9F) on the condition variable, signaling that the device is no longer busy. This notification enables other threads waiting for the device in `strategy`(9E) to proceed with the next data transfer.

   The following example shows a synchronous interrupt routine.

**EXAMPLE 15–4** Synchronous Interrupt Routine for Block Drivers

```
static u_int
xxintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    struct buf *bp;
    uint8_t status;
    mutex_enter(&xsp->mu);
    status = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
    if (!(status & INTERRUPTING)) {
       mutex_exit(&xsp->mu);
       return (DDI_INTR_UNCLAIMED);
    }
    /* Get the buf responsible for this interrupt */
    bp = xsp->bp;
    xsp->bp = NULL;
    /*
     * This example is for a simple device which either
     * succeeds or fails the data transfer, indicated in the
```

**EXAMPLE 15–4** Synchronous Interrupt Routine for Block Drivers *(Continued)*

```
     * command/status register.
     */
    if (status & DEVICE_ERROR) {
       /* failure */
       bp->b_resid = bp->b_bcount;
       bioerror(bp, EIO);
    } else {
       /* success */
       bp->b_resid = 0;
    }
    ddi_put8(xsp->data_access_handle, &xsp->regp->csr,
       CLEAR_INTERRUPT);
    /* The transfer has finished, successfully or not */
    biodone(bp);
         if the device has power manageable components that were marked busy in strategy(9F),
         mark them idle now with pm_idle_component(9F)
         release any resources used in the transfer, such as DMA resources (ddi_dma_unbind_handle(9F) and
         ddi_dma_free_handle(9F)).

    /* Let the next I/O thread have access to the device */
    xsp->busy = 0;
    cv_signal(&xsp->cv);
    mutex_exit(&xsp->mu);
    return (DDI_INTR_CLAIMED);
}
```

# Asynchronous Data Transfers (Block Drivers)

This section presents a method for performing asynchronous I/O transfers. The driver queues the I/O requests and then returns control to the caller. Again, the assumption is that the hardware is a simple disk device that allows one transfer at a time. The device interrupts when a data transfer has completed. An interrupt also takes place if an error occurs. The basic steps for performing asynchronous data transfers are:

1. Check for invalid `buf`(9S) requests.
2. Enqueue the request.
3. Start the first transfer.
4. Handle the interrupting device.

## Checking for Invalid `buf` Requests

As in the synchronous case, the device driver should check the `buf`(9S) structure passed to `strategy`(9E) for validity. See "Synchronous Data Transfers (Block Drivers)" on page 264 for more details.

## Enqueuing the Request

Unlike synchronous data transfers, a driver does not wait for an asynchronous request to complete. Instead, the driver adds the request to a queue. The head of the queue can be the current transfer. The head of the queue can also be a separate field in the state structure for holding the active request, as in Example 15–5.

If the queue is initially empty, then the hardware is not busy and `strategy`(9E) starts the transfer before returning. Otherwise, if a transfer completes with a non-empty queue, the interrupt routine begins a new transfer. Example 15–5 places the decision of whether to start a new transfer into a separate routine for convenience.

The driver can use the `av_forw` and the `av_back` members of the `buf`(9S) structure to manage a list of transfer requests. A single pointer can be used to manage a singly linked list, or both pointers can be used together to build a doubly linked list. The device hardware specification specifies which type of list management, such as insertion policies, is used to optimize the performance of the device. The transfer list is a per-device list, so the head and tail of the list are stored in the state structure.

The following example provides multiple threads with access to the driver shared data, such as the transfer list. You must identify the shared data and must protect the data with a mutex. See Chapter 3 for more details about mutex locks.

**EXAMPLE 15–5** Enqueuing Data Transfer Requests for Block Drivers

```
static int
xxstrategy(struct buf *bp)
{
    struct xxstate *xsp;
    minor_t instance;
    instance = getminor(bp->b_edev);
    xsp = ddi_get_soft_state(statep, instance);
    [...]
        validate transfer request
    [...]
        Add the request to the end of the queue. Depending on the device, a sorting algorithm, such as
        disksort(9F)
    may be used if it improves the performance of the device.
    mutex_enter(&xsp->mu);
    bp->av_forw = NULL;
    if (xsp->list_head) {
       /* Non-empty transfer list */
       xsp->list_tail->av_forw = bp;
```

**EXAMPLE 15–5** Enqueuing Data Transfer Requests for Block Drivers *(Continued)*

```
        xsp->list_tail = bp;
    } else {
        /* Empty Transfer list */
        xsp->list_head = bp;
        xsp->list_tail = bp;
    }
    mutex_exit(&xsp->mu);
    /* Start the transfer if possible */
    (void) xxstart((caddr_t)xsp);
    return (0);
}
```

# Starting the First Transfer

Device drivers that implement queuing usually have a `start()` routine. `start()` dequeues the next request and starts the data transfer to or from the device. In this example, `start()` processes all requests regardless of the state of the device, whether busy or free.

---

**Note –** `start()` must be written to be called from any context. `start()` can be called by both the strategy routine in kernel context and the interrupt routine in interrupt context.

---

`start()` is called by `strategy`(9E) every time `strategy()` queues a request so that an idle device can be started. If the device is busy, `start()` returns immediately.

`start()` is also called by the interrupt handler before the handler returns from a claimed interrupt so that a nonempty queue can be serviced. If the queue is empty, `start()` returns immediately.

Because `start()` is a private driver routine, `start()` can take any arguments and can return any type. The following code sample is written to be used as a DMA callback, although that portion is not shown. Accordingly, the example must take a `caddr_t` as an argument and return an `int`. See "Handling Resource Allocation Failures" on page 144 for more information about DMA callback routines.

**EXAMPLE 15–6** Starting the First Data Request for a Block Driver

```
static int
xxstart(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    struct buf *bp;
```

**EXAMPLE 15–6** Starting the First Data Request for a Block Driver *(Continued)*

```
    mutex_enter(&xsp->mu);
    /*
     * If there is nothing more to do, or the device is
     * busy, return.
     */
    if (xsp->list_head == NULL || xsp->busy) {
       mutex_exit(&xsp->mu);
       return (0);
    }
    xsp->busy = 1;
    /* Get the first buffer off the transfer list */
    bp = xsp->list_head;
    /* Update the head and tail pointer */
    xsp->list_head = xsp->list_head->av_forw;
    if (xsp->list_head == NULL)
       xsp->list_tail = NULL;
    bp->av_forw = NULL;
    mutex_exit(&xsp->mu);

    if the device has power manageable components,
    mark the device busy with pm_busy_components, and then ensure that the device
    is powered up by calling ddi_dev_is_needed.
    Set up DMA resources with ddi_dma_alloc_handle(9F) and
    ddi_dma_buf_bind_handle(9F).
    xsp->bp = bp;
    ddi_put32(xsp->data_access_handle, &xsp->regp->dma_addr,
        cookie.dmac_address);
    ddi_put32(xsp->data_access_handle, &xsp->regp->dma_size,
         (uint32_t)cookie.dmac_size);
    ddi_put8(xsp->data_access_handle, &xsp->regp->csr,
         ENABLE_INTERRUPTS | START_TRANSFER);
    return (0);
}
```

# Handling the Interrupting Device

The interrupt routine is similar to the asynchronous version, with the addition of the call to `start()` and the removal of the call to `cv_signal`(9F).

**EXAMPLE 15–7** Block Driver Routine for Asynchronous Interrupts

```
static u_int
xxintr(caddr_t arg)
{
    struct xxstate *xsp = (struct xxstate *)arg;
    struct buf *bp;
    uint8_t status;
    mutex_enter(&xsp->mu);
    status = ddi_get8(xsp->data_access_handle, &xsp->regp->csr);
```

**EXAMPLE 15–7** Block Driver Routine for Asynchronous Interrupts *(Continued)*

```
    if (!(status & INTERRUPTING)) {
        mutex_exit(&xsp->mu);
        return (DDI_INTR_UNCLAIMED);
    }
    /* Get the buf responsible for this interrupt */
    bp = xsp->bp;
    xsp->bp = NULL;
    /*
     * This example is for a simple device which either
     * succeeds or fails the data transfer, indicated in the
     * command/status register.
     */
    if (status & DEVICE_ERROR) {
        /* failure */
        bp->b_resid = bp->b_bcount;
        bioerror(bp, EIO);
    } else {
        /* success */
        bp->b_resid = 0;
    }
    ddi_put8(xsp->data_access_handle, &xsp->regp->csr,
        CLEAR_INTERRUPT);
    /* The transfer has finished, successfully or not */
    biodone(bp);
    if the device has power manageable components that were marked busy in strategy(9F)
    (9E), mark them idle now with pm_idle_component(9F)
    release any resources used in the transfer, such as DMA resources
    ddi_dma_unbind_handle(9F) and
    ddi_dma_free_handle(9F)
    /* Let the next I/O thread have access to the device */
    xsp->busy = 0;
    mutex_exit(&xsp->mu);
    (void) xxstart((caddr_t)xsp);
    return (DDI_INTR_CLAIMED);
}
```

# dump() and print() Entry Points

This section discusses the dump(9E) and print(9E) entry points.

## dump() Entry Point (Block Drivers)

The dump(9E) entry point is used to copy a portion of virtual address space directly to the specified device in the case of a system failure. dump() is also used to copy the state of the kernel out to disk during a checkpoint operation. See the cpr(7) and dump(9E) man pages for more information. The entry point must be capable of performing this operation without the use of interrupts, because interrupts are disabled during the checkpoint operation.

```
int dump(dev_t dev, caddr_t addr, daddr_t blkno, int nblk)
```

where:

*dev* Device number of the device to receive the dump.

*addr* Base kernel virtual address at which to start the dump.

*blkno* Block at which the dump is to start.

*nblk* Number of blocks to dump.

The dump depends upon the existing driver working properly.

## print() Entry Point (Block Drivers)

```
int print(dev_t dev, char *str)
```

The print(9E) entry point is called by the system to display a message about an exception that has been detected. print(9E) should call cmn_err(9F) to post the message to the console on behalf of the system. The following example demonstrates a typical print() entry point.

```
static int
 xxprint(dev_t dev, char *str)
 {
     cmn_err(CE_CONT, "xx: %s\n", str);
     return (0);
 }
```

# Disk Device Drivers

Disk devices represent an important class of block device drivers.

## Disk `ioctls`

Solaris disk drivers need to support a minimum set of `ioctl` commands specific to Solaris disk drivers. These I/O controls are specified in the `dkio`(7I) manual page. Disk I/O controls transfer disk information to or from the device driver. A Solaris disk device is supported by disk utility commands such as `format`(1M) and `newfs`(1M). The mandatory Sun disk I/O controls are as follows:

| | |
|---|---|
| `DKIOCINFO` | Returns information that describes the disk controller |
| `DKIOCGAPART` | Returns a disk's partition map |
| `DKIOCSAPART` | Sets a disk's partition map |
| `DKIOCGGEOM` | Returns a disk's geometry |
| `DKIOCSGEOM` | Sets a disk's geometry |
| `DKIOCGVTOC` | Returns a disk's Volume Table of Contents |
| `DKIOCSVTOC` | Sets a disk's Volume Table of Contents |

## Disk Performance

The Solaris DDI/DKI provides facilities to optimize I/O transfers for improved file system performance. A mechanism manages the list of I/O requests so as to optimize disk access for a file system. See "Asynchronous Data Transfers (Block Drivers)" on page 267 for a description of enqueuing an I/O request.

The `diskhd` structure is used to manage a linked list of I/O requests.

```
struct diskhd {
    long     b_flags;         /* not used, needed for consistency*/
    struct   buf *b_forw,    *b_back;       /* queue of unit queues */
    struct   buf *av_forw,    *av_back;    /* queue of bufs for this unit */
    long     b_bcount;            /* active flag */
};
```

The `diskhd` data structure has two `buf` pointers that the driver can manipulate. The `av_forw` pointer points to the first active I/O request. The second pointer, `av_back`, points to the last active request on the list.

A pointer to this structure is passed as an argument to `disksort`(9F), along with a pointer to the current `buf` structure being processed. The `disksort()` routine sorts the `buf` requests to optimize disk seek. The routine then inserts the `buf` pointer into the `diskhd` list. The `disksort()` program uses the value that is in `b_resid` of the `buf` structure as a sort key. The driver is responsible for setting this value. Most Sun disk drivers use the cylinder group as the sort key. This approach optimizes the file system read-ahead accesses.

When data has been added to the `diskhd` list, the device needs to transfer the data. If the device is not busy processing a request, the `xxstart()` routine pulls the first `buf` structure off the `diskhd` list and starts a transfer.

If the device is busy, the driver should return from the `xxstrategy()` entry point. When the hardware is done with the data transfer, an interrupt is generated. The driver's interrupt routine is then called to service the device. After servicing the interrupt, the driver can then call the `start()` routine to process the next `buf` structure in the `diskhd` list.

CHAPTER 16

# SCSI Target Drivers

The Solaris DDI/DKI divides the software interface to SCSI devices into two major parts: *target* drivers and *host bus adapter (HBA)* drivers. *Target* refers to a driver for a device on a SCSI bus, such as a disk or a tape drive. *Host bus adapter* refers to the driver for the SCSI controller on the host machine. SCSA defines the interface between these two components. This chapter discusses target drivers only. See Chapter 17 for information on host bus adapter drivers.

**Note –** The terms "host bus adapter" and "HBA" are equivalent to "host adapter," which is defined in SCSI specifications.

This chapter provides information on the following subjects:



## Introduction to Target Drivers

Target drivers can be either character or block device drivers, depending on the device. Drivers for tape drives are usually character device drivers, while disks are handled by block device drivers. This chapter describes how to write a SCSI target driver. The chapter discusses the additional requirements that SCSA places on block and character drivers for SCSI target devices.

The following reference documents provide supplemental information needed by the designers of target drivers and host bus adapter drivers.

*Small Computer System Interface 2 (SCSI-2)*, ANSI/NCITS X3.131-1994, Global Engineering Documents, 1998. ISBN 1199002488.

*The Basics of SCSI*, Fourth Edition, ANCOT Corporation, 1998. ISBN 0963743988.

Refer also to the SCSI command specification for the target device, provided by the hardware vendor.

# Sun Common SCSI Architecture Overview

The Sun Common SCSI Architecture (SCSA) is the Solaris DDI/DKI programming interface for the transmission of SCSI commands from a target driver to a host bus adapter driver. This interface is independent of the type of host bus adapter hardware, the platform, the processor architecture, and the SCSI command being transported across the interface.

Conforming to the SCSA lets the target driver pass SCSI commands to target devices without knowledge of the hardware implementation of the host bus adapter.

The SCSA conceptually separates building the SCSI command from transporting the command with data across the SCSI bus. The architecture defines the software interface between high-level and low-level software components. The higher level software component consists of one or more SCSI target drivers, which translate I/O requests into SCSI commands appropriate for the peripheral device. The following example illustrates the SCSI architecture.

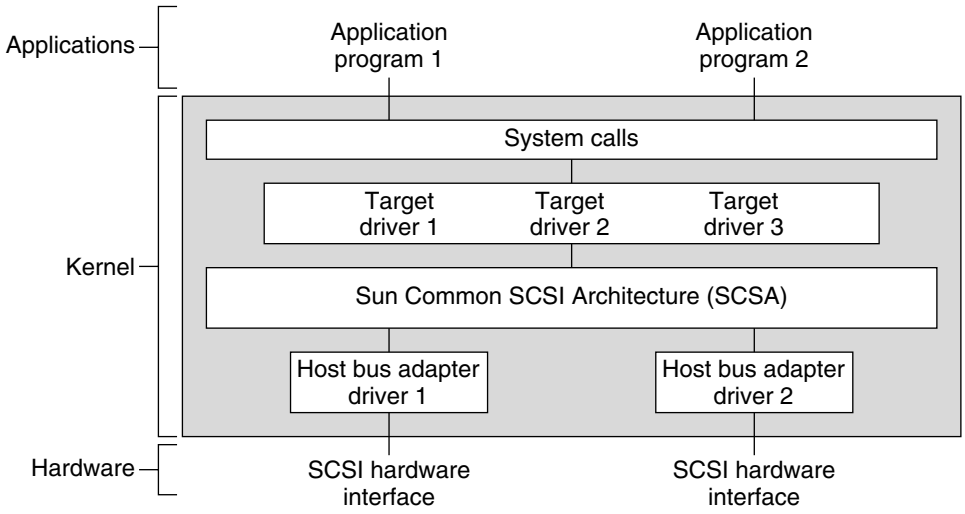



**FIGURE 16–1** SCSA Block Diagram

The lower-level software component consists of a SCSA interface layer and one or more host bus adapter drivers. The target driver is responsible for the generation of the proper SCSI commands required to execute the desired function and for processing the results.

# General Flow of Control

Assuming no transport errors occur, the following steps describe the general flow of control for a read or write request.

1. The target driver's `read`(9E) or `write`(9E) entry point is invoked. `physio`(9F) is used to lock down memory, prepare a `buf` structure, and call the strategy routine.
2. The target driver's `strategy`(9E) routine checks the request. `strategy()` then allocates a `scsi_pkt`(9S) by using `scsi_init_pkt`(9F). The target driver initializes the packet and sets the SCSI command descriptor block (CDB) using the `scsi_setup_cdb`(9F) function. The target driver also specifies a timeout. Then, the driver provides a pointer to a callback function. The callback function is called by the host bus adapter driver on completion of the command. The `buf`(9S) pointer should be saved in the SCSI packet's target-private space.
3. The target driver submits the packet to the host bus adapter driver by using `scsi_transport`(9F). The target driver is then free to accept other requests. The target driver should not access the packet while the packet is in transport. If either the host bus adapter driver or the target supports queueing, new requests can be submitted while the packet is in transport.

4. As soon as the SCSI bus is free and the target not busy, the host bus adapter driver selects the target and passes the CDB. The target driver executes the command. The target then performs the requested data transfers.
5. After the target sends completion status and the command completes, the host bus adapter driver notifies the target driver. To perform the notification, the host calls the completion function that was specified in the SCSI packet. At this time the host bus adapter driver is no longer responsible for the packet, and the target driver has regained ownership of the packet.
6. The SCSI packet's completion routine analyzes the returned information. The completion routine then determines whether the SCSI operation was successful. If a failure has occurred, the target driver retries the command by calling `scsi_transport`(9F) again. If the host bus adapter driver does not support auto request sense, the target driver must submit a request sense packet to retrieve the sense data in the event of a check condition.
7. After successful completion or if the command cannot be retried, the target driver calls `scsi_destroy_pkt`(9F). `scsi_destroy_pkt()` synchronizes the data. `scsi_destroy_pkt()` then frees the packet. If the target driver needs to access the data before freeing the packet, `scsi_sync_pkt`(9F) is called.
8. Finally, the target driver notifies the requesting application that the read or write transaction is complete. This notification is made by returning from the `read`(9E) entry point in the driver for character devices. Otherwise, notification is made indirectly through `biodone`(9F).

SCSA allows the execution of many of such operations, both overlapped and queued, at various points in the process. The model places the management of system resources on the host bus adapter driver. The software interface enables the execution of target driver functions on host bus adapter drivers by using SCSI bus adapters of varying degrees of sophistication.

# SCSA Functions

SCSA defines functions to manage the allocation and freeing of resources, the sensing and setting of control states, and the transport of SCSI commands. These functions are listed in the following table.

**TABLE 16–1** Standard SCSA Functions

| Function Name | Category |
|---|---|
| `scsi_abort`(9F) | Error handling |
| `scsi_alloc_consistent_buf`(9F) | |
| `scsi_destroy_pkt`(9F) | |

**TABLE 16–1** Standard SCSA Functions *(Continued)*

| Function Name | Category |
|---|---|
| scsi_dmafree(9F) | |
| scsi_free_consistent_buf(9F) | |
| scsi_ifgetcap(9F) | Transport information and control |
| scsi_ifsetcap(9F) | |
| scsi_init_pkt(9F) | Resource management |
| scsi_poll(9F) | Polled I/O |
| scsi_probe(9F) | Probe functions |
| scsi_reset(9F) | |
| scsi_setup_cdb(9F) | CDB initialization function |
| scsi_sync_pkt(9F) | |
| scsi_transport(9F) | Command transport |
| scsi_unprobe(9F) | |

**Note –** If your driver needs to work with a SCSI-1 device, use the makecom(9F).

# Hardware Configuration File

Because SCSI devices are not self-identifying, a hardware configuration file is required for a target driver. See the driver.conf(4) and scsi_free_consistent_buf(9F) man pages for details. The following is a typical configuration file:

```
name="xx" class="scsi" target=2 lun=0;
```

The system reads the file during autoconfiguration. The system uses the *class* property to identify the driver's possible parent. Then, the system attempts to attach the driver to any parent driver that is of class *scsi*. All host bus adapter drivers are of this class. Using the *class* property rather than the *parent* property is preferred. This approach enables any host bus adapter driver that finds the expected device at the specified *target* and *lun* IDs to attach to the target. The target driver is responsible for verifying the class in its probe(9E) routine.

# Declarations and Data Structures

Target drivers must include the header file <sys/scsi/scsi.h>.

SCSI target drivers must use the following command to generate a binary module:

```
ld -r xx xx.o -N"misc/scsi"
```

## scsi_device Structure

The host bus adapter driver allocates and initializes a scsi_device(9S) structure for the target driver before either the probe(9E) or attach(9E) routine is called. This structure stores information about each SCSI logical unit, including pointers to information areas that contain both generic and device-specific information. One scsi_device(9S) structure exists for each logical unit that is attached to the system. The target driver can retrieve a pointer to this structure by calling ddi_get_driver_private(9F).

**Caution –** Because the host bus adapter driver uses the private field in the target device's dev_info structure, target drivers must not use ddi_set_driver_private(9F).

The scsi_device(9S) structure contains the following fields:

```
struct scsi_device {
    struct scsi_address       sd_address;    /* opaque address */
    dev_info_t            *sd_dev;       /* device node */
    kmutex_t              sd_mutex;
    void              *sd_reserved;
    struct scsi_inquiry       *sd_inq;
    struct scsi_extended_sense    *sd_sense;
    caddr_t               sd_private;
};
```

where:

| | |
|---|---|
| sd_address | Data structure that is passed to the routines for SCSI resource allocation. |
| sd_dev | Pointer to the target's dev_info structure. |
| sd_mutex | Mutex for use by the target driver. This mutex is initialized by the host bus adapter driver and can be used by the target driver as a per-device mutex. Do not hold this mutex across a call to scsi_transport(9F) or scsi_poll(9F). See Chapter 3 for more information on mutexes. |

| | |
|---|---|
| `sd_inq` | Pointer for the target device's SCSI inquiry data. The `scsi_probe`(9F) routine allocates a buffer, fills the buffer in with inquiry data, and attaches the buffer to this field. |
| `sd_sense` | Pointer to a buffer to contain SCSI request sense data from the device. The target driver must allocate and manage this buffer. See "`attach()` Entry Point (SCSI Target Drivers)" on page 285. |
| `sd_private` | Pointer field for use by the target driver. This field is commonly used to store a pointer to a private target driver state structure. |

## `scsi_pkt` Structure (Target Drivers)

The `scsi_pkt` structure contains the following fields:

```
struct scsi_pkt {
    opaque_t  pkt_ha_private;    /* private data for host adapter */
    struct scsi_address pkt_address; /* destination packet is for */
    opaque_t  pkt_private;       /* private data for target driver */
    void     (*pkt_comp)(struct scsi_pkt *); /* completion routine */
    uint_t   pkt_flags;          /* flags */
    int      pkt_time;           /* time allotted to complete command */
    uchar_t  *pkt_scbp;          /* pointer to status block */
    uchar_t  *pkt_cdbp;          /* pointer to command block */
    ssize_t  pkt_resid;          /* data bytes not transferred */
    uint_t   pkt_state;          /* state of command */
    uint_t   pkt_statistics;     /* statistics */
    uchar_t  pkt_reason;         /* reason completion called */
};
```

where:

| | |
|---|---|
| `pkt_address` | Target device's address set by `scsi_init_pkt`(9F). |
| `pkt_private` | Place to store private data for the target driver. *pkt_private* is commonly used to save the `buf`(9S) pointer for the command. |
| `pkt_comp` | Address of the completion routine. The host bus adapter driver calls this routine when the driver has transported the command. Transporting the command does not mean that the command succeeded. The target might have been busy. Another possibility is that the target might not have responded before the time out period elapsed. See the description for `pkt_time` field. The target driver must supply a valid value in this field. This value can be `NULL` if the driver does not want to be notified. |

**Note –** Two different SCSI callback routines are provided. The `pkt_comp` field identifies a *completion callback* routine, which is called when the host bus adapter completes its processing. A *resource callback* routine is also available, which is called when currently unavailable resources are likely to be available. See the `scsi_init_pkt`(9F) man page.

| | |
|---|---|
| `pkt_flags` | Provides additional control information, for example, to transport the command without disconnect privileges (`FLAG_NODISCON`) or to disable callbacks (`FLAG_NOINTR`). See the `scsi_pkt`(9S) man page for details. |
| `pkt_time` | Time out value in seconds. If the command is not completed within this time, the host bus adapter calls the completion routine with `pkt_reason` set to `CMD_TIMEOUT`. The target driver should set this field to longer than the maximum time the command might take. If the timeout is zero, no timeout is requested. Timeout starts when the command is transmitted on the SCSI bus. |
| `pkt_scbp` | Pointer to the block for SCSI status completion. This field is filled in by the host bus adapter driver. |
| `pkt_cdbp` | Pointer to the SCSI command descriptor block, the actual command to be sent to the target device. The host bus adapter driver does not interpret this field. The target driver must fill the field in with a command that the target device can process. |
| `pkt_resid` | Residual of the operation. The `pkt_resid` field has two different uses depending on how `pkt_resid` is used. When `pkt_resid` is used to allocate DMA resources for a command `scsi_init_pkt`(9F), `pkt_resid` indicates the number of unallocable bytes. DMA resources might *not* be allocated due to DMA hardware scatter-gather or other device limitations. After command transport, `pkt_resid` indicates the number of non-transferable data bytes. The field is filled in by the host bus adapter driver before the completion routine is called. |
| `pkt_state` | Indicates the state of the command. The host bus adapter driver fills in this field as the command progresses. One bit is set in this field for each of the five following command states:<br>■ `STATE_GOT_BUS` – Acquired the bus<br>■ `STATE_GOT_TARGET` – Selected the target<br>■ `STATE_SENT_CMD` – Sent the command<br>■ `STATE_XFERRED_DATA` – Transferred data, if appropriate<br>■ `STATE_GOT_STATUS` – Received status from the device |

| | |
|---|---|
| `pkt_statistics` | Contains transport-related statistics set by the host bus adapter driver. |
| `pkt_reason` | Gives the reason the completion routine was called. The completion routine decodes this field. The routine then takes the appropriate action. If the command completes, that is, no transport errors occur, this field is set to `CMD_CMPLT`. Other values in this field indicate an error. After a command is completed, the target driver should examine the `pkt_scbp` field for a check condition status. See the `scsi_pkt`(9S) man page for more information. |

# Autoconfiguration for SCSI Target Drivers

SCSI target drivers must implement the standard autoconfiguration routines `_init`(9E), `_fini`(9E), and `_info`(9E). See "Loadable Driver Interfaces" on page 91 for more information.

The following routines are also required, but these routines must perform specific SCSI and SCSA processing:

- `probe`(9E)
- `attach`(9E)
- `detach`(9E)
- `getinfo`(9E)

## `probe()` Entry Point (SCSI Target Drivers)

SCSI target devices are not self-identifying, so target drivers must have a `probe`(9E) routine. This routine must determine whether the expected type of device is present and responding.

The general structure and the return codes of the `probe`(9E) routine are the same as the structure and return codes for other device drivers. SCSI target drivers must use the `scsi_probe`(9F) routine in their `probe`(9E) entry point. `scsi_probe`(9F) sends a SCSI inquiry command to the device and returns a code that indicates the result. If the SCSI inquiry command is successful, `scsi_probe`(9F) allocates a `scsi_inquiry`(9S) structure and fills the structure in with the device's inquiry data. Upon return from `scsi_probe`(9F), the `sd_inq` field of the `scsi_device`(9S) structure points to this `scsi_inquiry`(9S) structure.

Because probe(9E) must be stateless, the target driver must call scsi_unprobe(9F) before probe(9E) returns, even if scsi_probe(9F) fails.

Example 16–1 shows a typical probe(9E) routine. The routine in the example retrieves the scsi_device(9S) structure from the private field of its dev_info structure. The routine also retrieves the device's SCSI target and logical unit numbers for printing in messages. The probe(9E) routine then calls scsi_probe(9F) to verify that the expected device, a printer in this case, is present.

If successful, scsi_probe(9F) attaches the device's SCSI inquiry data in a scsi_inquiry(9S) structure to the sd_inq field of the scsi_device(9S) structure. The driver can then determine whether the device type is a printer, which is reported in the inq_dtype field. If the device is a printer, the type is reported with scsi_log(9F), using scsi_dname(9F) to convert the device type into a string.

**EXAMPLE 16–1** SCSI Target Driver probe(9E) Routine

```
static int
xxprobe(dev_info_t *dip)
{
    struct scsi_device *sdp;
    int rval, target, lun;
    /*
     * Get a pointer to the scsi_device(9S) structure
     */
    sdp = (struct scsi_device *)ddi_get_driver_private(dip);

    target = sdp->sd_address.a_target;
    lun = sdp->sd_address.a_lun;
    /*
     * Call scsi_probe(9F) to send the Inquiry command. It will
     * fill in the sd_inq field of the scsi_device structure.
     */
    switch (scsi_probe(sdp, NULL_FUNC)) {
    case SCSIPROBE_FAILURE:
    case SCSIPROBE_NORESP:
    case SCSIPROBE_NOMEM:
       /*
        * In these cases, device may be powered off,
        * in which case we may be able to successfully
        * probe it at some future time - referred to
        * as 'deferred attach'.
        */
        rval = DDI_PROBE_PARTIAL;
        break;
    case SCSIPROBE_NONCCS:
    default:
        /*
         * Device isn't of the type we can deal with,
         * and/or it will never be usable.
         */
        rval = DDI_PROBE_FAILURE;
        break;
```

**EXAMPLE 16–1** SCSI Target Driver `probe`(9E) Routine *(Continued)*

```
    case SCSIPROBE_EXISTS:
        /*
         * There is a device at the target/lun address. Check
         * inq_dtype to make sure that it is the right device
         * type. See scsi_inquiry(9S)for possible device types.
         */
        switch (sdp->sd_inq->inq_dtype) {
        case DTYPE_PRINTER:
        scsi_log(sdp, "xx", SCSI_DEBUG,
           "found %s device at target%d, lun%d\n",
            scsi_dname((int)sdp->sd_inq->inq_dtype),
            target, lun);
        rval = DDI_PROBE_SUCCESS;
        break;
        case DTYPE_NOTPRESENT:
        default:
        rval = DDI_PROBE_FAILURE;
        break;
        }
    }
    scsi_unprobe(sdp);
    return (rval);
}
```

A more thorough `probe`(9E) routine could check `scsi_inquiry`(9S) to make sure that the device is of the type expected by a particular driver.

## `attach()` Entry Point (SCSI Target Drivers)

After the `probe`(9E) routine has verified that the expected device is present, `attach`(9E) is called. `attach()` performs these tasks:

- Allocates and initializes any per-instance data.
- Creates minor device node information.
- Restores the hardware state of a device after a suspension of the device or the system. See "`attach()` Entry Point" on page 99 for details.

A SCSI target driver needs to call `scsi_probe`(9F) again to retrieve the device's inquiry data. The driver must also create a SCSI request sense packet. If the attach is successful, the `attach()` function should not call `scsi_unprobe`(9F).

Three routines are used to create the request sense packet: `scsi_alloc_consistent_buf`(9F), `scsi_init_pkt`(9F), and `scsi_setup_cdb`(9F). `scsi_alloc_consistent_buf`(9F) allocates a buffer that is suitable for consistent DMA. `scsi_alloc_consistent_buf()` then returns a

pointer to a buf(9S) structure. The advantage of a consistent buffer is that no explicit synchronization of the data is required. In other words, the target driver can access the data after the callback. The sd_sense element of the device's scsi_device(9S) structure must be initialized with the address of the sense buffer. scsi_init_pkt(9F) creates and partially initializes a scsi_pkt(9S) structure. scsi_setup_cdb(9F) creates a SCSI command descriptor block, in this case by creating a SCSI request sense command.

Note that a SCSI device is not self-identifying and does not have a reg property. As a result, the driver must set the pm-hardware-state property. Setting pm-hardware-state informs the framework that this device needs to be suspended and then resumed.

The following example shows the SCSI target driver's attach() routine.

**EXAMPLE 16–2** SCSI Target Driver attach(9E) Routine

```
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
    struct xxstate         *xsp;
    struct scsi_pkt        *rqpkt = NULL;
    struct scsi_device     *sdp;
    struct buf         *bp = NULL;
    int            instance;
    instance = ddi_get_instance(dip);
    switch (cmd) {
        case DDI_ATTACH:
        break;
        case DDI_RESUME:
            For information, see Chapter 9, Directory Memory Access(DMA)".
        default:
        return (DDI_FAILURE);
    }
        allocate a state structure and initialize it
    [...]
    xsp = ddi_get_soft_state(statep, instance);
    sdp = (struct scsi_device *)ddi_get_driver_private(dip);
    /*
     * Cross-link the state and scsi_device(9S) structures.
     */
    sdp->sd_private = (caddr_t)xsp;
    xsp->sdp = sdp;
        call scsi_probe(9F) again to get and validate inquiry data
    /*
     * Allocate a request sense buffer. The buf(9S) structure
     * is set to NULL to tell the routine to allocate a new
     * one. The callback function is set to NULL_FUNC to tell
     * the routine to return failure immediately if no
     * resources are available.
     */
    bp = scsi_alloc_consistent_buf(&sdp->sd_address, NULL,
    SENSE_LENGTH, B_READ, NULL_FUNC, NULL);
```

**EXAMPLE 16–2** SCSI Target Driver `attach`(9E) Routine *(Continued)*

```
    if (bp == NULL)
        goto failed;
    /*
     * Create a Request Sense scsi_pkt(9S) structure.
     */
    rqpkt = scsi_init_pkt(&sdp->sd_address, NULL, bp,
    CDB_GROUP0, 1, 0, PKT_CONSISTENT, NULL_FUNC, NULL);
    if (rqpkt == NULL)
        goto failed;
    /*
     * scsi_alloc_consistent_buf(9F) returned a buf(9S) structure.
     * The actual buffer address is in b_un.b_addr.
     */
    sdp->sd_sense = (struct scsi_extended_sense *)bp->b_un.b_addr;
    /*
     * Create a Group0 CDB for the Request Sense command
     */
    if (scsi_setup_cdb((union scsi_cdb *)rqpkt->pkt_cdbp,
        SCMD_REQUEST_SENSE, 0, SENSE__LENGTH, 0) == 0)
         goto failed;;
    /*
     * Fill in the rest of the scsi_pkt structure.
     * xxcallback() is the private command completion routine.
     */
    rqpkt->pkt_comp = xxcallback;
    rqpkt->pkt_time = 30; /* 30 second command timeout */
    rqpkt->pkt_flags |= FLAG_SENSING;
    xsp->rqs = rqpkt;
    xsp->rqsbuf = bp;
        create minor nodes, report device, and do any other initialization
    /*
     * Since the device does not have the 'reg' property,
     * cpr will not call its DDI_SUSPEND/DDI_RESUME entries.
     * The following code is to tell cpr that this device
     * needs to be suspended and resumed.
     */
    (void) ddi_prop_update_string(device, dip,
     "pm-hardware-state", "needs-suspend-resume");
    xsp->open = 0;
    return (DDI_SUCCESS);
failed:
    if (bp)
        scsi_free_consistent_buf(bp);
    if (rqpkt)
        scsi_destroy_pkt(rqpkt);
    sdp->sd_private = (caddr_t)NULL;
    sdp->sd_sense = NULL;
    scsi_unprobe(sdp);
        free any other resources, such as the state structure
    return (DDI_FAILURE);
}
```

## detach() Entry Point (SCSI Target Drivers)

The detach(9E) entry point is the inverse of attach(9E). detach() must free all resources that were allocated in attach(). If successful, the detach should call scsi_unprobe(9F). The following example shows a target driver detach() routine.

**EXAMPLE 16–3** SCSI Target Driver detach(9E) Routine

```
static int
xxdetach(dev_info_t *dip, ddi_detach_cmd_t cmd)
{
    struct xxstate *xsp;
    switch (cmd) {
    case DDI_DETACH:
          normal detach(9E) operations, such as getting a
          pointer to the state structure
      [...]
      scsi_free_consistent_buf(xsp->rqsbuf);
      scsi_destroy_pkt(xsp->rqs);
      xsp->sdp->sd_private = (caddr_t)NULL;
      xsp->sdp->sd_sense = NULL;
      scsi_unprobe(xsp->sdp);
          remove minor nodes
          free resources, such as the state structure and properties
          return (DDI_SUCCESS);
    case DDI_SUSPEND:
          For information, see Chapter 9, "Direct Memory Access (DMA)."
    default:
      return (DDI_FAILURE);
    }
}
```

## getinfo() Entry Point (SCSI Target Drivers)

The getinfo(9E) routine for SCSI target drivers is much the same as for other drivers (see "getinfo() Entry Point" on page 106 for more information on DDI_INFO_DEVT2INSTANCE case). However, in the DDI_INFO_DEVT2DEVINFO case of the getinfo() routine, the target driver must return a pointer to its dev_info node. This pointer can be saved in the driver state structure or can be retrieved from the sd_dev field of the scsi_device(9S) structure. The following example shows an alternative SCSI target driver getinfo() code fragment.

**EXAMPLE 16–4** Alternative SCSI Target Driver getinfo() Code Fragment

```
[...]
case DDI_INFO_DEVT2DEVINFO:
    dev = (dev_t)arg;
    instance = getminor(dev);
    xsp = ddi_get_soft_state(statep, instance);
    if (xsp == NULL)
```

**EXAMPLE 16–4** Alternative SCSI Target Driver `getinfo()` Code Fragment *(Continued)*

```
        return (DDI_FAILURE);
    *result = (void *)xsp->sdp->sd_dev;
    return (DDI_SUCCESS);
[...]
```

# Resource Allocation

To send a SCSI command to the device, the target driver must create and initialize a `scsi_pkt`(9S) structure. This structure must then be passed to the host bus adapter driver.

## `scsi_init_pkt()` Function

The `scsi_init_pkt`(9F) routine allocates and zeroes a `scsi_pkt`(9S) structure. `scsi_init_pkt()` also sets pointers to `pkt_private`, `*pkt_scbp`, and `*pkt_cdbp`. Additionally, `scsi_init_pkt()` provides a callback mechanism to handle the case where resources are not available. This function has the following syntax:

```
struct scsi_pkt *scsi_init_pkt(struct scsi_address *ap,
     struct scsi_pkt *pktp, struct buf *bp, int cmdlen,
     int statuslen, int privatelen, int flags,
     int (*callback)(caddr_t), caddr_t arg)
```

where:

| | |
|---|---|
| *ap* | Pointer to a `scsi_address` structure. `ap` is the `sd_address` field of the device's `scsi_device`(9S) structure. |
| *pktp* | Pointer to the `scsi_pkt`(9S) structure to be initialized. If this pointer is set to `NULL`, a new packet is allocated. |
| *bp* | Pointer to a `buf`(9S) structure. If this pointer is non-NULL with a valid byte count, DMA resources are allocated. |
| *cmdlen* | Length of the SCSI command descriptor block in bytes. |
| *statuslen* | Required length of the SCSI status completion block in bytes. |
| *privatelen* | Number of bytes to allocate for the `pkt_private` field. |
| *flags* | Set of flags: |

- PKT_CONSISTENT – This bit must be set if the DMA buffer was allocated using scsi_alloc_consistent_buf(9F). In this case, the host bus adapter driver guarantees that the data transfer is properly synchronized before performing the target driver's command completion callback.
- PKT_DMA_PARTIAL – This bit can be set if the driver accepts a partial DMA mapping. If set, scsi_init_pkt(9F) allocates DMA resources with the DDI_DMA_PARTIAL flag set. The pkt_resid field of the scsi_pkt(9S) structure can be returned with a nonzero residual. A nonzero value indicates the number of bytes for which scsi_init_pkt(9F) was unable to allocate DMA resources.

*callback* Specifies the action to take if resources are not available. If set to NULL_FUNC, scsi_init_pkt(9F) returns the value NULL immediately. If set to SLEEP_FUNC, scsi_init_pkt() does not return until resources are available. Any other valid kernel address is interpreted as the address of a function to be called when resources are likely to be available.

*arg* Parameter to pass to the callback function.

The scsi_init_pkt() routine synchronizes the data prior to transport. If the driver needs to access the data after transport, the driver should call scsi_sync_pkt(9F) to flush any intermediate caches. The scsi_sync_pkt() routine can be used to synchronize any cached data.

## scsi_sync_pkt() Function

If the target driver needs to resubmit the packet after changing the data, scsi_sync_pkt(9F) must be called before calling scsi_transport(9F). However, if the target driver does not need to access the data, scsi_sync_pkt() does not need to be called after the transport.

## scsi_destroy_pkt() Function

The scsi_destroy_pkt(9F) routine synchronizes any remaining cached data that is associated with the packet, if necessary. The routine then frees the packet and associated command, status, and target driver-private data areas. This routine should be called in the command completion routine.

## scsi_alloc_consistent_buf() Function

For most I/O requests, the data buffer passed to the driver entry points is not accessed directly by the driver. The buffer is just passed on to scsi_init_pkt(9F). If a driver sends SCSI commands that operate on buffers that the driver itself examines, the buffers should be DMA consistent. The SCSI request sense command is a good example. The scsi_alloc_consistent_buf(9F) routine allocates a buf(9S) structure and a data buffer that is suitable for DMA-consistent operations. The HBA performs any necessary synchronization of the buffer before performing the command completion callback.

---

**Note –** scsi_alloc_consistent_buf(9F) uses scarce system resources. Thus, you should use scsi_alloc_consistent_buf() sparingly.

---

## scsi_free_consistent_buf() Function

scsi_free_consistent_buf(9F) releases a buf(9S) structure and the associated data buffer allocated with scsi_alloc_consistent_buf(9F). See "attach() Entry Point (SCSI Target Drivers)" on page 285 and "detach() Entry Point (SCSI Target Drivers)" on page 288 for examples.

# Building and Transporting a Command

The host bus adapter driver is responsible for transmitting the command to the device. Furthermore, the driver is responsible for handling the low-level SCSI protocol. The scsi_transport(9F) routine hands a packet to the host bus adapter driver for transmission. The target driver has the responsibility to create a valid scsi_pkt(9S) structure.

## Building a Command

The routine scsi_init_pkt(9F) allocates space for a SCSI CDB, allocates DMA resources if necessary, and sets the pkt_flags field, as shown in this example:

```
pkt = scsi_init_pkt(&sdp->sd_address, NULL, bp,
CDB_GROUP0, 1, 0, 0, SLEEP_FUNC, NULL);
```

This example creates a new packet along with allocating DMA resources as specified in the passed buf(9S) structure pointer. A SCSI CDB is allocated for a Group 0 (6-byte) command. The pkt_flags field is set to zero, but no space is allocated for the pkt_private field. This call to scsi_init_pkt(9F), because of the SLEEP_FUNC parameter, waits indefinitely for resources if no resources are currently available.

The next step is to initialize the SCSI CDB, using the scsi_setup_cdb(9F) function:

```
if (scsi_setup_cdb((union scsi_cdb *)pkt->pkt_cdbp,
 SCMD_READ, bp->b_blkno, bp->b_bcount >> DEV_BSHIFT, 0) == 0)
 goto failed;
```

This example builds a Group 0 command descriptor block. The example fills in the pkt_cdbp field as follows:

- The command itself is in byte 0. The command is set from the parameter SCMD_READ.
- The address field is in bits 0-4 of byte 1 and bytes 2 and 3. The address is set from bp->b_blkno.
- The count field is in byte 4. The count is set from the last parameter. In this case, count is set to bp->b_bcount >> DEV_BSHIFT, where DEV_BSHIFT is the byte count of the transfer converted to the number of blocks.

---

**Note –** scsi_setup_cdb(9F) does not support setting a target device's logical unit number (LUN) in bits 5-7 of byte 1 of the SCSI command block. This requirement is defined by SCSI-1. For SCSI-1 devices that require the LUN bits set in the command block, use makecom_g0(9F) or some equivalent rather than scsi_setup_cdb(9F).

---

After initializing the SCSI CDB, initialize three other fields in the packet and store as a pointer to the packet in the state structure.

```
pkt->pkt_private = (opaque_t)bp;
pkt->pkt_comp = xxcallback;
pkt->pkt_time = 30;
xsp->pkt = pkt;
```

The buf(9S) pointer is saved in the pkt_private field for later use in the completion routine.

## Setting Target Capabilities

The target drivers use `scsi_ifsetcap`(9F) to set the capabilities of the host adapter driver. A *cap* is a name-value pair, consisting of a null-terminated character string and an integer value. The current value of a capability can be retrieved using `scsi_ifgetcap`(9F). `scsi_ifsetcap`(9F) allows capabilities to be set for all targets on the bus.

In general, however, setting capabilities of targets that are not owned by the target driver is not recommended. This practice is not universally supported by HBA drivers. Some capabilities, such as disconnect and synchronous, can be set by default by the HBA driver. Other capabilities might need to be set explicitly by the target driver. Wide-xfer and tagged-queueing must be set by the target drive, for example.

## Transporting a Command

After the `scsi_pkt`(9S) structure is filled in, use `scsi_transport`(9F) to hand the structure to the bus adapter driver:

```
if (scsi_transport(pkt) != TRAN_ACCEPT) {
 bp->b_resid = bp->b_bcount;
 bioerror(bp, EIO);
 biodone(bp);
 }
```

The other return values from `scsi_transport`(9F) are as follows:

- `TRAN_BUSY` – A command for the specified target is already in progress.
- `TRAN_BADPKT` – The DMA count in the packet was too large, or the host adapter driver rejected this packet for other reasons.
- `TRAN_FATAL_ERROR` – The host adapter driver is unable to accept this packet.

---

**Note –** The mutex `sd_mutex` in the `scsi_device`(9S) structure must not be held across a call to `scsi_transport`(9F).

---

If `scsi_transport`(9F) returns `TRAN_ACCEPT`, the packet becomes the responsibility of the host bus adapter driver. The packet should not be accessed by the target driver until the command completion routine is called.

### Synchronous `scsi_transport()` Function

If `FLAG_NOINTR` is set in the packet, then `scsi_transport`(9F) does not return until the command is complete. No callback is performed.

**Note –** Do not use `FLAG_NOINTR` in interrupt context.

# Command Completion

When the host bus adapter driver is through with the command, the driver invokes the packet's completion callback routine. The driver then passes a pointer to the `scsi_pkt`(9S) structure as a parameter. After decoding the packet, the completion routine takes the appropriate action.

Example 16–5 presents a simple completion callback routine. This code checks for transport failures. In case of failure, the routine gives up rather than retrying the command. If the target is busy, extra code is required to resubmit the command at a later time.

If the command results in a check condition, the target driver needs to send a request sense command unless auto request sense has been enabled.

Otherwise, the command succeeded. At the end of processing for the command, the command destroys the packet and calls `biodone`(9F).

In the event of a transport error, such as a bus reset or parity problem, the target driver can resubmit the packet by using `scsi_transport`(9F). No values in the packet need to be changed prior to resubmitting.

The following example does not attempt to retry incomplete commands.

**Note –** Normally, the target driver's callback function is called in interrupt context. Consequently, the callback function should never sleep.

**EXAMPLE 16–5** Completion Routine for a SCSI Driver

```
static void
xxcallback(struct scsi_pkt *pkt)
{
    struct buf        *bp;
    struct xxstate    *xsp;
    minor_t           instance;
    struct scsi_status *ssp;
    /*
     * Get a pointer to the buf(9S) structure for the command
     * and to the per-instance data structure.
     */
    bp = (struct buf *)pkt->pkt_private;
    instance = getminor(bp->b_edev);
```

**EXAMPLE 16–5** Completion Routine for a SCSI Driver *(Continued)*

```
    xsp = ddi_get_soft_state(statep, instance);
    /*
     * Figure out why this callback routine was called
     */
    if (pkt->pkt_reason != CMP_CMPLT) {
       bp->b_resid = bp->b_bcount;
       bioerror(bp, EIO);
       scsi_destroy_pkt(pkt);      /* release resources */
       biodone(bp);            /* notify waiting threads */ ;
    } else {
       /*
        * Command completed, check status.
        * See scsi_status(9S)
        */
       ssp = (struct scsi_status *)pkt->pkt_scbp;
       if (ssp->sts_busy) {
               error, target busy or reserved
       } else if (ssp->sts_chk) {
               send a request sense command
       } else {
        bp->b_resid = pkt->pkt_resid; /*packet completed OK */
        scsi_destroy_pkt(pkt);
        biodone(bp);
       }
    }
}
```

# Reuse of Packets

A target driver can reuse packets in the following ways:

- Resubmit the packet unchanged.
- Use `scsi_sync_pkt`(9F) to synchronize the data. Then, process the data in the driver. Finally, resubmit the packet.
- Free DMA resources, using `scsi_dmafree`(9F), and pass the `pkt` pointer to `scsi_init_pkt`(9F) for binding to a new `bp`. The target driver is responsible for reinitializing the packet. The CDB has to have the same length as the previous CDB.
- If only partial DMA is allocated during the first call to `scsi_init_pkt`(9F), subsequent calls to `scsi_init_pkt`(9F) can be made for the same packet. Calls can be made to `bp` as well to adjust the DMA resources to the next portion of the transfer.

# Auto-Request Sense Mode

Auto-request sense mode is most desirable if queuing is used, whether the queuing is tagged or untagged. A contingent allegiance condition is cleared by any subsequent command and, consequently, the sense data is lost. Most HBA drivers start the next command before performing the target driver callback. Other HBA drivers can use a separate, lower-priority thread to perform the callbacks. This approach might increase the time needed to notify the target driver that the packet completed with a check condition. In this case, the target driver might not be able to submit a request sense command in time to retrieve the sense data.

To avoid this loss of sense data, the HBA driver, or controller, should issue a request sense command if a check condition has been detected. This mode is known as auto-request sense mode. Note that not all HBA drivers are capable of auto-request sense mode, and some drivers can only operate with auto-request sense mode enabled.

A target driver enables auto-request-sense mode by using `scsi_ifsetcap`(9F). The following example shows auto-request sense enabling.

**EXAMPLE 16–6** Enabling Auto-Request Sense Mode

```
static int
xxattach(dev_info_t *dip, ddi_attach_cmd_t cmd)
{
    struct xxstate *xsp;
    struct scsi_device *sdp = (struct scsi_device *)
    ddi_get_driver_private(dip);
    [...]
    /*
     * enable auto-request-sense; an auto-request-sense cmd may
     * fail due to a BUSY condition or transport error. Therefore,
     * it is recommended to allocate a separate request sense
     * packet as well.
     * Note that scsi_ifsetcap(9F) may return -1, 0, or 1
     */
    xsp->sdp_arq_enabled =
    ((scsi_ifsetcap(ROUTE, “auto-rqsense”, 1, 1) == 1) ? 1 :
0);
    /*
     * if the HBA driver supports auto request sense then the
     * status blocks should be sizeof (struct scsi_arq_status);
else
     * one byte is sufficient
     */
    xsp->sdp_cmd_stat_size =  (xsp->sdp_arq_enabled ?
    sizeof (struct scsi_arq_status) : 1);
    [...]
}
```

If a packet is allocated using `scsi_init_pkt`(9F) and auto-request sense is desired on this packet, additional space is needed. The target driver must request this space for the status block to hold the auto-request sense structure. The sense length used in the request sense command is `sizeof`, from `struct scsi_extended_sense`. Auto-request sense can be disabled per individual packet by allocating `sizeof`, from `struct scsi_status`, for the status block.

The packet is submitted using `scsi_transport`(9F) as usual. When a check condition occurs on this packet, the host adapter driver takes the following steps:

- Issues a request sense command if the controller does not have auto-request sense capability
- Obtains the sense data
- Fills in the `scsi_arq_status` information in the packet's status block
- Sets `STATE_ARQ_DONE` in the packet's `pkt_state` field
- Calls the packet's callback handler (`pkt_comp()`)

The target driver's callback routine should verify that sense data is available by checking the `STATE_ARQ_DONE` bit in `pkt_state`. `STATE_ARQ_DONE` implies that a check condition has occurred and that a request sense has been performed. If auto-request sense has been temporarily disabled in a packet, subsequent retrieval of the sense data cannot be guaranteed.

The target driver should then verify whether the auto-request sense command completed successfully and decode the sense data.

# Dump Handling

The `dump`(9E) entry point copies a portion of virtual address space directly to the specified device in the case of system failure or checkpoint operation. See the `cpr`(7) and `dump`(9E) man pages. The `dump`(9E) entry point must be capable of performing this operation without the use of interrupts.

The arguments for `dump()` are as follows:

*dev* Device number of the dump device

*addr* Kernel virtual address at which to start the dump

*blkno* First destination block on the device

*nblk* Number of blocks to dump

**EXAMPLE 16–7** `dump`(9E) Routine

```
static int
xxdump(dev_t dev, caddr_t addr, daddr_t blkno, int nblk)
{
```

**EXAMPLE 16–7** dump(9E) Routine *(Continued)*

```
    struct xxstate    *xsp;
    struct buf    *bp;
    struct scsi_pkt    *pkt;
    int    rval;
    int    instance;

    instance = getminor(dev);
    xsp = ddi_get_soft_state(statep, instance);

    if (tgt->suspended) {
    (void) ddi_dev_is_needed(DEVINFO(tgt), 0, 1);
    }

    bp = getrbuf(KM_NOSLEEP);
    if (bp == NULL) {
    return (EIO);
    }
```

*Calculate block number relative to partition*

```
bp->b_un.b_addr = addr;
    bp->b_edev = dev;
    bp->b_bcount = nblk * DEV_BSIZE;
    bp->b_flags = B_WRITE | B_BUSY;
    bp->b_blkno = blkno;

    pkt = scsi_init_pkt(ROUTE(tgt), NULL, bp, CDB_GROUP1,
    sizeof (struct scsi_arq_status),
    sizeof (struct bst_pkt_private), 0, NULL_FUNC, NULL);
    if (pkt == NULL) {
    freerbuf(bp);
    return (EIO);
    }
    (void) scsi_setup_cdb((union scsi_cdb *)pkt->pkt_cdbp,
        SCMD_WRITE_G1, blkno, nblk, 0);

    /*
     * while dumping in polled mode, other cmds might complete
     * and these should not be resubmitted. we set the
     * dumping flag here which prevents requeueing cmds.
     */
    tgt->dumping = 1;
    rval = scsi_poll(pkt);
    tgt->dumping = 0;

    scsi_destroy_pkt(pkt);
    freerbuf(bp);

    if (rval != DDI_SUCCESS) {
    rval = EIO;
    }
```

**EXAMPLE 16–7** dump(9E) Routine *(Continued)*

```
    return (rval);
}
```

# SCSI Options

SCSA defines a global variable, *scsi_options*, for control and debugging. The defined bits in *scsi_options* can be found in the file <sys/scsi/conf/autoconf.h>. The *scsi_options* uses the bits as follows:

| | |
|---|---|
| SCSI_OPTIONS_DR | Enables global disconnect or reconnect. |
| SCSI_OPTIONS_FAST | Enables global FAST SCSI support: 10 Mbytes/sec transfers. The HBA should not operate in FAST SCSI mode unless the SCSI_OPTIONS_FAST (0x100) bit is set. |
| SCSI_OPTIONS_FAST20 | Enables global FAST20 SCSI support: 20 Mbytes/sec transfers. The HBA should not operate in FAST20 SCSI mode unless the SCSI_OPTIONS_FAST20 (0x400) bit is set. |
| SCSI_OPTIONS_FAST40 | Enables global FAST40 SCSI support: 40 Mbytes/sec transfers. The HBA should not operate in FAST40 SCSI mode unless the SCSI_OPTIONS_FAST40 (0x800) bit is set. |
| SCSI_OPTIONS_FAST80 | Enables global FAST80 SCSI support: 80 Mbytes/sec transfers. The HBA should not operate in FAST80 SCSI mode unless the SCSI_OPTIONS_FAST80 (0x1000) bit is set. |
| SCSI_OPTIONS_FAST160 | Enables global FAST160 SCSI support: 160 Mbytes/sec transfers. The HBA should not operate in FAST160 SCSI mode unless the SCSI_OPTIONS_FAST160 (0x2000) bit is set. |
| SCSI_OPTIONS_FAST320 | Enables global FAST320 SCSI support: 320 Mbytes/sec transfers. The HBA should not operate in FAST320 SCSI mode unless the SCSI_OPTIONS_FAST320 (0x4000) bit is set. |
| SCSI_OPTIONS_LINK | Enables global link support. |
| SCSI_OPTIONS_PARITY | Enables global parity support. |

| | |
|---|---|
| `SCSI_OPTIONS_QAS` | Enables the Quick Arbitration Select feature. QAS is used to decrease protocol overhead when devices arbitrate for and access the bus. QAS is only supported on Ultra4 (FAST160) SCSI devices, although not all such devices support QAS. The HBA should not operate in QAS SCSI mode unless the SCSI_OPTIONS_QAS (0x100000) bit is set. Consult the appropriate Sun hardware documentation to determine whether your machine supports QAS. |
| `SCSI_OPTIONS_SYNC` | Enables global synchronous transfer capability. |
| `SCSI_OPTIONS_TAG` | Enables global tagged queuing support. |
| `SCSI_OPTIONS_WIDE` | Enables global WIDE SCSI. |

---

**Note –** The setting of *scsi_options* affects *all* host bus adapter drivers and all target drivers that are present on the system. Refer to the `scsi_hba_attach`(9F) man page for information on controlling these options for a particular host adapter.

---

CHAPTER 17

# SCSI Host Bus Adapter Drivers

This chapter contains information on creating SCSI host bus adapter (HBA) drivers. The chapter provides sample code illustrating the structure of a typical HBA driver. The sample code shows the use of the HBA driver interfaces that are provided by the Sun Common SCSI Architecture (SCSA). This chapter provides information on the following subjects:



## Introduction to Host Bus Adapter Drivers

As described in Chapter 16, the Solaris 10 DDI/DKI divides the software interface to SCSI devices into two major parts:

- Target devices and drivers
- Host bus adapter devices and drivers

*Target device* refers to a device on a SCSI bus, such as a disk or a tape drive. *Target driver* refers to a software component installed as a device driver. Each target device on a SCSI bus is controlled by one instance of the target driver.

*Host bus adapter device* refers to HBA hardware, such as an SBus or PCI SCSI adapter card. *Host bus adapter driver* refers to a software component that is installed as a device driver. Some examples are the `esp` driver on a SPARC machine, the `ncrs` driver on an x86 machine, and the `isp` driver, which works on both architectures. An instance of the HBA driver controls each of its host bus adapter devices that are configured in the system.

The Sun Common SCSI Architecture (SCSA) defines the interface between the target and HBA components.

---

**Note –** Understanding SCSI target drivers is an essential prerequisite to writing effective SCSI HBA drivers. For information on SCSI target drivers, see Chapter 16. Target driver developers can also benefit from reading this chapter.

---

The host bus adapter driver is responsible for performing the following tasks:

- Managing host bus adapter hardware
- Accepting SCSI commands from the SCSI target driver
- Transporting the commands to the specified SCSI target device
- Performing any data transfers that the command requires
- Collecting status
- Handling auto-request sense (optional)
- Informing the target driver of command completion or failure

# SCSI Interface

SCSA is the Solaris 10 DDI/DKI programming interface for the transmission of SCSI commands from a target driver to a host adapter driver. By conforming to the SCSA, the target driver can easily pass any combination of SCSI commands and sequences to a target device. Knowledge of the hardware implementation of the host adapter is not necessary. Conceptually, SCSA separates the building of a SCSI command from the transporting of the command with data to the SCSI bus. SCSA manages the connections between the target and HBA drivers through an HBA *transport*layer, as shown in the following figure.

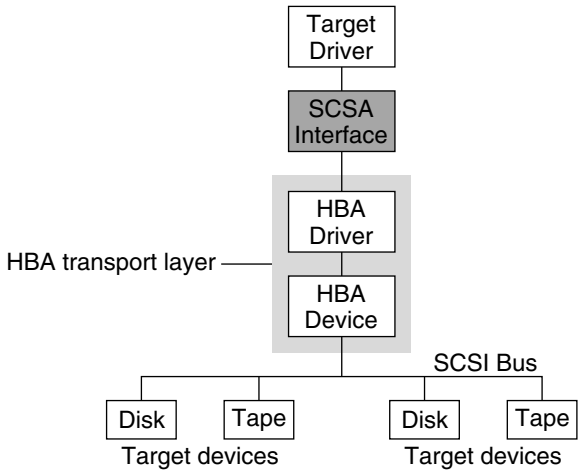



**FIGURE 17–1** SCSA Interface

The *HBA transport layer* is a software and hardware layer that is responsible for transporting a SCSI command to a SCSI target device. The HBA driver provides resource allocation, DMA management, and transport services in response to requests made by SCSI target drivers through SCSA. The host adapter driver also manages the host adapter hardware and the SCSI protocols necessary to perform the commands. When a command has been completed, the HBA driver calls the target driver's SCSI `pkt` command completion routine.

The following example illustrates this flow, with emphasis on the transfer of information from target drivers to SCSA to HBA drivers. The figure also shows typical transport entry points and function calls.

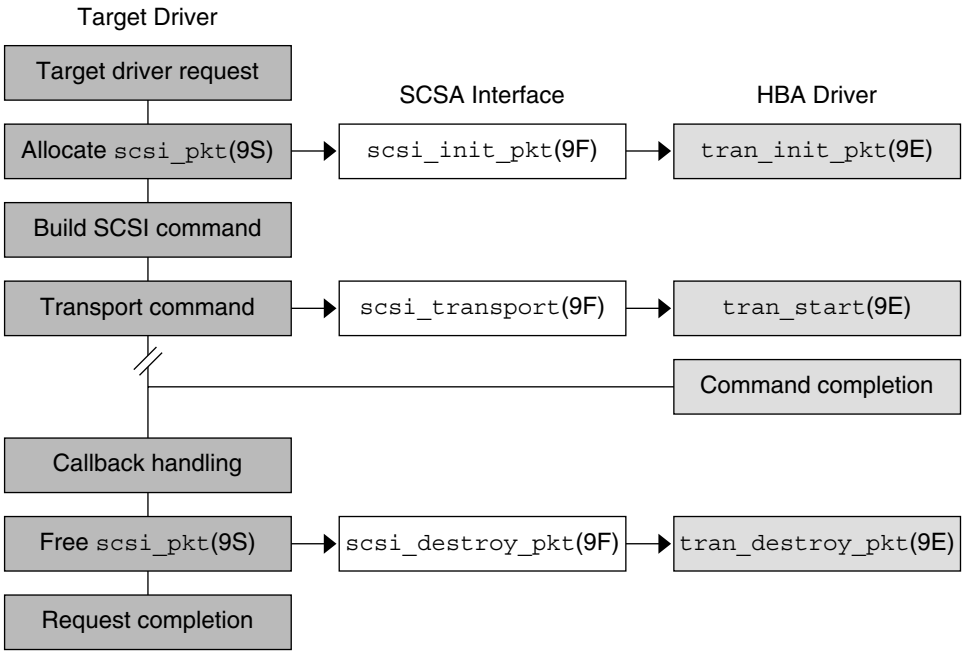



**FIGURE 17–2** Transport Layer Flow

# SCSA HBA Interfaces

SCSA HBA interfaces include HBA entry points, HBA data structures, and an HBA framework.

## SCSA HBA Entry Point Summary

SCSA defines a number of HBA driver entry points. These entry points are listed in the following table. The entry points are called by the system when a target driver instance connected to the HBA driver is configured. The entry points are also called when the target driver makes a SCSA request. See "Entry Points for SCSA HBA Drivers" on page 322 for more information.

**TABLE 17–1** SCSA HBA Entry Point Summary

| Function Name | Called as a Result of |
|---|---|
| tran_abort(9E) | Target driver calling scsi_abort(9F) |
| tran_bus_reset(9e) | System resetting bus |
| tran_destroy_pkt(9E) | Target driver calling scsi_destroy_pkt(9F) |
| tran_dmafree(9E) | Target driver calling scsi_dmafree(9F) |
| tran_getcap(9E) | Target driver calling scsi_ifgetcap(9F) |
| tran_init_pkt(9E) | Target driver calling scsi_init_pkt(9F) |
| tran_quiesce(9e) | System quiescing bus |
| tran_reset(9E) | Target driver calling scsi_reset(9F) |
| tran_reset_notify(9E) | Target driver calling scsi_reset_notify(9F) |
| tran_setcap(9E) | Target driver calling scsi_ifsetcap(9F) |
| tran_start(9E) | Target driver calling scsi_transport(9F) |
| tran_sync_pkt(9E) | Target driver calling scsi_sync_pkt(9F) |
| tran_tgt_free(9E) | System detaching target device instance |
| tran_tgt_init(9E) | System attaching target device instance |
| tran_tgt_probe(9E) | Target driver calling scsi_probe(9F) |
| tran_unquiesce(9e) | System resuming activity on bus |

# SCSA HBA Data Structures

SCSA defines data structures to enable the exchange of information between the target and HBA drivers. The following data structures are included:

- scsi_hba_tran(9S)
- scsi_address(9S)
- scsi_device(9S)
- scsi_pkt(9S)

## scsi_hba_tran() Structure

Each instance of an HBA driver must allocate a scsi_hba_tran(9S) structure using scsi_hba_tran_alloc(9F) in the attach(9E) entry point. scsi_hba_tran_alloc(9F) initializes the scsi_hba_tran(9S) structure before returning. The HBA driver must initialize specific vectors in the transport structure to point to entry points within the HBA driver. Once initialized, the HBA driver exports the transport structure to SCSA by calling scsi_hba_attach_setup(9F).

**Caution –** Because SCSA keeps a pointer to the transport structure in the driver-private field on the `devinfo` node, HBA drivers must not use `ddi_set_driver_private`(9F). HBA drivers can, however, use `ddi_get_driver_private`(9F) to retrieve the pointer to the transport structure.

The `scsi_hba_tran`(9S) structure contains the following fields:

```
struct scsi_hba_tran {
    dev_info_t      *tran_hba_dip;
    void        *tran_hba_private;      /* HBA soft state */
    void        *tran_tgt_private;      /* target-specific info */
    struct scsi_device      *tran_sd;
    int         (*tran_tgt_init)();
    int         (*tran_tgt_probe)();
    void        (*tran_tgt_free)();
    int         (*tran_start)();
    int         (*tran_reset)();
    int         (*tran_abort)();
    int         (*tran_getcap)();
    int         (*tran_setcap)();
    struct scsi_pkt *(*tran_init_pkt)();
    void        (*tran_destroy_pkt)();
    void        (*tran_dmafree)();
    void        (*tran_sync_pkt)();
    int         (*tran_reset_notify)();
    int         (*tran_quiesce)();
    int         (*tran_unquiesce)();
    int         (*tran_bus_reset)();
};
```

**Note –** Code fragments presented subsequently in this chapter use these fields to describe practical HBA driver operations. See "Entry Points for SCSA HBA Drivers" on page 322 for more information.

where:

| | |
|---|---|
| `tran_hba_dip` | Pointer to the HBA device instance `dev_info` structure. The function `scsi_hba_attach_setup`(9F) sets this field. |
| `tran_hba_private` | Pointer to private data maintained by the HBA driver. Usually, `tran_hba_private` contains a pointer to the state structure of the HBA driver. |
| `tran_tgt_private` | Pointer to private data maintained by the HBA driver when using cloning. By specifying `SCSI_HBA_TRAN_CLONE` when calling `scsi_hba_attach_setup`(9F), the `scsi_hba_tran`(9S) |

| | |
|---|---|
| | structure is cloned once per target. This approach permits the HBA to initialize this field to point to a per-target instance data structure in the `tran_tgt_init`(9E) entry point. If `SCSI_HBA_TRAN_CLONE` is not specified, `tran_tgt_private` is NULL, and `tran_tgt_private` must not be referenced. See "Transport Structure Cloning" on page 312 for more information. |
| `tran_sd` | Pointer to a per-target instance `scsi_device`(9S) structure used when cloning. If `SCSI_HBA_TRAN_CLONE` is passed to `scsi_hba_attach_setup`(9F), `tran_sd` is initialized to point to the per-target `scsi_device` structure. This initialization takes place before any HBA functions are called on behalf of that target. If `SCSI_HBA_TRAN_CLONE` is not specified, `tran_sd` is NULL, and `tran_sd` must not be referenced. See "Transport Structure Cloning" on page 312 for more information. |
| `tran_tgt_init` | Pointer to the HBA driver entry point that is called when initializing a target device instance. If no per-target initialization is required, the HBA can leave `tran_tgt_init` set to NULL. |
| `tran_tgt_probe` | Pointer to the HBA driver entry point that is called when a target driver instance calls `scsi_probe`(9F). This routine is called to probe for the existence of a target device. If no target probing customization is required for this HBA, the HBA should set `tran_tgt_probe` to `scsi_hba_probe`(9F). |
| `tran_tgt_free` | Pointer to the HBA driver entry point that is called when a target device instance is destroyed. If no per-target deallocation is necessary, the HBA can leave `tran_tgt_free` set to NULL. |
| `tran_start` | Pointer to the HBA driver entry point that is called when a target driver calls `scsi_transport`(9F). |
| `tran_reset` | Pointer to the HBA driver entry point that is called when a target driver calls `scsi_reset`(9F). |
| `tran_abort` | Pointer to the HBA driver entry point that is called when a target driver calls `scsi_abort`(9F). |
| `tran_getcap` | Pointer to the HBA driver entry point that is called when a target driver calls `scsi_ifgetcap`(9F). |
| `tran_setcap` | Pointer to the HBA driver entry point that is called when a target driver calls `scsi_ifsetcap`(9F). |
| `tran_init_pkt` | Pointer to the HBA driver entry point that is called when a target driver calls `scsi_init_pkt`(9F). |

| | |
|---|---|
| `tran_destroy_pkt` | Pointer to the HBA driver entry point that is called when a target driver calls `scsi_destroy_pkt`(9F). |
| `tran_dmafree` | Pointer to the HBA driver entry point that is called when a target driver calls `scsi_dmafree`(9F). |
| `tran_sync_pkt` | Pointer to the HBA driver entry point that is called when a target driver calls `scsi_sync_pkt`(9F). |
| `tran_reset_notify` | Pointer to the HBA driver entry point that is called when a target driver calls `tran_reset_notify`(9E). |

## `scsi_address` Structure

The `scsi_address`(9S) structure provides transport and addressing information for each SCSI command that is allocated and transported by a target driver instance.

The `scsi_address` structure contains the following fields:

```
struct scsi_address {
    struct scsi_hba_tran    *a_hba_tran;    /* Transport vectors */
    ushort_t        a_target;       /* Target identifier */
    uchar_t         a_lun;      /* LUN on that target */
    uchar_t         a_sublun;       /* Sub LUN on that LUN */
                        /* Not used */
};
```

| | |
|---|---|
| `a_hba_tran` | Pointer to the `scsi_hba_tran`(9S) structure, as allocated and initialized by the HBA driver. If `SCSI_HBA_TRAN_CLONE` was specified as the flag to `scsi_hba_attach_setup`(9F), `a_hba_tran` points to a copy of that structure. |
| `a_target` | Identifies the SCSI target on the SCSI bus. |
| `a_lun` | Identifies the SCSI logical unit on the SCSI target. |

## `scsi_device` Structure

The HBA framework allocates and initializes a `scsi_device`(9S) structure for each instance of a target device. The allocation and initialization occur before the framework calls the HBA driver's `tran_tgt_init`(9E) entry point. This structure stores information about each SCSI logical unit, including pointers to information areas that contain both generic and device-specific information. One `scsi_device`(9S) structure exists for each target device instance that is attached to the system.

If the per-target initialization is successful, the HBA framework sets the target driver's per-instance private data to point to the `scsi_device`(9S) structure, using `ddi_set_driver_private`(9F). Note that an initialization is successful if `tran_tgt_init()` returns success or if the vector is NULL.

The `scsi_device`(9S) structure contains the following fields:

```
struct scsi_device {
    struct scsi_address      sd_address;    /* routing information */
    dev_info_t           *sd_dev;       /* device dev_info node */
    kmutex_t             sd_mutex;      /* mutex used by device */
    void             *sd_reserved;
    struct scsi_inquiry      *sd_inq;
    struct scsi_extended_sense   *sd_sense;
    caddr_t              sd_private;    /* for driver's use */
};
```

where:

`sd_address` Data structure that is passed to the routines for SCSI resource allocation.

`sd_dev` Pointer to the target's `dev_info` structure.

`sd_mutex` Mutex for use by the target driver. This mutex is initialized by the HBA framework. The mutex can be used by the target driver as a per-device mutex. This mutex should not be held across a call to `scsi_transport`(9F) or `scsi_poll`(9F). See Chapter 3 for more information on mutexes.

`sd_inq` Pointer for the target device's SCSI inquiry data. The `scsi_probe`(9F) routine allocates a buffer, fills the buffer in, and attaches the buffer to this field.

`sd_sense` Pointer to a buffer to contain request sense data from the device. The target driver must allocate and manage this buffer itself. See the target driver's `attach`(9E) routine in "`attach()` Entry Point" on page 99 for more information.

`sd_private` Pointer field for use by the target driver. This field is commonly used to store a pointer to a private target driver state structure.

## scsi_pkt Structure (HBA)

To execute SCSI commands, a target driver must first allocate a scsi_pkt(9S) structure for the command. The target driver must then specify its own private data area length, the command status, and the command length. The HBA driver is responsible for implementing the packet allocation in the tran_init_pkt(9E) entry point. The HBA driver is also responsible for freeing the packet in its tran_destroy_pkt(9E) entry point. See "scsi_pkt Structure (Target Drivers)" on page 281 for more information.

The scsi_pkt(9S) structure contains these fields:

```
struct scsi_pkt {
    opaque_t pkt_ha_private;          /* private data for host adapter */
    struct scsi_address pkt_address;      /* destination address */
    opaque_t pkt_private;         /* private data for target driver */
    void (*pkt_comp)(struct scsi_pkt *);  /* completion routine */
    uint_t  pkt_flags;            /* flags */
    int     pkt_time;             /* time allotted to complete command */
    uchar_t *pkt_scbp;            /* pointer to status block */
    uchar_t *pkt_cdbp;            /* pointer to command block */
    ssize_t pkt_resid;            /* data bytes not transferred */
    uint_t  pkt_state;            /* state of command */
    uint_t  pkt_statistics;           /* statistics */
    uchar_t pkt_reason;           /* reason completion called */
};
```

where:

| | |
|---|---|
| pkt_ha_private | Pointer to per-command HBA-driver private data. |
| pkt_address | Pointer to the scsi_address(9S) structure providing address information for this command. |
| pkt_private | Pointer to per-packet target-driver private data. |
| pkt_comp | Pointer to the target-driver completion routine called by the HBA driver when the transport layer has completed this command. |
| pkt_flags | Flags for the command. |
| pkt_time | Specifies the completion timeout in seconds for the command. |
| pkt_scbp | Pointer to the status completion block for the command. |
| pkt_cdbp | Pointer to the command descriptor block (CDB) for the command. |
| pkt_resid | Count of the data bytes that were *not* transferred when the command completed. This field may also be used to specify the amount of data for which resources have not been allocated. The HBA must modify this field during transport. |

| | |
|---|---|
| `pkt_state` | State of the command. The HBA must modify this field during transport. |
| `pkt_statistics` | Provides a history of the events that the command experienced while in the transport layer. The HBA must modify this field during transport. |
| `pkt_reason` | Reason for command completion. The HBA must modify this field during transport. |

## Per-Target Instance Data

An HBA driver must allocate a `scsi_hba_tran`(9S) structure during `attach`(9E). The HBA driver must then initialize the vectors in this transport structure to point to the required entry points for the HBA driver. This `scsi_hba_tran`(9S) structure is then passed into `scsi_hba_attach_setup`(9F).

The `scsi_hba_tran`(9S) structure contains a `tran_hba_private` field, which can be used to refer to the HBA driver's per-instance state.

Each `scsi_address`(9S) structure contains a pointer to the `scsi_hba_tran`(9S) structure. In addition, the `scsi_address` structure provides the target, that is, `a_target`, and logical unit (`a_lun`) addresses for the particular target device. Each entry point for the HBA driver is passed a pointer to the `scsi_address`(9S) structure, either directly or indirectly through the `scsi_device`(9S) structure. As a result, the HBA driver can reference its own state. The HBA driver can also identify the target device that is addressed.

The following figure illustrates the HBA data structures for transport operations.

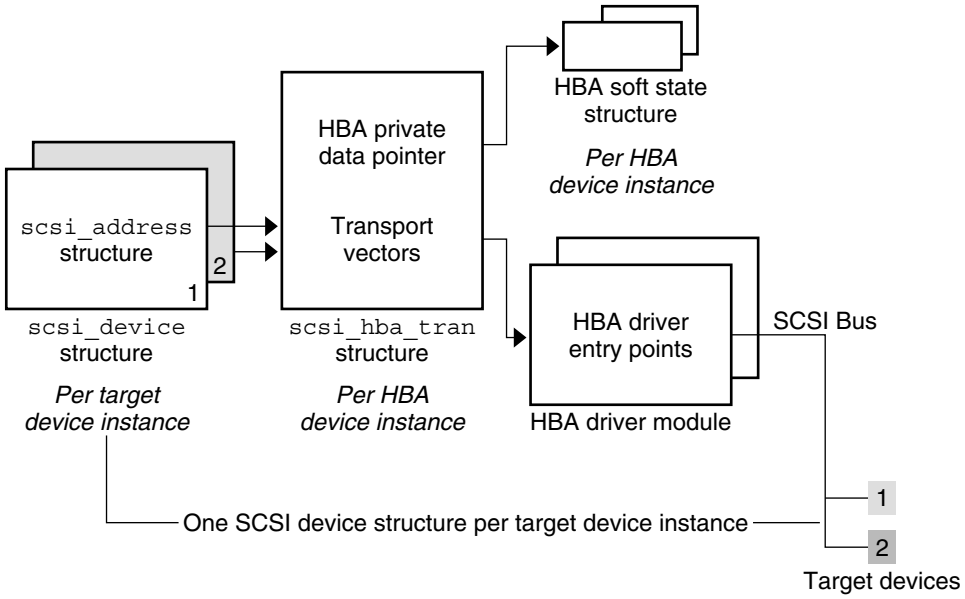



**FIGURE 17–3** HBA Transport Structures

# Transport Structure Cloning

Cloning can be useful if an HBA driver needs to maintain per-target private data in the `scsi_hba_tran`(9S) structure. Cloning can also be used to maintain a more complex address than is provided in the `scsi_address`(9S) structure.

In the cloning process, the HBA driver must still allocate a `scsi_hba_tran` structure at `attach`(9E) time. The HBA driver must also initialize the `tran_hba_private` soft state pointer and the entry point vectors for the HBA driver. The difference occurs when the framework begins to connect an instance of a target driver to the HBA driver. Before calling the HBA driver's `tran_tgt_init`(9E) entry point, the framework clones the `scsi_hba_tran` structure that is associated with that instance of the HBA. Accordingly, each `scsi_address`(9S) structure that is allocated and initialized for a particular target device instance points to a per-target instance *copy* of the `scsi_hba_tran` structure. The `scsi_address` structures do not point to the `scsi_hba_tran` structure that is allocated by the HBA driver at `attach`(9E) time.

An HBA driver can use two important pointers when cloning is specified. These pointers are contained in the `scsi_hba_tran` structure. The first pointer is the `tran_tgt_private` field, which the driver can use to point to per-target HBA private data. The `tran_tgt_private` pointer is useful, for example, if an HBA driver needs to maintain a more complex address than `a_target` and `a_lun` provide. The second pointer is the `tran_sd` field, which is a pointer to the `scsi_device`(9S) structure referring to the particular target device.

When specifying cloning, the HBA driver must allocate and initialize the per-target data. The HBA driver must then initialize the `tran_tgt_private` field to point to this data during its `tran_tgt_init`(9E) entry point. The HBA driver must free this per-target data during its `tran_tgt_free`(9E) entry point.

When cloning, the framework initializes the `tran_sd` field to point to the `scsi_device`(9S) structure before the HBA driver `tran_tgt_init`(9E) entry point is called. The driver requests cloning by passing the `SCSI_HBA_TRAN_CLONE` flag to `scsi_hba_attach_setup`(9F). The following figure illustrates the HBA data structures for cloning transport operations.

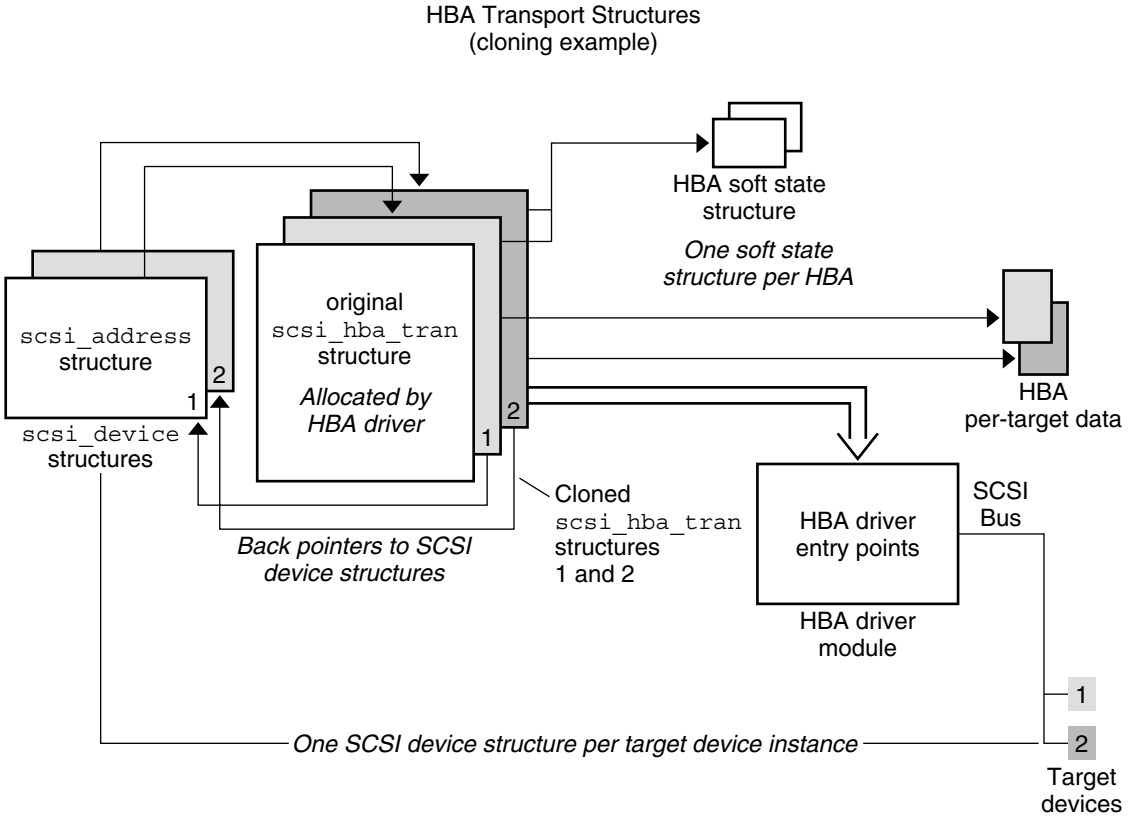



**FIGURE 17–4** Cloning Transport Operation

# SCSA HBA Functions

SCSA also provides a number of functions. The functions are listed in the following table, for use by HBA drivers.

**TABLE 17–2** SCSA HBA Functions

| Function Name | Called by Driver Entry Point |
|---|---|
| `scsi_hba_init`(9F) | `_init`(9E) |
| `scsi_hba_fini`(9F) | `_fini`(9E) |
| `scsi_hba_attach_setup`(9F) | `attach`(9E) |

**TABLE 17–2** SCSA HBA Functions *(Continued)*

| Function Name | Called by Driver Entry Point |
|---|---|
| `scsi_hba_detach`(9F) | `detach`(9E) |
| `scsi_hba_tran_alloc`(9F) | `attach`(9E) |
| `scsi_hba_tran_free`(9F) | `detach`(9E) |
| `scsi_hba_probe`(9F) | `tran_tgt_probe`(9E) |
| `scsi_hba_pkt_alloc`(9F) | `tran_init_pkt`(9E) |
| `scsi_hba_pkt_free`(9F) | `tran_destroy_pkt`(9E) |
| `scsi_hba_lookup_capstr`(9F) | `tran_getcap`(9E) and `tran_setcap`(9E) |

# HBA Driver Dependency and Configuration Issues

In addition to incorporating SCSA HBA entry points, structures, and functions into a driver, a developer must deal with driver dependency and configuration issues. These issues involve configuration properties, dependency declarations, state structure and per-command structure, entry points for module initialization, and autoconfiguration entry points.

## Declarations and Structures

HBA drivers must include the following header files:

```
#include <sys/scsi/scsi.h>
#include <sys/ddi.h>
#include <sys/sunddi.h>
```

To inform the system that the module depends on SCSA routines, the driver binary must be generated with the following command. See "SCSA HBA Interfaces" on page 304 for more information on SCSA routines.

```
% ld -r xx.o -o xx -N "misc/scsi"
```

The code samples are derived from a simplified `isp` driver for the QLogic Intelligent SCSI Peripheral device. The `isp` driver supports WIDE SCSI, with up to 15 target devices and 8 logical units (LUNs) per target.

## Per-Command Structure

An HBA driver usually needs to define a structure to maintain state for each command submitted by a target driver. The layout of this per-command structure is entirely up to the device driver writer. The layout needs to reflect the capabilities and features of the hardware and the software algorithms that are used in the driver.

The following structure is an example of a per-command structure. The remaining code fragments of this chapter use this structure to illustrate the HBA interfaces.

```
struct isp_cmd {
     struct isp_request        cmd_isp_request;
     struct isp_response       cmd_isp_response;
     struct scsi_pkt           *cmd_pkt;
     struct isp_cmd        *cmd_forw;
     uint32_t              cmd_dmacount;
     ddi_dma_handle_t          cmd_dmahandle;
     uint_t             cmd_cookie;
     uint_t             cmd_ncookies;
     uint_t             cmd_cookiecnt;
     uint_t             cmd_nwin;
     uint_t             cmd_curwin;
     off_t              cmd_dma_offset;
     uint_t             cmd_dma_len;
     ddi_dma_cookie_t          cmd_dmacookies[ISP_NDATASEGS];
     u_int              cmd_flags;
     u_short               cmd_slot;
     u_int              cmd_cdblen;
     u_int              cmd_scblen;
 };
```

# Entry Points for Module Initialization

This section describes the entry points for operations that are performed by SCSI HBA drivers.

The following code for a SCSI HBA driver illustrates a representative `dev_ops`(9S) structure. The driver must initialize the `devo_bus_ops` field in this structure to NULL. A SCSI HBA driver can provide leaf driver interfaces for special purposes, in which case the `devo_cb_ops` field might point to a `cb_ops`(9S) structure. In this example, no leaf driver interfaces are exported, so the `devo_cb_ops` field is initialized to NULL.

## `_init()` Entry Point (SCSI HBA Drivers)

The `_init`(9E) function initializes a loadable module. `_init()` is called before any other routine in the loadable module.

In a SCSI HBA, the `_init()` function must call `scsi_hba_init`(9F) to inform the framework of the existence of the HBA driver before calling `mod_install`(9F). If `scsi_hba__init()` returns a nonzero value,`_init()` should return this value. Otherwise, `_init()` must return the value returned by `mod_install`(9F).

The driver should initialize any required global state before calling `mod_install`(9F).

If `mod_install()` fails, the `_init()` function must free any global resources allocated. `_init()` must call `scsi_hba_fini`(9F) before returning.

The following example uses a global mutex to show how to allocate data that is global to all instances of a driver. The code declares global mutex and soft-state structure information. The global mutex and soft state are initialized during `_init()`.

## `_fini()` Entry Point (SCSI HBA Drivers)

The `_fini`(9E) function is called when the system is about to try to unload the SCSI HBA driver. The `_fini()` function must call `mod_remove`(9F) to determine whether the driver can be unloaded. If `mod_remove()` returns 0, the module can be unloaded. The HBA driver must deallocate any global resources allocated in `_init`(9E). The HBA driver must also call `scsi_hba_fini`(9F).

`_fini()` must return the value returned by `mod_remove()`.

---

**Note –** The HBA driver must not free any resources or call `scsi_hba_fini`(9F) unless `mod_remove`(9F) returns 0.

---

Example 17–1 shows module initialization for SCSI HBA.

**EXAMPLE 17–1** Module Initialization for SCSI HBA

```
static struct dev_ops isp_dev_ops = {
    DEVO_REV,       /* devo_rev */
    0,          /* refcnt  */
    isp_getinfo,    /* getinfo */
    nulldev,        /* probe */
    isp_attach,     /* attach */
    isp_detach,     /* detach */
    nodev,          /* reset */
    NULL,           /* driver operations */
    NULL,           /* bus operations */
    isp_power,      /* power management */
};

/*
 * Local static data
 */
static kmutex_t      isp_global_mutex;
```

**EXAMPLE 17–1** Module Initialization for SCSI HBA *(Continued)*

```
static void          *isp_state;

int
_init(void)
{
    int     err;

    if ((err = ddi_soft_state_init(&isp_state,
        sizeof (struct isp), 0)) != 0) {
        return (err);
    }
    if ((err = scsi_hba_init(&modlinkage)) == 0) {
        mutex_init(&isp_global_mutex, "isp global mutex",
        MUTEX_DRIVER, NULL);
        if ((err = mod_install(&modlinkage)) != 0) {
            mutex_destroy(&isp_global_mutex);
            scsi_hba_fini(&modlinkage);
            ddi_soft_state_fini(&isp_state);
        }
    }
    return (err);
}

int
_fini(void)
{
    int     err;

    if ((err = mod_remove(&modlinkage)) == 0) {
        mutex_destroy(&isp_global_mutex);
        scsi_hba_fini(&modlinkage);
        ddi_soft_state_fini(&isp_state);
    }
    return (err);
}
```

# Autoconfiguration Entry Points

Associated with each device driver is a `dev_ops`(9S) structure, which enables the kernel to locate the autoconfiguration entry points of the driver. A complete description of these autoconfiguration routines is given in Chapter 6. This section describes only those entry points associated with operations performed by SCSI HBA drivers. These entry points include `attach`(9E) and `detach`(9E).

## `attach()` Entry Point (SCSI HBA Drivers)

The `attach`(9E) entry point for a SCSI HBA driver performs several tasks when configuring and attaching an instance of the driver for the device. For a typical driver of real devices, the following operating system and hardware concerns must be addressed:

- Soft-state structure
- DMA
- Transport structure
- Attaching an HBA driver
- Register mapping
- Interrupt specification
- Interrupt handling
- Create power manageable components
- Report attachment status

### *Soft-State Structure*

When allocating the per-device-instance soft-state structure, a driver must clean up carefully if an error occurs.

### *DMA*

The HBA driver must describe the attributes of its DMA engine by properly initializing the `ddi_dma_attr_t` structure.

```
static ddi_dma_attr_t isp_dma_attr = {
     DMA_ATTR_V0,    /* ddi_dma_attr version */
     0,          /* low address */
     0xffffffff,     /* high address */
     0x00ffffff,     /* counter upper bound */
     1,          /* alignment requirements */
     0x3f,           /* burst sizes */
     1,          /* minimum DMA access */
     0xffffffff,     /* maximum DMA access */
     (1<<24)-1,      /* segment boundary restrictions */
     1,          /* scatter-gather list length */
     512,        /* device granularity */
     0           /* DMA flags */
};
```

The driver, if providing DMA, should also check that its hardware is installed in a DMA-capable slot:

```
    if (ddi_slaveonly(dip) == DDI_SUCCESS) {
         return (DDI_FAILURE);
     }
```

### *Transport Structure*

The driver should further allocate and initialize a transport structure for this instance. The `tran_hba_private`field is set to point to this instance's soft-state structure. `tran_tgt_probe` can be set to NULL to achieve the default behavior, if no special probe customization is needed.

```
tran = scsi_hba_tran_alloc(dip, SCSI_HBA_CANSLEEP);

 isp->isp_tran           = tran;
 isp->isp_dip            = dip;

 tran->tran_hba_private      = isp;
 tran->tran_tgt_private      = NULL;
 tran->tran_tgt_init         = isp_tran_tgt_init;
 tran->tran_tgt_probe        = scsi_hba_probe;
 tran->tran_tgt_free         = (void (*)())NULL;

 tran->tran_start        = isp_scsi_start;
 tran->tran_abort        = isp_scsi_abort;
 tran->tran_reset        = isp_scsi_reset;
 tran->tran_getcap           = isp_scsi_getcap;
 tran->tran_setcap           = isp_scsi_setcap;
 tran->tran_init_pkt         = isp_scsi_init_pkt;
 tran->tran_destroy_pkt      = isp_scsi_destroy_pkt;
 tran->tran_dmafree          = isp_scsi_dmafree;
 tran->tran_sync_pkt         = isp_scsi_sync_pkt;
 tran->tran_reset_notify     = isp_scsi_reset_notify;
 tran->tran_bus_quiesce      = isp_tran_bus_quiesce
 tran->tran_bus_unquiesce    = isp_tran_bus_unquiesce
 tran->tran_bus_reset        = isp_tran_bus_reset
```

## *Attaching an HBA Driver*

The driver should attach this instance of the device, and perform error cleanup if necessary.

```
i = scsi_hba_attach_setup(dip, &isp_dma_attr, tran, 0);
if (i != DDI_SUCCESS) {
     do error recovery
    return (DDI_FAILURE);
 }
```

## *Register Mapping*

The driver should map in its device's registers. The driver need to specify the following items:

- Register set index
- Data access characteristics of the device
- Size of the register to be mapped

```
ddi_device_acc_attr_t            dev_attributes;

 dev_attributes.devacc_attr_version = DDI_DEVICE_ATTR_V0;
 dev_attributes.devacc_attr_dataorder = DDI_STRICTORDER_ACC;
 dev_attributes.devacc_attr_endian_flags = DDI_STRUCTURE_LE_ACC;

 if (ddi_regs_map_setup(dip, 0, (caddr_t *)&isp->isp_reg,
```

```
0, sizeof (struct ispregs), &dev_attributes,
&isp->isp_acc_handle) != DDI_SUCCESS) {
    do error recovery
   return (DDI_FAILURE);
}
```

## *Adding an Interrupt Handler*

The driver must first obtain the *iblock cookie* to initialize any mutexes that are used in the driver handler. Only after those mutexes have been initialized can the interrupt handler be added.

```
i = ddi_get_iblock_cookie(dip, 0, &isp->iblock_cookie};
 if (i != DDI_SUCCESS) {
     do error recovery
    return (DDI_FAILURE);
 }

 mutex_init(&isp->mutex, "isp_mutex", MUTEX_DRIVER,
 (void *)isp->iblock_cookie);
 i = ddi_add_intr(dip, 0, &isp->iblock_cookie,
 0, isp_intr, (caddr_t)isp);
 if (i != DDI_SUCCESS) {
     do error recovery
    return (DDI_FAILURE);
 }
```

If a high-level handler is required, the driver should be coded to provide such a handler. Otherwise, the driver must be able to fail the attach. See "Handling High-Level Interrupts" on page 125 for a description of high-level interrupt handling.

## *Create Power Manageable Components*

With power management, if the host bus adapter only needs to power down when all target adapters are at power level 0, the HBA driver only needs to provide a `power`(9E) entry point. Refer to Chapter 12. The HBA driver also needs to create a `pm-components`(9P) property that describes the components that the device implements.

Nothing more is necessary, since the components will default to idle, and the power management framework's default dependency processing will ensure that the host bus adapter will be powered up whenever an target adapter is powered up. Provided that automatic power management is enabled automatically, the processing will also power down the host bus adapter when all target adapters are powered down ().

## *Report Attachment Status*

Finally, the driver should report that this instance of the device is attached and return success.

```
ddi_report_dev(dip);
 return (DDI_SUCCESS);
```

### `detach()` Entry Point (SCSI HBA Drivers)

The driver should perform standard detach operations, including calling `scsi_hba_detach`(9F).

## Entry Points for SCSA HBA Drivers

An HBA driver can work with target drivers through the SCSA interface. The SCSA interfaces require the HBA driver to supply a number of entry points that are callable through the `scsi_hba_tran`(9S) structure.

These entry points fall into five functional groups:

- Target driver instance initialization
- Resource allocation and deallocation
- Command transport
- Capability management
- Abort and reset handling
- Dynamic reconfiguration

The following table lists the entry points for SCSA HBA by function groups.

**TABLE 17–3** SCSA Entry Points

| Function Groups | Entry Points Within Group | Description |
|---|---|---|
| Target Driver Instance Initialization | `tran_tgt_init`(9E) | Performs per-target initialization (optional) |
| | `tran_tgt_probe`(9E) | Probes SCSI bus for existence of a target (optional) |
| | `tran_tgt_free`(9E) | Performs per-target deallocation (optional) |
| Resource Allocation | `tran_init_pkt`(9E) | Allocates SCSI packet and DMA resources |
| | `tran_destroy_pkt`(9E) | Frees SCSI packet and DMA resources |

**TABLE 17–3** SCSA Entry Points *(Continued)*

| Function Groups | Entry Points Within Group | Description |
|---|---|---|
| | `tran_sync_pkt`(9E) | Synchronizes memory before and after DMA |
| | `tran_dmafree`(9E) | Frees DMA resources |
| Command Transport | `tran_start`(9E) | Transports a SCSI command |
| Capability Management | `tran_getcap`(9E) | Inquires about a capability's value |
| | `tran_setcap`(9E) | Sets a capability's value |
| Abort and Reset | `tran_abort`(9E) | Aborts outstanding SCSI commands |
| | `tran_reset`(9E) | Resets a target device or the SCSI bus |
| | `tran_bus_reset`(9e) | Resets the SCSI bus |
| | `tran_reset_notify`(9E) | Request to notify target of bus reset (optional) |
| Dynamic Reconfiguration | `tran_quiesce`(9e) | Stops activity on the bus |
| | `tran_unquiesce`(9e) | Resumes activity on the bus |

# Target Driver Instance Initialization

The following sections describe target entry points.

## `tran_tgt_init()` Entry Point

The `tran_tgt_init`(9E) entry point enables the HBA to allocate and initialize any per-target resources. `tran_tgt_init()` also enables the HBA to qualify the device's address as valid and supportable for that particular HBA. By returning `DDI_FAILURE`, the instance of the target driver for that device is not probed or attached.

`tran_tgt_init()` is not required. If `tran_tgt_init()` is not supplied, the framework attempts to probe and attach all possible instances of the appropriate target drivers.

```
static int
isp_tran_tgt_init(
     dev_info_t         *hba_dip,
     dev_info_t         *tgt_dip,
     scsi_hba_tran_t        *tran,
     struct scsi_device     *sd)
 {
     return ((sd->sd_address.a_target < N_ISP_TARGETS_WIDE &&
```

```
        sd->sd_address.a_lun < 8) ? DDI_SUCCESS : DDI_FAILURE);
}
```

## tran_tgt_probe() Entry Point

The tran_tgt_probe(9E) entry point enables the HBA to customize the operation of scsi_probe(9F), if necessary. This entry point is called only when the target driver calls scsi_probe().

The HBA driver can retain the normal operation of scsi_probe() by calling scsi_hba_probe(9F) and returning its return value.

This entry point is not required, and if not needed, the HBA driver should set the tran_tgt_probe vector in the scsi_hba_tran(9S) structure to point to scsi_hba_probe().

scsi_probe() allocates a scsi_inquiry(9S) structure and sets the sd_inq field of the scsi_device(9S) structure to point to the data in scsi_inquiry. scsi_hba_probe() handles this task automatically. scsi_unprobe(9F) then frees the scsi_inquiry data.

Except for the allocation of scsi_inquiry data, tran_tgt_probe() must be stateless, because the same SCSI device might call tran_tgt_probe() several times. Normally, allocation of scsi_inquiry data is handled by scsi_hba_probe().

---

**Note –** The allocation of the scsi_inquiry(9S) structure is handled automatically by scsi_hba_probe(). This information is only of concern if you want custom scsi_probe() handling.

---

```
static int
 isp_tran_tgt_probe(
     struct scsi_device    *sd,
     int         (*callback)())
 {
         Perform any special probe customization needed.       /*
      * Normal probe handling
      */
     return (scsi_hba_probe(sd, callback));
 }
```

## tran_tgt_free() Entry Point

The tran_tgt_free(9E) entry point enables the HBA to perform any deallocation or clean-up procedures for an instance of a target. This entry point is optional.

```
static void
isp_tran_tgt_free(
     dev_info_t          *hba_dip,
```

```
    dev_info_t          *tgt_dip,
    scsi_hba_tran_t         *hba_tran,
    struct scsi_device      *sd)
{
        Undo any special per-target initialization done
        earlier in tran_tgt_init(9F) and tran_tgt_probe(9F)
}
```

# Resource Allocation

The following sections discuss resource allocation.

## `tran_init_pkt()` Entry Point

The `tran_init_pkt`(9E) entry point allocates and initializes a `scsi_pkt`(9S) structure and DMA resources for a target driver request.

The `tran_init_pkt`(9E) entry point is called when the target driver calls the SCSA function `scsi_init_pkt`(9F).

Each call of the `tran_init_pkt`(9E) entry point is a request to perform one or more of three possible services:

- Allocation and initialization of a `scsi_pkt`(9S) structure
- Allocation of DMA resources for data transfer
- Reallocation of DMA resources for the next portion of the data transfer

## Allocation and Initialization of a `scsi_pkt`(9S) Structure

The `tran_init_pkt`(9E) entry point must allocate a `scsi_pkt`(9S) structure if `pkt` is NULL through `scsi_hba_pkt_alloc`(9F).

`scsi_hba_pkt_alloc`(9F) allocates space for the following items:

- `scsi_pkt`(9S)
- SCSI CDB of length `cmdlen`
- Completion area for SCSI status of length `statuslen`
- Per-packet target driver private data area of length `tgtlen`
- Per-packet HBA driver private data area of length `hbalen`

The `scsi_pkt`(9S) structure members, including `pkt`, must be initialized to zero except for the following members:

- `pkt_scbp` – Status completion
- `pkt_cdbp` – CDB
- `pkt_ha_private` – HBA driver private data
- `pkt_private` – Target driver private data

These members are pointers to memory space where the values of the fields are stored, as shown in the following figure. For more information, refer to "scsi_pkt Structure (HBA)" on page 310.

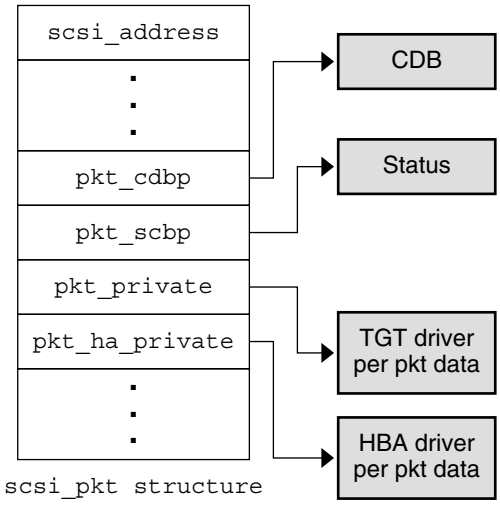



**FIGURE 17–5** scsi_pkt(9S) Structure Pointers

The following example shows allocation and initialization of a scsi_pkt structure.

**EXAMPLE 17–2** HBA Driver Initialization of a SCSI Packet Structure

```
static struct scsi_pkt                  *
isp_scsi_init_pkt(
    struct scsi_address    *ap,
    struct scsi_pkt        *pkt,
    struct buf         *bp,
    int            cmdlen,
    int            statuslen,
    int            tgtlen,
    int            flags,
    int            (*callback)(),
    caddr_t            arg)
{
    struct isp_cmd         *sp;
    struct isp         *isp;
    struct scsi_pkt        *new_pkt;

    ASSERT(callback == NULL_FUNC || callback == SLEEP_FUNC);

    isp = (struct isp *)ap->a_hba_tran->tran_hba_private;

    /*
     * First step of isp_scsi_init_pkt:  pkt allocation
     */
    if (pkt == NULL) {
```

**EXAMPLE 17–2** HBA Driver Initialization of a SCSI Packet Structure *(Continued)*

```
    pkt = scsi_hba_pkt_alloc(isp->isp_dip, ap, cmdlen,
     statuslen, tgtlen, sizeof (struct isp_cmd),
     callback, arg);
    if (pkt == NULL) {
     return (NULL);
    }

    sp = (struct isp_cmd *)pkt->pkt_ha_private;

    /*
     * Initialize the new pkt
     */
    sp->cmd_pkt         = pkt;
    sp->cmd_flags       = 0;
    sp->cmd_scblen      = statuslen;
    sp->cmd_cdblen      = cmdlen;
    sp->cmd_dmahandle       = NULL;
    sp->cmd_ncookies    = 0;
    sp->cmd_cookie      = 0;
    sp->cmd_cookiecnt       = 0;
    sp->cmd_nwin        = 0;
    pkt->pkt_address    = *ap;
    pkt->pkt_comp       = (void (*)())NULL;
    pkt->pkt_flags      = 0;
    pkt->pkt_time       = 0;
    pkt->pkt_resid      = 0;
    pkt->pkt_statistics     = 0;
    pkt->pkt_reason     = 0;

    new_pkt = pkt;
} else {
    sp = (struct isp_cmd *)pkt->pkt_ha_private;
    new_pkt = NULL;
}

/*
 * Second step of isp_scsi_init_pkt:  dma allocation/move
 */
if (bp && bp->b_bcount != 0) {
    if (sp->cmd_dmahandle == NULL) {
        if (isp_i_dma_alloc(isp, pkt, bp,
        flags, callback) == 0) {
        if (new_pkt) {
            scsi_hba_pkt_free(ap, new_pkt);
        }
        return ((struct scsi_pkt *)NULL);
     }
    } else {
        ASSERT(new_pkt == NULL);
        if (isp_i_dma_move(isp, pkt, bp) == 0) {
        return ((struct scsi_pkt *)NULL);
        }
    }
```

**EXAMPLE 17–2** HBA Driver Initialization of a SCSI Packet Structure *(Continued)*

```
    }

    return (pkt);
}
```

## Allocation of DMA Resources

The `tran_init_pkt`(9E) entry point must allocate DMA resources for a data transfer if the following conditions are true:

- `bp` is not NULL.
- `bp->b_bcount` is not zero.
- DMA resources have not yet been allocated for this `scsi_pkt`(9S).

The HBA driver needs to track how DMA resources are allocated for a particular command. This allocation may take place with a flag bit or a DMA handle in the per-packet HBA driver private data.

The `PKT_DMA_PARTIAL` flag in the `pkt` enables the target driver to break up a data transfer into multiple SCSI commands to accommodate the complete request. This approach is useful when the HBA hardware scatter-gather capabilities or system DMA resources cannot complete a request in a single SCSI command.

The `PKT_DMA_PARTIAL` flag enables the HBA driver to set the `DDI_DMA_PARTIAL` flag. The `DDI_DMA_PARTIAL` flag is useful when the DMA resources for this SCSI command are allocated. For example the `ddi_dma_buf_bind_handle`(9F)) command can be used to allocate DMA resources. The DMA attributes used when allocating the DMA resources should accurately describe any constraints placed on the ability of the HBA hardware to perform DMA. If the system can only allocate DMA resources for part of the request, `ddi_dma_buf_bind_handle`(9F) returns `DDI_DMA_PARTIAL_MAP`.

The `tran_init_pkt`(9E) entry point must return the amount of DMA resources not allocated for this transfer in the field `pkt_resid`.

A target driver can make one request to `tran_init_pkt`(9E) to simultaneously allocate both a `scsi_pkt`(9S) structure and DMA resources for that `pkt`. In this case, if the HBA driver is unable to allocate DMA resources, that driver must free the allocated `scsi_pkt`(9S) before returning. The `scsi_pkt`(9S) must be freed by calling `scsi_hba_pkt_free`(9F).

The target driver might first allocate the `scsi_pkt`(9S) and allocate DMA resources for this `pkt` at a later time. In this case, if the HBA driver is unable to allocate DMA resources, the driver must *not* free `pkt`. The target driver in this case is responsible for freeing the `pkt`.

**EXAMPLE 17–3** HBA Driver Allocation of DMA Resources

```
static int
isp_i_dma_alloc(
    struct isp     *isp,
    struct scsi_pkt    *pkt,
    struct buf     *bp,
    int        flags,
    int        (*callback)())
{
    struct isp_cmd    *sp  = (struct isp_cmd *)pkt->pkt_ha_private;
    int        dma_flags;
    ddi_dma_attr_t     tmp_dma_attr;
    int        (*cb)(caddr_t);
    int        i;

    ASSERT(callback == NULL_FUNC || callback == SLEEP_FUNC);

    if (bp->b_flags & B_READ) {
       sp->cmd_flags &= ~CFLAG_DMASEND;
       dma_flags = DDI_DMA_READ;
    } else {
       sp->cmd_flags |= CFLAG_DMASEND;
       dma_flags = DDI_DMA_WRITE;
    }
    if (flags & PKT_CONSISTENT) {
       sp->cmd_flags |= CFLAG_CMDIOPB;
       dma_flags |= DDI_DMA_CONSISTENT;
    }
    if (flags & PKT_DMA_PARTIAL) {
       dma_flags |= DDI_DMA_PARTIAL;
    }

    tmp_dma_attr = isp_dma_attr;
    tmp_dma_attr.dma_attr_burstsizes = isp->isp_burst_size;

    cb = (callback == NULL_FUNC) ? DDI_DMA_DONTWAIT :
DDI_DMA_SLEEP;

    if ((i = ddi_dma_alloc_handle(isp->isp_dip, &tmp_dma_attr,
      cb, 0, &sp->cmd_dmahandle)) != DDI_SUCCESS) {

    switch (i) {
    case DDI_DMA_BADATTR:
        bioerror(bp, EFAULT);
        return (0);

    case DDI_DMA_NORESOURCES:
        bioerror(bp, 0);
        return (0);
    }
    }

    i = ddi_dma_buf_bind_handle(sp->cmd_dmahandle, bp, dma_flags,
    cb, 0, &sp->cmd_dmacookies[0], &sp->cmd_ncookies);
```

**EXAMPLE 17–3** HBA Driver Allocation of DMA Resources *(Continued)*

```
    switch (i) {
    case DDI_DMA_PARTIAL_MAP:
    if (ddi_dma_numwin(sp->cmd_dmahandle, &sp->cmd_nwin) ==
            DDI_FAILURE) {
        cmn_err(CE_PANIC, "ddi_dma_numwin() failed\n");
    }

    if (ddi_dma_getwin(sp->cmd_dmahandle, sp->cmd_curwin,
        &sp->cmd_dma_offset, &sp->cmd_dma_len,
        &sp->cmd_dmacookies[0], &sp->cmd_ncookies) ==
           DDI_FAILURE) {
        cmn_err(CE_PANIC, "ddi_dma_getwin() failed\n");
    }
    goto get_dma_cookies;

    case DDI_DMA_MAPPED:
    sp->cmd_nwin = 1;
    sp->cmd_dma_len = 0;
    sp->cmd_dma_offset = 0;

get_dma_cookies:
    i = 0;
    sp->cmd_dmacount = 0;
    for (;;) {
        sp->cmd_dmacount += sp->cmd_dmacookies[i++].dmac_size;

        if (i == ISP_NDATASEGS || i == sp->cmd_ncookies)
        break;
        ddi_dma_nextcookie(sp->cmd_dmahandle,
        &sp->cmd_dmacookies[i]);
    }
    sp->cmd_cookie = i;
    sp->cmd_cookiecnt = i;

    sp->cmd_flags |= CFLAG_DMAVALID;
    pkt->pkt_resid = bp->b_bcount - sp->cmd_dmacount;
    return (1);

    case DDI_DMA_NORESOURCES:
    bioerror(bp, 0);
    break;

    case DDI_DMA_NOMAPPING:
    bioerror(bp, EFAULT);
    break;

    case DDI_DMA_TOOBIG:
    bioerror(bp, EINVAL);
    break;

    case DDI_DMA_INUSE:
    cmn_err(CE_PANIC, "ddi_dma_buf_bind_handle:"
```

**EXAMPLE 17–3** HBA Driver Allocation of DMA Resources *(Continued)*

```
        " DDI_DMA_INUSE impossible\n");

    default:
    cmn_err(CE_PANIC, "ddi_dma_buf_bind_handle:"
        " 0x%x impossible\n", i);
    }

    ddi_dma_free_handle(&sp->cmd_dmahandle);
    sp->cmd_dmahandle = NULL;
    sp->cmd_flags &= ~CFLAG_DMAVALID;
    return (0);
}
```

## Reallocation of DMA Resources for Data Transfer

For a previously allocated packet with data remaining to be transferred, the `tran_init_pkt`(9E) entry point must reallocate DMA resources when the following conditions apply:

- Partial DMA resources have already been allocated.
- A non-zero `pkt_resid` was returned in the previous call to `tran_init_pkt`(9E).
- `bp` is not NULL.
- `bp->b_bcount` is not zero.

When reallocating DMA resources to the next portion of the transfer, `tran_init_pkt`(9E) must return the amount of DMA resources not allocated for this transfer in the field `pkt_resid`.

If an error occurs while attempting to move DMA resources, `tran_init_pkt`(9E) must not free the `scsi_pkt`(9S). The target driver in this case is responsible for freeing the packet.

If the callback parameter is `NULL_FUNC`, the `tran_init_pkt`(9E) entry point must not sleep or call any function that might sleep. If the callback parameter is `SLEEP_FUNC` and resources are not immediately available, the `tran_init_pkt`(9E) entry point should sleep. Unless the request is impossible to satisfy, `tran_init_pkt()` should sleep until resources become available.

**EXAMPLE 17–4** DMA Resource Reallocation for HBA Drivers

```
static int
isp_i_dma_move(
    struct isp        *isp,
    struct scsi_pkt       *pkt,
    struct buf        *bp)
{
    struct isp_cmd    *sp  = (struct isp_cmd *)pkt->pkt_ha_private;
    int    i;
```

**EXAMPLE 17–4** DMA Resource Reallocation for HBA Drivers *(Continued)*

```
    ASSERT(sp->cmd_flags & CFLAG_COMPLETED);
    sp->cmd_flags &= ~CFLAG_COMPLETED;

    /*
     * If there are no more cookies remaining in this window,
     * must move to the next window first.
     */
    if (sp->cmd_cookie == sp->cmd_ncookies) {
    /*
     * For small pkts, leave things where they are
     */
    if (sp->cmd_curwin == sp->cmd_nwin && sp->cmd_nwin == 1)
        return (1);

    /*
     * At last window, cannot move
     */
    if (++sp->cmd_curwin >= sp->cmd_nwin)
        return (0);

    if (ddi_dma_getwin(sp->cmd_dmahandle, sp->cmd_curwin,
        &sp->cmd_dma_offset, &sp->cmd_dma_len,
        &sp->cmd_dmacookies[0], &sp->cmd_ncookies) ==
        DDI_FAILURE)
        return (0);

    sp->cmd_cookie = 0;
    } else {
    /*
     * Still more cookies in this window - get the next one
     */
    ddi_dma_nextcookie(sp->cmd_dmahandle,
        &sp->cmd_dmacookies[0]);
    }

    /*
     * Get remaining cookies in this window, up to our maximum
     */
    i = 0;
    for (;;) {
    sp->cmd_dmacount += sp->cmd_dmacookies[i++].dmac_size;
    sp->cmd_cookie++;
    if (i == ISP_NDATASEGS ||
        sp->cmd_cookie == sp->cmd_ncookies)
        break;
    ddi_dma_nextcookie(sp->cmd_dmahandle,
        &sp->cmd_dmacookies[i]);
    }
    sp->cmd_cookiecnt = i;

    pkt->pkt_resid = bp->b_bcount - sp->cmd_dmacount;
    return (1);
}
```

## tran_destroy_pkt() Entry Point

The tran_destroy_pkt(9E) entry point is the HBA driver function that deallocates scsi_pkt(9S) structures. The tran_destroy_pkt() entry point is called when the target driver calls scsi_destroy_pkt(9F).

The tran_destroy_pkt() entry point must free any DMA resources that have been allocated for the packet. An implicit DMA synchronization occurs if the DMA resources are freed and any cached data remains after the completion of the transfer. The tran_destroy_pkt() entry point frees the SCSI packet by calling scsi_hba_pkt_free(9F).

**EXAMPLE 17–5** HBA Driver tran_destroy_pkt(9E) Entry Point

```
static void
isp_scsi_destroy_pkt(
    struct scsi_address    *ap,
    struct scsi_pkt    *pkt)
{
    struct isp_cmd *sp = (struct isp_cmd *)pkt->pkt_ha_private;

    /*
     * Free the DMA, if any
     */
    if (sp->cmd_flags & CFLAG_DMAVALID) {
    sp->cmd_flags &= ~CFLAG_DMAVALID;
    (void) ddi_dma_unbind_handle(sp->cmd_dmahandle);
    ddi_dma_free_handle(&sp->cmd_dmahandle);
    sp->cmd_dmahandle = NULL;
    }
    /*
     * Free the pkt
     */
    scsi_hba_pkt_free(ap, pkt);
}
```

## tran_sync_pkt() Entry Point

The tran_sync_pkt(9E) entry point synchronizes the DMA object allocated for the scsi_pkt(9S) structure before or after a DMA transfer. The tran_sync_pkt() entry point is called when the target driver calls scsi_sync_pkt(9F).

If the data transfer direction is a DMA read from device to memory, tran_sync_pkt() must synchronize the CPU's view of the data. If the data transfer direction is a DMA write from memory to device, tran_sync_pkt() must synchronize the device's view of the data.

**EXAMPLE 17–6** HBA Driver tran_sync_pkt(9E) Entry Point

```
static void
isp_scsi_sync_pkt(
    struct scsi_address    *ap,
```

**EXAMPLE 17–6** HBA Driver `tran_sync_pkt`(9E) Entry Point *(Continued)*

```
    struct scsi_pkt    *pkt)
{
    struct isp_cmd *sp = (struct isp_cmd *)pkt->pkt_ha_private;

    if (sp->cmd_flags & CFLAG_DMAVALID) {
       (void)ddi_dma_sync(sp->cmd_dmahandle, sp->cmd_dma_offset,
        sp->cmd_dma_len,
        (sp->cmd_flags & CFLAG_DMASEND) ?
        DDI_DMA_SYNC_FORDEV : DDI_DMA_SYNC_FORCPU);
    }
    }
}
```

## `tran_dmafree()` Entry Point

The `tran_dmafree`(9E) entry point deallocates DMA resources that have been allocated for a `scsi_pkt`(9S) structure. The `tran_dmafree()` entry point is called when the target driver calls `scsi_dmafree`(9F).

`tran_dmafree()` must free only DMA resources allocated for a `scsi_pkt`(9S) structure, not the `scsi_pkt`(9S) itself. When DMA resources are freed, a DMA synchronization is implicitly performed.

---

**Note –** The `scsi_pkt`(9S) is freed in a separate request to `tran_destroy_pkt`(9E). Because `tran_destroy_pkt()` must also free DMA resources, the HBA driver must keep accurate note of whether `scsi_pkt()` structures have DMA resources allocated.

---

**EXAMPLE 17–7** HBA Driver `tran_dmafree`(9E) Entry Point

```
static void
isp_scsi_dmafree(
    struct scsi_address    *ap,
    struct scsi_pkt    *pkt)
{
    struct isp_cmd     *sp = (struct isp_cmd *)pkt->pkt_ha_private;

    if (sp->cmd_flags & CFLAG_DMAVALID) {
       sp->cmd_flags &= ~CFLAG_DMAVALID;
       (void)ddi_dma_unbind_handle(sp->cmd_dmahandle);
       ddi_dma_free_handle(&sp->cmd_dmahandle);
       sp->cmd_dmahandle = NULL;
    }
}
```

# Command Transport

An HBA driver goes through the following steps as part of command transport:

1. Accept a command from the target driver.
2. Issue the command to the device hardware.
3. Service any interrupts that occur.
4. Manage time outs.

## `tran_start()` Entry Point

The `tran_start`(9E) entry point for a SCSI HBA driver is called to transport a SCSI command to the addressed target. The SCSI command is described entirely within the `scsi_pkt`(9S) structure, which the target driver allocated through the HBA driver's `tran_init_pkt`(9E) entry point. If the command involves a data transfer, DMA resources must also have been allocated for the `scsi_pkt`(9S) structure.

The `tran_start()` entry point is called when a target driver calls `scsi_transport`(9F).

`tran_start()` should perform basic error checking along with any initialization that is required by the command. The `FLAG_NOINTR` flag in the `pkt_flags` field of the `scsi_pkt`(9S) structure can affect the behavior of `tran_start()`. If `FLAG_NOINTR` is not set, `tran_start()` must queue the command for execution on the hardware and return immediately. Upon completion of the command, the HBA driver should call the `pkt()` completion routine.

If the `FLAG_NOINTR` is set, then the HBA driver should not call the `pkt()` completion routine.

The following example demonstrates how to handle the `tran_start`(9E) entry point. The ISP hardware provides a queue per-target device. For devices that can manage only one active outstanding command, the driver is typically required to manage a per-target queue. The driver then starts up a new command upon completion of the current command in a round-robin fashion.

**EXAMPLE 17–8** HBA Driver `tran_start`(9E) Entry Point

```
static int
isp_scsi_start(
    struct scsi_address    *ap,
    struct scsi_pkt        *pkt)
{
    struct isp_cmd         *sp;
    struct isp         *isp;
    struct isp_request     *req;
    u_long             cur_lbolt;
    int            xfercount;
    int            rval    = TRAN_ACCEPT;
    int            i;
```

**EXAMPLE 17–8** HBA Driver `tran_start`(9E) Entry Point *(Continued)*

```
sp = (struct isp_cmd *)pkt->pkt_ha_private;
isp = (struct isp *)ap->a_hba_tran->tran_hba_private;

sp->cmd_flags = (sp->cmd_flags & ~CFLAG_TRANFLAG) |
            CFLAG_IN_TRANSPORT;
pkt->pkt_reason = CMD_CMPLT;

/*
 * set up request in cmd_isp_request area so it is ready to
 * go once we have the request mutex
 */
req = &sp->cmd_isp_request;

req->req_header.cq_entry_type = CQ_TYPE_REQUEST;
req->req_header.cq_entry_count = 1;
req->req_header.cq_flags        = 0;
req->req_header.cq_seqno = 0;
req->req_reserved = 0;
req->req_token = (opaque_t)sp;
req->req_target = TGT(sp);
req->req_lun_trn = LUN(sp);
req->req_time = pkt->pkt_time;
ISP_SET_PKT_FLAGS(pkt->pkt_flags, req->req_flags);

/*
 * Set up data segments for dma transfers.
 */
if (sp->cmd_flags & CFLAG_DMAVALID) {

if (sp->cmd_flags & CFLAG_CMDIOPB) {
    (void) ddi_dma_sync(sp->cmd_dmahandle,
    sp->cmd_dma_offset, sp->cmd_dma_len,
    DDI_DMA_SYNC_FORDEV);
}

ASSERT(sp->cmd_cookiecnt > 0 &&
    sp->cmd_cookiecnt <= ISP_NDATASEGS);

xfercount = 0;
req->req_seg_count = sp->cmd_cookiecnt;
for (i = 0; i < sp->cmd_cookiecnt; i++) {
    req->req_dataseg[i].d_count =
    sp->cmd_dmacookies[i].dmac_size;
    req->req_dataseg[i].d_base =
    sp->cmd_dmacookies[i].dmac_address;
    xfercount +=
    sp->cmd_dmacookies[i].dmac_size;
}

for (; i < ISP_NDATASEGS; i++) {
    req->req_dataseg[i].d_count = 0;
    req->req_dataseg[i].d_base = 0;
```

**EXAMPLE 17–8** HBA Driver `tran_start`(9E) Entry Point *(Continued)*

```
    }

    pkt->pkt_resid = xfercount;

    if (sp->cmd_flags & CFLAG_DMASEND) {
        req->req_flags |= ISP_REQ_FLAG_DATA_WRITE;
    } else {
        req->req_flags |= ISP_REQ_FLAG_DATA_READ;
    }
    } else {
    req->req_seg_count = 0;
    req->req_dataseg[0].d_count = 0;
    }

    /*
     * Set up cdb in the request
     */
    req->req_cdblen = sp->cmd_cdblen;
    bcopy((caddr_t)pkt->pkt_cdbp, (caddr_t)req->req_cdb,
    sp->cmd_cdblen);

    /*
     * Start the cmd.  If NO_INTR, must poll for cmd completion.
     */
    if ((pkt->pkt_flags & FLAG_NOINTR) == 0) {
    mutex_enter(ISP_REQ_MUTEX(isp));
    rval = isp_i_start_cmd(isp, sp);
    mutex_exit(ISP_REQ_MUTEX(isp));
    } else {
    rval = isp_i_polled_cmd_start(isp, sp);
    }

    return (rval);
}
```

## Interrupt Handler and Command Completion

The interrupt handler must check the status of the device to be sure the device is generating the interrupt in question. The interrupt handler must also check for any errors that have occurred and service any interrupts generated by the device.

If data is transferred, the hardware should be checked to determine how much data was actually transferred. The `pkt_resid` field in the `scsi_pkt`(9S) structure should be set to the residual of the transfer.

Commands that are marked with the `PKT_CONSISTENT` flag when DMA resources are allocated through `tran_init_pkt`(9E) take special handling. The HBA driver must ensure that the data transfer for the command is correctly synchronized before the target driver's command completion callback is performed.

Once a command has completed, you need to act on two requirements:

- If a new command is queued up, start the command on the hardware as quickly as possible.
- Call the command completion callback. The callback has been set up in the `scsi_pkt`(9S) structure by the target driver to notify the target driver when the command is complete.

Start a new command on the hardware, if possible, before calling the `PKT_COMP` command completion callback. The command completion handling can take considerable time. Typically, the target driver calls functions such as `biodone`(9F) and possibly `scsi_transport`(9F) to begin a new command.

The interrupt handler must return `DDI_INTR_CLAIMED` if this interrupt is claimed by this driver. Otherwise, the handler returns `DDI_INTR_UNCLAIMED`.

The following example shows an interrupt handler for the SCSI HBA `isp` driver. The `caddr_t` parameter is set up when the interrupt handler is added in `attach`(9E). This parameter is typically a pointer to the state structure, which is allocated on a per instance basis.

**EXAMPLE 17–9** HBA Driver Interrupt Handler

```
static u_int
isp_intr(caddr_t arg)
{
    struct isp_cmd         *sp;
    struct isp_cmd         *head,     *tail;
    u_short            response_in;
    struct isp_response    *resp;
    struct isp         *isp     = (struct isp *)arg;
    struct isp_slot        *isp_slot;
    int            n;

    if (ISP_INT_PENDING(isp) == 0) {
    return (DDI_INTR_UNCLAIMED);
    }

    do {
again:
    /*
     * head list collects completed packets for callback later
     */
    head = tail = NULL;

    /*
     * Assume no mailbox events (e.g., mailbox cmds, asynch
     * events, and isp dma errors) as common case.
     */
    if (ISP_CHECK_SEMAPHORE_LOCK(isp) == 0) {
        mutex_enter(ISP_RESP_MUTEX(isp));

        /*
```

**EXAMPLE 17–9** HBA Driver Interrupt Handler *(Continued)*

```
         * Loop through completion response queue and post
         * completed pkts.  Check response queue again
         * afterwards in case there are more.
         */
        isp->isp_response_in =
        response_in = ISP_GET_RESPONSE_IN(isp);

        /*
         * Calculate the number of requests in the queue
         */
        n = response_in - isp->isp_response_out;
        if (n < 0) {
        n = ISP_MAX_REQUESTS -
            isp->isp_response_out + response_in;
        }

        while (n-- > 0) {
        ISP_GET_NEXT_RESPONSE_OUT(isp, resp);
        sp = (struct isp_cmd *)resp->resp_token;

        /*
         * copy over response packet in sp
         */
        isp_i_get_response(isp, resp, sp);
        }

        if (head) {
            tail->cmd_forw = sp;
            tail = sp;
            tail->cmd_forw = NULL;
        } else {
            tail = head = sp;
            sp->cmd_forw = NULL;
        }
        }

        ISP_SET_RESPONSE_OUT(isp);
        ISP_CLEAR_RISC_INT(isp);
        mutex_exit(ISP_RESP_MUTEX(isp));

        if (head) {
        isp_i_call_pkt_comp(isp, head);
        }
    } else {
        if (isp_i_handle_mbox_cmd(isp) != ISP_AEN_SUCCESS) {
        return (DDI_INTR_CLAIMED);
        }
        /*
         * if there was a reset then check the response
         * queue again
         */
        goto again;
    }
```

**EXAMPLE 17–9** HBA Driver Interrupt Handler *(Continued)*

```
    } while (ISP_INT_PENDING(isp));

    return (DDI_INTR_CLAIMED);
}

static void
isp_i_call_pkt_comp(
    struct isp         *isp,
    struct isp_cmd     *head)
{
    struct isp         *isp;
    struct isp_cmd     *sp;
    struct scsi_pkt    *pkt;
    struct isp_response    *resp;
    u_char         status;

    while (head) {
    sp = head;
    pkt = sp->cmd_pkt;
    head = sp->cmd_forw;

    ASSERT(sp->cmd_flags & CFLAG_FINISHED);

    resp = &sp->cmd_isp_response;

    pkt->pkt_scbp[0] = (u_char)resp->resp_scb;
    pkt->pkt_state = ISP_GET_PKT_STATE(resp->resp_state);
    pkt->pkt_statistics = (u_long)
        ISP_GET_PKT_STATS(resp->resp_status_flags);
    pkt->pkt_resid = (long)resp->resp_resid;

    /*
     * if data was xferred and this is a consistent pkt,
     * we need to do a dma sync
     */
    if ((sp->cmd_flags & CFLAG_CMDIOPB) &&
        (pkt->pkt_state & STATE_XFERRED_DATA)) {

        (void) ddi_dma_sync(sp->cmd_dmahandle,
        sp->cmd_dma_offset, sp->cmd_dma_len,
        DDI_DMA_SYNC_FORCPU);
    }

    sp->cmd_flags = (sp->cmd_flags & ~CFLAG_IN_TRANSPORT) |
        CFLAG_COMPLETED;

    /*
     * Call packet completion routine if FLAG_NOINTR is not set.
     */
    if (((pkt->pkt_flags & FLAG_NOINTR) == 0) &&
        pkt->pkt_comp) {
        (*pkt->pkt_comp)(pkt);
```

**EXAMPLE 17–9** HBA Driver Interrupt Handler *(Continued)*

```
        }
        }
}
```

## Timeout Handler

The HBA driver is responsible for enforcing time outs. A command must be complete within a specified time unless a zero time out has been specified in the `scsi_pkt`(9S) structure.

When a command times out, the HBA driver should mark the `scsi_pkt`(9S) with `pkt_reason` set to `CMD_TIMEOUT` and `pkt_statistics` OR'd with `STAT_TIMEOUT`. The HBA driver should also attempt to recover the target and bus. If this recovery can be performed successfully, the driver should mark the `scsi_pkt`(9S) using `pkt_statistics` OR'd with either `STAT_BUS_RESET` or `STAT_DEV_RESET`.

After the recovery attempt has completed, the HBA driver should call the command completion callback.

---

**Note –** If recovery was unsuccessful or not attempted, the target driver might attempt to recover from the timeout by calling `scsi_reset`(9F).

---

The ISP hardware manages command timeout directly and returns timed-out commands with the necessary status. The timeout handler for the `isp` sample driver checks active commands for the time out state only once every 60 seconds.

The `isp` sample driver uses the `timeout`(9F) facility to arrange for the kernel to call the timeout handler every 60 seconds. The `caddr_t` argument is the parameter set up when the timeout is initialized at `attach`(9E) time. In this case, the `caddr_t` argument is a pointer to the state structure allocated per driver instance.

If timed-out commands have not been returned as timed-out by the ISP hardware, a problem has occurred. The hardware is not functioning correctly and needs to be reset.

# Capability Management

The following sections discuss capability management.

## `tran_getcap()` Entry Point

The `tran_getcap`(9E) entry point for a SCSI HBA driver is called by `scsi_ifgetcap`(9F). The target driver calls `scsi_ifgetcap()` to determine the current value of one of a set of SCSA-defined capabilities.

The target driver can request the current setting of the capability for a particular target by setting the `whom` parameter to nonzero. A `whom` value of zero indicates a request for the current setting of the general capability for the SCSI bus or for adapter hardware.

`tran_getcap()` should return `-1` for undefined capabilities or the current value of the requested capability.

The HBA driver can use the function `scsi_hba_lookup_capstr`(9F) to compare the capability string against the canonical set of defined capabilities.

**EXAMPLE 17–10** HBA Driver `tran_getcap`(9E) Entry Point

```
static int
isp_scsi_getcap(
    struct scsi_address    *ap,
    char           *cap,
    int            whom)
{
    struct isp         *isp;
    int            rval = 0;
    u_char         tgt = ap->a_target;

    /*
     * We don't allow getting capabilities for other targets
     */
    if (cap == NULL || whom  == 0)    {
    return (-1);
    }

    isp = (struct isp *)ap->a_hba_tran->tran_hba_private;

    ISP_MUTEX_ENTER(isp);

    switch (scsi_hba_lookup_capstr(cap)) {

    case SCSI_CAP_DMA_MAX:
    rval = 1 << 24; /* Limit to 16MB max transfer */
    break;
    case SCSI_CAP_MSG_OUT:
    rval = 1;
    break;
    case SCSI_CAP_DISCONNECT:
    if ((isp->isp_target_scsi_options[tgt] &
        SCSI_OPTIONS_DR) == 0) {
        break;
    } else if (
        (isp->isp_cap[tgt] & ISP_CAP_DISCONNECT) == 0) {
        break;
    }
    rval = 1;
    break;
    case SCSI_CAP_SYNCHRONOUS:
    if ((isp->isp_target_scsi_options[tgt] &
        SCSI_OPTIONS_SYNC) == 0) {
```

**EXAMPLE 17–10** HBA Driver `tran_getcap`(9E) Entry Point *(Continued)*

```
        break;
    } else if (
        (isp->isp_cap[tgt] & ISP_CAP_SYNC) == 0) {
        break;
    }
    rval = 1;
    break;
    case SCSI_CAP_WIDE_XFER:
    if ((isp->isp_target_scsi_options[tgt] &
        SCSI_OPTIONS_WIDE) == 0) {
        break;
    } else if (
        (isp->isp_cap[tgt] & ISP_CAP_WIDE) == 0) {
        break;
    }
    rval = 1;
    break;
    case SCSI_CAP_TAGGED_QING:
    if ((isp->isp_target_scsi_options[tgt] &
        SCSI_OPTIONS_DR) == 0 ||
        (isp->isp_target_scsi_options[tgt] &
        SCSI_OPTIONS_TAG) == 0) {
        break;
    } else if (
        (isp->isp_cap[tgt] & ISP_CAP_TAG) == 0) {
        break;
    }
    rval = 1;
    break;
    case SCSI_CAP_UNTAGGED_QING:
    rval = 1;
    break;
    case SCSI_CAP_PARITY:
    if (isp->isp_target_scsi_options[tgt] &
        SCSI_OPTIONS_PARITY) {
        rval = 1;
    }
    break;
    case SCSI_CAP_INITIATOR_ID:
    rval = isp->isp_initiator_id;
    break;
    case SCSI_CAP_ARQ:
    if (isp->isp_cap[tgt] & ISP_CAP_AUTOSENSE) {
        rval = 1;
    }
    break;
    case SCSI_CAP_LINKED_CMDS:
    break;
    case SCSI_CAP_RESET_NOTIFICATION:
    rval = 1;
    break;
    case SCSI_CAP_GEOMETRY:
    rval = (64 << 16) | 32;
```

**EXAMPLE 17–10** HBA Driver `tran_getcap`(9E) Entry Point *(Continued)*

```
    break;

    default:
    rval = -1;
    break;
    }

    ISP_MUTEX_EXIT(isp);

    return (rval);
}
```

## `tran_setcap()` Entry Point

The `tran_setcap`(9E) entry point for a SCSI HBA driver is called by `scsi_ifsetcap`(9F). A target driver calls `scsi_ifsetcap()` to change the current one of a set of SCSA-defined capabilities.

The target driver might request that the new value be set for a particular target by setting the `whom` parameter to nonzero. A `whom` value of zero means the request is to set the new value for the SCSI bus or for adapter hardware in general.

`tran_setcap()` should return the following values as appropriate:

- `-1` for undefined capabilities
- `0` if the HBA driver cannot set the capability to the requested value
- `1` if the HBA driver is able to set the capability to the requested value

The HBA driver can use the function `scsi_hba_lookup_capstr`(9F) to compare the capability string against the canonical set of defined capabilities.

**EXAMPLE 17–11** HBA Driver `tran_setcap`(9E) Entry Point

```
static int
isp_scsi_setcap(
    struct scsi_address    *ap,
    char           *cap,
    int            value,
    int            whom)
{
    struct isp         *isp;
    int            rval = 0;
    u_char         tgt = ap->a_target;
    int            update_isp = 0;

    /*
     * We don't allow setting capabilities for other targets
     */
    if (cap == NULL || whom == 0) {
    return (-1);
```

**EXAMPLE 17–11** HBA Driver `tran_setcap`(9E) Entry Point *(Continued)*

```
}

isp = (struct isp *)ap->a_hba_tran->tran_hba_private;

ISP_MUTEX_ENTER(isp);

switch (scsi_hba_lookup_capstr(cap)) {

case SCSI_CAP_DMA_MAX:
case SCSI_CAP_MSG_OUT:
case SCSI_CAP_PARITY:
case SCSI_CAP_UNTAGGED_QING:
case SCSI_CAP_LINKED_CMDS:
case SCSI_CAP_RESET_NOTIFICATION:
/*
 * None of these are settable via
 * the capability interface.
 */
break;
case SCSI_CAP_DISCONNECT:
if ((isp->isp_target_scsi_options[tgt] &
    SCSI_OPTIONS_DR) == 0) {
    break;
} else {
    if (value) {
    isp->isp_cap[tgt] |= ISP_CAP_DISCONNECT;
    } else {
    isp->isp_cap[tgt] &= ~ISP_CAP_DISCONNECT;
    }
}
rval = 1;
break;
case SCSI_CAP_SYNCHRONOUS:
if ((isp->isp_target_scsi_options[tgt] &
    SCSI_OPTIONS_SYNC) == 0) {
    break;
} else {
    if (value) {
    isp->isp_cap[tgt] |= ISP_CAP_SYNC;
    } else {
    isp->isp_cap[tgt] &= ~ISP_CAP_SYNC;
    }
}
rval = 1;
break;
case SCSI_CAP_TAGGED_QING:
if ((isp->isp_target_scsi_options[tgt] &
    SCSI_OPTIONS_DR) == 0 ||
    (isp->isp_target_scsi_options[tgt] &
    SCSI_OPTIONS_TAG) == 0) {
    break;
} else {
    if (value) {
```

**EXAMPLE 17–11** HBA Driver `tran_setcap`(9E) Entry Point *(Continued)*

```
        isp->isp_cap[tgt] |= ISP_CAP_TAG;
        } else {
        isp->isp_cap[tgt] &= ~ISP_CAP_TAG;
        }
    }
    rval = 1;
    break;
    case SCSI_CAP_WIDE_XFER:
    if ((isp->isp_target_scsi_options[tgt] &
        SCSI_OPTIONS_WIDE) == 0) {
        break;
    } else {
        if (value) {
        isp->isp_cap[tgt] |= ISP_CAP_WIDE;
        } else {
        isp->isp_cap[tgt] &= ~ISP_CAP_WIDE;
        }
    }
    rval = 1;
    break;
    case SCSI_CAP_INITIATOR_ID:
    if (value < N_ISP_TARGETS_WIDE) {
        struct isp_mbox_cmd mbox_cmd;

        isp->isp_initiator_id = (u_short) value;

        /*
         * set Initiator SCSI ID
         */
        isp_i_mbox_cmd_init(isp, &mbox_cmd, 2, 2,
        ISP_MBOX_CMD_SET_SCSI_ID,
        isp->isp_initiator_id,
        0, 0, 0, 0);
        if (isp_i_mbox_cmd_start(isp, &mbox_cmd) == 0) {
        rval = 1;
        }
    }
    break;
    case SCSI_CAP_ARQ:
    if (value) {
        isp->isp_cap[tgt] |= ISP_CAP_AUTOSENSE;
    } else {
        isp->isp_cap[tgt] &= ~ISP_CAP_AUTOSENSE;
    }
    rval = 1;
    break;

    default:
    rval = -1;
    break;
    }
    ISP_MUTEX_EXIT(isp);
```

**EXAMPLE 17–11** HBA Driver `tran_setcap`(9E) Entry Point *(Continued)*

```
    return (rval);
}
```

# Abort and Reset Management

The following sections discuss the abort and reset entry points for SCSI HBA.

## `tran_abort()` Entry Point

The `tran_abort`(9E) entry point for a SCSI HBA driver is called to abort any commands that are currently in transport for a particular target. This entry point is called when a target driver calls `scsi_abort`(9F).

The `tran_abort()` entry point should attempt to abort the command denoted by the *pkt* parameter. If the *pkt* parameter is NULL, `tran_abort()` should attempt to abort all outstanding commands in the transport layer for the particular target or logical unit.

Each command successfully aborted must be marked with `pkt_reason` `CMD_ABORTED` and `pkt_statistics` OR'd with `STAT_ABORTED`.

## `tran_reset()` Entry Point

The `tran_reset`(9E) entry point for a SCSI HBA driver is called to reset either the SCSI bus or a particular SCSI target device. This entry point is called when a target driver calls `scsi_reset`(9F).

The `tran_reset()` entry point must reset the SCSI bus if level is `RESET_ALL`. If level is `RESET_TARGET`, just the particular target or logical unit must be reset.

Active commands affected by the reset must be marked with `pkt_reason` `CMD_RESET`. The type of reset determines whether `STAT_BUS_RESET` or `STAT_DEV_RESET` should be used to OR `pkt_statistics`.

Commands in the transport layer, but not yet active on the target, must be marked with `pkt_reason` `CMD_RESET`, and `pkt_statistics` OR'd with `STAT_ABORTED`.

## `tran_bus_reset()` Entry Point

`tran_bus_reset`(9e) must reset the SCSI bus without resetting targets.

```
#include <sys/scsi/scsi.h>

int tran_bus_reset(dev_info_t *hba-dip, int level);
```

where:

| | |
|---|---|
| **hba-dip* | Pointer associated with the SCSI HBA |
| *level* | Must be set to `RESET_BUS` so that only the SCSI bus is reset, not the targets |

The `tran_bus_reset()` vector in the `scsi_hba_tran`(9S) structure should be initialized during the HBA driver's `attach`(9E). The vector should point to an HBA entry point that is to be called when a user initiates a bus reset.

Implementation is hardware specific. If the HBA driver cannot reset the SCSI bus without affecting the targets, the driver should fail `RESET_BUS` or not initialize this vector.

## `tran_reset_notify()` Entry Point

Use the `tran_reset_notify`(9E) entry point when a SCSI bus reset occurs. This function requests the SCSI HBA driver to notify the target driver by callback.

**EXAMPLE 17–12** HBA Driver `tran_reset_notify`(9E) Entry Point

```
isp_scsi_reset_notify(
    struct scsi_address     *ap,
    int             flag,
    void            (*callback)(caddr_t),
    caddr_t         arg)
{
    struct isp          *isp;
    struct isp_reset_notify_entry    *p, *beforep;
    int                  rval = DDI_FAILURE;

    isp = (struct isp *)ap->a_hba_tran->tran_hba_private;

    mutex_enter(ISP_REQ_MUTEX(isp));

    /*
     * Try to find an existing entry for this target
     */
    p = isp->isp_reset_notify_listf;
    beforep = NULL;

    while (p) {
    if (p->ap == ap)
        break;
    beforep = p;
    p = p->next;
    }

    if ((flag & SCSI_RESET_CANCEL) && (p != NULL)) {
    if (beforep == NULL) {
        isp->isp_reset_notify_listf = p->next;
```

**EXAMPLE 17–12** HBA Driver `tran_reset_notify`(9E) Entry Point *(Continued)*

```
    } else {
        beforep->next = p->next;
    }
    kmem_free((caddr_t)p, sizeof (struct
            isp_reset_notify_entry));
    rval = DDI_SUCCESS;

    } else if ((flag & SCSI_RESET_NOTIFY) && (p == NULL)) {
    p = kmem_zalloc(sizeof (struct isp_reset_notify_entry),
        KM_SLEEP);
    p->ap = ap;
    p->callback = callback;
    p->arg = arg;
    p->next = isp->isp_reset_notify_listf;
    isp->isp_reset_notify_listf = p;
    rval = DDI_SUCCESS;
    }

    mutex_exit(ISP_REQ_MUTEX(isp));

    return (rval);
}
```

# Dynamic Reconfiguration

To support the minimal set of hot-plugging operations, drivers might need to implement support for bus *quiesce*, bus *unquiesce*, and bus *reset*. The `scsi_hba_tran`(9S) structure supports these operations. If quiesce, unquiesce, or reset are not required by hardware, no driver changes are needed.

The `scsi_hba_tran` structure includes the following fields:

```
int (*tran_quiesce)(dev_info_t *hba-dip);
int (*tran_unquiesce)(dev_info_t *hba-dip);
int (*tran_bus_reset)(dev_info_t *hba-dip, int level);
```

These interfaces quiesce and unquiesce a SCSI bus.

```
#include <sys/scsi/scsi.h>

int prefixtran_quiesce(dev_info_t *hba-dip);

int prefixtran_unquiesce(dev_info_t *hba-dip);
```

`tran_quiesce`(9e) and `tran_unquiesce`(9e) are used for SCSI devices that are not designed for hot-plugging. These functions must be implemented by an HBA driver to support dynamic reconfiguration (DR).

The tran_quiesce(9e) and tran_unquiesce(9e) vectors in the scsi_hba_tran(9S) structure should be initialized to point to HBA entry points during attach(9E). These functions are called when a user initiates quiesce and unquiesce operations.

tran_quiesce(9e) stops all activity on a SCSI bus prior to and during the reconfiguration of devices that are attached to the SCSI bus. tran_unquiesce(9e) is called by the SCSA framework to resume activity on the SCSI bus after the reconfiguration operation has been completed.

HBA drivers are required to handle tran_quiesce(9e) by waiting for all outstanding commands to complete before returning success. After the driver has quiesced the bus, any new I/O requests must be queued until the SCSA framework calls the corresponding tran_unquiesce(9e) entry point.

HBA drivers handle calls to tran_unquiesce(9e) by starting any target driver I/O requests in the queue.

# SCSI HBA Driver Specific Issues

The section covers issues specific to SCSI HBA drivers.

## Installing HBA Drivers

A SCSI HBA driver is installed in similar fashion to a leaf driver. See Chapter 20. The difference is that the add_drv(1M) command must specify the driver class as SCSI, such as:

```
# add_drv -m" * 0666 root root" -i'"pci1077,1020"' -c scsi isp
```

## HBA Configuration Properties

When attaching an instance of an HBA device, scsi_hba_attach_setup(9F) creates a number of SCSI configuration properties for that HBA instance. A particular property is created only if no existing property of the same name is already attached to the HBA instance. This restriction avoids overriding any default property values in an HBA configuration file.

An HBA driver must use `ddi_prop_get_int`(9F) to retrieve each property. The HBA driver then modifies or accepts the default value of the properties to configure its specific operation.

## `scsi-reset-delay` Property

The `scsi-reset-delay` property is an integer specifying the recovery time in milliseconds for a reset delay by either a SCSI bus or SCSI device.

## `scsi-options` Property

The `scsi-options` property is an integer specifying a number of options through individually defined bits:

- `SCSI_OPTIONS_DR (0x008)` – If not set, the HBA should not grant disconnect privileges to a target device.
- `SCSI_OPTIONS_LINK (0x010)` – If not set, the HBA should not enable linked commands.
- `SCSI_OPTIONS_SYNC (0x020)` – If not set, the HBA driver must not negotiate synchronous data transfer. The driver should reject any attempt to negotiate synchronous data transfer initiated by a target.
- `SCSI_OPTIONS_PARITY (0x040)` – If not set, the HBA should run the SCSI bus without parity.
- `SCSI_OPTIONS_TAG (0x080)` – If not set, the HBA should not operate in Command Tagged Queuing mode.
- `SCSI_OPTIONS_FAST (0x100)` – If not set, the HBA should not operate the bus in FAST SCSI mode.
- `SCSI_OPTIONS_WIDE (0x200)` – If not set, the HBA should not operate the bus in WIDE SCSI mode.

## Per-Target `scsi-options`

An HBA driver might support a per-target `scsi-options` feature in the following format:

```
target<n>-scsi-options=<hex value>
```

In this example, < *n*> is the target ID. If the per-target `scsi-options` property is defined, the HBA driver uses that value rather than the per-HBA driver instance `scsi-options` property. This approach can provide more precise control if, for example, synchronous data transfer needs to be disabled for just one particular target device. The per-target `scsi-options` property can be defined in the `driver.conf`(4) file.

The following example shows a per-target `scsi-options` property definition to disable synchronous data transfer for target device 3:

```
target3-scsi-options=0x2d8
```

# x86 Target Driver Configuration Properties

Some x86 SCSI target drivers, such as the driver for *cmdk* disk, use the following configuration properties:

- `disk`
- `queue`
- `flow_control`

If you use the *cmdk* sample driver to write an HBA driver for an x86 platform, any appropriate properties must be defined in the `driver.conf`(4) file.

---

**Note –** These property definitions should appear only in an HBA driver's `driver.conf`(4) file. The HBA driver itself should not inspect or attempt to interpret these properties in any way. These properties are advisory only and serve as an adjunct to the `cmdk` driver. The properties should not be relied upon in any way. The property definitions might not be used in future releases.

---

The `disk` property can be used to define the type of disk supported by `cmdk`. For a SCSI HBA, the only possible value for the `disk` property is:

- `disk="scdk"` – Disk type is a SCSI disk

The `queue` property defines how the disk driver sorts the queue of incoming requests during `strategy`(9E). Two values are possible:

- `queue="qsort"` – One-way elevator queuing model, provided by `disksort`(9F)
- `queue="qfifo"` – FIFO, that is, first in, first out queuing model

The `flow_control` property defines how commands are transported to the HBA driver. Three values are possible:

- `flow_control="dsngl"` – Single command per HBA driver

- `flow_control="dmult"` – Multiple commands per HBA driver—when the HBA queue is full, the driver returns `TRAN_BUSY`
- `flow_control="duplx"` – The HBA can support separate read and write queues, with multiple commands per queue. FIFO ordering is used for the write queue. The queuing model that is used for the read queue is described by the *queue* property. When an HBA queue is full, the driver returns `TRAN_BUSY`

The following example is a `driver.conf`(4) file for use with an x86 HBA PCI device that has been designed for use with the *cmdk* sample driver:

```
#
# config file for ISP 1020 SCSI HBA driver
#
       flow_control="dsngl" queue="qsort" disk="scdk"
       scsi-initiator-id=7;
```

# Support for Queuing

For a definition of *tagged queuing*, refer to the SCSI-2 specification. To support tagged queuing, first check the *scsi_options* flag `SCSI_OPTIONS_TAG` to see whether tagged queuing is enabled globally. Next, check to see whether the target is a SCSI-2 device and whether the target has tagged queuing enabled. If these conditions are all true, attempt to enable tagged queuing by using `scsi_ifsetcap`(9F).

If tagged queuing fails, you can attempt to set *untagged queuing*. In this mode, you submit as many commands as you think necessary or optimal to the host adapter driver. Then the host adapter queues the commands to the target one command at a time, in contrast to tagged queuing. In tagged queuing, the host adapter submits as many commands as possible until the target indicates that the queue is full.

CHAPTER 18

# Drivers for Network Devices

Solaris network drivers are STREAMS-based. These types of drivers are covered in depth in the *STREAMS Programming Guide*. This chapter discusses the Generic LAN driver (GLD), which is a kernel module encapsulating features common to most network drivers. The GLD implements much of the STREAMS and Data Link Provider Interface (DLPI) functionality for a Solaris network driver.

The GLD module is available for network drivers for the Solaris SPARC platform and the Solaris x86 platform.

This chapter provides information on the following subjects:



For more information on GLDs, see the `gld`(7D), `dlpi`(7P), `gld`(9E), `gld`(9F), `gld_mac_info`(9S), and `gld_stats`(9S) man pages.

## Generic LAN Driver Overview

GLD is a multi-threaded, clonable, loadable kernel module providing support to device drivers for local area networks. Local area network (LAN) device drivers in the Solaris OS are STREAMS-based drivers that use DLPI to communicate with network protocol stacks. These protocol stacks use the network drivers to send and receive packets on a local area network.

A network device driver must implement and conform to these requirements:

- DDI/DKI specification
- STREAMS specification
- DLPI specification
- programmatic interface for the device

GLD implements most STREAMS and DLPI functionality required of a Solaris LAN driver. Several Solaris network drivers are implemented using GLD.

A Solaris network driver that is implemented using GLD is made up of two distinct parts: a generic component that deals with STREAMS and DLPI interfaces, and a device-specific component that deals with the particular hardware device. The device-specific module indicates its dependency on the GLD module, which is found at `/kernel/misc/gld`. The device-specific module then registers with GLD from within the driver's `attach`(9E) function. After the device-specific module is successfully loaded, the driver is DLPI-compliant. The device-specific part of the driver calls `gld`(9F) functions when that part receives data or needs some service from GLD. When the device-specific driver registers with the GLD, the driver provides pointers to the entry points for later use by GLD. GLD makes calls into the `gld`(9E) using these pointers. The `gld_mac_info`(9S) structure is the main data interface between GLD and the device-specific driver.

The GLD facility currently supports the following types of devices:

- `DL_ETHER`, that is, ISO 8802–3, IEEE 802.3 protocol
- `DL_TPR`, that is, IEEE 802.5, Token Passing Ring
- `DL_FDDI`, that is, ISO 9314–2, Fibre Distributed Data Interface

GLD drivers are expected to process fully formed MAC-layer packets and should not perform logical link control (LLC) handling.

In some cases, a full DLPI-compliant driver can be implemented without using the GLD facility. One case would be devices that are not ISO 8802-style, that is, IEEE 802, LAN devices. Another case would be devices or services that are not supported by GLD.

## Type `DL_ETHER`: Ethernet V2 and ISO 8802-3 (IEEE 802.3)

For devices designated type `DL_ETHER`, GLD provides support for both Ethernet V2 and ISO 8802-3 (IEEE 802.3) packet processing. Ethernet V2 enables a user to access a conforming provider of data link services without special knowledge of the provider's protocol. A service access point (SAP) is the point through which the user communicates with the service provider.

Streams bound to SAP values in the range [0-255] are treated as equivalent and denote that the user wants to use 8802-3 mode. If the SAP value of the `DL_BIND_REQ` is within this range, GLD computes the length of each subsequent `DL_UNITDATA_REQ`

message on that stream. The length does not include the 14-byte media access control (MAC) header. GLD then transmits 8802-3 frames that have those lengths in the MAC frame header `type` fields. Such lengths never exceed 1500.

All frames that are received from the media that have a `type` field in the range [0-1500] are assumed to be 8802-3 frames. These frames are routed up all open streams in 8802-3 mode. Those streams with SAP values in the [0-255] range are considered to be in 8802-3 mode. If more than one stream is in 8802-3 mode, the incoming frame is duplicated and routed up these streams.

Those streams that are bound to SAP values that are greater than 1500 are assumed to be in Ethernet V2 mode. These streams receive incoming packets whose Ethernet MAC header `type` value exactly matches the value of the SAP to which the stream is bound.

## Types `DL_TPR` and `DL_FDDI`: SNAP Processing

For media types `DL_TPR` and `DL_FDDI`, GLD implements minimal SNAP (Sub-Net Access Protocol) processing. This processing is for any stream that is bound to a SAP value that is greater than 255. SAP values in the range [0-255] are LLC SAP values. Such values are carried naturally by the media packet format. SAP values that are greater than 255 require a SNAP header, subordinate to the LLC header, to carry the 16-bit Ethernet V2-style SAP value.

SNAP headers are carried under LLC headers with destination SAP 0xAA.Outbound packets with SAP values that are greater than 255 require an LLC+SNAP header take the following form:

```
AA AA 03 00 00 00 XX XX
```

"XX XX" represents the 16-bit SAP, corresponding to the Ethernet V2 style "type." This header is unique in supporting non-zero organizational unique identifier fields. LLC control fields other than 03 are considered to be LLC packets with SAP 0xAA. Clients wanting to use SNAP formats other than this format must use LLC and bind to SAP 0xAA.

Incoming packets are checked for conformance with the above format. Packets that conform are matched to any streams that have been bound to the packet's 16-bit SNAP type. In addition, these packets are considered to match the LLC SNAP SAP 0xAA.

Packets received for any LLC SAP are passed up all streams that are bound to an LLC SAP, as described for media type `DL_ETHER`.

## Type DL_TPR: Source Routing

For type DL_TPR devices, GLD implements minimal support for source routing. Source routing support includes the following items:

- Specify routing information for a packet to be sent across a bridged medium. The routing information is stored in the MAC header. This information is used to determine the route.
- Learn routes.
- Solicit and respond to requests for information about possible multiple routes
- Select among available routes.

Source routing adds routing information fields to the MAC headers of outgoing packets. In addition, this support recognizes such fields in incoming packets.

GLD's source routing support does not implement the full route determination entity (RDE) specified in Section 9 of *ISO 8802-2 (IEEE 802.2)*. However, this support can interoperate with any RDE implementations that might exist in the same or a bridged network.

## Style 1 and Style 2 DLPI Providers

GLD implements both Style 1 and Style 2 DLPI providers. A physical point of attachment (PPA) is the point at which a system attaches itself to a physical communication medium. All communication on that physical medium funnels through the PPA. The Style 1 provider attaches the streams to a particular PPA based on the major or minor device that has been opened. The Style 2 provider requires the DLS, that is, the data link service, user to explicitly identify the desired PPA using DL_ATTACH_REQ. In this case, open(9E) creates a streams between the user and GLD, and DL_ATTACH_REQ subsequently associates a particular PPA with that streams. Style 2 is denoted by a minor number of zero. If a device node whose minor number is not zero is opened, Style 1 is indicated and the associated PPA is the minor number minus 1. In both Style 1 and Style 2 opens, the device is cloned.

## Implemented DLPI Primitives

GLD implements several DLPI primitives. The DL_INFO_REQ primitive requests information about the DLPI streams. The message consists of one M_PROTO message block. GLD returns device-dependent values in the DL_INFO_ACK response to this request. These values are based on information that the GLD-based driver specified in the gldm_mac_info(9S) structure that was passed to gld_register().

GLD returns the following values on behalf of all GLD-based drivers:

- Version is DL_VERSION_2
- Service mode is DL_CLDLS, GLD implements connectionless-mode service.
- Provider style is DL_STYLE1 or DL_STYLE2, depending on how the streams was opened.
- No optional Quality of Service (QOS) support is present. The QOS fields are zero.

---

**Note –** Contrary to the DLPI specification, GLD returns the device's correct address length and broadcast address in DL_INFO_ACK even before the streams has been attached to a PPA.

---

The DL_ATTACH_REQ primitive is used to associate a PPA with a streams. This request is needed for Style 2 DLS providers to identify the physical medium over which the communication is sent. Upon completion, the state changes from DL_UNATTACHED to DL_UNBOUND. The message consists of one M_PROTO message block. This request is not permitted when Style 1 mode is used. Streams that are opened using Style 1 are already attached to a PPA by the time the open completes.

The DL_DETACH_REQ primitive requests to detach the PPA from the streams. This detachment is allowed only if the streams was opened using Style 2.

The DL_BIND_REQ and DL_UNBIND_REQ primitives bind and unbind a DLSAP, that is, a data link service access point, to the streams. The PPA that is associated with a streams completes initialization before the completion of the processing of the DL_BIND_REQ on that streams. You can bind multiple streams to the same SAP. Each streams in this case receives a copy of any packets that were received for that SAP.

The DL_ENABMULTI_REQ and DL_DISABMULTI_REQ primitives enable and disable reception of individual multicast group addresses. Through iterative use of these primitives, an application or other DLS user can create or modify a set of multicast addresses. The streams must be attached to a PPA for these primitives to be accepted.

The DL_PROMISCON_REQ and DL_PROMISCOFF_REQ primitives turn promiscuous mode on or off on a per-streams basis. These controls operate at either at a physical level or at the SAP level. The DL Provider routes all received messages on the media to the DLS user. Routing continues until a DL_DETACH_REQ is received, a DL_PROMISCOFF_REQ is received, or the streams is closed. You can specify physical level promiscuous reception of all packets on the medium or of multicast packets only.

---

**Note –** The streams must be attached to a PPA for these promiscuous mode primitives to be accepted.

---

The DL_UNITDATA_REQ primitive is used to send data in a connectionless transfer. Because this service is not acknowledged, delivery is not guaranteed. The message consists of one M_PROTO message block followed by one or more M_DATA blocks containing at least one byte of data.

The DL_UNITDATA_IND type is used when a packet is to be passed on upstream. The packet is put into an M_PROTO message with the primitive set to DL_UNITDATA_IND.

The DL_PHYS_ADDR_REQ primitive requests the MAC address currently associated with the PPA attached to the streams. The address is returned by the DL_PHYS_ADDR_ACK primitive. When using Style 2, this primitive is only valid following a successful DL_ATTACH_REQ.

The DL_SET_PHYS_ADDR_REQ primitive changes the MAC address currently associated with the PPA attached to the streams. This primitive affects all other current and future streams attached to this device. Once changed, all streams currently or subsequently opened and attached to this device obtain this new physical address. The new physical address remains in effect until this primitive changes the physical address again or the driver is reloaded.

---

**Note –** The superuser is allowed to change the physical address of a PPA while other streams are bound to the same PPA.

---

The DL_GET_STATISTICS_REQ primitive requests a DL_GET_STATISTICS_ACK response containing statistics information associated with the PPA attached to the stream. Style 2 Streams must be attached to a particular PPA using DL_ATTACH_REQ before this primitive can succeed.

## Implemented ioctl Functions

GLD implements the ioctl *ioc_cmd* function described below. If GLD receives an unrecognizable ioctl command, GLD passes the command to the device-specific driver's gldm_ioctl() routine, as described in gld(9E).

The DLIOCRAW ioctl function is used by some DLPI applications, most notably the snoop(1M) command. The DLIOCRAW command puts the stream into a raw mode. In raw mode, the driver passes full MAC-level incoming packets upstream in M_DATA messages instead of transforming the packets into the DL_UNITDATA_IND form. The DL_UNITDATA_IND form is normally used for reporting incoming packets. Packet SAP filtering is still performed on streams that are in raw mode. If a stream user wants to receive all incoming packets, the user must also select the appropriate promiscuous modes. After successfully selecting raw mode, the application is also allowed to send fully formatted packets to the driver as M_DATA messages for transmission. DLIOCRAW takes no arguments. Once enabled, the stream remains in this mode until closed.

# GLD Driver Requirements

GLD-based drivers must include the header file `<sys/gld.h>`.

GLD-based drivers must be linked with the `-N"misc/gld"` option:

```
%ld -r -N"misc/gld" xx.o -o xx
```

GLD implements the following functions on behalf of the device-specific driver:

- `open`(9E)
- `close`(9E)
- `put`(9E), required for STREAMS
- `srv`(9E), required for STREAMS
- `getinfo`(9E)

The `mi_idname` element of the `module_info`(9S) structure is a string that specifies the name of the driver. This string must exactly match the name of the driver module as defined in the file system.

The read-side `qinit`(9S) structure should specify the following elements:

```
qi_putp     NULL
qi_srvp     gld_rsrv
qi_qopen    gld_open
qi_qclose   gld_close
```

The write-side `qinit`(9S) structure should specify these elements:

```
qi_putp     gld_wput
qi_srvp     gld_wsrv
qi_qopen    NULL
qi_qclose   NULL
```

The `devo_getinfo` element of the `dev_ops`(9S) structure should specify `gld_getinfo` as the `getinfo`(9E) routine.

The driver's `attach`(9E) function associates the hardware-specific device driver with the GLD facility. `attach()` then prepares the device and driver for use.

The `attach`(9E) function allocates a `gld_mac_info`(9S) structure using `gld_mac_alloc()`. The driver usually needs to save more information per device than is defined in the `macinfo` structure. The driver should allocate the additional required data structure and save a pointer to the structure in the `gldm_private` member of the `gld_mac_info`(9S) structure.

The attach(9E) routine must initialize the macinfo structure as described in the gld_mac_info(9S) man page. The attach() routine should then call gld_register() to link the driver with the GLD module. The driver should map registers if necessary and be fully initialized and prepared to accept interrupts before calling gld_register(). The attach(9E) function should add interrupts but should not enable the device to generate these interrupts. The driver should reset the hardware before calling gld_register() to ensure the hardware is quiescent. A device must not be put into a state where the device might generate an interrupt before gld_register() is called. The device is started later when GLD calls the driver's gldm_start() entry point, which is described in the gld(9E) man page. After gld_register() succeeds, the gld(9E) entry points might be called by GLD at any time.

The attach(9E) routine should return DDI_SUCCESS if gld_register() succeeds. If gld_register() fails, DDI_FAILURE is returned. If a failure occurs, the attach(9E) routine should deallocate any resources that were allocated before gld_register() was called. The attach routine should then also return DDI_FAILURE. A failed macinfo structure should never be reused. Such a structure should be deallocated using gld_mac_free().

The detach(9E)function should attempt to unregister the driver from GLD by calling gld_unregister(). For more information about gld_unregister(), see the gld(9F) man page. The detach(9E) routine can get a pointer to the needed gld_mac_info(9S) structure from the device's private data using ddi_get_driver_private(9F). gld_unregister() checks certain conditions that could require that the driver not be detached. If the checks fail, gld_unregister() returns DDI_FAILURE, in which case the driver's detach(9E) routine must leave the device operational and return DDI_FAILURE.

If the checks succeed, gld_unregister() ensures that the device interrupts are stopped. The driver's gldm_stop() routine is called if necessary. The driver is unlinked from the GLD framework. gld_unregister() then returns DDI_SUCCESS. In this case, the detach(9E) routine should remove interrupts and use gld_mac_free() to deallocate any macinfo data structures that were allocated in the attach(9E) routine. The detach() routine should then return DDI_SUCCESS. The routine must remove the interrupt *before* calling gld_mac_free().

# Network Statistics

Solaris network drivers must implement statistics variables. GLD tallies some network statistics, but other statistics must be counted by each GLD-based driver. GLD provides support for GLD-based drivers to report a standard set of network driver statistics. Statistics are reported by GLD using the kstat(7D) and kstat(9S) mechanisms. The DL_GET_STATISTICS_REQ DLPI command can also be used to retrieve the current statistics counters. All statistics are maintained as unsigned. The statistics are 32 bits unless otherwise noted.

GLD maintains and reports the following statistics.

| | |
|---|---|
| `rbytes64` | Total bytes successfully received on the interface. Stores 64-bit statistics. |
| `rbytes` | Total bytes successfully received on the interface |
| `obytes64` | Total bytes that have requested transmission on the interface. Stores 64-bit statistics. |
| `obytes` | Total bytes that have requested transmission on the interface. |
| `ipackets64` | Total packets successfully received on the interface. Stores 64-bit statistics. |
| `ipackets` | Total packets successfully received on the interface. |
| `opackets64` | Total packets that have requested transmission on the interface. Stores 64-bit statistics. |
| `opackets` | Total packets that have requested transmission on the interface. |
| `multircv` | Multicast packets successfully received, including group and functional addresses (`long`). |
| `multixmt` | Multicast packets requested to be transmitted, including group and functional addresses (`long`). |
| `brdcstrcv` | Broadcast packets successfully received (`long`). |
| `brdcstxmt` | Broadcast packets that have requested transmission (`long`). |
| `unknowns` | Valid received packets not accepted by any stream (`long`). |
| `noxmtbuf` | Packets discarded on output because transmit buffer was busy, or no buffer could be allocated for transmit (`long`). |
| `blocked` | Number of times a received packet could not be put up a stream because the queue was flow-controlled (`long`). |
| `xmtretry` | Times transmit was retried after having been delayed due to lack of resources (`long`). |
| `promisc` | Current “promiscuous” state of the interface (string). |

The device-dependent driver tracks the following statistics in a private per-instance structure. To report statistics, GLD calls the driver’s `gldm_get_stats()` entry point. `gldm_get_stats()` then updates device–specific statistics in the `gld_stats`(9S) structure. See the `gldm_get_stats`(9E) man page for more information. GLD then reports the updated statistics using the named statistics variables that are shown below.

| | |
|---|---|
| `ifspeed` | Current estimated bandwidth of the interface in bits per second. Stores 64-bit statistics. |
| `media` | Current media type in use by the device (string). |

| | |
|---|---|
| `intr` | Number of times that the interrupt handler was called, causing an interrupt (`long`). |
| `norcvbuf` | Number of times a valid incoming packet was known to have been discarded because no buffer could be allocated for receive (`long`). |
| `ierrors` | Total number of packets that were received but could not be processed due to errors (`long`). |
| `oerrors` | Total packets that were not successfully transmitted because of errors (`long`). |
| `missed` | Packets known to have been dropped by the hardware on receive (`long`). |
| `uflo` | Times FIFO underflowed on transmit (`long`). |
| `oflo` | Times receiver overflowed during receive (`long`). |

The following group of statistics applies to networks of type `DL_ETHER`. These statistics are maintained by device-specific drivers of that type, as shown previously.

| | |
|---|---|
| `align_errors` | Packets that were received with framing errors, that is, the packets did not contain an integral number of octets (`long`). |
| `fcs_errors` | Packets received with CRC errors (`long`). |
| `duplex` | Current duplex mode of the interface (string). |
| `carrier_errors` | Number of times carrier was lost or never detected on a transmission attempt (`long`). |
| `collisions` | Ethernet collisions during transmit (`long`). |
| `ex_collisions` | Frames where excess collisions occurred on transmit, causing transmit failure (`long`). |
| `tx_late_collisions` | Number of times a transmit collision occurred late, that is, after 512 bit times (`long`). |
| `defer_xmts` | Packets without collisions where first transmit attempt was delayed because the medium was busy (`long`). |
| `first_collisions` | Packets successfully transmitted with exactly one collision. |
| `multi_collisions` | Packets successfully transmitted with multiple collisions. |
| `sqe_errors` | Number of times that SQE test error was reported. |
| `macxmt_errors` | Packets encountering transmit MAC failures, except carrier and collision failures. |
| `macrcv_errors` | Packets received with MAC errors, except `align_errors`, `fcs_errors`, and `toolong_errors`. |

| | |
|---|---|
| `toolong_errors` | Packets received larger than the maximum permitted length. |
| `runt_errors` | Packets received smaller than the minimum permitted length (`long`). |

The following group of statistics applies to networks of type `DL_TPR`. These statistics are maintained by device-specific drivers of that type, as shown above.

| | |
|---|---|
| `line_errors` | Packets received with non-data bits or FCS errors. |
| `burst_errors` | Number of times an absence of transitions for five half-bit timers was detected. |
| `signal_losses` | Number of times loss of signal condition on the ring was detected. |
| `ace_errors` | Number of times that an AMP or SMP frame, in which A is equal to C is equal to 0, is followed by another SMP frame without an intervening AMP frame. |
| `internal_errors` | Number of times the station recognized an internal error. |
| `lost_frame_errors` | Number of times the TRR timer expired during transmit. |
| `frame_copied_errors` | Number of times a frame addressed to this station was received with the FS field 'A' bit set to `1`. |
| `token_errors` | Number of times the station acting as the active monitor recognized an error condition that needed a token transmitted. |
| `freq_errors` | Number of times the frequency of the incoming signal differed from the expected frequency. |

The following group of statistics applies to networks of type `DL_FDDI`. These statistics are maintained by device-specific drivers of that type, as shown above.

| | |
|---|---|
| `mac_errors` | Frames detected in error by this MAC that had not been detected in error by another MAC. |
| `mac_lost_errors` | Frames received with format errors such that the frame was stripped. |
| `mac_tokens` | Number of tokens that were received, that is, the total of non-restricted and restricted tokens. |
| `mac_tvx_expired` | Number of times that TVX has expired. |
| `mac_late` | Number of TRT expirations since either this MAC was reset or a token was received. |
| `mac_ring_ops` | Number of times the ring has entered the "Ring Operational" state from the "Ring Not Operational" state. |

# Declarations and Data Structures

This section describes the `gld_mac_info`(9S) and `gld_stats` structures.

## `gld_mac_info` Structure

The GLD MAC information (`gld_mac_info`) structure is the main data interface that links the device-specific driver with GLD. This structure contains data required by GLD and a pointer to an optional additional driver-specific information structure.

Allocate the `gld_mac_info` structure using `gld_mac_alloc()`. Deallocate the structure using `gld_mac_free()`. Drivers must not make any assumptions about the length of this structure, which might vary in different releases of the Solaris OS, GLD, or both. Structure members private to GLD, not documented here, should neither be set nor be read by the device-specific driver.

The `gld_mac_info`(9S) structure contains the following fields.

```
caddr_t          gldm_private;          /* Driver private data */
int          (*gldm_reset)();       /* Reset device */
int          (*gldm_start)();       /* Start device */
int          (*gldm_stop)();        /* Stop device */
int          (*gldm_set_mac_addr)();    /* Set device phys addr */
int          (*gldm_set_multicast)();   /* Set/delete multicast addr */
int          (*gldm_set_promiscuous)(); /* Set/reset promiscuous mode */
int          (*gldm_send)();        /* Transmit routine */
uint_t           (*gldm_intr)();        /* Interrupt handler */
int          (*gldm_get_stats)();       /* Get device statistics */
int          (*gldm_ioctl)();       /* Driver-specific ioctls */
char         *gldm_ident;           /* Driver identity string */
uint32_t         gldm_type;         /* Device type */
uint32_t         gldm_minpkt;           /* Minimum packet size */
                          /* accepted by driver */
uint32_t         gldm_maxpkt;           /* Maximum packet size */
                          /* accepted by driver */
uint32_t         gldm_addrlen;          /* Physical address length */
int32_t          gldm_saplen;           /* SAP length for DL_INFO_ACK */
unsigned char    *gldm_broadcast_addr;      /* Physical broadcast addr */
unsigned char    *gldm_vendor_addr;     /* Factory MAC address */
t_uscalar_t      gldm_ppa;          /* Physical Point of */
                         /* Attachment (PPA) number */
dev_info_t       *gldm_devinfo;         /* Pointer to device's */
                         /* dev_info node */
ddi_iblock_cookie_t  gldm_cookie;           /* Device's interrupt */
                         /* block cookie */
```

The gldm_private structure member is visible to the device driver. gldm_private is also private to the device-specific driver. gldm_private is not used or modified by GLD. Conventionally, gldm_private is used as a pointer to private data, pointing to a per-instance data structure that is both defined and allocated by the driver.

The following group of structure members must be set by the driver before calling gld_register(), and should not thereafter be modified by the driver. Because gld_register() might use or cache the values of structure members, changes made by the driver after calling gld_register() might cause unpredictable results. For more information on these structures, see the gld(9E) man page.

| | |
|---|---|
| gldm_reset | Pointer to driver entry point. |
| gldm_start | Pointer to driver entry point. |
| gldm_stop | Pointer to driver entry point. |
| gldm_set_mac_addr | Pointer to driver entry point. |
| gldm_set_multicast | Pointer to driver entry point. |
| gldm_set_promiscuous | Pointer to driver entry point. |
| gldm_send | Pointer to driver entry point. |
| gldm_intr | Pointer to driver entry point. |
| gldm_get_stats | Pointer to driver entry point. |
| gldm_ioctl | Pointer to driver entry point. This pointer is allowed to be NULL. |
| gldm_ident | Pointer to a string that contains a short description of the device. This pointer is used to identify the device in system messages. |
| gldm_type | Type of device the driver handles. GLD currently supports the following values:<br>■ DL_ETHER (ISO 8802-3 (IEEE 802.3) and Ethernet Bus)<br>■ DL_TPR (IEEE 802.5 Token Passing Ring)<br>■ DL_FDDI (ISO 9314-2 Fibre Distributed Data Interface)<br>This structure member must be correctly set for GLD to function properly. |
| gldm_minpkt | Minimum *Service Data Unit* size: the minimum packet size, not including the MAC header, that the device can transmit. This size is allowed to be zero if the device-specific driver handles any required padding. |

| | |
|---|---|
| `gldm_maxpkt` | Maximum *Service Data Unit* size: the maximum size of packet, not including the MAC header, that can be transmitted by the device. For Ethernet, this number is 1500. |
| `gldm_addrlen` | The length in bytes of physical addresses handled by the device. For Ethernet, Token Ring, and FDDI, the value of this structure member should be 6. |
| `gldm_saplen` | The length in bytes of the SAP address used by the driver. For GLD-based drivers, the length should always be set to `-2`. A length of `-2` indicates that 2-byte SAP values are supported and that the SAP appears *after* the physical address in a DLSAP address. See Appendix A.2, "Message DL_INFO_ACK," in the DLPI specification for more details. |
| `gldm_broadcast_addr` | Pointer to an array of bytes of length `gldm_addrlen` containing the broadcast address to be used for transmit. The driver must provide space to hold the broadcast address, fill the space with the appropriate value, and set `gldm_broadcast_addr` to point to the address. For Ethernet, Token Ring, and FDDI, the broadcast address is normally `0xFF-FF-FF-FF-FF-FF`. |
| `gldm_vendor_addr` | Pointer to an array of bytes of length `gldm_addrlen` that contains the vendor-provided network physical address of the device. The driver must provide space to hold the address, fill the space with information from the device, and set `gldm_vendor_addr` to point to the address. |
| `gldm_ppa` | PPA number for this instance of the device. The PPA number should always be set to the instance number that is returned from `ddi_get_instance`(9F). |
| `gldm_devinfo` | Pointer to the `dev_info` node for this device. |
| `gldm_cookie` | Interrupt block cookie returned by one of the following routines:<br>■ `ddi_get_iblock_cookie`(9F)<br>■ `ddi_add_intr`(9F)<br>■ `ddi_get_soft_iblock_cookie`(9F)<br>■ `ddi_add_softintr`(9F)<br>This cookie must correspond to the device's receive-interrupt, from which `gld_recv()` is called. |

# gld_stats Structure

After calling gldm_get_stats(), a GLD-based driver uses the (gld_stats) structure to communicate statistics and state information to GLD. See the gld(9E) and gld(7D) man pages. The members of this structure, having been filled in by the GLD-based driver, are used when GLD reports the statistics. In the tables below, the name of the statistics variable reported by GLD is noted in the comments. See the gld(7D) man page for a more detailed description of the meaning of each statistic.

Drivers must not make any assumptions about the length of this structure. The structure length might vary in different releases of the Solaris Operating System, GLD, or both. Structure members private to GLD, which are not documented here, should not be set or be read by the device-specific driver.

The following structure members are defined for all media types:

```
uint64_t    glds_speed;             /* ifspeed */
uint32_t    glds_media;             /* media */
uint32_t    glds_intr;              /* intr */
uint32_t    glds_norcvbuf;              /* norcvbuf */
uint32_t    glds_errrcv;            /* ierrors */
uint32_t    glds_errxmt;            /* oerrors */
uint32_t    glds_missed;            /* missed */
uint32_t    glds_underflow;             /* uflo */
uint32_t    glds_overflow;              /* oflo */
```

The following structure members are defined for media type DL_ETHER:

```
uint32_t    glds_frame;             /* align_errors */
uint32_t    glds_crc;               /* fcs_errors */
uint32_t    glds_duplex;            /* duplex */
uint32_t    glds_nocarrier;             /* carrier_errors */
uint32_t    glds_collisions;            /* collisions */
uint32_t    glds_excoll;            /* ex_collisions */
uint32_t    glds_xmtlatecoll;           /* tx_late_collisions */
uint32_t    glds_defer;             /* defer_xmts */
uint32_t    glds_dot3_first_coll;           /* first_collisions */
uint32_t    glds_dot3_multi_coll;           /* multi_collisions */
uint32_t    glds_dot3_sqe_error;        /* sqe_errors */
uint32_t    glds_dot3_mac_xmt_error;        /* macxmt_errors */
uint32_t    glds_dot3_mac_rcv_error;        /* macrcv_errors */
uint32_t    glds_dot3_frame_too_long;       /* toolong_errors */
uint32_t    glds_short;             /* runt_errors */
```

The following structure members are defined for media type DL_TPR:

```
uint32_t    glds_dot5_line_error         /* line_errors */
uint32_t    glds_dot5_burst_error        /* burst_errors */
uint32_t    glds_dot5_signal_loss        /* signal_losses */
uint32_t    glds_dot5_ace_error          /* ace_errors */
uint32_t    glds_dot5_internal_error     /* internal_errors */
uint32_t    glds_dot5_lost_frame_error       /* lost_frame_errors */
uint32_t    glds_dot5_frame_copied_error     /* frame_copied_errors */
```

```
uint32_t    glds_dot5_token_error        /* token_errors */
uint32_t    glds_dot5_freq_error         /* freq_errors */
```

The following structure members are defined for media type `DL_FDDI`:

```
uint32_t    glds_fddi_mac_error;        /* mac_errors */
uint32_t    glds_fddi_mac_lost;         /* mac_lost_errors */
uint32_t    glds_fddi_mac_token;        /* mac_tokens */
uint32_t    glds_fddi_mac_tvx_expired;      /* mac_tvx_expired */
uint32_t    glds_fddi_mac_late;         /* mac_late */
uint32_t    glds_fddi_mac_ring_op;          /* mac_ring_ops */
```

Most of the above statistics variables are counters that denote the number of times that the particular event was observed. The following statistics do not represent the number of times:

`glds_speed` Estimate of the interface's current bandwidth in bits per second. This object should contain the nominal bandwidth for those interfaces that do not vary in bandwidth or where an accurate estimate cannot be made.

`glds_media` Type of media (wiring) or connector used by the hardware. The following media names are supported:

- `GLDM_AUI`
- `GLDM_BNC`
- `GLDM_TP`
- `GLDM_10BT`
- `GLDM_100BT`
- `GLDM_100BTX`
- `GLDM_100BT4`
- `GLDM_RING4`
- `GLDM_RING16`
- `GLDM_FIBER`
- `GLDM_PHYMII`
- `GLDM_UNKNOWN`

`glds_duplex` Current duplex state of the interface. Supported values are `GLD_DUPLEX_HALF` and `GLD_DUPLEX_FULL`. `GLD_DUPLEX_UNKNOWN` is also permitted.

# GLD Arguments

The following arguments are used by the GLD routines.

*macinfo* Pointer to a `gld_mac_info`(9S) structure.

| | |
|---|---|
| *macaddr* | Pointer to the beginning of a character array that contains a valid MAC address. The array is of the length specified by the driver in the `gldm_addrlen` element of the `gld_mac_info`(9S) structure. |
| *multicastaddr* | Pointer to the beginning of a character array that contains a multicast, group, or functional address. The array is of the length specified by the driver in the `gldm_addrlen` element of the `gld_mac_info`(9S) structure. |
| *multiflag* | Flag indicating whether to enable or disable reception of the multicast address. This argument is specified as `GLD_MULTI_ENABLE` or `GLD_MULTI_DISABLE`. |
| *promiscflag* | Flag indicating what type of promiscuous mode, if any, is to be enabled. This argument is specified as `GLD_MAC_PROMISC_PHYS`, `GLD_MAC_PROMISC_MULTI`, or `GLD_MAC_PROMISC_NONE`. |
| *mp* | `gld_ioctl()` uses *mp* as a pointer to a STREAMS message block containing the `ioctl` to be executed. `gldm_send()` uses *mp* as a pointer to a STREAMS message block containing the packet to be transmitted. `gld_recv()` uses *mp* as a pointer to a message block containing a received packet. |
| *stats* | Pointer to a `gld_stats`(9S) structure to be filled in with the current values of statistics counters. |
| *q* | Pointer to the `queue`(9S) structure to be used in the reply to the `ioctl`. |
| *dip* | Pointer to the device's `dev_info` structure. |
| *name* | Device interface name. |

# GLD Entry Points

Entry points must be implemented by a device-specific network driver that has been designed to interface with GLD.

The `gld_mac_info`(9S) structure is the main structure for communication between the device-specific driver and the GLD module. See the `gld`(7D) man page. Some elements in that structure are function pointers to the entry points that are described here. The device-specific driver must, in its `attach`(9E) routine, initialize these function pointers before calling `gld_register()`.

## gldm_reset() Entry Point

```
int prefix_reset(gld_mac_info_t *macinfo);
```

`gldm_reset()` resets the hardware to its initial state.

## gldm_start() Entry Point

```
int prefix_start(gld_mac_info_t *macinfo);
```

`gldm_start()` enables the device to generate interrupts. `gldm_start()` also prepares the driver to call `gld_recv()` to deliver received data packets to GLD.

## gldm_stop() Entry Point

```
int prefix_stop(gld_mac_info_t *macinfo);
```

`gldm_stop()` disables the device from generating any interrupts and stops the driver from calling `gld_recv()` for delivering data packets to GLD. GLD depends on the `gldm_stop()` routine to ensure that the device will no longer interrupt. `gldm_stop()` must do so without fail. This function should always return `GLD_SUCCESS`.

## gldm_set_mac_addr() Entry Point

```
int prefix_set_mac_addr(gld_mac_info_t *macinfo, unsigned char *macaddr);
```

`gldm_set_mac_addr()` sets the physical address that the hardware is to use for receiving data. This function enables the device to be programmed via the passed MAC address *macaddr*. If sufficient resources are currently not available to carry out the request, `gldm_set_mac_add()` should return `GLD_NORESOURCES`. If the requested function is not supported, `gldm_set_mac_add()` should return `GLD_NOTSUPPORTED`.

## gldm_set_multicast() Entry Point

```
int prefix_set_multicast(gld_mac_info_t *macinfo,
     unsigned char *multicastaddr, int multiflag);
```

`gldm_set_multicast()` enables and disables device-level reception of specific multicast addresses. If the third argument *multiflag* is set to `GLD_MULTI_ENABLE`, then `gldm_set_multicast()` sets the interface to receive packets with the multicast address. `gldm_set_multicast()` uses the multicast address that is pointed to by the second argument. If *multiflag* is set to `GLD_MULTI_DISABLE`, the driver is allowed to disable reception of the specified multicast address.

This function is called whenever GLD wants to enable or disable reception of a multicast, group, or functional address. GLD makes no assumptions about how the device does multicast support and calls this function to enable or disable a specific multicast address. Some devices might use a hash algorithm and a bitmask to enable collections of multicast addresses. This procedure is allowed, and GLD filters out any superfluous packets. If disabling an address could result in disabling more than one address at the device level, the device driver should keep any necessary information. This approach avoids disabling an address that GLD has enabled but not disabled.

`gldm_set_multicast()` is not called to enable a particular multicast address that is already enabled. Similarly, `gldm_set_multicast()` is not called to disable an address that is not currently enabled. GLD keeps track of multiple requests for the same multicast address. GLD only calls the driver's entry point when the first request to enable, or the last request to disable, a particular multicast address is made. If sufficient resources are currently not available to carry out the request, the function should return `GLD_NORESOURCES`. The function should return `GLD_NOTSUPPORTED` if the requested function is not supported.

## `gldm_set_promiscuous()` Entry Point

`int` *prefix*`_set_promiscuous(gld_mac_info_t *`*macinfo*`, int` *promiscflag*`);`

`gldm_set_promiscuous()` enables and disables promiscuous mode. This function is called whenever GLD wants to enable or disable the reception of all packets on the medium. The function can also be limited to multicast packets on the medium. If the second argument *promiscflag* is set to the value of `GLD_MAC_PROMISC_PHYS`, then the function enables physical-level promiscuous mode. Physical-level promiscuous mode causes the reception of all packets on the medium. If *promiscflag* is set to `GLD_MAC_PROMISC_MULTI`, then reception of all multicast packets are enabled. If *promiscflag* is set to `GLD_MAC_PROMISC_NONE`, then promiscuous mode is disabled.

In promiscuous multicast mode, drivers for devices without multicast-only promiscuous mode must set the device to physical promiscuous mode. This approach ensures that all multicast packets are received. In this case, the routine should return `GLD_SUCCESS`. The GLD software filters out any superfluous packets. If sufficient resources are currently not available to carry out the request, the function should return `GLD_NORESOURCES`. `gld_set_promiscuous()` should return `GLD_NOTSUPPORTED` if the requested function is not supported.

For forward compatibility, `gldm_set_promiscuous()` routines should treat any unrecognized values for *promiscflag* as though these values were `GLD_MAC_PROMISC_PHYS`.

## `gldm_send()` Entry Point

```
int prefix_send(gld_mac_info_t *macinfo, mblk_t *mp);
```

`gldm_send()` queues a packet to the device for transmission. This routine is passed a STREAMS message containing the packet to be sent. The message might include multiple message blocks.The `send()` routine must traverse all the message blocks in the message to access the entire packet to be sent. The driver should be prepared to handle and skip over any zero-length message continuation blocks in the chain. The driver should also check that the packet does not exceed the maximum allowable packet size. The driver must pad the packet, if necessary, to the minimum allowable packet size. If the send routine successfully transmits or queues the packet, `GLD_SUCCESS` should be returned.

The send routine should return `GLD_NORESOURCES` if the packet for transmission cannot be immediately accepted. In this case, GLD retries later. If `gldm_send()` ever returns `GLD_NORESOURCES`, the driver must call `gld_sched()` at a later time when resources have become available. This call to `gld_sched()` informs GLD to retry packets that the driver previously failed to queue for transmission. (If the driver's `gldm_stop()` routine is called, the driver is absolved from this obligation until the driver returns `GLD_NORESOURCES` from the `gldm_send()` routine. However, extra calls to `gld_sched()` do not cause incorrect operation.)

If the driver's send routine returns `GLD_SUCCESS`, then the driver is responsible for freeing the message when the message is no longer needed. If the hardware uses DMA to read the data directly, the driver must not free the message until the hardware has completely read the data. In this case, the driver can free the message in the interrupt routine. Alternatively, the driver can reclaim the buffer at the start of a future send operation. If the send routine returns anything other than `GLD_SUCCESS`, then the driver must not free the message. Return `GLD_NOLINK` if `gldm_send()` is called when there is no physical connection to the network or link partner.

## `gldm_intr()` Entry Point

```
int prefix_intr(gld_mac_info_t *macinfo);
```

`gldm_intr()` is called when the device might have interrupted. Because interrupts can be shared with other devices, the driver must check the device status to determine whether that device actually caused the interrupt. If the device that the driver controls did not cause the interrupt, then this routine must return `DDI_INTR_UNCLAIMED`. Otherwise, the driver must service the interrupt and return `DDI_INTR_CLAIMED`. If the interrupt was caused by successful receipt of a packet, this routine should put the received packet into a STREAMS message of type `M_DATA` and pass that message to `gld_recv()`.

`gld_recv()` passes the inbound packet upstream to the appropriate next layer of the network protocol stack. The routine must correctly set the `b_rptr` and `b_wptr` members of the STREAMS message before calling `gld_recv()`.

The driver should avoid holding mutex or other locks during the call to `gld_recv()`. In particular, locks that could be taken by a transmit thread must not be held during a call to `gld_recv()`. In some cases, the interrupt thread that calls `gld_recv()` sends an outgoing packet, which results in a call to the driver's `gldm_send()` routine. If `gldm_send()` tries to acquire a mutex that is held by `gldm_intr()` when `gld_recv()` is called, a panic occurs due to recursive mutex entry. If other driver entry points attempt to acquire a mutex that the driver holds across a call to `gld_recv()`, deadlock can result.

The interrupt code should increment statistics counters for any errors. Errors include the failure to allocate a buffer that is needed for the received data and any hardware-specific errors, such as CRC errors or framing errors.

## `gldm_get_stats()` Entry Point

```
int prefix_get_stats(gld_mac_info_t *macinfo, struct gld_stats *stats);
```

`gldm_get_stats()` gathers statistics from the hardware, driver private counters, or both, and updates the `gld_stats`(9S) structure pointed to by *stats*. This routine is called by GLD for statistics requests. GLD uses the `gldm_get_stats()` mechanism to acquire device-dependent statistics from the driver before GLD composes the reply to the statistics request. See the `gld_stats`(9S), `gld`(7D), and `qreply`(9F) man pages for more information about defined statistics counters.

## `gldm_ioctl()` Entry Point

```
int prefix_ioctl(gld_mac_info_t *macinfo, queue_t *q, mblk_t *mp);
```

gldm_ioctl() implements any device-specific ioctl commands. This element is allowed to be NULL if the driver does not implement any ioctl functions. The driver is responsible for converting the message block into an ioctl reply message and calling the qreply(9F) function before returning GLD_SUCCESS. This function should always return GLD_SUCCESS. The driver should report any errors as needed in a message to be passed to qreply(9F). If the gldm_ioctl element is specified as NULL, GLD returns a message of type M_IOCNAK with an error of EINVAL.

## GLD Return Values

Some entry point functions in GLD can return the following values, subject to the restrictions above:

| | |
|---|---|
| GLD_BADARG | If the function detected an unsuitable argument, for example, a bad multicast address, a bad MAC address, or a bad packet |
| GLD_FAILURE | On hardware failure |
| GLD_SUCCESS | On success |

# GLD Service Routines

This section provides the syntax and description for the GLD service routines.

## gld_mac_alloc() Function

```
gld_mac_info_t *gld_mac_alloc(dev_info_t *dip);
```

gld_mac_alloc() allocates a new gld_mac_info(9S) structure and returns a pointer to the structure. Some of the GLD-private elements of the structure might be initialized before gld_mac_alloc() returns. All other elements are initialized to zero. The device driver must initialize some structure members, as described in the gld_mac_info(9S) man page, before passing the pointer to the gld_mac_info structure to gld_register().

## gld_mac_free() Function

```
void gld_mac_free(gld_mac_info_t *macinfo);
```

`gld_mac_free()` frees a `gld_mac_info`(9S) structure previously allocated by `gld_mac_alloc()`.

## `gld_register()` Function

```
int gld_register(dev_info_t *dip, char *name, gld_mac_info_t *macinfo);
```

`gld_register()` is called from the device driver's `attach`(9E) routine. `gld_register()` links the GLD-based device driver with the GLD framework. Before calling `gld_register()`, the device driver's `attach`(9E) routine uses `gld_mac_alloc()` to allocate a `gld_mac_info`(9S) structure, and then initializes several structure elements. See `gld_mac_info`(9S) for more information. A successful call to `gld_register()` performs the following actions:

- Links the device-specific driver with the GLD system
- Sets the device-specific driver's private data pointer, using `ddi_set_driver_private`(9F) to point to the `macinfo` structure
- Creates the minor device node
- Returns `DDI_SUCCESS`

The device interface name passed to `gld_register()` must exactly match the name of the driver module as that name exists in the file system.

The driver's `attach`(9E) routine should return `DDI_SUCCESS` if `gld_register()` succeeds. If `gld_register()` does not return `DDI_SUCCESS`, the `attach`(9E) routine should deallocate any allocated resources before calling `gld_register()`, and then return `DDI_FAILURE`.

## `gld_unregister()` Function

```
int gld_unregister(gld_mac_info_t *macinfo);
```

`gld_unregister()` is called by the device driver's `detach`(9E) function, and if successful, performs the following tasks:

- Ensures that the device's interrupts are stopped, calling the driver's `gldm_stop()` routine if necessary
- Removes the minor device node
- Unlinks the device-specific driver from the GLD system
- Returns `DDI_SUCCESS`

If gld_unregister() returns DDI_SUCCESS, the detach(9E) routine should deallocate any data structures allocated in the attach(9E) routine, using gld_mac_free() to deallocate the macinfo structure, and return DDI_SUCCESS. If gld_unregister() does not return DDI_SUCCESS, the driver's detach(9E) routine must leave the device operational and return DDI_FAILURE.

## gld_recv() Function

```
void gld_recv(gld_mac_info_t *macinfo, mblk_t *mp);
```

gld_recv() is called by the driver's interrupt handler to pass a received packet upstream. The driver must construct and pass a STREAMS M_DATA message containing the raw packet. gld_recv() determines which STREAMS queues should receive a copy of the packet, duplicating the packet if necessary. gld_recv() then formats a DL_UNITDATA_IND message, if required, and passes the data up all appropriate streams.

The driver should avoid holding mutex or other locks during the call to gld_recv(). In particular, locks that could be taken by a transmit thread must not be held during a call to gld_recv(). The interrupt thread that calls gld_recv() in some cases carries out processing that includes sending an outgoing packet. Transmission of the packet results in a call to the driver's gldm_send() routine. If gldm_send() tries to acquire a mutex that is held by gldm_intr() when gld_recv() is called, a panic occurs due to a recursive mutex entry. If other driver entry points attempt to acquire a mutex that the driver holds across a call to gld_recv(), deadlock can result.

## gld_sched() Function

```
void gld_sched(gld_mac_info_t *macinfo);
```

gld_sched() is called by the device driver to reschedule stalled outbound packets. Whenever the driver's gldm_send() routine returns GLD_NORESOURCES, the driver must call gld_sched() to inform the GLD framework to retry previously unsendable packets. gld_sched() should be called as soon as possible after resources become available so that GLD resumes passing outbound packets to the driver's gldm_send() routine. (If the driver's gldm_stop() routine is called, the driver need not retry until GLD_NORESOURCES is returned from gldm_send(). However, extra calls to gld_sched() do not cause incorrect operation.)

## gld_intr() Function

```
uint_t gld_intr(caddr_t);
```

`gld_intr()` is GLD's main interrupt handler. Normally, `gld_intr()` is specified as the interrupt routine in the device driver's call to `ddi_add_intr`(9F). The argument to the interrupt handler is specified as *int_handler_arg* in the call to `ddi_add_intr`(9F). This argument must be a pointer to the `gld_mac_info`(9S) structure. `gld_intr()`, when appropriate, calls the device driver's `gldm_intr()` function, passing that pointer to the `gld_mac_info`(9S) structure. However, to use a high-level interrupt, the driver must provide its own high-level interrupt handler and trigger a soft interrupt from within the handler. In this case, `gld_intr()` would normally be specified as the soft interrupt handler in the call to `ddi_add_softintr()`. `gld_intr()` returns a value that is appropriate for an interrupt handler.

CHAPTER 19

# USB Drivers

This chapter describes how to write a client USB device driver using the USBA 2.0 framework for the Solaris environment. This chapter discusses the following topics:



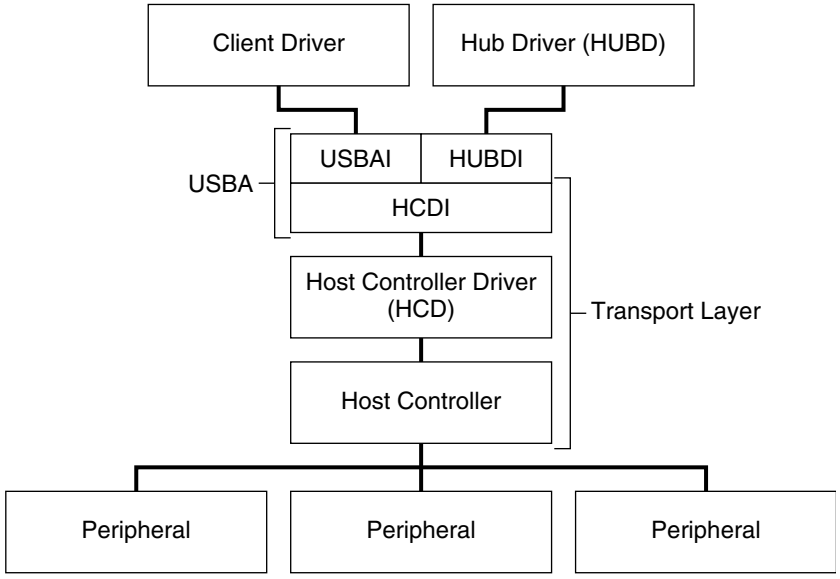
## USB in the Solaris Environment

The Solaris USB architecture includes the USBA 2.0 framework and USB client drivers.

### USBA 2.0 Framework

The USBA 2.0 framework is a service layer that presents an abstract view of USB devices to USBA-compliant client drivers. The framework enables USBA-compliant client drivers to manage their USB devices. The USBA 2.0 framework supports the USB 2.0 specification except for high speed isochronous pipes. For information on the USB 2.0 specification, see `http://www.usb.org/`.

The USBA 2.0 framework is platform-independent. The Solaris USB architecture is shown in the following figure. The USBA 2.0 framework is the USBA layer in the figure. This layer interfaces through a hardware-independent host controller driver interface to hardware-specific host controller drivers. The host controller drivers access the physical devices through the host controllers they manage.




USBAI: Solaris USB Architecture Interfaces, Interfaces between USBA and client drivers

HUBDI: Hub Driver Interfaces

HCDI: Host Controller Driver Interfaces

**FIGURE 19–1** Solaris USB Architecture

# USB Client Drivers

The USBA 2.0 framework is not a device driver itself. This chapter describes the client drivers shown in Figure 19–1 and Figure 19–2.

The USBA 2.0 framework supplements the standard Solaris DDI routines. USB drivers have the same structure as any other Solaris driver. USB drivers can be block drivers, character drivers, or STREAMS drivers. USB drivers follow the calling conventions and use the data structures and routines described in the Solaris 9F, 9S, and 9E man page sections.

The difference between USB drivers and other Solaris drivers is that USB drivers call USBA 2.0 framework functions to access the device instead of directly accessing the device. See the following figure.

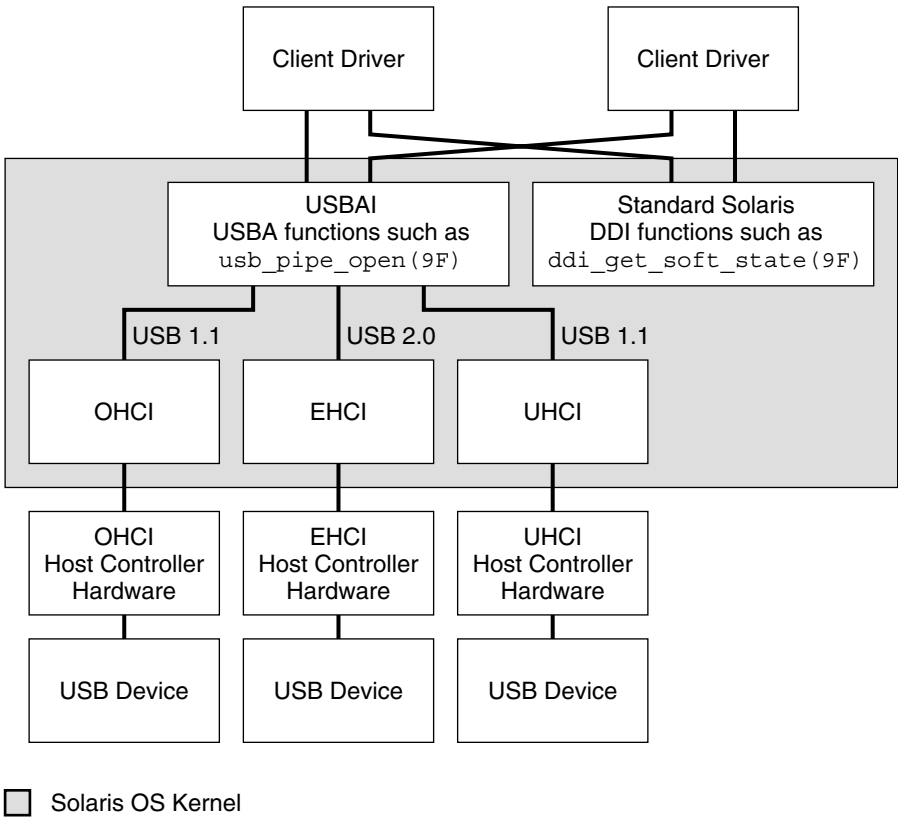



**FIGURE 19–2** Driver and Controller Interfaces

Figure 19–2 shows interfaces in more detail than Figure 19–1 does. Figure 19–2 shows that the USBA is a kernel subsystem into which a client driver can call, just as a client driver can call DDI functions.

Not all systems have all of the host controller interfaces shown in the USB portion of Figure 19–2. OHCI (Open Host Controller Interface) hardware is most prevalent on SPARC systems and third-party USB PCI cards. UHCI (Universal Host Controller Interface) hardware is most prevalent on x86 systems. However, both OHCI and UHCI hardware can be used on any system. When EHCI (Enhanced Host Controller Interface) hardware is present, the EHCI hardware is on the same card and shares the same ports with either OHCI or UHCI.

The host controllers, host controller drivers, and HCDI make up a transport layer that is commanded by the USBA. You cannot directly call into the OHCI, EHCI, or UHCI. You call into them indirectly through the platform-independent USBA interface.

# Binding Client Drivers

This section discusses binding a driver to a device. This section discusses compatible device names for devices with single interfaces and devices with multiple interfaces.

## How USB Devices Appear to the System

A USB device can support multiple configurations. Only one configuration is active at any given time. The active configuration is called the *current configuration*.

A configuration can have more than one *interface*. All interfaces of a configuration are active simultaneously. Different interfaces might be operated by different device drivers.

An interface can represent itself to the host system in different ways by using *alternate settings*. Only one alternate setting is active for any given interface.

Each alternate setting provides device access through *endpoints*. Each endpoint has a specific purpose. The host system communicates with the device by establishing a communication channel to an endpoint. This communication channel is called a *pipe*.

## USB Devices and the Solaris Device Tree

If a USB device has one configuration, one interface, and device class zero, the device is represented as a single *device node*. If a USB device has multiple interfaces, the device is represented as a hierarchical device structure. In a hierarchical device structure, the device node for each interface is a child of the top-level device node. An example of a device with multiple interfaces is an audio device that presents simultaneously to the host computer both an audio control interface and an audio streaming interface. The audio control interface and the audio streaming interface each could be controlled by its own driver.

## Compatible Device Names

The Solaris software builds an ordered list of compatible device names for USB binding based on identification information kept within each device. This information includes device class, subclass, vendor ID, product ID, revision, and protocol. See `http://www.usb.org/` for a list of USB classes and subclasses.

This name hierarchy enables binding to a general driver if a more device-specific driver is not available. An example of a general driver is a class-specific driver. Device names that begin with `usbif` designate single interface devices. See Example 19–1 for examples. The USBA 2.0 framework defines all compatible names for a device. Use the `prtconf` command to display these device names, as shown in Example 19–2.

The following example shows an example of compatible device names for a USB mouse device. This mouse device represents a combined node entirely operated by a single driver. The USBA 2.0 framework gives this device node the names shown in the example, in the order shown.

**EXAMPLE 19–1** USB Mouse Compatible Device Names

```
 1. 'usb430,100.102'      Vendor 430, product 100, revision 102
 2. 'usb430,100'      Vendor 430, product 100
 3. 'usbif430,class3.1.2' Vendor 430, class 3, subclass 1, protocol 2
 4. 'usbif430,class3.1'   Vendor 430, class 3, subclass 1
 5. 'usbif430,class3'     Vendor 430, class 3
 6. 'usbif,class3.1.2'    Class 3, subclass 1, protocol 2
 7. 'usbif,class3.1'      Class 3, subclass 1
 8. 'usbif,class3'    Class 3
```

Note that the names in the above example progress from the most specific to the most general. Entry 1 binds only to a particular revision of a specific product from a particular vendor. Entries 3, 4, and 5 are for class 3 devices manufactured by vendor 430. Entries 6, 7, and 8 are for class 3 devices from any vendor. The binding process looks for a match on the name from the top name down. To bind, drivers must be added to the system with an alias that matches one of these names. To get a list of compatible device names to which to bind when you add your driver, check the `compatible` property of the device in the output from the `prtconf -vp` command.

The following example shows compatible property lists for a keyboard and a mouse. Use the `prtconf -D` command to display the bound driver.

**EXAMPLE 19–2** Compatible Device Names Shown by the Print Configuration Command

```
# prtconf -vp | grep compatible
            compatible: 'usb430,5.200' + 'usb430,5' + 'usbif430,class3.1.1'
+ 'usbif430,class3.1' + 'usbif430,class3' + 'usbif,class3.1.1' +
'usbif,class3.1' + 'usbif,class3'
            compatible: 'usb2222,2071.200' + 'usb2222,2071' +
'usbif2222,class3.1.2' + 'usbif2222,class3.1' + 'usbif2222,class3' +
'usbif,class3.1.2' + 'usbif,class3.1' + 'usbif,class3'
```

Use the most specific name you can to more accurately identify a driver for a device or group of devices. To bind drivers written for a specific revision of a specific product, use the most specific name match possible. For example, if you have a USB mouse driver written by vendor 430 for revision 102 of their product 100, use the following command to add that driver to the system:

```
add_drv -n -i '"usb430,100.102"' specific_mouse_driver
```

To add a driver written for any USB mouse (class 3, subclass 1, protocol 2) from vendor 430, use the following command:

```
add_drv -n -i '"usbif430,class3.1.2"' more_generic_mouse_driver
```

If you install both of these drivers and then connect a compatible device, the system binds the correct driver to the connected device. For example, if you install both of these drivers and then connect a vendor 430, model 100, revision 102 device, this

device is bound to `specific_mouse_driver`. If you connect a vendor 430, model 98 device, this device is bound to `more_generic_mouse_driver`. If you connect a mouse from another vendor, this device also is bound to `more_generic_mouse_driver`. Even if multiple devices are connected simultaneously, the system binds the correct driver to each device. The system looks through the entire list of compatible device names until it finds a matching driver.

## Devices With Multiple Interfaces

*Composite devices* are devices that support multiple interfaces. Composite devices have compatible device name entries similar to the names shown in the previous section. The most general multiple interface entry is `usb,device`.

For a USB audio composite device, the compatible names are as follows:

```
1. 'usb471,101.100'     Vendor 471, product 101, revision 100
2. 'usb471,101'         Vendor 471, product 101
3. 'usb,device'         Generic USB device
```

The name `usb,device` is a compatible name that represents any whole USB device. The `usb_mid`(7D) driver (USB multiple-interface driver) binds to the `usb,device` device node if no other drivers have claimed the whole device. The `usb_mid` driver creates a child device node for each interface of the physical device. The `usb_mid` driver also generates a set of compatible names for each interface. Each of these generated compatible names begins with `usbif`. The system then uses these generated compatible names to find the best driver for each interface. In this way, different interfaces of one physical device can be bound to different drivers.

For example, the `usb_mid` driver binds to a multiple-interface audio device through the `usb,device` node name of that audio device. The `usb_mid` driver then creates interface-specific device nodes. Each of these interface-specific device nodes has its own compatible name list. For an audio control interface node, the compatible name list might look like the list shown in the following example.

**EXAMPLE 19–3** USB Audio Compatible Device Names

```
1. 'usbif471,101.100.config1.0' Vend 471, prod 101, rev 100, cnfg 1, iface 0
2. 'usbif471,101.config1.0'     Vend 471, product 101, config 1, interface 0
3. 'usbif471,class1.1.0'    Vend 471, class 1, subclass 1, protocol 0
4. 'usbif471,class1.1'      Vend 471, class 1, subclass 1
5. 'usbif471,class1'        Vend 471, class 1
6. 'usbif,class1.1.0'       Class 1, subclass 1, protocol 0
7. 'usbif,class1.1'         Class 1, subclass 1
8. 'usbif,class1'           Class 1
```

Use the following command to bind a vendor-specific, device-specific client driver named `vendor_model_audio_usb` to the vendor-specific, device-specific configuration 1, interface 0 interface compatible name shown in Example 19–3.

```
add_drv -n -i '"usbif471,101.config1.0"' vendor_model_audio_usb
```

Use the following command to bind a class driver named `audio_class_usb_if_driver` to the more general class 1, subclass 1 interface compatible name shown in Example 19–3:

```
add_drv -n -i '"usbif,class1.1"' audio_class_usb_if_driver
```

Use the `prtconf -D` command to show a list of devices and their drivers. In the following example, the `prtconf -D` command shows that the `usb_mid` driver manages the `audio` device. The `usb_mid` driver is splitting the `audio` device into interfaces. Each interface is indented under the `audio` device name. For each interface shown in the indented list, the `prtconf -D` command shows which driver manages the interface.

```
audio, instance #0 (driver name: usb_mid)
    sound-control, instance #2 (driver name: usb_ac)
    sound, instance #2 (driver name: usb_as)
    input, instance #8 (driver name: hid)
```

## Checking Device Driver Bindings

The file `/etc/driver_aliases` contains entries for the bindings that already exist on a system. Each line of the `/etc/driver_aliases` file shows a driver name, followed by a space, followed by a device name. Use this file to check existing device driver bindings.

---

**Note –** Do not edit the `/etc/driver_aliases` file manually. Use the `add_drv`(1M) command to establish a binding. Use the `update_drv`(1M) command to change a binding.

---

# Basic Device Access

This section describes how to access a USB client driver and how to register a driver. This section also discusses the descriptor tree.

## Before the Client Driver Is Attached

The following events take place before the client driver is attached:

1. The PROM (OBP/BIOS) and USBA framework gain access to the device before any client driver is attached.

2. The hub driver probes devices on each of its hub's ports for identity and configuration.
3. The default control pipe to each device is opened, and each device is probed for its device descriptor.
4. Compatible names properties are constructed for each device, using the device and interface descriptors.

The compatible names properties define different parts of the device that can be individually bound to client drivers. These different parts of the device might overlap. Client drivers can bind either to the entire device or to just one interface. See "Binding Client Drivers" on page 384.

## The Descriptor Tree

Parsing descriptors involves aligning structure members at natural boundaries and converting the structure members to the endianness of the host CPU. Parsed standard USB configuration descriptors, interface descriptors, and endpoint descriptors are available to the client driver in the form of a hierarchical tree for each configuration. Any raw class-specific or vendor-specific descriptor information also is available to the client driver in the same hierarchical tree.

Call the `usb_get_dev_data`(9F) function to retrieve the hierarchical descriptor tree. The "SEE ALSO" section of the `usb_get_dev_data`(9F) man page lists the man pages for each standard USB descriptor. Use the `usb_parse_data`(9F) function to parse raw descriptor information.

A descriptor tree for a device with two configurations might look like the tree shown in the following figure.

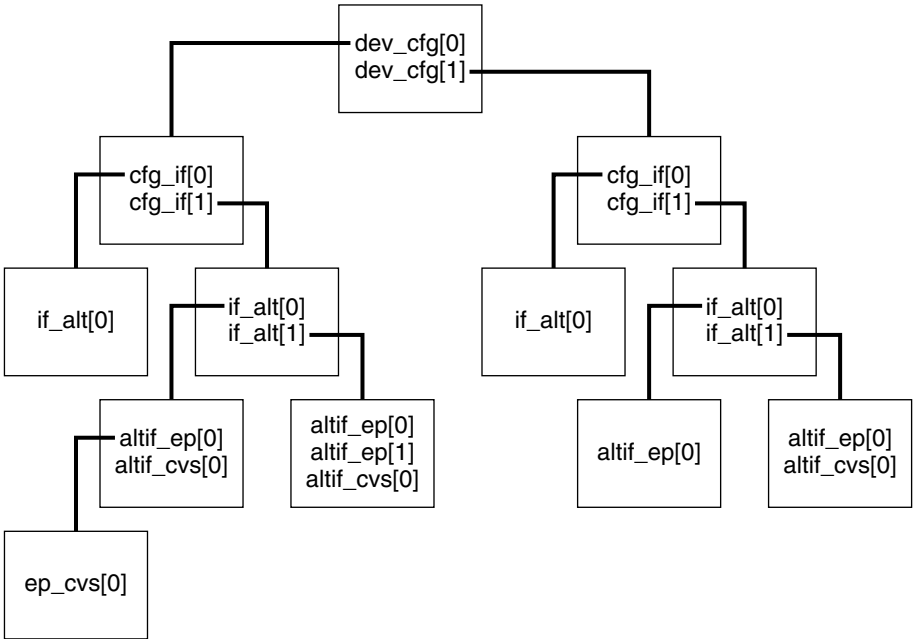



**FIGURE 19–3** A Hierarchical USB Descriptor Tree

The `dev_cfg` array shown in the above figure contains nodes that correspond to configurations. Each node contains the following information:

- A parsed configuration descriptor
- A pointer to an array of descriptors that correspond to the interfaces of that configuration
- A pointer to an array of class-specific or vendor-specific raw data, if any exists

The node that represents the second interface of the second indexed configuration is at `dev_cfg[1].cfg_if[1]` in the diagram. That node contains an array of nodes that represent the alternate settings for that interface. The hierarchy of USB descriptors propagates through the tree. ASCII strings from string descriptor data are attached where the USB specification says these strings exist.

The array of configurations is non-sparse and is indexed by the configuration index. The first valid configuration (configuration 1) is `dev_cfg[0]`. Interfaces and alternate settings have indices that align with their numbers. Endpoints of each alternate setting are indexed consecutively. The first endpoint of each alternate setting is at index 0.

This numbering scheme makes the tree easy to traverse. For example, the raw descriptor data of endpoint index 0, alternate 0, interface 1, configuration index 1 is at the node defined by the following path:

```
dev_cfg[1].cfg_if[1].if_alt[0].altif_ep[0].ep_descr
```

An alternative to using the descriptor tree directly is using the `usb_lookup_ep_data`(9F) function. The `usb_lookup_ep_data`(9F) function takes as arguments the interface, alternate, which endpoint, endpoint type, and direction. You can use the `usb_lookup_ep_data`(9F) function to traverse the descriptor tree to get a particular endpoint. See the `usb_get_dev_data`(9F) man page for more information.

# Registering Drivers to Gain Device Access

Two of the first calls into the USBA 2.0 framework by a client driver are calls to the `usb_client_attach`(9F) function and the `usb_get_dev_data`(9F) function. These two calls come from the client driver's `attach`(9E) entry point. You must call the `usb_client_attach`(9F) function before you call the `usb_get_dev_data`(9F) function.

The `usb_client_attach`(9F) function registers a client driver with the USBA 2.0 framework. The `usb_client_attach`(9F) function enforces versioning. All client driver source files must start with the following lines:

```
#define USBDRV_MAJOR_VER        2
#define USBDRV_MINOR_VER        minor-version
#include <sys/usb/usba.h>
```

The value of *minor-version* must be less than or equal to `USBA_MINOR_VER`. The symbol `USBA_MINOR_VER` is defined in the `<sys/usb/usbai.h>` header file. The `<sys/usb/usbai.h>` header file is included by the `<sys/usb/usba.h>` header file.

`USBDRV_VERSION` is a macro that generates the version number from `USBDRV_MAJOR_VERSION` and `USBDRV_MINOR_VERSION`. The second argument to `usb_client_attach()` must be `USBDRV_VERSION`. The `usb_client_attach()` function fails if the second argument is not `USBDRV_VERSION` or if `USBDRV_VERSION` reflects an invalid version. This restriction ensures programming interface compatibility.

The `usb_get_dev_data()` function returns information that is required for proper USB device management. For example, the `usb_get_dev_data()` function returns the following information:

- The default control pipe
- The *iblock_cookie* to use in mutex initializations (see `mutex_init`(9F))
- The parsed device descriptor
- ID strings
- The tree hierarchy as described in "The Descriptor Tree" on page 388

The call to the `usb_get_dev_data()` function is mandatory. Calling `usb_get_dev_data()` is the only way to retrieve the default control pipe and retrieve the *iblock_cookie* required for mutex initialization.

After calling `usb_get_dev_data()`, the client driver's `attach`(9E) routine typically copies the desired descriptors and data from the descriptor tree to the driver's soft state. Endpoint descriptors copied to the soft state are used later to open pipes to those endpoints. The `attach`(9E) routine usually calls `usb_free_descr_tree`(9F) to free the descriptor tree after copying descriptors. Alternatively, you might choose to keep the descriptor tree and not copy the descriptors.

Specify one of the following three parse levels to the `usb_get_dev_data`(9F) function to request the breadth of the descriptor tree you want returned. You need greater tree breadth if your driver needs to bind to more of the device.

- `USB_PARSE_LVL_IF`. If your client driver binds to a specific interface, the driver needs the descriptors for only that interface. Specify `USB_PARSE_LVL_IF` for the parse level in the `usb_get_dev_data()` call to retrieve only those descriptors.
- `USB_PARSE_LVL_CFG`. If your client driver binds to the whole device, specify `USB_PARSE_LVL_CFG` to retrieve all descriptors of the current configuration.
- `USB_PARSE_LVL_ALL`. Specify `USB_PARSE_LVL_ALL` to retrieve all descriptors of all configurations. For example, you need this greatest tree breadth to use `usb_print_descr_tree`(9F) to print a descriptor dump of all configurations of a device.

The client driver's `detach`(9E) routine must call the `usb_free_dev_data`(9F) function to release all resources allocated by the`usb_get_dev_data()` function. The `usb_free_dev_data()` function accepts handles where the descriptor tree has already been freed with the `usb_free_descr_tree()` function. The client driver's `detach()` routine also must call the `usb_client_detach`(9F) function to release all resources allocated by the `usb_client_attach`(9F) function.

# Device Communication

USB devices operate by passing requests through communication channels called *pipes*. Pipes must be open before you can submit requests. Pipes also can be flushed, queried, and closed. This section discusses pipes, data transfers and callbacks, and data requests.

## USB Endpoints

The four kinds of pipes that communicate with the four kinds of USB endpoints are:

- **Control**. Control pipes are used primarily to send commands and retrieve status. Control pipes are intended for non-periodic, host-initiated request and response communication of small-sized structured data. Control pipes are bidirectional. The default pipe is a control pipe. See "The Default Pipe" on page 392.

- **Bulk**. Bulk pipes are used primarily for data transfer. Bulk pipes offer reliable transportation of large amounts of data. Bulk pipes do not necessarily deliver the data in a timely manner. Bulk pipes are unidirectional.
- **Interrupt**. Interrupt pipes offer timely, reliable communication of small amounts of unstructured data. Periodic polling often is started on interrupt-IN pipes. Interrupt-IN pipes return data to the host when the data becomes present on the device. Some devices have interrupt-OUT pipes. Interrupt-OUT pipes transfer data to the device with the same timely, reliable "interrupt pipe" characteristics of interrupt-IN pipes. Interrupt pipes are unidirectional.
- **Isochronous**. Isochronous pipes offer a channel for transferring constant-rate, time-relevant data, such as for audio devices. Data is not retried on error. Isochronous pipes are unidirectional.

See Chapter 5 of the USB 2.0 specification or see "Requests" on page 395 for more information on the transfer types that correspond to these endpoints.

## The Default Pipe

Each USB device has a special control endpoint called the *default* endpoint. Its communication channel is called the default pipe. Most, if not all, device setup is done through this pipe. Many USB devices have this pipe as their only control pipe.

The `usb_get_dev_data`(9F) function provides the default control pipe to the client driver. This pipe is pre-opened to accommodate any special setup needed before opening other pipes. This default control pipe is special in the following ways:

- This pipe is shared. Drivers that are operating other interfaces of the same device use the same default control pipe. The USBA 2.0 framework arbitrates this pipe among the different drivers.
- This pipe cannot be opened, closed, or reset by the client driver. This restriction exists because the pipe is shared.
- The pipe is autocleared on an exception.

Other pipes, including other control pipes, must be opened explicitly and are exclusive-open only.

## Pipe States

Pipes are in one of the following states:

- `USB_PIPE_STATE_IDLE`
  - All control and bulk pipes, interrupt-OUT pipes, and isochronous-OUT pipes: No request is in progress.
  - Interrupt-IN and isochronous-IN pipes: No polling is in progress.
- `USB_PIPE_STATE_ACTIVE`
  - All control and bulk pipes, interrupt-OUT pipes, and isochronous-OUT pipes: The pipe is transferring data or an I/O request is active.
  - Interrupt-IN and isochronous-IN pipes: Polling is active.
- `USB_PIPE_STATE_ERROR`. An error occurred. If this pipe is not the default pipe and if autoclearing is not enabled, then the client driver must call the `usb_pipe_reset`(9F) function.
- `USB_PIPE_STATE_CLOSING`. The pipe is being closed.
- `USB_PIPE_STATE_CLOSED`. The pipe is closed.

Call the `usb_pipe_get_state`(9F) function to retrieve the state of a pipe.

## Opening Pipes

To open a pipe, pass to the `usb_pipe_open`(9F) function the endpoint descriptor that corresponds to the pipe you want to open. Use the `usb_get_dev_data`(9F) and `usb_lookup_ep_data`(9F) functions to retrieve the endpoint descriptor from the descriptor tree. The `usb_pipe_open`(9F) function returns a handle to the pipe.

You must specify a pipe policy when you open a pipe. The pipe policy contains an estimate of the number of concurrent asynchronous operations that require separate threads that will be needed for this pipe. An estimate of the number of threads is the number of parallel operations that could occur during a callback. The value of this estimate must be at least 2. See the `usb_pipe_open`(9F) man page for more information on pipe policy.

## Closing Pipes

The driver must use the `usb_pipe_close`(9F) function to close pipes other than the default pipe. The `usb_pipe_close`(9F) function enables all remaining requests in the pipe to complete. The function then allows one second for all callbacks of those requests to complete.

# Data Transfer

For all pipe types, the programming model is as follows:

1. Allocate a request.
2. Submit the request using one of the pipe transfer functions. See the `usb_pipe_bulk_xfer`(9F), `usb_pipe_ctrl_xfer`(9F), `usb_pipe_intr_xfer`(9F), and `usb_pipe_isoc_xfer`(9F) man pages.
3. Wait for completion notification.
4. Free the request.

See "Requests" on page 395 for more information on requests. The following sections describe the features of different request types.

## Synchronous and Asynchronous Transfers and Callbacks

Transfers are either synchronous or asynchronous. Synchronous transfers block until they complete. Asynchronous transfers callback into the client driver when they complete. Most transfer functions called with the `USB_FLAGS_SLEEP` flag set in the *flags* argument are synchronous.

Continuous transfers such as polling and isochronous transfers cannot be synchronous. Calls to transfer functions for continuous transfers made with the `USB_FLAGS_SLEEP` flag set block only to wait for resources before the transfer begins.

Synchronous transfers are the most simple transfers to set up because synchronous transfers do not require any callback functions. Synchronous transfers also are the most limited. Synchronous transfer functions return a transfer start status, even though synchronous transfer functions block until the transfer is completed. Upon completion, you can find additional information about the transfer status in the completion reason field and callback flags field of the request. Completion reasons and callback flags fields are discussed below.

When you call a transfer function with the `USB_FLAGS_SLEEP` flag clear in the *flags* argument, that transfer operation is asynchronous. Asynchronous transfer operations set up and start the transfer, and then return before the transfer is complete. Asynchronous transfer operations return a transfer start status. The client driver receives transfer completion status through callback handlers.

Callback handlers are functions that are called when asynchronous transfers complete. Do not set up an asynchronous transfer without callbacks. The two types of callback handlers are:

- **Normal completion**. A normal completion callback handler is called to notify of a normally completed transfer.
- **Exception**. An exception callback handler is called to notify of an abnormally completed transfer and to process its errors.

Both completion handlers and exception handlers receive the transfer's request as an argument. Exception handlers use the completion reason and callback status in the request to find out what happened. The completion reason (`usb_cr_t`) indicates how the original transaction completed. For example, a completion reason of `USB_CR_TIMEOUT` indicates that the transfer timed out. As another example, if a USB device is removed while in use, client drivers might receive `USB_CR_DEV_NOT_RESP` as the completion reason on their outstanding requests. The callback status (`usb_cb_flags_t`) indicates what the USBA framework did to remedy the situation. For example, a callback status of `USB_CB_STALL_CLEARED` indicates that the USBA framework cleared a functional stall condition. See the `usb_completion_reason`(9S) man page for more information on completion reasons. See the `usb_callback_flags`(9S) man page for more information on callback status flags.

The context of the callback and the policy of the pipe on which the requests are run limit what you can do in the callback.

- **Callback context**. Most callbacks execute in kernel context and usually can block. Some callbacks execute in interrupt context and cannot block. The `USB_CB_INTR_CONTEXT` flag is set in the callback flags to denote interrupt context. See the `usb_callback_flags`(9S) man page for more information on callback context and details on blocking.
- **Pipe policy**. The pipe policy's hint on concurrent asynchronous operations limits the number of operations that can be run in parallel, including those executed from a callback handler. Blocking on a synchronous operation counts as one operation. See the `usb_pipe_open`(9F) man page for more information on pipe policy.

## Requests

This section discusses request structures and allocating and deallocating different types of requests.

### *Request Allocation and Deallocation*

Requests are implemented as initialized request structures. Each different endpoint type takes a different type of request. Each type of request has a different request structure type. The following table shows the structure type for each type of request. This table also lists the functions to use to allocate and free each type of structure.

**TABLE 19–1** Request Initialization

| Pipe or Endpoint Type | Request Structure | Request Structure Allocation Function | Request Structure Free Function |
|---|---|---|---|
| Control | `usb_ctrl_req_t` (see the `usb_ctrl_request`(9S) man page) | `usb_alloc_ctrl_req`(9F) | `usb_free_ctrl_req`(9F) |
| Bulk | `usb_bulk_req_t` (see the `usb_bulk_request`(9S) man page) | `usb_alloc_bulk_req`(9F) | `usb_free_bulk_req`(9F) |
| Interrupt | `usb_intr_req_t` (see the `usb_intr_request`(9S) man page) | `usb_alloc_intr_req`(9F) | `usb_free_intr_req`(9F) |
| Isochronous | `usb_isoc_req_t` (see the `usb_isoc_request`(9S) man page) | `usb_alloc_isoc_req`(9F) | `usb_free_isoc_req`(9F) |

The following table lists the transfer functions that you can use for each type of request.

**TABLE 19–2** Request Transfer Setup

| Pipe or Endpoint Type | Transfer Functions |
|---|---|
| Control | `usb_pipe_ctrl_xfer`(9F), `usb_pipe_ctrl_xfer_wait`(9F) |
| Bulk | `usb_pipe_bulk_xfer`(9F) |
| Interrupt | `usb_pipe_intr_xfer`(9F), `usb_pipe_stop_intr_polling`(9F) |
| Isochronous | `usb_pipe_isoc_xfer`(9F), `usb_pipe_stop_isoc_polling`(9F) |

Use the following procedure to allocate and deallocate a request:

1. Use the appropriate allocation function to allocate a request structure for the type of request you need. The man pages for the request structure allocation functions are listed in Table 19–1.
2. Initialize any fields you need in the structure. See "Request Features and Fields" on page 397 or the appropriate request structure man page for more information. The man pages for the request structures are listed in Table 19–1.
3. When the data transfer is complete, use the appropriate free function to free the request structure. The man pages for the request structure free functions are listed in Table 19–1.

### *Request Features and Fields*

Data for all requests is passed in message blocks so that the data is handled uniformly whether the driver is a STREAMS, character, or block driver. The message block type, `mblk_t`, is described in the `mblk`(9S) man page. The Solaris software offers several routines for manipulating message blocks. Examples include `allocb`(9F) and `freemsg`(9F). To learn about other routines for manipulating message blocks, see the "SEE ALSO" sections of the `allocb`(9F) and `freemsg`(9F) man pages. Also see the *STREAMS Programming Guide*.

The following request fields are included in all transfer types. In each field name, the possible values for *xxxx* are: *ctrl*, *bulk*, *intr*, or *isoc*.

| | |
|---|---|
| *xxxx_client_private* | This field value is a pointer that is intended for internal data to be passed around the client driver along with the request. This pointer is not used to transfer data to the device. |
| *xxxx_attributes* | This field value is a set of transfer attributes. While this field is common to all request structures, the initialization of this field is somewhat different for each transfer type. See the appropriate request structure man page for more information. These man pages are listed in Table 19–1. See also the `usb_request_attributes`(9S) man page. |
| *xxxx_cb* | This field value is a callback function for normal transfer completion. This function is called when an asynchronous transfer completes without error. |
| *xxxx_exc_cb* | This field value is a callback function for error handling. This function is called only when asynchronous transfers complete with errors. |
| *xxxx_completion_reason* | This field holds the completion status of the transfer itself. If an error occurred, this field shows what went wrong. See the `usb_completion_reason`(9S) man page for more information. This field is updated by the USBA 2.0 framework. |
| *xxxx_cb_flags* | This field lists the recovery actions that were taken by the USBA 2.0 framework before calling the callback handler. The `USB_CB_INTR_CONTEXT` flag indicates whether a callback is running in interrupt context. See the `usb_callback_flags`(9S) man page for more information. This field is updated by the USBA 2.0 framework. |

The following sections describe the request fields that are different for the four different transfer types. These sections describe how to initialize these structure fields. These sections also describe the restrictions on various combinations of attributes and parameters.

### *Control Requests*

Use control requests to initiate message transfers down a control pipe. You can set up transfers manually, as described below. You can also set up and send synchronous transfers using the `usb_pipe_ctrl_xfer_wait`(9F) wrapper function.

The client driver must initialize the *ctrl_bmRequestType*, *ctrl_bRequest*, *ctrl_wValue*, *ctrl_wIndex*, and *ctrl_wLength* fields as described in the USB 2.0 specification.

The *ctrl_data* field of the request must be initialized to point to a data buffer. The `usb_alloc_ctrl_req`(9F) function initializes this field when you pass a positive value as the buffer *len*. The buffer must, of course, be initialized for any outbound transfers. In all cases, the client driver must free the request when the transfer is complete.

Multiple control requests can be queued. Queued requests can be a combination of synchronous and asynchronous requests.

The *ctrl_timeout* field defines the maximum wait time for the request to be processed, excluding wait time on the queue. This field applies to both synchronous and asynchronous requests. The *ctrl_timeout* field is specified in seconds.

The *ctrl_exc_cb* field accepts the address of a function to call if an exception occurs. The arguments of this exception handler are specified in the `usb_ctrl_request`(9S) man page. The second argument of the exception handler is the `usb_ctrl_req_t` structure. Passing the request structure as an argument allows the exception handler to check the *ctrl_completion_reason* and *ctrl_cb_flags* fields of the request to determine the best recovery action.

The `USB_ATTRS_ONE_XFER` and `USB_ATTRS_ISOC_*` flags are invalid attributes for all control requests. The `USB_ATTRS_SHORT_XFER_OK` flag is valid only for host-bound requests.

### *Bulk Requests*

Use bulk requests to send data that is not time-critical. Bulk requests can take several USB frames to complete, depending on overall bus load.

All requests must receive an initialized message block. See the `mblk`(9S) man page for a description of the `mblk_t` message block type. This message block either supplies the data or stores the data, depending on the transfer direction. Refer to the `usb_bulk_request`(9S) man page for more details.

The `USB_ATTRS_ONE_XFER` and `USB_ATTRS_ISOC_*` flags are invalid attributes for all bulk requests. The `USB_ATTRS_SHORT_XFER_OK` flag is valid only for host-bound requests.

The `usb_pipe_get_max_bulk_transfer_size`(9F) function specifies the maximum number of bytes per request. The value retrieved can be the maximum value used in the client driver's `minphys`(9F) routine.

Multiple bulk requests can be queued.

### *Interrupt Requests*

Interrupt requests typically are for periodic inbound data. Interrupt requests are used to field device requests for service. However, the USBA 2.0 framework supports one-time inbound interrupt data requests, as well as outbound interrupt data requests. All interrupt requests can take advantage of the USB interrupt transfer features of timeliness and retry.

The `USB_ATTRS_ISOC_*` flags are invalid attributes for all interrupt requests. The `USB_ATTRS_SHORT_XFER_OK` and `USB_ATTRS_ONE_XFER` flags are valid only for host-bound requests.

Only one-time polls can be done as synchronous interrupt transfers. Specifying the `USB_ATTRS_ONE_XFER` attribute in the request results in a one-time poll.

Periodic polling is started as an asynchronous interrupt transfer. An original interrupt request is passed to `usb_pipe_intr_xfer`(9F). When polling finds new data to return, a new `usb_intr_req_t` structure is cloned from the original and is populated with an initialized data block. When allocating the request, specify zero for the *len* argument to the `usb_alloc_intr_req`(9F) function. The *len* argument is zero because the USBA 2.0 framework allocates and fills in a new request with each callback. After you allocate the request structure, fill in the *intr_len* field to specify the number of bytes you want the framework to allocate with each poll. Data beyond *intr_len* bytes is not returned.

The client driver must free each request it receives. If the message block is sent upstream, decouple the message block from the request before you send the message block upstream. To decouple the message block from the request, set the data pointer of the request to `NULL`. Setting the data pointer of the request to `NULL` prevents the message block from being freed when the request is deallocated.

Call the `usb_pipe_stop_intr_polling`(9F) function to cancel periodic polling. When polling is stopped or the pipe is closed, the original request structure is returned through an exception callback. This returned request structure has its completion reason set to `USB_CR_STOPPED_POLLING`.

Do not start polling while polling is already in progress. Do not start polling while a call to `usb_pipe_stop_intr_polling`(9F) is in progress.

### *Isochronous Requests*

Isochronous requests are for streaming, constant-rate, time-relevant data. Retries are not made on errors. Isochronous requests have the following request-specific fields:

| | |
|---|---|
| *isoc_frame_no* | Specify this field when the overall transfer must start from a specific frame number. The value of this field must be greater than the current frame number. Use `usb_get_current_frame_number`(9F) to find the current frame number. Note that the current frame number is a moving target. For low-speed and full-speed buses, the current frame is new each millisecond. For high-speed buses, the current frame is new each 0.125 millisecond. Set the `USB_ATTR_ISOC_START_FRAME` attribute so that the *isoc_frame_no* field is recognized.<br><br>To ignore this frame number field and start as soon as possible, set the `USB_ATTR_ISOC_XFER_ASAP` flag. |
| *isoc_pkts_count* | This field is the number of packets in the request. This value is bounded by the value returned by the `usb_get_max_pkts_per_isoc_request`(9F) function and by the size of the *isoc_pkt_descr* array (see below). The number of bytes transferable with this request is equal to the product of this *isoc_pkts_count* value and the *wMaxPacketSize* value of the endpoint. |
| *isoc_pkts_length* | This field is the sum of the lengths of all packets of the request. This value is set by the initiator. |
| *isoc_error_count* | This field is the number of packets that completed with errors. This value is set by the USBA 2.0 framework. |
| *isoc_pkt_descr* | This field points to an array of packet descriptors that define how much data to transfer per packet. For an outgoing request, this value defines a private queue of sub-requests to process. For an incoming request, this value describes how the data arrived in pieces. The client driver allocates these descriptors for outgoing requests. The framework allocates and initializes these descriptors for incoming requests. Descriptors in this array contain framework-initialized fields that hold the number of bytes actually transferred and the status of the transfer. See the `usb_isoc_request`(9S) man page for more details. |

All requests must receive an initialized message block. This message block either supplies the data or stores the data. See the `mblk`(9S) man page for a description of the `mblk_t` message block type.

The `USB_ATTR_ONE_XFER` flag is an illegal attribute because the system decides how to vary the amounts of data through available packets. The `USB_ATTR_SHORT_XFER_OK` flag is valid only on host-bound data.

The usb_pipe_isoc_xfer(9F) function makes all isochronous transfers asynchronous, regardless of whether the USB_FLAGS_SLEEP flag is set. All isochronous input requests start polling.

Call the usb_pipe_stop_isoc_polling(9F) function to cancel periodic polling. When polling is stopped or the pipe is closed, the original request structure is returned through an exception callback. This returned request structure has its completion reason set to USB_CR_STOPPED_POLLING.

Do not make a new isochronous input request while polling is already in progress. Do not make a new isochronous input request while a call to usb_pipe_stop_isoc_polling(9F) is in progress.

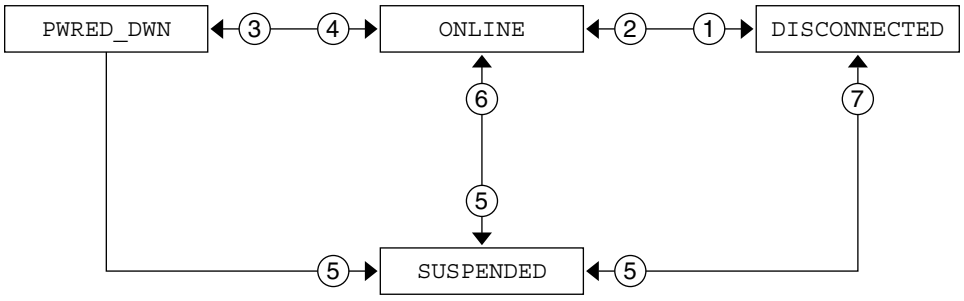
## Flushing Pipes

You might need to clean up a pipe after errors, or you might want to wait for a pipe to clear. Use one of the following methods to flush or clear pipes:

- The usb_pipe_reset(9F) function resets the pipe and flushes all of its requests. Do this for pipes that are in an error state if autoclearing is not enabled on those pipes. Use usb_pipe_get_state(9F) to determine the state of a pipe.
- The usb_pipe_drain_reqs(9F) function blocks waiting for all pending requests to complete before continuing. This function can wait indefinitely, or it can timeout after a specified period of time. The usb_pipe_drain_reqs(9F) function neither closes nor flushes the pipe.

# Device State Management

Managing a USB device includes accounting for hotplugging, system power management (checkpoint and resume), and device power management. All client drivers should implement the basic state machine shown in the following figure. For more information, see /usr/include/sys/usb/usbai.h.




1. Device unplugged.
2. Original device reconnected.
3. Device idles for time *T* and transitions to low power state.
4. Remote wakeup by the device or by an application sending I/O to the device.
5. Notification to save state via DDI_SUSPEND.
6. Notification to restore state via DDI_RESUME with correct device.
7. Notification to restore state via DDI_RESUME with device disconnected or a wrong device.

**FIGURE 19–4** USB Device State Machine

This state machine and its four states can be augmented with driver-specific states. Device states `0x80` to `0xff` can be defined and used only by client drivers.

# Hotplugging USB Devices

USB devices support hotplugging. A USB device can be inserted or removed at any time. The client driver must handle removal and reinsertion of an open device. Use hotplug callbacks to handle open devices. Insertion and removal of closed devices is handled by the `attach`(9E) and `detach`(9E) entry points.

## Hotplug Callbacks

The USBA 2.0 framework supports the following event notifications:

- The client driver receives a callback when the device is hot removed.
- The client driver receives a callback when the device is returned after hot removal. This event callback can occur when the user returns the device to its original port if the driver instance of the device is not offlined. If the driver instance is held open, then the driver instance cannot be offlined.

Client drivers must call `usb_register_hotplug_cbs`(9F) in their `attach`(9E) routine to register for event callbacks. Drivers must call `usb_unregister_hotplug_cbs`(9F) in their `detach`(9E) routine before dismantling.

## Hot Insertion

The sequence of events for hot insertion of a USB device is as follows:

1. The hub driver, `hubd`(7D), waits for a port connect status change.
2. The `hubd` driver detects a port connect.
3. The `hubd` driver enumerates the device, creates child device nodes, and attaches client drivers. Refer to "Binding Client Drivers" on page 384 for compatible names definitions.
4. The client driver manages the device. The driver is in the `ONLINE` state.

## Hot Removal

The sequence of events for hot removal of a USB device is as follows:

1. The hub driver, `hubd`(7D), waits for a port connect status change.
2. The `hubd` driver detects a port disconnect.
3. The `hubd` driver sends a disconnect event to the child client driver. If the child client driver is the `hubd` driver or the `usb_mid`(7D) multi-interface driver, then the child client driver propagates the event to its children.
4. The client driver receives the disconnect event notification in kernel thread context. Kernel thread context enables the driver's disconnect handler to block.
5. The client driver moves to the `DISCONNECTED` state. Outstanding I/O transfers fail with the completion reason of `device not responding`. All new I/O transfers and attempts to open the device node also fail. The client driver is not required to close pipes. The driver is required to save the device and driver context that needs to be restored if the device is reconnected.
6. The `hubd` driver attempts to offline the OS device node and its children in bottom-up order.

The following events take place if the device node is not open when the `hubd` driver attempts to offline the device node:

1. The client driver's `detach`(9E) entry point is called.
2. The device node is destroyed.
3. The port becomes available for a new device.
4. The hotplug sequence of events starts over. The `hubd` driver waits for a port connect status change.

The following events take place if the device node is open when the hubd driver attempts to offline the device node:

1. The hubd driver puts the offline request in the periodic offline retry queue.
2. The port remains unavailable for a new device.

If the device node was open when the hubd driver attempted to offline the device node and the user later closes the device node, the hubd driver periodic offlining of that device node succeeds and the following events take place:

1. The client driver's detach(9E) entry point is called.
2. The device node is destroyed.
3. The port becomes available for a new device.
4. The hotplug sequence of events starts over. The hubd driver waits for a port connect status change.

If the user closes all applications that use the device, the port becomes available again. If the application does not terminate or does not close the device, the port remains unavailable.

## Hot Reinsertion

The following events take place if a previously-removed device is reinserted into the same port while the device node of the device is still open:

1. The hub driver, hubd(7D), detects a port connect.
2. The hubd driver restores the bus address and the device configuration.
3. The hubd driver cancels the offline retry request.
4. The hubd driver sends a connect event to the client driver.
5. The client driver receives the connect event.
6. The client driver determines whether the new device is the same as the device that was previously connected. The client driver makes this determination first by comparing device descriptors. The client driver might also compare serial numbers and configuration descriptor clouds.

The following events might take place if the client driver determines that the current device is not the same as the device that was previously connected:

1. The client driver might issue a warning message to the console.
2. The user might remove the device again. If the user removes the device again, the hot remove sequence of events starts over. The hubd driver detects a port disconnect. If the user does not remove the device again, the following events take place:
   a. The client driver remains in the DISCONNECTED state, failing all requests and opens.
   b. The port remains unavailable. The user must close and disconnect the device to free the port.

c. The hotplug sequence of events starts over when the port is freed. The `hubd` driver waits for a port connect status change.

The following events might take place if the client driver determines that the current device is the same as the device that was previously connected:

1. The client driver might restore its state and continue normal operation. This policy is up to the client driver. Audio speakers are a good example where the client driver should continue.
2. If it is safe to continue using the reconnected device, the hotplug sequence of events starts over. The `hubd` driver waits for a port connect status change. The device is in service once again.

# Power Management

This section discusses device power management and system power management.

Device power management manages individual USB devices depending on their I/O activity or idleness.

System power management uses checkpoint and resume to checkpoint the state of the system into a file and shut down the system completely. (Checkpoint is sometimes called "system suspend.") The system is resumed to its pre-suspend state when the system is powered up again.

## Device Power Management

The following summary lists what your driver needs to do to power manage a USB device. A more detailed description of power management follows this summary.

1. Create power management components during `attach`(9E). See the `usb_create_pm_components`(9F) man page.
2. Implement the `power`(9E) entry point.
3. Call `pm_busy_component`(9F) and `pm_raise_power`(9F) before accessing the device.
4. Call `pm_idle_component`(9F) when finished accessing the device.

The USBA 2.0 framework supports four power levels as specified by the USB interface power management specification. See `/usr/include/sys/usb/usbai.h` for information on mapping USB power levels to operating system power levels.

The `hubd` driver suspends the port when the device goes to the `USB_DEV_OS_PWR_OFF` state. The `hubd` driver resumes the port when the device goes to the `USB_DEV_OS_PWR_1` state and above. Note that port suspend is different from system suspend. In port suspend, only the USB port is shut off. System suspend is defined in "System Power Management" on page 408.

The client driver might choose to enable remote wakeup on the device. See the `usb_handle_remote_wakeup`(9F) man page. When the `hubd` driver sees a remote wakeup on a port, the `hubd` driver completes the wakeup operation and calls `pm_raise_power`(9F) to notify the child.

The following figure shows the relationship between the different pieces of power management.

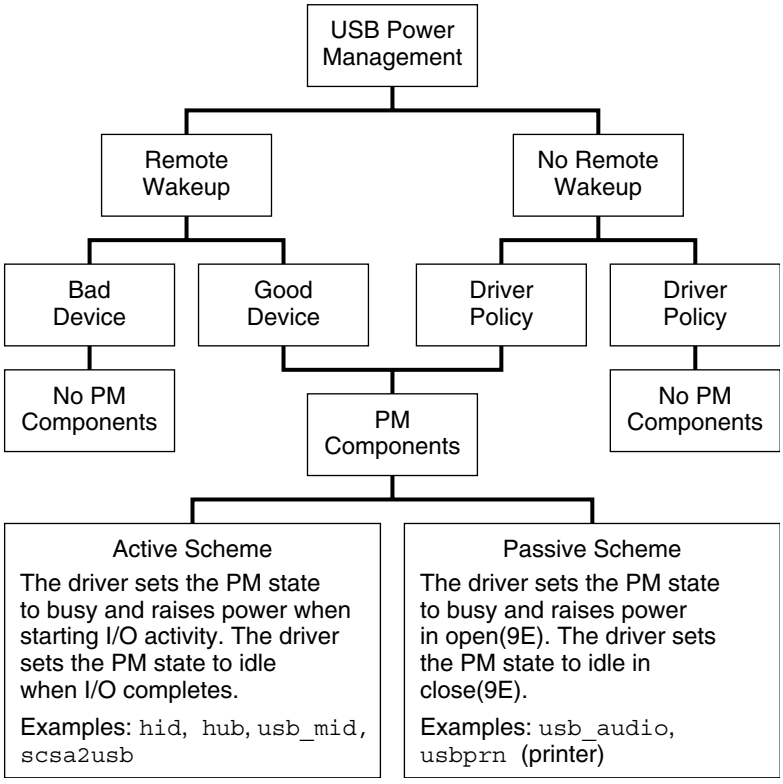



**FIGURE 19–5** USB Power Management

The driver can implement one of the two power management schemes described at the bottom of Figure 19–5. The passive scheme is simpler than the active scheme because the passive scheme does not do power management during device transfers.

## *Active Power Management*

This section describes the functions you need to use to implement the active power management scheme.

Do the following work in the `attach`(9E) entry point for your driver:

1. Call `usb_create_pm_components`(9F).

2. Optionally call usb_handle_remote_wakeup(9F) with USB_REMOTE_WAKEUP_ENABLE as the second argument to enable a remote wakeup on the device.
3. Call pm_busy_component(9F).
4. Call pm_raise_power(9F) to take power to the USB_DEV_OS_FULL_PWR level.
5. Communicate with the device to initialize the device.
6. Call pm_idle_component(9F).

Do the following work in the detach(9E) entry point for your driver:

1. Call pm_busy_component(9F).
2. Call pm_raise_power(9F) to take power to the USB_DEV_OS_FULL_PWR level.
3. If you called the usb_handle_remote_wakeup(9F) function in your attach(9E) entry point, call usb_handle_remote_wakeup(9F) here with USB_REMOTE_WAKEUP_DISABLE as the second argument.
4. Communicate with the device to cleanly shut down the device.
5. Call pm_lower_power(9F) to take power to the USB_DEV_OS_PWR_OFF level.

   This is the only time a client driver calls pm_lower_power(9F).
6. Call pm_idle_component(9F).

When a driver thread wants to start I/O to the device, that thread does the following tasks:

1. Call pm_busy_component(9F).
2. Call pm_raise_power(9F) to take power to the USB_DEV_OS_FULL_PWR level.
3. Begin the I/O transfer.

The driver calls pm_idle_component(9F) when the driver receives notice that an I/O transfer has completed.

In the power(9E) entry point for your driver, check whether the power level to which you are transitioning is valid. You might also need to account for different threads calling into power(9E) at the same time.

The power(9E) routine might be called to take the device to the USB_DEV_OS_PWR_OFF state if the device has been idle for some time or the system is shutting down. This state corresponds to the PWRED_DWN state shown in Figure 19–4. If the device is going to the USB_DEV_OS_PWR_OFF state, do the following work in your power(9E) routine:

1. Put all open pipes into the idle state. For example, stop polling on the interrupt pipe.
2. Save any device or driver context that needs to be saved.

   The port to which the device is connected is suspended after the call to power(9E) completes.

The power(9E) routine might be called to power on the device when either a device-initiated remote wakeup or a system-initiated wakeup is received. Wakeup notices occur after the device has been powered down due to extended idle time or system suspend. If the device is going to the USB_DEV_OS_PWR_1 state or above, do the following work in your power(9E) routine:

1. Restore any needed device and driver context.
2. Restart activity on the pipe that is appropriate to the specified power level. For example, start polling on the interrupt pipe.

If the port to which the device is connected was previously suspended, that port is resumed before power(9E) is called.

### *Passive Power Management*

The passive power management scheme is simpler than the active power management scheme described above. In this passive scheme, no power management is done during transfers. To implement this passive scheme, call pm_busy_component(9F) and pm_raise_power(9F) when you open the device. Then call pm_idle_component(9F) when you close the device.

## System Power Management

System power management consists of turning off the entire system after saving its state, and restoring the state after the system is turned back on. This process is called *CPR* (checkpoint and resume). USB client drivers operate the same way that other client drivers operate with respect to CPR. To suspend a device, the driver's detach(9E) entry point is called with a *cmd* argument of DDI_SUSPEND. To resume a device, the driver's attach(9E) entry point is called with a *cmd* argument of DDI_RESUME. When you handle the DDI_SUSPEND command in your detach(9E) routine, clean up device state and clean up driver state as much as necessary for a clean resume later. (Note that this corresponds to the SUSPENDED state in Figure 19–4.) When you handle the DDI_RESUME command in your attach(9E) routine, always take the device to full power to put the system in sync with the device.

For USB devices, suspend and resume are handled similarly to a hotplug disconnect and reconnect (see "Hotplugging USB Devices" on page 402). An important difference between CPR and hotplugging is that with CPR the driver can fail the checkpoint process if the device is not in a state from which it can be suspended. For example, the device cannot be suspended if the device has an error recovery in progress. The device also cannot be suspended if the device is busy and cannot be stopped safely.

# Serialization

In general, a driver should not call USBA functions while the driver is holding a mutex. Therefore, race conditions in a client driver can be difficult to prevent.

Do not allow normal operational code to run simultaneously with the processing of asynchronous events such as a disconnect or CPR. These types of asynchronous events normally clean up and dismantle pipes and could disrupt the normal operational code.

One way to manage race conditions and protect normal operational code is to write a serialization facility that can acquire and release an exclusive-access synchronization object. You can write the serialization facility in such a way that the synchronization object is safe to hold through calls to USBA functions. The `usbskel` sample driver demonstrates this technique. See "Sample USB Device Driver" on page 412 for information on the `usbskel` driver.

# Utility Functions

This section describes several functions that are of general use.

## Device Configuration Facilities

This section describes functions related to device configuration.

### Getting Interface Numbers

If you are using a multiple-interface device where the `usb_mid`(7D) driver is making only one of its interfaces available to the calling driver, you might need to know the number of the interface to which the calling driver is bound. Use the `usb_get_if_number`(9F) function to do any of the following tasks:

- Return the number of the interface to which the calling driver is bound. The `usb_get_if_number`(9F) function returns an interface number greater than zero in this case.
- Discover that the calling driver manages an entire multi-interface device. The driver is bound at the device level so that `usb_mid` has not split it. The `usb_get_if_number`(9F) function returns `USB_DEVICE_NODE` in this case.
- Discover that the calling driver manages an entire device by managing the only interface that device offers in its current configuration. The `usb_get_if_number`(9F) function returns `USB_COMBINED_NODE` in this case.

## Managing Entire Devices

If a driver manages an entire composite device, that driver can bind to the entire device by using a compatible name that contains vendor ID, product ID, and revision ID. A driver that is bound to an entire composite device must manage all the interfaces of that device as a nexus driver would. In general, you should not bind your driver to an entire composite device. Instead, you should use the generic multiple-interface driver `usb_mid`(7D).

Use the `usb_owns_device`(9F) function to determine whether a driver owns an entire device. The device might be a composite device. The `usb_owns_device`(9F) function returns `TRUE` if the driver owns the entire device.

## Multiple-Configuration Devices

USB devices make only a single configuration available to the host at any particular time. Most devices support only a single configuration. However, a few USB devices support multiple configurations.

Any device that has multiple configurations is placed into the first configuration for which a driver is available. When seeking a match, device configurations are considered in numeric order. If no matching driver is found, the device is set to the first configuration. In this case, the `usb_mid` driver takes over the device and splits the device into interface nodes. Use the `usb_get_cfg`(9F) function to return the current configuration of a device.

You can use either of the following two methods to request a different configuration. Using either of these two methods to modify the device configuration ensures that the USBA module remains in sync with the device.

- Use the `cfgadm_usb`(1M) command.
- Call the `usb_set_cfg`(9F) function from the driver.

  Because changing device configuration affects an entire device, the client driver must meet all of the following criteria to call the `usb_set_cfg`(9F) function successfully:

  - The client driver must own the entire device.
  - The device must have no child nodes, because other drivers could drive the device through them.
  - All pipes except the default pipe must be closed.
  - The device must have multiple configurations.

**Caution –** Do not change the device configuration by doing a `SET_CONFIGURATION` USB request manually. Using a `SET_CONFIGURATION` request to change the configuration is not supported.

## Modifying or Getting the Alternate Setting

A client driver can call the `usb_set_alt_if`(9F) function to change the selected alternate setting of the currently selected interface. Be sure to close all pipes that were opened explicitly. When switching alternate settings, the `usb_set_alt_if`(9F) function verifies that only the default pipe is open. Be sure the device is settled before you call `usb_set_alt_if`(9F).

Changing the alternate setting can affect which endpoints and which class-specific and vendor-specific descriptors are available to the driver. See "The Descriptor Tree" on page 388 for more information about endpoints and descriptors.

Call the `usb_get_alt_if`(9F) function to retrieve the number of the current alternate setting.

**Note –** When you request a new alternate setting, a new configuration, or a new interface, all pipes except the default pipe to the device must be closed. This is because changing an alternate setting, a configuration, or an interface changes the mode of operation of the device. Also, changing an alternate setting, a configuration, or an interface changes the device's presentation to the system.

# Other Utility Functions

This section describes other functions that are useful in USB device drivers.

## Retrieving a String Descriptor

Call the `usb_get_string_descr`(9F) function to retrieve a string descriptor given its index. Some configuration, interface, or device descriptors have string IDs associated with them. Such descriptors contain string index fields with nonzero values. Pass a string index field value to the `usb_get_string_descr`(9F) to retrieve the corresponding string.

## Pipe Private Data Facility

Each pipe has one pointer of space set aside for the client driver's private use. Use the `usb_pipe_set_private`(9F) function to install a value. Use the `usb_pipe_get_private`(9F) function to retrieve the value. This facility is useful in callbacks, when pipes might need to bring their own client-defined state to the callback for specific processing.

## Clearing a USB Condition

Use the `usb_clr_feature`(9F) function to do the following tasks:

- Issue a USB `CLEAR_FEATURE` request to clear a halt condition on an endpoint.
- Clear a remote wakeup condition on a device.
- Clear a device-specific condition at a device, interface, or endpoint level.

## Getting Device, Interface, or Endpoint Status

Use the `usb_get_status`(9F) function to issue a USB `GET_STATUS` request to retrieve the status of a device, interface, or endpoint.

- **Device status**. Self-powered and remote-wakeup-enabled.
- **Interface status**. Returns zero, per USB 2.0 specification.
- **Endpoint status**. Endpoint halted. This status indicates a functional stall. A halt must be cleared before the device can operate again.

  A protocol stall indicates that an unsupported control pipe request has been made. A protocol stall is cleared automatically at the beginning of the next control transfer.

## Getting the Bus Address of a Device

Use the `usb_get_addr`(9F) function to get the USB bus address of a device for debugging purposes. This address maps to a particular USB port.

# Sample USB Device Driver

This section describes a template USB device driver that uses the USBA 2.0 framework for the Solaris environment. This driver demonstrates many of the features discussed in this chapter. This template or skeleton driver is named `usbskel`.

The `usbskel` driver is a template that you can use to start your own USB device driver. The `usbskel` driver demonstrates the following features:

- Reading the raw configuration data of a device. Every USB device needs to be able to report device raw configuration data.
- Managing pipes. The `usbskel` driver opens an interrupt pipe to show how to manage pipes.
- Polling. Comments in the `usbskel` driver discuss how to do polling.
- USB version management and registration.
- USB logging.
- Accommodations for USB hotplugging.
- Accommodations for Solaris suspend and resume.
- Accommodations for power management.
- USB serialization.
- Use of USB callbacks.

This `usbskel` driver is available on Sun's web site at `http://www.sun.com/bigadmin/software/usbskel/`.

This `usbskel` driver is also available on Sun's web site as part of the USB DDK (Driver Development Kit). The USB DDK includes many example USB drivers in addition to the `usbskel` template driver. To download the USB DDK and to read about the latest updates to the USBA 2.0 framework for the Solaris environment, go to USB early access site, which is at:
*http://developers.sun.com/solaris/developer/support/driver/usb.html*.

# PART III Building a Device Driver

The third part of this book provides advice on building device drivers for the Solaris Operating Solaris:

- Chapter 20 provides information on compiling, linking, and installing a driver.
- Chapter 21 describes techniques for debugging, testing, and testing drivers.
- Chapter 22 describes the recommended coding practices for writing drivers.

CHAPTER 20

# Compiling, Loading, Packaging, and Testing Drivers

This chapter describes the procedure for driver development, including code layout, compilation, packaging, and testing. The chapter provides information on the following subjects:



## Driver Development Summary

This chapter and the following two chapters, Chapter 21 and Chapter 22, provide detailed information on developing a device driver. A driver developer takes the following steps to build a device driver:

1. Write, compile, and link the new code.

   See "Driver Code Layout" on page 418 for the conventions on naming files. Use a C compiler to compile the driver. Link the driver using `ld`(1). See "Compiling and Linking the Driver" on page 421 and "Module Dependencies" on page 422.

2. Create the necessary hardware configuration files.

   You need to create a hardware configuration file unique to the device called *xx*`.conf` where *xx* is the prefix for the device. This file is used to update the `driver.conf`(4) file. See "Writing a Hardware Configuration File" on page 422. For a pseudo device driver, you need to create a `pseudo`(4) file.

3. Copy the driver to the appropriate module directory.

   See "Copying the Driver to a Module Directory" on page 422.

4. Install the device driver using `add_drv`(1M).

   Installing the driver with `add_drv` is usually done as part of a postinstall script. See "Installing Drivers with `add_drv`" on page 424. The `update_drv`(1M) command is used to make any changes to the driver. See "Updating Driver Information" on page 424.

5. Load the driver.

   Loading the driver can be done programmatically by opening the special file for the device. See "Loading and Unloading Drivers" on page 425 and "Package Postinstall" on page 425. Drivers can also be loaded by using the `modload`(1M) command. The `modload` command does not call any routines in the module and is actually more suitable for testing. See "Loading and Unloading Test Modules" on page 437.

6. Test the driver.

   Drivers should be rigorously tested in the following areas:

   - "Configuration Testing" on page 427
   - "Functionality Testing" on page 428
   - "Error Handling" on page 428
   - "Testing Loading and Unloading" on page 429
   - "Stress, Performance, and Interoperability Testing" on page 429
   - "DDI/DKI Compliance Testing" on page 430
   - "Installation and Packaging Testing" on page 430

   For additional driver-specific testing, see "Testing Specific Types of Drivers" on page 430.

7. Remove the driver if necessary.

   Removal of a device driver is done using the `rem_drv`(1M) command. See "Removing the Driver" on page 424 and "Package Preremove" on page 426.

# Driver Code Layout

The code for a device driver is usually divided into the following files:

- Header files (`.h` files)
- Source files (`.c` files)
- Optional configuration file (`driver.conf` file)

## Header Files

Header files provide the following definitions:

- Data structures specific to the device, such as a structure representing the device registers
- Data structures defined by the driver for maintaining state information
- Defined constants, such as those representing the bits of the device registers
- Macros, such as those defining the static mapping between the minor device number and the instance number

Some of the header file definitions, such as the state structure, might be needed only by the device driver. This information should go in *private* header files that are only included by the device driver itself.

Any information that an application might require, such as the I/O control commands, should be in *public* header files. These files are included by the driver and by any applications that need information about the device.

While there is no standard for naming private and public files, one convention is to name the private header file *xx*`impl.h` and the public header file *xx*`io.h`.

## `.c` Files

A `.c` file for a device driver has the following responsibilities:

- Contains the data declarations and the code for the entry points of the driver
- Contains the `#include` statements that are needed by the driver
- Declares extern references
- Declares local data
- Sets up the `cb_ops` and `dev_ops` structures
- Declares and initializes the module configuration section, that is, the `modlinkage`(9S) and `modldrv`(9S) structures
- Makes any other necessary declarations
- Defines the driver entry points

## `driver.conf` Files

`driver.conf` files are required for devices that are not self-identifying. Entries in the `driver.conf` file specify possible device instances that the driver can probe for existence. For more information, see the `driver.conf`(4) man page.

Driver global properties can also be set by entries in the `driver.conf` file. `driver.conf` files are optional for self-identifying devices (SID), where the entries can be used to add properties into SID nodes. The `driver.conf` file generally defines all of the properties that drivers need, but exceptions do exist.

Drivers that use the SBus peripheral bus generally get property information from the SBus card. In cases where additional properties are needed, the `driver.conf` file can contain properties that are defined by `sbus`(4).

The properties of a PCI bus can generally be derived from the PCI configuration space. In cases where private driver properties are needed, the `driver.conf` file can contain properties that are defined by `pci`(4).

Drivers on the ISA bus can use additional properties that are defined by `isa`(4).

# Preparing for Driver Installation

The following steps precede installation of a driver.

1. Compile the driver.
2. Create a configuration file if necessary.
3. Identify the driver module to the system through either of these alternatives:
   - Match the driver's name to the name of the device node.
   - Use either `add_drv`(1M) or `update_drv`(1M) to inform the system of the module names.

The system maintains a one-to-one association between the name of the driver module and the name of the `dev_info` node. For example, consider a `dev_info` node for a device that is named *wombat*. The device *wombat* is handled by a driver module that is also named `wombat`. The *wombat* module resides in a subdirectory that is called `drv`, which is in the module path. In this case, the module can be found in `drv/wombat` if you are using a 32–bit kernel or in `drv/sparcv9/wombat` if you are using a 64–bit kernel.

If the driver is a STREAMS network driver, then the driver name needs to meet the following constraints:

- Only alphanumeric characters (a-z, A-Z, 0-9), plus the underscore ('_'), are permitted.
- Neither the first nor the last character of the name may be a digit.
- The name cannot exceed 16 characters in length. Names in the range of 3-8 characters in length are preferable.

If the driver should manage `dev_info` nodes with different names, the `add_drv`(1M) utility can create aliases. The `-i` flag specifies the names of other `dev_info` nodes that the driver handles. The `update_drv()` function can also modify aliases for an installed device driver.

# Compiling and Linking the Driver

You need to compile each driver source file and link the resulting object files into a driver module.

The example below shows a driver that is called *xx* with two C-language source files. A driver module that is called *xx* is generated. The driver that is created in this example is intended for the 32–bit kernel:

```
% cc -D_KERNEL -c xx1.c
% cc -D_KERNEL -c xx2.c
% ld -r -o xx xx1.o xx2.o
```

The `_KERNEL` symbol must be defined while compiling kernel (driver) code. No other symbols, such as `sun4m`, should be defined, aside from driver private symbols. `DEBUG` can also be defined to enable any calls to `assert`(9F). You do not have to use the `-I` flag for the standard headers.

Drivers that are intended for the 64-bit SPARC kernel should specify the `-xarch=v9` option. Use the following line to compile:

```
% cc -D_KERNEL -xarch=v9 -c xx1.c
```

After the driver is stable, optimization flags can be used to build a production quality driver. For the C compiler from the Sun Studio 10, C Compiler 5.7, the normal `-O` flag, or its equivalent `-xO`*N*, can be used. All global variables should all be treated as `volatile`, which is a good practice for device drivers. The `volatile` tag is discussed in greater detail in "Declaring a Variable Volatile" on page 469. Use of the flag depends on the platform as follows:

- SPARC architecture: The `-xO2` flag treats all global variables as `volatile`. For optimization levels above `-xO2`, global variables need to be specifically marked as `volatile`.
- x86 architecture: Global variables need to be specifically marked as `volatile` at all optimization levels unless you use the `-g` option.

See the `cc(1)` man page for more specific information on optimization and other compile issues.

The following compile line creates 64–bit SPARC drivers for the Solaris 10 Operating System:

```
% cc -D_KERNEL -xarch=v9 -xcode=abs32 -xO3 -c xx1.c
```

The use of `-xcode=abs32` leads to more compact code.

---

**Note –** `ld -r` must be run even if only one object module exists.

---

Drivers that are intended for the 64–bit kernel are compiled as follows:

```
% cc -D_KERNEL -xarch=amd64 -xmodel=kernel -c xx1.c
```

## Module Dependencies

If the driver module depends on symbols exported by another kernel module, the dependency can be specified by the `-dy` and `-N` options of `ld`. If the driver depends on a symbol exported by `misc/mySymbol`, the example below should be used to create the driver binary. See the `ld`(1) man page.

```
% ld -dy -r -o xx xx1.o xx2.o -N misc/mySymbol
```

## Writing a Hardware Configuration File

If a device is non-self-identifying, the kernel requires a hardware configuration file for that device. If the driver is called *xx*, the hardware configuration file for the driver should be called *xx*`.conf`. See the `driver.conf`(4), `pseudo`(4), `sbus`(4), `scsi_free_consistent_buf`(9F), and `update_drv`(1M) man pages for more information on hardware configuration files. On the x86 platform, device information is now supplied by the booting system. Hardware configuration files should no longer be needed, even for non-self-identifying devices.

Arbitrary properties can be defined in hardware configuration files. Entries in the configuration file are in the form *property=value*, where *property* is the property name and *value* is its initial value. The configuration file approach enables devices to be configured by changing the property values.

# Installing, Updating, and Removing Drivers

Before a driver can be used, the system must be informed that the driver exists. The `add_drv`(1M) utility *must* be used to correctly install the device driver. After a driver is installed, that driver can be both loaded and unloaded from memory without using `add_drv`(1M) again.

## Copying the Driver to a Module Directory

Three conditions determine a device driver module's path:

- The platform that the driver runs on
- The architecture for which the driver is compiled

- Whether the path is needed at boot time

Device drivers reside in the following locations:

`/platform/‘uname -i‘/kernel/drv`
Contains 32–bit drivers that run only on a specific platform.

`/platform/‘uname -i‘/kernel/drv/sparcv9`
Contains 64–bit drivers that run only on a specific SPARC-based platform.

`/platform/‘uname -i‘/kernel/drv/amd64`
Contains 64–bit drivers that run only on a specific x86-based platform.

`/platform/‘uname -m‘/kernel/drv`
Contains 32–bit drivers that run only on a specific family of platforms.

`/platform/‘uname -m‘/kernel/drv/sparcv9`
Contains 64–bit drivers that run only on a specific family of SPARC-based platforms.

`/platform/‘uname -m‘/kernel/drv/amd64`
Contains 64–bit drivers that run only on a specific family of x86-based platforms.

`/usr/kernel/drv`
Contains 32–bit drivers that are independent of platforms.

`/usr/kernel/drv/sparcv9`
Contains 64–bit drivers on SPARC-based systems that are independent of platforms.

`/usr/kernel/drv/amd64`
Contains 64–bit drivers on x86-based systems that are independent of platforms.

To install a 32–bit driver, the driver and its configuration file must be copied to a `drv` directory in the module path. For example, to copy a driver to `/usr/kernel/drv`, type:

```
$ su
# cp xx /usr/kernel/drv
# cp xx.conf /usr/kernel/drv
```

To install a 64-bit SPARC driver, copy the driver to a `drv/sparcv9` directory in the module path. Copy the driver configuration file to the `drv` directory in the module path. For example, to copy a driver to `/usr/kernel/drv`, you would type:

```
$ su
# cp xx /usr/kernel/drv/sparcv9# cp xx.conf /usr/kernel/drv
```

---

**Note –** All driver configuration files (`.conf` files) *must* go in the `drv` directory in the module path. Even on 64–bit systems, the `.conf` file goes in the `drv` directory, not the `drv/sparcv9` directory.

---

## Installing Drivers with `add_drv`

Run `add_drv` to install the driver in the system. If the driver installs successfully,`add_drv` runs `devfsadm`(1M) to create the logical names in `/dev`.

```
# add_drv xx
```

In this case, the device identifies itself as *xx*. The device special files have default ownership and permissions (`0600 root sys`). `add_drv`(1M) also allows additional names for the device (aliases) to be specified. See the `add_drv`(1M) man page for information on adding aliases and setting file permissions explicitly.

---

**Note –** `add_drv`(1M) should not be run when installing a STREAMS module. See the *STREAMS Programming Guide* for details.

---

If the driver creates minor nodes that do not represent terminal devices, that is, disks, tapes, or ports, `/etc/devlink.tab` can be modified to cause `devfsadm`(1M) to create logical device names in `/dev`.

Alternatively, logical names can be created by a program run at driver installation time.

## Updating Driver Information

Use the `update_drv`(1M) command to notify the system of any changes to an installed device driver. By default, the system re-reads the `driver.conf`(4) file and reloads the driver binary module.

## Removing the Driver

To remove a driver from the system, use `rem_drv`(1M), then delete the driver module and configuration file from the module path. A driver cannot be used again until that driver is reinstalled with `add_drv`(1M). The removal of a SCSI HBA driver requires a reboot to take effect.

# Loading and Unloading Drivers

Opening a special file that is associated with a device driver causes that driver to be loaded. `modload`(1M) can also be used to load the driver into memory, but `modload()` does not call any routines in the module. The preferred method is to open the device.

Normally, the system automatically unloads device drivers that are no longer in use. During development, use of `modunload`(1M) might be necessary to unload the driver explicitly. In order for `modunload`(1M) to be successful, the device driver must be inactive. No outstanding references to the device should exist, such as through `open`(2) or `mmap`(2).

`modunload` takes a runtime-dependent `module_id` as an argument. To find the `module_id`, use `grep` to search the output of `modinfo` for the driver name in question. Check in the first column.

```
# modunload -i module-id
```

To unload all currently unloadable modules, specify module ID zero:

```
# modunload -i 0
```

In addition to being inactive, the driver must have working `detach`(9E) and `_fini`(9E) routines for `modunload`(1M) to succeed.

# Driver Packaging

The normal delivery vehicle for software is to create a package that contains all of the software components. A package provides a controlled mechanism for installation and removal of all the components of a software product. In addition to the files for using the product, the package includes control files for installing and uninstalling the application. The postinstall and preremove installation scripts are two such control files.

## Package Postinstall

After a package with a driver binary is installed onto a system, the `add_drv`(1M) command must be run. `add_drv()` completes the installation of the driver. Typically, `add_drv` is run as a postinstall script, as in the following example.

```
#!/bin/sh
#
```

```
#       @(#)postinstall 1.1

PATH="/usr/bin:/usr/sbin:${PATH}"
export PATH

#
# Driver info
#
DRV=<driver-name>
DRVALIAS="<company-name>,<driver-name>"
DRVPERM='* 0666 root sys'

ADD_DRV=/usr/sbin/add_drv

#
# Select the correct add_drv options to execute.
# add_drv touches /reconfigure to cause the
# next boot to be a reconfigure boot.
#
if [ "${BASEDIR}" = "/" ]; then
    #
    # On a running system, modify the
    # system files and attach the driver
    #
    ADD_DRV_FLAGS=""
else
    #
    # On a client, modify the system files
    # relative to BASEDIR
    #
    ADD_DRV_FLAGS="-b ${BASEDIR}"
fi

#
# Make sure add_drv has not been previously executed
# before attempting to add the driver.
#
grep "^${DRV} " $BASEDIR/etc/name_to_major > /dev/null 2>&1
if [ $? -ne 0 ]; then
    ${ADD_DRV} ${ADD_DRV_FLAGS} -m "${DRVPERM}" -i "${DRVALIAS}" ${DRV}
    if [ $? -ne 0 ]; then
        echo "postinstall: add_drv $DRV failed\n" >&2
        exit 1
    fi
fi
exit 0
```

# Package Preremove

When removing a package that includes a driver, the `rem_drv`(1M) command must be run prior to removing the driver binary and other components. The following example demonstrates a `preremove` script that uses `rem_drv`(1M) for driver removal.

```
#!/bin/sh
#
#       @(#)preremove  1.1

PATH="/usr/bin:/usr/sbin:${PATH}"
export PATH

#
# Driver info
#
DRV=<driver-name>
REM_DRV=/usr/sbin/rem_drv

#
# Select the correct rem_drv options to execute.
# rem_drv touches /reconfigure to cause the
# next boot to be a reconfigure boot.
#
if [ "${BASEDIR}" = "/" ]; then
    #
    # On a running system, modify the
    # system files and remove the driver
    #
    REM_DRV_FLAGS=""
else
    #
    # On a client, modify the system files
    # relative to BASEDIR
    #
    REM_DRV_FLAGS="-b ${BASEDIR}"
fi

${REM_DRV} ${REM_DRV_FLAGS} ${DRV}

exit 0
```

# Criteria for Testing Drivers

Once a device driver is functional, that driver should be thoroughly tested prior to distribution. Besides testing the features in traditional UNIX device drivers, Solaris 10 drivers require testing power management features, such as dynamic loading and unloading of drivers.

## Configuration Testing

A driver's ability to handle multiple device configurations is an important part of the test process. Once the driver is working on a simple, or default, configuration, additional configurations should be tested. Depending on the device, configuration

testing can be accomplished by changing jumpers or DIP switches. If the number of possible configurations is small, all configurations should be tried. If the number is large, various classes of possible configurations should be defined, and a sampling of configurations from each class should be tested. Defining these classes depends on the potential interactions among the different configuration parameters. These interactions are a function of the type of the device and the way in which the driver was written.

For each device configuration, the basic functions must be tested, which include loading, opening, reading, writing, closing, and unloading the driver. Any function that depends upon the configuration deserves special attention. For example, changing the base memory address of device registers is not likely to affect the behavior of most driver functions. If a driver works well with one address, that driver is likely to work as well with a different address. On the other hand, a special I/O control call might have different effects depending on the particular device configuration.

Loading the driver with varying configurations ensures that the `probe`(9E) and `attach`(9E) entry points can find the device at different addresses. For basic functional testing, using regular UNIX commands such as `cat`(1) or `dd`(1M) is usually sufficient for character devices. Mounting or booting might be required for block devices.

## Functionality Testing

After a driver has been completely tested for configuration, all of the driver's functionality should be thoroughly tested. These tests require exercising the operation of all of the driver's entry points.

Many drivers require custom applications to test functionality. However, basic drivers for devices such as disks, tapes, or asynchronous boards can be tested using standard system utilities. All entry points should be tested in this process, including `devmap`(9E), `chpoll`(9E), and `ioctl`(9E), if applicable. The `ioctl`(9E) tests might be quite different for each driver. For nonstandard devices, a custom testing application is generally required.

## Error Handling

A driver might perform correctly in an ideal environment but fail in cases of errors, such as erroneous operations or bad data. Therefore, an important part of driver testing is the testing of the driver's error handling.

All possible error conditions of a driver should be exercised, including error conditions for actual hardware malfunctions. Some hardware error conditions might be difficult to induce, but an effort should be made to force or to simulate such errors if possible. All of these conditions could be encountered in the field. Cables should be removed or be loosened, boards should be removed, and erroneous user application code should be written to test those error paths.

**Caution –** Be sure to take proper electrical precautions when testing.

## Testing Loading and Unloading

Because a driver that does not load or unload can force unscheduled downtime, loading and unloading must be thoroughly tested.

A script like the following example should suffice:

```
#!/bin/sh
cd <location_of_driver>
while [ 1 ]
do
    modunload -i 'modinfo | grep " <driver_name> " | cut -cl-3' &
    modload <driver_name> &
done
```

## Stress, Performance, and Interoperability Testing

To help ensure that a driver performs well, that driver should be subjected to vigorous stress testing. For example, running single threads through a driver does not test locking logic or conditional variables that have to wait. Device operations should be performed by multiple processes at once to cause several threads to execute the same code simultaneously.

Techniques for performing simultaneous tests depends upon the driver. Some drivers require special testing applications, while starting several UNIX commands in the background is suitable for others. Appropriate testing depends upon where the particular driver uses locks and condition variables. Testing a driver on a multiprocessor machine is more likely to expose problems than testing on a single-processor machine.

Interoperability between drivers must also be tested, particularly because different devices can share interrupt levels. If possible, configure another device at the same interrupt level as the one being tested. A stress-test can determine whether the driver correctly claims its own interrupts and operates according to expectations. Stress tests should be run on both devices at once. Even if the devices do not share an interrupt level, this test can still be valuable. For example, consider a case in which serial communication devices experience errors when a network driver is tested. The same problem might be causing the rest of the system to encounter interrupt latency problems as well.

Driver performance under these stress tests should be measured using UNIX performance-measuring tools. This type of testing can be as simple as using the `time`(1) command along with commands to be used in the stress tests.

# DDI/DKI Compliance Testing

To ensure compatibility with later releases and reliable support for the current release, every driver should be Solaris 10 DDI/DKI compliant. One way to determine whether the driver is compliant is by inspection. Check that only kernel routines in *man pages section 9: DDI and DKI Kernel Functions* and data structures in *man pages section 9: DDI and DKI Properties and Data Structures* are used.

The Solaris 10 Driver Developer Kit (DDK) includes a DDI compliance tool (DDICT). This tool checks C source code in a device driver for non-DDI/DKI compliance. The tool issues either error or warning messages when non-compliant code is found. For best results, all drivers should be written to pass DDICT. For more information, check out the Solaris Developer Connection, which is currently at `http://wwws.sun.com/software/solaris/ddk/`.

# Installation and Packaging Testing

Drivers are delivered to customers in *packages*. A package can be added or be removed from the system using a standard mechanism (see the *Application Packaging Developer's Guide*).

The ability of a user to add or remove the package from a system should be tested. In testing, the package should be both installed and removed from every type of media to be used for the release. This testing should include several system configurations. Packages must not make unwarranted assumptions about the directory environment of the target system. Certain valid assumptions, however, can be made about where standard kernel files are kept. Also test adding and removing of packages on newly installed machines that have not been modified for a development environment. A common packaging error is for a package to rely on a tool or file that is used in development only. For example, no tools from the Source Compatibility package, `SUNWscpu`, should be used in driver installation programs.

The driver installation must be tested on a minimal Solaris system without any optional packages.

# Testing Specific Types of Drivers

This section provides some information about how to test certain types of standard devices. An all-inclusive list of tests for each different type of device would be impossible.

## Tape Drivers

Tape drivers should be tested by performing several archive and restore operations. The `cpio`(1) and `tar`(1) commands can be used for this purpose. Use the `dd`(1M) command to write an entire disk partition to tape. Next, read back the data, and write

the data to another partition of the same size. Then compare the two copies. The `mt`(1) command can exercise most of the I/O controls that are specific to tape drivers. See the `mtio`(7I) man page. Try to use all the options. These three techniques can test the error-handling capabilities of tape drivers:

- Remove the tape and try various operations
- Write-protect the tape and try a write
- Turn off power in the middle of different operations

Tape drivers typically implement exclusive-access `open`(9E) calls. These `open()` calls can be tested by opening a device and then having a second process try to open the same device.

## Disk Drivers

Disk drivers should be tested in both the raw and block device modes. For block device tests, create a new file system on the device. Then try to mount the new file system. Then try to perform multiple file operations.

---

**Note –** The file system uses a page cache, so reading the same file over and over again does not really exercise the driver. The page cache can be forced to retrieve data from the device by memory-mapping the file with `mmap`(2). Then use `msync`(3C) to invalidate the in-memory copies.

---

Copy another (unmounted) partition of the same size to the raw device. Then use a command such as `fsck`(1M) to verify the correctness of the copy. The new partition can also be mounted and later compared to the old partition on a file-by-file basis.

## Asynchronous Communication Drivers

Asynchronous drivers can be tested at the basic level by setting up a `login` line to the serial ports. A good test is see whether a user can log in on this line. To sufficiently test an asynchronous driver, however, all the I/O control functions must be tested, with many interrupts at high speed. A test involving a loopback serial cable and high data transfer rates can help determine the reliability of the driver. You can run `uucp`(1C) over the line to provide some exercise. However, because `uucp`(1C) performs its own error handling, verify that the driver is not reporting excessive numbers of errors to the `uucp`(1C) process.

These types of devices are usually STREAMS-based. See the *STREAMS Programming Guide* for more information.

## Network Drivers

Network drivers can be tested using standard network utilities. `ftp`(1) and `rcp`(1) are useful because the files can be compared on each end of the network. The driver should be tested under heavy network loading, so that various commands can be run by multiple processes. Heavy network loading includes the following conditions:

- Traffic to the test machine is heavy.
- Traffic among all machines on the network is heavy.

Network cables should be unplugged while the tests are executing to ensure that the driver recovers gracefully from the resulting error conditions. Another important test is for the driver to receive multiple packets in rapid succession, that is, *back-to-back* packets. In this case, a relatively fast host on a lightly loaded network should send multiple packets in quick succession to the test machine. Verify that the receiving driver does not drop the second and subsequent packets.

These types of devices are usually STREAMS-based. See the *STREAMS Programming Guide* for more information.

CHAPTER 21

# Debugging, Testing, and Tuning Device Drivers

This chapter presents an overview of the various tools that are provided to assist with the debugging, tuning, and testing of device drivers. This chapter provides information on the following subjects:

- "Testing Drivers" on page 433 – Testing a driver can potentially impair a system's ability to function. Use of both serial connections and alternate kernels helps facilitate recovery from crashes.
- "Debugging Tools" on page 443 – Integral debugging facilities enable you to exercise and observe driver features conveniently without having to run a separate debugger.
- "Tuning Drivers" on page 456 – The Solaris OS provides facilities for measuring the performance of device drivers. Writing kernel statistics structures for your device exports continuous statistics as the device is running. If an area for performance improvement is determined, then the DTrace dynamic instrumentation tool can help determine any problems more precisely.

## Testing Drivers

To avoid data loss and other problems, you should take special care when testing a new device driver. This section discusses various testing strategies. For example, setting up a separate system that you control through a serial connection is the safest way to test a new driver. You can load test modules with various kernel variable settings to test performance under different kernel conditions. Should your system crash, you should be prepared to restore back-up data, analyze any crash dumps, and rebuild the device directory.

## Testing With a Serial Connection

Using a serial connection is a good way to test drivers. Use the `tip`(1) command to make a serial connection between a host system and a test system. With this approach, the *tip window* on the host console is used as the console of the test machine. See the `tip`(1) man page for additional information.

A tip window has the following advantages:

- Interactions with the test system and kernel debuggers can be monitored. For example, the window can keep a log of the session for use if the driver crashes the test system.
- The test machine can be accessed remotely by logging into a *tip host* machine and using `tip`(1) to connect to the test machine.

---

**Note –** Although using a tip connection and a second machine are not required to debug a Solaris 10 device driver, this technique is still recommended.

---

### ▼ To Set Up the Host System for a `tip` Connection

**Steps**

1. **Connect the host system to the test machine using serial port A on both machines.**

   This connection must be made with a null modem cable.

2. **On the host system, make sure there is an entry in `/etc/remote` for the connection. See the `remote`(4) man page for details.**

   The terminal entry must match the serial port that is used. The Solaris 10 Operating System comes with the correct entry for serial port B, but a terminal entry must be added for serial port A:

   ```
   debug:\
           :dv=/dev/term/a:br#9600:el=^C^S^Q^U^D:ie=%$:oe=^D:
   ```

   ---

   **Note –** The baud rate must be set to 9600.

   ---

3. **In a shell window on the host, run `tip`(1) and specify the name of the entry:**

   ```
   % tip debug
   connected
   ```

   The shell window is now a tip window with a connection to the console of the test machine.

**Caution –** Do not use `STOP-A` for SPARC machines or `F1-A` for x86 architecture machines on the host machine to stop the test machine. This action actually stops the host machine. To send a break to the test machine, type **~#** in the tip window. Commands such as **~#** are recognized only if these characters on first on the line. If the command has no effect, press either the Return key or Control-U.

## Setting Up a Target System on the SPARC Platform

A quick way to set up the test machine on the SPARC platform is to unplug the keyboard before turning on the machine. The machine then automatically uses serial port A as the console.

Another way to set up the test machine is to use boot PROM commands to make serial port A the console. On the test machine, at the boot PROM `ok` prompt, direct console I/O to the serial line. To make the test machine always come up with serial port A as the console, set the environment variables: `input-device` and `output-device`.

**EXAMPLE 21–1** Setting `input-device` and `output-device` With Boot PROM Commands

```
ok setenv input-device ttya
ok setenv output-device ttya
```

The `eeprom` command can also be used to make serial port A the console. As superuser, execute the following commands to make the *input-device* and *output-device* parameters point to serial port A. The following example demonstrates the `eeprom` command.

**EXAMPLE 21–2** Setting `input-device` and `output-device` With the `eeprom` Command

```
# eeprom input-device=ttya
# eeprom output-device=ttya
```

The `eeprom` commands cause the console to be redirected to serial port A at each subsequent system boot.

## Setting Up a Target System on the x86 Platform

On x86 platforms, use the `eeprom` command to make serial port A the console. This procedure is the same as the SPARC platform procedure. See "Setting Up a Target System on the SPARC Platform" on page 435. The `eeprom` command causes the console to switch to serial port A (COM1) during reboot.

**Note –** x86 machines do not transfer console control to the *tip* connection until an early stage in the boot process unless the BIOS supports console redirection to a serial port. In SPARC machines, the *tip* connection maintains console control throughout the boot process.

# Setting Up Test Modules

The `system`(4) file in the `/etc` directory enables you to set the value of kernel variables at boot time. With kernel variables, you can toggle different behaviors in a driver and take advantage of debugging features that are provided by the kernel. The kernel variables, `moddebug` and `kmem_flags`, which can be very useful in debugging, are discussed later in this section.

Changes to kernel variables after boot are unreliable, because `/etc/system` is read only once when the kernel boots. After this file is modified, the system must be rebooted for the changes to take effect. If a change in the file causes the system not to work, boot with the ask (`-a`) option. Then specify `/dev/null` as the system file.

**Note –** Kernel variables cannot be relied on to be present in subsequent releases.

## Setting Kernel Variables

The `set` command changes the value of module or kernel variables. To set module variables, specify the module name and the variable:

`set` *module_name*`:variable=value`

For example, to set the variable `test_debug` in a driver that is named *myTest*, use `set` as follows:

```
% set myTest:test_debug=1
```

To set a variable that is exported by the kernel itself, omit the module name.

You can also use a bitwise OR operation to set a value, for example:

```
% set moddebug | 0x80000000
```

## Loading and Unloading Test Modules

The commands, `modload`(1M), `modunload`(1M), and `modinfo`(1M) can be quite handy for adding test modules, which is a useful technique for debugging and stress-testing drivers. These commands are generally not needed in normal operation, because the kernel automatically loads needed modules and unloads unused modules. The `moddebug` kernel variable works with these commands to provide information and set controls.

### *Using the `modload()` Function*

Use `modload` to force a module into memory. `modload` verifies that the driver has no unresolved references when that driver is loaded. Loading a driver does *not* necessarily mean that the driver can attach. When a driver loads successfully, the driver's `_info`(9E) entry point is called. The `attach()` entry point is not necessarily called.

### *Using the `modinfo()` Function*

Use `modinfo` to confirm that the driver is loaded.

**EXAMPLE 21–3** Using `modinfo` to Confirm a Loaded Driver

```
$ modinfo
 Id Loadaddr   Size Info Rev Module Name
  6 101b6000    732   -   1  obpsym (OBP symbol callbacks)
  7 101b65bd  1acd0 226   1  rpcmod (RPC syscall)
  7 101b65bd  1acd0 226   1  rpcmod (32-bit RPC syscall)
  7 101b65bd  1acd0   1   1  rpcmod (rpc interface str mod)
  8 101ce8dd  74600   0   1  ip (IP STREAMS module)
  8 101ce8dd  74600   3   1  ip (IP STREAMS device)
[...]

$ modinfo | grep mydriver
169 781a8d78   13fb   0   1  mydriver (Test Driver 1.5)
```

The number in the `info` field is the major number that has been chosen for the driver. `modunload` can be used to unload a module if the module ID can be provided. The module ID is found in the left column of `modinfo` output.

Sometimes a driver does not unload as expected after a `modunload` is issued, because the driver is assumed to be busy. This situation occurs when the driver fails `detach`(9E), either because the driver really is busy, or because the `detach` entry point is implemented incorrectly.

### *Using* `modunload()`

To remove all of the currently unused modules from memory, run `modunload` with a module ID of 0:

```
# modunload -i 0
```

### *Setting the* `moddebug` *Kernel Variable*

`moddebug` is a kernel variable that controls the module loading process. The possible values of `moddebug` are:

| | |
|---|---|
| `0x80000000` | Prints messages to the console when loading or unloading modules. |
| `0x40000000` | Gives more detailed error messages. |
| `0x20000000` | Prints more detail when loading or unloading, such as including the address and size. |
| `0x00001000` | No auto-unloading drivers. The system does not attempt to unload the device driver when the system resources become low. |
| `0x00000080` | No auto-unloading streams. The system does not attempt to unload the STREAMS module when the system resources become low. |
| `0x00000010` | No auto-unloading of kernel modules of any type. |
| `0x00000001` | If running with `kmdb`, `moddebug` causes a breakpoint to be executed and a return to `kmdb` immediately before each module's `_init`(9E) routine is called. This setting also generates additional debug messages when the module's `_info` and `_fini` routines are executed. |

## Setting `kmem_flags` Debugging Flags

`kmem_flags` is a kernel variable used to enable debugging features in the kernel's memory allocator. Set `kmem_flags` to `0xf` to enable the allocator's debugging features. These features include runtime checks to find the following code conditions:

- Writing to a buffer after the buffer is freed
- Using memory before the memory is initialized
- Writing past the end of a buffer

The *Solaris Modular Debugger Guide* describes how to use the kernel memory allocator to analyze such problems.

**Note –** Testing and developing with `kmem_flags` set to `0xf` can help detect latent memory corruption bugs. Because setting `kmem_flags` to `0xf` changes the internal behavior of the kernel memory allocator, you should thoroughly test without `kmem_flags` as well.

# Avoiding Data Loss on a Test System

A driver bug can sometimes render a system incapable of booting. By taking precautions, you can avoid system reinstallation in this event, as described in this section.

## Back Up Critical System Files

A number of driver-related system files are difficult, if not impossible, to reconstruct. Files such as `/etc/name_to_major`, `/etc/driver_aliases`, `/etc/driver_classes`, and `/etc/minor_perm`can be corrupted if the driver crashes the system during installation. See the `add_drv`(1M) man page.

To be safe, make a backup copy of the root file system after the test machine is in the proper configuration. If you plan to modify the `/etc/system` file, make a backup copy of the file before making modifications.

### ▼ To Boot With an Alternate Kernel

To avoid rendering a system inoperable, you should boot from a copy of the kernel and associated binaries rather than from the default kernel.

**Steps**

1. **Make a copy of the drivers in `/platform/*`.**

   ```
   # cp -r /platform/‘uname -i‘/kernel /platform/‘uname -i‘/kernel.test
   ```

2. **Place the driver module in `/platform/‘uname -i‘/kernel.test/drv`.**

3. **Boot the alternate kernel instead of the default kernel.**

   After you have created and stored the alternate kernel, you can boot this kernel in a number of ways.

   - You can boot the alternate kernel by rebooting:

     ```
     # reboot -- kernel.test/unix
     ```

   - On a SPARC-based system, you can also boot from the PROM:

```
ok boot kernel.test/unix
```

---

**Note –** To boot with the `kmdb` debugger, use the `-k` option as described in "Getting Started With the Modular Debugger" on page 447.

---

- On an x86–based system, when the `Select (b)oot or (i)nterpreter:` message is displayed in the boot process, type the following:

  ```
  boot kernel.test/unix
  ```

### Example 21–4 Booting an Alternate Kernel

The following example demonstrates booting with an alternate kernel.

```
ok boot kernel.test/unix
Rebooting with command: boot kernel.test/unix
Boot device: /sbus@1f,0/espdma@e,8400000/esp@e,8800000/sd@0,0:a File and \
    args:
kernel.test/unix
SunOS Release 5.10 Version Generic 32-bit
Copyright 1983-2002 Sun Microsystems, Inc. All rights reserved.
[...]
```

### Example 21–5 Booting an Alternate Kernel With the `-a` Option

Alternatively, the module path can be changed by booting with the ask (`-a`) option. This option results in a series of prompts for configuring the boot method.

```
ok boot -a
Rebooting with command: boot -a
Boot device: /sbus@1f,0/espdma@e,8400000/esp@e,8800000/sd@0,0:a File and \
args: -a
Enter filename [kernel/sparcv9/unix]: kernel.test/sparcv9/unix
Enter default directory for modules
[/platform/sun4u/kernel.test /kernel /usr/kernel]: <CR>
Name of system file [etc/system]: <CR>
SunOS Release 5.10 Version Generic 64-bit
Copyright 1983-2002 Sun Microsystems, Inc. All rights reserved.
root filesystem type [ufs]: <CR>
Enter physical name of root device
[/sbus@1f,0/espdma@e,8400000/esp@e,8800000/sd@0,0:a]: <CR>
```

## Consider Alternative Back–Up Plans

If the system is attached to a network, the test machine can be added as a client of a server. If a problem occurs, the system can be booted from the network. The local disks can then be mounted, and any fixes can be made. Alternatively, the system can be booted directly from the Solaris 10 CD-ROM.

Another way to recover from disaster is to have another bootable root file system. Use `format`(1M) to make a partition that is the exact size of the original. Then use `dd`(1M) to copy the bootable root file system. After making a copy, run `fsck`(1M) on the new file system to ensure its integrity.

Subsequently, if the system cannot boot from the original root partition, boot the backup partition. Use `dd`(1M) to copy the backup partition onto the original partition. You might have a situation where the system cannot boot even though the root file system is undamaged. For example, the damage might be limited to the boot block or the boot program. In such a case, you can boot from the backup partition with the ask (`-a`) option. You can then specify the original file system as the root file system.

## Capture System Crash Dumps

When a system panics, the system writes an image of kernel memory to the dump device. The dump device is by default the most suitable swap device. The dump is a system crash dump, similar to core dumps generated by applications. On rebooting after a panic, `savecore`(1M) checks the dump device for a crash dump. If a dump is found, `savecore()` makes a copy of the kernel's symbol table, which is called `unix.`*n*. `savecore()` then dumps a core file that is called `vmcore.`*n* in the core image directory. By default, the core image directory is `/var/crash/`*machine_name*. If `/var/crash` has insufficient space for a core dump, the system displays the needed space but does not actually save the dump. `mdb`(1) can then be used on the core dump and the saved kernel.

In the Solaris 10 Operating System, crash dump is enabled by default. The `dumpadm`(1M) command is used to configure system crash dumps. Use the `dumpadm`(1M) command to verify that crash dumps are enabled and to determine the location of core files that have been saved. See the `dumpadm`(1M) man page for more information.

---

**Note –** `savecore`(1M) can be prevented from filling the file system. Add a file that is named `minfree` to the directory in which the dumps are to be saved. In this file, specify the number of kilobytes to remain free after `savecore`(1M) has run. If insufficient space is available, the core file is not saved.

---

# Recovering the Device Directory

Damage to the /devices and /dev directories can occur if the driver crashes during attach(9E). If either directory is damaged, you can rebuild the directory by booting the system and running fsck(1M) to repair the damaged root file system. The root file system can then be mounted. Re-create /dev and /devices by running devfsadm(1M) and specifying the /devices directory on the mounted disk.

The following example shows how to repair a damaged root file system on a SPARC system. In this example, the damaged disk is /dev/dsk/c0t3d0s0, and an alternate boot disk is /dev/dsk/c0t1d0s0.

**EXAMPLE 21–6** Recovering a Damaged Device Directory

```
ok boot disk1
[...]

Rebooting with command: boot kernel.test/unix
Boot device: /sbus@1f,0/espdma@e,8400000/esp@e,8800000/sd@31,0:a File and \
    args:
kernel/unix
SunOS Release 5.10 Version Generic 32-bit
Copyright 1983-2002 Sun Microsystems, Inc. All rights reserved.
...
# fsck /dev/dsk/c0t3d0s0** /dev/dsk/c0t3d0s0
** Last Mounted on /
** Phase 1 - Check Blocks and Sizes
** Phase 2 - Check Pathnames
** Phase 3 - Check Connectivity
** Phase 4 - Check Reference Counts
** Phase 5 - Check Cyl groups
1478 files, 9922 used, 29261 free
     (141 frags, 3640 blocks, 0.4% fragmentation)
# mount /dev/dsk/c0t3d0s0 /mnt
# devfsadm -r /mnt
```

---

**Note –** A fix to /devices and /dev can allow the system to boot while other parts of the system are still corrupted. Such repairs are only a temporary fix to save information, such as system crash dumps, before reinstalling the system.

---

# Debugging Tools

This section describes two debuggers that can be applied to device drivers:

- `kmdb`(1) **kernel debugger** – `kmdb` provides typical runtime debugger facilities, such as breakpoints, watch points, and single-stepping. `kmdb` supersedes `kadb`, which was available in previous releases. The commands that were previously available from `kadb` are used in `kmdb`, in addition to new functionality. Where `kadb` could only be loaded at boot time, `kmdb` can be loaded at any time. `kmdb` is preferred for live, interactive debugging due to its execution controls.
- `mdb`(1) **modular debugger** – In contrast to `kmdb`, `mdb` has limited usefulness as a real-time debugger but has rich facilities for postmortem debugging.

`kmdb` and `mdb` share the same user interface, for the most part. Many debugging techniques can therefore be applied with the same commands in both tools. Both debuggers support macros, dcmds, and dmods. A *dcmd* (pronounced dee-command) is a routine in the debugger that can access any of the properties of the current target program. A dcmd can be dynamically loaded at runtime. A *dmod*, which is short for debugger module, is a package of dcmds that can be loaded to provide non-standard behavior.

Both `mdb` and `kmdb` are backwards-compatible with legacy debuggers like `adb` and `kadb`. `mdb` can execute all of the macros that are available to `kmdb` as well as any legacy user-defined macros for `adb`. The standard 32–bit macro set can be found in `/usr/lib/adb` and in `/usr/platform/‘uname -i‘/lib/adb`. 64-bit versions are in `/usr/lib/adb/sparcv9` and `/usr/platform/‘uname -i‘/lib/adb/sparcv9`.

# Postmortem Debugging

Postmortem analysis offers numerous advantages to driver developers. More than one developer can examine a problem in parallel. Multiple instances of the debugger can be used simultaneously on a single crash dump. The analysis can be performed offline so that the crashed system can be returned to service, if possible. Postmortem analysis enables the use of user-developed debugger functionality in the form of dmods. Dmods can bundle functionality that would be too memory-intensive for real-time debuggers, such as `kmdb`.

When a system panics while kmdb is loaded, control is passed to the debugger for immediate investigation. If kmdb does not seem appropriate for analyzing the current problem, a good strategy is to use ':c' to continue execution and save the crash dump. When the system reboots, you can perform postmortem analysis with mdb on the saved crash dump. This process is analogous to debugging an application crash from a process core file.

---

**Note –** In earlier versions of the Solaris Operating System, adb(1) was the recommended tool for postmortem analysis. In the Solaris 10 operating system, mdb(1) is the recommended tool for postmortem analysis. The mdb() feature set surpasses the set of commands from the legacy crash(1M) utility, which has been removed from theSolaris 10 release.

---

# Using the kmdb Kernel Debugger

kmdb is an interactive kernel debugger that provides the following capabilities:

- Control of kernel execution
- Inspection of the kernel state
- Live modifications to the code

This section assumes that you are already familiar with the kmdb debugger. The focus in this section is on kmdb capabilities that are useful in device driver design. To learn how to use kmdb in detail, refer to the kmdb(1) man page and to the *Solaris Modular Debugger Guide*, Sun Microsystems, Inc., 2005. If you are familiar with kadb, refer to the kadb(1M) man page for the major differences between kadb and kmdb.

The kmdb debugger can be loaded and unloaded at will. The complete instructions for loading and unloading kmdb is in *Solaris Modular Debugger Guide*. For safety and convenience, booting with an alternate kernel is highly encouraged. The boot process is slightly different between the SPARC platform and the x86 platform, as described in this section.

---

**Note –** By default, kmdb uses the CPU ID as the prompt when kmdb is running. In the examples in this chapter [0] is used as the prompt unless otherwise noted.

---

## Booting kmdb With an Alternate Kernel on the SPARC Platform

Use either of the following commands to boot a SPARC system with both kmdb and an alternate kernel:

```
boot kmdb -D kernel.test/unix
boot kernel.test/unix -k
```

## Booting kmdb With an Alternate Kernel on the x86 Platform

Use either of the following commands to boot an x86 system with both kmdb and an alternate kernel:

```
b kmdb -D kernel.test/unix
b kernel.test/unix -k
```

## Setting Breakpoints in kmdb

Breakpoints are set with the command bp and the location, as shown in the following example.

**EXAMPLE 21–7** Setting Standard Breakpoints in kmdb

```
[0]> myModule`myBreakpointLocation::bp
```

If the target module has not been loaded, then an error message that indicates this condition is displayed, and the breakpoint is not created. One solution to this situation is to use a deferred breakpoint. A *deferred breakpoint* activates automatically when the specified module is loaded.You set a deferred breakpoint by specifying the target location after the bp command. The following example demonstrates a deferred breakpoint.

**EXAMPLE 21–8** Setting Deferred Breakpoints in kmdb

```
[0]>::bp myModule`myBreakpointLocation
```

For more information on using breakpoints, see *Solaris Modular Debugger Guide*. You can also get help by typing either of the following two lines:

```
> ::help bp
> ::bp dcmd
```

## kmdb Macros for Driver Developers

kmdb(1M) supports macros that can be used to display kernel data structures. kmdb macros can be displayed with $M. Macros are used in the form:

```
    [ address ] $<macroname
```

**Note –** Neither the information displayed by these macros nor the format in which the information is displayed, constitutes an interface. Therefore, the information and format can change at any time.

The `kmdb` macros in the following table are particularly useful to developers of device drivers. For convenience, legacy macro names are shown where applicable.

**TABLE 21–1** `kmdb` Macros

| Dcmd | Legacy Macro | Description |
|---|---|---|
| `::devinfo` | `devinfo`<br>`devinfo_brief`<br>`devinfo.prop` | Print a summary of a device node |
| `::walk devinfo_parents` | `devinfo.parent` | Walk the ancestors of a device node |
| `::walk devinfo_sibling` | `devinfo.sibling` | Walk the siblings of a device node |
| `::minornodes` | `devinfo.minor` | Print the minor nodes that correspond to the given device node |
| `::major2name` | | Print the name of a device that is bound to a given device node. |
| `::devbindings` | | Print the device nodes that are bound to a given device node or major number. |

The `::devinfo` dcmd displays a node state that can have one of the following values:

`DS_ATTACHED` The driver's `attach`(9E) routine returned successfully.

`DS_BOUND` The node is bound to a driver, but the driver's `probe`(9E) routine has not yet been called.

`DS_INITIALIZED` The parent nexus has assigned a bus address for the driver. The implementation-specific initializations have been completed. The driver's `probe`(9E) routine has not yet been called at this point.

`DS_LINKED` The device node has been linked into the kernel's device tree, but the system has not yet found a driver for this node.

`DS_PROBED` The driver's `probe`(9E) routine returned successfully.

`DS_READY` The device is fully configured.

## Using the `mdb` Modular Debugger

The `mdb` modular debugger can be applied to the following types of files:

- Live operating system components
- Operating system crash dumps
- User processes
- User process core dumps
- Object files

The modular debugger, `mdb`, provides sophisticated debugging support for analyzing kernel problems. This section provides an overview of `mdb` features. For a more complete discussion of `mdb`, refer to the *Solaris Modular Debugger Guide*.

Although `mdb` can be used to alter live kernel state, `mdb` lacks the kernel execution control that is provided by `kmdb`. As a result `kmdb` is preferred for runtime debugging. `mdb` is used more for static situations.

---

**Note –** The prompt for `mdb` is `>`.

---

## Getting Started With the Modular Debugger

`mdb` provides an extensive programming API for implementing debugger modules so that driver developers can implement custom debugging support. `mdb` also provides a host of usability features, such as command-line editing, command history, an output pager, and online help.

---

**Note –** The `adb` macros should no longer be used. That functionality has largely been superseded by the dcmds in `mdb`.

---

`mdb` provides a rich set of modules and dcmds. With these tools, you can debug the Solaris kernel, any associated modules, and device drivers. These facilities enable you to do activities such as:

- Formulate complex debugging queries
- Locate all the memory allocated by a particular thread
- Print a visual picture of a kernel STREAM
- Determine what type of structure a particular address refers to
- Locate leaked memory blocks in the kernel

- Analyze memory to locate stack traces
- Assemble dcmds into modules called *dmods* for creating customized operations

To get started, you switch to the crash directory and type `mdb` and specify a system crash dump, as illustrated in the following example.

**EXAMPLE 21–9** Invoking `mdb` on a Crash Dump

```
% cd /var/crash/testsystem
% ls
bounds     unix.0    vmcore.0
% mdb unix.0 vmcore.0
Loading modules: [ unix krtld genunix ufs_log ip usba s1394 cpc nfs ]
> ::status
debugging crash dump vmcore.0 (64-bit) from testsystem
operating system: 5.10 Generic (sun4u)
panic message: zero
dump content: kernel pages only
```

When `mdb` responds with the '`>`' prompt, you can run commands.

To examine the running kernel on a live system, you run `mdb` from the system prompt as follows.

**EXAMPLE 21–10** Invoking `mdb` on a Running Kernel

```
# mdb -k
Loading modules: [ unix krtld genunix ufs_log ip usba s1394 ptm cpc ipc nfs ]
> ::status
debugging live kernel (64-bit) on testsystem
operating system: 5.10 Generic (sun4u)
```

# Useful Debugging Tasks With `kmdb` and `mdb`

This section provides examples of useful debugging tasks. The tasks in this section can be performed with either `mdb` or `kmdb` unless specifically noted. This section assumes a basic knowledge of the use of `kmdb` and `mdb`. Note that the information presented here is dependent on the type of system used. A Sun Blade™ 100 workstation running the 64-bit kernel was used to produce these examples

**Caution –** Because irreversible destruction of data can result from modifying data in kernel structures, you should exercise extreme caution. Never modify or rely on data in structures that are not part of the Solaris DDI. See the `Intro`(9S) man page.

## Exploring System Registers With kmdb

kmdb can display machine registers as a group or individually. To display all registers as a group, use $r as shown in the following example.

**EXAMPLE 21–11** Reading All Registers on a SPARC Processor With kmdb

```
[0]: $r

g0    0                                  l0      0
g1    100130a4      debug_enter          l1      edd00028
g2    10411c00      tsbmiss_area+0xe00   l2      10449c90
g3    10442000      ti_statetbl+0x1ba    l3      1b
g4    3000061a004                        l4      10474400     ecc_syndrome_tab+0x80
g5    0                                  l5      3b9aca00
g6    0                                  l6      0
g7    2a10001fd40                        l7      0
o0    0                                  i0      0
o1    c                                  i1      10449e50
o2    20                                 i2      0
o3    300006b2d08                        i3      10
o4    0                                  i4      0
o5    0                                  i5      b0
sp    2a10001b451                        fp      2a10001b521
o7    1001311c      debug_enter+0x78     i7      1034bb24     zsa_xsint+0x2c4
y     0
tstate: 1604  (ccr=0x0, asi=0x0, pstate=0x16, cwp=0x4)
pstate: ag:0 ie:1 priv:1 am:0 pef:1 mm:0 tle:0 cle:0 mg:0 ig:0
winreg: cur:4 other:0 clean:7 cansave:1 canrest:5 wstate:14
tba   0x10000000
pc    edd000d8 edd000d8:        ta      %icc,%g0 + 125
npc   edd000dc edd000dc:        nop
```

The debugger exports each register value to a variable with the same name as the register. If you read the variable, the current value of the register is returned. If you write to the variable, the value of the associated machine register is changed. The following example changes the value of the %o0 register from 0 to 1 on an x86 machine.

**EXAMPLE 21–12** Reading and Writing Registers on an x86 Machine With kmdb

```
[0]> &lt;eax=K
        c1e6e0f0
[0]> 0>eax
[0]> &lt;eax=K
        0
[0]>  c1e6e0f0>eax
```

If you need to inspect the registers of a different processor, you can use the `::cpuregs` dcmd. The ID of the processor to be examined can be supplied as either the address to the dcmd or as the value of the `-c` option, as shown in the following example.

**EXAMPLE 21–13** Inspecting the Registers of a Different Processor

```
[0]> 0::cpuregs
   %cs = 0x0158            %eax = 0xc1e6e0f0 kmdbmod`kaif_dvec
   %ds = 0x0160            %ebx = 0x00000000
   [...]
```

The following example switches from processor `0` to processor `3` on a SPARC machine. The `%g3` register is inspected and then cleared. To confirm the new value, `%g3` is read again.

**EXAMPLE 21–14** Retrieving the Value of an Individual Register From a Specified Processor

```
[0]> 3::switch
[3]> <g3=K
        24
[3]> 0>g3
[3]> <g3
        0
```

## Detecting Kernel Memory Leaks

The `::findleaks` dcmd provides powerful, efficient detection of memory leaks in kernel crash dumps. The full set of kernel-memory debugging features need to be enabled for `::findleaks` to be effective. For more information, see "Setting `kmem_flags` Debugging Flags" on page 438. Run `::findleaks` during driver development and testing to detect code that leaks memory, thus wasting kernel resources. See "Debugging With the Kernel Memory Allocator" in the *Solaris Modular Debugger Guide* for a complete discussion of `::findleaks`.

---

**Note –** Code that leaks kernel memory can render the system vulnerable to denial-of-service attacks.

---

## Writing Debugger Commands With `mdb`

`mdb` provides a powerful API for implementing debugger facilities that you customize to debug your driver. The *Solaris Modular Debugger Guide* explains the programming API in detail.

The SUNWmdbdm package installs sample mdb source code in the directory /usr/demo/mdb. You can use mdb to automate lengthy debugging chores or help to validate that your driver is behaving properly. You can also package your mdb debugging modules with your driver product. With packaging, these facilities are available to service personnel at a customer site.

## Obtaining Kernel Data Structure Information

The Solaris kernel provides data type information in structures that can be inspected with either kmdb or mdb.

---

**Note –** The kmdb and mdb dcmds can be used only with objects that contain compressed symbolic debugging information that has been designed for use with mdb. This information is currently available only for certain Solaris kernel modules. The SUNWzlib package must be installed to process the symbolic debugging information.

---

The following example demonstrates how to display the data in the scsi_pkt structure.

**EXAMPLE 21–15** Displaying Kernel Data Structures With a Debugger

```
> 7079ceb0::print -t 'struct scsi_pkt'
{
    opaque_t pkt_ha_private = 0x7079ce20
    struct scsi_address pkt_address = {
        struct scsi_hba_tran *a_hba_tran = 0x70175e68
        ushort_t a_target = 0x6
        uchar_t a_lun = 0
        uchar_t a_sublun = 0
    }
    opaque_t pkt_private = 0x708db4d0
    int (*)() *pkt_comp = sd_intr
    uint_t pkt_flags = 0
    int pkt_time = 0x78
    uchar_t *pkt_scbp = 0x7079ce74
    uchar_t *pkt_cdbp = 0x7079ce64
    ssize_t pkt_resid = 0
    uint_t pkt_state = 0x37
    uint_t pkt_statistics = 0
    uchar_t pkt_reason = 0
}
```

The size of a data structure can be useful in debugging. Structure size is obtained with the ::sizeof dcmd, as shown in the following example.

**EXAMPLE 21–16** Displaying the Size of a Kernel Data Structure

```
> ::sizeof struct scsi_pkt
sizeof (struct scsi_pkt) = 0x58
```

The address of a specific member within a structure is also useful in debugging. Several methods are available for determining a member's address.

Use the `::offsetof` command to obtain the offset for a given member of a structure, as in the following example.

**EXAMPLE 21–17** Displaying the Offset to a Kernel Data Structure

```
> ::offsetof struct scsi_pkt pkt_state
offsetof (struct pkt_state) = 0x48
```

Use the `::print` command can be used with the `-a` option to display the addresses of all members of a structure, as in the following example.

**EXAMPLE 21–18** Displaying the Relative Addresses of a Kernel Data Structure

```
> ::print -a struct scsi_pkt
{
    0 pkt_ha_private
    8 pkt_address {
    [...]

    }
    18 pkt_private
    [...]
}
```

If an address is specified with `::print` in conjunction with the `-a` option, the absolute address for each member is displayed.

**EXAMPLE 21–19** Displaying the Absolute Addresses of a Kernel Data Structure

```
> 10000000::print -a struct scsi_pkt
{
    10000000 pkt_ha_private
    10000008 pkt_address {
    [...]

    }
    10000018 pkt_private
    [...]

}
```

The `::print`, `::sizeof` and `::offsetof` facilities enable you to debug problems when your driver interacts with the Solaris kernel.

**Caution –** This facility provides access to *raw* kernel data structures. You can examine any structure whether or not that structure appears as part of the DDI. Therefore, you should refrain from relying on any data structure that is not explicitly part of the DDI.

**Note –** These dcmds should be used only with objects that contain compressed symbolic debugging information that has been designed for use with `mdb`. Symbolic debugging information is currently available for certain Solaris kernel modules only. The `SUNWzlib` (32-bit) or `SUNWzlibx` (64-bit) decompression software must be installed in order to process the symbolic debugging information. `kmdb` can process symbolic type data with or without the `SUNWzlib*` packages.

## Obtaining Device Tree Information

`mdb` provides the `::prtconf` dcmd for displaying the kernel device tree. The output of the `::prtconf` dcmd is similar to the output of the `prtconf`(1M) command.

**EXAMPLE 21–20** Using the `::prtconf` Dcmd

```
> ::prtconf
300015d3e08      SUNW,Sun-Blade-100
    300015d3c28      packages (driver not attached)
        300015d3868      SUNW,builtin-drivers (driver not attached)
        300015d3688      deblocker (driver not attached)
        300015d34a8      disk-label (driver not attached)
        300015d32c8      terminal-emulator (driver not attached)
        300015d30e8      obp-tftp (driver not attached)
        300015d2f08      dropins (driver not attached)
        300015d2d28      kbd-translator (driver not attached)
        300015d2b48      ufs-file-system (driver not attached)
    300015d3a48      chosen (driver not attached)
    300015d2968      openprom (driver not attached)
    ...
```

You can display the node by using a macro, such as the `::devinfo` dcmd, as shown in the following example.

**EXAMPLE 21–21** Displaying Device Information for an Individual Node

```
> 300015d3e08::devinfo
300015d3e08      SUNW,Sun-Blade-100
        System properties at 0x300015abdc0:
```

**EXAMPLE 21–21** Displaying Device Information for an Individual Node *(Continued)*

```
            name='relative-addressing' type=int items=1
                value=00000001
            name='MMU_PAGEOFFSET' type=int items=1
                value=00001fff
            name='MMU_PAGESIZE' type=int items=1
                value=00002000
            name='PAGESIZE' type=int items=1
                value=00002000
        Driver properties at 0x300015abe00:
            name='pm-hardware-state' type=string items=1
                value='no-suspend-resume'
```

Use `::prtconf` to see where your driver has attached in the device tree, and to display device properties. You can also specify the verbose (`-v`) flag to `::prtconf` to display the properties for each device node, as follows.

**EXAMPLE 21–22** Using the `::prtconf` Dcmd in Verbose Mode

```
> ::prtconf -v
DEVINFO          NAME
300015d3e08      SUNW,Sun-Blade-100
        System properties at 0x300015abdc0:
            name='relative-addressing' type=int items=1
                value=00000001
            name='MMU_PAGEOFFSET' type=int items=1
                value=00001fff
            name='MMU_PAGESIZE' type=int items=1
                value=00002000
            name='PAGESIZE' type=int items=1
                value=00002000
        Driver properties at 0x300015abe00:
            name='pm-hardware-state' type=string items=1
                value='no-suspend-resume'
        [...]

        300015ce798      pci10b9,5229, instance #0
                Driver properties at 0x300015ab980:
                    name='target2-dcd-options' type=any items=4
                        value=00.00.00.a4
                    name='target1-dcd-options' type=any items=4
                        value=00.00.00.a2
                    name='target0-dcd-options' type=any items=4
                        value=00.00.00.a4
         [...]
```

Another way to locate instances of your driver is the `::devbindings` dcmd. Given a driver name, the command displays a list of all instances of the named driver as demonstrated in the following example.

**EXAMPLE 21–23** Using the `::devbindings` Dcmd to Locate Driver Instances

```
> ::devbindings dad
300015ce3d8      ide-disk (driver not attached)
300015c9a60      dad, instance #0
        System properties at 0x300015ab400:
            name='lun' type=int items=1
                value=00000000
            name='target' type=int items=1
                value=00000000
            name='class_prop' type=string items=1
                value='ata'
            name='type' type=string items=1
                value='ata'
            name='class' type=string items=1
                value='dada'
[    ...]

300015c9880      dad, instance #1
        System properties at 0x300015ab080:
            name='lun' type=int items=1
                value=00000000
            name='target' type=int items=1
                value=00000002
            name='class_prop' type=string items=1
                value='ata'
            name='type' type=string items=1
                value='ata'
            name='class' type=string items=1
                value='dada'
    ...
```

## Retrieving Driver Soft State Information

A common problem when debugging a driver is retrieving the *soft state* for a particular driver instance. The soft state is allocated with the `ddi_soft_state_zalloc`(9F) routine. The driver can obtain the soft state through `ddi_get_soft_state`(9F). The name of the *soft state pointer* is the first argument to `ddi_soft_state_init`(9F)). With the name, you can use `mdb` to retrieve the soft state for a particular driver instance through the `::softstate` dcmd:

```
> *bst_state::softstate 0x3
702b7578
```

In this case, `::softstate` is used to fetch the soft state for instance 3 of the `bst` sample driver. This pointer references a `bst_soft` structure that is used by the driver to track state for this instance.

## Modifying Kernel Variables

You can use both `kmdb` and `mdb` to modify kernel variables or other kernel state. Kernel state modification with `mdb` should be done with care, because `mdb` does not stop the kernel before making modifications. Groups of modifications can be made atomically by using `kmdb`, because `kmdb` stops the kernel before allowing access by the user. `mdb` is capable of making single atomic modifications only.

Be sure to use the proper format specifier to perform the modification. The formats are:

- `w` – Writes the lowest two bytes of the value of each expression to the target beginning at the location specified by dot
- `W` – Writes the lowest 4 bytes of the value of each expression to the target beginning at the location specified by dot
- `Z` – Write the complete 8 bytes of the value of each expression to the target beginning at the location specified by dot

Use the `::sizeof` dcmd to determine the size of the variable to be modified.

The following example overwrites the value of `moddebug` with the value 0x80000000.

**EXAMPLE 21–24** Modifying a Kernel Variable With a Debugger

```
> moddebug/W 0x80000000
    moddebug:       0 = 0x80000000
```

# Tuning Drivers

The Solaris OS provides kernel statistics structures so that you can implement counters for your driver. The DTrace facility lets you analyze performance and experiment in real time. This section presents the following topics on device performance:

- "Kernel Statistics" on page 457 – The Solaris OS provides a set of data structures and functions for capturing performance statistics in the kernel. Kernel statistics enable your driver to export continuous statistics while the system is running. The structure for kernel statistics is referred to as a `kstat`. The `kstat` data is handled programmatically by using the `kstat` functions.
- "DTrace for Dynamic Instrumentation" on page 459 – DTrace lets you add instrumentation to your driver dynamically so that you can perform tasks like analyzing the system and measuring performance. DTrace takes advantages of predefined `kstat` structures.

# Kernel Statistics

To assist in performance tuning, the Solaris kernel provides the `kstat`(3KSTAT) facility. The `kstat` facility provides a set of functions and data structures for device drivers and other kernel modules to export module-specific kernel statistics.

A `kstat` is a data structure for recording quantifiable aspects of a device's usage. A `kstat` is stored as a NULL-terminated linked list. Each `kstat` has a common header section and a type-specific data section. The header section is defined by the `kstat_t` structure.

## `kstat` Members

The members of the `kstat` structure are:

| | |
|---|---|
| `ks_class[KSTAT_STRLEN]` | Categorizes the `kstat` type as `bus`, `controller`, `device_error`, `disk`, `hat`, `kmem_cache`, `kstat`, `misc`, `net`, `nfs`, `pages`, `partition`, `rps`, `ufs`, `vm`, or `vmem`. |
| `ks_crtime` | Time at which the `kstat` was created. `ks_crtime` is commonly used in calculating rates of various counters. |
| `ks_data` | Points to the data section for the `kstat`. |
| `ks_data_size` | Total size of the data section in bytes. |
| `ks_instance` | The instance of the kernel module that created this `kstat`. `ks_instance` is combined with `ks_module` and `ks_name` to give the `kstat` a unique, meaningful name. |
| `ks_kid` | Unique ID for `kstat`. |
| `ks_module[KSTAT_STRLEN]` | Identifies the kernel module that created this `kstat`. `ks_module` is combined with `ks_instance` and `ks_name` to give the `kstat` a unique, meaningful name. `KSTAT_STRLEN` sets the maximum length of `ks_module`. |
| `ks_name[KSTAT_STRLEN]` | A name assigned to the `kstat` in combination with `ks_module` and `ks_instance`. `KSTAT_STRLEN` sets the maximum length of `ks_module`. |
| `ks_ndata` | Indicates the number of data records for those `kstat` types that support multiple records: `KSTAT_TYPE_RAW`, `KSTAT_TYPE_NAMED`, and `KSTAT_TYPE_TIMER` |

| | |
|---|---|
| `ks_next` | Points to next `kstat` in chain. |
| `ks_resv` | A reserved field. |
| `ks_snaptime` | The timestamp for the last data snapshot, useful in calculating rates. |
| `ks_type` | The data type, which can be `KSTAT_TYPE_RAW` for binary data, `KSTAT_TYPE_NAMED` for name/value pairs, `KSTAT_TYPE_INTR` for interrupt statistics, `KSTAT_TYPE_IO` for I/O statistics, and `KSTAT_TYPE_TIMER` for event timers. |

## `kstat` Structures

The structures for the different kinds of `kstat` structures:

`kstat`(9S) Each kernel statistic (`kstat`) that is exported by device drivers consists of a header section and a data section. The `kstat` structure is the header portion of the statistic.

`kstat_intr`(9S) Structure for interrupt `kstats`. The types of interrupts are:

- Hard interrupt – Sourced from the hardware device itself
- Soft interrupt – Induced by the system through the use of some system interrupt source
- Watchdog interrupt – Induced by a periodic timer call
- Spurious interrupt – An interrupt entry point was entered but there was no interrupt to service
- Multiple service – An interrupt was detected and serviced just prior to returning from any of the other types

Drivers generally report only claimed hard interrupts and soft interrupts from their handlers, but measurement of the spurious class of interrupts is useful for auto-vectored devices to locate any interrupt latency problems in a particular system configuration. Devices that have more than one interrupt of the same type should use multiple structures.

`kstat_io`(9S) Structure for I/O `kstats`.

`kstat_named`(9S) Structure for named `kstats`. A named `kstat` is an array of name-value pairs. These pairs are kept in the `kstat_named` structure.

## `kstat` Functions

The functions for using `kstats` are:

`kstat_create`(9F)
Allocate and initialize a `kstat`(9S) structure.

`kstat_delete`(9F)
Remove a `kstat` from the system.

`kstat_install`(9F)
Add a fully initialized `kstat` to the system.

`kstat_named_init`(9F), `kstat_named_setstr`(9F)
Initialize a named `kstat`. `kstat_named_setstr()` associates `str`, a string, with the named `kstat` pointer.

`kstat_queue`(9F)
A large number of I/O subsystems have at least two basic queues of transactions to be managed. One queue is for transactions that have been accepted for processing but for which processing has yet to begin. The other queue is for transactions that are actively being processed but not yet done. For this reason, two cumulative time statistics are kept: *wait time* and *run time*. Wait time is prior to service. Run time is during the service. The `kstat_queue()` family of functions manages these times based on the transitions between the driver wait queue and run queue:

- `kstat_runq_back_to_waitq`(9F)
- `kstat_runq_enter`(9F)
- `kstat_runq_exit`(9F)
- `kstat_waitq_enter`(9F)
- `kstat_waitq_exit`(9F)
- `kstat_waitq_to_runq`(9F)

# DTrace for Dynamic Instrumentation

DTrace is a comprehensive dynamic tracing facility for examining the behavior of both user programs and the operating system itself. With DTrace, you can collect data at strategic locations in your environment, referred to as *probes*. DTrace lets you record such data as stack traces, timestamps, the arguments to a function, or simply counts of how often the probe fires. Because DTrace enables you to insert probes dynamically. You do not need to recompile your code. For more information on DTrace, see *Solaris Dynamic Tracing Guide*.

CHAPTER 22

# Recommended Coding Practices

This chapter describes how to write drivers that are robust. Drivers that are written in accordance with the guidelines that are discussed in this chapter are easier to debug. The recommended practices also protect the system from hardware and software faults.

This chapter provides information on the following subjects:



## Debugging Preparation Techniques

Driver code is more difficult to debug than user programs because:

- The driver interacts directly with the hardware
- The driver operates without the protection of the operating system that is available to user processes

Be sure to build debugging support into your driver. This support facilitates both maintenance work and future development.

### Use `cmn_err()` to Log Driver Activity

Use the `cmn_err()` function to print messages to the console from within the device driver. `cmn_err()` is similar to `printf`(3C), but provides additional format characters, such as `%b`, to print device register bits. See the `cmn_err`(9F) man page for more information.

**Note –** To ensure that the driver is DDI-compliant, use `cmn_err()` instead of `printf()` and `uprintf()`.

## Use `ASSERT()` to Catch Invalid Assumptions

Assertions are an extremely valuable form of active documentation. The syntax for `ASSERT`(9F) is as follows:

```
void ASSERT(EXPRESSION)
```

`ASSERT()` is a macro that is used to halt the execution of the kernel if a condition *expected* to be true is *actually* false. `ASSERT` provides a way for the programmer to validate the assumptions made by a piece of code.

The `ASSERT()` macro is defined only when the `DEBUG` compilation symbol is defined. However, when `DEBUG` is not defined, the `ASSERT()` macro has no effect.

For example, if a driver pointer should be non-`NULL` and is not, the following assertion can be used to check the code:

```
ASSERT(ptr != NULL);
```

Assume that the driver has been compiled with `DEBUG`. If the assertion fails, a panic message is printed to the console as follows:

```
panic: assertion failed: ptr != NULL, file: driver.c, line: 56
```

**Note –** Because `ASSERT`(9F) uses the `DEBUG` compilation symbol, any conditional debugging code should also use `DEBUG`.

## Use `mutex_owned()` to Validate and Document Locking Requirements

The syntax for `mutex_owned`(9F) is as follows:

```
int mutex_owned(kmutex_t *mp);
```

A significant portion of driver development involves properly handling multiple threads. Comments should always be used when a mutex is acquired. Comments can be even more useful when an apparently necessary mutex is *not* acquired. To determine whether a mutex is held by a thread, use `mutex_owned()` within `ASSERT`(9F):

```
void helper(void)
{
```

```
    /* this routine should always be called with xsp's mutex held */
    ASSERT(mutex_owned(&xsp->mu));
    [...]
}
```

**Note –** `mutex_owned()` is only valid within `ASSERT()` macros. You should use `mutex_owned()` to control the behavior of a driver.

# Use Conditional Compilation to Toggle Costly Debugging Features

You can insert code for debugging into a driver through conditional compiles by using a preprocessor symbol such as `DEBUG` or by using a global variable. With conditional compilation, unnecessary code can be removed in the production driver. Use a variable to set the amount of debugging output at runtime. The output can be specified by setting a debugging level at runtime with an `ioctl` or through a debugger. Commonly, these two methods are combined.

The following example relies on the compiler to remove unreachable code, in this case, the code following the always-false test of zero.The example also provides a local variable that can be set in `/etc/system` or patched by a debugger.

```
#ifdef DEBUG
comments on values of xxdebug and what they do
static int xxdebug;
#define dcmn_err if (xxdebug) cmn_err
#else
#define dcmn_err if (0) cmn_err
#endif
...
    dcmn_err(CE_NOTE, "Error!\n");
```

This method handles the fact that `cmn_err`(9F) has a variable number of arguments. Another method relies on the fact that the macro has one argument, a parenthesized argument list for `cmn_err`(9F). The macro removes this argument. This macro also removes the reliance on the optimizer by expanding the macro to nothing if `DEBUG` is not defined.

```
#ifdef DEBUG
    comments on values of xxdebug and what they do
static int xxdebug;
#define dcmn_err(X) if (xxdebug) cmn_err X
#else
#define dcmn_err(X) /* nothing */
#endif
    [...]
/* Note:double parentheses are required when using dcmn_err. */
    dcmn_err((CE_NOTE, "Error!"));
```

You can extend this technique in many ways. One way is to specify different messages from `cmn_err`(9F), depending on the value of `xxdebug`. However, in such a case, you must be careful not to obscure the code with too much debugging information.

Another common scheme is to write an `xxlog()` function, which uses `vsprintf`(9F) or `vcmn_err`(9F) to handle variable argument lists.

# Defensive Programming

The following defensive programming techniques can help avoid the following problems: system panics or hangs, waste of system resources, or the spread of corrupted data.

All Solaris drivers should abide by these coding practices:

- Each piece of hardware should be controlled by a separate instance of the device driver. (See "Device Configuration Concepts" on page 94.)
- Programmed I/O (PIO) must be performed *only* through the DDI access functions, using the appropriate data access handle. (See Chapter 7.)
- The device driver must assume that data that is received from the device might be corrupted. The driver must check the integrity of the data before the data is used.
- The driver must avoid releasing bad data to the rest of the system.
- Use only documented DDI functions and interfaces in your driver.
- The driver must ensure that the device writes only into pages of memory in the DMA buffers (`DDI_DMA_READ`) that are controlled entirely by the driver. This technique prevents a DMA fault from corrupting an arbitrary part of the system's main memory.
- The device driver must not be an unlimited drain on system resources if the device locks up. The driver should time out if a device claims to be continuously busy. The driver should also detect a pathological (stuck) interrupt request and take appropriate action.
- The device driver must support hotplugging in the Solaris OS.
- The device driver must use callbacks instead of waiting on resources.
- The driver must free up resources after a fault. For example, the system must be able to close all minor devices and detach driver instances even after the hardware fails.

## Using Separate Device Driver Instances

The Solaris kernel allows multiple instances of a driver. Each instance has its own data space but shares the text and some global data with other instances. The device is managed on a per-instance basis. Drivers should use a separate instance for each piece of hardware unless the driver is designed to handle any failover internally. Multiple instances of a driver per slot can occur, for example, multifunction cards.

## Exclusive Use of DDI Access Handles

All PIO access by a driver must use Solaris DDI access functions from the following families of routines:

- `ddi_get`*X*
- `ddi_put`*X*
- `ddi_rep_get`*X*
- `ddi_rep_put`*X*

The driver should not directly access the mapped registers by the address that is returned from `ddi_regs_map_setup`(9F). Avoid the `ddi_peek`(9F) and `ddi_poke`(9F) routines because these routines do not use access handles.

The DDI access mechanism is important because DDI access provides an opportunity to control how data is read into the kernel.

## Detecting Corrupted Data

The following sections describe where data corruption can occur, with a focus on how to detect corruption.

### Corruption of Device Management and Control Data

The driver should assume that any data obtained from the device, whether by PIO or DMA, could have been corrupted. In particular, extreme care should be taken with pointers, memory offsets, and array indexes that are based on data from the device. Such values can be *malignant*, in that these values can cause a kernel panic if dereferenced. All such values should be checked for range and alignment (if required) before use.

Even a pointer that is not malignant can still be misleading. For example, such a pointer can to a valid but not correct instance of an object. Where possible, the driver should cross-check the pointer with the object to which it is pointing, or otherwise validate the data obtained through that pointer.

Other types of data can also be misleading, such as packet lengths, status words, or channel IDs. These data types should be checked to the extent possible. A packet length can be range-checked to ensure that the length is neither negative nor larger than the containing buffer. A status word can be checked for ”impossible” bits. A channel ID can be matched against a list of valid IDs.

Where a value is used to identify a stream, the driver must ensure that the stream still exists. The asynchronous nature of processing STREAMS means that a stream can be dismantled while device interrupts are still outstanding.

The driver should not reread data from the device. The data should be read once, validated, and stored in the driver's local state. This technique avoids the hazard of data that is correct when initially read, but is incorrect when reread later.

The driver should also ensure that all loops are bounded. For example, a device that returns a continuous `BUSY` status should not be able to lock up the entire system.

## Corruption of Received Data

Device errors can result in corrupted data being placed in receive buffers. Such corruption is indistinguishable from corruption that occurs beyond the domain of the device, for example, within a network. Typically, existing software is already in place to handle such corruption. One example is the integrity checks at the transport layer of a protocol stack. Another example is integrity checks within the application that uses the device.

If the received data is not to be checked for integrity at a higher layer, the data can be integrity-checked within the driver itself. Methods of detecting corruption in received data are typically device-specific, that is, checksums, CRC, and so forth.

# DMA Isolation

A defective device might initiate an improper DMA transfer over the bus. This data transfer could corrupt good data that was previously delivered. A device that fails might generate a corrupt address that can contaminate memory that does not even belong to its own driver.

In systems with an IOMMU, a device can write only to pages mapped as writable for DMA. Therefore, such pages should be owned solely by one driver instance. These pages should not be shared with any other kernel structure. While the page in question is mapped as writable for DMA, the driver should be suspicious of data in that page. The page must be unmapped from the IOMMU before the page is passed beyond the driver, and before any validation of the data.

You can use `ddi_umem_alloc`(9F) to guarantee that a whole aligned page is allocated, or allocate multiple pages and ignore the memory below the first page boundary. You can find the size of an IOMMU page by using `ddi_ptob`(9F).

Alternatively, the driver can choose to copy the data into a safe part of memory before processing it. If this is done, the data must first be synchronized using `ddi_dma_sync`(9F).

Calls to `ddi_dma_sync`(9F) should specify `SYNC_FOR_DEV` before using DMA to transfer data to a device, and `SYNC_FOR_CPU` after using DMA to transfer data from the device to memory.

On some PCI-based systems with an IOMMU, devices can use PCI dual address cycles (64-bit addresses) to bypass the IOMMU. This capability gives the device the potential to corrupt any region of main memory. Device drivers must not attempt to use such a mode and should disable it.

## Handling Stuck Interrupts

The driver must identify stuck interrupts because a persistently asserted interrupt severely affects system performance, almost certainly stalling a single-processor machine.

Sometimes the driver might have difficulty in identifying a particular interrupt as invalid. For network drivers, if a receive interrupt is indicated but no new buffers have been made available, no work was needed. When this situation is an isolated occurrence, it is not a problem, as the actual work might already have been completed by another routine, for example, read service.

On the other hand, continuous interrupts with no work for the driver to process can indicate a stuck interrupt line. For this reason, all platforms allow a number of apparently invalid interrupts to occur before taking defensive action.

While appearing to have work to do, a hung device might be failing to update its buffer descriptors. The driver should defend against such repetitive requests.

In some cases, platform–specific bus drivers might be capable of identifying a persistently unclaimed interrupt and can disable the offending device. However, this relies on the driver's ability to identify the valid interrupts and return the appropriate value. The driver should therefore return a `DDI_INTR_UNCLAIMED` result unless the driver detects that the device legitimately asserted an interrupt, that is, the device actually requires the driver to do some useful work.

The legitimacy of other, more incidental, interrupts is much harder to certify. An interrupt-expected flag is a useful tool for evaluating whether an interrupt is valid. Consider an interrupt such as *descriptor free*, which can be generated if all the device's descriptors had been previously allocated. If the driver detects that it has taken the last descriptor from the card, it can set an interrupt-expected flag. If this flag is not set when the associated interrupt is delivered, the interrupt is suspicious.

Some informative interrupts might not be predictable, such as one indicating that a medium has become disconnected or frame sync has been lost. The easiest method of detecting whether such an interrupt is stuck is to mask this particular source on first occurrence until the next polling cycle.

If the interrupt occurs again while disabled, the interrupt should be considered false. Some devices have interrupt status bits that can be read even if the mask register has disabled the associated source and might not be causing the interrupt. Driver designers can devise more appropriate algorithms specific to their devices.

Avoid looping on interrupt status bits indefinitely. Break such loops if none of the status bits set at the start of a pass requires any real work.

# Additional Programming Considerations

In addition to the requirements discussed in the previous sections, the driver developer must consider a few other issues, such as:

- Thread interaction
- Threats from top-down requests
- Adaptive strategies

## Thread Interaction

Kernel panics in a device driver are often caused by unexpected interaction of kernel threads after a device failure. When a device fails, threads can interact in ways that the designer had not anticipated.

If processing routines terminate early, the condition variable waiters are blocked because an expected signal is never given. Attempting to inform other modules of the failure or handling unanticipated callbacks can result in undesirable thread interactions. Consider the sequence of mutex acquisition and relinquishing that can occur during device failures.

Threads that originate in an upstream STREAMS module can run into unfortunate paradoxes if used to return to that module unexpectedly. You might use alternative threads to handle exception messages. For instance, a `wput` procedure might use a read-side service routine to communicate an `M_ERROR`, rather than handling the error directly with a read-side `putnext`.

A failing STREAMS device that cannot be quiesced during close because of a fault can generate an interrupt after the stream has been dismantled. The interrupt handler must not attempt to use a stale stream pointer to try to process the message.

## Threats From Top-Down Requests

While protecting the system from defective hardware, the driver designer also needs to protect against driver misuse. Although the driver can assume that the kernel infrastructure is always correct (a trusted core), user requests passed to it can be potentially destructive.

For example, a user can request an action to be performed upon a user-supplied data block (`M_IOCTL`) that is smaller than the block size that is indicated in the control part of the message. The driver should never trust a user application.

The design should consider the construction of each type of `ioctl` that it can receive with a view to the potential harm that it could cause. The driver should make checks to be sure that it does not process malformed `ioctl`s.

## Adaptive Strategies

A driver can continue to provide service with faulty hardware, attempting to work around the identified problem by using an alternative strategy for accessing the device. Given that broken hardware is unpredictable and given the risk associated with additional design complexity, adaptive strategies are not always wise. At most, these strategies should be limited to periodic interrupt polling and retry attempts. Periodically retrying the device lets the driver know when a device has recovered. Periodic polling can control the interrupt mechanism after a driver has been forced to disable interrupts.

Ideally, a system always has an alternative device to provide a vital system service. Service multiplexors in kernel or user space offer the best method of maintaining system services when a device fails. Such practices are beyond the scope of this chapter.

# Declaring a Variable Volatile

`volatile` is a keyword that must be applied when declaring any variable that will reference a device register. Without the use of `volatile`, the compile-time optimizer can inadvertently delete important accesses. Neglecting to use `volatile` might result in bugs that are difficult to track down.

The correct use of `volatile` is necessary to prevent elusive bugs. The `volatile` keyword instructs the compiler to use exact semantics for the declared objects, in particular, not to remove or reorder accesses to the object. Two instances where device drivers must use the `volatile` qualifier are:

- When data refers to an external hardware device register, that is, memory that has side effects other than just storage. Note, however, that if the DDI data access functions are used to access device registers, you do not have to use `volatile`.

- When data refers to global memory that is accessible by more than one thread, that is not protected by locks, and that relies on the sequencing of memory accesses. Using `volatile`consumes fewer resources than using lock.

The following example uses `volatile`. A busy flag is used to prevent a thread from continuing while the device is busy and the flag is not protected by a lock:

```
while (busy) {
  /* do something else */
  }
```

The testing thread will continue when another thread turns off the `busy` flag:

```
busy = 0;
```

Because `busy` is accessed frequently in the testing thread, the compiler can potentially optimize the test by placing the value of `busy` in a register and test the contents of the register without reading the value of `busy` in memory before every test. The testing thread would never see `busy` change and the other thread would only change the value of `busy` in memory, resulting in deadlock. Declaring the `busy` flag as `volatile` forces its value to be read before each test.

---

**Note –** An alternative to the `busy` flag is to use a condition variable. See "Condition Variables in Thread Synchronization" on page 66.

---

When using the `volatile` qualifier, avoid the risk of accidental omission. For example, the following code

```
struct device_reg {
 volatile uint8_t csr;
 volatile uint8_t data;
 };
 struct device_reg *regp;
```

is preferable to the next example:

```
struct device_reg {
 uint8_t csr;
 uint8_t data;
 };
 volatile struct device_reg *regp;
```

Although the two examples are functionally equivalent, the second one requires the writer to ensure that `volatile` is used in every declaration of type `struct device_reg`. The first example results in the data being treated as volatile in all declarations and is therefore preferred. As mentioned above, using the DDI data access functions to access device registers makes qualifying variables as `volatile` unnecessary.

# Serviceability

To ensure serviceability, the driver must be enabled to take the following actions:

- Detect faulty devices and report the fault
- Remove a device as supported by the Solaris hot-plug model
- Add a new device as supported by the Solaris hot-plug model
- Perform periodic health checks to enable the detection of latent faults

## Periodic Health Checks

A latent fault is one that does not show itself until some other action occurs. For example, a hardware failure occurring in a device that is a cold standby could remain undetected until a fault occurs on the master device. At this point, the system now contains two defective devices and might be unable to continue operation.

Latent faults that are allowed to remain undetected typically cause system failure eventually. Without latent fault checking, the overall availability of a redundant system is jeopardized. To avoid this situation, a device driver must detect latent faults and report them in the same way as other faults.

You should provide the driver with a mechanism for making periodic health checks on the device. In a fault-tolerant situation where the device can be the secondary or failover device, early detection of a failed secondary device is essential to ensure that the secondary device can be repaired or replaced before any failure in the primary device occurs.

Periodic health checks can be used to perform the following activities:

- Check any register or memory location on the device whose value might have been altered since the last poll.

  Features of a device that typically exhibit deterministic behavior include heartbeat semaphores, device timers (for example, local `lbolt` used by download), and event counters. Reading an updated predictable value from the device gives a degree of confidence that things are proceeding satisfactorily.
- Timestamp outgoing requests such as transmit blocks or commands that are issued by the driver.

  The periodic health check can look for any suspect requests that have not completed.
- Initiate an action on the device that should be completed before the next scheduled check.

  If this action is an interrupt, this check is an ideal way to ensure that the device's circuitry can deliver an interrupt.

# PART IV Appendixes

The appendixes provide the following background material:

- Appendix A discusses multiplatform hardware issues for device drivers.
- Appendix B provides tables of kernel functions for device drivers. Deprecated functions are indicated as well.
- Appendix C provides guidelines for updating a device driver to run in a 64-bit environment.

APPENDIX **A**

# Hardware Overview

This appendix discusses general issues about hardware that is capable of supporting the Solaris 10 Operating System. The discussion includes the processor, bus architectures, and memory models that are supported by the Solaris 10 OS. Various device issues and the PROM used in Sun platforms are also covered.

---

**Note –** The material in this appendix is for informational purposes only. This information might be of use during driver debugging. However, many of these implementation details are hidden from device drivers by the DDI/DKI interfaces.

---

This appendix provides information on the following subjects:



## SPARC Processor Issues

This section describes a number of SPARC processor-specific topics such as data alignment, byte ordering, register windows, and availability of floating-point instructions. For information on x86 processor-specific topics, see "x86 Processor Issues" on page 477.

**Note –** Drivers should never perform floating-point operations, because these operations are not supported in the kernel.

## SPARC Data Alignment

All quantities must be aligned on their natural boundaries, using standard C data types:

- `short` integers are aligned on 16-bit boundaries.
- `int` integers are aligned on 32-bit boundaries.
- `long` integers are aligned on either 32-bit boundaries or 64-bit boundaries, depending on whether the data model of the kernel is 64-bit or 32-bit. For information on data models, see Appendix C.
- `long long` integers are aligned on 64-bit boundaries.

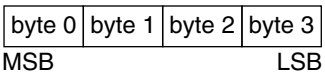
Usually, the compiler handles any alignment issues. However, driver writers are more likely to be concerned about alignment because the proper data types must be used to access the devices. Because device registers are commonly accessed through a pointer reference, drivers must ensure that pointers are properly aligned when accessing the device.

## Member Alignment in SPARC Structures

Because of the data alignment restrictions imposed by the SPARC processor, C structures also have alignment requirements. Structure alignment requirements are imposed by the most strictly aligned structure component. For example, a structure containing only characters has no alignment restrictions, while a structure containing a `long long` member must be constructed to guarantee that this member falls on a 64-bit boundary.

## SPARC Byte Ordering

The SPARC processor uses *big-endian* byte ordering. The most significant byte (MSB) of an integer is stored at the lowest address of the integer. The least significant byte is stored at the highest address for words in this processor. For example, byte 63 is the least significant byte for 64–bit processors.




## SPARC Register Windows

SPARC processors use register windows. Each register window consists of eight *in* registers, eight *local* registers, eight *out* registers, and eight *global* registers. Out registers are the in registers for the next window. The number of register windows ranges from 2 to 32, depending on the processor implementation.

Because drivers are normally written in C, the compiler usually hides the fact that register windows are used. However, you might have to use register windows when debugging the driver.

## SPARC Multiply and Divide Instructions

The Version 7 SPARC processors do not have multiply or divide instructions. The multiply and divide instructions are emulated in software. Because a driver might run on a Version 7, Version 8, or Version 9 processor, avoid intensive integer multiplication and division. Instead, use bitwise left and right shifts to multiply and divide by powers of two.

The *SPARC Architecture Manual, Version 9*, contains more specific information on the SPARC CPU. The *SPARC Compliance Definition*, Version 2.4, contains details of the application binary interface (ABI) for SPARC V9. The manual describes the 32–bit SPARC V8 ABI and the 64–bit SPARC V9 ABI. You can obtain this document from SPARC International at `http://www.sparc.com`.

# x86 Processor Issues

Data types have no alignment restrictions. However, extra memory cycles might be required for the x86 processor to properly handle misaligned data transfers.

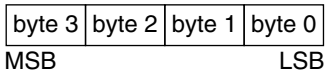
---

**Note –** Drivers should not perform floating-point operations, as these operations are not supported in the kernel.

---

## x86 Byte Ordering

The x86 processor uses *little-endian* byte ordering. The least significant byte (LSB) of an integer is stored at the lowest address of the integer. The most significant byte is stored at the highest address for data items in this processor. For example, byte 7 is the most significant byte for 64–bit processors.




## x86 Architecture Manuals

Both Intel Corporation and AMD publish a number of books on the x86 family of processors. See `http://www.intel.com` and `http://www.amd.com`.

# Endianness

To achieve the goal of multiple-platform, multiple-instruction-set architecture portability, host bus dependencies were removed from the drivers. The first dependency issue to be addressed was the endianness, that is, byte ordering, of the processor. For example, the x86 processor family is little-endian while the SPARC architecture is big-endian.

Bus architectures display the same endianness types as processors. The PCI local bus, for example, is little-endian, the SBus is big-endian, the ISA bus is little-endian, and so on.

To maintain portability between processors and buses, DDI-compliant drivers must be endian neutral. Although drivers can manage their endianness by runtime checks or by preprocessor directives like `#ifdef _LITTLE_ENDIAN` in the source code, long-term maintenance can be troublesome. In some cases, the DDI framework performs the byte swapping using a software approach. In other cases, byte swapping can be done by hardware page-level swapping as in memory management unit (MMU) or by special machine instructions. The DDI framework can take advantage of the hardware features to improve performance.

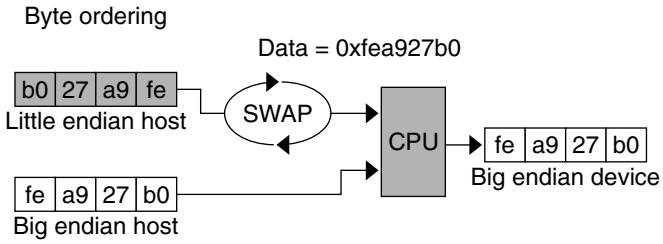



**FIGURE A–1** Byte Ordering Required for Host Bus Dependency

Along with being endian-neutral, portable drivers must also be independent from data ordering of the processor. Under most circumstances, data must be transferred in the sequence instructed by the driver. However, sometimes data can be merged, batched, or reordered to streamline the data transfer, as illustrated in the following figure. For example, data merging can be applied to accelerate graphics display on frame buffers. Drivers have the option to advise the DDI framework to use other optimal data transfer mechanisms during the transfer.

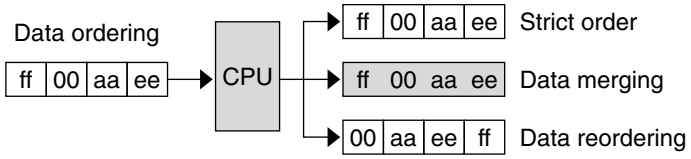



**FIGURE A–2** Data Ordering Host Bus Dependency

# Store Buffers

To improve performance, the CPU uses internal store buffers to temporarily store data. Using internal buffers can affect the synchronization of device I/O operations. Therefore, the driver needs to take explicit steps to make sure that writes to registers are completed at the proper time.

For example, consider the case where access to device space, such as registers or a frame buffer, is synchronized by a lock. The driver needs to check that the store to the device space has actually completed before releasing the lock. The release of the lock does not guarantee the flushing of I/O buffers.

To give another example, when acknowledging an interrupt, the driver usually sets or clears a bit in a device control register. The driver must ensure that the write to the control register has reached the device before the interrupt handler returns. Similarly, a device may require a delay, that is, driver busy-waits, after writing a command to the control register. In such a case, the driver must ensure that the write has reached the device before delaying.

Where device registers can be read without undesirable side effects, verification of a write can simply consist of reading the register immediately after the write. If that particular register cannot be read without undesirable side effects, another device register in the same register set can be used.

# System Memory Model

The system memory model defines the semantics of memory operations such as *load* and *store* and specifies how the order in which these operations are issued by a processor is related to the order in which they reach memory. The memory model applies to both uniprocessors and shared-memory multiprocessors. Two memory models are supported: total store ordering (TSO) and partial store ordering (PSO).

## Total Store Ordering (TSO)

TSO guarantees that the sequence in which store, FLUSH, and atomic load-store instructions appear in memory for a given processor is identical to the sequence in which they were issued by the processor.

Both x86 and SPARC processors support TSO.

## Partial Store Ordering (PSO)

PSO does not guarantee that the sequence in which store, FLUSH, and atomic load-store instructions appear in memory for a given processor is identical to the sequence in which they were issued by the processor. The processor can reorder the stores so that the sequence of stores to memory is not the same as the sequence of stores issued by the CPU.

SPARC processors support PSO; x86 processors do not.

For SPARC processors, conformance between *issuing* order and *memory* order is provided by the system framework using the STBAR instruction. If two of the above instructions are separated by an STBAR instruction in the issuing order of a processor,

or if the instructions reference the same location, the memory order of the two instructions is the same as the issuing order. Enforcement of strong data-ordering in DDI-compliant drivers is provided by the `ddi_regs_map_setup`(9F) interface. Compliant drivers cannot use the STBAR instruction directly.

See the *SPARC Architecture Manual, Version 9*, for more details on the SPARC memory model.

# Bus Architectures

This section describes device identification, device addressing, and interrupts.

## Device Identification

Device identification is the process of determining which devices are present in the system. Some devices are self-identifying meaning that the device itself provides information to the system so that the system can identify the device driver that needs to be used. SBus and PCI local bus devices are examples of self-identifying devices. On SBus, the information is usually derived from a small Forth program stored in the FCode PROM on the device. Most PCI devices provide a configuration space containing device configuration information. See the `sbus`(4) and `pci`(4) man pages for more information.

All modern bus architectures require devices to be self-identifying.

## Supported Interrupt Types

The Solaris platform supports both polling and vectored interrupts. The Solaris 10 DDI/DKI interrupt model is the same for both types of interrupts. See Chapter 8 for more information about interrupt handling.

# Bus Specifics

This section covers addressing and device configuration issues specific to the buses that the Solaris platform supports.

# PCI Local Bus

The PCI local bus is a high-performance bus designed for high-speed data transfer. The PCI bus resides on the system board. This bus is normally used as an interconnect mechanism between highly integrated peripheral components, peripheral add-on boards, and host processor or memory systems. The host processor, main memory, and the PCI bus itself are connected through a PCI host bridge, as shown in Figure A–3.

A tree structure of interconnected I/O buses is supported through a series of PCI bus bridges. Subordinate PCI bus bridges can be extended underneath the PCI host bridge to enable a single bus system to be expanded into a complex system with multiple secondary buses. PCI devices can be connected to one or more of these secondary buses. In addition, other bus bridges, such as SCSI or USB, can be connected.

Every PCI device has a unique vendor ID and device ID. Multiple devices of the same kind are further identified by their unique device numbers on the bus where they reside.

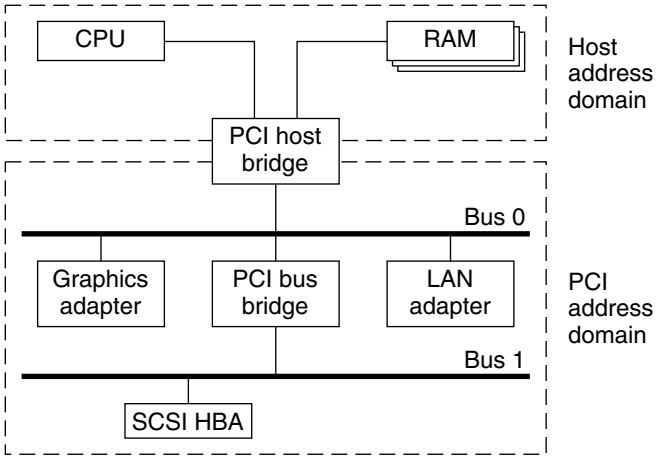



**FIGURE A–3** Machine Block Diagram

The PCI host bridge provides an interconnect between the processor and peripheral components. Through the PCI host bridge, the processor can directly access main memory independent of other PCI bus masters. For example, while the CPU is fetching data from the cache controller in the host bridge, other PCI devices can also access the system memory through the host bridge. The advantage of this architecture lies in its separation of the I/O bus from the processor's host bus.

The PCI host bridge also provides data access mappings between the CPU and peripheral I/O devices. The bridge maps every peripheral device to the host address domain so that the processor can access the device through programmed I/O. On the local bus side, the PCI host bridge maps the system memory to the PCI address domain so that the PCI device can access the host memory as a bus master. Figure A–3 shows the two address domains.

# PCI Address Domain

The PCI address domain consists of three distinct address spaces: configuration, memory, and I/O space.

## PCI Configuration Address Space

Configuration space is defined geographically. The location of a peripheral device is determined by its physical location within an interconnected tree of PCI bus bridges. A device is located by its *bus number* and *device* (*slot*) *number*. Each peripheral device contains a set of well-defined configuration registers in its PCI configuration space. The registers are used not only to identify devices but also to supply device configuration information to the configuration framework. For example, base address registers in the device configuration space must be mapped before a device can respond to data access.

The method for generating configuration cycles is host dependent. In x86 machines, special I/O ports are used. On other platforms, the PCI configuration space can be memory-mapped to certain address locations corresponding to the PCI host bridge in the host address domain. When a device configuration register is accessed by the processor, the request is routed to the PCI host bridge. The bridge then translates the access into proper configuration cycles on the bus.

## PCI Configuration Base Address Registers

The PCI configuration space consists of up to six 32-bit base address registers for each device. These registers provide both size and data type information. System firmware assigns base addresses in the PCI address domain to these registers.

Each addressable region can be either memory or I/O space. The value contained in bit 0 of the base address register identifies the type. A value of 0 in bit 0 indicates a memory space and a value of 1 indicates an I/O space. The following figure shows two base address registers: one for memory and the other for I/O types.

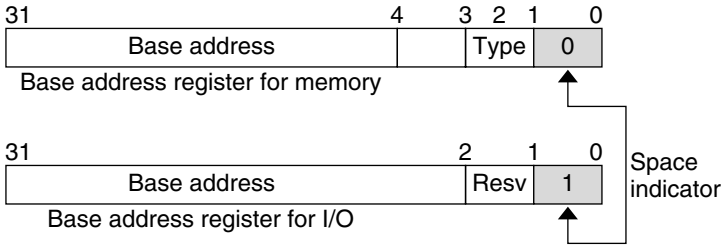



**FIGURE A–4** Base Address Registers for Memory and I/O

## PCI Memory Address Space

PCI supports both 32-bit and 64-bit addresses for memory space. System firmware assigns regions of memory space in the PCI address domain to PCI peripherals. The base address of a region is stored in the base address register of the device's PCI configuration space. The size of each region must be a power of two, and the assigned base address must be aligned on a boundary equal to the size of the region. Device addresses in memory space are *memory-mapped* into the host address domain so that data access to any device can be performed by the processor's native load or store instructions.

## PCI I/O Address Space

PCI supports 32-bit I/O space. I/O space can be accessed differently on different platforms. Processors with special I/O instructions, like the Intel processor family, access the I/O space with `in` and `out` instructions. Machines without special I/O instructions will map to the address locations corresponding to the PCI host bridge in the host address domain. When the processor accesses the memory-mapped addresses, an I/O request will be sent to the PCI host bridge, which then translates the addresses into I/O cycles and puts them on the PCI bus. Memory-mapped I/O is performed by the native load/store instructions of the processor.

## PCI Hardware Configuration Files

Hardware configuration files should be unnecessary for PCI local bus devices. However, on some occasions drivers for PCI devices need to use hardware configuration files to augment the driver private information. See the `driver.conf`(4) and `pci`(4) man pages for further details.

# SBus

Typical SBus systems consist of a motherboard (containing the CPU and SBus interface logic), a number of SBus devices on the motherboard itself, and a number of SBus expansion slots. An SBus can also be connected to other types of buses through an appropriate bus bridge.

The SBus is geographically addressed. Each SBus slot exists at a fixed physical address in the system. An SBus card has a different address, depending on which slot it is plugged into. Moving an SBus device to a new slot causes the system to treat this device as a new device.

The SBus uses polling interrupts. When an SBus device interrupts, the system only knows which of several devices might have issued the interrupt. The system interrupt handler must ask the driver for each device whether that device is responsible for the interrupt.

## SBus Physical Address Space

The following table shows the physical address space layout of the Sun UltraSPARC 2 computer. A physical address on the UltraSPARC 2 model consists of 41 bits. The 41-bit physical address space is further broken down into multiple 33-bit address spaces identified by `PA(40:33)`.

**TABLE A–1** Device Physical Space in the Ultra 2

| PA(40:33) | 33-bit Space | Usage |
|---|---|---|
| 0x0 | `0x000000000 - 0x07FFFFFF` | 2 Gbytes main memory |
| 0x80 – 0xDF | `Reserved on Ultra 2` | Reserved on Ultra 2 |
| 0xE0 | `Processor 0` | Processor 0 |
| 0xE1 | `Processor 1` | Processor 1 |
| 0xE2 – 0xFD | `Reserved on Ultra 2` | Reserved on Ultra 2 |
| 0xFE | `0x000000000 - 0x1FFFFFFFF` | UPA Slave (FFB) |
| 0xFF | `0x000000000 - 0x0FFFFFFFF` | System I/O space |
| | `0x100000000 - 0x10FFFFFFF` | SBus Slot 0 |
| | `0x110000000 - 0x11FFFFFFF` | SBus Slot 1 |
| | `0x120000000 - 0x12FFFFFFF` | SBus Slot 2 |
| | `0x130000000 - 0x13FFFFFFF` | SBus Slot 3 |
| | `0x1D0000000 - 0x1DFFFFFFF` | SBus Slot D |

**TABLE A–1** Device Physical Space in the Ultra 2 *(Continued)*

| PA(40:33) | 33-bit Space | Usage |
|---|---|---|
| | 0x1E0000000 - 0x1EFFFFFFF | SBus Slot E |
| | 0x1F0000000 - 0x1FFFFFFFF | SBus Slot F |

## Physical SBus Addresses

The SBus has 32 address bits, as described in the *SBus Specification*. The following table describes how the Ultra 2 uses the address bits.

**TABLE A–2** Ultra 2 SBus Address Bits

| Bits | Description |
|---|---|
| 0 - 27 | These bits are the SBus address lines used by an SBus card to address the contents of the card. |
| 28 - 31 | Used by the CPU to select one of the SBus slots. These bits generate the SlaveSelect lines. |

This addressing scheme yields the Ultra 2 addresses shown in Table A–1. Other implementations might use a different number of address bits.

The Ultra 2 has seven SBus slots, four of which are physical. Slots 0 through 3 are available for SBus cards. Slots 4-12 are reserved. The slots are used as follows:

- Slots 0–3 are physical slots that have DMA-master capability.
- Slots D, E, and F are not actual physical slots, but refer to the onboard direct memory access (DMA), SCSI, Ethernet, and audio controllers. For convenience, these classes of devices are viewed as being plugged into slots D, E, and F.

---

**Note –** Some SBus slots are slave-only slots. Drivers that require DMA capability should use `ddi_slaveonly`(9F) to determine whether their device is in a DMA-capable slot. For an example of this function, see "`attach()` Entry Point" on page 99.

---

## SBus Hardware Configuration Files

Hardware configuration files are normally unnecessary for SBus devices. However, on some occasions, drivers for SBus devices need to use hardware configuration files to augment the information provided by the SBus card. See the `driver.conf`(4) and `sbus`(4) man page for further details.

# Device Issues

This section describes issues with special devices.

## Timing-Critical Sections

While most driver operations can be performed without mechanisms for synchronization and protection beyond those provided by the locking primitives, some devices require that a sequence of events occur in order without interruption. In conjunction with the locking primitives, the function `ddi_enter_critical`(9F) asks the system to guarantee, to the best of its ability, that the current thread will neither be preempted nor interrupted. This guarantee stays in effect until a closing call to `ddi_exit_critical`(9F) is made. See the `ddi_enter_critical`(9F) man page for details.

## Delays

Many chips specify that they can be accessed only at specified intervals. For example, the Zilog Z8530 SCC has a "write recovery time" of 1.6 microseconds. This specification means that a delay must be enforced with `drv_usecwait`(9F) when writing characters with an 8530. In some instances, the specifications do not make explicit what delays are needed, so the delays must be determined empirically.

Be careful not to compound delays for parts of devices that might exist in large numbers, for example, thousands of SCSI disk drives.

## Internal Sequencing Logic

Devices with internal sequencing logic map multiple internal registers to the same external address. The various kinds of internal sequencing logic include the following types:

- The Intel 8251A and the Signetics 2651 alternate the same external register between *two* internal mode registers. Writing to the first internal register is accomplished by writing to the external register. This write, however, has the side effect of setting up the sequencing logic in the chip so that the next read/write operation refers to the second internal register.
- The NEC PD7201 PCC has multiple internal data registers. To write a byte into a particular register, two steps must be performed. The first step is to write into register zero the number of the register into which the following byte of data will go. The data is then written to the specified data register. The sequencing logic

automatically sets up the chip so that the next byte sent will go into data register zero.

- The AMD 9513 timer has a data pointer register that points at the data register into which a data byte will go. When sending a byte to the data register, the pointer is incremented. The current value of the pointer register *cannot* be read.

## Interrupt Issues

Note the following common interrupt-related issues:

- A controller interrupt does *not* necessarily indicate that *both* the controller *and* one of its slave devices are ready. For some controllers, an interrupt can indicate that either the controller is ready or one of its devices is ready but not both.
- Not all devices power up with interrupts disabled and can begin interrupting at any time.
- Some devices do not provide a way to determine that the board has generated an interrupt.
- Not all interrupting boards shut off interrupts when told to do so or after a bus reset.

# PROM on SPARC Machines

Some platforms have a PROM monitor that provides support for debugging a device without an operating system. This section describes how to use the PROM on SPARC machines to map device registers so that they can be accessed. Usually, the device can be exercised enough with PROM commands to determine whether the device is working correctly.

See the `boot`(1M) man page for a description of the x86 boot subsystem.

The PROM has several purposes, including:

- Bringing the machine up from power on, or from a hard reset PROM `reset` command
- Providing an interactive tool for examining and setting memory, device registers, and memory mappings
- Booting the Solaris system.

  Simply powering up the computer and attempting to use its PROM to examine device registers can fail. While the device might be correctly installed, those mappings are specific to the Solaris Operating System and do not become active until the Solaris kernel is booted. Upon power up, the PROM maps only essential

system devices, such as the keyboard.

- Taking a system crash dump using the `sync` command

# Open Boot PROM 3

For complete documentation on the Open Boot PROM, see the *Open Boot PROM Toolkit User's Guide* and the `monitor`(1M) man page. The examples in this section refer to a Sun4U™ architecture. Other architectures might require different commands to perform actions.

---

**Note –** The Open Boot PROM is currently used on Sun machines with an SBus or UPA/PCI. The Open Boot PROM uses an "`ok`" prompt. On older machines, you might have to type '`n`' to get the "`ok`" prompt.

---

If the PROM is in *secure mode* (the `security-mode` parameter is not set to *none*), the PROM password might be required (set in the `security-password` parameter).

The `printenv` command displays all parameters and their values.

Help is available with the `help` command.

EMACS-style command-line history is available. Use Control-N (next) and Control-P (previous) to traverse the history list.

## Forth Commands

The Open Boot PROM uses the Forth programming language. Forth is a stack-based language. Arguments must be pushed on the stack before running the correct command (called a *word*), and the result is left on the stack.

To place a number on the stack, type its value.

```
ok 57
ok 68
```

To add the two top values on the stack, use the + operator.

```
ok +
```

The result remains on the stack. The stack is shown with the `.s` *word*.

```
ok .s
bf
```

The default base is hexadecimal. The `hex` and `decimal` *words* can be used to switch bases.

```
ok decimal
ok .s
191
```

See the *Forth User's Guide* for more information.

## Walking the PROMs Device Tree

The commands `pwd`, `cd`, and `ls` walk the PROM device tree to get to the device. The `cd` command must be used to establish a position in the tree before `pwd` will work. This example is from an Ultra 1 workstation with a `cgsix` frame buffer on an SBus.

```
ok cd /
```

To see the devices attached to the current node in the tree, use `ls`.

```
ok ls
f006a064 SUNW,UltraSPARC@0,0
f00598b0 sbus@1f,0
f00592dc counter-timer@1f,3c00
f004eec8 virtual-memory
f004e8e8 memory@0,0
f002ca28 aliases
f002c9b8 options
f002c880 openprom
f002c814 chosen
f002c7a4 packages
```

The full node name can be used:

```
ok cd sbus@1f,0
ok ls
f006a4e4 cgsix@2,0
f0068194 SUNW,bpp@e,c800000
f0065370 ledma@e,8400010
f006120c espdma@e,8400000
f005a448 SUNW,pll@f,1304000
f005a394 sc@f,1300000
f005a24c zs@f,1000000
f005a174 zs@f,1100000
f005a0c0 eeprom@f,1200000
f0059f8c SUNW,fdtwo@f,1400000
f0059ec4 flashprom@f,0
f0059e34 auxio@f,1900000
f0059d28 SUNW,CS4231@d,c000000
```

Rather than using the full node name in the previous example, you could also use an abbreviation. The abbreviated command-line entry looks like the following example:

```
ok cd sbus
```

The name is actually `device@slot,offset` (for SBus devices). The `cgsix` device is in slot 2 and starts at offset 0. If an SBus device is displayed in this tree, the device has been recognized by the PROM.

The `.properties` command displays the PROM properties of a device. These properties can be examined to determine which properties the device exports. This information is useful later to ensure that the driver is looking for the correct hardware properties. These properties are the same properties that can be retrieved with `ddi_getprop`(9F).

```
ok cd cgsix
ok .properties
character-set            ISO8859-1
intr                     00000005 00000000
interrupts               00000005
reg                      00000002 00000000 01000000
dblbuf                   00 00 00 00
vmsize                   00 00 00 01
...
```

The *reg* property defines an array of register description structures containing the following fields:

```
uint_t        bustype;       /* cookie for related bus type*/
uint_t        addr;          /* address of reg relative to bus */
uint_t        size;          /* size of this register set */
```

For the `cgsix` example, the address is 0.

## Mapping the Device

A device must be mapped into memory to be tested. The PROM can then be used to verify proper operation of the device by using data-transfer commands to transfer bytes, words, and long words. If the device can be operated from the PROM, even in a limited way, the driver should also be able to operate the device.

To set up the device for initial testing, perform the following steps:

1. Determine the SBus slot number the device is in.

   In this example, the *cgsix* device is located in slot 2.

2. Determine the offset within the physical address space used by the device.

   The offset used is specific to the device. In the `cgsix` example, the video memory happens to start at an offset of 0x800000.

3. Use the `select-dev` *word* to select the Sbus device and the `map-in` *word* to map the device in.

   The `select-dev` *word* takes a string of the device path as its argument. The `map-in` *word* takes an *offset*, a *slot number*, and a *size* as arguments to map. Like the offset, the size of the byte transfer is specific to the device. In the `cgsix` example, the size is set to 0x100000 bytes.

   In the following code example, the Sbus path is displayed as an argument to the `select-dev` word, and the offset, slot number, and size values for the frame buffer are displayed as arguments to the `map-in` word. Notice the space between the opening quote and / in the `select-dev` argument. The virtual address to use

remains on top of the stack. The stack is shown using the `.s` word. The stack can be assigned a name with the `constant` operation.

```
ok " sbus@1f,0" select-dev
ok 800000 2 100000 map-in
ok .s
ffe98000
ok constant fb
```

# Reading and Writing

The PROM provides a variety of 8-bit, 16-bit, and 32-bit operations. In general, a `c` (character) prefix indicates an 8-bit (one-byte) operation; a `w` (word) prefix indicates a 16-bit (two-byte) operation; and an `L` (longword) prefix indicates a 32-bit (four-byte) operation.

A suffix of `!` indicates a write operation. The write operation takes the first two items off the stack. The first item is the address, and the second item is the value.

```
ok 55 ffe98000 c!
```

A suffix of `@` indicates a read operation. The read operation takes the address off the stack.

```
ok ffe98000 c@
ok .s
55
```

A suffix of `?` is used to display the value without affecting the stack.

```
ok ffe98000 c?
55
```

Be careful when trying to query the device. If the mappings are not set up correctly, trying to read or write could cause errors. Special words are provided to handle these cases. `cprobe`, `wprobe`, and `lprobe`, for example, read from the given address but return zero if the location does not respond, or nonzero if it does.

```
ok fffa4000 c@
Data Access Error

ok fffa4000 cprobe
ok .s0

ok ffe98000 cprobe
ok .s
0 ffffffffffffffff
```

A region of memory can be shown with the `dump` word. This takes an *address* and a *length*, and displays the contents of the memory region in bytes.

In the following example, the `fill` word is used to fill video memory with a pattern. `fill` takes the address, the number of bytes to fill, and the byte to use. Use `wfill` and an `Lfill` for words and longwords. This fill example causes the *cgsix* to display simple patterns based on the byte passed.

```
ok " /sbus" select-dev
ok 800000 2 100000 map-in
ok constant fb
ok fb 10000 ff fill
ok fb 20000 0 fill
ok fb 18000 55 fill
ok fb 15000 3 fill
ok fb 10000 5 fillok fb 5000 f9 fill
```

APPENDIX **B**

# Summary of Solaris DDI/DKI Services

This appendix discusses the interfaces provided by the Solaris DDI/DKI. These descriptions should not be considered complete or definitive, nor do they provide a thorough guide to usage. The descriptions are intended to describe what the functions do in general terms. See `physio`(9F) for more detailed information. The categories are:



This appendix does not discuss STREAMS interfaces; to learn more about network drivers, see the *STREAMS Programming Guide*.

# Module Functions

The module functions are:

| | |
|---|---|
| `mod_info` | Query a loadable module |
| `mod_install` | Add a loadable module |
| `mod_remove` | Remove a loadable module |

# Device Information Tree Node (`dev_info_t`) Functions

The device information tree node functions are:

| | |
|---|---|
| `ddi_binding_name()` | Return driver binding name |
| `ddi_dev_is_sid()` | Tell whether a device is self-identifying |
| `ddi_driver_major()` | Return driver major device number |
| `ddi_driver_name()` | Return normalized driver name |
| `ddi_node_name()` | Return the devinfo node name |
| `ddi_get_devstate()` | Check device state |
| `ddi_get_instance()` | Get device instance number |
| `ddi_get_name()` | Return driver binding name |
| `ddi_get_parent()` | Find the parent of a device information structure |
| `ddi_root_node()` | Get the root of the `dev_info` tree |

# Device (`dev_t`) Functions

The device functions are:

| | |
|---|---|
| `ddi_create_minor_node()` | Create a minor node for a device |

| | |
|---|---|
| `ddi_getiminor()` | Get kernel internal minor number from an external `dev_t` |
| `ddi_remove_minor_node()` | Remove a minor mode for a device |
| `getmajor()` | Get major device number |
| `getminor()` | Get minor device number |
| `makedevice()` | Make device number from major and minor numbers |

# Property Functions

The property functions are:

| | |
|---|---|
| `ddi_prop_exists()` | Check for the existence of a property |
| `ddi_prop_free()` | Free resources consumed by property lookup |
| `ddi_prop_get_int()` | Look up integer property |
| `ddi_prop_get_int64()` | Look up 64–bit integer property |
| `ddi_prop_lookup_byte_array()` | Look up byte array property |
| `ddi_prop_lookup_int_array()` | Look up integer array property |
| `ddi_prop_lookup_int64_array()` | Look up 64–bit integer array property |
| `ddi_prop_lookup_string()` | Look up string property |
| `ddi_prop_lookup_string_array()` | Look up string array property |
| `ddi_prop_remove()` | Remove a property of a device |
| `ddi_prop_remove_all()` | Remove all properties of a device |
| `ddi_prop_undefine()` | Hide a property of a device |
| `ddi_prop_update_byte_array()` | Create or update byte array property |
| `ddi_prop_update_int()` | Create or update integer property |
| `ddi_prop_update_int64()` | Create or update 64–bit integer property |
| `ddi_prop_update_int_array()` | Create or update integer array property |
| `ddi_prop_update_int64_array()` | Create or update 64–bit integer array property |
| `ddi_prop_update_string()` | Create or update string property |

| | |
|---|---|
| `ddi_prop_update_string_array()` | Create or update string array property |

**TABLE B–1** Deprecated Property Functions

| Deprecated Functions | Replacements |
|---|---|
| `ddi_getlongprop()` | see ddi_prop_lookup |
| `ddi_getlongprop_buf()` | `ddi_prop_lookup()` |
| `ddi_getprop()` | `ddi_prop_get_int()` |
| `ddi_getproplen()` | `ddi_prop_lookup()` |
| `ddi_prop_create()` | `ddi_prop_lookup()` |
| `ddi_prop_modify()` | `ddi_prop_lookup()` |
| `ddi_prop_op()` | `ddi_prop_lookup()` |

# Device Software State Functions

The device software state functions are:

| | |
|---|---|
| `ddi_get_driver_private()` | Get the address of the device's private data area |
| `ddi_get_soft_state()` | Get pointer to instance soft-state structure |
| `ddi_set_driver_private()` | Set the address of the device's private data area |
| `ddi_soft_state_fini()` | Destroy driver soft-state structure |
| `ddi_soft_state_free()` | Free instance soft-state structure |
| `ddi_soft_state_init()` | Initialize driver soft-state structure |
| `ddi_soft_state_zalloc()` | Allocate instance soft-state structure |

# Memory Allocation and Deallocation Functions

The memory allocation and deallocation functions are:

| | |
|---|---|
| `kmem_alloc()` | Allocate kernel memory |
| `kmem_free()` | Free kernel memory |

`kmem_zalloc()` Allocate zero-filled kernel memory

The following functions allocate and free memory intended to be used for DMA. See "Direct Memory Access (DMA) Functions" on page 507.

`ddi_dma_mem_alloc()` Allocate memory for DMA transfer

`ddi_dma_mem_free()` Free previously allocated DMA memory

The following functions allocate and free memory intended to be exported to user space. See "User Space Access Functions" on page 509.

`ddi_umem_alloc()` Allocate page-aligned kernel memory

`ddi_umem_free()` Free page-aligned kernel memory

**TABLE B–2** Deprecated Memory Allocation and Deallocation Functions

| Deprecated Function | Replacement |
|---|---|
| `ddi_iopb_alloc()` | `ddi_dma_mem_alloc()` |
| `ddi_iopb_free()` | `ddi_dma_mem_free()` |
| `ddi_mem_alloc()` | `ddi_dma_mem_alloc()` |
| `ddi_mem_free()` | `ddi_dma_mem_free()` |

# Kernel Thread Control and Synchronization Functions

The kernel thread control and synchronization functions are:

`cv_broadcast()` Wake up all waiting threads

`cv_destroy()` Free an allocated condition variable

`cv_init()` Allocate a condition variable

`cv_signal()` Wake up one waiting thread

`cv_timedwait()` Await an event with timeout

`cv_timedwait_sig()` Await an event or signal with timeout

`cv_wait()` Await an event

`cv_wait_sig()` Await an event or signal

`ddi_can_receive_sig()` Determine whether the current thread can receive a signal

| | |
|---|---|
| `ddi_enter_critical()` | Enter a critical region of control |
| `ddi_exit_critical()` | Exit a critical region of control |
| `mutex_destroy()` | Destroy mutual exclusion lock |
| `mutex_enter()` | Acquire mutual exclusion lock |
| `mutex_exit()` | Release mutual exclusion lock |
| `mutex_init()` | Initialize mutual exclusion lock |
| `mutex_owned()` | Determine whether current thread is holding mutual exclusion lock |
| `mutex_tryenter()` | Attempt to acquire mutual exclusion lock without waiting |
| `rw_destroy()` | Destroy a readers/writer lock |
| `rw_downgrade()` | Downgrade a readers/writer lock holding from writer to reader |
| `rw_enter()` | Acquire a readers/writer lock |
| `rw_exit()` | Release a readers/writer lock |
| `rw_init()` | Initialize a readers/writer lock |
| `rw_read_locked()` | Determine whether readers/writer lock is held for read or write |
| `rw_tryenter()` | Attempt to acquire a readers/writer lock without waiting |
| `rw_tryupgrade()` | Attempt to upgrade readers/writer lock holding from reader to writer |
| `sema_destroy()` | Destroy a semaphore |
| `sema_init()` | Initialize a semaphore |
| `sema_p()` | Decrement semaphore and possibly block |
| `sema_p_sig()` | Decrement semaphore but do not block if signal is pending |
| `sema_tryp()` | Attempt to decrement semaphore but do not block |
| `sema_v()` | Increment semaphore and possibly unblock waiter |

# Interrupt Functions

The interrupt functions are:

| | |
|---|---|
| `ddi_add_intr()` | Register a hardware interrupt handler |
| `ddi_add_softintr()` | Register a software interrupt handler |
| `ddi_dev_nintrs()` | Return the number of interrupt specifications a device has |
| `ddi_get_iblock_cookie()` | Get a hardware interrupt block cookie |
| `ddi_get_soft_iblock_cookie()` | Get a software interrupt block cookie |
| `ddi_intr_hilevel()` | Indicate interrupt type |
| `ddi_remove_intr()` | Unregister a hardware interrupt handler |
| `ddi_remove_softintr()` | Unregister a software interrupt handler |
| `ddi_trigger_softintr()` | Trigger a software interrupt |

# Programmed I/O Functions

The programmed I/O functions are:

| | |
|---|---|
| `ddi_dev_nregs()` | Return the number of register sets a device has |
| `ddi_dev_regsize()` | Return the size of a device's register |
| `ddi_regs_map_setup()` | Set up a mapping for a register address space |
| `ddi_regs_map_free()` | Free a previously mapped register address space |
| `ddi_device_copy()` | Copy data from one device register to another device register |
| `ddi_device_zero()` | Zero fill the device |
| `ddi_check_acc_handle()` | Check data access handle |
| `ddi_get8()` | Read 8–bit data from mapped memory, device register, or DMA memory |
| `ddi_get16()` | Read 16–bit data from mapped memory, device register, or DMA memory |

| | |
|---|---|
| `ddi_get32()` | Read 32–bit data from mapped memory, device register, or DMA memory |
| `ddi_get64()` | Read 64–bit data from mapped memory, device register, or DMA memory |
| `ddi_put8()` | Write 8–bit data to mapped memory, device register, or DMA memory |
| `ddi_put16()` | Write 16–bit data to mapped memory, device register, or DMA memory |
| `ddi_put32()` | Write 32–bit data to mapped memory, device register, or DMA memory |
| `ddi_put64()` | Write 64–bit data to mapped memory, device register, or DMA memory |
| `ddi_rep_get8()` | Read multiple 8–bit data from mapped memory, device register, or DMA memory |
| `ddi_rep_get16()` | Read multiple 16–bit data from mapped memory, device register, or DMA memory |
| `ddi_rep_get32()` | Read multiple 32–bit data from mapped memory, device register, or DMA memory |
| `ddi_rep_get64()` | Read multiple 64–bit data from mapped memory, device register, or DMA memory |
| `ddi_rep_put8()` | Write multiple 8–bit data to mapped memory, device register, or DMA memory |
| `ddi_rep_put16()` | Write multiple 16–bit data to mapped memory, device register, or DMA memory |
| `ddi_rep_put32()` | Write multiple 32–bit data to mapped memory, device register, or DMA memory |
| `ddi_rep_put64()` | Write multiple 64–bit data to mapped memory, device register, or DMA memory |
| `ddi_peek8()` | Cautiously read an 8–bit value from a location |
| `ddi_peek16()` | Cautiously read a 16–bit value from a location |
| `ddi_peek32()` | Cautiously read a 32–bit value from a location |
| `ddi_peek64()` | Cautiously read a 64–bit value from a location |
| `ddi_poke8()` | Cautiously write an 8–bit value to a location |
| `ddi_poke16()` | Cautiously write a 16–bit value to a location |
| `ddi_poke32()` | Cautiously write a 32–bit value to a location |
| `ddi_poke64()` | Cautiously write a 64–bit value to a location |

The general programmed I/O functions listed above can always be used rather than the `mem`, `io`, and `pci_config` functions that follow. However, the following functions can be used as alternatives in cases where the type of access is known at compile time.

| | |
|---|---|
| `ddi_io_get8()` | Read 8-bit data from a mapped device register in I/O space |
| `ddi_io_get16()` | Read 16-bit data from a mapped device register in I/O space |
| `ddi_io_get32()` | Read 32-bit data from a mapped device register in I/O space |
| `ddi_io_put8()` | Write 8-bit data to a mapped device register in I/O space |
| `ddi_io_put16()` | Write 16-bit data to a mapped device register in I/O space |
| `ddi_io_put32()` | Write 32-bit data to a mapped device register in I/O space |
| `ddi_io_rep_get8()` | Read multiple 8-bit data from a mapped device register in I/O space |
| `ddi_io_rep_get16()` | Read multiple 16-bit data from a mapped device register in I/O space |
| `ddi_io_rep_get32()` | Read multiple 32-bit data from a mapped device register in I/O space |
| `ddi_io_rep_put8()` | Write multiple 8-bit data to a mapped device register in I/O space |
| `ddi_io_rep_put16()` | Write multiple 16-bit data to a mapped device register in I/O space |
| `ddi_io_rep_put32()` | Write multiple 32-bit data to a mapped device register in I/O space |
| `ddi_mem_get8()` | Read 8-bit data from a mapped device in memory space or DMA memory |
| `ddi_mem_get16()` | Read 16-bit data from a mapped device in memory space or DMA memory |
| `ddi_mem_get32()` | Read 32-bit data from a mapped device in memory space or DMA memory |
| `ddi_mem_get64()` | Read 64-bit data from a mapped device in memory space or DMA memory |
| `ddi_mem_put8()` | Write 8-bit data to a mapped device in memory space or DMA memory |

| | |
|---|---|
| `ddi_mem_put16()` | Write 16-bit data to a mapped device in memory space or DMA memory |
| `ddi_mem_put32()` | Write 32-bit data to a mapped device in memory space or DMA memory |
| `ddi_mem_put64()` | Write 64-bit data to a mapped device in memory space or DMA memory |
| `ddi_mem_rep_get8()` | Read multiple 8-bit data from a mapped device in memory space or DMA memory |
| `ddi_mem_rep_get16()` | Read multiple 16-bit data from a mapped device in memory space or DMA memory |
| `ddi_mem_rep_get32()` | Read multiple 32-bit data from a mapped device in memory space or DMA memory |
| `ddi_mem_rep_get64()` | Read multiple 64-bit data from a mapped device in memory space or DMA memory |
| `ddi_mem_rep_put8()` | Write multiple 8-bit data to a mapped device in memory space or DMA memory |
| `ddi_mem_rep_put16()` | Write multiple 16-bit data to a mapped device in memory space or DMA memory |
| `ddi_mem_rep_put32()` | Write multiple 32-bit data to a mapped device in memory space or DMA memory |
| `ddi_mem_rep_put64()` | Write multiple 64-bit data to a mapped device in memory space or DMA memory |
| `pci_config_setup()` | Set up access to PCI Local Bus Configuration space |
| `pci_config_teardown()` | Tear down access to PCI Local Bus Configuration space |
| `pci_config_get8()` | Read 8-bit data from the PCI Local Bus Configuration space |
| `pci_config_get16()` | Read 16-bit data from the PCI Local Bus Configuration space |
| `pci_config_get32()` | Read 32-bit data from the PCI Local Bus Configuration space |
| `pci_config_get64()` | Read 64-bit data from the PCI Local Bus Configuration space |
| `pci_config_put8()` | Write 8-bit data to the PCI Local Bus Configuration space |
| `pci_config_put16()` | Write 16-bit data to the PCI Local Bus Configuration space |

| | |
|---|---|
| `pci_config_put32()` | Write 32-bit data to the PCI Local Bus Configuration space |
| `pci_config_put64()` | Write 64-bit data to the PCI Local Bus Configuration space |

**TABLE B–3** Deprecated Programmed I/O Functions

| Deprecated Function | Replacement |
|---|---|
| `ddi_getb()` | `ddi_get8()` |
| `ddi_getl()` | `ddi_get32()` |
| `ddi_getll()` | `ddi_get64()` |
| `ddi_getw()` | `ddi_get16()` |
| `ddi_io_getb()` | `ddi_io_get8()` |
| `ddi_io_getl()` | `ddi_io_get32()` |
| `ddi_io_getw()` | `ddi_io_get16()` |
| `ddi_io_putb()` | `ddi_io_put8()` |
| `ddi_io_putl()` | `ddi_io_put32()` |
| `ddi_io_putw()` | `ddi_io_put16()` |
| `ddi_io_rep_getb()` | `ddi_io_rep_get8()` |
| `ddi_io_rep_getl()` | `ddi_io_rep_get32()` |
| `ddi_io_rep_getw()` | `ddi_io_rep_get16()` |
| `ddi_io_rep_putb()` | `ddi_io_rep_put8()` |
| `ddi_io_rep_putl()` | `ddi_io_rep_put32()` |
| `ddi_io_rep_putw()` | `ddi_io_rep_put16()` |
| `ddi_map_regs()` | `ddi_regs_map_setup()` |
| `ddi_mem_getb()` | `ddi_mem_get8()` |
| `ddi_mem_getl()` | `ddi_mem_get32()` |
| `ddi_mem_getll()` | `ddi_mem_get64()` |
| `ddi_mem_getw()` | `ddi_mem_get16()` |
| `ddi_mem_putb()` | `ddi_mem_put8()` |
| `ddi_mem_putl()` | `ddi_mem_put32()` |
| `ddi_mem_putll()` | `ddi_mem_put64()` |
| `ddi_mem_putw()` | `ddi_mem_put16()` |

**TABLE B–3** Deprecated Programmed I/O Functions *(Continued)*

| Deprecated Function | Replacement |
|---|---|
| ddi_mem_rep_getb() | ddi_mem_rep_get8() |
| ddi_mem_rep_getl() | ddi_mem_rep_get32() |
| ddi_mem_rep_getll() | ddi_mem_rep_get64() |
| ddi_mem_rep_getw() | ddi_mem_rep_get16() |
| ddi_mem_rep_putb() | ddi_mem_rep_put8() |
| ddi_mem_rep_putl() | ddi_mem_rep_put32() |
| ddi_mem_rep_putll() | ddi_mem_rep_put64() |
| ddi_mem_rep_putw() | ddi_mem_rep_put16() |
| ddi_peekc() | ddi_peek8() |
| ddi_peekd() | ddi_peek64() |
| ddi_peekl() | ddi_peek32() |
| ddi_peeks() | ddi_peek16() |
| ddi_pokec() | ddi_poke8() |
| ddi_poked() | ddi_poke64() |
| ddi_pokel() | ddi_poke32() |
| ddi_pokes() | ddi_poke16() |
| ddi_putb() | ddi_put8() |
| ddi_putl() | ddi_put32() |
| ddi_putll() | ddi_put64() |
| ddi_putw() | ddi_put16() |
| ddi_rep_getb() | ddi_rep_get8() |
| ddi_rep_getl() | ddi_rep_get32() |
| ddi_rep_getll() | ddi_rep_get64() |
| ddi_rep_getw() | ddi_rep_get16() |
| ddi_rep_putb() | ddi_rep_put8() |
| ddi_rep_putl() | ddi_rep_put32() |
| ddi_rep_putll() | ddi_rep_put64() |
| ddi_rep_putw() | ddi_rep_put16() |
| ddi_unmap_regs() | ddi_regs_map_free() |

**TABLE B–3** Deprecated Programmed I/O Functions *(Continued)*

| Deprecated Function | Replacement |
|---|---|
| inb() | ddi_io_get8() |
| inl() | ddi_io_get32() |
| inw() | ddi_io_get16() |
| outb() | ddi_io_put8() |
| outl() | ddi_io_put32() |
| outw() | ddi_io_put16() |
| pci_config_getb() | pci_config_get8() |
| pci_config_getl() | pci_config_get32() |
| pci_config_getll() | pci_config_get64() |
| pci_config_getw() | pci_config_get16() |
| pci_config_putb() | pci_config_put8() |
| pci_config_putl() | pci_config_put32() |
| pci_config_putll() | pci_config_put64() |
| pci_config_putw() | pci_config_put16() |
| repinsb() | ddi_io_rep_get8() |
| repinsd() | ddi_io_rep_get32() |
| repinsw() | ddi_io_rep_get16() |
| repoutsb() | ddi_io_rep_put8() |
| repoutsd() | ddi_io_rep_put32() |
| repoutsw() | ddi_io_rep_put16() |

# Direct Memory Access (DMA) Functions

The DMA functions are:

| | |
|---|---|
| ddi_dma_alloc_handle() | Allocate a DMA handle |
| ddi_dma_free_handle() | Free a DMA handle |
| ddi_dma_mem_alloc() | Allocate memory for a DMA transfer |
| ddi_dma_mem_free() | Free previously allocated DMA memory |

| | |
|---|---|
| `ddi_dma_addr_bind_handle()` | Bind an address to a DMA handle |
| `ddi_dma_buf_bind_handle()` | Bind a system buffer to a DMA handle |
| `ddi_dma_unbind_handle()` | Unbind the address in a DMA handle |
| `ddi_dma_nextcookie()` | Retrieve the subsequent DMA cookie |
| `ddi_dma_getwin()` | Activate a new DMA window |
| `ddi_dma_numwin()` | Retrieve number of DMA windows |
| `ddi_dma_sync()` | Synchronize CPU and I/O views of memory |
| `ddi_check_dma_handle()` | Check a DMA handle |
| `ddi_dma_set_sbus64()` | Allow 64-bit transfers on SBus |
| `ddi_slaveonly()` | Report whether a device is installed in a slave access-only location |
| `ddi_iomin()` | Find the minimum alignment and transfer size for DMA |
| `ddi_dma_burstsizes()` | Find out the allowed burst sizes for a DMA mapping |
| `ddi_dma_devalign()` | Find DMA mapping alignment and minimum transfer size |
| `ddi_dmae_alloc()` | Acquire a DMA channel |
| `ddi_dmae_release()` | Release a DMA channel |
| `ddi_dmae_getattr()` | Get the DMA engine attributes |
| `ddi_dmae_prog()` | Program a DMA channel |
| `ddi_dmae_stop()` | Terminate a DMA engine operation |
| `ddi_dmae_disable()` | Disable a DMA channel |
| `ddi_dmae_enable()` | Enable a DMA channel |
| `ddi_dmae_getcnt()` | Get the remaining DMA engine count |
| `ddi_dmae_1stparty()` | Configure the DMA channel cascade mode |
| `ddi_dma_coff()` | Convert a DMA cookie to an offset within a DMA handle |

**TABLE B–4** Deprecated Direct Memory Access (DMA) Functions

| Deprecated Function | Replacement |
|---|---|
| `ddi_dma_addr_setup()` | `ddi_dma_alloc_handle()`, `ddi_dma_addr_bind_handle()` |

**TABLE B–4** Deprecated Direct Memory Access (DMA) Functions *(Continued)*

| Deprecated Function | Replacement |
|---|---|
| `ddi_dma_buf_setup()` | `ddi_dma_alloc_handle()`, `ddi_dma_buf_bind_handle()` |
| `ddi_dma_curwin()` | `ddi_dma_getwin()` |
| `ddi_dma_free()` | `ddi_dma_free_handle()` |
| `ddi_dma_htoc()` | `ddi_dma_addr_bind_handle()`, `ddi_dma_buf_bind_handle()` |
| `ddi_dma_movwin()` | `ddi_dma_getwin()` |
| `ddi_dma_nextseg()` | `ddi_dma_nextcookie()` |
| `ddi_dma_segtocookie()` | `ddi_dma_nextcookie()` |
| `ddi_dma_setup()` | `ddi_dma_alloc_handle()`, `ddi_dma_addr_bind_handle()`, `ddi_dma_buf_bind_handle()` |
| `ddi_dmae_getlim()` | `ddi_dmae_getattr()` |
| `ddi_iopb_alloc()` | `ddi_dma_mem_alloc()` |
| `ddi_iopb_free()` | `ddi_dma_mem_free()` |
| `ddi_mem_alloc()` | `ddi_dma_mem_alloc()` |
| `ddi_mem_free()` | `ddi_dma_mem_free()` |
| `hat_getkpfnum()` | `ddi_dma_addr_bind_handle()`, `ddi_dma_buf_bind_handle()`, `ddi_dma_nextcookie()` |

# User Space Access Functions

The user space access functions are:

| | |
|---|---|
| `ddi_copyin()` | Copy data to a driver buffer |
| `ddi_copyout()` | Copy data from a driver |
| `uiomove()` | Copy kernel data using a `uio` structure |
| `ureadc()` | Add character to a `uio` structure |
| `uwritec()` | Remove a character from a `uio` structure |
| `ddi_getminor()` | Get kernel internal minor number from an external `dev_t` |

| | |
|---|---|
| `ddi_model_convert_from()` | Determine a data model type mismatch |
| `IOC_CONVERT_FROM()` | Determine whether there is a need to translate M_IOCTL contents |
| `STRUCT_DECL()` | Establish the handle to application data in a possibly differing data model |
| `STRUCT_HANDLE()` | Establish the handle to application data in a possibly differing data model |
| `STRUCT_INIT()` | Establish the handle to application data in a possibly differing data model |
| `STRUCT_SET_HANDLE()` | Establish the handle to application data in a possibly differing data model |
| `SIZEOF_PTR()` | Return the size of pointer in specified data model |
| `SIZEOF_STRUCT()` | Return the size of a structure in the specified data model |
| `STRUCT_SIZE()` | Return the size of a structure in the application data model |
| `STRUCT_BUF()` | Return a pointer to the native mode instance of the structure |
| `STRUCT_FADDR()` | Return a pointer to the specified field of a structure |
| `STRUCT_FGET()` | Return the specified field of a structure in the application data model |
| `STRUCT_FGETP()` | Return the specified pointer field of a structure in the application data model |
| `STRUCT_FSET()` | Set a specified field of a structure in the application data model |
| `STRUCT_FSETP()` | Set a specified pointer field of a structure in the application data model |

**TABLE B–5** Deprecated User Space Access Functions

| Deprecated Function | Replacement |
|---|---|
| `copyin()` | `ddi_copyin()` |
| `copyout()` | `ddi_copyout()` |

# User Process Event Functions

The user process event functions are:

| | |
|---|---|
| `pollwakeup()` | Inform a process that an event has occurred |
| `proc_ref()` | Get a handle on a process to signal |
| `proc_unref()` | Release a handle on a process to signal |
| `proc_signal()` | Send a signal to a process |

# User Process Information Functions

The user process information functions are:

| | |
|---|---|
| `ddi_get_cred()` | Return a pointer to the credential structure of the caller |
| `drv_priv()` | Determine process credentials privilege |
| `ddi_get_pid()` | Return the process ID |

**TABLE B–6** Deprecated User Process Information Functions

| Deprecated Functions | Replacement |
|---|---|
| `drv_getparm()` | `ddi_get_pid(),ddi_get_cred()` |

# User Application Kernel and Device Access Functions

The user application kernel and device access functions are:

`ddi_dev_nregs()`
Return the number of register sets a device has

`ddi_dev_regsize()`
Return the size of a device's register

`ddi_devmap_segmap(),devmap_setup()`
Set up a user mapping to device memory using the `devmap` framework

`devmap_devmem_setup()`
Export device memory to user space

`devmap_load()`
Validate memory address translations

`devmap_unload()`
Invalidate memory address translations

`devmap_do_ctxmgt()`
Perform device context switching on a mapping

`devmap_set_ctx_timeout()`
Set the timeout value for the context management callback

`devmap_default_access()`
Default driver memory access function

`ddi_umem_alloc()`
Allocate page-aligned kernel memory

`ddi_umem_free()`
Free page-aligned kernel memory

`ddi_umem_lock()`
Lock memory pages

`ddi_umem_unlock()`
Unlock memory pages

`ddi_umem_iosetup()`
Setup I/O requests to application memory

`devmap_umem_setup()`
Export kernel memory to user space

`ddi_model_convert_from()`
Determine data model type mismatch

**TABLE B–7** Deprecated User Application Kernel and Device Access Functions

| Deprecated Function | Replacement |
|---|---|
| `ddi_mapdev()` | `devmap_setup()` |
| `ddi_mapdev_intercept()` | `devmap_load()` |
| `ddi_mapdev_nointercept()` | `devmap_unload()` |
| `ddi_mapdev_set_device_acc_attr()` | `devmap()` |
| `ddi_segmap()` | `devmap()` |
| `ddi_segmap_setup()` | `devmap_setup()` |

**TABLE B–7** Deprecated User Application Kernel and Device Access Functions *(Continued)*

| Deprecated Function | Replacement |
|---|---|
| `hat_getkpfnum()` | `devmap()` |
| `ddi_mmap_get_model()` | `devmap()` |

# Time-Related Functions

The time-related functions are:

| | |
|---|---|
| `ddi_get_lbolt()` | Return the number of clock ticks since reboot |
| `ddi_get_time()` | Return the current time in seconds |
| `delay()` | Delay execution for a specified number of clock ticks |
| `drv_hztousec()` | Convert clock ticks to microseconds |
| `drv_usectohz()` | Convert microseconds to clock ticks |
| `drv_usecwait()` | Busy-wait for specified interval |
| `gethrtime()` | Get high-resolution time |
| `gethrvtime()` | Get high-resolution LWP virtual time |
| `timeout()` | Execute a function after a specified length of time |
| `untimeout()` | Cancel the previous time out function call |
| `drv_getparm()` | `ddi_get_lbolt()`,`ddi_get_time()` |

**TABLE B–8** Deprecated Time-Related Functions

| Deprecated Function | Replacement |
|---|---|
| `drv_getparm()` | `ddi_get_lbolt()`,`ddi_get_time()` |

# Power Management Functions

The functions are:

| | |
|---|---|
| `ddi_removing_power()` | Check if device loses power with DDI_SUSPEND |
| `pci_report_pmcap()` | Report the power management capability of a PCI device |

| | |
|---|---|
| `pm_busy_component()` | Mark a component as busy |
| `pm_idle_component()` | Mark a component as idle |
| `pm_raise_power()` | Raise the power level of a component |
| `pm_lower_power()` | Lower the power level of a component |
| `pm_power_has_changed()` | Notify the power management framework of an autonomous power level change |
| `pm_trans_check()` | Device power cycle advisory check |

**TABLE B–9** Deprecated Power Management Functions

| Function Name | Description |
|---|---|
| `ddi_dev_is_needed()` | Inform the system that a device's component is required |
| `pm_create_components()` | Create power-manageable components |
| `pm_destroy_components()` | Destroy power-manageable components |
| `pm_get_normal_power()` | Get the normal power level of a device component |
| `pm_set_normal_power()` | Set the normal power level of a device component |

# Kernel Statistics Functions

The kernel statistics functions are:

| | |
|---|---|
| `kstat_create()` | Create and initialize a new `kstat` |
| `kstat_delete()` | Remove a `kstat` from the system |
| `kstat_install()` | Add a fully initialized `kstat` to the system |
| `kstat_named_init()` | Initialize a named `kstat` |
| `kstat_runq_back_to_waitq()` | Record a transaction migration from run queue to the wait queue |
| `kstat_runq_enter()` | Record a transaction addition to the run queue |
| `kstat_runq_exit()` | Record a transaction removal from the run queue |
| `kstat_waitq_enter()` | Record a transaction addition to the wait queue |
| `kstat_waitq_exit()` | Record a transaction removal from the wait queue |

| | |
|---|---|
| `kstat_waitq_to_runq()` | Record a transaction migration from the wait queue to the run queue |

# Kernel Logging and Printing Functions

The kernel logging and printing functions are:

| | |
|---|---|
| `cmn_err(),vcmn_err()` | Display an error message |
| `ddi_report_dev()` | Announce a device |
| `strlog()` | Submit messages to the log driver |
| `ddi_dev_report_fault()` | Report a hardware failure |
| `scsi_errmsg()` | Display a SCSI request sense message |
| `scsi_log()` | Display a SCSI-device-related message |
| `scsi_vu_errmsg()` | Display a SCSI request sense message |

# Buffered I/O Functions

The buffered I/O functions are:

| | |
|---|---|
| `physio()` | Perform physical I/O |
| `aphysio()` | Perform asynchronous physical I/O |
| `anocancel()` | Prevent cancellation of an asynchronous I/O request |
| `minphys()` | Limit the `physio()` buffer size |
| `biowait()` | Suspend processes pending completion of block I/O |
| `biodone()` | Release the buffer after buffer I/O transfer and notify blocked threads |
| `bioerror()` | Indicate the error in a buffer header |
| `geterror()` | Return an I/O error |
| `bp_mapin()` | Allocate virtual address space |
| `bp_mapout()` | Deallocate virtual address space |
| `disksort()` | Use a single-direction elevator seek strategy to sort for buffers |

| | |
|---|---|
| `getrbuf()` | Get a raw buffer header |
| `freerbuf()` | Free a raw buffer header |
| `biosize()` | Return the size of a buffer structure |
| `bioinit()` | Initialize a buffer structure |
| `biofini()` | Uninitialize a buffer structure |
| `bioreset()` | Reuse a private buffer header after I/O is complete |
| `bioclone()` | Clone another buffer |
| `biomodified()` | Check whether a buffer is modified |
| `clrbuf()` | Erase the contents of a buffer |

# Virtual Memory Functions

The virtual memory functions are:

| | |
|---|---|
| `ddi_btop()` | Convert device bytes to pages (round down) |
| `ddi_btopr()` | Convert device bytes to pages (round up) |
| `ddi_ptob()` | Convert device pages to bytes |
| `btop()` | Convert size in bytes to size in pages (round down) |
| `btopr()` | Convert size in bytes to size in pages (round up) |
| `ptob()` | Convert size in pages to size in bytes |

**TABLE B–10** Deprecated Virtual Memory Functions

| Deprecated Functions | Replacement |
|---|---|
| `hat_getkpfnum()` | `devmap()`,`ddi_dma_*_bind_handle()`, `ddi_dma_nextcookie()` |

# Device ID Functions

The device ID functions are:

| | |
|---|---|
| `ddi_devid_init()` | Allocate a device ID structure |

| | |
|---|---|
| `ddi_devid_free()` | Free a device ID structure |
| `ddi_devid_register()` | Register a device ID |
| `ddi_devid_unregister()` | Unregister a device ID |
| `ddi_devid_compare()` | Compare two device IDs |
| `ddi_devid_sizeof()` | Return the size of a device ID |
| `ddi_devid_valid()` | Validate a device ID |
| `ddi_devid_str_encode()` | Encode a device ID and minor_name into a null-terminated ASCII string; return a pointer to that string |
| `ddi_devid_str_decode()` | Decode the device ID and minor_name from a previously encoded string; allocate and return pointers to the extracted parts |
| `ddi_devid_str_free()` | Free all strings returned by the `ddi_devid_*` functions |

# SCSI Functions

The SCSI functions are:

| | |
|---|---|
| `scsi_probe()` | Probe a SCSI device |
| `scsi_unprobe()` | Free resources allocated during initial probing |
| `scsi_alloc_consistent_buf()` | Allocate an I/O buffer for SCSI DMA |
| `scsi_free_consistent_buf()` | Free a previously allocated SCSI DMA I/O buffer |
| `scsi_init_pkt()` | Prepare a complete SCSI packet |
| `scsi_destroy_pkt()` | Free an allocated SCSI packet and its DMA resource |
| `scsi_setup_cdb()` | Set up SCSI command descriptor block (CDB) |
| `scsi_transport()` | Start a SCSI command |
| `scsi_poll()` | Run a polled SCSI command |
| `scsi_ifgetcap()` | Get SCSI transport capability |
| `scsi_ifsetcap()` | Set SCSI transport capability |

| | |
|---|---|
| `scsi_sync_pkt()` | Synchronize CPU and I/O views of memory |
| `scsi_abort()` | Abort a SCSI command |
| `scsi_reset()` | Reset a SCSI bus or target |
| `scsi_reset_notify()` | Notify the target driver of bus resets |
| `scsi_cname()` | Decode a SCSI command |
| `scsi_dname()` | Decode a SCSI peripheral device type |
| `scsi_mname()` | Decode a SCSI message |
| `scsi_rname()` | Decode a SCSI packet completion reason |
| `scsi_sname()` | Decode a SCSI sense key |
| `scsi_errmsg()` | Display a SCSI request sense message |
| `scsi_log()` | Display a SCSI-device-related message |
| `scsi_vu_errmsg()` | Display a SCSI request sense message |
| `scsi_hba_init()` | SCSI HBA system initialization routine |
| `scsi_hba_fini()` | SCSI HBA system completion routine |
| `scsi_hba_attach_setup()` | SCSI HBA attach routine |
| `scsi_hba_detach()` | SCSI HBA detach routine |
| `scsi_hba_probe()` | Default SCSI HBA probe function |
| `scsi_hba_tran_alloc()` | Allocate a transport structure |
| `scsi_hba_tran_free()` | Free a transport structure |
| `scsi_hba_pkt_alloc()` | Allocate a scsi_pkt structure |
| `scsi_hba_pkt_free()` | Free a scsi_pkt structure |
| `scsi_hba_lookup_capstr()` | Return an index matching capability string |

**TABLE B–11** Deprecated SCSI Functions

| Deprecated Function | Replacement |
|---|---|
| `free_pktiopb()` | `scsi_free_consistent_buf()` |
| `get_pktiopb()` | `scsi_alloc_consistent_buf()` |
| `makecom_g0()` | `scsi_setup_cdb()` |
| `makecom_g0_s()` | `scsi_setup_cdb()` |
| `makecom_g1()` | `scsi_setup_cdb()` |
| `makecom_g5()` | `scsi_setup_cdb()` |

**TABLE B–11** Deprecated SCSI Functions *(Continued)*

| Deprecated Function | Replacement |
|---|---|
| `scsi_dmafree()` | `scsi_destroy_pkt()` |
| `scsi_dmaget()` | `scsi_init_pkt()` |
| `scsi_hba_attach()` | `scsi_hba_attach_setup()` |
| `scsi_pktalloc()` | `scsi_init_pkt()` |
| `scsi_pktfree()` | `scsi_destroy_pkt()` |
| `scsi_resalloc()` | `scsi_init_pkt()` |
| `scsi_resfree()` | `scsi_destroy_pkt()` |
| `scsi_slave()` | `scsi_probe()` |
| `scsi_unslave()` | `scsi_unprobe()` |

# Resource Map Management Functions

The resource map management functions are:

| | |
|---|---|
| `rmallocmap()` | Allocate a resource map |
| `rmallocmap_wait()` | Allocate a resource map, wait if necessary |
| `rmfreemap()` | Free a resource map |
| `rmalloc()` | Allocate space from a resource map |
| `rmalloc_wait()` | Allocate space from a resource map, wait if necessary |
| `rmfree()` | Free space back into a resource map |

# System Global State

| | |
|---|---|
| `ddi_in_panic()` | Determine whether the system is in panic state |

# Utility Functions

The utility functions are:

| | |
|---|---|
| `nulldev()` | Zero return function |
| `nodev()` | Error return function |
| `nochpoll()` | Error return function for non-pollable devices |
| `ASSERT()` | Expression verification |
| `bcopy()` | Copy data between address locations in the kernel |
| `bzero()` | Clear memory for a given number of bytes |
| `bcmp()` | Compare two byte arrays |
| `ddi_ffs()` | Find the first bit set in a long integer |
| `ddi_fls()` | Find the last bit set in a long integer |
| `swab()` | Swap bytes in 16-bit halfwords |
| `strcmp()` | Compare two null-terminated strings |
| `strncmp()` | Compare two null-terminated strings, with length limit |
| `strlen()` | Determine the number of non-null bytes in a string |
| `strcpy()` | Copy a string from one location to another |
| `strncpy()` | Copy a string from one location to another, with length limit |
| `strchr()` | Find a character in a string |
| `sprintf(),vsprintf()` | Format characters in memory |
| `numtos()` | Convert an integer to a decimal string |
| `stoi()` | Convert a decimal string to an integer |
| `max()` | Return the larger of two integers |
| `min()` | Return the lesser of two integers |
| `va_arg()` | Finds the next value in a variable argument list |
| `va_copy()` | Copies the state of a variable argument list |
| `va_end()` | Deletes pointer to a variable argument list |
| `va_start()` | Finds the pointer to the start of a variable argument list |

APPENDIX C

# Making a Device Driver 64-Bit Ready

This appendix provides information for device driver writers who are converting their device drivers to support the 64-bit kernel. It presents the differences between 32-bit and 64-bit device drivers and describes the steps to convert 32-bit device drivers to 64-bit. This information is specific to regular character and block device drivers only.

This appendix provides information on the following subjects:



## Introduction to 64–Bit Driver Design

For drivers that need support for the 32-bit kernel only, existing 32-bit device drivers will continue to work without recompilation. However, most device drivers require some changes to run correctly in the 64-bit kernel, and all device drivers require recompilation to create a 64-bit driver module. The information in this appendix will help you to enable drivers for 32-bit and 64-bit environments to be generated from common source code, thus increasing code portability and reducing the maintenance effort.

Before starting to clean up a device driver for the 64-bit environment, you should understand how the 32-bit environment differs from the 64-bit environment. In particular, you must be familiar with the C language data type models ILP32 and LP64. See the following table.

**TABLE C–1** Comparison of ILP32 and LP64 Data Types

| C Type | ILP32 | LP64 |
|---|---|---|
| `char` | 8 | 8 |
| `short` | 16 | 16 |
| `int` | 32 | 32 |
| `long` | 32 | 64 |
| `long long` | 64 | 64 |
| `float` | 32 | 32 |
| `double` | 64 | 64 |
| `long double` | 96 | 128 |
| `pointer` | 32 | 64 |

The driver-specific issues due to the differences between ILP32 and LP64 are the subject of this appendix. More general topics are covered in the *Solaris 64-bit Developer's Guide*.

In addition to general code cleanup to support the data model changes for LP64, driver writers have to provide support for both 32-bit and 64-bit applications.

The `ioctl`(9E), `devmap`(9E), and `mmap`(9E) entry points enable data structures to be shared directly between applications and device drivers. If those data structures change size between the 32-bit and 64-bit environments, then the entry points must be modified so that the driver can determine whether the data model of the application is the same as that of the kernel. When the data models differ, data structures can be adjusted. See "I/O Control Support for 64-Bit Capable Device Drivers" on page 248, "32–bit and 64–bit Data Structure Macros" on page 251, and "Associating Kernel Memory With User Mappings" on page 157.

In many drivers, only a few `ioctls` need this kind of handling. The other `ioctls` should work without change as long as these `ioctls` pass data structures that do not change in size.

# General Conversion Steps

The sections below provide information on converting drivers to run in a 64-bit environment. Driver writers might need to perform one or more of the following tasks:

1. Use fixed-width types for hardware registers.

2. Use fixed-width common access functions.
3. Check and extend use of derived types.
4. Check changed fields within DDI data structures.
5. Check changed arguments of DDI functions.
6. Modify the driver entry points that handle user data, where needed.
7. Check structures that use 64–bit long types on x86 platforms.

These steps are explained in detail below.

After each step is complete, fix all compiler warnings, and use `lint` to look for other problems. The SC5.0 (or newer) version of `lint` should be used with `-Xarch=v9` and `-errchk=longptr64` specified to find 64–bit problems. See the notes on using and interpreting the output of `lint` in the *Solaris 64-bit Developer's Guide*.

---

**Note –** Do not ignore compilation warnings during conversion for LP64. Warnings that were safe to ignore previously in the ILP32 environment might now indicate a more serious problem.

---

After all the steps are complete, compile and test the driver as both a 32-bit and 64-bit module.

# Use Fixed-Width Types for Hardware Registers

Many device drivers that manipulate hardware devices use C data structures to describe the layout of the hardware. In the LP64 data model, data structures that use `long` or unsigned long to define hardware registers are almost certainly incorrect, because `long` is now a 64-bit quantity. Start by including `<sys/inttypes.h>`, and update this class of data structure to use `int32_t` or `uint32_t` instead of `long` for 32-bit device data. This approach preserves the binary layout of 32-bit data structures. For example, change:

```
struct device_regs {
    ulong_t        addr;
    uint_t         count;
};      /* Only works for ILP32 compilation */
```

to:

```
struct device_regs {
    uint32_t        addr;
    uint32_t        count;
};      /* Works for any data model */
```

## Use Fixed-Width Common Access Functions

The Solaris DDI permits device registers to be accessed by access functions for portability to multiple platforms. Previously, the DDI common access functions specified the size of data in terms of bytes, words, and so on. For example, `ddi_getl`(9F) is used to access 32-bit quantities. This function is not available in the 64-bit DDI environment, and has been replaced by versions of the function that specify the number of bits to be acted on.

These routines were added to the 32-bit kernel in the Solaris 2.6 operating environment, to permit their early adoption by driver writers. For example, to be portable to both 32-bit and 64-bit kernels, the driver must use `ddi_get32`(9F) to access 32-bit data rather than `ddi_getl`(9F).

All common access routines are replaced by their fixed-width equivalents. See the `ddi_get8`(9F), `ddi_put8`(9F), `ddi_rep_get8`(9F), and `ddi_rep_put8`(9F) man pages for details.

## Check and Extend Use of Derived Types

System-derived types, such as `size_t`, should be used where possible so that the resulting variables make sense when passed between functions. The new derived types `uintptr_t` or `intptr_t` should be used as the integral type for pointers.

Fixed-width integer types are useful for representing explicit sizes of binary data structures or hardware registers, while fundamental C language data types, such as `int`, can still be used for loop counters or file descriptors.

Some system-derived types represent 32-bit quantities on a 32-bit system but represent 64-bit quantities on a 64-bit system. Derived types that change size in this way include: `clock_t`, `daddr_t`, `dev_t`, `ino_t`, `intptr_t`, `off_t`, `size_t`, `ssize_t`, `time_t`, `uintptr_t`, and `timeout_id_t`.

When designing drivers that use these derived types, pay particular attention to the use of these types, particularly if the drivers are assigning these values to variables of another derived type, such as a fixed-width type.

## Check Changed Fields in DDI Data Structures

The data types of some of the fields within DDI data structures, such as `buf`(9S), have been changed. Drivers that use these data structures should make sure that these fields are being used appropriately. The data structures and the fields that were changed in a significant way are listed below.

## buf Structure Changes

The fields listed below pertain to transfer size, which can now exceed more than 4 Gbytes.

```
size_t        b_bcount;          /* was type unsigned int */
size_t        b_resid;           /* was type unsigned int */
size_t        b_bufsize;         /* was type long */
```

## ddi_dma_attr

The ddi_dma_attr(9S) structure defines attributes of the DMA engine and the device. Because these attributes specify register sizes, fixed-width data types have been used instead of fundamental types.

## ddi_dma_cookie Structure Changes

```
uint32_t     dmac_address;    /* was type unsigned long */
size_t       dmac_size;       /* was type u_int */
```

The ddi_dma_cookie(9S) structure contains a 32-bit DMA address, so a fixed-width data type has been used to define the address. The size has been redefined as size_t.

## csi_arq_status Structure Changes

```
uint_t    sts_rqpkt_state;         /* was type u_long */
uint_t    sts_rqpkt_statistics;    /* was type u_long */
```

These fields in the structure do not need to grow and have been redefined as 32-bit quantities.

## scsi_pkt Structure Changes

```
uint_t      pkt_flags;           /* was type u_long */
int     pkt_time;        /* was type long */
ssize_t     pkt_resid;           /* was type long */
uint_t      pkt_state;           /* was type u_long */
uint_t      pkt_statistics;      /* was type u_long */
```

Because the pkt_flags, pkt_state, and pkt_statistics fields in the scsi_pkt(9S) structure do not need to grow, these fields have been redefined as 32-bit integers. The data transfer size pkt_resid field *does* grow and has been redefined as ssize_t.

# Check Changed Arguments of DDI Functions

This section describes the DDI function argument data types that have been changed.

## `getrbuf()` Argument Changes

```
struct buf *getrbuf(int sleepflag);
```

In previous releases, `sleepflag` was defined as a type `long`.

## `drv_getparm()` Argument Changes

```
int drv_getparm(unsigned int parm, void *value_p);
```

In previous releases, `value_p` was defined as type `unsigned long`. In the 64-bit kernel, `drv_getparm(9F)` can fetch both 32-bit and 64-bit quantities. The interface does not define data types of these quantities, and simple programming errors can occur.

The following new routines offer a safer alternative:

```
clock_t       ddi_get_lbolt(void);
time_t        ddi_get_time(void);
cred_t        *ddi_get_cred(void);
pid_t         ddi_get_pid(void);
```

Driver writers are strongly urged to use these routines instead of `drv_getparm`(9F).

## `delay()` and `timeout()` Argument Changes

```
void delay(clock_t ticks);
timeout_id_t timeout(void (*func)(void *), void *arg, clock_t ticks);
```

The *ticks* argument to the `delay`(9F) and `timeout`(9F) routines has been changed from `long` to `clock_t`.

## `rmallocmap()` and `rmallocmap_wait()` Argument Changes

```
struct map *rmallocmap(size_t mapsize);
struct map *rmallocmap_wait(size_t mapsize);
```

The `mapsize` argument to the `rmallocmap`(9F) and `rmallocmap_wait`(9F) routines has been changed from `ulong_t` to `size_t`.

## `scsi_alloc_consistent_buf()` Argument Changes

```
struct buf *scsi_alloc_consistent_buf(struct scsi_address *ap,
    struct buf *bp, size_t datalen, uint_t bflags,
    int (*callback )(caddr_t), caddr_t arg);
```

In previous releases, `datalen` was defined as an `int` and `bflags` was defined as a `ulong`.

## `uiomove()` Argument Changes

```
int uiomove(caddr_t address, size_t nbytes,
    enum uio_rw rwflag, uio_t *uio_p);
```

The `nbytes` argument was defined as a type `long`, but because `nbytes` represents a size in bytes, `size_t` is more appropriate.

## `cv_timedwait()` and `cv_timedwait_sig()` Argument Changes

```
int cv_timedwait(kcondvar_t *cvp, kmutex_t *mp, clock_t timeout);
int cv_timedwait_sig(kcondvar_t *cvp, kmutex_t *mp,    clock_t timeout);
```

In previous releases, the *timeout* argument to the `cv_timedwait`(9F) and `cv_timedwait_sig`(9F) routines was defined to be of type `long`. Because these routines represent time in ticks, `clock_t` is more appropriate.

## `ddi_device_copy()` Argument Changes

```
int ddi_device_copy(ddi_acc_handle_t src_handle,
    caddr_t src_addr, ssize_t src_advcnt,
    ddi_acc_handle_t dest_handle, caddr_t dest_addr,
    ssize_t dest_advcnt, size_t bytecount, uint_t dev_datasz);
```

The *src_advcnt*, *dest_advcnt*, *dev_datasz* arguments have changed type. These arguments were previously defined as `long`, `long`, and `ulong_t` respectively.

## `ddi_device_zero()` Argument Changes

```
int ddi_device_zero(ddi_acc_handle_t handle,
    caddr_t dev_addr, size_t bytecount, ssize_t dev_advcnt,
    uint_t dev_datasz):
```

In previous releases, *dev_advcnt* was defined as a type `long` and *dev_datasz* as a `ulong_t`.

## `ddi_dma_mem_alloc()` Argument Changes

```
int ddi_dma_mem_alloc(ddi_dma_handle_t handle,
    size_t length, ddi_device_acc_attr_t *accattrp,
    uint_t flags, int (*waitfp)(caddr_t), caddr_t arg,
```

```
    caddr_t *kaddrp, size_t *real_length,
    ddi_acc_handle_t *handlep);
```

In previous releases, *length*, *flags*, and *real_length* were defined with types `uint_t`, `ulong_t`, and `uint_t *`.

# Modify Routines That Handle Data Sharing

If a device driver shares data structures that contain `long`s or pointers with a 32-bit application using `ioctl`(9E), `devmap`(9E), or `mmap`(9E), and the driver is recompiled for a 64-bit kernel, the binary layout of data structures will be incompatible. If a field is currently defined in terms of type `long` and 64-bit data items are not used, change the data structure to use data types that remain as 32–bit quantities (`int` and `unsigned int`). Otherwise, the driver needs to be aware of the different structure shapes for ILP32 and LP64 and determine whether a model mismatch between the application and the kernel has occurred.

To handle potential data model differences, the `ioctl()`, `devmap()`, and `mmap()` driver entry points, which interact directly with user applications, need to be written to determine whether the argument came from an application using the same data model as the kernel.

## Data Sharing in `ioctl()`

To determine whether a model mismatch exists between the application and the driver, the driver uses the `FMODELS` mask to determine the model type from the `ioctl()` *mode* argument. The following values are OR-ed into mode to identify the application data model:

- `FLP64` – Application uses the LP64 data model
- `FILP32` – Application uses the ILP32 data model

The code examples in "I/O Control Support for 64-Bit Capable Device Drivers" on page 248 show how this situation can be handled using `ddi_model_convert_from`(9F).

## Data Sharing in `devmap()`

To enable a 64-bit driver and a 32-bit application to share memory, the binary layout generated by the 64-bit driver must be the same as the layout consumed by the 32-bit application. The mapped memory being exported to the application might need to contain data-model-dependent data structures.

Few memory-mapped devices face this problem because the device registers do not change size when the kernel data model changes. However, some pseudo-devices that export mappings to the user address space might want to export different data

structures to ILP32 or LP64 applications. To determine whether a data model mismatch has occurred, devmap(9E) uses the *model* parameter to describe the data model expected by the application. The *model* parameter is set to one of the following values:

- DDI_MODEL_ILP32 – The application uses the ILP32 data model
- DDI_MODEL_LP64 – The application uses the LP64 data model

The model parameter can be passed untranslated to the ddi_model_convert_from(9F) routine or to STRUCT_INIT(). See "32–bit and 64–bit Data Structure Macros" on page 251.

### Data Sharing in mmap()

Because mmap(9E) does not have a parameter that can be used to pass data model information, the driver's mmap(9E) entry point can be written to use the new DDI function ddi_model_convert_from(9F). This function returns one of the following values to indicate the application's data type model:

- DDI_MODEL_ILP32 – Application expects the ILP32 data model
- DDI_MODEL_ILP64 – Application expects the LP64 data model
- DDI_FAILURE – Function was not called from mmap(9E)

As with ioctl() and devmap(), the model bits can be passed to ddi_model_convert_from(9F) to determine whether data conversion is necessary, or the model can be handed to STRUCT_INIT().

Alternatively, migrate the device driver to support the devmap(9E) entry point.

## Check Structures with 64–bit Long Data Types on x86–Based Platforms

You should carefully check structures that use 64–bit long types, such as uint64_t, on the x86 platforms. The alignment and size can differ between compilation in 32–bit mode versus a 64–bit mode. Consider the following example.

```
#include &lt;studio>
#include &ltsys>

struct myTestStructure {
        uint32_t        my1stInteger;
        uint64_t        my2ndInteger;
};

main()
{
        struct myTestStructure a;

        printf("sizeof myTestStructure is: %d\n", sizeof(a));
        printf("offset to my2ndInteger is: %d\n", (uintptr_t)&amp;a.bar - (uintptr_t)&amp;a);
}
```

On a 32–bit system, this example displays the following results:

```
sizeof myTestStructure is: 12
offset to my2ndInteger is: 4
```

Conversely, on a 64–bit system, this example displays the following results:

```
sizeof myTestStructure is: 16
offset to my2ndInteger is: 8
```

Thus, the 32–bit application and the 64–bit application view the structure differently. As a result, trying to make the same structure work in both a 32–bit and 64–bit environment can cause problems. This situation occurs often, particularly in situations where structures are passed into and out of the kernel through `ioctl()` calls.

# Well-known `ioctl` Interfaces

Many `ioctl`(9E) operations are common to a class of device drivers. For example, most disk drivers implement many of the `dkio`(7I) family of `ioctls`. Many of these interfaces copy in or copy out data structures from the kernel, and some of these data structures have changed size in the LP64 data model. The following section lists the `ioctls`that now require explicit conversion in 64-bit driver `ioctl` routines for the `dkio`, `fdio`(7I), `fbio`(7I), `cdio`(7I), and `mtio`(7I) families of `ioctls`.

| ioctl command | Affected data structure | Reference |
|---|---|---|
| DKIOCGAPART | dk_map | dkio(7I) |
| DKIOCSAPART | dk_allmap | |

| ioctl command | Affected data structure | Reference |
|---|---|---|
| DKIOGVTOC | partition | dkio(7I) |
| DKIOSVTOC | vtoc | |
| FBIOPUTCMAP | fbcmap | fbio(7I) |
| FBIOGETCMAP | | |
| FBIOPUTCMAPI | fbcmap_i | fbio(7I) |
| FBIOGETCMAPI | | |
| FBIOCCURSOR | fbcursor | fbio(7I) |
| FBIOSCURSOR | | |
| CDROMREADMODE1 | cdrom_read | cdio(7I) |
| CDROMREADMODE2 | | |
| CDROMCDDA | cdrom_cdda | cdio(7I) |
| CDROMCDXA | cdrom_cdxa | cdio(7I) |
| CDROMSUBCODE | cdrom_subcode | cdio(7I) |
| FDIOCMD | fd_cmd | fdio(7I) |
| FDRAW | fd_raw | fdio(7I) |
| MTIOCTOP | mtop | mtio(7I) |
| MTIOCGET | mtget | mtio(7I) |
| MTIOCGETDRIVETYPE | mtdrivetype_request | mtio(7I) |
| USCSICMD | uscsi_cmd | scsi_free_consistent_buf Function |

# Device Sizes

The `nblocks` property is exported by each slice of a block device driver. This property contains the number of 512–byte blocks that each slice of the device can support. The `nblocks` property is defined as signed 32-bit quantity, which limits the maximum size of a slice to 1 Tbyte.

Disk devices that provide more than 1 Tbyte of storage per disk must define the `Nblocks` property, which should still contain the number of 512 byte blocks that the device can support. However, `Nblocks` is a signed 64-bit quantity, which removes any practical limit on disk space.

The `nblocks` property is now deprecated. All disk devices should provide the `Nblocks` property.

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