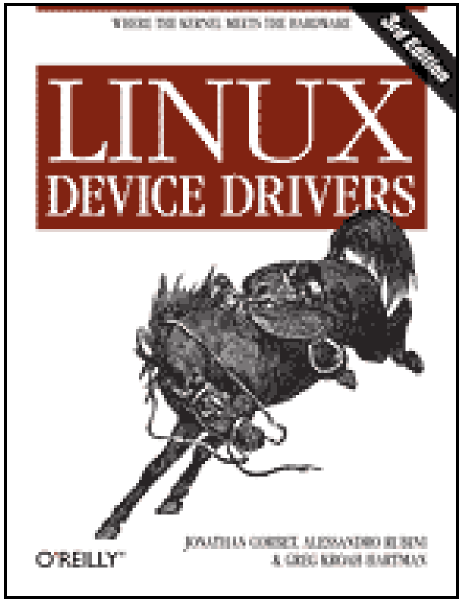
Linux Device Drivers



LINUX
DEVICE DRIVERS

O'REILLY

Modules

- A piece of code that can be added to the kernel at runtime is called a “module”
- A device driver is one kind of module
- Each module is made up of object code that can be dynamically linked to the running kernel
  - Dynamic linking done using *insmod* program
  - Unlinking done using *rmmod* program
- Keep kernel small

Character Devices

- Char device drivers
  - stream of bytes (sequential access)
  - open, close, read, write
  - E.g. console, serial ports

- Block device drivers
  - buffering

Character Device Drivers

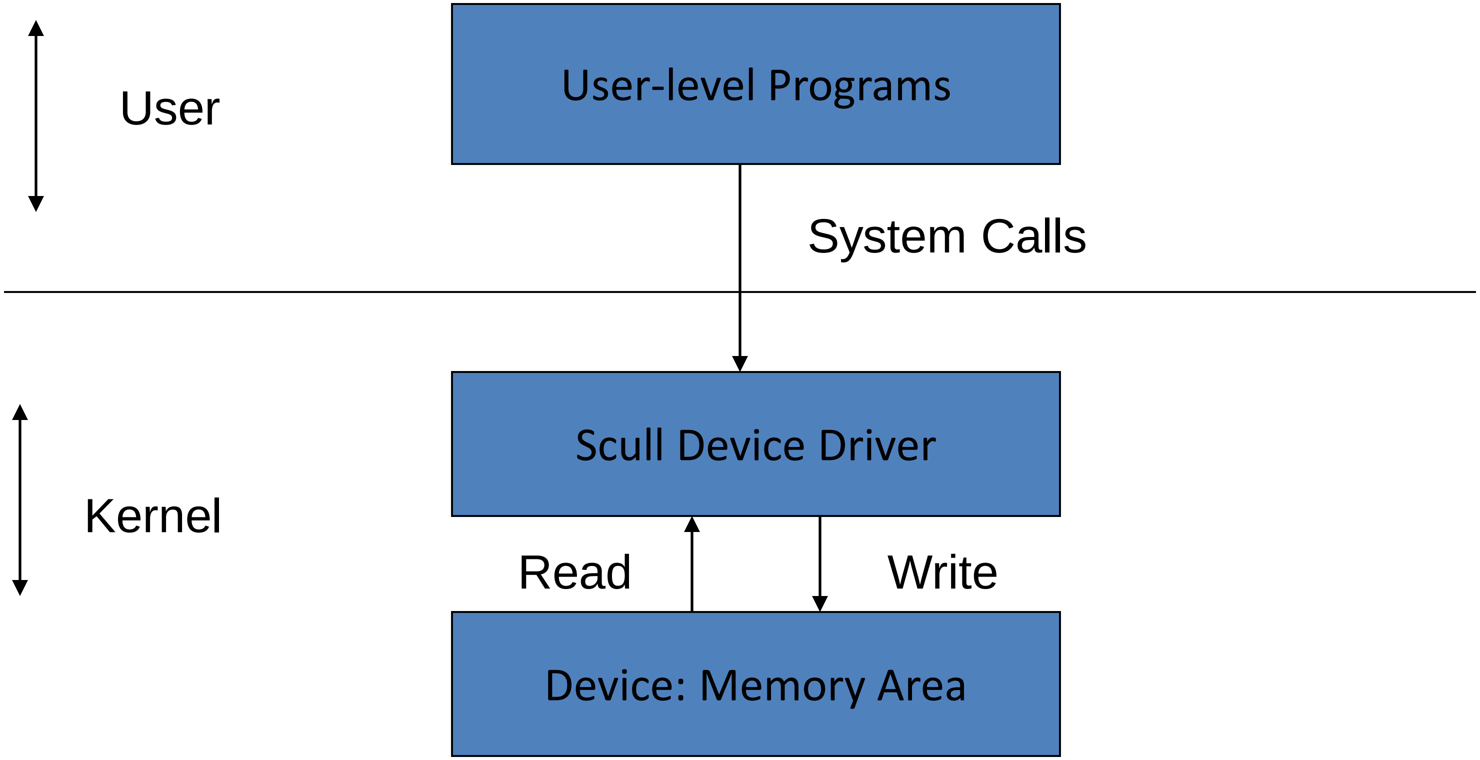
- Char devices are accessed through nodes of the filesystem tree located in the /dev directory

- Special files for char drivers are identified by “c” in the first character of the ls -l listing in /dev
- `crw--w----  1 root tty      4,  … tty40`

Example Character Device

- Scull:
  - Simple Character Utility for Loading Localities (scull)
  - A memory based device
  - Does not connect to any real device

Character Device Driver: Scull



User

User-level Programs

System Calls

Kernel

Scull Device Driver

Read

Write

Device: Memory Area

Scull devices are persistent; can be shared

Device Numbers

- Major number
  - Identifies the driver associated with the device
  - Available in: /proc/devices
- Minor number
  - Used by the Kernel to determine exactly which device is being referred to
- Idea: many devices can share the same driver
  - e.g. many terminals might share the same driver

Device Numbers

- `dev_t type`
  - Used to hold device numbers
  - Major and minor parts
  - 32 bit (12 bits for major number, 20 bits for minor number)
- Macros
  - To obtain the major or minor parts of a `dev_t`
    - `MAJOR(dev_t dev);`
    - `MINOR(dev_t dev);`
  - To convert major and minor numbers into `dev_t`
    - `MKDEV(int major, int minor);`

Device Major Number: Static Allocation

int register_chrdev_region (dev_t first, unsigned int count,
char *name)

- first: beginning device number of the range you would like to allocate
- count: total device numbers (minor) you are requesting (will be 1 for us)
- name: name of the device that should be associated with this range

Device Major Number: Dynamic Allocation **

```
int alloc_chrdev_region (dev_t *dev, unsigned int firstminor,
                         unsigned int count, char *name)
```

- dev: output parameter; on successful completion, holds the first number in your allocated range
- firstminor: requested first minor number to use; usually 0
- count: total number of contiguous device numbers (minor) you are requesting
- name: name of the device that should be associated with this number range

Example of Device Number Allocation

```
extern int scull_major; // auto allocation => 0
extern int scull_minor; // assume this is 0

if (scull_major) {
    dev = MKDEV(scull_major, scull_minor);
    result = register_chrdev_region (dev, scull_nr_devs, “scull”);
}
else {
    result = alloc_chrdev_region (&dev, scull_minor,
                                  scull_nr_devs, “scull”);
    scull_major = MAJOR(dev);
}
```

Device Driver Life-cycle

- Stage 1: Registration and Initialization
  - module_init (called when insmod is invoked)
- Stage 2: Serving requests from user-space programs
  - open, read, write, close, lseek
- Stage 3: De-registration and clean-up
  - module_exit (called when rmmod is invoked)

Hello World

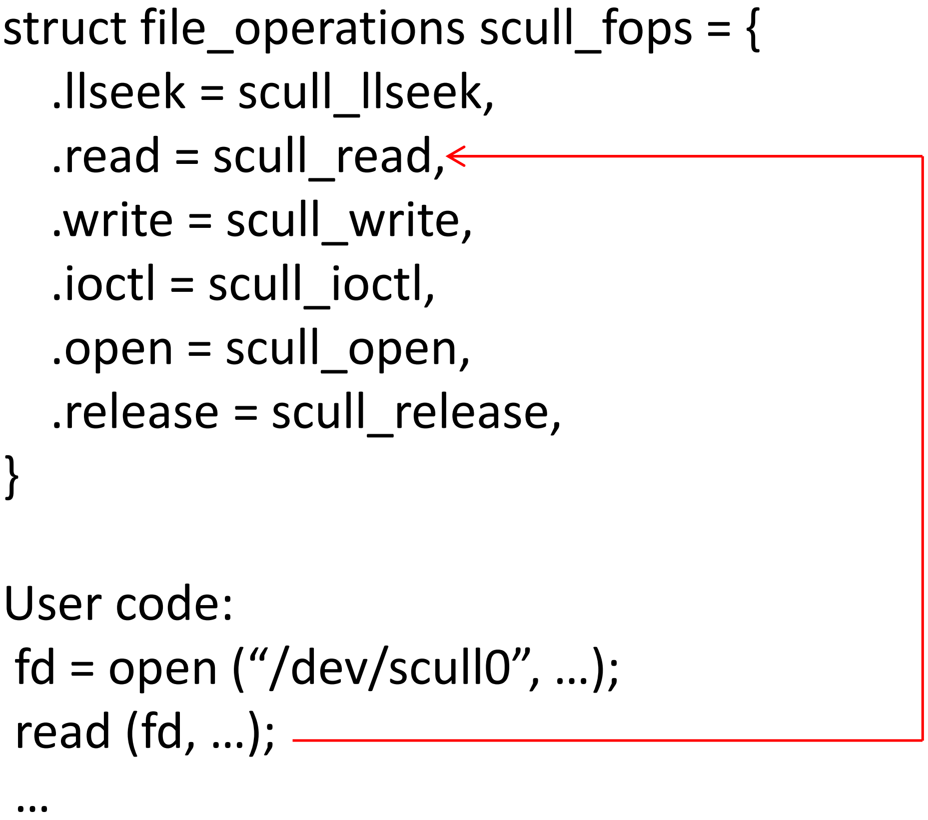
```
#include <linux/init.h>
#include <linux/module.h>
static char *charArg = "foo";
static int intArg = 25;

/* declare that intArg and charArg are args to the module and list their types and permissions */
module_param (intArg, int, S_IRUGO);
module_param (charArg, charp, S_IRUGO);

/* module initialize function */
static int hello_init(void)
{
  printk (KERN_INFO "HelloWorld: You passed: %d and %s\n", intArg, charArg);
}

/* module remove function */
static void hello_exit(void)
{
   printk (KERN_INFO "HelloWorld: So long and thanks for all the fish..\n");
}

/* specify the module init and remove functions */
module_init(hello_init);
module_exit(hello_exit);
```

```
root# insmod ./hello.ko HelloWorld: You passed 25 and foo
root# rmmod hello HelloWorld: So long and thanks for all the fish..
```

Important Data Structures

- struct file
  - This structure is created every time a file/dev is opened. It is maintained while the file is open
- struct inode
  - An inode is maintained for each file/dev; contains pointers to the device structure (cdev)
- struct cdev
  - the char device; contains a pointer to the file operations structure
- struct file_operations
  - contains pointers to functions for device interface functions
- struct your_device
  - contains state, storage, … and cdev

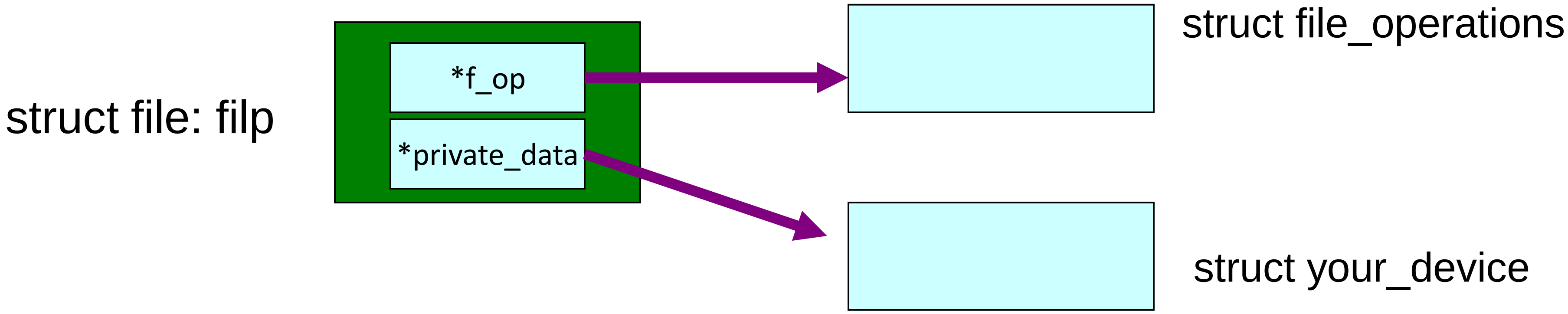
struct file_operations



```
struct file_operations scull_fops = {
    .llseek = scull_llseek,
    .read = scull_read,
    .write = scull_write,
    .ioctl = scull_ioctl,
    .open = scull_open,
    .release = scull_release,
}

User code:
 fd = open (“/dev/scull0”, …);
 read (fd, …);
 …
```

struct file

- Some important fields: open file
  - struct file_operations *fops
    - The operations associated with the file
  - void *private_data (~ device-specific data)
    - Useful resource for preserving state information across system calls



Scull Device

```
struct scull_dev {  // up to you (i.e.. struct your_device)
    … data, bookkeeping, buffers, …
   struct semaphore sem;
   struct cdev cdev;
}
```

- struct cdev is Kernel’s internal structure that represents char devices

- The scull device driver needs to initialize this structure, initialize the cdev structure and register cdev with the Kernel

struct inode

- Passed to open function

- Some important fields
  - dev_t i_rdev
    - For inodes of device files, this field contains the actual device number
  - struct cdev *i_cdev
    - struct cdev is Kernel’s internal structure that represents char devices

  - container_of: from i_cdev => *struct your_device

Char Device Registration

- Kernel uses structures of type struct cdev to represent char devices internally
- Before Kernel can invoke device's operations, we must do the following
  - 1. Set the file_operations pointer inside this structure
  - 2. Allocate and register one or more such structures

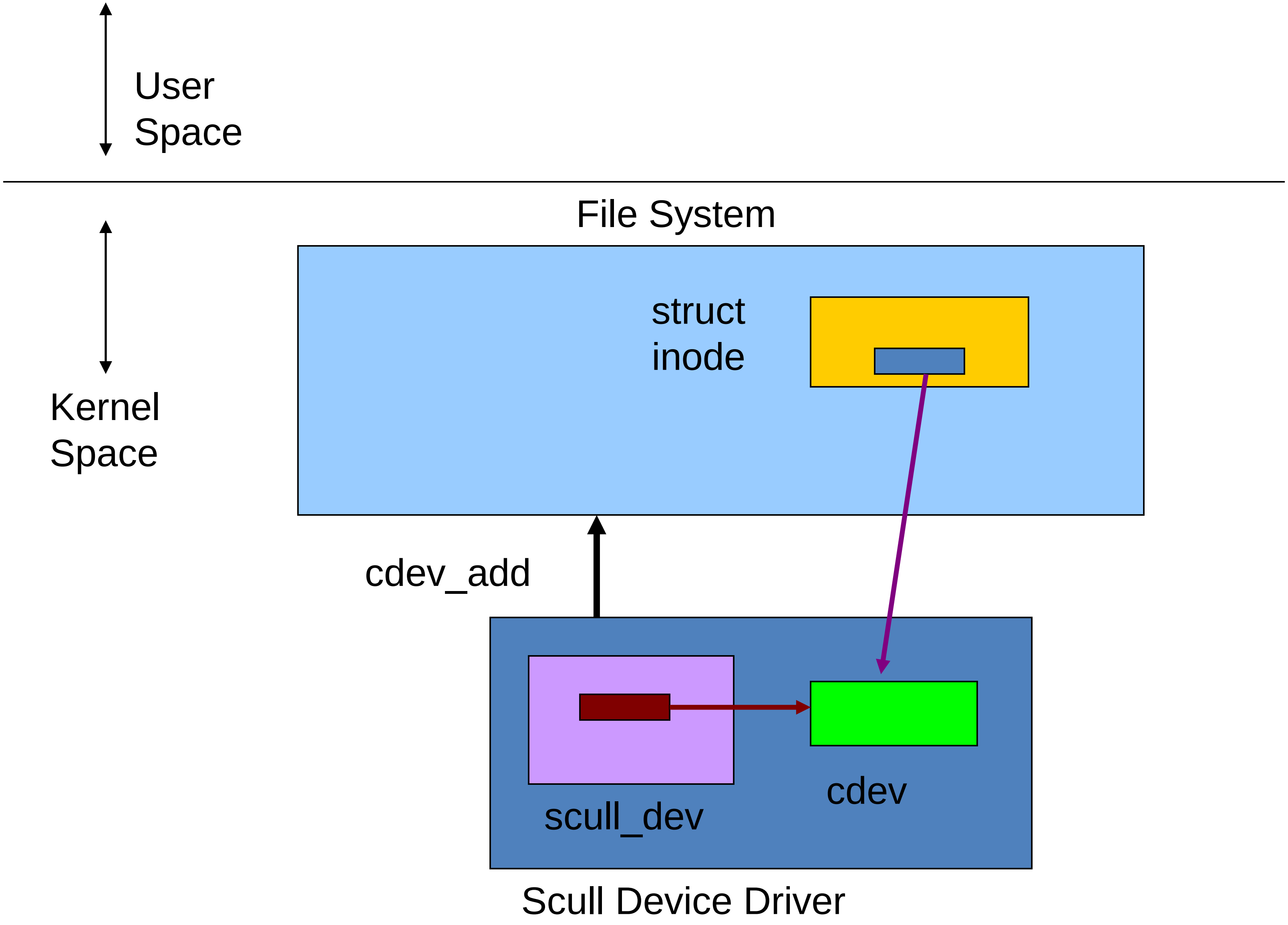
Char Device Registration

```
void cdev_init (struct cdev *cdev, struct file_operations *fops)

int cdev_add (struct cdev *dev, dev_t num,
                    unsigned int count);
```

count: #of device numbers (usually, this is 1)

Device is now “live”

Status after Char Device Registration



User
Space

Kernel
Space

File System

struct
inode

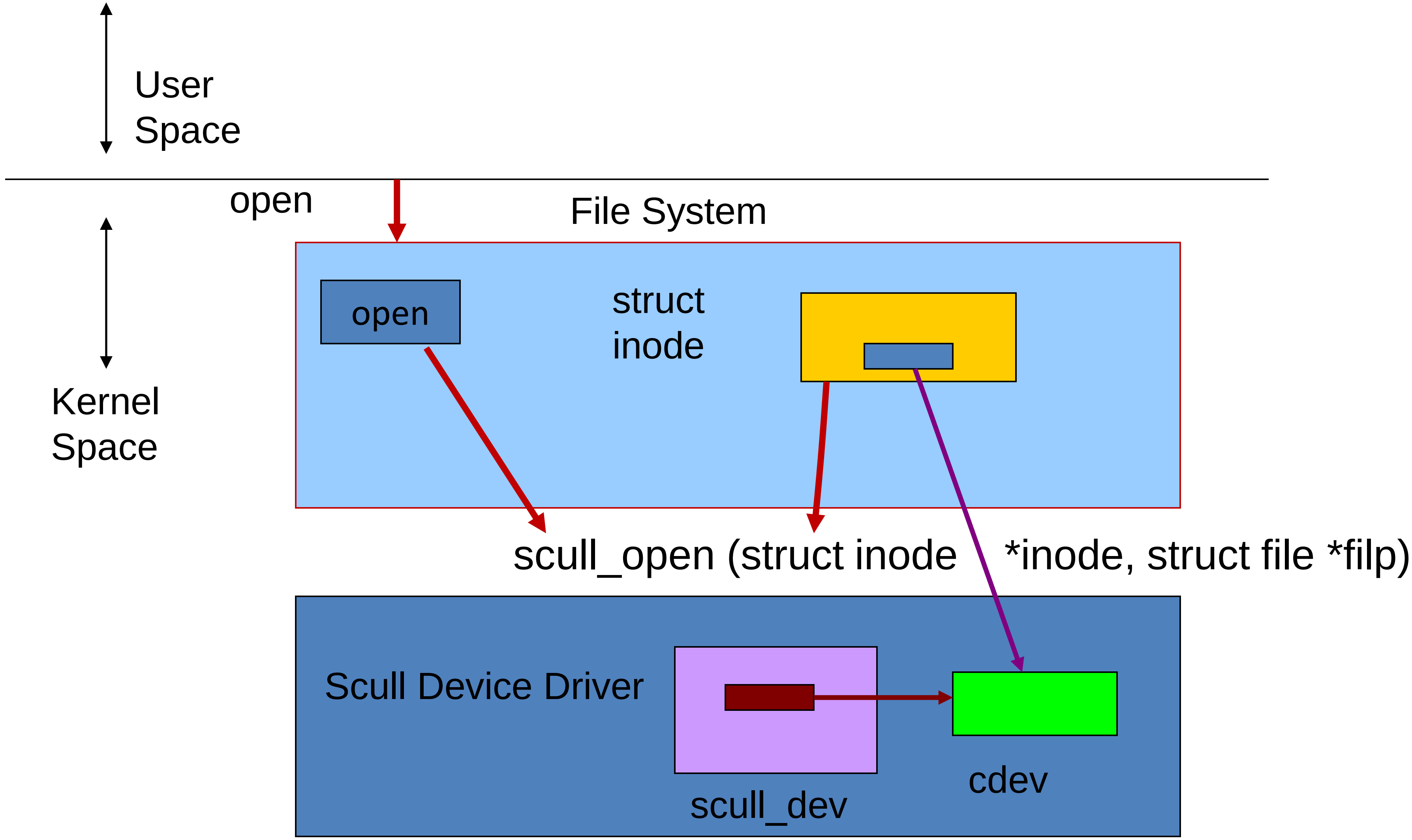
cdev_add

scull_dev

cdev

Scull Device Driver

Handling of open call



User Space

open

File System

open

struct inode

scull_open (struct inode *inode, struct file *filp)

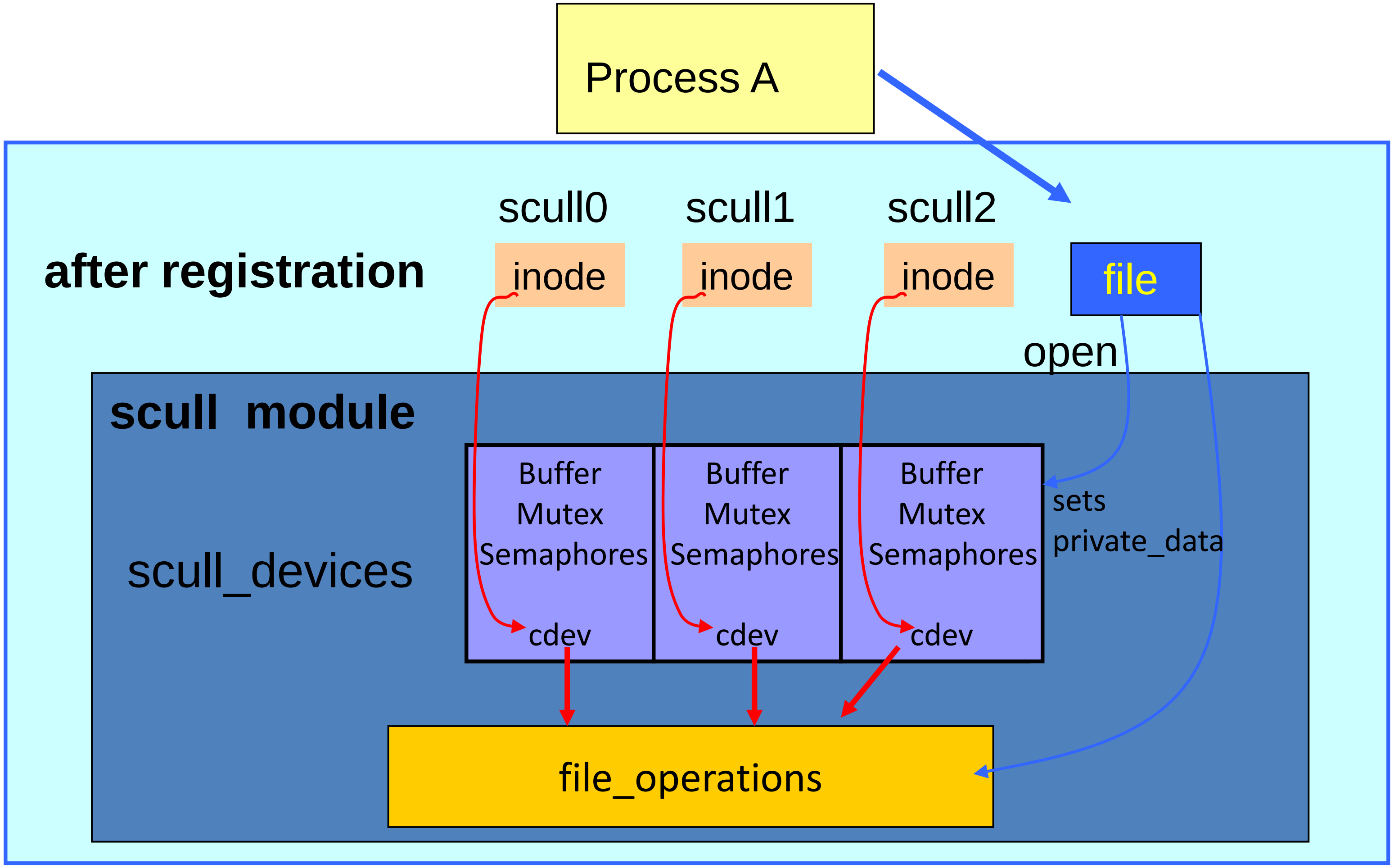
Kernel Space

Scull Device Driver

scull_dev

cdev

Conceptual View



Process A

after registration

scull0

scull1

scull2

inode

inode

inode

file

open

scull module

scull_devices

Buffer
Mutex
Semaphores
cdev

Buffer
Mutex
Semaphores
cdev

Buffer
Mutex
Semaphores
cdev

sets
private_data

file_operations

Open and release

- open (*inode, *filp)
  - setup filp->private_data for subsequent methods
  - device-specific initialization
- release (*inode, *filp)   // close
  - device-specific dealloc / release resources

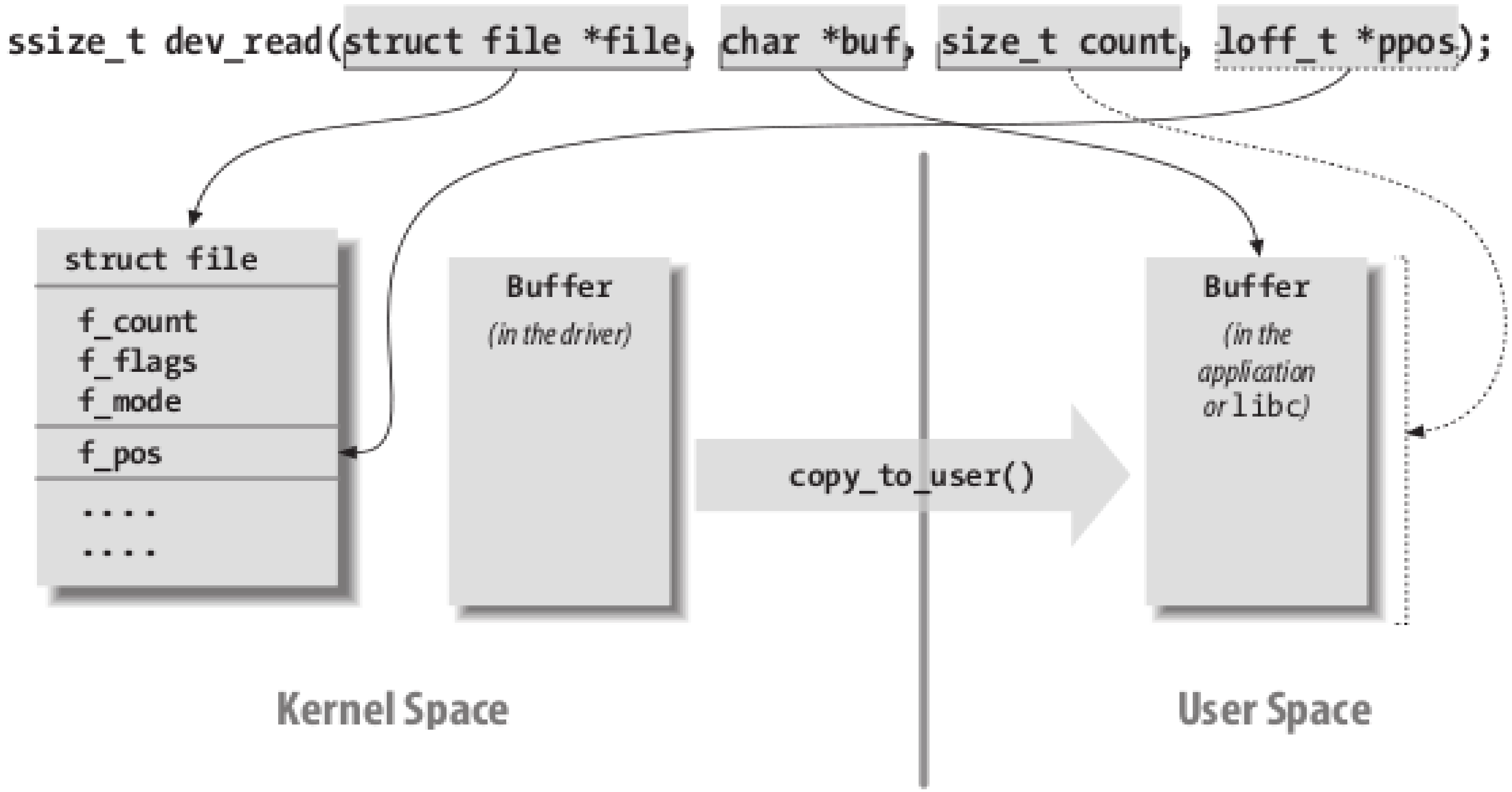
Read and write

- read (*filp, *buff, count, *offp)
- write (*filp, *buff, count, *offp)

- returns: <0 on error; >= 0 is bytes transferred
- buff – user space pointer

- copy_to_user (toAddr, fromAddr)
- copy_from_user (toAddr, fromAddr)

Closer look at read ...



Allocating memory in the kernel

- kmalloc (size, GFP_KERNEL)
  - similar to malloc
  - memory is not cleared
- kfree (memPtr)

- allocate buffers within your device

Synchronization

- Block processes calling your device
- Semaphores
  - sema_init (*sem, val)
  - down (*sem), down_interruptible, down_trylock
  - up (*sem)

- WaitQueues
  - init_waitqueue_head()
  - wait_event(), wait_event_interruptible() ...
  - wake_up(), wake_up_interruptible()