Linux Device Drivers

An Introduction

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Introduction

Familiarity Check

- Good C & Programming Skills
- Linux & the Filesytem
  - Root, User Space Headers & Libraries
- Files
  - Regular, Special, Device
- Toolchain
  - gcc & friends
- Make & Makefiles
- Kernel Sources (Location & Building)

The Flow

- Introduction
  - Linux kernel Ecosystem
  - Kernel Souce Organization
  - Command set and Files
  - Writing the first driver (Module)
- Character Drivers
  - Device files
  - Device access from user space (End to End flow)
  - Registering the driver
  - File Operations and registration
  - Data transfer between User and Kernel space
  - ioctl
- Memory & Hardware
- Time & Timings
- USB Drivers
- Interrupt Handling
- Block Drivers
- PCI Drivers
- Debugging

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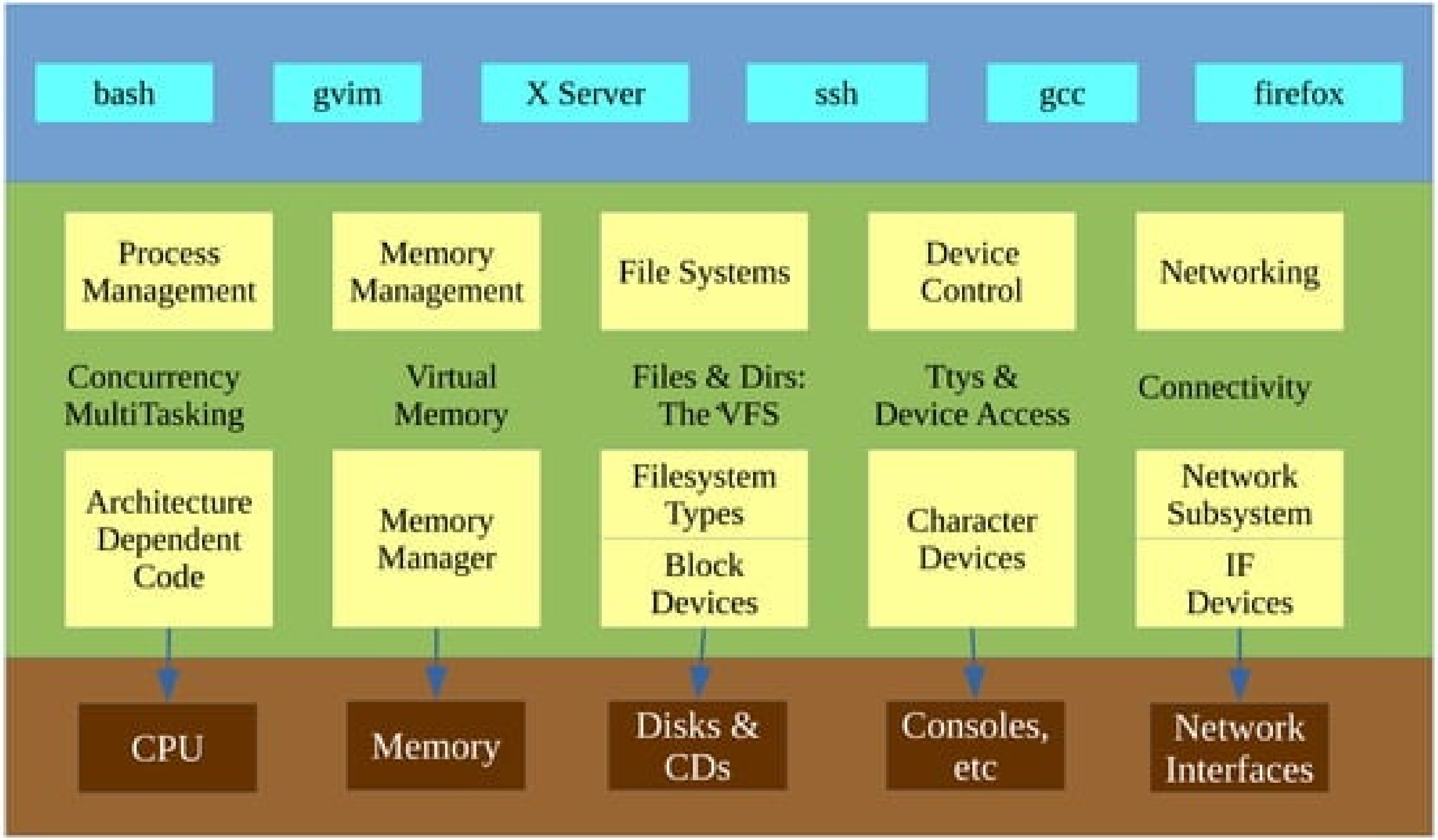
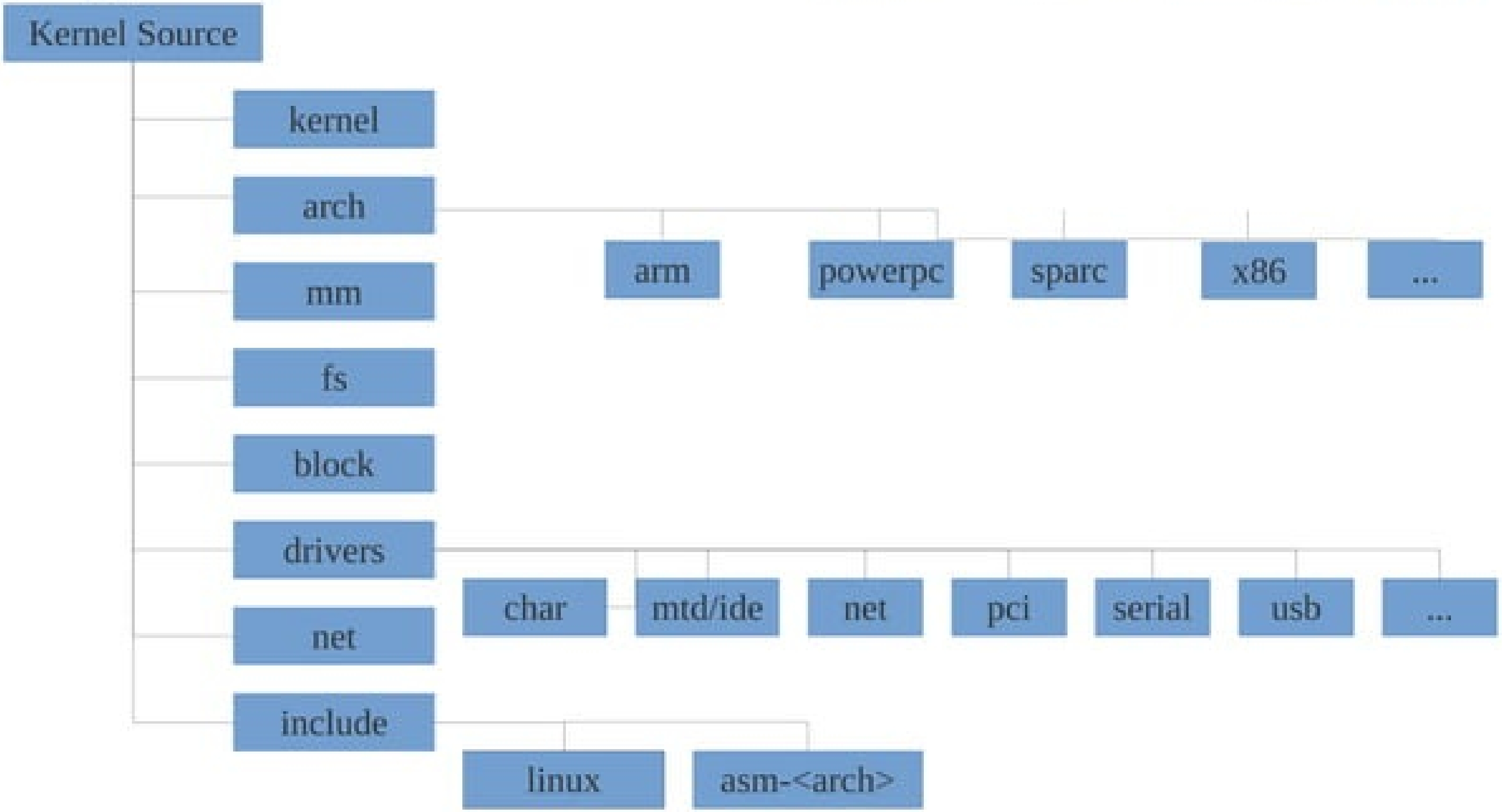
Hands-On

- Your First Driver
- Character Drivers
  - Null Driver
  - Memory Driver
  - UART Driver for Customized Hardware
- USB Drivers
  - USB Device Hot-plug-ability
  - USB to Serial Hardware Driver
- Filesystem Modules
  - VFS Interfacing
  - “Pseudo” File System with Memory Files

Linux Driver Ecosystem



Kernel Source Organization



The Locations & Config Files

- Kernel Source Path: /usr/src/linux
- Std Modules Path:
  - /lib/modules/<kernel version>/kernel/...
- Module Configuration: /etc/modprobe.conf
- Kernel Windows:
  - /proc
  - /sys
- System Logs: /var/log/messages

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The Commands

- lsmod
- insmod
- modprobe
- rmmod
- dmesg
- objdump
- nm
- cat /proc/<file>

The Kernel's C

- ctor & dtor
  - init_module, cleanup_module
- printf
  - printk
- Libraries
  - <kernel src>/kernel
- Headers
  - <kernel src>/include

The Init Code

```
static int __init mfd_init(void)
{
    printk(KERN_INFO "mfd registered");
    ...
    return 0;
}
module_init(mfd_init);
```

The Cleanup Code

```
static void __exit mfd_exit(void)
{
    printk(KERN_INFO "mfd deregistered");
    ...
}
module_exit(mfd_exit);
```

Usage of printk

- <linux/kernel.h>
- Constant String for Log Level
  - KERN_EMERG "<0>" /* system is unusable */
  - KERN_ALERT "<1>" /* action must be taken immediately */
  - KERN_CRIT "<2>" /* critical conditions */
  - KERN_ERR "<3>" /* error conditions */
  - KERN_WARNING "<4>" /* warning conditions */
  - KERN_NOTICE "<5>" /* normal but significant condition */
  - KERN_INFO "<6>" /* informational */
  - KERN_DEBUG "<7>" /* debug-level messages */
- printf like arguments

The Other Basics & Ornaments

- Headers
  - #include <linux/module.h>
  - #include <linux/version.h>
  - #include <linux/kernel.h>
- MODULE_LICENSE("GPL");
- MODULE_AUTHOR("Emertxe");
- MODULE_DESCRIPTION("First Device Driver");

Building the Module

- Our driver needs
  - The Kernel Headers for Prototypes
  - The Kernel Functions for Functionality
  - The Kernel Build System & the Makefile for Building
- Two options
  - Building under Kernel Source Tree
    - Put our driver under drivers folder
    - Edit Kconfig(s) & Makefile to include our driver
  - Create our own Makefile to do the right invocation

Our Makefile

```
ifneq (${KERNELRELEASE},)
    obj-m += <module>.o
else
    KERNEL_SOURCE := <kernel source directory path>
    PWD := $(shell pwd)
default:
    $(MAKE) -C ${KERNEL_SOURCE} SUBDIRS=$(PWD) modules
clean:
    $(MAKE) -C ${KERNEL_SOURCE} SUBDIRS=$(PWD) clean
endif
```

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Try Out your First Driver

Character Drivers

Major & Minor Number

- ls -l /dev
- Major is to Driver; Minor is to Device
- <linux/types.h> (>= 2.6.0)
  - dev_t: 12 & 20 bits for major & minor
- <linux/kdev_t.h>
  - MAJOR(dev_t dev)
  - MINOR(dev_t dev)
  - MKDEV(int major, int minor)

Registering & Unregistering

- Registering the Device Driver
  - int register_chrdev_region(dev_t first, unsigned int count, char *name);
  - int alloc_chrdev_region(dev_t *dev, unsigned int firstminor, unsigned int cnt, char *name);
- Unregistering the Device Driver
  - void unregister_chrdev_region(dev_t first, unsigned int count);
- Header: <linux/fs.h>

The file operations

- #include <linux/fs.h>
- struct file_operations
  - int (*open)(struct inode *, struct file *);
  - int (*release)(struct inode *, struct file *);
  - ssize_t (*read)(struct file *, char __user *, size_t, loff_t *);
  - ssize_t (*write)(struct file *, const char __user *, size_t, loff_t *);
  - struct module owner = THIS_MODULE; / linux/module.h> */
  - loff_t (*llseek)(struct file *, loff_t, int);
  - int (*ioctl)(struct inode *, struct file *, unsigned int, unsigned long);

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User level I/O

- int open(const char *path, int oflag, ...)
- int close(int fd);
- ssize_t write(int fd, const void *buf, size_t nbyte)
- ssize_t read(int fd, void *buf, size_t nbyte)
- int ioctl(int d, int request, ...)
  - The ioctl() function manipulates the underlying device parameters of special files.
  - The argument d must be an open file descriptor.
  - The second argument is a device-dependent request code.

The file & inode structures

- struct file
  - mode_t f_mode
  - loff_t f_pos
  - unsigned int f_flags
  - struct file_operations *f_op
  - void * private_data
- struct inode
  - unsigned int iminor(struct inode *);
  - unsigned int imajor(struct inode *);

Registering the file operations

- #include <linux/cdev.h>
- 1st way initialization:
  - struct cdev *my_cdev = cdev_alloc();
  - my_cdev->owner = THIS_MODULE;
  - my_cdev->ops = &my_fops;
- 2nd way initialization:
  - struct cdev my_cdev;
  - cdev_init(&my_cdev, &my_fops);
  - my_cdev.owner = THIS_MODULE;
  - my_cdev.ops = &my_fops;

Registering the file operations...

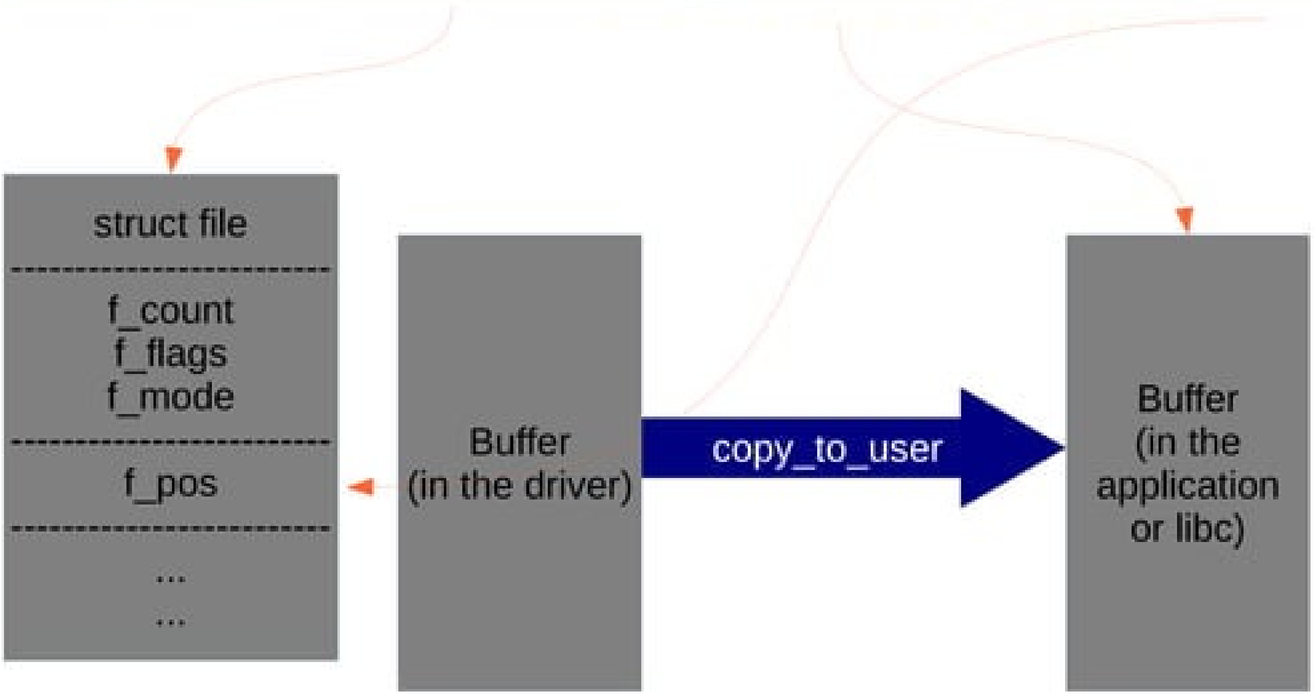
- The Registration
  - int cdev_add(struct cdev *cdev, dev_t num, unsigned int count);
- The Unregistration
  - void cdev_del(struct cdev *cdev);

Registering/Unregistering Old Way

- Registering the Device Driver
  - int register_chrdev(undigned int major, const char *name, struct file_operations *fops);
- Unregistering the Device Driver
  - int unregister_chrdev(undigned int major, const char *name);

The read flow

ssize_t my_read(struct file *f, char __user *buf, size_t cnt, loff_t *off)



Kernel Space (Non-swappable)

User Space (Swappable)

The /dev/null read & write

```
ssize_t my_read(struct file *f, char __user *buf, size_t cnt, loff_t
    *off)
{
    ...
    return read_cnt;
}
ssize_t my_write(struct file *f, char __user *buf, size_t cnt, loff_t
    *off)
{
    ...
    return wrote_cnt;
}
```

The mem device read

```
ssize_t my_read(struct file *f, char __user *buf, size_t cnt, loff_t
    *off)
{
    ...
    if (copy_to_user(buf, from, cnt) != 0)
    {
        return -EFAULT;
    }
    ...
    return read_cnt;
}
```

The mem device write

```
ssize_t my_write(struct file *f, char __user *buf, size_t cnt, loff_t
    *off)
{
    ...
    if (copy_from_user(to, buf, cnt) != 0)
    {
        return -EFAULT;
    }
    ...
    return wrote_cnt;
}
```

Dynamic Device Node & Classes

- Class Operations
  - struct class *class_create(struct module *owner, char *name);
  - void class_destroy(struct class *cl);
- Device into & Out of Class
  - struct class_device *device_create(struct class *cl, NULL, dev_t devnum, NULL, const char *fmt, ...);
  - void device_destroy(struct class *cl, dev_t devnum);

The I/O Control API

- int (*ioctl)(struct inode *, struct file *, unsigned int cmd, unsigned long arg)
- int (*unlocked_ioctl)(struct file *, unsigned int cmd, unsigned long arg)
- Command
  - <linux/ioctl.h> -> ... -> <asm-generic/ioctl.h>
  - Macros
    - _IO, _IOR, _IOW, _IOWR
  - Parameters
    - type (Magic character) [15:8]
    - number (index) [7:0]
    - size (param type) [29:16]

The I/O Control API

- Macro Usage

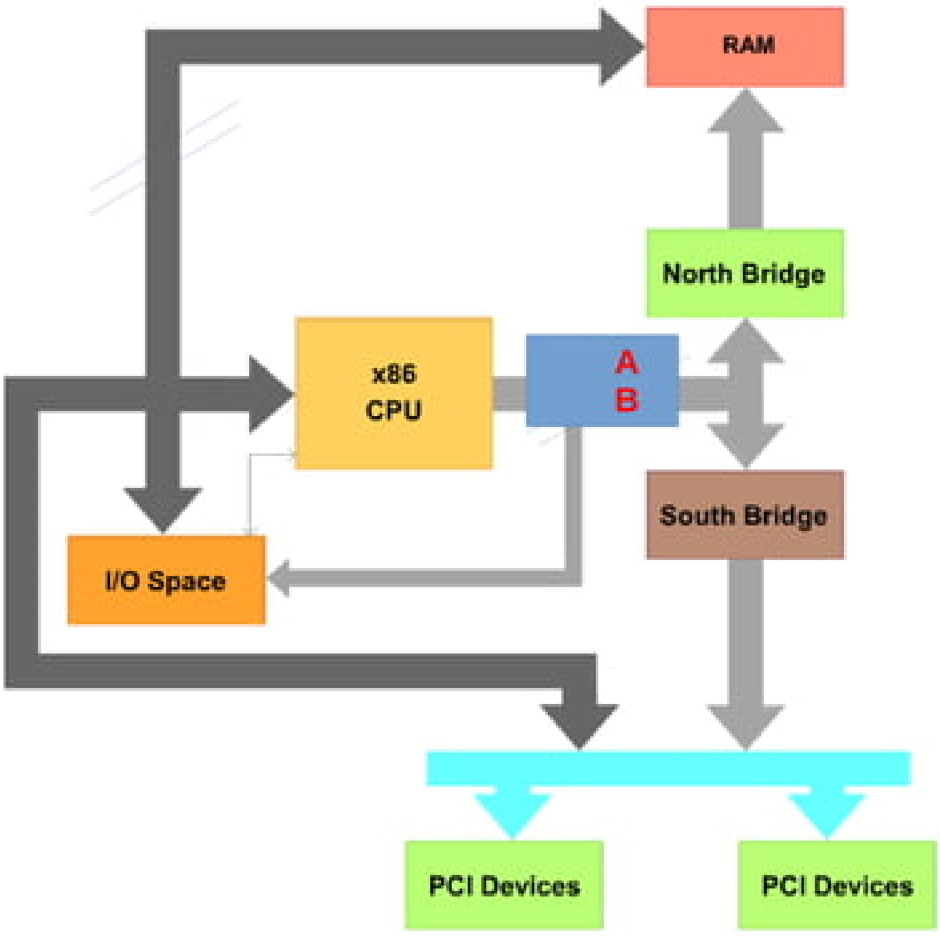
  _IO(type, index)

  [_IOR | _IOW | _IOWR](type, index, datatype/size)

Module Parameters

- <linux/moduleparam.h>
  - Macros
    - module_param(name, type, perm)
    - module_param_array(name, type, num, perm)
    - Perm (is a bitmask)
      - 0
      - S_IRUGO
      - S_IWUSR | S_IRUGO
  - Loading
    - insmod driver.ko name=10

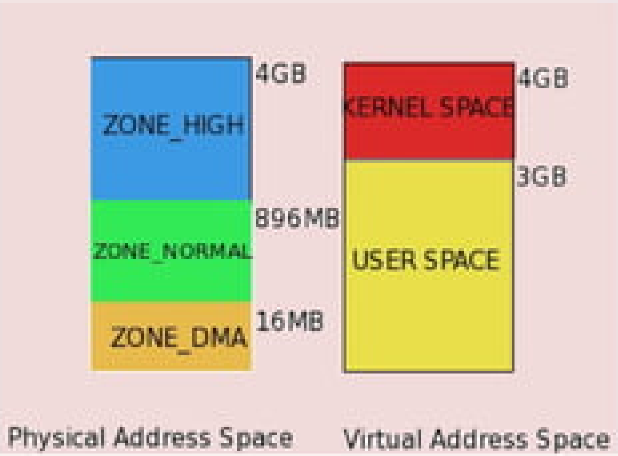
x86 Architecture



Memory Access

Physical Vs Virtual Memory

- The kernel Organizes Physical memory in to pages
  - Page size Depends on Arch
    - X86-based 4096 bytes
- On 32-bit X86 system Kernel total Virtual address space
  - Total 4GB (pointer size)
  - Kernel Configuration Splits 4GB in to
    - 3BG Virtual Sp for US
    - 1GB Virtual Sp for Kernel
      - 128MB KDS
  - Virtual Address also called



Memory Access from Kernel Space

- Virtual Address on Physical Address
  - #include <linux/gfp.h>
    - unsigned long __get_free_pages(flags, order); etc
    - void free_pages(addr, order); etc
  - #include <linux/slab.h>
    - void *kmalloc(size_t size, gfp_t flags);
      - GFP_ATOMIC, GFP_KERNEL, GFP_DMA
    - void kfree(void *obj);
  - #include <linux/vmalloc.h>
    - void *vmalloc(unsigned long size);
    - void vfree(void *addr);

Memory Access from Kernel Space...

- Virtual Address for Bus/IO Address
  - #include <asm/io.h>
    - void *ioremap(unsigned long offset, unsigned long size);
    - void iounmap(void *addr);
- I/O Memory Access
  - #include <asm/io.h>
    - unsigned int ioread[8|16|32](void *addr);
    - unsigned int iowrite[8|16|32](u[8|16|32] value, void *addr);
- Barriers
  - #include <linux/kernel.h>: void barrier(void);
  - #include <asm/system.h>: void [r|w|]mb(void);

Hardware Access

I/O Accesses from Kernel Space

- I/O Port Access
  - #include <asm/io.h>
    - unsigned in[b|w|l](unsigned port);
    - void out[b|w|l](unsigned [char|short|int] value, unsigned port);

Hands-On the Hardware