Overview

- This Lecture
  - Debugging & Concurrency in kernel
  - Source: LDD ch4 & ch5, ELDD ch2, ch21

Kernel debugging options

- There are some configuration options for supporting debugging in the kernel
  - CONFIG_DEBUG_KERNEL
  - CONFIG_DEBUG_SLAB/SLUB
  - CONFIG_DEBUG_PAGEALLOC
  - CONFIG_DEBUG_SPINLOCK
  - CONFIG_DEBUG_SPINLOCK_SLEEP
  - CONFIG_DEBUG_INFO
  - CONFIG_MAGIC_SYSRQ
  - CONFIG_DEBUG_STACKOVERFLOW
  - CONFIG_DEBUG_STACK_USAGE

Kernel debugging options (cont.)

- CONFIG_KALLSYMS
- CONFIG_IKCONFIG
- CONFIG_IKCONFIG_PROC
- CONFIG_DEBUG_DRIVER
- CONFIG_INPUT_EVBUG
- CONFIG_PROFILING
- ……

Debugging by printing

- Use **printk**
- Be aware of eight priority levels
  - KERN_EMERG, KERN_ALERT, KERN_CRIT, KERN_ERR, KERN_WARNING, KERN_NOTICE, KERN_INFO, KERN_DEBUG
- Mind the console level
  - Not all printk messages appear at the console
  - Check /proc/sys/kernel/printk
- You may need a separate console for debugging
  - Use ioctl(TIOCLINUX) to redirect the console message
- klogd is used to read all kernel messages from /proc/kmsg

Turn debugging messages on/off

- You may turn on/off debugging message using conditional compilation

```
#undef PDEBUG             /* undef it, just in case */
#ifdef SCULL_DEBUG
#  ifdef __KERNEL__
     /* This one if debugging is on, and kernel space */
#    define PDEBUG(fmt, args...) printk( KERN_DEBUG "scull: " fmt,
    ## args)
#  else      /* This one for user space */
#    define PDEBUG(fmt, args...) fprintf(stderr, fmt, ## args)
#  endif
#else
#  define PDEBUG(fmt, args...) /* not debugging: nothing */
#endif
#undef PDEBUGG
#define PDEBUGG(fmt, args...) /* nothing: it's a placeholder */
```

Rate limit

- Use printk_ratelimit to limit printing rate

```
if (printk_ratelimit())
printk(KERN_NOTICE "The printer is still on fire\n");
```

- Print device numbers
  - int print_dev_t(char *buffer, dev_t dev);
  - char *format_dev_t(char *buffer, dev_t dev);

Debugging by querying

- Use /proc to query important variables
- Create a /proc entry
  - struct proc_dir_entry *proc_create_data(const char *name, mode_t mode, struct proc_dir_entry *base, struct file_operations *proc_fops, void *data);
  - Example
    - proc_create_data("scullmem", 0 /* default mode */, NULL /* parent dir */, &test_proc_fops, NULL /* driver data */);
  - remove_proc_entry("scullmem", NULL /* parent dir */);

Querying with ioctl

- Use undocumented ioctl commands to expose internal status of driver programs.
- More details for ioctl will be addressed later (refer to chapter 6 of LDD)

Debugging by watching

- Watch behavior of user space applications
  - Use strace
  - …

Debugging system faults

- Check oops message
  - Important fields: EIP, stack, call trace
  - Examples
- System hangs
  - Use `schedule` call
  - Use the magic **SysRq** key
    - Use "`echo 1 > /proc/sys/kernel/sysrq`" to enable it
- They are for advanced kernel programmers!

Using debuggers

- Using gdb
  - gdb /usr/src/linux/vmlinux /proc/kcore
  - But the changing variables are found the same
  - Use the command core-file /proc/kcore to get updated.
  - For modules, the add-symbol-file command should be used.
    - add-symbol-file scull.ko 0xd0832000 -s .bss 0xd0837100 -s .data 0xd0836be0
- Using kdb and kgdb (need special patches)
- QEMU, Linux Trace Toolkit, and Dynamic Probes

Data race

- Data race condition
  - occurs when a variable is accessed concurrent R/W operations and one of them is write
- Semaphores, mutexes and locks are used to prevent data races
- Linux semaphores
  - void sema_init(struct semaphore *sem, int val);
  - DECLARE_MUTEX(name);
  - DECLARE_MUTEX_LOCKED(name);
  - Void init_MUTEX(struct semaphore *sem);
  - void init_MUTEX_LOCKED(struct semaphore *sem);

Linux semaphores

- Operations on semaphores
  - void down(struct semaphore *sem);
  - int down_interruptible(struct semaphore *sem);
  - int down_trylock(struct semaphore *sem);
  - void up(struct semaphore *sem);
- Reader/writer semaphores
  - Allow multiple readers access the resource simultaneously.
- Completion
  - A faster constructor for synchronization between processes/threads

Mutex

- Mutex API
  - DEFINE_MUTEX(name);
  - mutex_init(mutex);
  - void mutex_lock(struct mutex *lock);
  - int mutex_lock_interruptible(struct mutex *lock);
  - int mutex_trylock(struct mutex *lock);
  - void mutex_unlock(struct mutex *lock);
  - int mutex_is_locked(struct mutex *lock);
  - void mutex_lock_nested(struct mutex *lock, unsigned int subclass);
  - int mutex_lock_interruptible_nested(struct mutex *lock, unsigned int subclass);
  - int atomic_dec_and_mutex_lock(atomic_t *cnt, struct mutex *lock);
  - Why mutex? http://www.kernel.org/doc/Documentation/mutex-design.txt

Spinlocks

- Spinlock is a busy waiting lock
  - Used to protect quick accesses to resources
- Spinlock API
  - spinlock_t my_lock = SPIN_LOCK_UNLOCKED;
  - void spin_lock_init(spinlock_t *lock);
  - void spin_lock(spinlock_t *lock);
  - void spin_unlock(spinlock_t *lock);
- When a spinlock is acquired, the critical section shouldn't lose CPU, meaning the critical section should be atomic
  - Functions such as copy_to_user shouldn't be called.

Spinlocks (cont.)

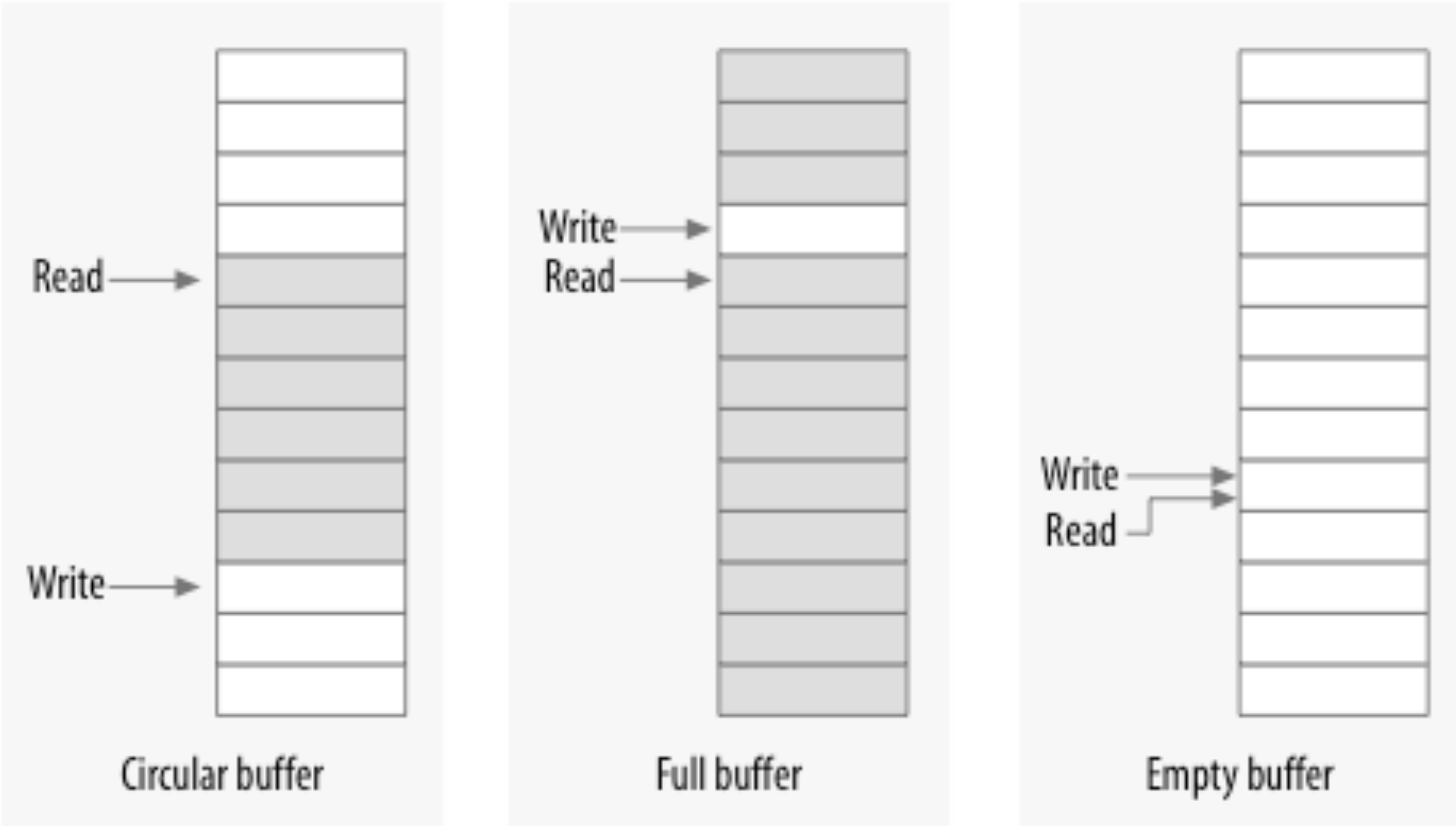
- More spinlock functions
  - void spin_lock(spinlock_t *lock);
  - void spin_lock_irqsave(spinlock_t *lock, unsigned long flags);
  - void spin_lock_irq(spinlock_t *lock);
  - void spin_lock_bh(spinlock_t *lock)
  - void spin_unlock(spinlock_t *lock);
  - void spin_unlock_irqrestore(spinlock_t *lock, unsigned long flags);
  - void spin_unlock_irq(spinlock_t *lock);
  - void spin_unlock_bh(spinlock_t *lock);
- Reader/Writer spinlocks

Tips for locking

- Locking order
  - Always the same order for acquiring multiple locks
- Locking granularity
  - As fine as possible so that parallelism is maximized, but there is a tradeoff between locking overhead and parallelism.
- Don’t protect unnecessary code sections
- …

Lock-free data structure

- Circular buffer



Other lock-free algorithms

- Using CAS (compare-and-swap)
  - For integers n and n' and a memory location a
  - CAS(n, a, n')
    - If the value at address a is n, write the value of n' to address a; return true
    - Otherwise, return false
- Lock-free algorithm for shared stack

Shared stack

- Example
  - Push an item onto a lock-free stack (using linked list)
- Pseudo-code
  - Push(new){
  - do {
  -     T' = Top;
  -     new->next = T';
  -     ret = CAS(T', &Top, new);
  -     } while(!ret);
  - }

Atomic variables

- Use type *atomic_t*
- Functions and macros
  - void atomic_set(atomic_t *v, int i);
  - atomic_t v = ATOMIC_INIT(i);
  - int atomic_read(atomic_t *v);
  - void atomic_add(int i, atomic_t *v);
  - void atomic_sub(int i, atomic_t *v);
  - void atomic_inc(atomic_t *v);
  - void atomic_dec(atomic_t *v);
  - int atomic_inc_and_test(atomic_t *v);
  - int atomic_dec_and_test(atomic_t *v);
  - int atomic_sub_and_test(int i, atomic_t *v);

Other solutions for data race

- Bit operations
  - Linux kernel provides atomic functions for bit-wise operations
- Seqlocks
  - For situations where the resource to be protected is small, simple, and frequently accessed, and where write access is rare but must be fast.
- Read-Copy-Update (RCU)
  - for situations where reads are common and writes are rare