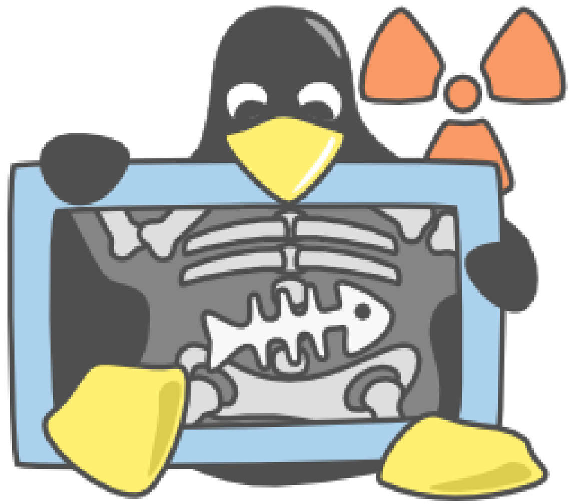


Linux Kernel Programming

Raoul Rivas

Kernel vs Application Programming

KERNEL

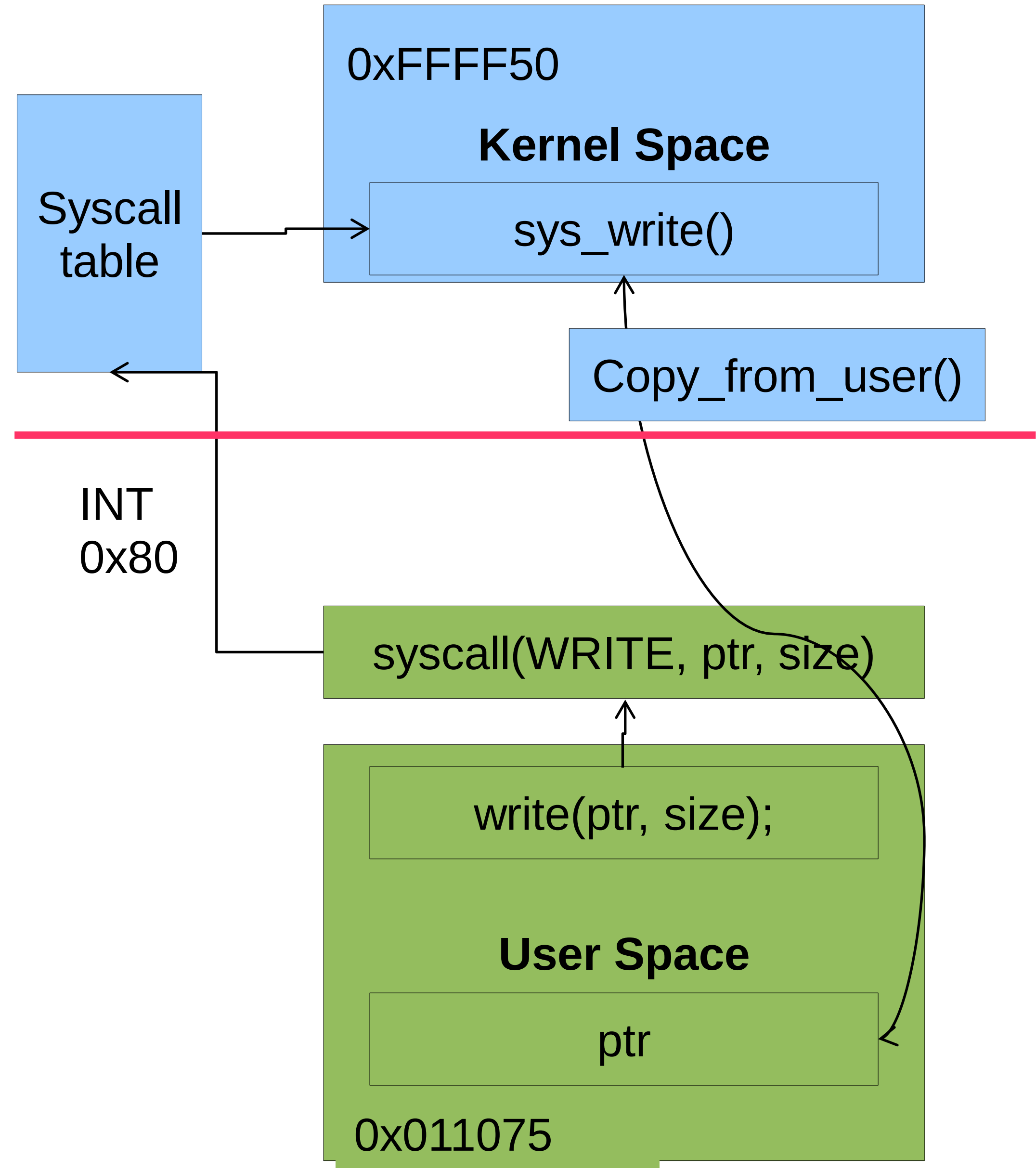
- No memory protection
  - We share memory with devices, scheduler
- Sometimes no preemption
  - Can hog the CPU
  - Concurrency is difficult
- No libraries
  - No Printf(), fopen()
- No security descriptors
- In Linux no access to files
- Direct access to hardware

APPLICATION

- Memory Protection
  - Segmentation Fault
- Preemption
  - Scheduling isn't our responsibility
- Signals (Control-C)
- Libraries
- Security Descriptors
- In Linux everything is a file descriptor
- Access to hardware as files

System Calls

- A system call involves an interrupt
  - syscall(number, arguments)
- The kernel runs in a different address space
- Data must be copied back and forth
  - copy_to_user(), copy_from_user()
- Never directly dereference any pointer from user space



Context

- Context: Entity whom the kernel is running code on behalf of
- Process context and Kernel Context are preemptible. We can sleep in them
- Interrupts cannot sleep and should be small!
- All these entities are concurrent!
- Process context and Kernel context have a PID:
  - Struct task_struct* current

Race Conditions

- Process context, Kernel Context and Interrupts run concurrently
- How to protect critical zones from race conditions?
  - Spinlocks
  - Mutex
  - Semaphores
  - Reader-Writer Locks (Mutex, Semaphores)
  - Reader-Writer Spinlocks

THE SPINLOCK SPINS...

THE MUTEX SLEEPS

Inside Locking Primitives

- Spinlock

```
//spinlock_lock:
disable_interrupts();
while(locked==true);

//critical region

//spinlock_unlock:
enable_interrupts();
locked=false;
```

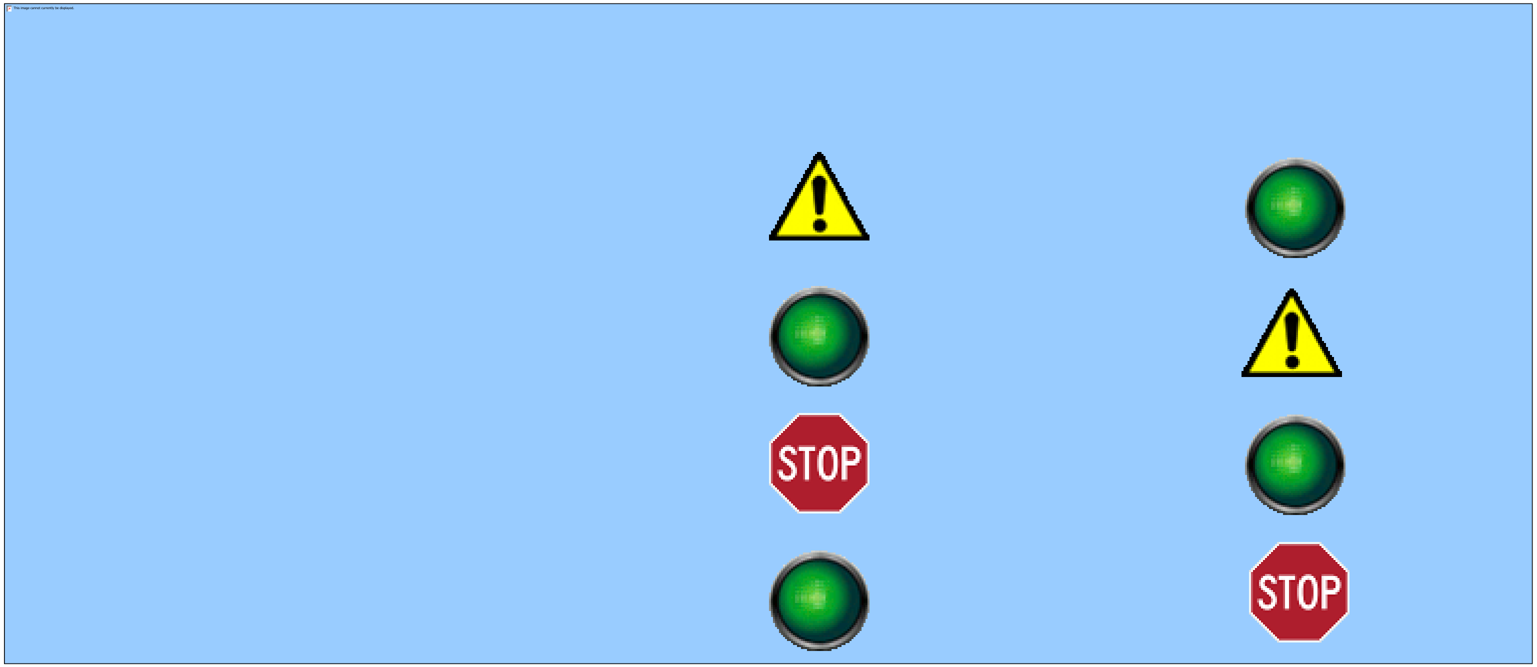
We can't sleep while the spinlock is locked! → DEADLOCK

We can't use a mutex in an interrupt because interrupts can't sleep!

- Mutex

```
//mutex_lock:
If (locked==true)
{
   Enqueue(this);
   Yield();
}
locked=true;

//critical region

//mutex_unlock:
If !isEmpty(waitqueue)
{
 wakeup(Dequeue());
}
Else locked=false;
```

When to use what?



- Usually functions that handle memory, user space or devices and scheduling sleep
  - Kmalloc, printk, copy_to_user, schedule
- wake_up_process does not sleep

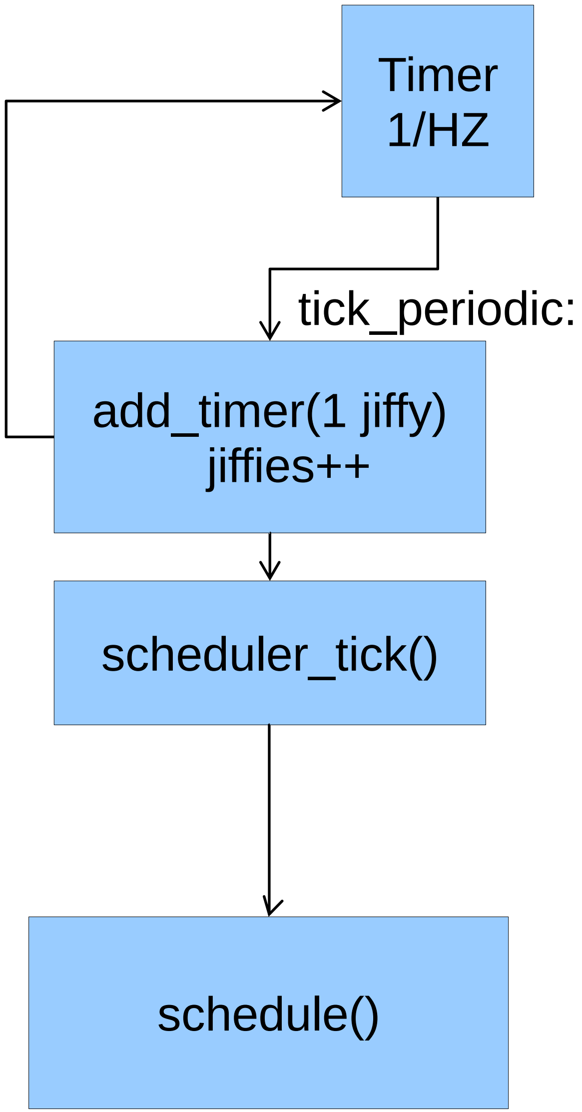
Linux Kernel Modules

- Extensibility
  - Ideally you don't want to patch but build a kernel module
- Separate Compilation
- Runtime-Linkage
- Entry and Exit Functions
  - Run in Process Context
- LKM “Hello-World”

```
#define MODULE

#define LINUX

#define __KERNEL__

#include <linux/module.h> #include
   <linux/kernel.h> #include
   <linux/init.h>

static int __init myinit(void)
{
   printk(KERN_ALERT ”Hello, world\n”);
   Return 0;
}

static void __exit myexit(void)
{
   printk(KERN_ALERT ”Goodbye,
   world\n”);
}

module_init(myinit);
module_exit(myexit);
MODULE_LICENSE(”GPL”);
```

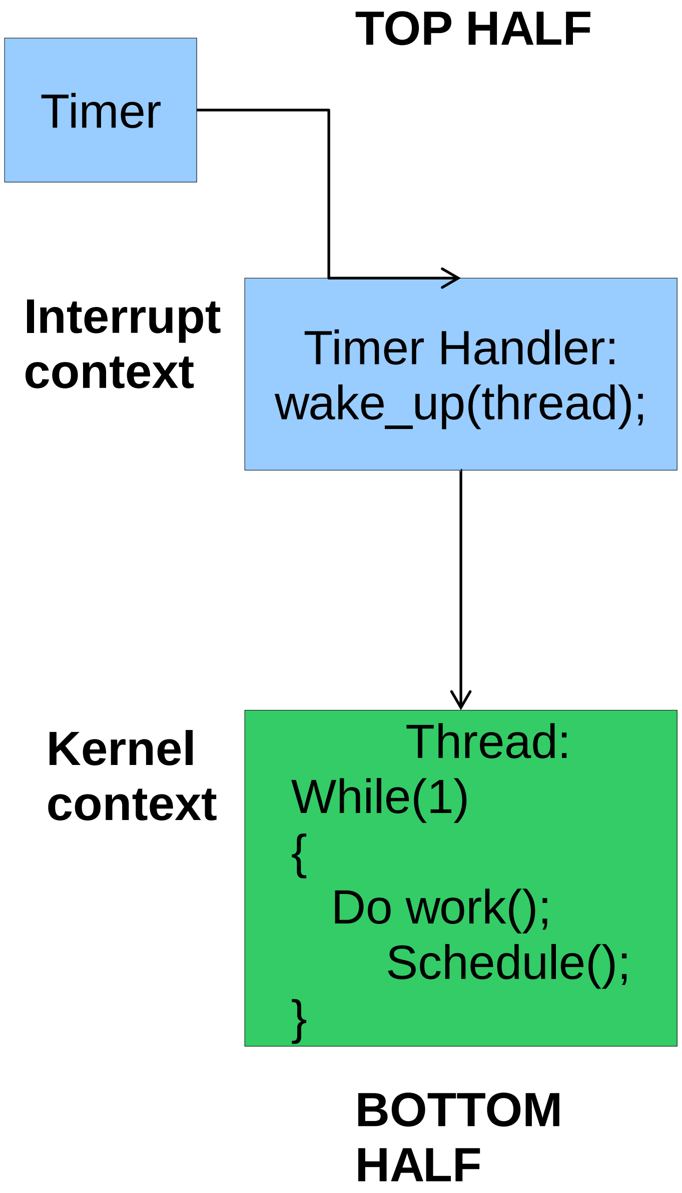
Jiffies and The Kernel Loop

- The Linux kernel uses the concept of jiffies to measure time
- Inside the kernel there is a loop to measure time and preempt tasks
- A jiffy is the period at which the timer in this loop is triggered
  - Varies from system to system 100 Hz, 250 Hz, 1000 Hz.
  - Use the variable HZ to get the value.
- The schedule function is the function that preempts tasks

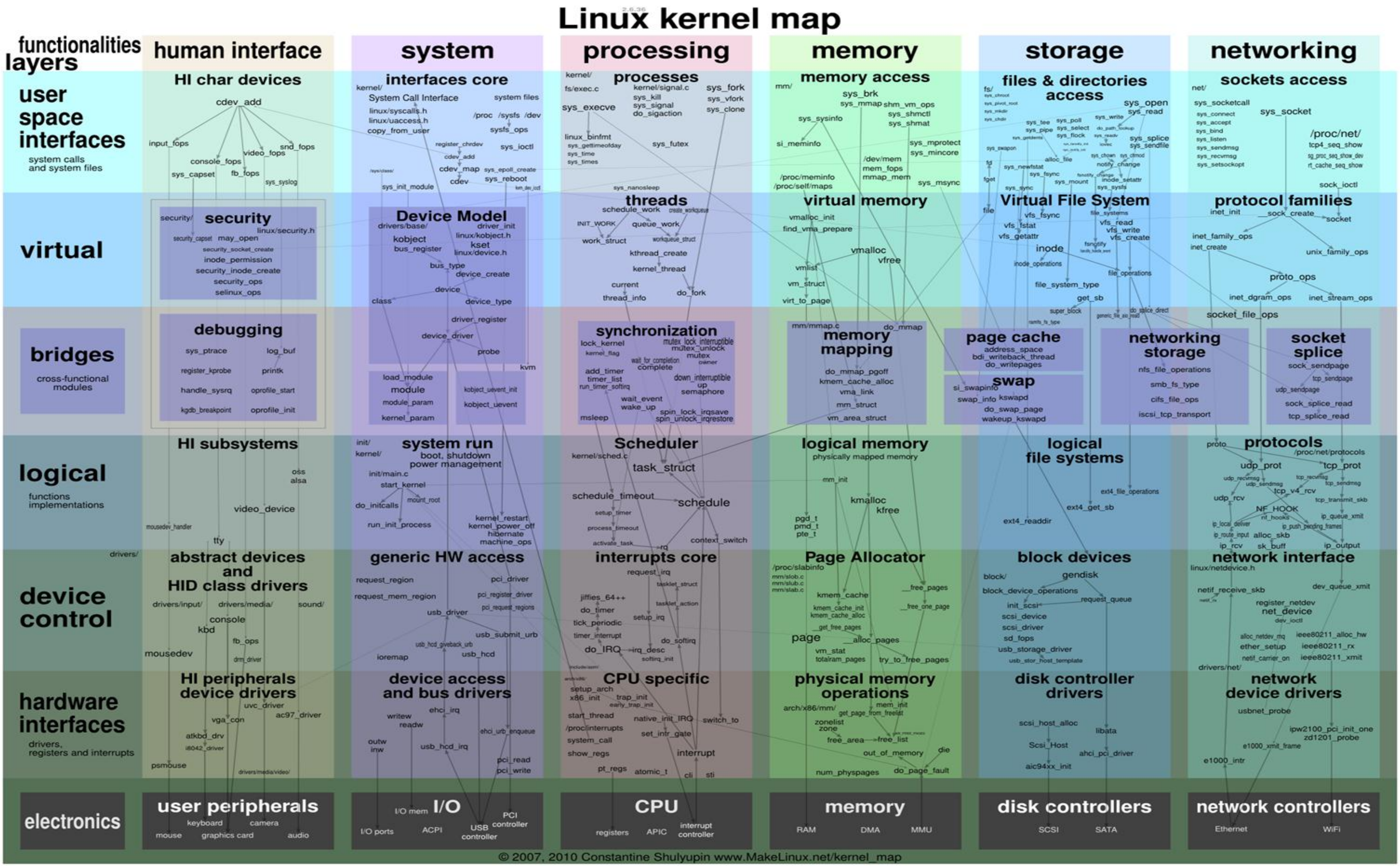


Deferring Work / Two Halves

- Kernel Timers are used to create timed events
- They use jiffies to measure time
- Timers are interrupts
  - We can't sleep or hog CPU in them!
- Solution: Divide the work in two parts
  - Use the timer handler to signal a thread. (TOP HALF)
  - Let the kernel thread do the real job. (BOTTOM HALF)



Linux Kernel Map



Optimizing Performance

- Minimize copying
- Use good data structures
- Optimize the common case
  - Branch optimization: likely(), unlikely()
- Avoid process migration or cache misses
  - Avoid dynamic assignment of interrupts to different CPUs
- Combine Operations within the same layer to minimize passes to the data
  - e.g: Checksum + data copying

Optimizing Performance

- Cache/Reuse as much as you can
  - Cache Headers, SLAB allocator
- Hierarchical Design + Information Hiding
  - Data encapsulation
- Separation of concerns
- Interrupt Moderation/Mitigation
  - Group Timers if possible

Conclusion

- The Linux kernel has 3 main contexts: Kernel, Process and Interrupt.
- Use spinlock for interrupt context and mutexes if you plan to sleep holding the lock
- Implement a module avoid patching the kernel main tree
- To defer work implement two halves. Timers + Threads

References

- Linux Kernel Map http://www.makelinux.net/kernel_map
- Linux Kernel Cross Reference Source
- R. Love, Linux Kernel Development , 2nd Edition, Novell Press, 2006