Linux Kernel Hacking Free Course, 3rd edition

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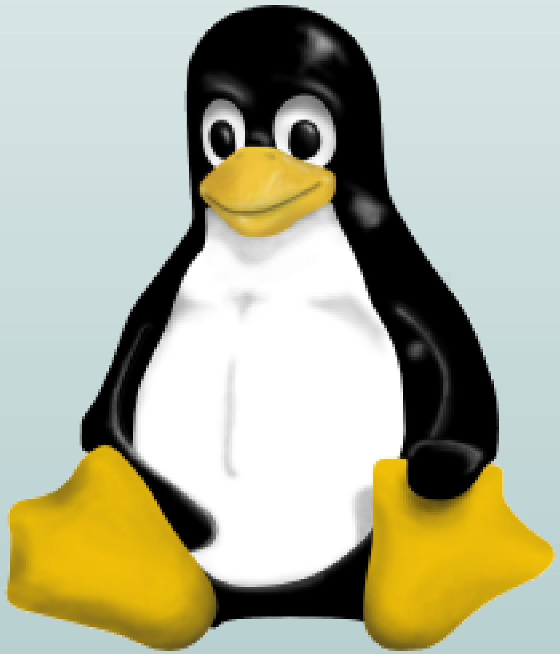
An introduction to Linux



January 18, 2006

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- from the Open Software Foundation website: *Variants of the GNU operating system, which use the kernel Linux, are now widely used; though these systems are often referred to as Linux, they are more accurately called GNU/Linux system*

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- In the IA-32 computers, the 16-bit Code Segment register contains 2 bits that can encode up to 4 different privilege levels: level 0 (most privileged), level 1, level 2, level 3 (less privileged)

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- Linux uses only 2 privilege levels called *User Mode* and *Kernel Mode*

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- A program in Kernel Mode can put the CPU back in User Mode by executing the `iret` (Interrupt Return) instruction

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  - It does not have a single entry point; a different entry point must be provided for every type of interrupt recognized by the kernel
  - The kernel image produced by the gcc linker cannot be loaded as any other executable file, simply because the loader is not available when booting the system: a more rudimentary technique based on bootstrapping must be used

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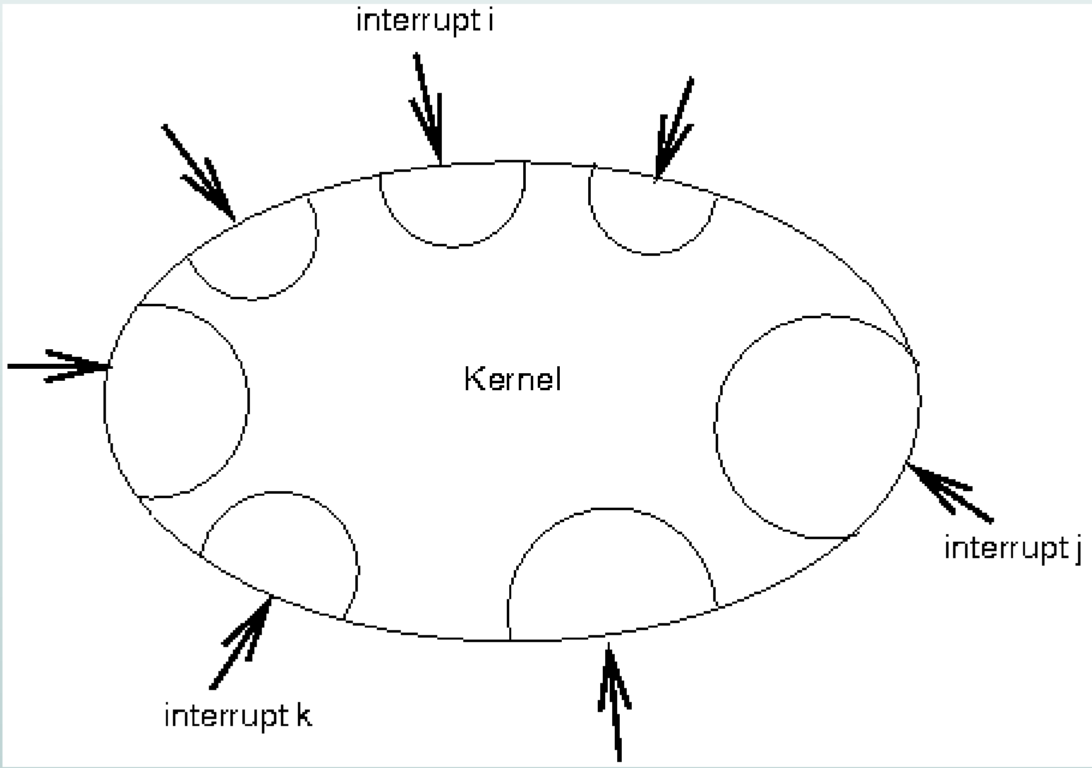

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- To improve portability to new hardware platforms, the architecture-dependent code is placed in the `linux/arch` directory
- A symbolic link called `linux/include/asm` identifies all the architecture-dependent header files for a given hardware platform

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  - the `__attribute__((regparm(3))` function qualifier to pass up to 3 integer parameters using registers instead of the stack (macro `FASTCALL(x)`)

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- The syntax of Extended Inline Assembly is not obvious

An example of Extended Inline Assembly code

```
static inline int _raw_spin_trylock(spinlock_t *lock)
{
        char oldval;
        __asm__ __volatile__(
                "xchgb %b0,%1"
                :"=q" (oldval), "=m" (lock->slock)
                :"0" (0) : "memory");
        return oldval > 0;
}
```

Expanding the example of Extended Inline Assembly code

```
        xorl %eax, %eax
#APP
        xchgb %al,-4(%ebp)  ; lock variable stored in -4(%ebp)
#NO_APP
        testb %al, %al
        setg %al
        andl $255, %eax
```

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- When linking the kernel, gcc creates a `System.map` file which lists the addresses assigned to all global kernel symbols. This file is used by debuggers and kernel profilers

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- Linux 2.6.11 (2005) includes roughly 6 million lines of code

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A process is traditionally defined as an instance of a program in execution (or, shortly, an execution context)

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- A kernel thread is a process that runs only in Kernel Mode, that is, it never executes code of users' applications

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The `current` macro yields the address of the descriptor relative to the process currently executed by the CPU

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• Terminated	`EXIT_ZOMBIE`, `EXIT_DEAD`

Processes in state `TASK_INTERRUPTIBLE` or `TASK_UNINTERRUPTIBLE` are equivalently said to be *sleeping* or *blocked*

The double life of processes

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Often we say something like: "*the kernel is doing this and that...*"; however, we must never forget that there is always a current process in execution!

Process address space

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When running in Kernel Mode every process makes use of linear addresses in the fourth gigabyte (above `0xc0000000`); the mapping of these "kernel" linear addresses is identical for all processes

Process context and interrupt context

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While in interrupt context, the kernel cannot make any assumption on the process that is currently in execution. In particular, the kernel cannot

- perform a process switch (thus, it cannot start blocking operations)
- reference memory by means of linear addresses below the fourth gigabyte

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- timer functions: timers allow to execute arbitrary functions after predefined delays

Scheduling processes

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Actually, some processes (the so-called real-time processes) are not handled with the time sharing policy, but with a priority-based FIFO or Round-Robin policy

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Starting from version 2.6, kernel preemption can be enabled or disabled when compiling the kernel

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The virtual memory subsystem works in chunks of RAM called *pages*

In IA-32, each page is 4096 bytes long

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The bottom line is: at any given instant there are several processes in execution

Support to multiprocessor systems

Several kernel components, such as the scheduler and the memory allocator, behave differently according to the type of multiprocessor system:

- Intel CPUs with Hyper-Threading Technology (several logical processing units on the same chip)
- Multicore chips (several physical processing units, each with its hardware caches, on the same chip)
- Non-uniform Memory Access (NUMA) systems (several CPUs, each having its own local physical memory)

The bottom line is: at any given instant there are several processes in execution

Synchronization, or how to make order out of chaos

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The Linux kernel sports a large number of synchronization primitives: atomic operations, memory barriers, interrupt disabling, deferrable function disabling, per-CPU data, semaphores, read/write semaphores, spin locks, read/write spin locks, Read-Copy-Update (RCU), seqlocks, mutexes (in the forthcoming version 2.6.16), and others

Device driver developer’s easy receipt for synchronization

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1. semaphores (or better mutexes, when they will be available)

2. spin locks (optionally coupled with interrupt disabling)

Semaphores

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Basically, a semaphore cannot be used in interrupt context!

Using a semaphore as a MUTEX

To allocate a semaphore to be used as a MUTEX (one process at a time):

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To release the semaphore:

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up(&foo_semaphore);
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Therefore, a process waiting for a spin lock is never blocked! (However, if the kernel is preemptive, the process may be replaced by another runnable process)

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- The kernel automatically disables the kernel preemption once a spin lock has been acquired
- In uniprocessor systems, the atomic variable is not really useful: when compiling for uniprocessor systems, that variable is simply optimized away (but spin lock primitives are still necessary!)

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To allocate and initialize a spin lock:

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spin_lock_irqsave(&foo_lock, flags);
```
[locked]

To release the spin lock and restore the previous interrupt status:

```
spin_unlock_irqrestore(&foo_lock, flags);
```
[unlocked]