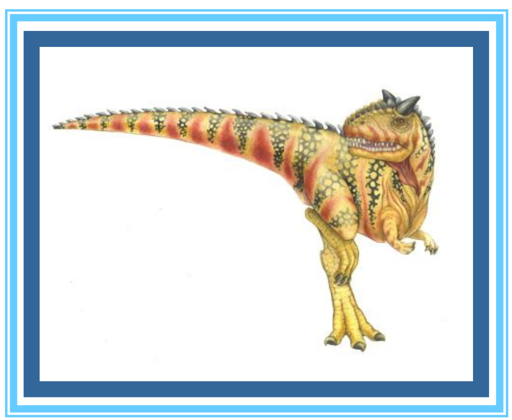
Chapter 18: The Linux System



Chapter 18: The Linux System

- Linux History
- Design Principles
- Kernel Modules
- Process Management
- Scheduling
- Memory Management
- File Systems
- Input and Output
- Interprocess Communication
- Network Structure
- Security

Objectives

To explore the history of the UNIX operating system from which Linux is derived and the principles upon which Linux's design is based

To examine the Linux process model and illustrate how Linux schedules processes and provides interprocess communication

To look at memory management in Linux

To explore how Linux implements file systems and manages I/O devices

History

- Linux is a modern, free operating system based on UNIX standards
- First developed as a small but self-contained kernel in 1991 by Linus Torvalds, with the major design goal of UNIX compatibility, released as open source
- Its history has been one of collaboration by many users from all around the world, corresponding almost exclusively over the Internet
- It has been designed to run efficiently and reliably on common PC hardware, but also runs on a variety of other platforms
- The core Linux operating system **kernel** is entirely original, but it can run much existing free UNIX software, resulting in an entire UNIX-compatible operating system free from proprietary code
- **Linux system** has many, varying **Linux distributions** including the kernel, applications, and management tools

The Linux Kernel

- Version 0.01 (May 1991) had no networking, ran only on 80386-compatible Intel processors and on PC hardware, had extremely limited device-drive support, and supported only the Minix file system
- Linux 1.0 (March 1994) included these new features:
  - Support for UNIX's standard TCP/IP networking protocols
  - BSD-compatible socket interface for networking programming
  - Device-driver support for running IP over an Ethernet
  - Enhanced file system
  - Support for a range of SCSI controllers for high-performance disk access
  - Extra hardware support
- Version 1.2 (March 1995) was the final PC-only Linux kernel
- Kernels with odd version numbers are **development kernels**, those with even numbers are **production kernels**

Linux 2.0

- Released in June 1996, 2.0 added two major new capabilities:
  - Support for multiple architectures, including a fully 64-bit native Alpha port
  - Support for multiprocessor architectures
- Other new features included:
  - Improved memory-management code
  - Improved TCP/IP performance
  - Support for internal kernel threads, for handling dependencies between loadable modules, and for automatic loading of modules on demand
  - Standardized configuration interface
- Available for Motorola 68000-series processors, Sun Sparc systems, and for PC and PowerMac systems
- 2.4 and 2.6 increased SMP support, added journaling file system, preemptive kernel, 64-bit memory support
- 3.0 released in 2011, 20th anniversary of Linux, improved virtualization support, new page write-back facility, improved memory management, new Completely Fair Scheduler

The Linux System

Linux uses many tools developed as part of Berkeley's BSD operating system, MIT's X Window System, and the Free Software Foundation's GNU project

The main system libraries were started by the GNU project, with improvements provided by the Linux community

Linux networking-administration tools were derived from 4.3BSD code; recent BSD derivatives such as Free BSD have borrowed code from Linux in return

The Linux system is maintained by a loose network of developers collaborating over the Internet, with a small number of public ftp sites acting as de facto standard repositories

File System Hierarchy Standard document maintained by the Linux community to ensure compatibility across the various system components

- Specifies overall layout of a standard Linux file system, determines under which directory names configuration files, libraries, system binaries, and run-time data files should be stored

Linux Distributions

- Standard, precompiled sets of packages, or **distributions**, include the basic Linux system, system installation and management utilities, and ready-to-install packages of common UNIX tools
- The first distributions managed these packages by simply providing a means of unpacking all the files into the appropriate places; modern distributions include advanced package management
- Early distributions included SLS and Slackware
  - **Red Hat** and **Debian** are popular distributions from commercial and noncommercial sources, respectively, others include **Canonical** and **SuSE**
- The RPM Package file format permits compatibility among the various Linux distributions

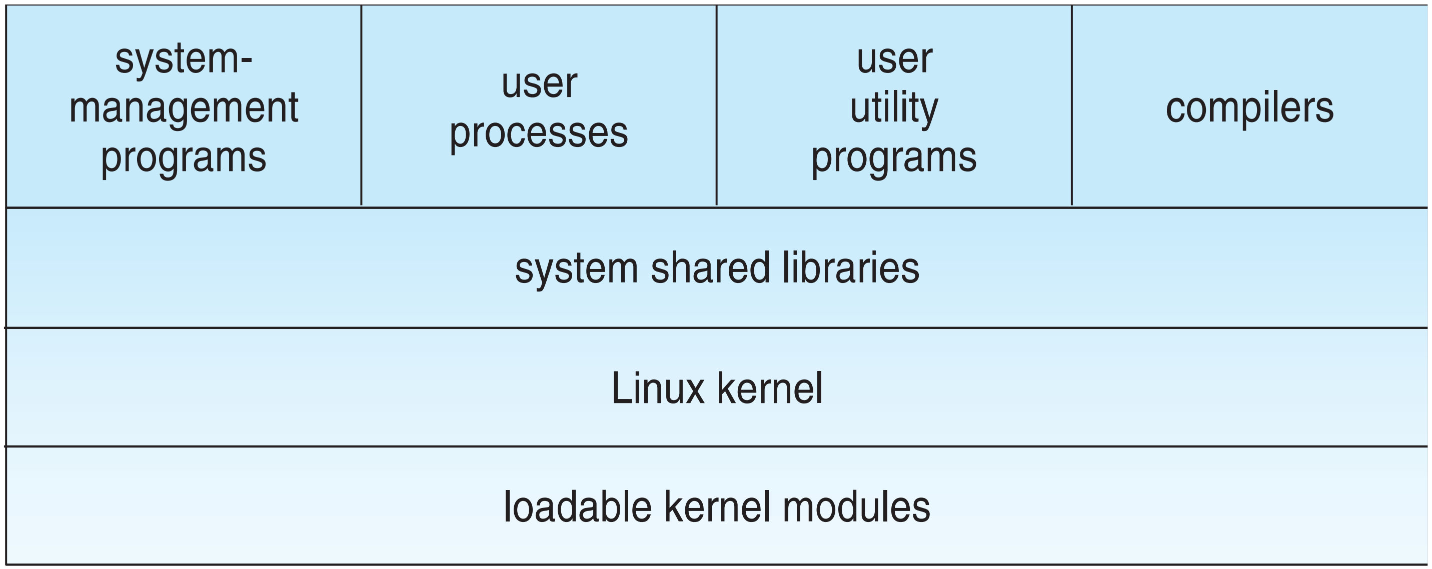
Linux Licensing

- The Linux kernel is distributed under the GNU General Public License (GPL), the terms of which are set out by the Free Software Foundation
  - Not **public domain**, in that not all rights are waived
- Anyone using Linux, or creating their own derivative of Linux, may not make the derived product proprietary; software released under the GPL may not be redistributed as a binary-only product
  - Can sell distributions, but must offer the source code too

Design Principles

- Linux is a multiuser, multitasking system with a full set of UNIX-compatible tools
- Its file system adheres to traditional UNIX semantics, and it fully implements the standard UNIX networking model
- Main design goals are speed, efficiency, and standardization
- Linux is designed to be compliant with the relevant POSIX documents; at least two Linux distributions have achieved official POSIX certification
  - Supports Pthreads and a subset of POSIX real-time process control
- The Linux programming interface adheres to the SVR4 UNIX semantics, rather than to BSD behavior

Components of a Linux System



Components of a Linux System

- Like most UNIX implementations, Linux is composed of three main bodies of code; the most important distinction between the kernel and all other components.
- The **kernel** is responsible for maintaining the important abstractions of the operating system
  - Kernel code executes in *kernel mode* with full access to all the physical resources of the computer
  - All kernel code and data structures are kept in the same single address space

Components of a Linux System (Cont.)

- The **system libraries** define a standard set of functions through which applications interact with the kernel, and which implement much of the operating-system functionality that does not need the full privileges of kernel code
- The **system utilities** perform individual specialized management tasks
- User-mode programs rich and varied, including multiple **shells** like the **bourne-again** (**bash**)

Kernel Modules

Sections of kernel code that can be compiled, loaded, and unloaded independent of the rest of the kernel.

A kernel module may typically implement a device driver, a file system, or a networking protocol

The module interface allows third parties to write and distribute, on their own terms, device drivers or file systems that could not be distributed under the GPL.

Kernel modules allow a Linux system to be set up with a standard, minimal kernel, without any extra device drivers built in.

Four components to Linux module support:

- **module-management system**
- **module loader and unloader**
- **driver-registration system**
- **conflict-resolution mechanism**

Module Management

- Supports loading modules into memory and letting them talk to the rest of the kernel
- Module loading is split into two separate sections:
  - Managing sections of module code in kernel memory
  - Handling symbols that modules are allowed to reference
- The module requestor manages loading requested, but currently unloaded, modules; it also regularly queries the kernel to see whether a dynamically loaded module is still in use, and will unload it when it is no longer actively needed

Driver Registration

- Allows modules to tell the rest of the kernel that a new driver has become available
- The kernel maintains dynamic tables of all known drivers, and provides a set of routines to allow drivers to be added to or removed from these tables at any time
- Registration tables include the following items:
  - Device drivers
  - File systems
  - Network protocols
  - Binary format

Conflict Resolution

A mechanism that allows different device drivers to reserve hardware resources and to protect those resources from accidental use by another driver.

The conflict resolution module aims to:

- Prevent modules from clashing over access to hardware resources
- Prevent **autoprobes** from interfering with existing device drivers
- Resolve conflicts with multiple drivers trying to access the same hardware:
  1. Kernel maintains list of allocated HW resources
  2. Driver reserves resources with kernel database first
  3. Reservation request rejected if resource not available

Process Management

- UNIX process management separates the creation of processes and the running of a new program into two distinct operations.
  - The `fork()` system call creates a new process
  - A new program is run after a call to `exec()`
- Under UNIX, a process encompasses all the information that the operating system must maintain to track the context of a single execution of a single program
- Under Linux, process properties fall into three groups: the process's identity, environment, and context

Process Identity

Process ID (PID) - The unique identifier for the process; used to specify processes to the operating system when an application makes a system call to signal, modify, or wait for another process

Credentials - Each process must have an associated user ID and one or more group IDs that determine the process's rights to access system resources and files

Personality - Not traditionally found on UNIX systems, but under Linux each process has an associated personality identifier that can slightly modify the semantics of certain system calls

- Used primarily by emulation libraries to request that system calls be compatible with certain specific flavors of UNIX

Namespace – Specific view of file system hierarchy

- Most processes share common namespace and operate on a shared file-system hierarchy
- But each can have unique file-system hierarchy with its own root directory and set of mounted file systems

Process Environment

The process's environment is inherited from its parent, and is composed of two null-terminated vectors:

The **argument vector** lists the command-line arguments used to invoke the running program; conventionally starts with the name of the program itself.

The **environment vector** is a list of "NAME=VALUE" pairs that associates named environment variables with arbitrary textual values.

Passing environment variables among processes and inheriting variables by a process's children are flexible means of passing information to components of the user-mode system software.

The environment-variable mechanism provides a customization of the operating system that can be set on a per-process basis, rather than being configured for the system as a whole.

Process Context

- The (constantly changing) state of a running program at any point in time
- The **scheduling context** is the most important part of the process context; it is the information that the scheduler needs to suspend and restart the process
- The kernel maintains **accounting** information about the resources currently being consumed by each process, and the total resources consumed by the process in its lifetime so far
- The **file table** is an array of pointers to kernel file structures
  - When making file I/O system calls, processes refer to files by their index into this table, the **file descriptor** (**fd**)

Process Context (Cont.)

- Whereas the file table lists the existing open files, the **file-system context** applies to requests to open new files
  - The current root and default directories to be used for new file searches are stored here
- The **signal-handler table** defines the routine in the process's address space to be called when specific signals arrive
- The **virtual-memory context** of a process describes the full contents of the its private address space

Processes and Threads

- Linux uses the same internal representation for processes and threads; a thread is simply a new process that happens to share the same address space as its parent
  - Both are called ***tasks*** by Linux
- A distinction is only made when a new thread is created by the `clone()` system call
  - `fork()` creates a new task with its own entirely new task context
  - `clone()` creates a new task with its own identity, but that is allowed to share the data structures of its parent
- Using `clone()` gives an application fine-grained control over exactly what is shared between two threads

flag	meaning
`CLONE_FS`	File-system information is shared.
`CLONE_VM`	The same memory space is shared.
`CLONE_SIGHAND`	Signal handlers are shared.
`CLONE_FILES`	The set of open files is shared.

Scheduling

- The job of allocating CPU time to different tasks within an operating system
- While scheduling is normally thought of as the running and interrupting of processes, in Linux, scheduling also includes the running of the various kernel tasks
- Running kernel tasks encompasses both tasks that are requested by a running process and tasks that execute internally on behalf of a device driver
- As of 2.5, new scheduling algorithm – preemptive, priority-based, known as *O*(1)
  - Real-time range
  - nice value
  - Had challenges with interactive performance
- 2.6 introduced **Completely Fair Scheduler** (**CFS**)

CFS

- Eliminates traditional, common idea of time slice
- Instead all tasks allocated portion of processor's time
- CFS calculates how long a process should run as a function of total number of tasks
- *N* runnable tasks means each gets 1/*N* of processor's time
- Then weights each task with its nice value
  - Smaller nice value -> higher weight (higher priority)

CFS (Cont.)

Then each task run with for time proportional to task's weight divided by total weight of all runnable tasks

Configurable variable **target latency** is desired interval during which each task should run at least once

- Consider simple case of 2 runnable tasks with equal weight and target latency of 10ms – each then runs for 5ms
  - If 10 runnable tasks, each runs for 1ms
  - **Minimum granularity** ensures each run has reasonable amount of time (which actually violates fairness idea)

Kernel Synchronization

A request for kernel-mode execution can occur in two ways:

- A running program may request an operating system service, either explicitly via a system call, or implicitly, for example, when a page fault occurs
- A device driver may deliver a hardware interrupt that causes the CPU to start executing a kernel-defined handler for that interrupt

Kernel synchronization requires a framework that will allow the kernel’s critical sections to run without interruption by another critical section

Kernel Synchronization (Cont.)

Linux uses two techniques to protect critical sections:

1. Normal kernel code is nonpreemptible (until 2.6)
   – when a time interrupt is received while a process is executing a kernel system service routine, the kernel's **need_resched** flag is set so that the scheduler will run once the system call has completed and control is about to be returned to user mode

2. The second technique applies to critical sections that occur in an interrupt service routines

   – By using the processor's interrupt control hardware to disable interrupts during a critical section, the kernel guarantees that it can proceed without the risk of concurrent access of shared data structures

   Provides spin locks, semaphores, and reader-writer versions of both

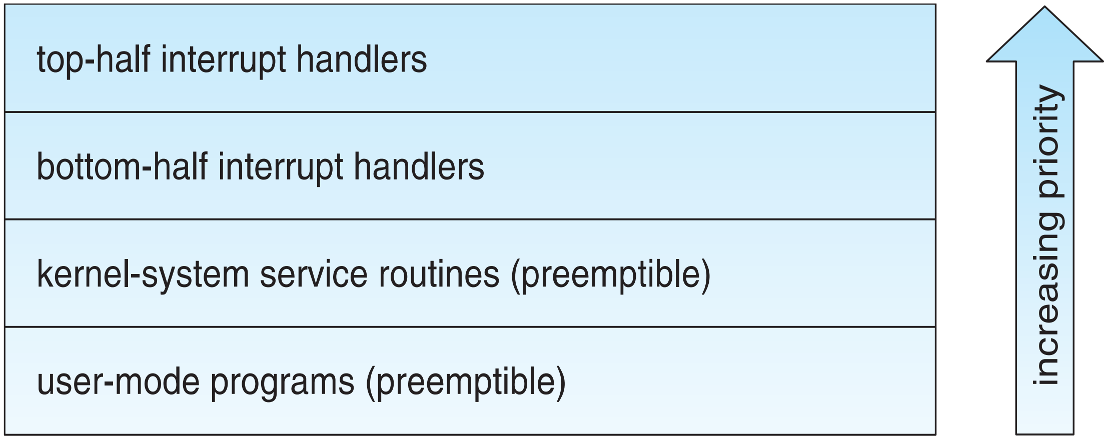
   - Behavior modified if on single processor or multi:

single processor	multiple processors
Disable kernel preemption.	Acquire spin lock.
Enable kernel preemption.	Release spin lock.

Kernel Synchronization (Cont.)

- To avoid performance penalties, Linux's kernel uses a synchronization architecture that allows long critical sections to run without having interrupts disabled for the critical section's entire duration
- Interrupt service routines are separated into a *top half* and a *bottom half*
  - The top half is a normal interrupt service routine, and runs with recursive interrupts disabled
  - The bottom half is run, with all interrupts enabled, by a miniature scheduler that ensures that bottom halves never interrupt themselves
  - This architecture is completed by a mechanism for disabling selected bottom halves while executing normal, foreground kernel code

Interrupt Protection Levels



Each level may be interrupted by code running at a higher level, but will never be interrupted by code running at the same or a lower level

User processes can always be preempted by another process when a time-sharing scheduling interrupt occurs

Symmetric Multiprocessing

- Linux 2.0 was the first Linux kernel to support **SMP** hardware; separate processes or threads can execute in parallel on separate processors
- Until version 2.2, to preserve the kernel's nonpreemptible synchronization requirements, SMP imposes the restriction, via a single kernel spinlock, that only one processor at a time may execute kernel-mode code
- Later releases implement more scalability by splitting single spinlock into multiple locks, each protecting a small subset of kernel data structures
- Version 3.0 adds even more fine-grained locking, processor affinity, and load-balancing

Memory Management

- Linux's physical memory-management system deals with allocating and freeing pages, groups of pages, and small blocks of memory
- It has additional mechanisms for handling virtual memory, memory mapped into the address space of running processes
- Splits memory into four different **zones** due to hardware characteristics
  - Architecture specific, for example on x86:

zone	physical memory
ZONE_DMA	< 16 MB
ZONE_NORMAL	16 .. 896 MB
ZONE_HIGHMEM	> 896 MB

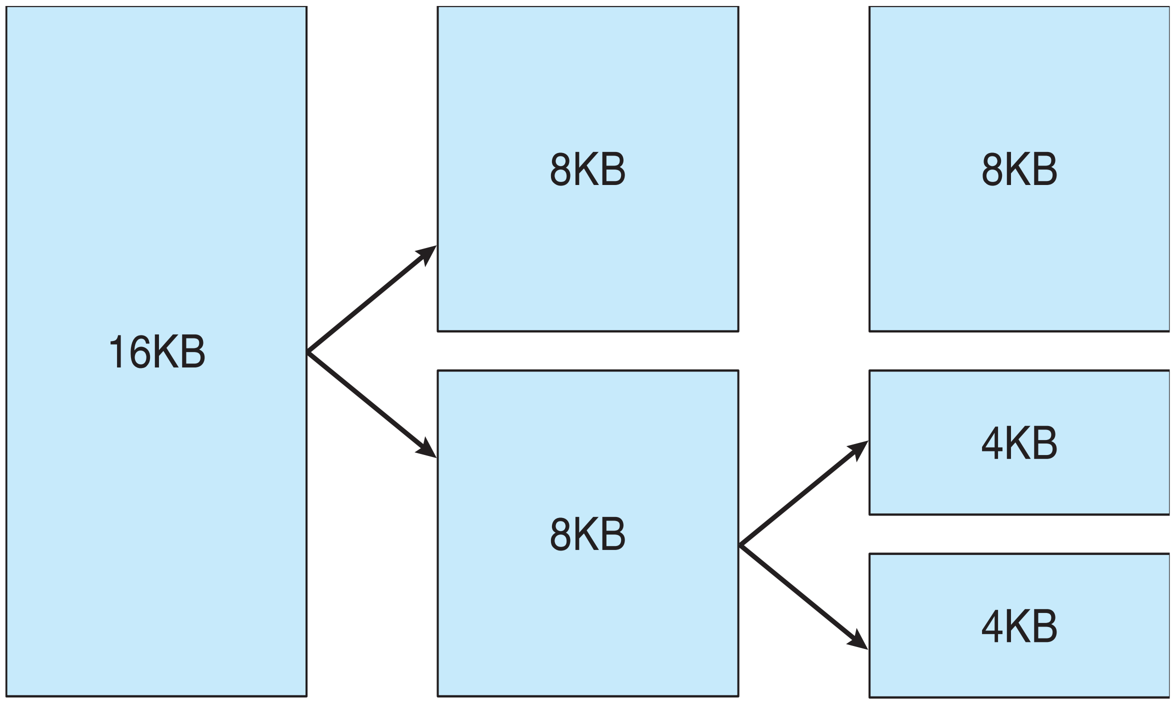
Managing Physical Memory

- The page allocator allocates and frees all physical pages; it can allocate ranges of physically-contiguous pages on request
- The allocator uses a buddy-heap algorithm to keep track of available physical pages
  - Each allocatable memory region is paired with an adjacent partner
  - Whenever two allocated partner regions are both freed up they are combined to form a larger region
  - If a small memory request cannot be satisfied by allocating an existing small free region, then a larger free region will be subdivided into two partners to satisfy the request

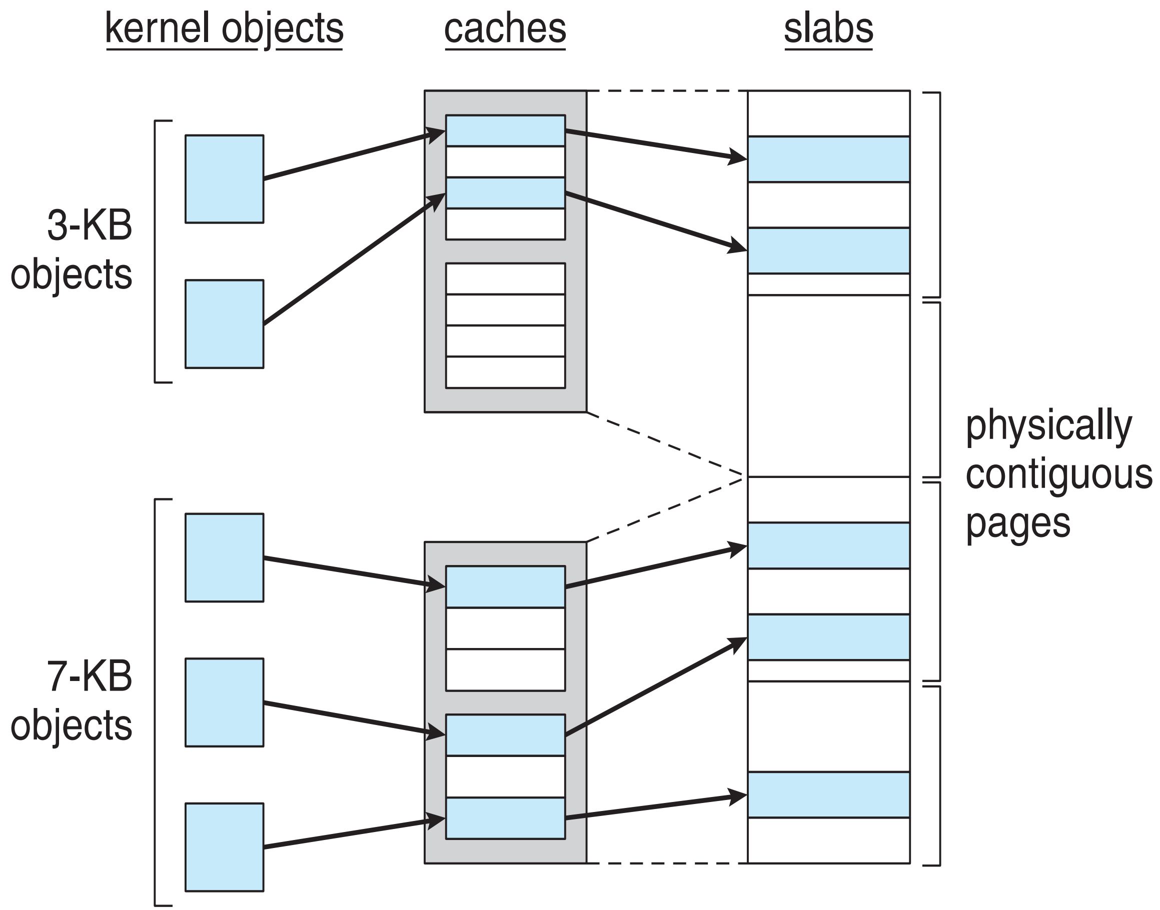
Managing Physical Memory (Cont.)

- Memory allocations in the Linux kernel occur either statically (drivers reserve a contiguous area of memory during system boot time) or dynamically (via the page allocator)
- Also uses **slab allocator** for kernel memory
- **Page cache** and virtual memory system also manage physical memory
  - Page cache is kernel's main cache for files and main mechanism for I/O to block devices
  - Page cache stores entire pages of file contents for local and network file I/O

Splitting of Memory in a Buddy Heap



Slab Allocator in Linux



Virtual Memory

The VM system maintains the address space visible to each process: It creates pages of virtual memory on demand, and manages the loading of those pages from disk or their swapping back out to disk as required.

The VM manager maintains two separate views of a process's address space:

- A logical view describing instructions concerning the layout of the address space
  - The address space consists of a set of non-overlapping regions, each representing a continuous, page-aligned subset of the address space
- A physical view of each address space which is stored in the hardware page tables for the process

Virtual Memory (Cont.)

Virtual memory regions are characterized by:

- The backing store, which describes from where the pages for a region come; regions are usually backed by a file or by nothing (**demand-zero memory**)
- The region's reaction to writes (page sharing or copy-on-write

The kernel creates a new virtual address space

1. When a process runs a new program with the `exec()` system call
2. Upon creation of a new process by the `fork()` system call

Virtual Memory (Cont.)

- On executing a new program, the process is given a new, completely empty virtual-address space; the program-loading routines populate the address space with virtual-memory regions
- Creating a new process with `fork()` involves creating a complete copy of the existing process's virtual address space
  - The kernel copies the parent process's VMA descriptors, then creates a new set of page tables for the child
  - The parent's page tables are copied directly into the child's, with the reference count of each page covered being incremented
  - After the fork, the parent and child share the same physical pages of memory in their address spaces

Swapping and Paging

- The VM paging system relocates pages of memory from physical memory out to disk when the memory is needed for something else
- The VM paging system can be divided into two sections:
  - The **pageout-policy** algorithm decides which pages to write out to disk, and when
  - The **paging mechanism** actually carries out the transfer, and pages data back into physical memory as needed
  - Can page out to either swap device or normal files
  - Bitmap used to track used blocks in swap space kept in physical memory
  - Allocator uses next-fit algorithm to try to write contiguous runs

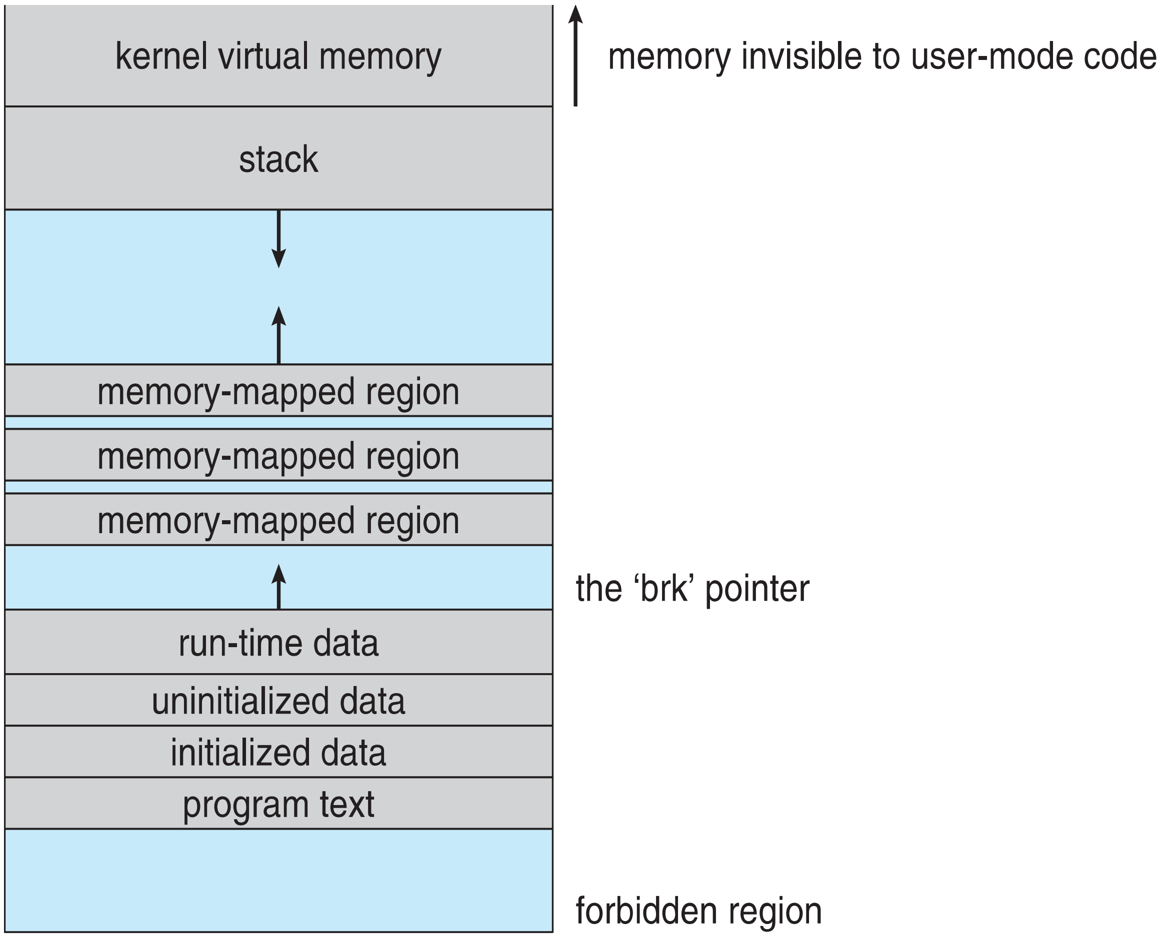
Kernel Virtual Memory

- The Linux kernel reserves a constant, architecture-dependent region of the virtual address space of every process for its own internal use
- This kernel virtual-memory area contains two regions:
  - A static area that contains page table references to every available physical page of memory in the system, so that there is a simple translation from physical to virtual addresses when running kernel code
  - The reminder of the reserved section is not reserved for any specific purpose; its page-table entries can be modified to point to any other areas of memory

Executing and Loading User Programs

- Linux maintains a table of functions for loading programs; it gives each function the opportunity to try loading the given file when an exec system call is made
- The registration of multiple loader routines allows Linux to support both the **ELF** and **a.out** binary formats
- Initially, binary-file pages are mapped into virtual memory
  - Only when a program tries to access a given page will a page fault result in that page being loaded into physical memory
- An ELF-format binary file consists of a header followed by several page-aligned sections
  - The ELF loader works by reading the header and mapping the sections of the file into separate regions of virtual memory

Memory Layout for ELF Programs



Static and Dynamic Linking

A program whose necessary library functions are embedded directly in the program's executable binary file is ***statically*** linked to its libraries

The main disadvantage of static linkage is that every program generated must contain copies of exactly the same common system library functions

Dynamic linking is more efficient in terms of both physical memory and disk-space usage because it loads the system libraries into memory only once

Static and Dynamic Linking (Cont.)

- Linux implements dynamic linking in user mode through special linker library
  - Every dynamically linked program contains small statically linked function called when process starts
  - Maps the link library into memory
  - Link library determines dynamic libraries required by process and names of variables and functions needed
  - Maps libraries into middle of virtual memory and resolves references to symbols contained in the libraries
  - Shared libraries compiled to be **position-independent code** (**PIC**) so can be loaded anywhere

File Systems

To the user, Linux's file system appears as a hierarchical directory tree obeying UNIX semantics

Internally, the kernel hides implementation details and manages the multiple different file systems via an abstraction layer, that is, the virtual file system (VFS)

The Linux VFS is designed around object-oriented principles and is composed of four components:

A set of definitions that define what a file object is allowed to look like

- The **inode object** structure represent an individual file
- The **file object** represents an open file
- The **superblock object** represents an entire file system
- A **dentry object** represents an individual directory entry

File Systems (Cont.)

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- The Linux VFS is designed around object-oriented principles and layer of software to manipulate those objects with a set of operations on the objects
  - For example for the file object operations include (from struct file_operations in /usr/include/linux/fs.h
    - int open(. . .) — Open a file
    - ssize t read(. . .) — Read from a file
    - ssize t write(. . .) — Write to a file
    - int mmap(. . .) — Memory-map a file

The Linux ext3 File System

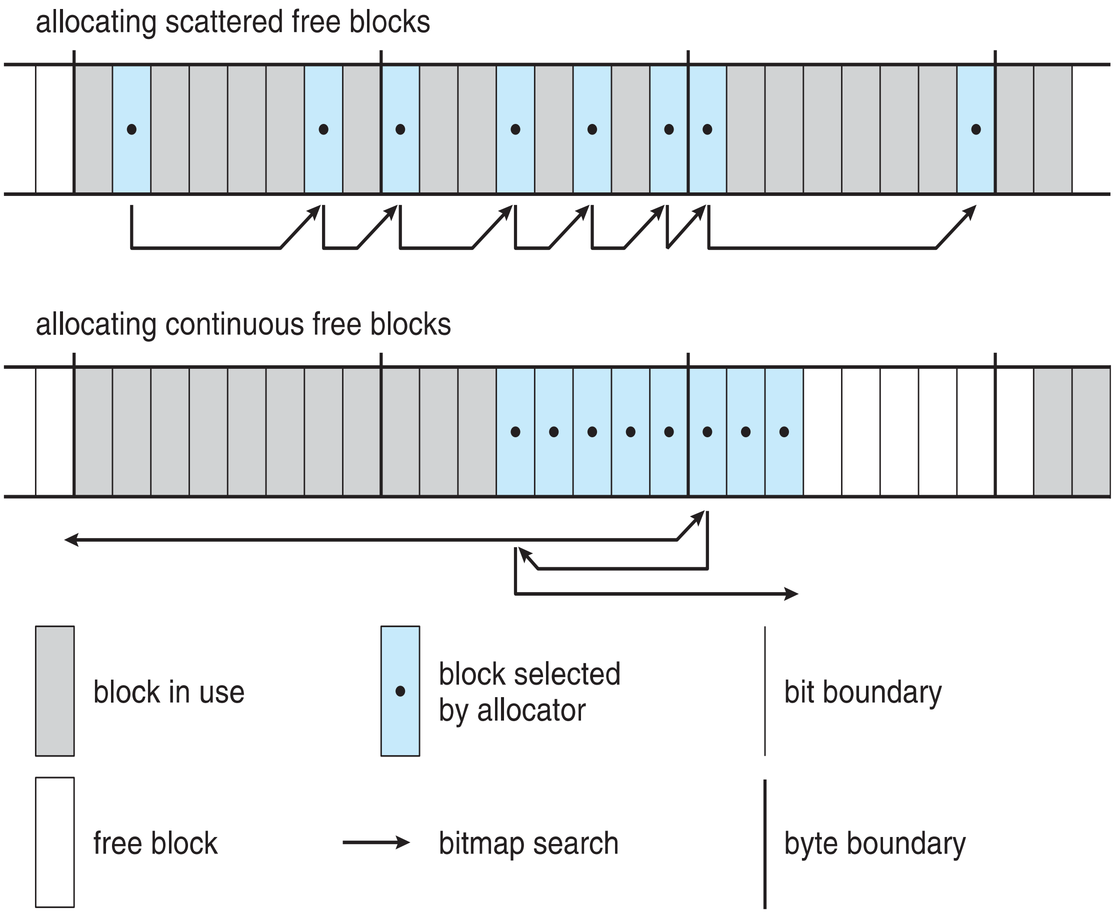
- **ext3** is standard on disk file system for Linux
  - Uses a mechanism similar to that of BSD Fast File System (FFS) for locating data blocks belonging to a specific file
  - Supersedes older **extfs**, **ext2** file systems
  - Work underway on ext4 adding features like extents
  - Of course, many other file system choices with Linux distros

The Linux ext3 File System (Cont.)

The main differences between ext2fs and FFS concern their disk allocation policies

- In ffs, the disk is allocated to files in blocks of 8Kb, with blocks being subdivided into fragments of 1Kb to store small files or partially filled blocks at the end of a file
- ext3 does not use fragments; it performs its allocations in smaller units
  - The default block size on ext3 varies as a function of total size of file system with support for 1, 2, 4 and 8 KB blocks
- ext3 uses cluster allocation policies designed to place logically adjacent blocks of a file into physically adjacent blocks on disk, so that it can submit an I/O request for several disk blocks as a single operation on a **block group**
- Maintains bit map of free blocks in a block group, searches for free byte to allocate at least 8 blocks at a time

Ext2fs Block-Allocation Policies



Journaling

- ext3 implements **journaling**, with file system updates first written to a log file in the form of **transactions**
  - Once in log file, considered committed
  - Over time, log file transactions replayed over file system to put changes in place
- On system crash, some transactions might be in journal but not yet placed into file system
  - Must be completed once system recovers
  - No other consistency checking is needed after a crash (much faster than older methods)
- Improves write performance on hard disks by turning random I/O into sequential I/O

The Linux Proc File System

- The **proc file system** does not store data, rather, its contents are computed on demand according to user file I/O requests
- **proc** must implement a directory structure, and the file contents within; it must then define a unique and persistent inode number for each directory and files it contains
  - It uses this inode number to identify just what operation is required when a user tries to read from a particular file inode or perform a lookup in a particular directory inode
  - When data is read from one of these files, **proc** collects the appropriate information, formats it into text form and places it into the requesting process's read buffer

Input and Output

The Linux device-oriented file system accesses disk storage through two caches:

- Data is cached in the page cache, which is unified with the virtual memory system
- Metadata is cached in the buffer cache, a separate cache indexed by the physical disk block

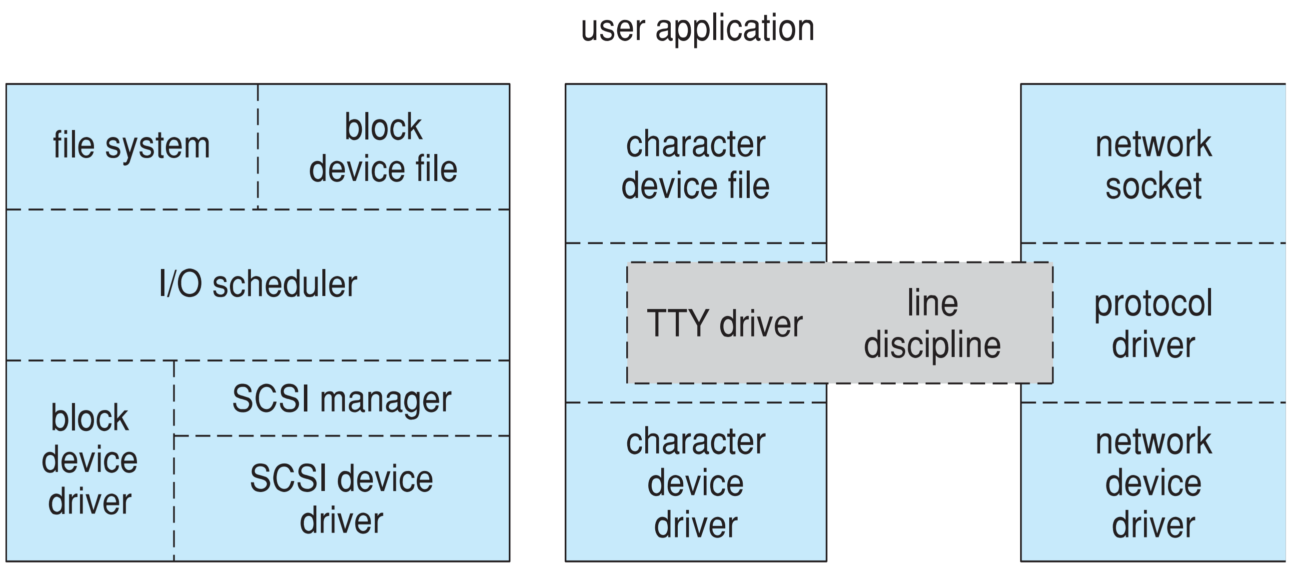
Linux splits all devices into three classes:

- **block devices** allow random access to completely independent, fixed size blocks of data
- **character devices** include most other devices; they don't need to support the functionality of regular files
- **network devices** are interfaced via the kernel's networking subsystem

Block Devices

- Provide the main interface to all disk devices in a system
- The block buffer cache serves two main purposes:
  - it acts as a pool of buffers for active I/O
  - it serves as a cache for completed I/O
- The **request manager** manages the reading and writing of buffer contents to and from a block device driver
- Kernel 2.6 introduced **Completely Fair Queueing** (**CFQ**)
  - Now the default scheduler
  - Fundamentally different from elevator algorithms
  - Maintains set of lists, one for each process by default
  - Uses C-SCAN algorithm, with round robin between all outstanding I/O from all processes
  - Four blocks from each process put on at once

Device-Driver Block Structure



Character Devices

- A device driver which does not offer random access to fixed blocks of data
- A character device driver must register a set of functions which implement the driver's various file I/O operations
- The kernel performs almost no preprocessing of a file read or write request to a character device, but simply passes on the request to the device
- The main exception to this rule is the special subset of character device drivers which implement terminal devices, for which the kernel maintains a standard interface

Character Devices (Cont.)

- **Line discipline** is an interpreter for the information from the terminal device
  - The most common line discipline is tty discipline, which glues the terminal's data stream onto standard input and output streams of user's running processes, allowing processes to communicate directly with the user's terminal
  - Several processes may be running simultaneously, tty line discipline responsible for attaching and detaching terminal's input and output from various processes connected to it as processes are suspended or awakened by user
  - Other line disciplines also are implemented have nothing to do with I/O to user process – i.e. PPP and SLIP networking protocols

Interprocess Communication

- Like UNIX, Linux informs processes that an event has occurred via **signals**
- There is a limited number of signals, and they cannot carry information: Only the fact that a signal occurred is available to a process
- The Linux kernel does not use signals to communicate with processes with are running in kernel mode, rather, communication within the kernel is accomplished via scheduling states and **`wait_queue`** structures
- Also implements System V Unix semaphores
  - Process can wait for a signal or a semaphore
  - Semaphores scale better
  - Operations on multiple semaphores can be atomic

Passing Data Between Processes

The **pipe** mechanism allows a child process to inherit a communication channel to its parent, data written to one end of the pipe can be read a the other

Shared memory offers an extremely fast way of communicating; any data written by one process to a shared memory region can be read immediately by any other process that has mapped that region into its address space

To obtain synchronization, however, shared memory must be used in conjunction with another Interprocess-communication mechanism

Network Structure

- Networking is a key area of functionality for Linux
  - It supports the standard Internet protocols for UNIX to UNIX communications
  - It also implements protocols native to non-UNIX operating systems, in particular, protocols used on PC networks, such as Appletalk and IPX
- Internally, networking in the Linux kernel is implemented by three layers of software:
  - The socket interface
  - Protocol drivers
  - Network device drivers
- Most important set of protocols in the Linux networking system is the internet protocol suite
  - It implements routing between different hosts anywhere on the network
  - On top of the routing protocol are built the UDP, TCP and ICMP protocols
- Packets also pass to **firewall management** for filtering based on **firewall chains** of rules

Security

The **pluggable authentication modules** *(***PAM***)* system is available under Linux

PAM is based on a shared library that can be used by any system component that needs to authenticate users

Access control under UNIX systems, including Linux, is performed through the use of unique numeric identifiers (**uid** and **gid**)

Access control is performed by assigning objects a *protections mask*, which specifies which access modes—read, write, or execute—are to be granted to processes with owner, group, or world access

Security (Cont.)

- Linux augments the standard UNIX **setuid** mechanism in two ways:
  - It implements the POSIX specification's saved ***user-id*** mechanism, which allows a process to repeatedly drop and reacquire its effective uid
  - It has added a process characteristic that grants just a subset of the rights of the effective uid
- Linux provides another mechanism that allows a client to selectively pass access to a single file to some server process without granting it any other privileges

End of Chapter 18