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Operating System Kernel and the boot process

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A computing department

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Operating System: Kernel and boot process

What is it?

What does it do?

How does it start up?

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The OS is the kernel

- The operating system is the kernel
- When the computer boots the operating system, it loads the kernel into memory.

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What is an operating system?

- Is it what you get when you install Linux, Windows XP or Windows 2000?
- Does it include such things as (g)notepad, g++ or Visual C++?
- How about `bash`, `cmd.exe` or `command.com`?

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Kernel in Linux

- In Linux, kernel can be loaded by LILO or grub
- Kernel is in `/boot`
- In RH 9, it is
 - `/boot/vmlinuz-2.4.20-20.9`,
 - or if you build your own, something like `/boot/vmlinuz-2.4.22-ac6`
- It is a *monolithic kernel*

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Kernel in Windows XP, 2000, Win NT

- In %SystemRoot%\System32
 - %SystemRoot% = C:\winnt, or D:\winnt,...
- Called `ntoskrnl.exe`
- Microsoft call it a *layered kernel* or *microkernel*.
- sometimes called the “Executive services” and the “NT executive”
- Bottom layer is the *hardware abstraction layer*

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What does an OS do?

- Provides a “government” to share out the *hardware resources* fairly
- Provides a way for the programmer to easily work with the hardware and software through a set of *system calls* — see slides §15–§18.
 - Sometimes also called *supervisor calls*

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Is there a User Friendly OS?

- Some people have said that the Windows OSS are more user friendly than Linux
- Can this be the case?
 - Are the *system calls* more user friendly?
 - (see slides §15–§18 for more about system calls)
 - Does Windows *manage the hardware* in a more user friendly way?
- No!
- The user interface is not an operating system issue. See your subject Human Computer Interfaces (HCI)
- Do you want a more user friendly interface for Linux?
 - Then write one! Contribute to the Gnome or KDE projects.

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Example: MAC OS X

- The Mac has a deserved reputation for a great user interface
- OS X is the latest OS from Apple
- Very beautiful, easy to use
- But it is Unix, built on FreeBSD!
 - The Unix that till now has mostly been used on servers;
 - considered by some to be less user friendly than Linux
- The User Interface is not part of the OS

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Is IE part of Windows OSS?

- Is Internet Explorer part of the Windows operating systems?
- Please discuss this question with your neighbour.
- See <http://news.com.com/2100-1001-219029.html?legacy=cnet>

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What resources does OS manage?

- The OS manages resources such as:
 - Use of CPU
 - Memory
 - Files and disk access
 - Printing
 - Network access
 - I/O devices such as keyboard, mouse, display, USB devices, ...

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... Allocated to who/what?

- An operating system can be *multiuser*
 - In this case, resources must be allocated to the users fairly
- “Proper” operating systems are *multitasking*
 - Resources must be allocated fairly to the processes
- Users, processes must be protected from each other.

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Kernel mode and user mode

- *Kernel* means “central part”
- The kernel is the central part of OS
- It is a program running at all times
- Application programs run in “*user mode*”
 - Cannot access hardware directly
- Kernel runs in “*kernel mode*” (or “*supervisor mode*”)
 - *Can access hardware, special CPU registers*

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How does user program access hardware?

- A program that writes to the disk accesses hardware
- How?
- Standard library call, e.g., `fprintf()`
- Library contains **system calls**
 - see slides §15–§18
- A system call passes the request to the kernel
- The kernel, (executing in kernel mode always) writes to the disk
- Returns telling user program that it was successful or not

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System Call

- Low level details:
 - CPU provides a **trap** instruction which puts the CPU into a privileged mode, i.e., kernel mode
 - On Intel ix86 architecture, the trap instruction is the `int 0x80` instruction
 - See `include/asm-i386/unistd.h` and `arch/i386/kernel/entry.S` in Linux source code. See also <http://en.tldp.org/LDP/khg/ByperNews/get/syscall/syscall186.html>
 - Sometimes called a **software interrupt**
 - put parameters into CPU registers before the call
 - save values of many registers on a stack
- High level: all this buried in external library interface

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Kernel: programmers' standard interface

- This is the **second important function** of the operating system
- Provides a standard set of **system calls**, used by the libraries
- User programs usually use the system calls indirectly
 - since libraries give higher level interface

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System Calls — Linux

- POSIX specifies particular function calls that usually map directly to system calls — see `man` section 2
- Provide a higher level interface to system calls
- Less than 300 of them. Examples:

Call	Description
<code>pid = fork()</code>	Create a child process identical to parent process
<code>exit(status)</code>	Terminate process and return status
<code>fd = open(file, O_RDONLY)</code>	Open a file for reading, writing or both
<code>status = close(fd)</code>	Close an open file
<code>n = read(fd, buffer, nbytes)</code>	Read data from file into a buffer
<code>n = write(fd, buffer, nbytes)</code>	Write data from buffer into a file
<code>status = chdir(dirname)</code>	Change working directory of process

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System Calls — Windows and Win32 API

- Win32 API provides many thousands of calls
- No one-one mapping to system calls
- Not all make a system call
- On some versions of Windows OSS, graphics calls are system calls, on others they are not
- Win32 API documented on MSDN. Examples:

POSIX	Win32	Description
<code>fork</code>	<code>CreateProcess</code>	create a new process
<code>exit</code>	<code>ExitProcess</code>	Terminate execution
<code>open</code>	<code>CreateFile</code>	Create a file or open existing file
<code>close</code>	<code>CloseHandle</code>	Close a file
<code>read</code>	<code>ReadFile</code>	Read data from a file
<code>write</code>	<code>WriteFile</code>	Write data to a file

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Types of Operating System

A rough breakdown of the types of OS

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What types of operating systems are there?

- There are **four main categories**; depends on **organisation** of the **kernel**
- **Monolithic** operating systems
 - **Linux** is a monolithic OS
- **Layered** operating systems
 - **Windows NT/2000/XP/2003** is described as a layered architecture
- **Microkernel with client server architecture**
 - The **QNX** real-time OS is truly a microkernel; the kernel is said to be only eight kilobytes in size!
 - Andrew Tanenbaum wrote the **MINIX** operating system as an example microkernel OS for students to study
 - The **GNU Hurd** OS has a microkernel architecture
 - **Windows 2000** is described as having a hybrid layered-microkernel architecture, although Andrew Tanenbaum disagrees:

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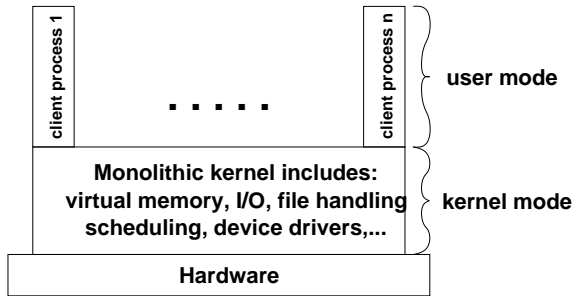
Monolithic Kernel

- A monolithic kernel has all **procedures** in the same **address space**.
 - This means that all the code can see the same global variables, same functions calls, and
 - there is only one set of addresses for all the kernel
- Purpose is **speed**:
 - to reduce overhead of communication between layers

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Monolithic kernel — 2



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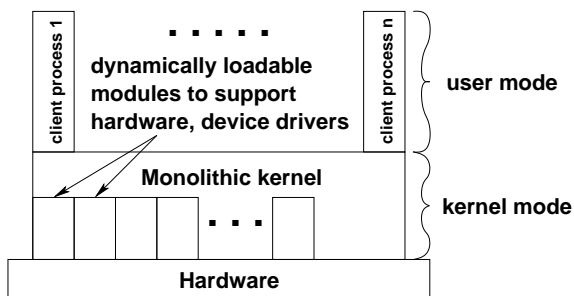
Structure in a Monolithic Kernel

- To avoid chaos, a monolithic kernel must be well structured
- Linux kernel uses **loadable modules**, which support hardware and various software features
- Such as RAID, Logical Volume Managers, various file systems, support for various networking protocols, firewalling and packet filtering,...

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Monolithic kernel: loadable modules



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Monolithic kernel: Loadable Modules

- Loadable modules in Linux kernel support:
 - Dynamic Linking**: modules can be loaded and linked with the kernel, or unloaded, while kernel is executing
 - Stackable Modules**: Modules can provide support for each other, so many modules can be stacked on a lower level module.
- Reduces replication of code
- Hierarchical structure ensures that modules will remain loaded while required
- View loaded modules by typing `lsmod`

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Layered kernel

- Has different levels; example:
 - Lowest level manages hardware
 - Next level up manages, e.g., memory and disks
 - Next level up manages I/O, ...
 - Each layer may have its own address space
 - Communication between layers requires overhead
 - Advantage is different layers cannot interfere with each other.

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Layered Kernel — 2

5	User Programs
4	File Systems
3	Interprocess Communication
2	I/O and device management
1	Virtual memory
0	Primitive process management
Hardware	

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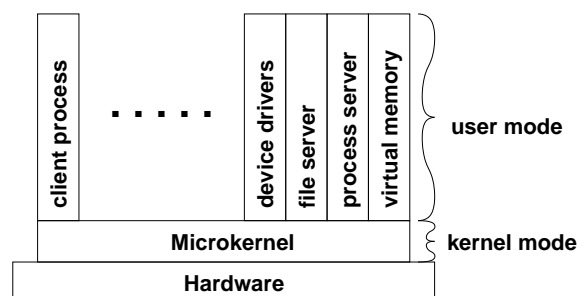
Microkernel with Client-Server Arch.

- Microkernel** architecture keeps the kernel **as small as possible**, for the sake of reliability and security
- As much is done in the user space as possible**
- User space provides servers, such as memory server, file server, terminal server, process server
- Kernel directs requests from user programs to user servers

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Microkernel Architecture — 2

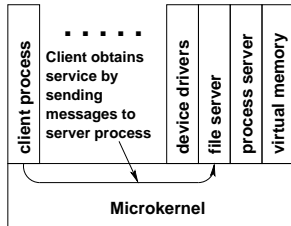


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Microkernel Architecture — 3

- Most of operating system is a set of user processes
- the server processes do most of the work
- The microkernel mostly just passes requests from client processes to server processes



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Microkernel Architecture — Examples

- Mach kernel used as core for many Unix OS
 - including the MAC OS X
- GNU Hurd OS, initiated by Richard Stallman for the GNU project
- The QNX distributed real-time Unix-like OS
 - kernel only 8 KB in size!
- It can be *debated* whether Windows NT/2000/XP/2003 operating systems are microkernels:
 - “With all the security problems Windows has now, it is increasingly obvious to everyone that tiny microkernels, like that of MINIX, are a better base for operating systems than huge monolithic systems.”

— Prof. Andrew Tanenbaum,

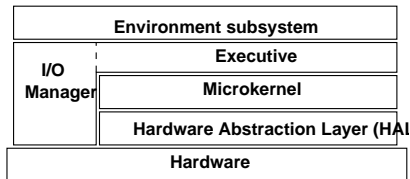
<http://www.cs.vu.nl/~ast/brown/>

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Windows 2000 Architecture

- Windows 2000 is described as a hybrid between a layered architecture and microkernel architecture.
- HAL provides an abstract machine—aim to make porting to other hardware architectures easier
- HAL + Microkernel \approx normal microkernel



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Windows 2000 Architecture — 2

- Environment subsystem aims to support DOS, Win32, OS/2 applications
 - each environment subsystem uses a DLL (dynamic link library) to convert system calls to Windows 2000 calls
- The I/O manager contains file system and device drivers
- Microkernel, HAL and “many functions of the executive” execute in kernel mode.
 - Sacrifice advantage of microkernel of reduced code executing in kernel mode
 - to reduce communication overhead

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Virtual machine

- Virtual hardware
- Many operating systems run independently on same computer
- IBM now selling *mainframes* running many instances of Linux to Telecom companies — see next slides
- VMWare allows something similar on PC:
 - <http://www.VMWare.com>
- <http://www.connectix.com/> used to sell *Virtual PC* and *Virtual Server*, but they have been bought out by Microsoft, who of course, have dropped Linux support:
 - <http://www.msfm.org/comments.php?id=5516&catid=1>
- Java Virtual machine* also provides virtual hardware that all programs can execute on.

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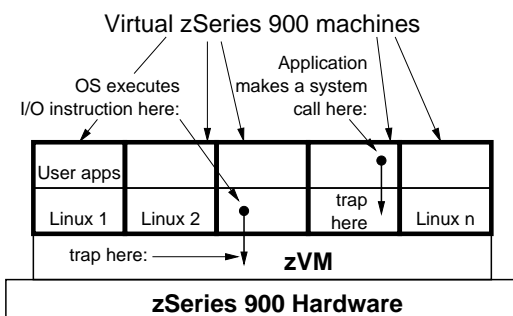
Virtual Machine OS Examples

- IBM designed the CP/CMS virtual OS for their S/360 mainframe.
- Later called VM/370 to run on their S/370 mainframes
- Later called VM/ESA on the S/390 hardware
- Now sold as zVM[®] running on zSeries mainframes
 - Supports running many different OS, particularly Linux
 - See <http://www.vm.ibm.com/>
- See how MIT run Linux on VM/ESA on their S/390 mainframe:
 - <http://mitvma.mit.edu/system/vm.html>
- Search the web for articles on Linux running on mainframes.

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Linux on zVM on ZSeries Mainframe



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Many Individual Machines

- A data centre may have many servers
 - Each must be powerful enough to meet *peak demand*
 - Most are not at peak demand most of the time
 - ... so most are *underused*
 - ... but must pay for electricity for cooling, and for powering all that *reserve capacity*

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Many Virtual Machines, one Mainframe

- Can replace many individual servers with one mainframe running many instances of an OS such as Linux
 - The demand spread out among all the virtual machines,
 - total **utilisation high** — demand shared
 - busy virtual machines get more CPU power to meet peak demand
 - Much lower power requirements
 - Much less air conditioning cost
 - Much less floor space required
- Virtual machines partitioned from each other, like the individual machines in data centre

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With Kernels, “small is beautiful”

- The **reliable operation** of any computer depends on its operating system, i.e., its kernel.
- More complex software has **higher chance of bugs**, security problems, vulnerability to worms and viruses
- Linus Torvalds imposes a strict discipline on kernel developers to carefully restrict code that will increase size of kernel
- Linux does not suffer from “kernel bloat”
 - Compare the size of the Windows 2000 “microkernel:” several megabytes, cannot be booted from floppy
 - Linux: small enough to fit on one floppy together with many useful tools: <http://www.toms.net/rb/>
- **Movies:**
 - Linus discusses Monolithic, Microkernel design, ETU, avi, avi2

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Booting an Operating System

The OS manages the hard disks.

How can the system read the hard disk to start the OS?

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Booting a PC

- The process of starting the computer ready for use
- How does a computer boot?
- Involves:
 - BIOS (“basic input output system”) finding the **boot loader**
 - The boot loader starting the kernel
- For Linux:
 - The kernel starting `init`
 - `init` starting everything else

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Boot Loader

- A **boot loader** is a piece of software that runs before any operating system, and is
 - responsible for loading an operating system kernel, and transferring control to it
- Microsoft OS provides a boot loader that starts their OS from the first active primary partition
- We use the grub (Grand Unified Boot Loader) boot loader that can start any operating system from almost any hard disk, floppy or network.

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The boot process for a PC

- the BIOS performs a power on self-test (POST)
- the BIOS initialises PCI (Peripheral Component Interconnect) devices
- the boot loader loads the first part of the kernel into system RAM
- the kernel identifies and initialises the hardware in the computer
- the kernel changes the CPU to protected mode
- `init` starts and reads the file `/etc/inittab`
- the system executes the script `/etc/rc.d/rc.sysinit`
- the system executes scripts in `/etc/rc.d/init.d` to start services (daemons)

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Before the bootloader: The BIOS

- The BIOS runs in **real** mode (like old 8086)
- BIOS tests hardware with basic Power On Self Test (POST)
- BIOS then initialises the hardware.
- Very important for the PCI devices, to ensure no conflicts with interrupts.
- See a list of PCI devices.
- BIOS settings determine order of boot devices; when finds one, loads first sector into RAM, starts executing that code.

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VMWare Boot Screen



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Boot Loaders: what they do

- Syslinux is the simplest, grub has the most features, LILO in between
- Grub provides many interactive commands that allow:
 - Reading many different file systems
 - Interactively choosing what to boot
 - Many, many more things (do pinfo grub)
 - All before any operating system started!!
- Grub and LILO let you choose what OS to boot

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The kernel is loaded

- Boot loader reads first part of the kernel into RAM, executes the code
- This initial kernel code loads the rest of the kernel into RAM
- The kernel checks the hardware again
- The kernel switches from *real* mode to *protected* mode

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Real and Protected mode

- **Real mode** exists for booting, and so that can run old DOS programs
- Uses only bottom 16 bits of registers
- Can only access the bottom 1 MB RAM
- BIOS only supports real mode
- **Protected mode** uses all 32 bits of address registers
- Allows access to all RAM
- Allows use of memory management unit
- Normal mode of operation for modern OSes on Intel platform.
- Cannot call BIOS functions in protected mode

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Kernel in Protected Mode: *init*, PID 1

- The kernel then starts the *first process*, process 1: /sbin/init
- /sbin/init reads the /etc/inittab
- Init starts reading the script /etc/rc.d/rc.sysinit
- /etc/inittab tells init to do this
- init then executes scripts in /etc/rc.d/init.d to start services

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Runlevels

- A standard Linux system has 7 modes called *runlevels*:
 - 0: halt (shut down the machine)
 - 1: single user mode
 - 2: multiuser with no network services
 - 3: full multiuser mode
 - 4: can be customised; default same as 3
 - 5: multiuser with graphical login
 - 6: reboot

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Directories for each runlevel

- If you look in /etc/rc.d, you see one directory for each runlevel, and a directory called *init.d*:

```
$ ls /etc/rc.d
init.d rc0.d rc2.d rc4.d rc6.d rc.sysinit
rc rc1.d rc3.d rc5.d rc.local
```
- *init.d* contains one script for each service. You execute these scripts with the *service* command, i.e.,

```
$ sudo service autofsd start
```

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Runlevel directories

- Each of /etc/rc.d/rc[0-6].d contains *symbolic links* to scripts in /etc/rc.d/init.d
 - A symbolic link is a bit like a shortcut in Windows (but more fundamental)
 - We cover symbolic links in detail later
- If name of link begins with *K*, the script will stop (*kill*) the service
- If name of link begins with *S*, will start the service
- The *chkconfig* program creates these symbolic links

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Example of service: yum

- In the laboratory, you set up the *yum* service to automatically install software updates
- You used the *chkconfig* program to enable the service.
 - For a complete manual on *chkconfig*, type:

```
$ man chkconfig
```
 - For a brief summary of options, type:

```
$ /sbin/chkconfig --help
```
- Here we use the program *find* (covered in detail later) to see the links before and after

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Turning yum Service Off

```
$ sudo /sbin/chkconfig yum off
$ /sbin/chkconfig yum --list
yum                                0:off  1:off  2:off  3:off  4:off  5:off  6:off
$ find /etc/rc.d -name '*yum'
/etc/rc.d/init.d/yum
/etc/rc.d/rc5.d/S01yum
/etc/rc.d/rc1.d/S01yum
/etc/rc.d/rc2.d/S01yum
/etc/rc.d/rc3.d/S01yum
/etc/rc.d/rc4.d/S01yum
/etc/rc.d/rc5.d/S01yum
```

- After turning the service off, all the links start with 'K' in all runlevels: 0, 1, 2, 3, 4, 5 and 6.

Turning yum Service On

```
$ sudo /sbin/chkconfig yum on
$ /sbin/chkconfig yum --list
yum                                0:off  1:off  2:on   3:on   4:on   5:on   6:off
$ find /etc/rc.d -name '*yum'
/etc/rc.d/init.d/yum
/etc/rc.d/rc0.d/S01yum
/etc/rc.d/rc1.d/S01yum
/etc/rc.d/rc2.d/S01yum
/etc/rc.d/rc3.d/S01yum
/etc/rc.d/rc4.d/S01yum
/etc/rc.d/rc5.d/S01yum
```

- Notice that after turning the service on, there are links that start with 'S' in runlevels 2, 3, 4 and 5.

References

- *Modern Operating Systems*, Second Edition, Andrew S. Tanenbaum, Prentice Hall, 2001, Chapter 1. Good discussion of system calls.
- *Operating Systems*, Fourth Edition, William Stallings, Prentice Hall, 2001, chapter 2 particularly pp 85–91 and 98–99, chapter 4, pp 172–178
- *Operating Systems: A Concept Based Approach*, D. M. Dhamdhere, McGraw Hill, 2002