

Linux Essentials for Application Developers

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Introduction

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Introduction

- The purpose of this document is to provide sufficient information for an experienced programmer to become proficient in a Linux environment
- Notation:
 - commands that are entered at a shell (command-line) prompt are in **fixed-width font**
 - command arguments are *italicized*
 - ... indicates an argument that can appear any number of times
 - examples are indented:
`echo 'text to display'`
- Exercises have the answer on the following slide

Linux

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What is Linux?

- Free and open source multiuser operating system
 - Free: anyone is free to do whatever they would like with the code, subject to license agreement
 - Open source: the source code is publicly available for anyone to study and modify
 - Operating system: the executing code (program) that manages all system resources, including hardware and software
 - Multiuser: supports simultaneous use by multiple users
- Some refer to GNU/Linux when referring to the entire operating system, including GNU tools and the Linux kernel

Where is Linux?

- Linux is a free and open source operating system
- Linux runs on everything from embedded IoT devices to supercomputers
- The Android cellphone operating system is based on the Linux kernel
- So Linux is running on billions of devices worldwide

Linux distribution families

- A Linux distribution typically includes the Linux kernel, a suite of programs, and a package distribution system
- Most currently supported Linux distributions derive from one of these distributions, first released in 1993 (except Android):
 - Slackware/SuSE
 - Debian
 - Red Hat
 - most of the distribution-specific examples in this deck will be based on Red Hat
 - Android, first released in 2005
- A. Lundqvist and D. Rodic have prepared a fascinating GNU/Linux Distribution Timeline, at

https://upload.wikimedia.org/wikipedia/commons/5/58/Linux_Distribution_Timeline_with_Android.svg

Can I emulate Linux on Mac or Windows?

- On Mac, open the terminal app. Most of the commands in this deck will work on it. Though some, such as find, are slightly different
 - Mac OS X and later are based on Mach, a Unix variant
- On Windows, Cygwin provides the feel of Linux. To install, download and run https://www.cygwin.com/setup-x86_64.exe
 - its package management is different but intuitive
- Alternatively, Linux virtual machines can be run on Mac, Windows, or any other platform that supports them

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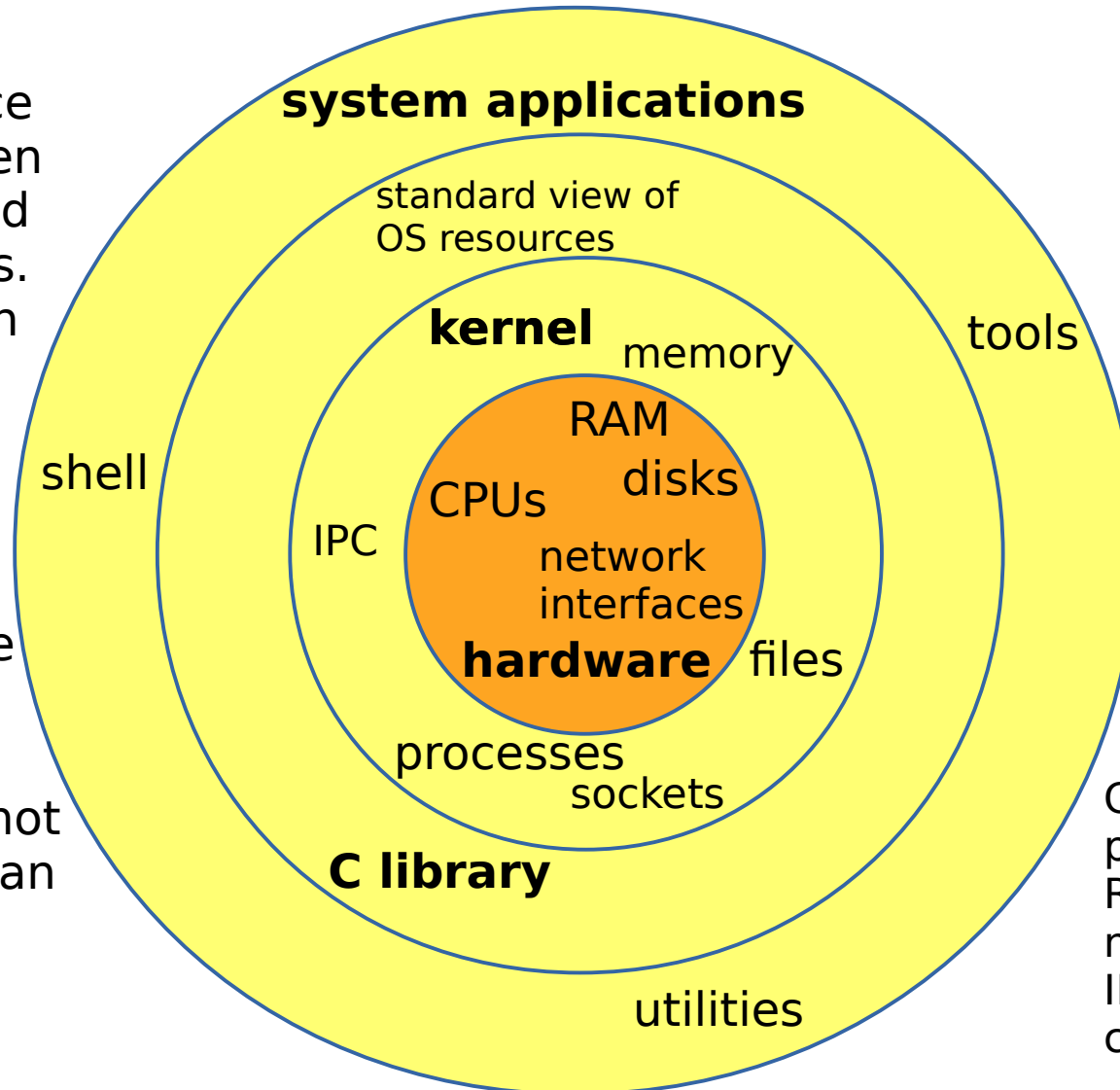
Where did Linux come from?

- MIT, Bell Labs, and GE developed Multics in mid-1960s
 - Multiplexed Information and Computer Services
- AT&T Bell Labs developed Unix in the early 1970s for internal use
 - Uniplexed Information and Computer Service
 - stylized as Unix, trademarked as UNIX®
- Unix licensed to others starting in 1983 as AT&T System V
 - University of California, Berkeley developed UCB version
 - POSIX (Portable Operating System Interface) standardizes user and programmer interfaces
- Linus Torvalds developed Linux in 1991 in response to restrictive licensing of Unix

What is an operating system?

An OS is a software resource manager between the hardware and user applications. Each OS layer (in yellow here) provides resources to layers above through a well-defined interface

User applications (not shown here) can access OS facilities and resources



CPU = central processing unit
RAM = random access memory
IPC = interprocess communication

The Unix philosophy

- As summarized by Doug McIlroy in 1978:
 1. Each program (application) should do one thing, and do it well
 2. The output of one program can be the input to another
 - Loose coupling, i.e., not dependent on particular formats
 3. Design and build software to be tried early
 - Rapid prototyping, agile
 4. Build and use tools, even for one use

Command basics

- Commands have a name, any number of options, and any number of arguments
 - options are also called flags or switches, and may themselves take arguments
 - all are separated by whitespace: one or more space or tab characters
 - options are indicated with a leading single or double dash
 - single-dash options are usually single letter
 - double-dash options are usually more descriptive, and preferred in scripts and documentation
 - arguments usually don't start with a dash
 - some commands use a double-dash, with no other characters, to separate the command options and arguments

Commands and programs

- A command executes either a built-in shell command or external program
 - built-in shell commands, documented in the shell man page
 - an external program is contained in an executable disk file
 - execute permission is required for the user to execute the program
 - an external program may either be a shell script or binary
 - shell scripts should start with line of the form:
`#!/bin/bash`
and can contain any commands for that shell
 - binary files contain executable code, or code in and intermediate form that is executed by another program such as a Java virtual machine

Help

- Every command should have a man page
 - view with `man(1p)` command, e.g.,
`man less`
 - shows man pages related to a topic
`man -k topic`
 - `man` can be run directly on a man page
`man /usr/share/man/man1/ls.1.gz`
- Most commands have a `--help`, `-h`, or `-?` help option

Reference manual sections

- Manual pages are arranged in sections, see those with
`man man`
- To specify a specific section when using `man`, precede the topic with the section number, e.g.,
`man 3 sleep`
 - Without the section, `man` would show the documentation for the `sleep(1p)` command

Reference conventions

- Commands, system calls, file formats, and other Unix entities are often referred to with their manual section in parentheses the first time the command is mentioned, e.g.,
 - `less(1)` is the `less` command, described in section 1 of the reference manual
 - `regex(7)` documents POSIX regular expressions in section 7 of the reference manual
- In this document, POSIX standard commands are shown with a section 1p reference, e.g, `more(1p)`. The corresponding section 1 man page shows any non-POSIX features of the command
 - Section 3p man pages correspond to Section 2 pages
- Non-POSIX commands are shown with a section 1 reference, e.g, `less(1)`

The console

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Keyboard: prompt shortcuts

- These are the default (emacs mode) bindings. vi bindings can be selected by entering `set -o vi`
 - Ctrl-a/Ctrl-e: beginning/end of line
 - Ctrl-b/Ctrl-f: backward/forward one character
 - or left/right arrows
 - Ctrl-p/Ctrl-n: previous/next command in history
 - or up/down arrows
 - Ctrl-r: search back through command history
 - Ctrl-u: erase input
 - Can be used at password prompt
 - Ctrl-d: end of input
- The `reset(1)` command fixes a “messed up” terminal

Keyboard: tab completion

- bash and other shells offer tab completion
- After entering the first few characters of a command, hitting the Tab key will complete if unique
 - If there isn't a unique completion, nothing happens
 - Then, hitting the Tab key a second time shows all possible completions
 - Enter more characters until the completion is unique
- Tab completion also works for filenames
- Tab completion may also be supported for command arguments

Keyboard: job control shortcuts

- Ctrl-z: put job in background
- Ctrl-s/Ctrl-q: stop/resume foreground job
- Ctrl-c: terminates foreground process by sending it the keyboard interrupt signal
- Ctrl-\\: terminates foreground process by sending it the quit signal
 - Only try if Ctrl-c doesn't terminate the process

Keyboard: virtual consoles

- Ctrl-Alt-F1 through Ctrl-Alt-F6 (typically): go to the specified virtual console.
 - X windows runs on one of them, usually the first
- If your X windows environment enters an unusable state, you might be able to switch to another virtual console, login, and try to kill an errant process
 - Example:
 1. Run a process, such as `xlock(1)`, in a window
 2. Switch to another virtual console using Ctrl-Alt-F2
 3. Login
 4. Kill the process started in step one using the `kill(1p)` command
 5. Logout
 6. Switch back to X windows using Ctrl-Alt-F1 (usually)

The X Window System™

- The X Window System™ provides the basis for the graphical user interface (GUI) of most Linux distributions, except Android
 - The X Window System is a trademark of The Open Group
 - The latest version is X11R6.4
 - Also called X11, X windows, or X
- Client-server based
 - The X server renders and manages displays, including pointer and audio
 - Graphical applications are clients
- X.Org provides the server, Xorg(1), implementation for many distributions

Using X

- Start using `startx(1)` or `xinit(1)`
 - usually done for the user on login
- The `DISPLAY` environment variable controls where windows are displayed
 - Default value is something like `:0`
 - Must be set manually if unset, e.g., after `su`
`export DISPLAY=:0.0`

Window managers

- With an X server running the user can start a *window manager*
 - Again, this is usually done for users in a system that has been configured with graphical interfaces
 - Sometimes run user's `~/.xinitrc` script, which should end by starting a window manager
 - Or, the `startx` program may start a particular window manager
- The window manager supports root (on the display background) menus, manages physical displays, manages application windows, and manages events such as keyboard and pointer (mouse) input, and audio output
- Example window managers include `mwm`, `twm`, and `xfce`

xterm(1)

- xterm(1) is a terminal emulator for X
- Each invocation opens a new window with a terminal (command) prompt
 - Runs the user's shell, as set in /etc/passwd
 - A user can change their shell with chsh(1)
- Appearance can be customized in ~/.Xresources file
 - Usually read by xrdb(1)
 - Contains settings for other X clients, not just xterm

Desktop environments

- Desktop environments such as GNOME and KDE provide a higher level abstraction
- Include a GUI server such as X
- Include a window manager
- Include applications for various user-level tasks

Text tools

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Text tools

- View: `cat(1p)`, `less(1)`, `od(1p)` or `hexdump(1)`, `wc(1p)`
 - `more(1p)` is a predecessor of `less` that allows only forward movement
 - `od` and `hexdump` show the content as bytes
- Search: `grep(1p)`, `strings(1p)`, `cut(1p)`, `join(1p)`
 - `fgrep` (`grep -F`) and `egrep` (`grep -E`) are variants that disable and enhance the `grep` regular expressions
- Compare: `diff(1p)`, `cmp(1p)`
- Modify/transform: `python(1)`, `sed(1p)`, `tr(1p)`
 - `perl(1)` and `awk(1p)` are older tools that are sometimes useful

less customization

- Options to less can be stored in the LESS environment variable. That can be set your shell profile such as `~/.bash_profile`, e.g.,
`export LESS=eMqRsX`
 - e removes the need to use “q” to terminate less
 - M causes less to prompt verbosely
 - q suppresses alerts when trying to view before the beginning or past the end of the file
 - R interpret ANSI color escape sequences, so that text colors are retained
 - s squeezes multiple blank lines into one
 - X disables clearing the screen on termination

grep

- grep searches for text matching a regular expression pattern

grep [*options*] *pattern* [*file...*]

- -i case insensitive
- -c just returns count
- -h suppresses filename in output, with multiple files (not POSIX)
- -E (or egrep): extended regular expression pattern
- -F (or fgrep): literal pattern

grep regular expressions

- This is just a general introduction, please see the `grep(1p)` and `regex(7)` man pages for details
- An item can be a single character, a character class, or a parenthesized group of items
- A period, `.`, matches any single character
- Some special characters specify the quantity of the preceding item
 - `*` matches any number of the item
 - `+` matches one or more of the item
 - `?` matches zero or one of the item
- `[]` indicates a character class, such as `[A-Za-z0-9]` or `[:alpha:]`

grep examples

- Count occurrences of “error” or “warning” in log files

```
grep -cEi 'error|warning' files
```

- Set exit status to non-zero if “error” or “warning” occurs in log files

```
grep -Eiq 'error|warning' files
```

- Show all processes match pattern, except grep itself

```
ps -ef | grep '[f]oo'
```

List of dictionary words

- `/usr/share/dict/words` contains a list of English words
 - if the words package is installed
 - `/usr/share/docs/words/readme.txt` describes the contents
- Can be useful, though it is not authoritative

Dictionary word exercise 1

- List all 6-letter words, excluding proper names, that start with 'a' and end with 'x'

solve exercise before proceeding

Dictionary word exercise 1

- List all 6-letter words, excluding proper names, that start with 'a' and end with 'x'

```
grep '^a...x$' /usr/share/dict/words
```

Dictionary word exercise 2

- List all 6-letter words, including proper names, that start with 'a' and end with 'x'

solve exercise before proceeding

Dictionary word exercise 2

- List all 6-letter words, including proper names, that start with 'a' and end with 'x'

```
grep '^[Aa]...x$' /usr/share/dict/words
```

or

```
grep -i '^a...x$' /usr/share/dict/words
```


Files and directories

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File and directory names

- File and directory names can contain any character except /
 - Though it's best to avoid non-printable characters in names
- Names are case sensitive
 - For example, foo and Foo refer to two distinct files and/or directories
- File and directory names are just entries in tables
 - Removing a file does not remove its contents from disk
 - Though in practice, recovering the contents of a removed file is difficult, or impossible if the contents were overwritten for use by another file

File types

- The most common file types are:
 - Plain file, containing bytes
 - Symbolic link, which points to another file
 - created with **ln -s**
 - Directory, which is an entry in a directory's list of contained files
 - Special files, often used as the OS interface to a hardware device
- The `file(1p)` command shows the type of a file
- Plain files are in turn categorized based on their content
 - `/etc/mime.types` lists many types
- In general, filename extensions are not authoritative

File management commands

- `cp(1p)`: copies one or more files, `-p` preserves ownership, permissions, and timestamps

```
cp [-p] foo bar
```

- `rm(1p)`: removes (deletes) a file

```
rm [-i] foo[...]
```

- `mv(1p)`: move (rename) a file

```
mv foo bar
```

- `touch(1p)`: create new file or update last modification time on existing one
- `file(1p)`: show the type of a file
- `stat(1)`: show ownership, permissions, and timestamps

Directory management commands

- `mkdir(1p)`: makes one more more new directories
 - The `-p` option allows creation of multiple levels
- `rmdir(1p)`: removes one or more empty directories
 - So does `rm -r`
- `ls(1p)`: lists contents of one or more directories
- `cd(1p)`: changes current directory
- `pushd/popd`: shell built-ins to change current directory, pushing/popping to/from a stack
 - `dirs` displays the contents of the stack

File and directory permissions

- Permissions restrict actions on a file or directory
 - The actions are read, write, and execute
 - A file can only be executed if it allows execute permission
 - Separate permissions for owner, group, and all others
- `ls -l` and `stat(1)` show permissions
- `chmod(1p)` allows owner, and root, to change permissions

rm

- The `rm(1p)` command removes files and directories
- The `-i` option causes `rm` to request confirmation from the user of each removal
 - Many people add a shell alias to their profile to always enable `-i`. This can be overridden by adding `-f` when executing the command, or bypassing the alias with `\rm`
- The `-r` option is required to remove a directory
 - all of the files and directories are removed first, recursively
- Removal does not actually remove the data in the file
 - removal just unlinks the file name from its directory
 - the space for the data can be reused by the operating system

rsync

- rsync(1) is a handy and efficient tool for copying files and directories to a remote machine, or on the local machine
 - synchronizes files or directories
- The general format is:

```
rsync [options] src... dest
```
- The source(s) and destination can be local or remote files or directories. Remote files and directories are indicated with a leading *[user@]host*:
- There is one subtlety: source directories should always include a trailing /
- Usually use -a (--archive) option with directories
- Other common options: -v for verbose, --delete to delete, --exclude to exclude specified files/directories

rsync examples

- Copy directory on local machine

```
rsync -av /path1/dir/ /path2/dir
```

- Copy remote directory to local machine

```
rsync -av remote:path1/dir/ path2/dir
```

- Can use absolute or relative paths in either of the above examples

- Copy, excluding .o files

```
rsync -av --exclude '*.o' remote:/path1/dir/ path2/dir
```

- Test if contents of two directories are identical

```
rsync -nav --delete dir1/ dir2
```

File compression

- Compression can drastically reduce the size of a large text file
- Compression effectiveness on a binary file depends on its content; it can even increase the size

Compression	File extension	Introduced in
compress	.Z	1983
gzip	.gz	1992
bzip2	.bz2	1996
lzma	.lzma	1999
xz	.xz	2009

Common compression formats

- Each compression format has a corresponding program of the same name, see man pages for usage info

File compression examples

- decompress a gzip file

```
gzip -d foo.gz
```

or

```
gunzip foo.gz
```

- detect type of contents of gzip file

```
gzip -cd foo.gz | file -
```

or

```
zcat foo.gz | file -
```

- compress file using bzip2

```
bzip2 foo
```

File archives

- Archives are used for packaging a collection of files

Archive format	File extension	Compressed
ar	.a	no
ZIP	.zip	yes
tar	.tar	no
gzipped tar	.tgz	yes
cpio	.cpio	no
gzipped cpio	.cgz	yes
7-Zip	.7z	yes

Common archive formats

- See man pages for usage info

File archive examples

- view contents of ar archive

```
ar t foo.a
```

- extract contents of gzipped tar archive

```
tar xvpf foo.tgz
```

- extract contents of gzipped cpio archive

```
zcat foo.cgz | cpio -imdv
```

or

```
gzip -cd foo.gz | file -
```

- create compressed tar archive

```
tar cvzf foo.tgz files.. directories..
```

Disk management

- Disks are divided into *partitions*, e.g.,

Device	Boot	Start	End	Sectors	Size	Id	Type
/dev/sda1	*	2048	163842047	163840000	78.1G	7	HPFS/NTFS/exFAT
/dev/sda2		163842048	348162047	184320000	87.9G	83	Linux
/dev/sda3		348162048	409602047	61440000	29.3G	83	Linux
/dev/sda4		409602048	488397167	78795120	37.6G	5	Extended
/dev/sda5		409606144	411703295	2097152	1G	83	Linux
/dev/sda6		411705344	473151487	61446144	29.3G	83	Linux
/dev/sda7		473153536	488396799	15243264	7.3G	82	Linux swap

- fdisk(1) can view and modify local disks
- df(1p) reports partition space usage

Filesystems

- Each partition contains a *filesystem* e.g.,

Filesystem	1K-blocks	Used	Available	Use%	Mounted on
/dev/sda2	90581112	79042092	6914636	92%	/home
/dev/sda3	30106488	14921476	13632628	53%	/mnt/Fedora28
/dev/sda5	999320	505968	424540	55%	/boot
/dev/sda6	30109560	15885504	12671520	56%	/

- mkfs(1) creates a filesystem on a partition

Devices: /dev/null

- /dev/ contains special files and directories, e.g., to easily access hardware
 - Documented by name, e.g., null in manual section 4
- /dev/null: reads nothing, like reading an empty file; discards data written to it
 - POSIX grep does not have --quiet, so:
`grep foo file >/dev/null && echo file contains foo`
 - Can be used to discard unexpected error messages, though will also discard unexpected error messages
`grep foo * 2>/dev/null`

Devices: /dev/zero, RNGs

- /dev/zero: reads endless stream of 0 (null) bytes

```
head --bytes 10 /dev/zero | od -x
```

- /dev/full: always full device, useful for testing behavior of programs that write to full disk

```
ls >/dev/full
```

- /dev/urandom: returns random bytes, non-blocking so relies on pseudorandom number generator
- /dev/random: random number generator (RNG) that blocks to achieve sufficient entropy

Devices: hardware

- `/dev/cdrom`, `/dev/cdrw`, `/dev/dvd`, or similar: CD or DVD drive(s)
- `/dev/sd*`: disk drives, starting with `/dev/sda`
 - Partitions are numbered following the drive letter, starting with `/dev/sda1`
 - `sd` refers to Small System Computer Interface (SCSI), which might be emulated by the disk driver
- `/dev/hd*`: non-SCSI hard disk drives
- `/dev/fd*`: floppy disk drives

Devices: terminals

- `/dev/tty*`: terminals (consoles)
 - You can write to, and read from, terminal `/dev/tty`
- `/dev/pts/*`: pseudoterminals
 - Used for windows: each window is associated with a different pseudoterminal
 - You can write to, and read from, your own pseudoterminals:

```
echo 'guess who!' >/dev/pts/0
```
 - The `w(1)` command shows all terminals and pseudoterminals in use
- `/dev/ttyS*`: serial terminals
 - Used for connection to serial devices such as networking equipment and embedded computers

Devices: I/O

- `/dev/stdin`, `/dev/stdout`, `/dev/stderr`: input and output (I/O) devices
 - Correspond to the 3 standard streams associated with every Unix program
 - Within the program, each stream is associated with a *file descriptor (fd)*
 - An fd is an integer handle to the open file
 - 0 for stdin, 1 for stdout, 2 for stderr
- stdin (standard input) is for console (keyboard) input
- stdout (standard output) is for normal program output
- stderr (standard error) is for error messages or other unusual output

Devices exercises

- Write a simple, non-blocking shell command to display 10 random bytes
solve exercise before proceeding
- Write a command to read input from your own terminal and display it on the terminal
- Write a command to read input from your own terminal and not echo back to the terminal

Devices exercises

- Write a simple, non-blocking shell command to display 10 random bytes

```
head --bytes 10 /dev/urandom | od -x
```

or

```
head -c 10 /dev/urandom | od -x
```

- Write a command to read input from your own terminal and display it on the terminal
solve exercise before proceeding
- Write a command to read input from your own terminal and not echo back to the terminal

Devices exercises

- Write a simple, non-blocking shell command to display 10 random bytes

```
head --bytes 10 /dev/urandom | od -x
```

or

```
head -c 10 /dev/urandom | od -x
```

- Write a command to read input from your own terminal and display it on the terminal

```
cat </dev/tty
```

- Write a command to read input from your own terminal and not echo back to the terminal

solve exercise before proceeding

Devices exercises

- Write a simple, non-blocking shell command to display 10 random bytes

```
head --bytes 10 /dev/urandom | od -x
```

or

```
head -c 10 /dev/urandom | od -x
```

- Write a command to read input from your own terminal and display it on the terminal

```
cat </dev/tty
```

- Write a command to read input from your own terminal and not echo back to the terminal

```
cat </dev/tty >/dev/null
```


Reading CDs and DVDs

- Mount a CD or DVD using `mount(1)`:

```
mount /dev/cdrw /mnt/tmp
```

- The device might be something else, such as `cdrom` or `dvd`. The mount point can be any directory and must already exist. It usually should be empty, because its contents won't be visible after the mount.
- The mount point, `/mnt/tmp/`, can then be used like any other directory. Though it is read-only, so it can't be modified.
- Unmount the filesystem using `umount(1)`:

```
umount /mnt/tmp
```

Writing CDs and DVDs

- CDs and DVDs usually contain ISO9660 filesystems
- Copy a directory hierarchy to a so-called iso image:
`mkisofs -DRU -max-iso9660-filenames -o image.iso directory`
- Mount an iso image so its contents can be viewed:
`mount -o loop image.iso /mnt/tmp`
 - On Macs, the command is:
`hdiutil attach image.iso`
`umount` as usual with `umount` (`hdiutil detach` on Macs)
- Burn an iso image to a CD:
`cdrecord -v dev=/dev/cdrw -data image.iso`
- Burn an iso image to a DVD:
`growisofs -dvd-compatible -Z /dev/dvd=image.iso`

Image files

- The ImageMagick package has useful utilities for viewing and manipulating image files
- View with display
 - left click to access modifications menus
 - right click to manage files
- Convert to different format with convert

```
convert foo.jpg foo.png
```
- List all formats supported by convert

```
convert -list format
```
- For more complex image manipulation, try gimp
- The ffmpeg package has useful utilities for viewing and manipulating video files

PDF files

- View pdf files with `xpdf(1)`
- Adobe has an old version of acrobat reader available at http://ardownload.adobe.com/pub/adobe/reader/unix/9.x/9.5.5/enu/AdbeRdr9.5.5-1_i486linux_enu.rpm
 - It's 32-bit, so might require many the installation of many library packages
- The `poppler-utils` package contains tools for manipulating PDF files, including:
 - `pdftotext(1)`
 - `pdfinfo(1)`
 - `pdfseparate(1)`
 - `pdfunite(1)`
 - `pdftotext(1)`
- `unoconv(1)` can convert documents to and from pdf

PostScript files

- Before PDF, PostScript was a widely used electronic document format
 - Both PostScript and PDF were created by Adobe
- Still used by printers
- And used as an intermediate format when converting text to PDF, e.g.,

```
enscript -Bp- foo.txt | ps2pdf - foo.pdf
```

- enscript(1) isn't always installed on modern systems

Unix and DOS files

- Unix files use ASCII LF (line feed, newline), hex 0A, to indicate the end of a text line
- Microsoft products use a two-character line end sequence: ASCII CR (carriage return), hex 0D followed by LF
- Mac OS X and later use LF, prior used just CR
- dos2unix(1) and unix2dos(1) convert files between the formats

```
dos2unix -n dos_file.txt unix_file.txt
```

```
unix2dos <unix_file.txt >dos_file.txt
```

- The ascii(7) man page lists the 128 ASCII characters and their hex values

Memory and processes

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Memory management

- `top(1)` shows current usage and uses of CPU and memory
- `free(1)` reports current memory usage, e.g,

- `$ free -h`

	total	used	free	shared	buff/cache	available
Mem:	7.5Gi	670Mi	4.6Gi	82Mi	2.3Gi	6.5Gi
Swap:	0B	0B	0B			

- `vmstat(1)` reports virtual memory statistics

Process management

- `top(1)` lists processes as well as CPU and memory utilization
- `ps(1p)` lists processes
 - `ps -efj | less`
 - To see all of your own processes: `ps x`
 - Options preceded with `-` are different than options not preceded with dash (BSD options)
- `pgrep(1)` searches for processes by name
- `kill(1p)` sends a signal to a process, see next slide
- `pkill(1)` kills processes by name

Process termination

- Ctrl-C or Ctrl-\ usually terminate the foreground process
- Background processes can be usually be terminated by looking up its pid and sending one of these signals:

```
kill -INT pid
```

```
kill -QUIT pid
```

```
kill -TERM pid
```

```
kill -KILL pid
```

- -KILL (or -9) should only be used as last resort, because it does not allow the process to perform any cleanup operations
- Some programs can also be killed with -HUP, but some other programs use -HUP to cause reload of a configuration file

Date and time

- UNIX times start (are 0) at midnight of January 1, 1970, the *epoch*
- The `date(1p)` command gets and sets the current system date and time
- A service, `ntpd`, is often used to synchronize the system date and time with known sources
 - `ntpq -p` can be used to query the status of `ntpd`

Timing a command

- The `time(1p)` command (also a built-in bash command) shows how long it takes to run another command
 - `time -p` provides a familiar output on many different systems
 - real (elapsed), user (CPU time spent executing the user program), and system (CPU time spent executing system processes on behalf of the user for the program)
- Example:

```
time -p sleep 2
```

produces

```
real 2.00
```

```
user 0.00
```

```
sys 0.00
```

bash

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The shell

- The shell provides a so-called command line
 - it waits for a user to enter a command, then executes the command
- You can do just about anything from the command line
- Most modern Linux installations default to the bash shell
 - Bourne-again shell
- Other shells include Bourne shell (/bin/sh), csh, tcsh, and Korn shell (ksh)
 - Shells are listed in /etc/shells, but it usually contains other programs that aren't useful for interactive, i.e., command line, use

Shell basics

- A shell provides the following capabilities:
 - a command prompt, where command are entered
 - \$ by default, but can be set to anything
 - ability to redirect input to and output from commands
 - < and > to redirect standard input and output, respectively, from a file
 - | to pipe the standard output of one command to the standard input of another
 - job control
 - parameter substitution
 - a language with conditional and iteration constructs

Types of commands

- Internal (built-in) command
 - When entered at the command prompt, the shell performs the command without loading it from a file
 - Includes control flow such as conditionals and iteration
 - Varies by shell, but often includes **echo** and **test**
- External command
 - Contained in a file, so must be loaded each time it is run
- Alias
 - An alias is just another name for a command
- Function
 - A function can be defined, that when run performs a sequence of specified commands

PATH search

- External commands are found on the user's PATH
 - PATH is an environment variable
 - PATH contains a colon-separated list of directories
 - When the file containing an external command must be found, the shell looks for it in each directory, in order, of the PATH
 - Not used if the file *absolute* or *relative* path
 - An absolute paths starts with /
 - A relative path contains at least one / but does not start with a /
 - Subdirectory, e.g., *foo/program*
 - Sibling directory, e.g., *../dir/program*
 - Current directory, *./program*
- To prevent an attack by a malicious program in current directory, do not include . in PATH

Job control

- Appending & to a command starts it in the background
 - If the command's standard input and error are redirected to /dev/null, it can be detached from the terminal, e.g.,

```
command >/dev/null 2>&1 &
```
 - 2>&1 redirects standard error to the standard output stream
- Ctrl-z followed by bg(1p) can be used to move the foreground job to background
- fg(1p) brings a background job to foreground

Command history

- bash stores the history of commands
 - View using the history built-in command
 - Saved in file named by \$HISTFILE
 - Defaults to ~/.bash_history
 - Disabled by unsetting HISTFILE
- Can be navigated at command prompt using Ctrl-p, Ctrl-n, Ctrl-r, Ctrl-s, etc.

Shell variables

- Shell variables are assigned with =, without any spaces, e.g.,

```
myvar=foo
```

- Be sure to quote values with special characters

```
myvar='foo bar'
```

- The value of a shell variable is accessed by preceding the name with \$

```
echo $myvar
```

- Brace expressions can provide a default or alternate value, see Parameter Expansion in the bash(1) man page

```
echo ${myvar:+replacement value}
```

Environment variables

- Every program execution has an *environment*, which includes *environment variables*, each of which is a unique name and a (possibly null) value
- Shell variables can be designed to be in the environment

```
export MY_PORT=1000
```

 - bash allows combined assignment and export, Bourne shell separates them
- A program cannot modify its parent's environment
- A parent's environment is passed to its children
 - At the time the child is forked: subsequently changing the parent's environment does not alter the environment of the child process

Environment control

- The source (or `.`) built-in command can update the current environment from commands in a file

```
echo ${X:-X not set}
```

```
cat >/tmp/X <<<X=x
```

```
. /tmp/X
```

```
echo ${X:-X not set}
```

- The `-i` option to `env(1p)` suppresses the environment transfer from parent to child

```
env -i program
```

and add specific settings

```
env -i FOO=bar program
```

Shell variable exercise

- What is the output from the first and last of this sequence of commands?

```
echo ${X:-X not set}
```

solve exercise before proceeding

```
echo X=x >/tmp/X
```

```
. /tmp/X
```

```
echo ${X:-X not set}
```

solve exercise before proceeding

Shell variable exercise

- What is the output from the first and last of this sequence of commands?

```
echo ${X:-X not set}
```

```
    X not set
```

```
echo X=x >/tmp/X
```

```
. /tmp/X
```

```
echo ${X:-X not set}
```

```
    x
```


Shell aliases

- Shell aliases are typically defined in an initialization file so that they are always available
- A common alias is 'rm -i' for rm(1p), so that it prompts for every removal

```
alias rm='rm -i'
```

- Can an alias be bypassed? How do I remove many files at once without responding to the prompt for each?
 - Prepending a backslash to the command bypasses its alias:

```
\rm -fr foo
```
 - Alternatively, the full path to an external command can be used to bypass the alias:

```
/bin/rm -fr foo
```

- An alias can be removed with unalias

bash initialization files

- Per user:
 - `~/.bash_profile` is sourced for the user's login shells
 - `~/.bashrc` is also sourced by each new interactive shell
- System wide:
 - `/etc/profile` is sourced for login shells
 - Other files, such as `/etc/bashrc` and the files in `/etc/profile.d/`, may be sources as well
- Cleanup files can also be created, see the FILES section of the `bash(1)` man page

Shell command prompt

- Default command prompt is \$ for Bourne shell and derivatives
 - Except it is # for superuser
 - Can be changed by setting PS1 through PS4 parameters (variables)
- The bash function on the next slide can be used to customize the primary bash command prompt
 - To always enable it, add the function to your ~/.bash_profile
 - To try it once, put it in a file and **source** the file
 - See PROMPT_COMMAND shell variable description in the bash(1) man page for more information

bash function to customize prompt

```
if [ "$PS1" ]; then
    export PROMPT_COMMAND=prompt_command
    function prompt_command() {
        local exit_status=$?
        local reset='\[\e[0m\]'
        local red='\[\e[1;31m\]'
        local yellow='\[\e[0;33m\]'
        local blue='\[\e[0;34m\]'

        if [ $exit_status = 0 ]; then
            #### hostname in blue, directory in yellow
            PS1="${blue}\h ${yellow}\W${reset}$ "
        else
            #### plus exit status of previous command, all in red
            PS1="${red}[exit ${exit_status}] \h \W${reset}$ "
        fi
    }
fi
```

bash tidbits

- `~` expands to the user's home directory when encountered by the shell in appropriate context
 - Bourne shell does not have this expansion
- `{x..y}` is the sequence of numbers from `x` to `y`
- `$((expr))` evaluates an integer math expression
 - For floating point, use `bc(1p)`, `bc -lq`
- `(command)` executes `command` in a *subshell*
 - To run in a different environment, employ complex output redirection, and other obscure purposes
- The bash man page has nearly 6,000 lines of useful information

bash exercises

- Write a one-line command sequence to print “done” after 30 seconds

solve exercise before proceeding

- How do you execute a program named **xyz** in your current directory (assuming no . in your PATH)?

bash exercises

- Write a one-line command sequence to print “done” after 30 seconds

```
sleep 30 && echo done
```

or less concise

```
if sleep 30; then echo done; fi
```

- How do you execute a program named **xyz** in your current directory (assuming no . in your PATH)?

solve exercise before proceeding

bash exercises

- Write a one-line command sequence to print “done” after 30 seconds

```
sleep 30 && echo done
```

or less concise

```
if sleep 30; then echo done; fi
```

- How do you execute a program named **xyz** in your current directory (assuming no . in your PATH)?

```
./xyz
```


Shell scripts

- If you're going to perform a sequence of commands more than once, put them in a file, called a shell script
- Check each command for success
 - In bash and other Bourne shell derivatives, can exit execution of the immediately on any failure by setting `-e` shell variable in (near the top of) the shell script
`set -e`
- `true(1p)` and `false(1p)` for avoiding or forcing their respective exit status
 - E.g., to proceed if no errors in a log file:
`grep -iq error logfile || true`

Shell (script) facilities

- Conditionals (if, &&, ||), iteration (for, while, until)
 - && and || allow concise conditional execution, e.g.,
`grep -q foo file && echo found || echo not found`
- Input (<) and output (>, >>) redirection, pipes (|)
 - > overwrites output file, >> appends to it
- *Here documents* and *bash here strings* allow in-line provision of text input, e.g.,

```
cat >file <<-EOF
```

```
    this text input will be redirected to the file  
EOF
```

Basic output

- `echo(1p)` outputs its argument
 - Most shells contain a built-in version, which may be slightly different
 - Examples:
- `printf(1p)` outputs using C-style formatting
 - bash contains built-in version
 - Example, to print hex value of a decimal number:

```
echo $LESS
```

```
echo $((6*7))
```

```
printf '%x\n' 255
```

Output redirection

- bash supports redirection of output in every imaginable way, and then some. Some very simple examples:
 - redirect stdout to file: `command >file`
 - redirect stderr to file: `command 2>file`
 - redirect stdout and stderr to same file: `command &>file`
or: `command >file 2>&1`
 - stdout is buffered but stderr is not, so they may be interleaved messily
 - redirect stderr through pipe: `command1 |& command2`
or: `command1 2>&1 | command2`
 - redirect stdout to stderr: `command 1>&2`

Command substitution

- Command substitution executes a command and provides its output
 - Bourne shell provides backticks, ``
 - bash also provides `$()`, which can be embedded
- Examples

```
start_dir=`pwd`
```

```
myid=$(id -u)
```

find(1p) and xargs(1p)

- find(1p) searches for files meeting specified criteria
 - The criteria can include properties such as filename, permissions, type, owner, group, size, and time of creation, last update, or last access
- xargs(1p) applies an operation to the arguments fed to its standard input
- Together, find and xargs provide a powerful tool to search files for specified content
 - Example, find all .txt files under my home directory that contain the string *Foo*

```
find ~ -name '*.txt' -print0 | xargs -0 egrep -l Foo
```
 - The print0 option to find and -0 option to xargs allow proper handling of filenames with special characters

Living on the command line

- `bc(1p)` calculator

`bc -lq`

- `cal(1p)` calender

`cal -3`

- `date(1p)` shows the current date and time

- And components can be selected with the `+` format option
- To show seconds since epoch:

`date +%s`

Command-line word lookup

- Here is a bash function to provide command-line access to online dictionary:

```
function dict() {  
    # First parameter is word to look up. Can be optionally be  
    # appended with :database.  
    # Second, optional, parameter is either d (define), m (match),  
    # or show (for first arguments of db or strat).  
    curl dict://dict.org/${2:-d}:$1  
}
```

- To set up, add that function to your `~/.bash_profile` and source it

```
. ~/.bash_profile
```

- To use:

```
dict word
```


Networking

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Networking: hosts

- Every node (machine) on an Internet network has an address
 - IPv4: 32 bit address, e.g., 10.0.0.1
 - IPv6: 128 bit address, e.g.,
2601:018f:0902:7700:0000:0000:0000:0004
- Names are more convenient than numbers, so they are mapped to addresses using host tables and domain name service (DNS)
 - The host table is stored in file `/etc/hosts` and/or is available from DNS servers
 - DNS servers are listed in `/etc/resolv.conf`(5)
 - View with `getent hosts` or `host(1)`
- Local host is 127.0.0.1 (IPv4) and `::1` (IPv6)

Networking: ports

- Each host can offer services on ports, numbered 1 through 65535
- Names are more convenient than numbers, so they are mapped to services using a services file and network resources
 - The services table is stored in file `/etc/services` and/or is available from network servers
 - View with `getent services`
- Examples of ports include:
 - 22 for ssh
 - 80 for http
 - 443 for https

Networking: protocols

- A protocol is a standardized arrangement for data
- Internet Protocol (IP) forms the foundation for the Internet by supporting addressing and routing
- Transmission Control Protocol (TCP) provides reliable connection-oriented message communication using IP
- User Datagram Protocol provides datagram communication using IP
 - connectionless, unreliable
 - A datagram includes a header and payload (data)

Web file retrieval

- curl(1) and wget(1) retrieve web content

```
curl -O url
```

```
wget url
```

- w3m(1) and lynx(1) can be useful for quick viewing of a web page or html file

ssh

- ssh runs a shell on a remote machine using an encrypted connection
- ssh is safest to use with public-private key pair
 - ssh-keygen(1) can generate the key pair
 - Some installations disable use of passwords
 - Some installations disable remote logins by root
- Two options are useful, but only use on trusted networks:
 - -X option forwards X11 session, allowing remote windows
 - -A option forwards authentication agent (ssh-agent) connection
- scp can copy files and directories to/from remote machines; it is useful when rsync is not installed

ssh-keygen

- Example usage:

```
ssh-keygen -t rsa [-f keyfile]
```

- Keys are stored in `~/.ssh` directory, which should not be accessible by others

```
chmod go-rwx ~/.ssh
```

- it's good practice to create a separate key pair for each group of remote hosts that you use
- Never allow anyone else to access any of your private keys
- Public keys may be provided to others. If added to the `~/.ssh/authorized_keys` file on a remote machine, you will be able to access the account on that machine without a password

Networking tools, basic

- ping(1) can tell you if you can reach a host
 - Unless the host has disabled ping responses
- traceroute(1) can show you the path to a host
- tcpdump(1) captures network packets
 - Should specify the network interface or **any**
 - Has many options to, e.g., write or read captures to a file, filter packets by host or protocol, display numbers instead of names, display the packet contents. A simple example is:
`tcpdump -i any -s0 -w all_traffic.pcap not arp`

Networking tools, for testing

- telnet(1) attempts to open a TCP connection to a host
 - To see if sshd is running on a specific host:
`telnet 10.0.0.2 22`
- nc(1)/ncat(1)/netcat(1) create a trivial TCP or UDP client or server
 - Input/output can be redirected from/to a file
 - Example UDP server/client pair, in separate windows or on separate machines:
`nc -lu 5500`
`nc -u localhost 5500`
 - To terminate, Ctrl-d in client and Ctrl-c n server

Networking configuration

- ifconfig(1) lists all (active) network interfaces
 - -a option adds inactive interfaces
- To list all Internet addresses of the host:

```
ifconfig | egrep 'inet '
```

- To bring an interface up:

```
ifup ifname
```

- To bring an interface down:

```
ifdown ifname
```

- To list all routes from the host:

```
route
```

or

```
netstat -rn
```

System administration

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User accounts

- Every account has a name, sometimes called a *login*
- The `/etc/passwd` file, and/or a directory service, maintains the accounts on a system
 - `getent(1)` shows account information
`getent passwd [name ...]`
- Each account can be a member of any number of groups
 - `getent(1)` shows the members of a group
`getent group [groupname ...]`
- Internally, accounts and groups are represented by numbers
- `id(1p)` shows the numbers, and group memberships of any account

The superuser and su command

- Unix and Linux systems have a privileged user account
 - referred to as the superuser
 - login (account) name is **root**
 - can perform any operation on the system
 - strictly minimize use, and use carefully
- The su command allows a user to substitute as another user, including the superuser.
 - requires the user, other than the superuser, to know the password of the substitute user account
 - superuser can substitute as any other user without knowing their password
 - su discouraged in favor of sudo

sudo command

- The sudo (**s**uperuser **d**o) command is the preferred mechanism to execute a command as another user, including the superuser.
 - does not require password of substitute user account
 - does require setup
 - tracks usage in, typically, /var/log/secure
 - To run a command as superuser, just prepend with sudo, e.g.,
sudo less /var/log/secure
- Setup is via files added to /etc/sudoers.d
 - edit them using sudoedit, for safety

RPM package management: rpm

- Red Hat-based systems use rpm and dnf for package management. rpm can refer to:
 1. the rpm (RPM package manager) system
 2. the rpm program
 3. an actual package file
- All software on the system is packaged into package files, which have a .rpm extension.
 - rpm files are stored in cpio format, if low-level manipulation is needed
 - a software package may comprise multiple rpms, e.g.,
 - bzip2-1.0.6-28.fc29.x86_64
 - bzip2-devel-1.0.6-28.fc29.x86_64
 - bzip2-libs-1.0.6-28.fc29.x86_64
 - bzip2-static-1.0.6-28.fc29.x86_64

RPM package management: rpm

- The rpm program can be used to install, remove, or upgrade packages on a system. It can also be used to query installed packages and to query an rpm file. E.g.,

```
rpm -ivh rpm-file
```

```
rpm -e package
```

```
rpm -q package
```

- rpms are built from source rpm packages
 - the rpm-build program can be used for the build
 - source rpm files have .srpm file extensions
- The rpm program should usually not be used directly
 - instead, use dnf

rpm examples

- show the info of an rpm

```
rpm -qip foo.rpm
```

- list the files that would be installed by an rpm

```
rpm -qlp foo.rpm
```

- list the dependencies of an rpm

```
rpm -qp -R foo.rpm
```

- For each of the above, remove the `p` to query an installed package

- list the actual contents of an rpm

```
rpm2cpio foo.rpm | cpio -it
```

- extract `/etc/bar.cnf` from an rpm

```
rpm2cpio foo.rpm | cpio -imdv ./etc/bar.cnf
```

rpm exercises

- List all of the rpms installed on a system
solve exercise before proceeding
- List the information about, and files contained in, the installed **words** rpm
- List the information about the package that contains the **w** command

rpm exercises

- List all of the rpms installed on a system

`rpm -qa`

- List the information about, and files contained in, the installed **words** rpm

solve exercise before proceeding

- List the information about the package that contains the **w** command

rpm exercises

- List all of the rpms installed on a system

```
rpm -qa
```

- List the information about, and files contained in, the installed **words** rpm

```
rpm -qil words
```

- List the information about the package that contains the **w** command

solve exercise before proceeding

rpm exercises

- List all of the rpms installed on a system

```
rpm -qa
```

- List the information about, and files contained in, the installed **words** rpm

```
rpm -qil words
```

- List the information about the package that contains the **w** command

```
rpm -qif $(type -p w)
```

RPM package management: dnf

- To address deficiencies of rpm, especially with package dependencies, yum (Yellowdog Updater, Modified) was developed
- dnf (dandified yum) has replaced yum, with the same subcommands

```
dnf install package
```

```
dnf localinstall rpm-file
```

```
dnf upgrade package
```

```
dnf remove package
```

```
dnf whatprovides glob
```

dnf exercises

- What does this command do?

```
dnf whatprovides *bin/valgrind
```

solve exercise before proceeding

dnf exercises

- What does this command do?

```
dnf whatprovides *bin/valgrind
```

It lists all of the packages that provide a valgrind program, e.g.,

valgrind-1:3.14.0-7.fc29.x86_64 : Tool for finding memory management bugs in programs

Repo : updates

Matched from:

Other : *bin/valgrind

Service control with service(1)

- System V-based systems, including RedHat 6 and earlier, use System V init scripts to control system services
 - Scripts in `/etc/rc.d/` subdirectories are used to start, stop, and check the status of each service
- Init scripts are run at system startup to start services in proper order
- After startup, an init script can be used at any time, e.g.,

```
/etc/rc.d/init.d/network status
```

```
/etc/rc.d/init.d/network restart
```
- The service command is the preferred way to run init scripts

```
service network status
```

```
service network restart
```
- `chkconfig(1)` can be used to manage the scripts
 - add, del, on, off, etc.

Service control with systemctl(1)

- RedHat 7 and later use systemctl(1) to manage services
 - systemd(1) manages the services
 - systemd is the first running process, so it has pid 1
- systemctl controls systemd, e.g.,
 - `systemctl status network.target`
 - `systemctl restart network.target`
- To list all services:
 - `systemctl list-units`
- systemd logs events to a journal, which can be queried using journalctl(1)

systemd

- The first process launched after boot is systemd(1)
 - All other *units* are *activated* by systemd
 - See systemctl(1), including its list-units command
- systemd replaces the System V init(1) command
 - init uses the concept of runlevels, which can vary but typically include:
 - 0: power off
 - 1: single user, without network
 - 2: multi-user without network
 - 3: multi-user
 - 5: multi-user with display manager, such as using X server
 - 6: reboot
 - telinit(1) changes runlevel

fork and exec

- All programs are launched using the fork and execve system calls
- fork(3p) creates a new *child* process that is an exact copy of the *parent* process, but with a different process ID (pid)
- execve(3p) executes a program
 - The C library contains wrappers such as exec(3), execl(3), and execv(3)
 - support different arrangements of program arguments
 - support PATH searching
 - support provision environment
- pstree(1), ps -eH, and ps axf show how all user processes descend from systemd

Name service configuration

- `/etc/nsswitch.conf(5)` configures each name service
- For example, this entry directs `passwd` information to be provided by `sss` (System Security Services Daemon) and `files` (`/etc/passwd`), in that order:

```
passwd: sss files
```
- Another example is this entry, which provides host information from `files` (`/etc/hosts`) and `DNS`, in that order:

```
hosts: files dns
```
- `getent(1)` obeys `nsswitch.conf`, providing quick access to the information provided by each name service

Name service exercises

- How can you view the passwd information of your own login?

solve exercise before proceeding

- How can you view all (both IPv4 and IPv6) of the information about your local host?

Name service exercises

- How can you view the passwd information of your own login?

```
getent passwd $(id -u)
```

- How can you view all (both IPv4 and IPv6) of the information about your local host?

solve exercise before proceeding

Name service exercises

- How can you view the passwd information of your own login?

```
getent passwd $(id -u)
```

- How can you view all (both IPv4 and IPv6) of the information about your local host?

```
getent hosts | grep localhost
```

or

```
getent hosts localhost ::1
```


Shutdown

- For systems with `poweroff(1)` and `reboot(1)`, they can be used from the command line to turn off or reboot, respectively
- Through the GUI, there should be shutdown and reboot selections
- The GUI may have a power button
 - red
 - with a 0/1 indication
- Older systems use the `shutdown(1)` command
`shutdown -h now`

Software development tools

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Software build

- A traditional software build process includes configure, build, test, install
 - configure can be used to customize install directories, compile and link options, etc.
 - make runs the compile and link
 - make *targets* are typically used to test, install, clean up, etc.
- On one line:
`./configure && make && make test && make install`

Software analysis tools

- For dynamic (run-time) testing of native binaries, valgrind is indispensable
 - just prepend the invocation with valgrind
 - valgrind can significantly slow down execution, so it's not suitable for real-time programs
- Run-time profiling can help isolate performance bottlenecks
 1. Compile and link with -pg
 2. After execution, analysis with gprof
- <http://brendangregg.com/linuxperf.html>

Debugging symbols

- Programs must be compiled with an option, such as `-g`, to include debugging symbols in the linked file
- `strip(1p)` removes the debugging symbols, if desired at a later time
- `size(1)` shows the size of the program, excluding debugging symbols
- A debugger such as `gdb(1)` can run the program under precise control
 - breakpoints, to stop execution at specified points such as functions or source code locations
 - watchpoints, to stop execution on specified conditions such as variable values

Execution tracing

- `strace(1)` shows the system calls executed by a process
 - For example, to show all `openat(3p)` calls executed by `ls(1p)`:
`strace -e trace=openat ls`
- `ltrace(1)` shows the library calls executed by a process
- Both put their output on the standard error stream

Symbols

- nm(1p) shows the symbols in a binary object file
 - An object file is compiled code
 - Includes linked objects, which results in an executable binary file
 - excludes shell scripts
 - Symbols include names of data and functions
 - These names may be *mangled*, i.e., decorated with additional information such as function parameter types
 - Functions were originally named without any of their arguments, preventing overloading

Source code (version) control

- Source code control systems manage all **versions** of files and, with some systems, directories
 - support retrieval of any version at any time
 - support comparison of versions of text files
- Useful for more than code, such as documents, spreadsheets, and any other files that change
- Some support simultaneous updates by multiple users
- Usually view version history as a tree with multiple branches
 - merge changes from one branch to another
 - typically one branch has designation such as main or master

git

- Developed in 2005 by Linus Torvalds in response to restrictive licensing of existing systems
- Pros: popular, powerful, free and open source, geared to multiuser environments, supports off-line use
- Cons: steep learning curve
- Githubs are commonly used for software distribution
 - e.g., <https://www.github.com/>

Basic git commands

- git init
 - one-time setup of local git repository
- git add
 - stage files/directories for commit to local repository into an *index*
- git commit
 - commit the index
- git pull/push
 - synchronize local repository with remote repository
- git status
 - view state of index
- git log/whatchanged
 - view history of local repository
- git diff
 - view changes, such as uncommitted changes in workspace

git bisect

- Bisect is an invaluable capability
 - Narrows down change in behavior (bug) to single commit
- Usage: initialize, then repeatedly checkout and test a version between known good and bad points

```
git bisect init
```

```
git bisect good
```

or

```
git bisect bad
```

- Can streamline with git run if a test program is provided
- To finish:

```
git bisect reset
```

User versus kernel space

- Memory regions that are in use by the kernel is referred to as *kernel space*
- Memory regions that have been allocated to a user program are referred to as *user space*
 - By default, memory allocated to one program cannot be accessed by other programs
 - Memory can optionally be *shared* with other programs

How do applications access the OS?

- The OS interface is accessed through *system calls*
 - Applications invoke a system call just like any other function call
 - Each system call is documented in a man page, in section 2 of the system manual
 - Example: the unlink system call removes a (file or directory) name from a filesystem
 - Its signature is `int unlink (const char *)`
 - Its one argument is the name and it returns a integer status
 - If the name has no more links and doesn't refer to a file that is opened by a running process, the file is removed

System call return values

- System calls often return an integer
 - Called a return value or status
- 0 indicates success
 - If a request was made, then it was performed successfully
- Non-0 indicates failure
 - The man page describes possible values and their meanings
 - The global variable `errno` is often set to provide further information on the failure
 - The man page for the particular system call lists the possible values
 - The `errno.h(0p)` man page lists the usual meanings for each value

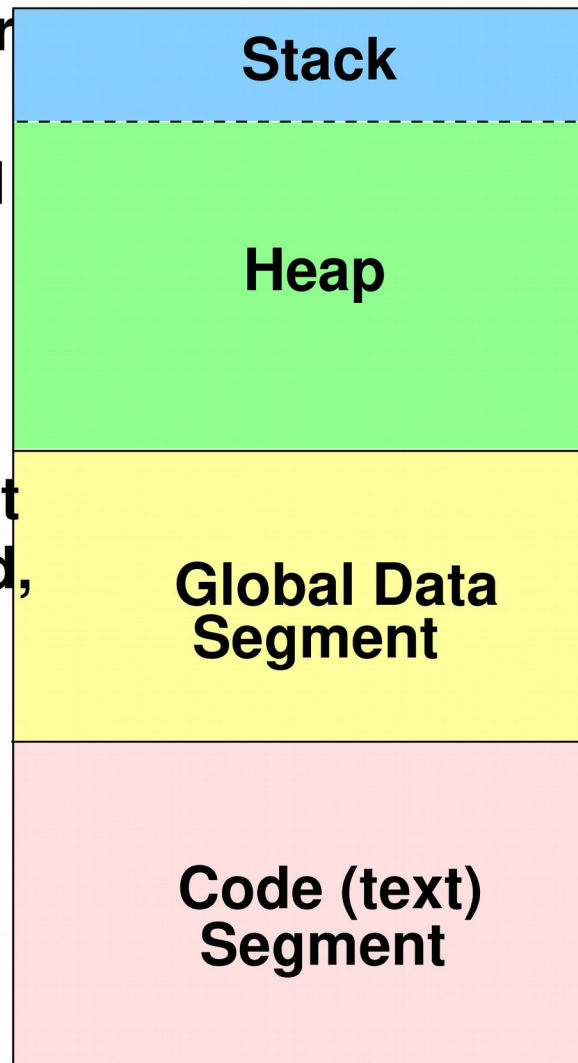
Program memory layout

memory managed by
compiler: used for
each function call

memory managed
explicitly by
application (new/
delete)

global data: object
locations are fixed,
but their values
can be modified

code: read-only



function params,
local objects

dynamically
allocated
objects

global objects

function definitions