UNIX

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Overview

History
Practicalities
User Interface
Shell
Toolbox
Processes
Users, Groups
File System
Development System
Cluster Computing

UNIX / Linux History

1969

- UNIX at Bell Labs (antithesis to MULTICS, Thompson, Ritchie, et al.)
  goals: simple & general time sharing system which supports
  programming, authoring, collaboration
- (Re)written in C (→ portable), internal use only (chance to mature)

Thompson & Ritchie @ PDP-11

UNIX / Linux History

1970s

- Given to universities → BSD
- Commercialization → System V

- Concepts
  simplicity, "everything is a file", toolbox (small specialized utilities, shell = glue)

1980s – early 2000s

- Widespread adoption by market, UNIX wars + diversification (DEC, HP, IBM, SGI, SUN, ...)
  → Standardization (POSIX)
- HPC: graphical RISC workstations & servers, Vector Computers

SGI Personal IRIS

Convex C220

UNIX / Linux History

1990 - 2010s Linux

- GNU core utilities & toolchain (reimplementation of UNIX utilities & compilers), but no kernel
- Linus Torvalds develops new kernel and ports GNU utilities → GNU/Linux
- widespread adoption by end users, academia, and industry
- runs on commodity hardware (mobile devices, desktops, large computers)
- diversification + bloat (distributions, uncontrolled development + duplication of features)

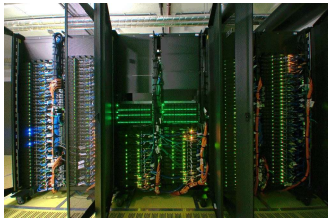
Important UNIX versions 2010s: Linux, 4.4BSD, AIX, Solaris, macOS

In this turorial:

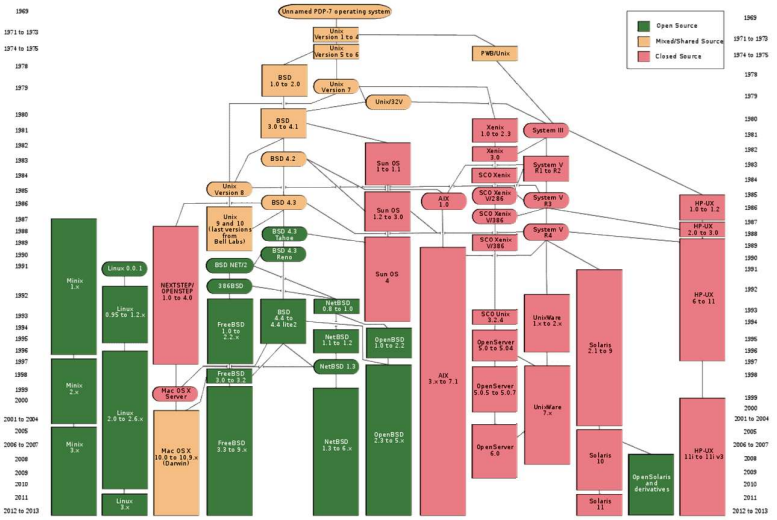
UNIX generically refers to any type of UNIX-like OS
Linux specifically refers to GNU/Linux

HPC and Linux

- Beowulf clusters (Donald Becker, Thomas Sterling)
  networked commodity machines
- HPC Clusters
  Small SMP machines coupled by high performance interconnect (IB)
  Parallel programming using message passing (MPI)
- Shared Memory Systems (SGI Altix, Ultraviolet)
  SMP → ccNUMA
  100s-1000s CPUs share large memory (10s TB), single OS instance



UNIX / Linux History



UNIX heritage tree (simplified)

Relevance
many implementations of the same utilities (portability issues)

Linux: GNU utilities
have been ported to many other platforms

UNIX - basic concepts

OS Layer Model

- Kernel
  - Process management (schedule processes)
  - Memory management (for processes and devices)
  - File system (files and directories)
  - Device drivers (disks, terminals, networking etc.)
- All interaction through System Calls
- Library Calls provide abstracted interface

Everything Is A File

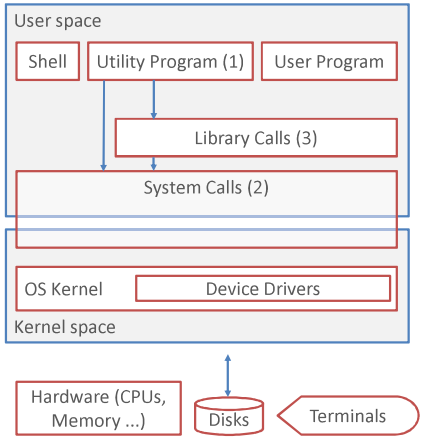
Files, Terminal I/O (/dev/tty), Disks (/dev/sdx) ...

Technically, shell, utility programs, and user programs are on the same level

Utility programs: simple, specialized:

- "just do one thing" (e.g. copy file, edit text, search text ...)
- do work silently → can use utilities to build programs
- brief error messages identifying root cause of error

Shell: provides interactive + programmable interface to OS, used to orchestrate utilities and user programs



Accessing a Server

Server

- get account (workgroup: sysadmin; large sites: apply for account)

Preparing your workstation

Linux

- make sure X11 + openssh-client are installed
- $HOME/.ssh/config: `ForwardX11 yes`

- using: start terminal emulation (e.g. xterm) and issue `ssh hostname.domainname`

Windows

- Install ssh client (includes terminal emulation - putty) and X11 server (Xming + Xming-fonts)
- putty: enable X11 forwarding (connection/ssh/X11)

- using: start putty (and Xming if needed) and enter `hostname.domainname` in Host Name field

Common Commands, Working with Files

• Change password	`passwd`	
• Log out	`exit`	
• Read documentation	`man command`	display the “man-page” for *command* (./..)
• Display contents of file	`cat file [...]`	copy contents of all named files to terminal window
	`less file [...]`	browse file contents
• Edit text file	`nano file`	many other editors available.
	`vi file`	UNIX standard editor (Linux: replaced by vim) (*)
		(Bill Joy: An Introduction to Display Editing with Vi)
	`nedit file`	NCSA editor (graphical, needs X11)
• List words in command line	`echo word [...]`	useful for checking and debugging

(*) not easy to learn, very powerful, very popular,
only editor that works well on slow network connections

Using Less to Browse Files and Man Pages

`less [option ...] [file ...]` browse contents of named *files* or stdin. man uses less to display man page

`-c`	repaint screen from top of window
`-i`	ignore case in searches
`-s`	squeeze multiple blank lines

default options may be set in environment variable $LESS

commands while browsing (single key stroke - similar to vi) - may be prefixed with number *n*

`h`	help
`q`	quit
`f ^F SPACE`	scroll forward *n* lines (default: full screen)
`b ^B`	scroll backward - " -
`d u`	scroll forward / backward *n* lines (default: half screen)
`j k`	scroll forward / backward *n* (default: 1) lines
`r ^R ^L`	repaint screen
`g`	go to beginning of file
`G`	go to line *n* (default: end of file)
`F`	go to end of file and watch it growing (terminate with ^C)
`/pattern ?pattern`	forward / backward search for *pattern*
`n N`	repeat previous search in opposite direction
`ESC u`	undo highlight of search results
`:n :p :x`	view next / previous / first file
`^G`	view info about current file (name, size, current position)

Using vi and vim to Edit Files

`{vi|view|vim} file [...]` invoke standard UNIX editor vi (edit/readonly) or its improved derivative vim

Concept

Editor has three modes:
- insert mode (text entry): start with commands like `i a` (insert, append), end with `ESC` key
- command mode (cursor movement, text buffer manipulations): shorthand English
  many commands can be prefixed with number *n*
- command line entry: start from command mode with `:` , end with `ENTER` key

Commands	Mnemonic	Function
`h j k l`	keys next to each other	cursor movement ← ↓ ↑ → (j think ^J) one (*n*) characters
`0 $ ENTER`	$ matches EOL in regex	cursor to beginning / end of current line, beginning of text in next line
`H M L`	home middle last	cursor movement to first, middle, last line in window
`w b W B`	word back	cursor movement one (*n*) words forward / backwards; nonblank words
`^F ^D ^B ^U`	forward down backward up	scroll forward (full page, half page), backward (full page, half page)
`^E ^Y`	end (?)	scroll forward, backward one (*n*) lines: cursor stays put
`zENTER z.`	zap	scroll current line to beginning/center of window, cursor stays on line
`i a I A`	insert append	start insert mode before/after cursor; “beginning” / end of current line
`x dw dnw dd D`	scissor, delete...	delete character, word, *n* words, rest of current line
`s ns S`	substitute	start insert mode, overwriting 1, *n* characters, entire line
`cw cnw C`	change	start insert mode, overwriting 1, *n* words, rest of current line
`:w :w!`	write	write current file, force overwrite even if readonly
`:q :q!`	quit	quit, force quit discarding changes
`ZZ :x`	eXit	write file if changes were made, then quit.

Recommendation: to avoid clobbering files, do NOT use `wq`, NEVER EVER use `wq!`
Why: wq modifies file although no changes were made; wq! forces inadvertent changes to go to file

Further vi Commands and Remarks

More cursor movement commands

Commands	Mnemonic	Function
`fc tc`	Find character *c*, up To *c*	move cursor to first (n'th) instance of *c* or to preceding character
`Fc Tc`		same to the left
`; ,`		repeat last f or t in same / opposite direction
`/stringENTER`	/ delimits regex	forward search *string* (actually regex) in file
`?stringENTER`		backward search *string* in file
`n N`		repeat last search in same / opposite direction

Deleting, copying and moving text

Structure of commands: single-letter commands d y c take address (cursor movement command) as argument
doubling command dd yy cc refers to entire line, prefix (*n*)

Commands	Mnemonic	Function
`caddress cc S ncc`	change	change text from cursor to *address*
`daddress dd ndd`	delete	delete data, copy to unnamed buffer
`yaddress yy nyy`	yank	copy data to unnamed buffer
`p P`	put	insert buffer contents after / before cursor

Using named buffers: prefix these commands by `"c` (single character a-z: 26 named buffers)

Recommended reading

Bill Joy, “An Introduction to Display Editing with Vi”
vim online documentation

Getting Information - Accessing System Documentation

UNIX man pages and GNU documentation

`man [section] name`	view description of command or utility *name* in *section* (default: first found)
`man section intro`	view introduction to *section*
`man -k string`	search man pages for *string*
`info [name]`	start GNU info browser
`info [name] | less`	browse GNU documentation for *name* (if installed by sysadmin) using `less` as browser

man sections

1 user commands
2 system calls (interface to operating system kernel)
3 library functions
4 special files (interface to devices)
5 file formats
6 games
7 miscellany
8 administrative commands

Referring to documentation

In texts: *name*(*section*) e.g.: The ls(1) command lists files and directories.
The fopen(3) library routine internally uses the open(2) system call

Working with Directories

Concepts

Data organized in tree structure, starting at "root" (/), "directory" ≈ "folder"
Each file and directory has full (absolute) path starting with / . example: `/home/c102mf/mydir/myfile`
Path components separated by / character
File names are case sensitive
CWD (current working directory): starting point for relative path

Example: if CWD = `/home/c102mf/mydir` then `myfile` → `/home/c102mf/mydir/myfile`

Special directories

`$HOME`	your HOME directory. CWD after login	
`.`	this directory	present in every directory
`..`	parent directory	present in every directory

e.g. if CWD = `/home/c102mf/mydir` then `./myfile` → `/home/c102mf/mydir/myfile`
`../myfile` → `/home/c102mf/myfile`

Commands

Display working directory	`pwd`	or `/bin/pwd`
List directory contents	`ls [-l] [-a] [-R]`	(`-l` display attributes `-a` include „hidden" `-R` recursive)
Create directory	`mkdir name`	
Change working directory	`cd [name]`	(default: `$HOME`)
Remove directory	`rmdir directory`	*directory* must be empty

Copying, Moving, and Deleting Data

Commands

Copy files	`cp file1 file2`	copy contents of *file1* to *file2*
	`cp file [...] directory`	copy *files* to target *directory*
	`cp -r [-p] [-a] dir1 dir2`	recursively copy directory (`-p` keep permissions `-a` keep everyting)
Rename or move files	`mv file1 file2`	rename *file1* to *file2*
	`mv name [...] directory`	move named *files* or *directories* to target *directory*
Remove (=delete file)	`rm [-i] [-f] file [...]`	remove named *files* (`-i` ask before removing)
	`rm -r [-f] directory`	recursively remove *directory* and all of its contents (`-f` force, suppress errors)

Note: removing a file does not free the occupied space if the file is still held open by a running process.

Understanding File Systems & Capacity

Concept

File system = collection of files + directories on partition (or disk or disk array)
Capacity of file system (data + metadata) limited by size of partition
All file systems organized in tree (mount points)

Commands

`df [-h]`	display mount point and capacity of all file systems (`-h` human readable)
`df [-h] .`	display file system info for working directory
`quota -v`	display your file system quota (if defined by sysadmin)

Transferring Files Between Workstation and Server

Windows use WinSCP graphical client

Note Text file format differs between
UNIX (Lines separated by LF) and
Windows (Lines separated by CRLF)

Use TEXT MODE for text files and BINARY MODE for binary files
STANDARD MODE often guesses wrong - will damage binary files

Linux use scp (command line, similar to cp) or sftp (interactive)

```
scp file [...]  user@server:[targetdirectory]          upload files
scp -r directory [...]  user@server:[targetdirectory]  upload directories

scp user@server:[directory]/file [...]  targetdirectory  download files
scp -r user@server:directory [...]  targetdirectory      download directories

sftp user@server          start interactive file transfer session
    { cd | lcd } directory  remotely / locally change to directory
    get file [localfile]    download
    put file [remotefile]   upload
```

Motivation: Understanding the UNIX Toolbox

UNIX design principles

Main interface: Shell = command interpreter (interactive + programming language)
makes functionality of UNIX kernel available to user

shells POSIX shell (portable), bash (standard Linux shell, ported to many UNIXes), many others

Individual utilities (ls, cp, grep .....) do the work

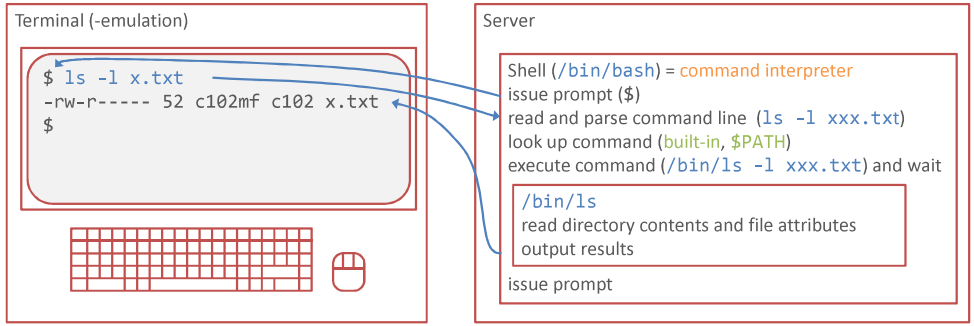
- external programs, simple + specialized
- standardized data flow model: read data from stdin or set of files given in command line
  write data to stdout - can be used by other programs or shell
  most utilities avoid side effects: usually do not modify other files

Shell = glue. Orchestrates utilities & puts them to work

- Controls execution of programs: start, foreground, background
- Assembles command lines: from command line arguments typed by user
  can create list of files from wildcards (e.g. *, ?)
  can use output from other commands
  to create parts of or entire command lines (command substitution)
- Establishes data flow between programs: I/O redirection, pipelines
- Full-featured programming language: variables, loops, conditionals

"Everything is a file", strongly text based

Understanding Command Entry and Execution



Understanding the UNIX Command Line

Command line is sequence of words, separated by white space.

```
command  [argument ...]      →  argv[0] argv[1] ...
```

Conventions

- first word is name of command (built-in or external program)
- arguments are processed sequentially by program avoid positional arguments in your own programs
- arguments can be options or operands

- options modify behavior of programs (how), results should be independent of order
  varying conventions, sometimes used alternatively in same program. most common:
  - `-x [value]` single letter preceded by minus, directly followed by option value if required by option (POSIX)
    option letters may be grouped: -x -y equivalent to -xy , -y -x , -yx
  - `-option [value]` option word preceded by one minus character
  - `--option[=value]` option word preceded by two minus characters,
    followed by equal sign and argument if required (GNU)
  - `xyz [value ...]` first argument contains single letter options, followed by values in order if required (BSD)

  and more - see man pages

- remaining arguments are operands (often files; what)
  warning: some programs ignore this convention and allow options after operands

Understanding the UNIX Command Line

Examples

`ls -l -a directory` same as `ls -la directory`

`cp [-p] file1 file2` make copy under different name
`cp [-p] file1 [...] directory` make copies of multiple files in target directory

`cc -O3 myprog.c mysub.c -o myprog` compile two program sources (max optimization) + create executable *myprog*

Same commands may allow mixed conventions.
Most well-known: GNU-tar (create and extract files to/from archive) and ps

POSIX
```
tar -c -v -f my_project.tar.gz -z my_project
```

BSD
```
tar cvfz my_project.tar.gz my_project
```

GNU
```
tar --create --verbose --file=my_project.tar.gz --gzip my_project
```

Automating Work: Using Wildcards to Supply File Names

Wildcards: automatically create list of file names as operands for commands
replacements done by shell before program is started

wildcard	meaning
*	0 or more arbitrary characters
?	1 arbitrary character
[abcs-z]	square brackets: character class (enumeration or range): one of a, b, c, s, t, ... z

Examples

`rm *.o`	remove all object files. warning: what happens with `rm * .o` ?
`ls -l *.[ch]`	all C source and header files. almost equivalent: `ls -l *.c *.h`
`mv *.txt *.doc mydir`	move all .txt and .doc files into directory *mydir*

Counterexample

`mv *.for *.f`	does not work (why?)

Understanding Standard Input / Output

Concept

Fundamental for toolbox design of UNIX
Every process has three preconnected data streams

descriptor	name	usage
0	stdin	standard input
1	stdout	standard output
2	stderr	standard error - error messages

Normally: all three connected to terminal (tty)
Programs conforming to this convention are called filters

Shell Syntax: Redirecting standard input / output to files

redirections done by shell before program starts

command < *inputfile*	*command* takes its stdin from *inputfile*
command > *outputfile*	*command* writes its stdout to *outputfile* (existing file is overwritten)
command >> *outputfile*	*command* appends its stdout to *outputfile*
command 2> *errorfile*	*command* writes its stderr to *errorfile*
command >&2	redirect stdout of *command* to current stderr

Combining redirections (examples)

`command < infile > outfile 2> errfile`	connect all three streams to separate files
`command < infile > outfile 2>&1`	send stderr to same stream as stdout (order matters)

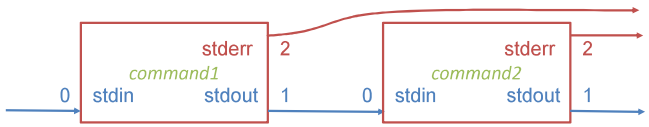
Connecting Programs: Building Pipelines

Concept

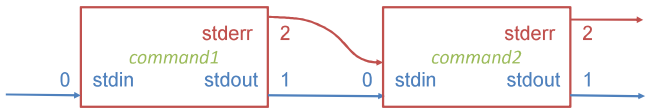
Pipeline: program sends its stdout directly to stdin of another program

Shell Syntax

command1 | *command2* [| ...] stdout of *command1* is directly connected to stdin of *command2*
command1's stderr is still connected to original stderr (default: tty)



command1 2>&1 | *command2* stdout and stderr of *command1* are sent to stdin of *command2*



pipeline set up by shell before commands start

Understanding Shell Variables + Environment Variables

Concepts

Three ways to pass information to program

- Input data (stdin; program may open any files)
- Command line arguments
- Environment variables

Environment variables

environment is set of *name*=*value* pairs, many predefined
used to modify (default) behavior of programs
environment copied (one way) from parent to child when program starts main(int argc, char *argv[], char *envp[])
accessing environment: `getenv` (C, Matlab), `os.environ['name']`, (Python), `$name` (bash), `$ENV{name}` (perl)...

Shell variable (AKA parameter)

Shell has local variables, can be connected to environment of current shell by `export` command

Convention

Most system- or software-specific variables have UPPERCASE names

Shell syntax and commands

`name=value`	set shell variable *name* to *value* (no whitespace around =)
`export name`	associate shell variable *name* with environment
`export name=value`	set *name* to *value* and associate with environment
`$name` `${name}`	use variable: substitute *value* in command line (use {...} to separate from adjacent characters)
`env`	print all environment variables to stdout
`name=value [...] command`	run *command* in temporarily modified environment

Important Environment Variables - Examples

$HOME	User's HOME directory Default for cd command Many programs search initialization files in $HOME (convention: $HOME/.*xxxx* "invisible")
$USER	Login name of current user
$PATH	Colon-separated list of directories - searched by shell for executable programs e.g.: PATH=/bin:/usr/bin/:/usr/local/bin:/usr/X11/bin
$SHELL	Which command interpreter to use in shell-escapes e.g.: SHELL=/bin/bash
$EDITOR	Which editor to use e.g.: EDITOR=/usr/bin/vi
$TERM	Type of terminal emulator - needed by editors, less, and other screen-oriented software e.g.: TERM=xterm
$HOSTNAME	Name of host (server) on which command runs
$PS1 $PS2	Shell's command prompt strings; bash: many macros
$DISPLAY	Network address of X Server - needed by all X11 clients (GUI programs) e.g.: DISPLAY=localhost:12.0
$TEMP	Directory where some programs put their temporary files. Default: /tmp
$SCRATCH	Set by some installations: location of scratch directory

Using the PATH Variable to Determine Search for Programs

Syntax

`PATH=directory:directory:...` colon-separated list of directories

Examples

```
PATH=/home/c102mf/bin:/usr/local/bin:/usr/bin:/bin
PATH=/home/c102mf/bin:/usr/local/bin:/usr/bin:/bin:
```
empty entry means . (CWD)

Semantics

when *command* is entered, shell

- tests if *command* is alias or shell-builtin. If yes, run this. Else...
- if *command* contains / , try to locate executable using *command* as path to file. Else, shell...
- searches executable file *directory*/*command* for each *directory* component of $PATH

first match is executed.

Important recommendation

- CWD (.) should be avoided in PATH, but if necessary, put it as empty (*) entry at end
  why: other users may plant Trojans in directories with public write access (e.g. /tmp)
  example: executable /tmp/ls may contain malicious code.
  `cd /tmp ; ls` triggers this code if CWD comes in PATH before legitimate directory
- (*) why empty: so one can extend PATH: `PATH=${PATH}/usr/site/bin:`

Querying where command is

`which command` prints path of *command* that would be executed to stdout

Example: `which ls` → `/bin/ls`

Protecting Parts of Command Line Against Shell Substitutions

Concept

Shell

reads command line
substitutes wildcards and variables (special characters: * ? [ ] $)
breaks result into words at whitespace (blank, tab) → arguments for program

This behavior may be changed by quoting

Syntax

`'...'`	Text between single quotes: literally preserve all special characters and whitespace, one argument
`"..."`	Double quotes: expand variables, preserve other special characters and whitespace, one argument
\	Escape character: suppress special meaning of following character

Examples

`rm 'my file'`	Remove a file with blank character in its name
`rm my\ file`	Same

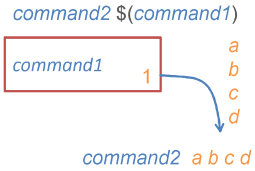
```
a='my file'
```

`rm $a`	tries to remove two files 'my' and 'file'
`rm "$a"`	tries to remove one file named 'my file'

Command Substitution: Feeding Program Output into Command Line

Concept

The output of one command can be inserted into the command line of another command



Syntax

`` `command` ``	(old syntax - backticks) or	
`$(command)`	(new syntax)	anywhere in a command line
`$(<file)`	shorthand for `$(cat file)`	

Semantics

The output of *command* is split into words using the $IFS environment variable (default value: blank, tab, newline)

The result is substituted in the embedding command line

Examples

```
which myscript  →  /home/c102mf/bin/myscript
vi $(which myscript)  edit myscript (found via $PATH)

ls > ls.out
vi ls.out          edit list of files to be removed
rm $(<ls.out)      remove files in list
```

Beware of blanks in file names (set IFS to newline)

Example: Using Command Substitution + Variables in Interactive Session

Goal

keeping track of directories for re-use in commands

How to

After cd-ing into some directory containing interesting files

```
p=$(/bin/pwd)
```
remember current working directory in variable p .
/bin/pwd resolves real path to CWD, ignoring redirections by symbolic links (later)

Then cd to some other directory, and

```
q=$(/bin/pwd)
```
remember new working directory in variable q .

Later you can do things like

```
cd $p
cp -p $q/*.c .
tar cvf $q/../project.tar .
```

Here Documents: Feeding Shell Script Text into Stdin

Concept

The input of a command can be taken directly from the shell script

Syntax

```
command [arg ...] <<[-]WORD
arbitrary lines of text          # this is the here-document
WORD
```

Semantics

if *WORD* is not quoted, the here document undergoes variable expansion and command substitution
else no substitutions are made

if *<<-WORD* was used, leading tabs are stripped from the here-document

the resulting lines are connected to the stdin of command

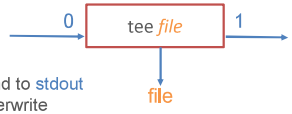
Example: verbose error message

```
cat <<EOF >&2
Error in $0 on $(date): could not find $1 in \$PATH = $PATH
called as $0 "$@"
Aborting.
EOF
```

Useful Commands

for more information: see man *command*

duplicate data from pipeline to file(s)




```
tee [option ...] [outfile ...]   copy stdin to each outfile and to stdout
  -a                             append to outfile, do not overwrite
```

create text for pipelines and command substitutions - output written to stdout - often used in shell scripts

```
date [option ...]                print date to stdout
  +format                        use format e.g.: +%Y%m%d-%H%M%S

seq [option ...] [first] last    print sequence of numbers to stdout , used e.g. in loops
  -f format                      use format (like in printf(3))
  -w                             pad output with zeros to equal width
  -s string                      separate output with string instead of newline

basename name [suffix]           remove directory components (and suffix) from name and print to stdout

dirname name                     strip last component from path name and print result to stdout
```

Useful Commands - Examples

Sending output of long running *program* to stdout and file

```
program | tee program.out
```

Saving program output to dated file

```
date                    →  Don Sep 28 09:40:14 CEST 2017
LANG=en_US date         →  Thu Sep 28 09:43:32 CEST 2017
date +%Y%m%d-%H%M%S     →  20170928-094027

program > program.$(date +%Y%m%d-%H%M%S).out
```

Using basename and dirname to dissect path names

```
file=/home/c102mf/project/src/main.c
basename $file          →  main.c
basename $file .c       →  main
dirname $file           →  /home/c102mf/project/src
```

Useful Filter Commands (1)

use these commands to filter text in pipelines and command substitutions

for all commands: if no files are given, read input from stdin
for more options see man *command*

`cat [option ...] [file ...]`	concatenate *file* contents and print to stdout
`-n`	number output lines
`-s`	suppress repeated blank lines
`sort [option ...] [file ...]`	print sorted concatenation of *files* to stdout
`-n`	numeric
`-r`	reverse
`-f`	ignore case - fold lower case to upper case
`-s`	stable sort (do not change order of lines with same key)
`-k fstart,fstop`	key fields (start, stop), origin = 1
`uniq [option ...] [infile [outfile]]`	eliminate repeated adjacent lines and print results to stdout or *outfile* (warning: file arguments do not follow [*file* ...] convention)
`-c`	prefix output lines by number of occurrences
`-d`	print only duplicated lines
`-u`	print only unique lines

Useful Filter Commands (2)

`wc [option ...] [file ...]`	(word count) print file name, line, word, and byte counts for each *file* to stdout
`-c`	bytes
`-m`	characters (different from bytes when using unicode)
`-w`	words
`-l`	lines
	note: to suppress output of file name, read from stdin
`head [option ...] [file ...]`	print first *num* (10) lines of each *file* to stdout
`-n num`	number of lines to print
`-q`	do not print headers giving file names
`tail [option ...] [file ...]`	print last *num* (10) lines of each *file* to stdout
`-n num`	number of lines to print
`-q`	do not print headers giving file names
`-f`	output appended data as file grows
	(useful for watching output of long running background program)
`--pid=pid`	(with `-f` : terminate when process *pid* dies)
`--retry`	keep trying until file is accessible
`expand [option ...] [file ...]`	convert tab characters to spaces
`-t [tab[,...]]`	specify tab stops (default: 8)

Useful Filter Commands (grep)

Ethymology: editor command g/regular expression/p

`grep [option ...] [-e] pattern [name ...]` search contents of named *files* for matches of *pattern* and print matching lines to stdout

`-e pattern`	protect a *pattern* (possibly) beginning with '-' from option processing
`-i`	ignore case
`-v`	invert match: only print non-matching lines
`-w`	match only whole words
`-c`	print only counts of matching lines
`-l`	(list files) print only names of files containing at least one match
`-s`	(silent) no error messages about missing or unreadable files
`-q`	(quiet) no output, only exit status (0 .. match(es) found, 1 .. no match, 2 .. error)
`-H -h`	prefix output lines with file name (default if more than one file) ; suppress file name prefix
`-n`	prefix output lines with line number
`-r`	recursively search all files in *directories*
`-E`	use extended regular expressions (./.)

pattern search pattern given as regular expression: describes set of strings.

Regular Expressions

- used throughout UNIX utilities (grep, sed, vi, awk, perl; regex library functions). several slightly differing varieties
- similar, but different from shell wildcards
- do not create lists of file names, but match strings; metacharacters and their meanings differ from wildcards

Understanding Regular Expressions (1)

Regular expressions (use quotes to protect metacharacters from shell) (-E) denotes extended regex

simple string	*abc*	matches string *abc* — `grep 'abc' ...` prints all lines containing abc
period	.	matches one arbitrary character. a.c matches aac abc a8c a(c ..... but not abb
character class	[*abcs-z*]	matches one character from those between brackets a[abcs-z]c matches aac abc acc asc ... azc but not akc
negation	[^*abc*]	matches anything but enclosed characters a[^mno]c matches abc akc azc but not amc aaac ....
anchoring	^ $ \< \>	match the beginning / end of line / word ^abc matches lines beginning with abc, but not lines containing abc somewhere else \<abc\> matches word abc but not xabc abcy ....
repetition	*	preceding item matches zero or more times ab*c matches ac abc abbc abbbbbbbbc
repetition (-E)	+	preceding item matches one or more times ab+c matches abc abbc abbbbbbbbc ... but not ac
optional (-E)	?	preceding item matches zero times or once ab?c matches ac abc but not abbc ...
count (-E)	{*n*}	preceding item matches exactly n times ab{3}c matches abbbc but not ac abc abbc abbbbc ....
	{*n*,} {,*m*} {*n*,*m*}	preceding item matches at least *n* times, at most *m* times, from *n* to *m* times

Understanding Regular Expressions (2)

Regular expressions (continued) (-E) denotes extended regex

grouping (-E)	( )	turn regex between parentheses into new item x(abc)*y matches xy xabcy xabcabcy but not xaby etc.
alternation (-E)	|	matches regex on either side of pipe character x(abc|def)y matches xabcy xdefy but not xaefy ....
back reference (-E)	*n*	matches what previous *n*-th group matched - counting opening (x(ab|cd)y\1z matches xabyabz xcdycdz but not xabycdz

Combined example

x(ab|cd).*\1y matches xababy xab___aby xcdlllcdy

Difference between basic and extended regular expressions

In basic regex, metacharacters ? + { } | ( ) have no special meaning, but . * [ ] \ do
Using prefix \ (backslash) reverses meaning

Grep examples

`grep -r 'foo' .`	recursively search for string foo in all files
`vi $(grep -rwl 'foo' .)`	edit all files that contain variable named foo
`ls -l | grep -E '\.(cc|cp|cxx|cpp|CPP|c++|C)$'`	list all C++ source files
`grep -iv '^[c*]' *.f`	find non-comment lines in Fortran 77 source files
`grep '#include[<"][a-z0-9/]+.h[>"]' *.[ch]`	find include lines in C source and header files

Useful Filter Commands (sed)

sed [*option* ...] *script* [*file* ...] stream editor - perform text transformations on input, print result to stdout

-n	suppress automatic output
-i	edit in place
-r	use extended regular expressions
-s	treat files separately, reset line number for each file
-e *script*	add *script* to sed commands to be executed

Commands

s/*regex*/*replacement*/[g]	try to match *regex* and replace by *replacement* if successful. suffix g : replace all occurrences, not only first match can use backreferences (\n) to insert previously matched text
d	delete line, skip to next line
p	print line (useful with -n)
; { ... }	separate / group commands (many more)

Commands may be prefixed by *addresses*, which select lines

number	match line *number*
$	match last line
/*regex*/	match lines matching *regex*
addr1,*addr2*	match from *addr1* to *addr2* (can be used as a multiple on / off switch)

Examples (./.)

Useful Filter Commands (sed) Examples

Examples

`sed 's/foo/bar/'`	replace first foo in each input line by bar . e.g. foo foo → bar foo foot → bart
`sed 's/foo/bar/g'`	replace all foo by bar foo foo → bar bar foon foot → barn bart
`sed 's/\<foo\>/bar/g'`	replace all entire words foo by bar foo foo → bar bar but foot → foot
`sed -E 's/(foo|bar)/X\1/g'`	replace foo and bar by Xfoo and Xbar
`sed -E 's/"([a-z]+)"/>>\1<</g'`	replace quoted lowercase strings by same between >> and <<
`sed 's/ *//g'`	eliminate all blanks from input
`sed '/^begin$/,/^end$/s/foo/bar/g'`	in all sections between pairs of lines begin and end , replace foo by bar

Useful Filter Commands (awk)

`awk [options] program [file ...]` invoke the awk pattern scanning and processing language
`-F fs` use field separator *fs* to separate input fields (default: white space)

Concept

program is sequence of *pattern* { *action* } statements

awk reads its input lines, splits them into fields `$1 $2 ....` and executes *action* on each line if *pattern* matches

Patterns are logical expressions involving

- regular expressions
- special words e.g. BEGIN END (match exactly once before / after all input)
- relational expressions
- operators `~ ( ) && || ! ,` for matching, grouping, and, or, negation, range

Actions are statements in C-like programming language

- data types: scalar, associative array (i.e. indexed by string value)
- builtin variables: FS / OFS (input/output field separator), NF (number of fields), NR (number of input records so far)
- i/o statements: print, next, ... control statements: if, while, for....

Example

split input data into fields, lookup line, print selected fields

```
getent passwd | awk -F: ' $1 ~ /^string$/ { print $1, $3, $5 }'
```

- awk often used to extract data from program output
- Recommended reading: `info awk | less` (GNU awk implementation)
- see also perl(1)

Example from Demo

```
getent passwd | awk -F: 'BEGIN { OFS="," } $1 ~ /^c102mf$/ { print $1, $3, $5 } '
```

```
awk ' BEGIN { n = 0 ; } { n += $1 ; } END { print n ; } ,
```

Understanding Processes

Concept

process = running instance of a program

UNIX is multitasking / multiprocessing system: many processes at any time sharing one / many CPUs

Process hierarchy: every process has exactly one parent, may have children

Properties

USER UID	process owner
PID	process ID (number)
PPID	parent's process ID
CMD COMMAND	command line
STAT	process state (running, stopped, I/O wait, defunct ...)

Commands

`ps -ef` display all running processes (POSIX)
output USER PID %CPU %MEM VSZ RSS TTY STAT START TIME COMMAND

`ps aux` display all running processes (BSD)
output UID PID C STIME TTY TIME CMD

`kill [-9] pid` terminate running process with numerical ID *pid* (-9 force termination)

Foreground + Background Processes

Concepts

Foreground process: Shell waits until process has finished (normal case)
Background process: Shell immediately issues new prompt, process runs asynchronously

Syntax and commands

command	start foreground process
command &	start background process
nohup *command* &	start background process - not terminated at logout
$!	special parameter (later): PID of last background process
wait *pid*	wait for background process *pid* to finish. Example: wait $!

Hint: compute cluster: use batch system to put long-running processes on cluster nodes

Examples

`ps -f`	`ps ux`	display processes under current shell
`ps -ef`	`ps aux`	display all processes on system
`ps -ef | grep $USER`		display all my processes
`ps -ef | sed -n -e '1{p;d}; /'"$USER"'/p'`		display all my processes including header line (→ script)

Manipulating Processes, Signals

Concept

Shell and TTY driver of OS (using special characters) work together to allow state changes to running program

Typically special characters are <ctrl-*x*> ≈ ^*x* sequences

Some actions send signals to running processes

Processes may catch signals (except -9) to perform cleanup, otherwise most signals terminate

Actions

`^C`	terminate running program (keyboard interrupt SIGINT = 2)
`^Z`	suspend running program: stop execution (SIGTSTP), may be continued in foreground or background
`jobs`	display all jobs (= individual processes or pipelines) under current shell (note: different from batch job) output contains job number [*n*] , + (current job) or - (previous job)
`bg %n`	continue job *n* in background (SIGCONT) `bg +` `bg -` same for current and previous jobs
`fg %n`	continue job *n* in foreground (SIGCONT) `fg +` `fg -` for current / previous
`wait %n`	wait for background job *n* to finish
`kill [-9] %n`	kill (suspended or background) job *n* (SIGTERM = 15 | SIGKILL = 9)
`kill [-9] pid`	kill process with process ID *pid* (SIGTERM | SIGKILL)
`exit`	Exiting login shell sends SIGHUP = 1 to all shell's children (jobs). use nohup to ignore
`man 7 signal`	documentation for all valid signals

Working With Terminal Sessions

Special characters

Interrupting and suspending running programs

`^C` `^Z`	interrupt / suspend (as described before)

Erasing typos in command line

`^H` `^W` `^U`	erase single character, last word, entire line from typed input

Terminating input

`^D`	End Of File. Terminates input for any command reading from TTY If shell reads EOF, it will exit.

Controlling terminal output

`^S` `^Q`	stop / continue output from running program (stop start)

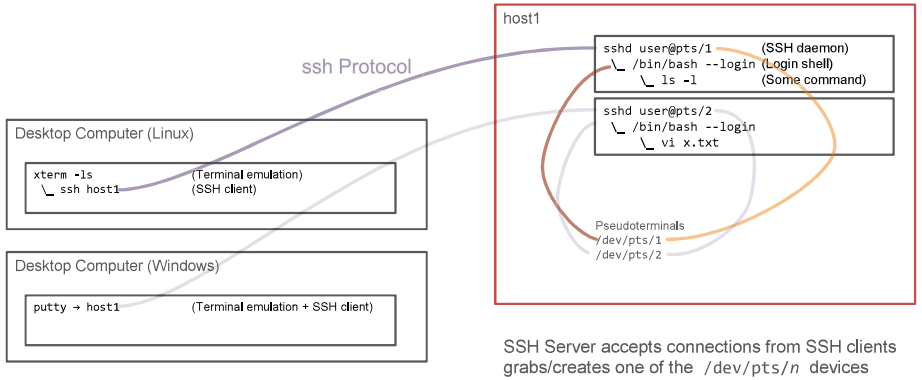
Suppressing special meaning of character

`^V`	next typed character will be passed verbatim to command's input

Commands

`stty -a`	display all tty parameters, including special characters
`stty ....`	change tty settings (many)
`reset`	re-initialize terminal settings after errors (e.g. abort of editor) sometimes you need to enter `^Jreset^J`

Understanding Remote (SSH) Terminal Sessions



SSH Server accepts connections from SSH clients
grabs/creates one of the `/dev/pts/n` devices
Starts login shell for user

SSH Client	connects to host sends input to host receives output from host
Terminal emulation	displays output in window reads keyboard and mouse input

Getting Information About Current Session and Host

`hostname`	print system's host name to stdout
`uptime`	tell how long system has been running and load averages (1, 5, 15 minutes)
`uname [-a]`	print system information (host name, OS version, hardware name etc.)
`tty`	print to stdout the file name of the terminal (TTY) connected to stdin
`who am i`	print current session's user name, TTY, login time and origin

Using the ps and top Commands to Display Processes in System

POSIX Options

`ps [option ...]`

- `-e` every process (default: processes in same session)
- `-j` jobs format (process ID, process group (=job) ID, session ID, CPU time, command)
- `-f` full format (user, process ID, parent process ID, TTY, CPU time, command)
- `-l` long format (UID, process ID, parent process ID, wchan, TTY, CPU time, command)
- `-H` tree format

} combine these as needed

BSD Options

`ps [optionletters] text`

- `a` all processes (default: only yourself)
- `x` include processes without a TTY
- `u` user oriented format (user, PID, %CPU, %MEM, virtual + resident size, TTY, state, start time, CPU time, cmd)
- `f` forest (tree format)

top

`top [-u user] [-p pid]` display real-time view of running system, including load average and running processes. many options and commands

Example: Identifying Left-over Processes for Killing

Situation

- Session was interrupted. Left-over processes are suspected to run on server. Or
- You have started several nohup processes - need to see what's left over

Workflow

ssh to server

`tty`	identify my own TTY to prevent suicide later
`ps -efH | grep $USER | less`	list (tree) all my processes running in system, including TTY name. note PIDs to be killed (processes running on other or with no terminals), sparing those running on my own TTY
`kill PID [...]`	terminate PIDs in question
`ps -efH | less`	check for success. If processes cannot be terminated try hard kill
`kill -9 PID [...]`	kill PIDs in question

Alternate kill command

`killall [ -g pgid ] [ -s signal ] [ -u user ] [ name ...]` kill all processes matching criteria.

Remarks on Running Processes While You are Logged Off

Processes running after logging off or broken session

- accidental disconnect in middle of some activity
  → log on, check + kill remaining processes

- use nohup then log off
  use on machines with no batch system
  → occasionally check for running processes
  check output
  kill processes not performing as expected
  note: check with sysadmin if nohup is welcome
  UIBK HPC systems: do NOT run production jobs with nohup, use batch system instead

- submit batch jobs (qsub or sbatch) if present
  preferred method if there is a batch system
  → occasionally check for running jobs (qstat or squeue commands)
  check output
  cancel jobs not performing as expected (qdel or scancel commands)

- use screen(1) / VNC to protect interactive tty / X11 sessions against diconnects

Automating Work: Using the Shell as a Programming Language

Concepts

Shell	command interpreter - used interactively or for writing programs (scripts)
Shell Script	Text file with execute permission, containing shell commands and programming constructs Well-written shell script can behave like executable program in every respect

Workflow: Writing and using a shell script

`vi script`	use editor to create / modify shell script
`chmod +x script`	make text file *script* executable
`script [arg ...]`	can be called like normal command if in $PATH
`./script [arg ...]`	CWD normally not in $PATH

Syntax

`#!/bin/bash`	In first line tell system which interpreter to use (magic (5) / "shebang"; default: /bin/sh)
`# comment`	All text after hash sign is ignored (comment)

all features (wildcards, variables, special characters) may be used in scripts

Recommendation

use Bourne Shell compatible shell for interactive use and programming. bash is OK, wide-spread and powerful

definitely do NOT use "C-Shell" or derivative. Why?
Google "csh programming considered harmful" (https://www-uxsup.csx.cam.ac.uk/misc/csh.html - still valid)

Using and Setting Shell Arguments

Processing arguments

`$0`	Name of script	`argv[0]`
`$1, $2, ....`	Positional arguments	`argv[1], argv[2], ....`
`$*  "$*"  "$@"`	All arguments: broken into words at whitespace, as one word, preserve original arguments	
`$#`	Number of arguments	
`shift [n]`	drop first *n* (default: 1) arguments - useful in sequential processing of arguments	

Example: `shift 2` discards values of $1, $2, copies values of $3, $4 ... to $1, $2 ...

Some special variables, set automatically by shell

`$?`	Exit status of last command
`$$`	Process ID (PID) of current shell
`$!`	Process ID (PID) of most recent background process

Setting arguments

`set [word ...]` current arguments ($1, $2,... - if any) are discarded and replaced by *words*

Using Compound Commands and Functions

Compound commands

`(commands)` *commands* are executed in a subshell environment.
changes to environment or shell have no effect in the calling context
exit status is that of last command executed

`{ commands; }` *commands* are executed in current shell environment.
group command can be used in many places where simple command is expected (e.g. in && ||)
{ and } must be separated by blanks, commands must be terminated with ; or newline
exit status is that of last command executed

Defining a function

`name () compound-command` defines *name* as a shell function

Calling a function

`name [argument ...]` commands in *compound-command* of function definition *name* are executed ...
... in the context of current shell (if { ... ; } was used - usual case) or
... in a subshell environment (if (...) was used)
positional parameters $1, ... are set to *arguments* while function is ecuted
variables etc. in the function definition are expanded when function is executed
exit status is that of last command executed

Running Scripts in Current Shell, Initializing Sessions and Shell Scripts

Concept

Normally shell scripts are started in a separate process (new shell) → changes to variables etc. have no effect
If script shall be run in the same shell, use source command

Syntax

`. file [argument ...]`	portable syntax (first word is a period)
`source file [argument ...]`	read and execute commands in named *file* in current shell. arguments become $1 $2 ... only while *file* is executed

Initialization files

Some files are automatically sourced when shell starts or exits
Files in $HOME automatically created when account is created

initialization file	scope	executed when
`/etc/profile`	system wide	begin of login shells
`$HOME/.bash_profile`	personal	begin of login shells
`/etc/bashrc`	system wide	invoked by `$HOME/.bashrc` (if not deleted by user)
`$HOME/.bashrc`	personal	begin of interactive shells, also invoked by `$HOME/.bash_profile`

Recommendation: change these files with caution
e.g. set shell options, set environment variables, add $HOME/bin to PATH

Understanding the Exit Status of Programs

Concept

Exit status: small integer number returned by process to parent on exit

0	success, true
nonzero	failure, false

Meaning of exit status depends on program. (e.g. 1 ... could not open input file, 2 ... incorrect syntax etc.)
Used in conditionals and loops

Shell syntax

`$?`	special parameter: exit status of last command	
`command1 && command2`	run *command1*. if success, run *command2*	
`command1 || command2`	run *command1*. if fail, run *command2*	Example remove original after succesful copy: `cp file1 file2 && rm file1`
`command1 ; command2`	run *command1*, then run *command2*	
`exit n`	shell-builtin: exit this shell with status *n*	Example (precedence): `command && echo success || echo failure`

Commands used to return exit status

`true`	/bin/true exits immediately with success (0)
`false`	/bin/false exits immediately with failure (1)
`test expression`	exit with 0 if expression (./.) is true, else 1

Testing and Computing Expressions (portable - replaced by bash builtins)

`test` *expression*		return 0 if *expression* is true, 1 else
`[` *expression* `]`		alternate form, `[` is *really* `/usr/bin/[`
e.g:	`-f` *name*	*name* exists and is a regular file
	`-d` *name*	*name* exists and is a directory
	`-s` *file*	*file* exists and has size > 0
	`-r|-w|-x` *name*	*name* exists and has read / write / execute permission for current user
	`-t` *fildes*	file descriptor *fildes* is connected to tty (0=stdin, 1=stdout, 2=stderr)
	`[-n]` *word*	length of *word* is nonzero - warning: protect variables with " ... " (quotes)
	`-z` *word*	length of *word* is zero (quotes!)
	word1 `=` *word2*	string comparison: equal (!= not equal - use whitespace)
	word1 `-eq` *word2*	compare numerical value (`-eq -ne -gt -lt -ge -le`)
	`\(` *expression* `\)`	group expressions - use quotes or \ to remove special meaning of parentheses
	expr1 `-a` *expr2*	true if both are true (and)
	expr1 `-o` *expr2*	true if any are true (or)
bash builtin:	`[[` *expression* `]]`	different syntax, more functionality
`expr` *expression*		print value of *expression* to stdout
e.g.	*word1* *op* *word2*	*op* may be one of `+ - * /` arithmetic operations
bash builtin:	`((` *expression* `))`	different syntax, more functionality

Shell Programming: Conditionals

Syntax

Note for C programmers: *commands* in conditionals play same role as logical expressions in C
exit status 0 ≈ true 1 ≈ false is slightly counterintuitive

```
if cmd1
then
  commands
fi
```

```
if cmd1
then
  commands
else
  commands
fi
```

```
if cmd1
then
  commands
elif cmd2
then
  commands
else
  commands
fi
```

Semantics

Run *cmd1* - if success (exit status 0) run *commands* in `then` clause
Otherwise (if present) run *cmd2* - if success run *commands* after corresponding `then` clause ... and so on
Otherwise (if present) run *commands* after `else` clause

Shell Programming: Taking Branches on Patterns

Syntax

```
case word in
[pattern [ | pattern ] ... )
  commands
;;
 [...]
esac
```

Semantics

word (typically variable) is expanded and compared against *patterns*
at first match, *commands* after matching pattern until `;;` are executed
execution continues after `esac`
use * pattern as a match-all (default)

Example:

```
case "$a" in
cow|dog|frog) echo "animal" ;;
daisy|violet) echo "flower" ;;
b..)          echo "a three letter word starting with b" ;;
*)            echo "unknown species" ;;
esac
```

Shell Programming: While Loops

Syntax

```
while cmd
do
  commands
done
```

Semantics

Run *cmd* - if success (exit status 0) run *commands* after `do` clause
Repeat until *cmd* exits with nonzero status

`break [n]` exits from innermost loop (or from *n* levels)

Example: watch files appearing and growing while other programs create and write to them

```
while true
do
  clear
  date
  ls -l *.out
  sleep 2
done
```

Better version:

```
watch 'ls -l *.out'
```

Q: why the quotes?

Example: Option Processing

Example:

Sequential option processing for a script with usage

script [-d] [-f file] [arg ...]

caution: need to add error checking

```
debug=0
file=script.in
```
set defaults

```
while test $# -gt 0
do
  case "$1" in
  -d)  debug=1 ; shift ;;
  -f)  file="$2" ; shift 2 ;;
  -*)  echo >&2 "$0: error: $1: invalid option" ; exit 2 ;;
  *)   break ;;      # remaining arguments are non-option
  esac
done
```
process options

```
for arg
do
  ...
done
```
process operande

Shell Programming: For Loops

Syntax

```
for variable [in word [...]]
do
  commands
done
```

Semantics

Set shell *variable* to successive values in list of *words* (default "$@" - useful in scripts) and execute *commands* for each value of *variable*

`break [n]` exits from innermost loop (or from *n* levels)

Example

```
for i in $(ls *.c)
do
  cp  $i  $i.backup
done
```

Putting it Together - Examples - Renaming Many Files

Task

rename many files from xxx.for to xxx.f

```
for i in *.for
do
  mv -i $i $(basename $i .for).f
done
```

Demo

`touch a.for b.for` create example files

`set -x` set shell option: display commands before they are executed (good for debugging and analyzing)

running above loop yields

```
+ for i in '*.for'
++ basename a.for .for
+ mv -i a.for a.f
+ for i in '*.for'
++ basename b.for .for
+ mv -i b.for b.f
```

note: this example fails if file names contain blanks

Examples - Displaying Arguments

Writing a simple shell argument checker

$HOME/bin/pargs

```
#!/bin/bash
for i
do
  echo ">>$i<<"
done
```

Usage examples: file name containing blank

```
$ echo "$IFS" | od -bc
0000000 040 011 012 012
            \t  \n  \n
$ ls -l
-rw-rw-r-- 1 c102mf c102mf  0 Sep 27 11:13 a b
-rw-rw-r-- 1 c102mf c102mf 82 Sep 27 14:58 c

$ pargs *
>>a b<<
>>c<<
$ pargs $(ls)
>>a<<
>>b<<
>>c<<
```

```
$ oldifs="$IFS"; IFS='^J'
$ pargs $(ls)
>>a b<<
>>c<<
$ IFS="oldifs"
```

Shell Programming: Opening and Reading Files

Shell-builtins

`read [-u fd] [name ...]` — read one line from stdin, split into words (IFS) and put each word in variable $*name*. remaining data goes to last variable. returns 0 (true) unless end of file.

`-u fd` — read from file descriptor *fd* instead of 0 = stdin

`exec [command [args ...]] [redirections]` — if *command* is given, it replaces current shell. otherwise, *redirections* are performed for current shell.

use exec with no command to open descriptors in current shell

Example

fragment from shell script

```
infile=myfile.in          in real application, would take file name e.g. from command line
exec 3<$infile            open $infile in current shell's file descriptor 3 for reading
while read -u 3 line      each iteration reads one line from file fd=3 and puts entire line into variable named "line"
do
  pargs $line             $line not quoted: split into words here. (do useful stuff instead of calling pargs)
done
echo "finished"           loop ends when all lines have been read (read returns non-zero exit status)
```

Examples - Grep Command to Include Header Lines

Defining new grep-like command that always displays first line of input (head grep)

$HOME/bin/hgrep

```
#!/bin/bash
# usage: hgrep PATTERN [FILE ...]
test $# -ge 1 || { echo >&2 "$0: error: no pattern given" ; exit 2 ; }
pattern="$1"; shift
sed -s -n -e '1{p;d}; /'"$pattern"'/p' "$@"
```

Usage example:

```
09:26:57 c102mf@login.leo3e:~ $ ps -efH | hgrep $USER
UID        PID  PPID  C STIME TTY          TIME CMD
root     23002  2055  0 08:45 ?        00:00:00     sshd: c102mf [priv]
c102mf   23005 23002  0 08:45 ?        00:00:00       sshd: c102mf@pts/4
c102mf   23006 23005  0 08:45 pts/4    00:00:00         -bash
c102mf   32350 23006  0 09:27 pts/4    00:00:00           ps -efH
c102mf   32351 23006  0 09:27 pts/4    00:00:00           /bin/bash /home/c102/c102mf/bin/hgrep c102mf
c102mf   32352 32351  0 09:27 pts/4    00:00:00             sed -n -e 1{p;d}; /c102mf/p
c102mf   26023     1  0 Sep19 ?        00:00:00   SCREEN -D -R
c102mf   26024 26023  0 Sep19 pts/17   00:00:00     /bin/bash
```

Exercise:

make this more general: add "-n lines" option

Examples - Listing all Includes in a Programming Project

Goal: create a complete list of included files in a source file hierarchy
demonstration of a slightly non-trivial sed replacement construct

Steps: (use source of some arbitrary sourceforge/gitlab project)

```
$ wget https://gitlab.com/procps-ng/procps/repository/master/archive.tar.gz -O procps-ng.tar.gz
$ tar xf procps-ng.tar.gz ; mv procps-master-* procps-ng
$ cd procps-ng
```

first sighting

```
$ grep -r  '#include' . |less
```

lines of interest look like `#include <getopt.h>` or `#include "libiberty.h"` , sometimes with leading and trailing stuff

complete construct

from output, get rid of everything outside `<...>` and `"..."` , then sort trimmed output and remove duplicate lines

grep -h would get rid of file names output, do not need because we eliminate this with other leading text

```
$ grep -r '#include' . | sed 's/^.*\([<"][^>"]*[>"]\).*$/\1/' | sort | uniq | less
```

grouping construct `\( ... \)` in search expression permits back-reference `\1` in replacement

within, we first look for opening quote (character class `[<"]`),
then all characters except closing quote `[^>"]*`, then closing quote `[^>"]`

outside parentheses, we use match-all `.*` and anchor this to the beginning (^) respectively end ($) of line

in the replacement, only the found text between parentheses is inserted

Examples - Processing Options and Arguments

Example: famous / silly pingpong program as script

```
#!/bin/bash

# pingpong: count replacing multiples of 3 with ping, 5 with pong

usage () {
  cat <<-STOP >&2
        usage: $0 [-n pingmod] [-m pongmod] [-d] [number ...]
        defaults: pingmod = 3, pongmod = 5
        -d print some debugging output
STOP
}

debug=no
pingmod=3
pongmod=5

while test $# -gt 0
do

  case "$1" in
  -n) pingmod="$2"; shift 2 ;;
  -m) pongmod="$2"; shift 2 ;;
  -d) debug=yes; shift ;;
  -*) echo >&2 "$0: unknown option $1"; usage ; exit 2 ;;
  *)  break ;;      # no more options
  esac

done

if test "$debug" = yes
then
  cat <<-STOP
        parameters in effect:
        -n $pingmod -m $pongmod debug: $debug numbers: $@
STOP
fi

for number
do
  echo "=========="
  for i in $(seq $number)
  do

    unset pp
    test $(expr $i % $pingmod) = 0 && { echo -n ping ; pp=1 ; }
    test $(expr $i % $pongmod) = 0 && { echo -n pong ; pp=1 ; }
    test -z "$pp" && echo -n $i
    echo

  done
done
echo "=========="
```

Examples - Parameter Study (shell loop) - no error checking

Parameter study: run program "mean" with command line taken from *n*-th line of file containing parameters

Idea: later, we get value of *n* from batch system (job array)

Example program: `mean -t {a|g|h} -f file` -t type (arithmetic, geometric, harmonic) -f file containing numbers

Input files: ari.txt geo.txt hrm.txt each containing test data with "simple" arithmetic, geometric, and harmonic means

Parameter file params.in
```
-t a -f ari.txt
-t g -f ari.txt
-t h -f ari.txt
-t a -f geo.txt
[...]
```

ari.txt
```
 11 12 13 14
```

geo.txt
```
1 10 100 1000 10000
```

hrm.txt
```
 1 .5 .333333333333333 .25 .2
```

Driver script runall.sh
```
#!/bin/bash
file="$1"

for i in $(seq $(wc -l < "$file" ))
do
  ./mean $(sed -n "$i p" "$file")
done
```

doubly nested command substitution
inner counts input lines
outer makes list of line numbers

extracts i-th line of file
and substitutes it as
command arguments

Usage
```
$ ./runall.sh params.in
ari.txt: 4 a     12.500000
ari.txt: 4 g     12.449770
ari.txt: 4 h     12.399484
geo.txt: 5 a   2222.200000
geo.txt: 5 g    100.000000
geo.txt: 5 h      4.500045
hrm.txt: 5 a      0.456667
hrm.txt: 5 g      0.383852
hrm.txt: 5 h      0.333333
```

Examples - Parameter Study (GNU parallel) - no error checking

GNU parallel:

build and execute shell command lines from stdin in parallel on same host - similar to xargs

Execution script runone.sh
```
#!/bin/bash

file="$1"; line="$2"
length=$(wc -l < "$file" )

./mean $(sed -n "$line p" "$file")
```

Driver script runparallel.sh
```
#!/bin/bash

file="$1"

seq $(wc -l < "$file" ) |
  parallel -k ./runone.sh "$file"
```

Usage
```
$ ./runparallel.sh params.in
ari.txt: 4 a     12.500000
ari.txt: 4 g     12.449770
ari.txt: 4 h     12.399484
geo.txt: 5 a   2222.200000
geo.txt: 5 g    100.000000
geo.txt: 5 h      4.500045
hrm.txt: 5 a      0.456667
hrm.txt: 5 g      0.383852
hrm.txt: 5 h      0.333333
```

Examples - Parameter Study (batch system) - no error checking

Job array:

run multiple instances acrosss hosts of identical job with unique value of $SGE_TASK_ID between 1 and *n*

Job script runonejob.sge
```
#!/bin/bash
#$ -q short.q
#$ -N onejob
#$ -cwd

file="$1"; line="$SGE_TASK_ID"

length=$(wc -l < "$file" )

./mean $(sed -n "$line p" "$file") > oneout.$line
```

Usage
```
$ ./submitparallel.sh params.in
```
output will go to individual files

collect output in correct order after jobs have run
```
for i in $(seq $(wc -l < params.in ))
do
  cat oneout.$i
done
```

Driver script submitparallel.sh
```
#!/bin/bash

file="$1"

length=$(wc -l < "$file" )
qsub -t 1-$length ./runone.sh "$file"
```

Examples - Parameter Study (shell loop)

Parameter study: run program "mean" with command line taken from *n*-th line of file containing parameters

Idea: later, we get value of *n* from batch system (job array)

Example program: `mean -t {a|g|h} -f file` -t type (arithmetic, geometric, harmonic) -f file containing numbers

Input files: ari.txt geo.txt hrm.txt each containing test data with "simple" arithmetic, geometric, and harmonic means

Parameter file params.in
```
-t a -f ari.txt
-t g -f ari.txt
-t h -f ari.txt
-t a -f geo.txt
[...]
```

ari.txt
```
 11 12 13 14
```

geo.txt
```
1 10 100 1000 10000
```

hrm.txt
```
 1 .5 .333333333333333 .25 .2
```

Driver script runall.sh
```
#!/bin/bash
usage () { echo >&2 "usage: $0 PARAMETERFILE"; exit 2 ; }
# set -x
file="$1"
test -n "$file" || usage
test -f "$file" -a -r "$file" ||
  { echo >&2 "$0: cannot read file $file" ; exit 1 ; }
for i in $(seq $(wc -l < "$file" ))
do
  ./mean $(sed -n "$i p" "$file")
done
```

Usage
```
$ ./runall.sh params.in
ari.txt: 4 a     12.500000
ari.txt: 4 g     12.449770
ari.txt: 4 h     12.399484
geo.txt: 5 a   2222.200000
geo.txt: 5 g    100.000000
geo.txt: 5 h      4.500045
hrm.txt: 5 a      0.456667
hrm.txt: 5 g      0.383852
hrm.txt: 5 h      0.333333
```

Examples - Parameter Study (GNU parallel)

GNU parallel:

build and execute shell command lines from stdin in parallel on same host - similar to xargs

Execution script runone.sh

```
#!/bin/bash
usage () { echo >&2 "usage: $0 PARAMETERFILE LINE"; exit 2 ; }
test $# = 2 || usage
file="$1"; line="$2"
test -n "$file" || usage
test -f "$file" -a -r "$file" ||
  { echo >&2 "$0: cannot read file $file" ; exit 1 ; }
length=$(wc -l < "$file" )
test "$line" -gt 0 -a "$line" -le $length ||
  { echo >&2 "$0: line $line not in (1 .. length $file = $length)" ; exit 1 ;
}
./mean $(sed -n "$line p" "$file")
```

Driver script runparallel.sh

```
#!/bin/bash
usage () { echo >&2 "usage: $0 PARAMETERFILE "; exit 2 ; }
test $# = 1 || usage
file="$1"
test -n "$file" || usage
test -f "$file" -a -r "$file" ||
  { echo >&2 "$0: cannot read file $file" ; exit 1 ; }
seq $(wc -l < "$file" ) |
  parallel -k ./runone.sh "$file"
```

Usage

```
$ ./runparallel.sh params.in
ari.txt: 4 a     12.500000
ari.txt: 4 g     12.449770
ari.txt: 4 h     12.399484
geo.txt: 5 a   2222.200000
geo.txt: 5 g    100.000000
geo.txt: 5 h      4.500045
hrm.txt: 5 a      0.456667
hrm.txt: 5 g      0.383852
hrm.txt: 5 h      0.333333
```

Examples - Parameter Study (batch system)

Job array:

run multiple instances acrosss hosts of identical job with unique value of $SGE_TASK_ID between 1 and *n*

Job script runonejob.sge

```
#!/bin/bash
#$ -q std.q
#$ -N onejob
#$ -l h_rt=10
#$ -cwd
usage () { echo >&2 "usage: $0 PARAMETERFILE"; exit 2 ; }
test $# = 1 || usage
file="$1"; line="$SGE_TASK_ID"
test -n "$file" || usage
test -f "$file" -a -r "$file" ||
  { echo >&2 "$0: cannot read file $file" ; exit 1 ; }
length=$(wc -l < "$file" )
test "$line" -gt 0 -a "$line" -le $length ||
  { echo >&2 "$0: line $line not in (1 .. length $file = $length)" ; exit 1 ; }

./mean $(sed -n "$line p" "$file")  > oneout.$line
```

Driver script submitparallel.sh

```
#!/bin/bash
usage () { echo >&2 "usage: $0 PARAMETERFILE "; exit 2 ; }
test $# = 1 || usage
file="$1"
test -n "$file" || usage
test -f "$file" -a -r "$file" ||
  { echo >&2 "$0: cannot read file $file" ; exit 1 ; }

length=$(wc -l < "$file" )
qsub -t 1-$length ./runonejob.sge "$file"
```

Usage

```
$ ./submitparallel.sh params.in
```

output will go to individual files

collect output after jobs have run

```
for i in $(seq $(wc -l < "$file" ))
do
  cat oneout.$i
done
```

Understanding Users and Groups

Concept: UNIX is a multiuser system

User = entity to identify multiple persons using a computer as well as special system accounts

Group = logical collection of users
every user is a member of one default group and may be member of additional groups

Users and groups are used to

- identify and validate persons trying to access system (login procedure)
- manage permissions for
  - files and directories
  - control of processes

Properties of user

User name (login name: lower case alphanumeric), password, numerical UID, default group, login shell, home directory

Properties of group

Group name, numerical GID, list of members (beyond default members)

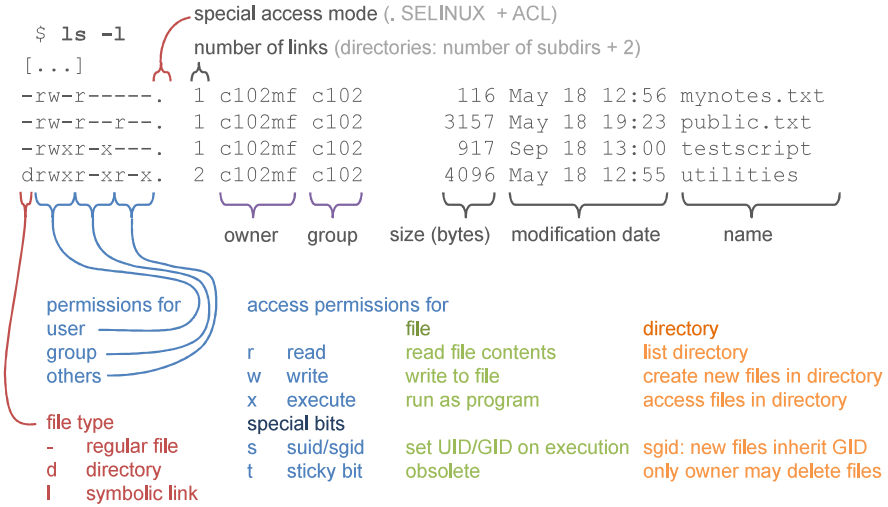
Process attributes: effective UID and GID (used for access checking), real UID and GID (original IDs)
Superuser (root) has UID = 0 special privileges

Using Commands to Identify Users

Commands

`whoami` `logname`	print effective user ID, login name
`groups [user ...]`	print list of group memberships of named (default: current) user
`id [option ...] [user ...]`	print user and group information on named (default: current) user
`-u -g -G -r`	print only: user, group, list of memberships, real instead of effective IDs
`who [option ...]`	list information on users who are currently logged in
`-a`	more information
`-m`	only user using this command (“who am i”)
`finger [option ...] [user ...]`	display information on users (default: all currently logged in)
`-l`	long format (default if *user* is given)

Understanding File Access Permissions



Setting File Access Permissions

`chmod [option ...] mode[,mode...] file [...]` set or clear file access permission bits

- `-R` recursive
- `-v -c` verbose, report changes only

mode is one or more of the following (comma separated)

`[ugoa...][+-=][perms]`

- `u` user who owns the file
- `g` users in the file's group
- `o` other users not in the file's group
- `a` (default) all users, do not affect bits set in umask
- `+` add permissions
- `-` remove permissions
- `=` set or copy permissions

or numerical mode (. / .)

perms is zero or more of the following

- `r` read
- `w` write
- `x` execute (directory: search)
- `X` execute (set only if execute set for some user)
- `s` set user ID or group ID on execution (directory: inherit group)
- `t` sticky bit (directories: restrict deletion to file owner. e.g. /tmp)
- `[ugo]` copy permission from user, grop or others

Understanding Access Bits, Using umask

Numerical *mode* 1-4 octal digits: (special) (user) (group) (others)
value = 0-7 by adding values 1, 2 and 4)
omitted digits = leading zeros

Values

special
- 4 set user ID on execution
- 2 set group ID on execution (files) inherit group ID (directories)
- 1 sticky bit

user group others
- 4 read
- 2 write
- 1 execute

Examples

`chmod u=rwx,g=rx,o= file` same as `chmod 0750 file`
`chmod u=rx,g=r,o= file` same as `chmod 0640 file`

Umask and umask command (shell-builtin)

The umask (user file creation mask) is a property of every process
When a new file is created, bits set in umask are cleared in file's permissions
`umask [-S] [-p] [mode]` set or report umask (-S symbolic form, -p print umask in command format)

Examples

`umask → 0027` same as `umask -S → u=rwx,g=rx,o=`
`umask 0077` set strict umask (new files have no permissions for group and others)

Understanding and Setting File Times

File times (time + date)

time attribute	meaning	displaying	setting
modification time	when file contents last changed	`ls -l file`	`touch -m -d string file`
access time	last file access (e.g. read)	`ls -lu file`	`touch -a -d string file`
change time	last modification of attributes	`ls -lc file`	

Changing a file's attributes (times or access permission)
will always set its change time (AKA inode modification time) to current time

Understanding Links and Symbolic Links

Link count, inode

every file has a unique index number (inode number) in file system
any file may have one or more directory entries (hard link = pair name inode)

create additional hard links with
`ln existingname newname`

every directory has at least two directory entries: named entry in parent and **.** in current directory
plus one **..** in each subdirectory

Symbolic link (AKA symlink or soft link)

named reference to other file or directory with relative or absolute path
create with
`ln -s target newame`
displayed in ls -l output as `l ..... name -> target`
Example:

```
$ ln -s /scratch/c102mf Scratch
$ ls -ld Scratch
lrwxrwxrwx. 1 c102mf c102 15 Sep 28 14:42 Scratch -> /scratch/c102mf
$ ls -Lld Scratch
drwx--x---. 51 c102mf c102 32768 Oct  3 18:50 Scratch
```

Using the ls command

`ls [option ...] [name ...]` list information about named *files* or *directories* (default: current working directory)

`-a`	all entries (do not ignore entries starting with `.`)
`-d`	list directories themselves, not their contents
`-l`	long listing (default: compact multicolumn listing)
`-L`	resolve symbolic link, list target instead of link
`-F`	compact listing, mark directories with `/` and executables with `*`
`-i`	print inode number
`-s`	print effectively occupied space (*) on disk (blocks; use `-k` to force kB)
`-h`	print size human-readable
`-R`	recursively list named *directories*
`-1`	single column even when output goes to tty
`-t`	sort by modification time, newest first
`-u`	sort by (and show if `-l`) access time
`-c`	sort by (and show if `-l`) inode modification time
`-r`	reverse sort order

(*) may differ from logical size:
includes disk addressing metadata for large files; files may have zero-filled holes occupying no space

Getting More Information About Files

`file [option ...] [name ...]` try to classify each file and print results to stdout

`-b`	brief. no filenames in output
`-i`	output mime type
`-p`	preserve access date
`-z`	try look inside compressed files
(many)	

For each file name given in command line, file heuristically guesses the file type
from its permissions and contents (see magic(5))

Output format
name: description
Example

```
file *
a.out:      ELF 64-bit LSB executable [...] not stripped
bin:        directory
myscript:   Bourne-Again shell script, ASCII text executable
README:     ASCII text
```

Using find to Search for Files in Directory Hierarchy (1)

`find [path ...] [expression]` recursively traverses named *directories* (default: current)
and evaluate expression for each entry found (default: -print)

expression is made up of
- options (affect overall operation, always true)
- tests (return true or false)
- actions (have side effects, return true or false)
- operators (default: and)

options

`-depth`	process directory contents before directory
`-xdev`	do not cross mount points (same as -mount)

tests numeric arguments may be *n* (exactly) *+n* (greater than) *-n* (less than)

`-name pattern`	name matches *pattern* (wildcards - use quotes)
`-iname pattern`	name matches *pattern* - ignore case
`-type c`	d directory f regular file l symbolic link
`-mtime n` `-mmin n`	modified *n* days or minutes ago
`-atime n` `-amin n`	accessed *n* days or minutes ago
`-newer file`	found item was modified more recently than named *file*
`-size n[kMG]`	size is *n* bytes, kilo- mega- gigabytes (binary)

actions
(./.)

Using find (2)

actions

`-print`	(default) print path name of found object to stdout
`-print0`	print path name of found object, terminated by NULL character instead of newline
`-ls`	print `ls -dils` output for each found object
`-exec command ;`	for each found object execute shell command. `{}` inserts path name (use quotes), `;` terminates command (quotes)
`-execdir command ;`	for each found object, cd into directory containing object and execute shell command.
`-delete`	delete file (dangerous), true if success
`-prune`	if file is directory, do not descend into it (incompatible with -depth)

operators

`( expr )`	grouping of expressions (use quotes)
`! expr`	logical negation
`expr1 [-a] expr2`	logical and: *expr2* is not evaluated if *expr1* is false
`expr1 -o expr2`	logical or: *expr2* is not evaluated if *expr1* is true
`expr1 , expr2`	list: *expr1* and *expr2* are always evaluated, return truth value of *expr2*

Using xargs and parallel to Process Large Number of Objects

Concept

Command lines are limited in number of arguments and total length.

Use xargs to split list of arguments into suitable portions and call command for each portion
useful e.g. for commands that have no *recursive* option

GNU parallel is similar to xargs but allows parallel execution on same and remote hosts

`xargs [option ...] command [initial-arguments]` build and execute command lines from standard input

`-a file`	read arguments from *file* instead of stdin
`-d delim`	use *delim* to separate arguments instead of whiltespace; e.g. `-d '\n'`
`-n max-args`	use at most *max-args* arguments per command line
`-S max-size`	use at most *max-size* characters per command line
`-t`	verbose mode
`-0`	input items terminated by NULL character instead of *delim* (corresponds to -print0 of find)

`parallel [option ...] command [initial-arguments]` build and execute command lines from standard input in parallel (many options)

Example

set all files in directory *my-project* to fixed modification time

```
touch -t 201709100000 ref-file
```

then

```
find my-project -type f -print0 | xargs -0 touch -r ref-file
```

Compressing and Uncompressing Files (gzip, bzip2)

`{gzip|bzip2} [option ...] [file ...]`	compress files using { Lempel-Ziv coding | block-sorting compressor }, replace originals by compressed files appending { `.gz` | `.bz2` } to file name
`{gunzip|bunzip2} [option ...] [file ...]`	uncompress files, replace compressed files by originals
`{zcat|bzcat} [option ...] [file ...]`	uncompress files to stdout
`-c`	compress / uncompress to stdout
`-1 ... -9`	fast ... best (default: 6 - ignored by bzip2)
other options, some specific to gzip / bzip2 family	

Note

multiple concatenated compressed files can be correctly uncompressed

Example

```
gzip -c file1 > foo.gz
gzip -c file2 >> foo.gz
gunzip -c foo
```

is equivalent to

```
cat file1 file2
```

Packing and Unpacking Collections of Files (tar)

Concept

Pack entire directory hierarchy into single archive file, suitable for archive and distribution purposes

Most software packages are distributed this way

`tar {c|x|t}...f... archive.tar[.suffix] [name ...]`

`c`	Create. Pack named *files* and (recursively) *directories* into named *archive* file or write to stdout
`t`	Table of contents of named *archive* file or from stdin
`x`	eXtract date from named *archive* file or from stdin, recreating files and directories
`v`	verbose mode
`z`	use gzip compression, *suffix* should be `.gz`
`j`	use bzip2 compression, *suffix* should be `.bz2`
`p`	preserve permissions when extracting

Note

Tar is traditionally used with BSD-style single letter options.

GNU tar also supports standard POSIX (-x value) and GNU (--option=value) options; using BSD style helps portability

Examples

`tar cvfz my_project.tar.gz my_project`	recursively pack directory my_project into my_project.tar.gz
`tar tvfz my_project.tar.gz`	lists table of contents
`tar xvfz my_project.tar.gz`	unpacks data, recreating the directory my_project

Note: for `t` and `x`, the compression option (`z` or `j`) may be omitted when using GNU tar

Understanding UNIX File Systems

Concepts

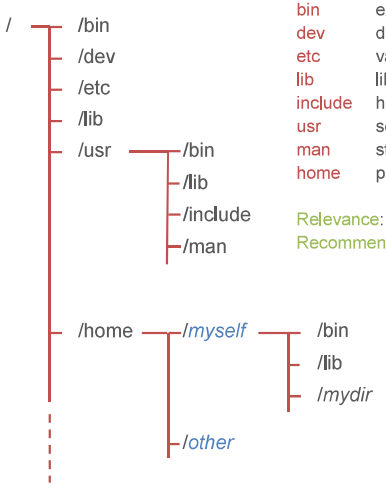
File system = collection of files and directories on one disk, partition, disk array or file server
All file systems organized in one tree
Mount point = directory at which another file system starts
Root directory / is starting point for all absolute paths

Facts

Each file system has its own capacity (total file size, number of files) and quota (if defined)
Hard links work only within file system: use symlinks to link across file systems
Moving a file to another file system involves copying all data (move within file system: will create new hard link)
Data loss typically affects an entire file system: backup your files

UNIX file system organization follows certain conventions ./.

Understanding the UNIX File System Hierarchy



Naming conventions

bin	executable programs (utilities)
dev	device files - interface to system hardware
etc	various configuration files
lib	libraries - collection of object files (components of executables)
include	header files - collection of interface definitions (#include <*xxxx*.h>)
usr	secondary hierarchy - files and utilities used in multiuser operation
man	starting point of documentation (often share/man)
home	parent of all users' home directories

Relevance: 3rd party and self written software should follow same conventions
Recommended: add $HOME/bin to your $PATH variable

Using Special Device Files

Some special device files are useful with shell scripts and programs

`/dev/null`	reading from /dev/null gives immediate EOF data writen to /dev/null is discarded
`/dev/zero`	reading from /dev/zero returns bytes containing "zero" characters
`/dev/tty`	process's controlling terminal. reading and writing from/to /dev/tty will read / write to terminal independent of current stdin or stdout
`/dev/random`	reading returns random bytes, waiting for entropy pool to supply enough bits (slow!)
`/dev/urandom`	random bytes, using pseudorandom generator if enough entropy is not available

Understanding Text File Structure + Conversions

Concepts

File	sequence of bytes
Text file	sequence of lines, each terminated by Newline (Line Feed) character (NL , LF , ^J , \n)
Line	sequence of characters consisting of single bytes ASCII, Latin1 or varying numbers of bytes (UTF-8)

Character set determined by environment variable $LANG (e.g. C (ASCII) en-US (Latin1) en_US.UTF-8 (UTF))
Note for C programmers: same structure as expected by C programs

Windows: differences to UNIX

In Windows text files, lines are separated by Carriage Return + Newline sequence (CR NL , ^M^J , \r\n)
C programs must open text files in text mode to effect conversion
Character set encoding determined by invisible bytes at beginning of file
Various nonstandard encodings (code pages) used

Analyzing file contents

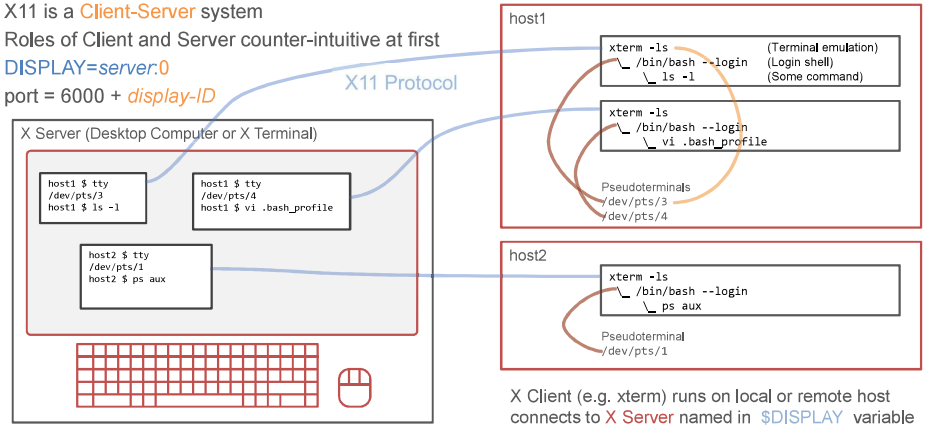
`od` [*option* ...] [*file* ...] dump file contents in octal and other formats, output to stdout.
Useful options: `-t o1` `-t x1` `-t c` (octal, hexadecimal, character bytes)

Converting file formats

[`dos2unix` | `unix2dos`] [*option* ...] [*file* ...] [`-n` *infile outfile*] convert file formats & windows encodings
`iconv` [*option* ...] [`-f` *from-encoding*] [`-t` *to-encoding*] [*file* ...] convert standard encodings

Understanding the X Window System (X11)

X11 is a Client-Server system
Roles of Client and Server counter-intuitive at first
DISPLAY=*server*:0
port = 6000 + *display-ID*



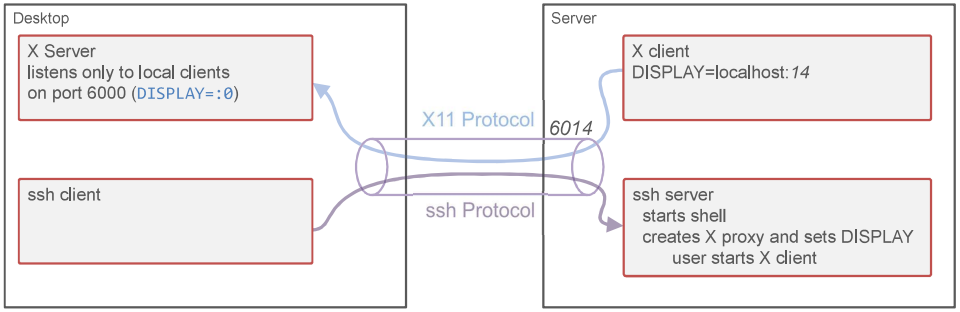
X Server controls screen, keyboard, mouse
accepts connections from X Clients (e.g. xterm)
sends events (keyboard, mouse) to client that has focus

X Client (e.g. xterm) runs on local or remote host
connects to X Server named in $DISPLAY variable
uses X server to open window and display text and graphics
does useful work (e.g. editor or terminal emulation)
may start other programs (xterm: default: login shell)

Using the X11 Tunnel

Security: X Server should only accept local connections
Q: how to connect remote clients?
A: X11 tunneling through SSH: client connects to server's localhost
ssh forwards connection to desktop
X server accepts local connection

Usage: `ssh -X server` enables X11 forwarding, ssh server automatically sets $DISPLAY
add line `ForwardX11 yes` to `$HOME/.ssh/config` to enable by default



Using Xterm

`xterm [option ...] &`		start the xterm terminal emulator in the background (as typically with all X clients)
`-ls`		run the shell as a login shell
`-e program [args ...]`		run program instead of shell. Must be last argument
`-display display`		use named display instead of $DISPLAY
`-geometry WIDTHxHEIGHT+XOFF+YOFF`		width and height in characters, offsets in pixels from left and top edge of screen. negative offsets are from right and bottom
`-title title`		window title string

Recommended resource definitions in `$HOME/.Xresources` or `$HOME/.Xdefaults` (*)

`XTerm*selectToClipboard:`	`True`	allows cut/paste integration with newer X clients and non-X programs
`XTerm*faceName:`	`Mono`	use scalable fonts, recommended for high resolution displays
`XTerm*faceSize:`	`8`	change value for convenience
`XTerm*saveLines:`	`10000`	size of scrollback buffer
`XTerm*scrollBar:`	`True`	display scroll bar

(*) .Xresources is automatically loaded into X server when an X display manager session is started.
load manually with `xrdb -load $HOME/.Xdefaults`
.Xdefaults supplies these settings on the client side when no resources have been loaded.
Use this when not using X display manager (e.g. X server on non-UNIX workstation)

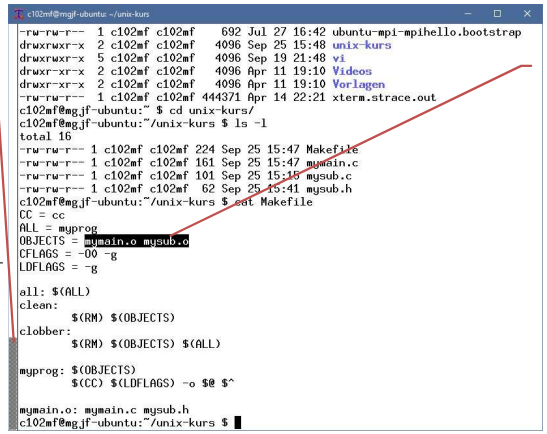
Using Xterm Mouse Actions

xterm uses MIT Athena widgets - non-intuitive but powerful

size of scroll bar
shows visible fraction
of total buffer

scroll bar mouse actions
right click: scroll back
left click: scroll forward
distance of mouse pointer
from top = scroll amount

middle click or drag:
scroll absolute



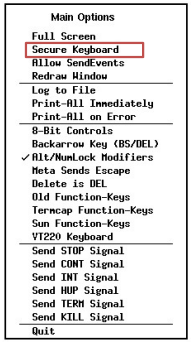
text area mouse actions

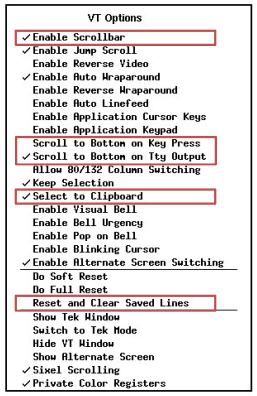
left click + drag:
select text
left double click:
select word
left triple click:
select line
right click or drag:
extend or reduce
selection (both ends)

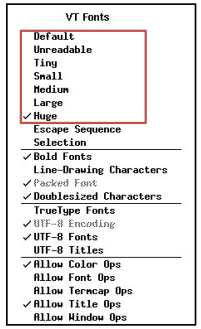
middle click:
insert selection (or
clipboard if enabled)
a cursor position

Using Xterm Popup Menus

ctrl + left / middle / right mouse button gives popup menus







Setting Xterm Character Classes

Concept

double click selects word - meaning of word is configuration dependent
many new distributions define classes optimized for web users
programmers prefer words to be syntactic units

Recommendation

Use the original default character class definition in .Xresources or .Xdefaults:

```
XTerm*charClass: 0:32,1-8:1,9:32,10-
31:1,32:32,33:33,34:34,35:35,36:36,37:37,38:38,39:39,40:40,41:41,42:42,43:43,44:44,45:45,46:46,4
7:47,48-57:48,58:58,59:59,60:60,61:61,62:62,63:63,64:64,65-
90:48,91:91,92:92,93:93,94:94,95:48,96:96,97-122:48,123:123,124:124,125:125,126:126,127-
159:1,160:160,161:161,162:162,163:163,164:164,165:165,166:166,167:167,168:168,169:169,170:170,17
1:171,172:172,173:173,174:174,175:175,176:176,177:177,178:178,179:179,180:180,181:181,182:182,18
3:183,184:184,185:185,186:186,187:187,188:188,189:189,190:190,191:191,192-214:48,215:215,216-
246:48,247:247,248-255:48
```

Note

Windows registry definition to give putty an xterm-like behavior is available

UNIX as a Programming Environment

Programming language C originated with UNIX

Default compilers for Linux: GCC = the GNU Compiler Collection
Supported languages, standards

- C (1990, 1999, 2011 + GNU extensions)
- C++ (1998, 2003, 2011, 2014, 2017), Objective-C
- GNU Fortran (supports Fortran 95, Fortran 90, Fortran 77)

"UNIX is an IDE"

Automate creation of programs and libraries from source using make(1)
UNIX utilities designed to support program development and file management

Program Example

mymain.c

```
#include <stdio.h>
#include "mysub.h"

int main(int argc, char **argv) {
  int i, j, k;
  sub1(&i, &j);
  sub2(i, j, &k);
  printf("%d + %d = %d\n", i, j, k);
}
```

mysub.h

```
void sub1(int *i, int *j) ;
void sub2(int i, int j, int *k) ;
```

mysub.c

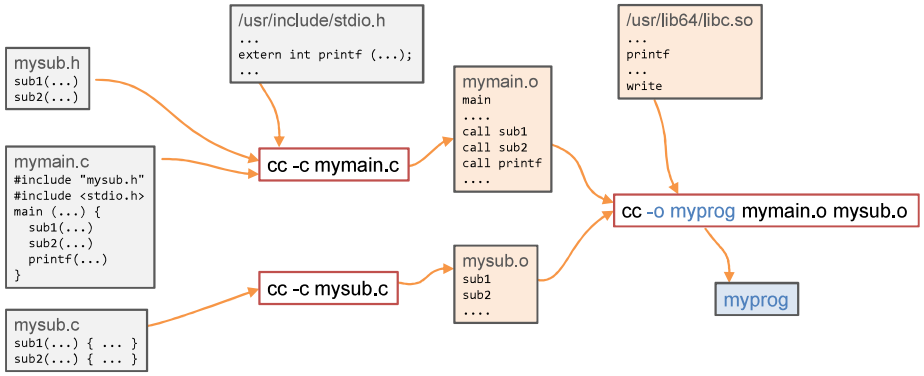
```
void sub1(int *i, int *j) {
  *i = 2;
  *j = 3;
}

void sub2(int i, int j, int *k) {
  *k = i + j;
}
```

Understanding the Compilation Dataflow

```
cc -c mymain.c                  compile source of main program into object file (relocatable machine program)
cc -c mysub.c                   same for subroutines
cc -o myprog mymain.o mysub.o   link object files and create executable program  myprog
```

Note: certain files (`mysub.h`, `stdio.h`, `libc.so` , `*.o`) are opened / created implicitly (i.e. not on command line)



Using the Compiler

compiler [*option* ...] *file* ... Invoke the compiler driver: preprocess, compile, assemble, link program files

`cc` `gcc`	C Language / GNU C
`c++` `g++`	C++ / GNU C++
`f95` `gfortran`	Fortran / GNU Fortran

Other vendors use different driver names, e.g. Intel: `icc` `icpc` `ifort` and different options

File naming conventions: file suffix indicates file language and type

Suffix	Type
`.c`	C source program
`.C` `.cc` `.cxx` `.cpp` etc.	C++ source program
`.f` `.f90` `.f95` `.f03` `.f08`	Fortran source program conforming to Fortran 77, 90, 95, 2003, 2008 standard
`.o`	translated object file
`.a` `.so`	library (static or shared object) to search for function definitions
(none)	executable. default: `a.out`

Options

`-c`	only compile *`file.suffix`* , do not link, write output to file with *`.suffix`* replaced by `.o`
`-o` *`name`*	compile: use *`name`* instead of *`file.o`* (compile) or `a.out` (link)
`-g` `-pg`	compile and link: create symbol tables for debugging (`-g`) or extra code for execution profiling (`-pg`)
`-O` `-O0` `-O1` `-O2` `-O3`	compile: optimization level. `-O0` is default, `-O1` and `-O` are the same
	optimization increases execution speed and reduces code size, may change program semantics
`-I`*`dir`*	compile: add *`dir`* to search path for `#include <....>` header files
`-l` *`name`*	link: search function definitions in files `lib`*`name`*`.a` and `lib`*`name`*`.so` in standard library search path
`-L`*`dir`*	link: add *`dir`* to library search path for `-l` argument

(many more - optimization, target architecture, language standard / extensions, warning+debugging, ...)

Using make to Automate the Compiler Workflow

Concept

Large programming project may consist of many source files, complex dependencies
Compile and link steps must be executed in correct order
After changes, only those parts affected by change need recompiling / linking

Make

Uses built in and user defined rules and dependencies to automate and optimize compilation workflow
User analyzes dependencies and codes these in `Makefile` (or `makefile`)
The `make` utility reads `Makefile` and runs compile / link steps necessary to (re)create target

Makefile Syntax

Makefile consists of rules.
Each rule is
one dependency line *`target`*`: `*`prerequisite ...`*
zero or more recipe lines `→` *`command`* where `→` is the `TAB` (`^I` `\t`) character (invisible)

`make` [*`target`*] rebuilds the named *`target`* by...
1. making all prerequisites (recursive)
2. executing recipe lines for current rule (if empty: use builtin rule if existent)

`target` default: first target in Makefile

Why the tab in column 1? Yacc was new, Lex was brand new. I hadn't tried either, so I figured this would be a good excuse to learn. After getting myself snarled up with my first stab at Lex, I just did something simple with the pattern newline-tab. It worked, it stayed. And then a few weeks later I had a user population of about a dozen, most of them friends, and I didn't want to screw up my embedded base. The rest, sadly, is history.
— Stuart Feldman

Example Makefile

Example `Makefile` (version 1: all rules explicit)

corresponds to example in dataflow graph

note: you must explicitly declare dependencies (e.g mymain.o also depends on myprog.h)
the makedepend utility can automate this

```
myprog: mymain.o mysub.o
→       cc -o myprog mymain.o mysub.o
mymain.o: mymain.c mysub.h
→       cc -c mymain.c
mysub.o: mysub.c
→       cc -c mysub.c
```

make
first run: compiles mymain.c, mysub.c, links
after changing mymain.c or mysub.h: compiles only mymain.c, links

Invoking make, Variables

`make [option ...] [target ...]`

`-B`	unconditionally make all targets
`-C dir`	change to *dir* before reading Makefile (used in recursive make)
`-f file`	use *file* instead of Makefile
`-j njobs`	run *njobs* (commands) simultaneously (may be unreliable)
`-n`	dry run
`-p`	print all rules and macros / variables to stdout

`info make | less` complete Make documentation

Variables

defining variable: all environment variables are copied to Make variables
NAME = *definition* in Makefile - creates variable, overrides environment (except with `-e`)

using variable: `$(`*NAME*`)` in Makefile is replaced by *definition* (dependency and command lines)

special variables:

`$@`	name of current target
`$<`	name of first requisite
`$^`	list of all requisites

standard variables:

`CC CFLAGS`	Name of C Compiler and list of compiler options (flags)
`CXX CXXFLAGS`	C++ Compiler and flags
`FC FFLAGS`	Fortran Compiler and flags
`LDLAGS`	Flags used when linking programs
`RM`	Command used to remove files

Example Makefile: Using Variables and Macros

Example `Makefile` (version 2: using variables and macros, cleanup)

Goal: reduce redundancy

Note: using a different C compiler now only involves changing CC

```
CC = cc
ALL = myprog            # targets to make. add more targets here
OBJECTS = mymain.o mysub.o
CFLAGS = -O0 -g         # debug
LDFLAGS = -g            # debug

all: $(ALL)             # first rule: catch-all for make called with no arguments. add more targets here
clean:
→      - $(RM) $(OBJECTS)
clobber:
→      - $(RM) $(ALL) $(OBJECTS)

myprog: $(OBJECTS)
→      $(CC) $(LDFLAGS) -o $@ $^

mymain.o: mymain.c mysub.h
→       $(CC) $(CFLAGS) -c $<
mysub.o: mysub.c
→       $(CC) $(CFLAGS) -c $<
```

Using Predefined Rules to Further Simplify Makefiles

Make has many predefined rules → may omit many trivial recipes

`make -p` in directory w/ no Makefile: print out predefined rules

Example `Makefile` (version 3: using predefined rules)

```
CC = cc
ALL = myprog
OBJECTS = mymain.o mysub.o
CFLAGS = -O0 -g
LDFLAGS = -g

all: $(ALL)
clean:
→      - $(RM) $(OBJECTS)
clobber:
→      - $(RM) $(ALL) $(OBJECTS)

myprog: $(OBJECTS)
→      $(CC) $(LDFLAGS) -o $@ $^

mymain.o: mymain.c mysub.h
```

Installing Third Party Software into Your HOME or SCRATCH

Goal

Install third party software as non-root user from sources

Workflow

- Read the instructions provided by the program authors
- If source distribution release is in a tar archive ("tarball")
  - Download and extract tarball, cd into source directory
- If Github is used
  - get latest development version with git clone, cd into source directory, git checkout
  - tpically it is necessary to do a `./autogen.sh` or similar to create the Configure script
- Read README, INSTALL and other files that could contain instructions
- `./Configure --prefix=$HOME` (or `$SCRATCH`) discover facts about your system and create `Makefile`
- `make`
- `make test` if provided
- `make install` copy executable, libraries, man pages into `$PREFIX/bin`, `$PREFIX/lib`, `$PREFIX/man`

Debugging Programs

Goal: Diagnosing and correcting program errors:

- insert print statements, compile, and run. Repeat over and over until problem found. NOT RECOMMENDED
- execute program under debugger.
  - controlled execution (stepwise, up to breakpoint, when in function, when condition is met)
  - displaying values of variables, stack trace, etc.

Workflow

- Compile program with options `-g` and `-O0` , link with `-g`
  `-g` creates symbol tables, allowing debugger to identify source lines and variables.
  debugging optimized programs is possible, but is "fuzzy", and variables may be optimized away
- Run executable under debugger. Most popular: GNU debugger. Commercial debugger for || programs: TotalView
  `gdb name [core]` invokes GNU debugger for program *name* and issue command prompt
- Issue debugging commands. Most used commands:

`b [file:]{func|line}`	break	set breakpoint in function *func* or line number *line*
`r [arg ...]`	run	run program, supplying arguments
`whe bt`	where, backtrace	display current location, call stack
`p expr`	print	display value of expr (use syntax of debugged program)
`c`	continue	continue running program
`s n`	step next	stepwise execution: step (into subprogram), next (source line)
`l [file:]{func|line}`	list	display source lines
`h`	help	
`q`	quit	

- Fix problem and recompile

Profiling Programs

Concept

Optimizing programs: need knowledge where program spends its time, what happens where
Create execution profile showing execution times of routines, including call graph

Workflow (unverified)

Compile with -pg
Run representative test case - creates execution profile in gmon.out
Run `gprof [options] executable [gmon.out]`
... displays call graph profile.

Note

Numerous tools, some by compiler vendors
Modern CPUs have performance counters, allowing simultaneous timing of multiple specific events, allowing line-sharp hot spot analysis, e.g. cache misses vs. instructions executed
Multiple profiling methods (statistic sampling vs. code instrumentation, event counting, timing, ...)

Look e.g for Open|SpeedShop, HPC Toolkit, TAU, ...

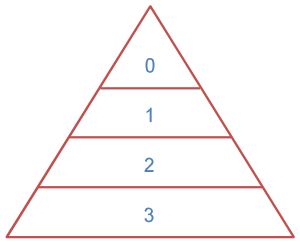
Understanding the HPC Ecosystem

What it is

HPC Cluster = set of interconnected independent compute servers (nodes)

- consistent setup & software installation, modular software environment
- shared HOME and high performance / high capacity Scratch directories
- high bandwidth low latency interconnect (Infiniband) + software supporting parallel computation (MPI)
- load management (batch) system for placement of sequential and parallel jobs on nodes

HPC tier model



Supranational HPC installations
e.g. PRACE

National HPC installations
e.g. VSC

Local HPC clusters
e.g. LEO, MACH(*)

Workgroup clusters

HPC Enabling Research

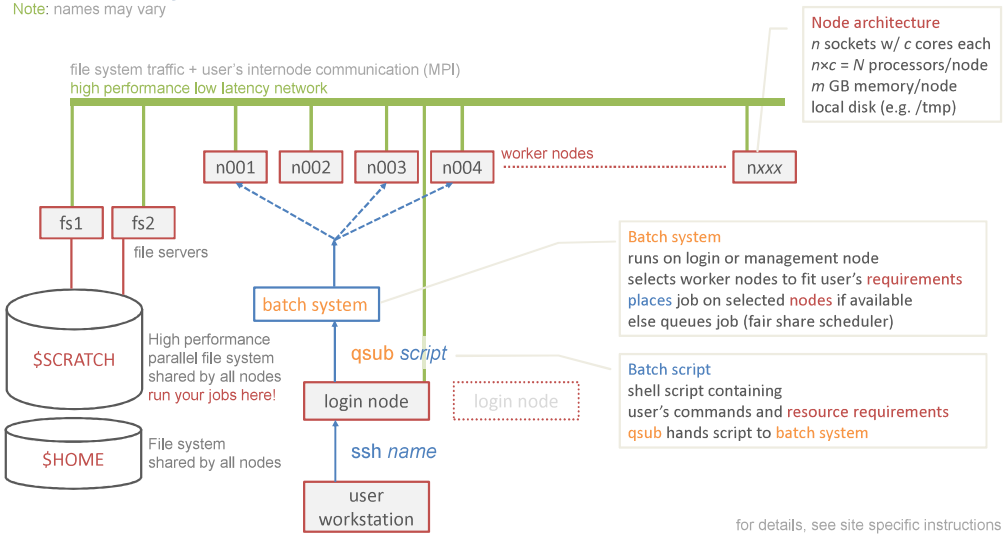
Capability Computing
Big machine enables
large scale computations that
cannot be solved on smaller system

Capacity Computing
Big number of CPUs + memory
used to solve many instances of
simple problems in much shorter time

(*) MACH actually not a cluster

Understanding the Architecture of an HPC Cluster

Note: names may vary



for details, see site specific instructions