GNU/Linux
Application Programming

Lecture Handouts

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References

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Course Web Links

- https://cs6.swfu.edu.cn/moodle
- https://cs2.swfu.edu.cn/~wx672/lecture_notes/linux-app/slides/
- https://cs2.swfu.edu.cn/~wx672/lecture_notes/linux-app/src/
- https://cs3.swfu.edu.cn/tech

`/etc/hosts`

```
202.203.132.241   cs6.swfu.edu.cn
202.203.132.242   cs2.swfu.edu.cn
202.203.132.245   cs3.swfu.edu.cn
```

Homework

Weekly tech question

1. What was I trying to do?
2. How did I do it? (steps)
3. The expected output? The real output?
4. How did I try to solve it? (steps, books, web links)
5. How many hours did I struggle?

✉ *wx672ster+linux@gmail.com*
𝔼 Preferably in English
in stackoverflow style
Or simply show me the tech questions you asked on any website

1 Getting Started

Linux Commands

Where to find them? `/bin`, `/usr/bin`, `/usr/local/bin`, `~/bin`, …

```
$ echo $PATH
```

How to find them? `which`, `whereis`, `type`

Command not found?

First double check your spelling

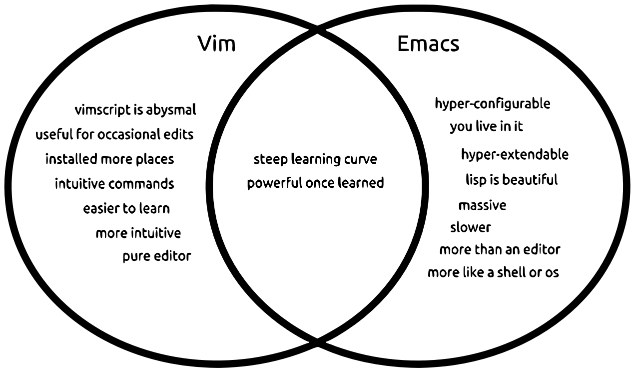
Then try:

```
aptitude search xxx
apt-cache search xxx
apt-file search xxx
sudo apt install packagename
```

Google `"linux command xxx"`

Text Editors

vs.

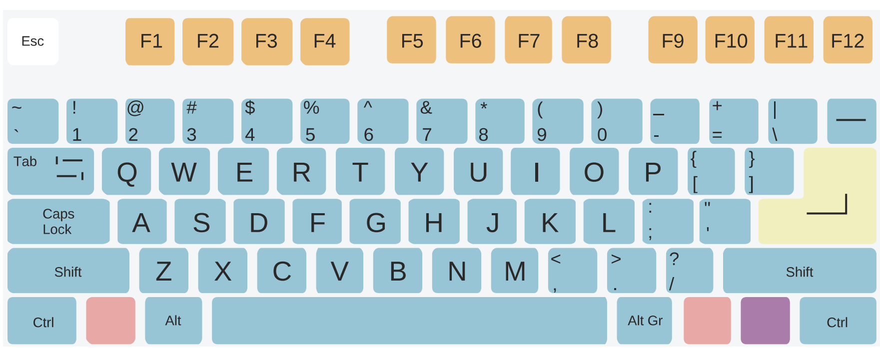


Help Your Editor

Suffix matters

- `$ vim` ✘
- `$ vim hello` ✘
- `$ vim hello.c` ✔
- `$ vim hello.py` ✔
- `$ emacs` ✘
- `$ emacs hello` ✘
- `$ emacsclient hello.c` ✔
- `$ emacsclient hello.py` ✔

Keyboard

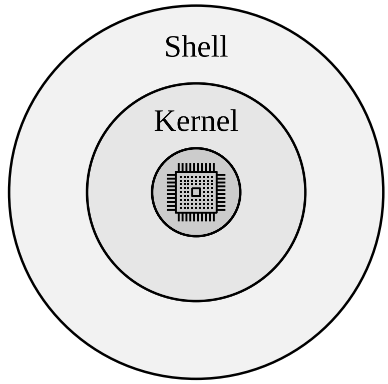


- vimtutor
- Ctrl+h t

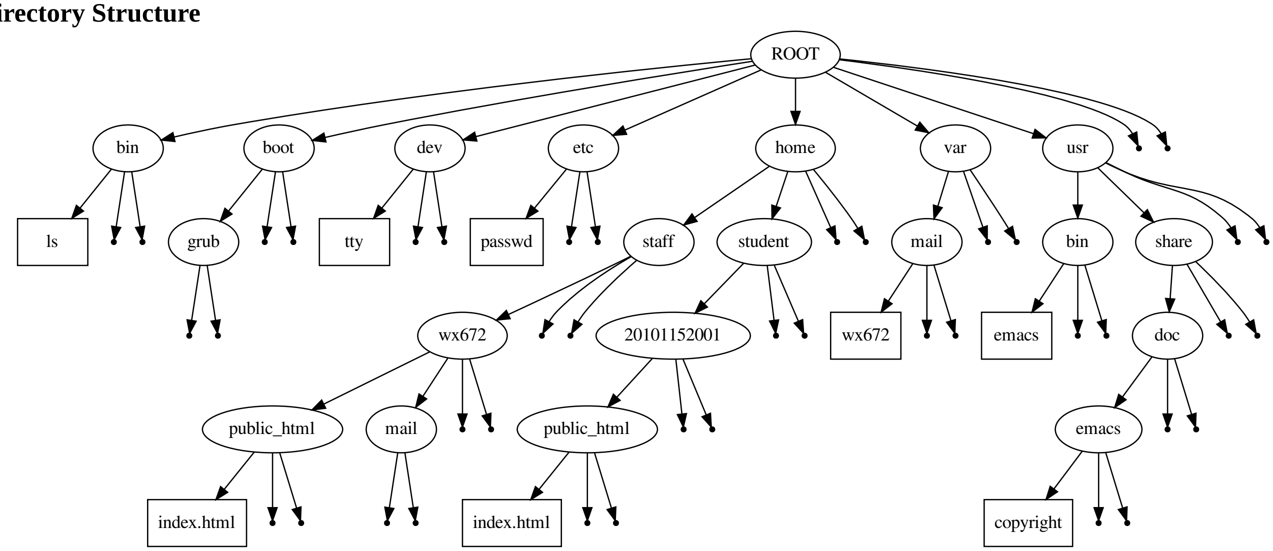
2 Shell Basics

Shell

- A command line interpreter
- A programming language



Directory Structure



Todo	How
Where am I?	`pwd`
What's in it?	`ls`
Move around?	`cd`
Disk usage?	`du, df`
USB drive?	`lsblk, mount`
New folder?	`mkdir`

File Operations

Ways to create a file

- Using an editor (vim, emacs, nano…), or
- `$ cat > filename`
- `$ echo "hello, world" > filename`
- `$ touch filename`

More file operations:

Todo	How	Todo	How
Copy?	`cp`	Move/Rename?	`mv`
Delete?	`rm`	What's it?	`file`
Link?	`ln`	Permission?	`chmod, chown`
Count?	`wc`	Archive?	`tar, gzip, 7z, …`
Sort?	`sort, uniq`	Search?	`find, grep`

Redirection

Redirecting output

```
$ ls -l > output.txt
$ ps aux >> output.txt
```

Redirecting input

```
$ more < output.txt
```

Process Operations

Todo	How	Todo	How
Kill?	`kill, Ctrl-c`	suspend?	`Ctrl-z`
background?	`bg, &`	forground?	`fg, jobs`
status?	`ps, top`		

System Info

Todo	How	Todo	How
who?	`w, who, whoami`	how long?	`uptime`
software?	`apt, aptitude, dpkg`	kernel?	`uname, lsmod`
hardware?	`lspci, lsusb, lscpu`	memory?	`free, lsmem`

APT — package management

Todo	How
upgrading?	`apt update && apt upgrade`
install?	`apt install xxx`
remove?	`apt purge xxx`
search?	`apt search xxx`
details?	`apt show xxx`
friendly UI?	`aptitude`

CLI Shortcuts

Ctrl + a :	beginning of line	Ctrl + e :	end of line
Ctrl + f :	forward	Ctrl + b :	backward
Ctrl + n :	next	Ctrl + p :	previous
Ctrl + r :	reverse search	Ctrl + u :	cut to beginning
Ctrl + k :	kill (cut to end)	Ctrl + y :	yank (paste)
Ctrl + d :	delete a character	↹ :	completion

Tmux

Ctrl + a c :	create window	Ctrl + a Ctrl + a :	switch window
Ctrl + a n :	next window	Ctrl + a p :	previous window
Ctrl + a - :	split window	Ctrl + a | :	split widnow
Ctrl + a j :	go down	Ctrl + a k :	go up
Ctrl + a l :	go right	Ctrl + a h :	go left

Understanding “`ls -l`”

```
-rw------- 1 sam sam   57 Apr 17  1998 weather.txt
drwxr-xr-x 6 sam sam  102 Oct  9  1999 web_page
-rw-rw-r-- 1 sam sam 7648 Feb 11 20:41 web_site.tar
-rw------- 1 sam sam  574 Dec 16  1998 file.txt
                                         └ File Name
                                  └ Modification Time
                                  Size (in bytes)
                                  Group
                                  Owner
                                  Number of hard links
                                  File Permissions
                                  File types
```

d - directory
- - regular file
l - soft link
c - character device
b - block device
s - socket
p - named pipe (FIFO)

9-bit permission

```
 7   5   5
111 101 101
rwx r-x r-x
          └ Other
      Group
  User
```

```
$ chmod 755 foo     $ chmod 644 foo
$ chmod 000 foo     $ chmod 777 foo
$ chmod a-r foo     $ chmod u+x foo
$ chmod g+w foo     $ chmod go=rx foo
```

Wildcard Expansion

Character	Meaning	Example
`?`	any one	`$ ls ???.txt`
`*`	zero or more	`$ ls *.c`
`[]`	or	`$ ls *.[ch]`
`{}`	and	`$ ls *.{c,h,cpp}`

Example

```
$ touch {2,3,4,234}.{jpg,png} && ls
```

output:

2.jpg	234.jpg	3.jpg	4.jpg
2.png	234.png	3.png	4.png

```
$ rm [234].jpg
$ rm {2,3,4,234}.jpg
$ rm 2*
```

```
$ rm ?.jpg
$ rm ?.*
$ rm *
```

Everything Is A File

```
$ cat /dev/null > /var/log/messages # empty a file
    $ : > /var/log/messages # no new process
$ ls > /dev/null
$ dd if=/dev/zero of=/tmp/clean bs=1k count=1k
$ dd if=/dev/urandom of=/tmp/random bs=1k count=1k
```

`/proc`

Allow higher-level access to driver and kernel information

```
$ cat /proc/cpuinfo
$ cat /proc/meminfo
$ cat /proc/version
$ cat /proc/1/status
# echo 100000 > /proc/sys/kernel/pid_max
```

Pipe
Chain processes together

Unnamed pipe

```
$ ps aux | sort | less
```

Named pipe

1. `$ mkfifo mypipe`
2. `$ gzip -9 -c < mypipe > out.gz`
3. `$ cat file > mypipe`

- https://en.wikipedia.org/wiki/Named_pipe

3 Shell Programming

$ — Give Me The Value Of …
`$var` Give me the value of variable “`var`”
`$(echo hello)` Give me the value (output) of command “`echo hello`”
`$((1+1))` Give me the value (result) of “1+1”
`$$` Give me the value of special variable “`$`”
`$?` Give me the value of special variable “`?`”
`$0` Give me the value of special variable “`0`”
`$@` Give me the value of special variable “`@`”

Variables

```
$ a=8; b=2
$ a=a+5; a=$a+5 ☹
$ let a=a+5; let a+=5 ☺
$ let b=b+a; let b+=a ☺
$ echo a; echo $a
$ (( a=5, b=6, a+=b )) ☺
$ (( b=a<5?8:9 )) ☺
$ r=$(( RANDOM%100 )) ☺
$ echo "$a" # partial quoting
$ echo '$a' # full quoting
$ a=$(ls -l); echo $a; echo "$a"
$ a=hello; b=world; let a+=b ☹
```

Positional Parameters
`$0, $1, $2, …, $@, $#`

```bash
#!/bin/bash

echo "You said:"

echo -e "\t$@"
echo
echo -e "\targc = $#"
echo -e "\targv[0] = $0"

i=1
for arg in $@; do
  echo -e "\targv[$i] = $arg"
  let i++
done
```

```c
#include <stdio.h>

int main(int argc, char *argv[])
{
  int i;
  printf("You said:\n\t");

  for(i=1; i<argc; i++)
    printf("%s ",argv[i]);

  printf("\n\n\targc = %d\n", argc);

  for(i=0; i<argc; i++)
    printf("\targv[%d] = %s\n",i,argv[i]);

  return 0;
}
```

Parameter Substitution

Default value

```
$ echo ${s:=abc}
$ echo ${s:=xyz}
```

```
$ echo ${v:-8}
$ echo ${v:-10}
```

Example

```
#!/bin/bash

echo -n Hello, ${1:-world}
echo !
```

Parameter Substitution

Substring removal

```
$ for f in *.pbm; do ppm2tiff $f ${f%pbm}tif; done
```

Substring replacement

```
$ for f in *.jpg; do mv $f ${f/jpg/JPG}; done
```

Environmental Variables

Each process has an environment

$PATH	$PWD	$HOME	$UID	$USER
$GROUPS	$SHELL	$TERM	$DISPLAY	$TEMP
$HOSTNAME	$HOSTTYPE	$IFS	$EDITOR	$BROWSER
$HISTSIZE	$FUNCNAME	$TMOUT	…	

```
export HISTSIZE=2000
export BROWSER='/usr/bin/x-www-browser'
export EDITOR='vim'
export ALTERNATE_EDITOR="vim"
export PDFVIEWER='/usr/bin/zathura'
```

```
$ env
$ declare
```

Tests

```
$ (( 5 < 6 )) && echo should be
$ [[ 1 < 2 ]] && echo of course
$ [[ $a -lt $b ]] && echo yes || echo no
$ if [[ $a -lt $b ]]; then echo yes; else echo no; fi
$ if test $a -lt $b; then echo of course; fi
$ if a = 5; then echo a=$a; fi # whitespace matters ✘
$ if a=5; then echo a=$a; fi ☹
$ if test a=5; then echo a=$a; fi ☹
$ if test a = 5; then echo a=$a; fi ☹
$ if test $a = 5; then echo a=$a; fi ✔
$ test $a = 5 && echo a=$a ✔
$ [[ $a = 5 ]] && echo a=$a ✔
$ [[ cmp a b ]] && echo same file ✘
$ if test cmp a b; then echo same file; fi ✘
$ if cmp a b; then echo same file; fi ✔
$ [[ -f ~/.bash_aliases ]] && . ~/.bash_aliases
$ [[ -x /usr/bin/xterm ]] && /usr/bin/xterm -e tmux &
$ [[ "$pass" != "$MYPASS" ]] && echo 'Wrong password!' && exit 1
$ help test
```

```bash
#!/bin/bash

words=$@
string=linux
if echo "$words" | grep -q "$string"
then
  echo "$string found in $words"
else
  echo "$string not found in $words"
fi
```

Loops

for ARG in LIST; do COMMAND(s); done

```
$ for i in 1 2 3; do echo -n i="$i "; done
$ for i in {1..10}; do echo $i; done
$ for i in $(seq 10); do echo $i; done
$ for ((i=1; i<=10; i++)); do echo $i; done
$ for ((i=1, j=1; i<=10; i++, j++)); do
  echo $i-$j ☹
  echo $(($i-$j)) ☺
  done
$ for ((i=1; i<=10; i++)) { echo $i; } # C style
$ for i in hello world; do echo -n "$i "; done
```

Loops

while CONDITION; do COMMAND(s); done

```
$ a=0; while [[ a < 10 ]]; do echo $a; ((a++)); done ☹
$ while [[ $a < 10 ]]; do echo $a; ((a++)); done ☹
$ while [[ $a -lt 10 ]]; do echo $a; ((a++)); done ✔
$ while [ $a -lt 10 ]; do echo $a; ((a++)); done ✔
$ while (( a < 10 )); do echo $a; ((a++)); done ✔
$ until (( a = 10 )); do echo $a; ((a++)); done ☹
$ until (( a == 10 )); do echo $a; ((a++)); done ✔
$ while read n; do n2 $n; done
$ while read n; do n2 $n; done < datafile
$ until (( n == 0 )); do read n; n2 $n; done
```

`case`

```
#!/bin/bash

[ -z "$1" ] && echo "Usage: `basename $0` [dhb]<number>" && exit 0;

case "$1" in
	[dD]*)
		NUM=$(echo $1 | cut -b 2-)
		printf "\tDec\tHex\tBin\n"
		printf "\t%d\t0x%02X\t%s\n" $NUM $NUM $(bc <<< "obase=2;$NUM")
		;;
	[hH]*)
		NUM=$(echo $1 | cut -b 2-)
		NUM=$(echo $NUM | tr [:lower:] [:upper:])
		printf "\tHex\t\tDec\t\tBin\n"
		printf "\t0x%s\t\t%s\t\t%s\n" $NUM $(bc <<< "ibase=16;obase=A;$NUM") \
			$(bc <<< "ibase=16;obase=2;$NUM")
		;;
	0[xX]*)
		NUM=$(echo $1 | cut -b 3-)
		NUM=$(echo $NUM | tr [:lower:] [:upper:])
		printf "\tHex\t\tDec\t\tBin\n"
		printf "\t0x%s\t\t%s\t\t%s\n" $NUM $(bc <<< "ibase=16;obase=A;$NUM") \
			$(bc <<< "ibase=16;obase=2;$NUM")
		;;
	[bB]*)
		NUM=$(echo $1 | cut -b 2-)
		printf "\tBin\t\tHex\t\tDec\n"
		printf "\t%s\t\t0x%s\t\t%s\n" $NUM $(bc <<< "ibase=2;obase=10000;$NUM") \
			$(bc <<< "ibase=2;obase=1010;$NUM")
		;;
	    *)
		printf "Dec\tHex\tBin\n"
		printf "%d\t0x%08X\t%08d\n" $1 $1 $(bc <<< "obase=2;$1")
		;;
esac
```

select

```
#!/bin/bash

PS3='Your favorite OS? '

select OS in "Linux" "Mac OSX" "Windows"
do
  [[ "$OS" = "Linux" ]] && echo wise guy.
  [[ "$OS" = "Mac OSX" ]] && echo rich guy.
  [[ "$OS" = "Windows" ]] && echo patient guy.
  break
done
```

Functions

```bash
#!/bin/bash

function screencapture(){
  ffmpeg -f x11grab -s 1920x1080 -r 30 -i :0.0 \
         -c:v libx264 -crf 0 -preset ultrafast screen.mkv
}

w2pdf(){
  libreoffice --convert-to pdf:writer_pdf_Export "$1"
}

rfc(){
    [[ -n "$1" ]] || {
                cat <<EOF
  rfc - Command line RFC viewer
  Usage: rfc <index>
EOF
                return 1
        }
        find /usr/share/doc/RFC/ -type f -iname "rfc$1.*" | xargs less
}
```

Array

https://www.tutorialspoint.com/unix/unix-using-arrays.htm

4 C Programming Basics

4.1 Programming Environment

Program Languages

Machine code

The *binary numbers* that the CPUs can understand.

```
1001110000111011110011111 ... and so on ...
```

Assembly language — friendly to humans

People don't think in numbers.

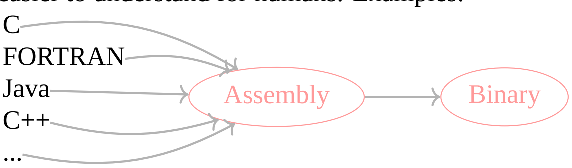
```
MOV A,47 ;1010 1111
ADD A,B  ;0011 0111
HALT     ;0111 0110
```

The ASM programs are translated to machine code by *assemblers*.

High level languages

Even easier to understand for humans. Examples:

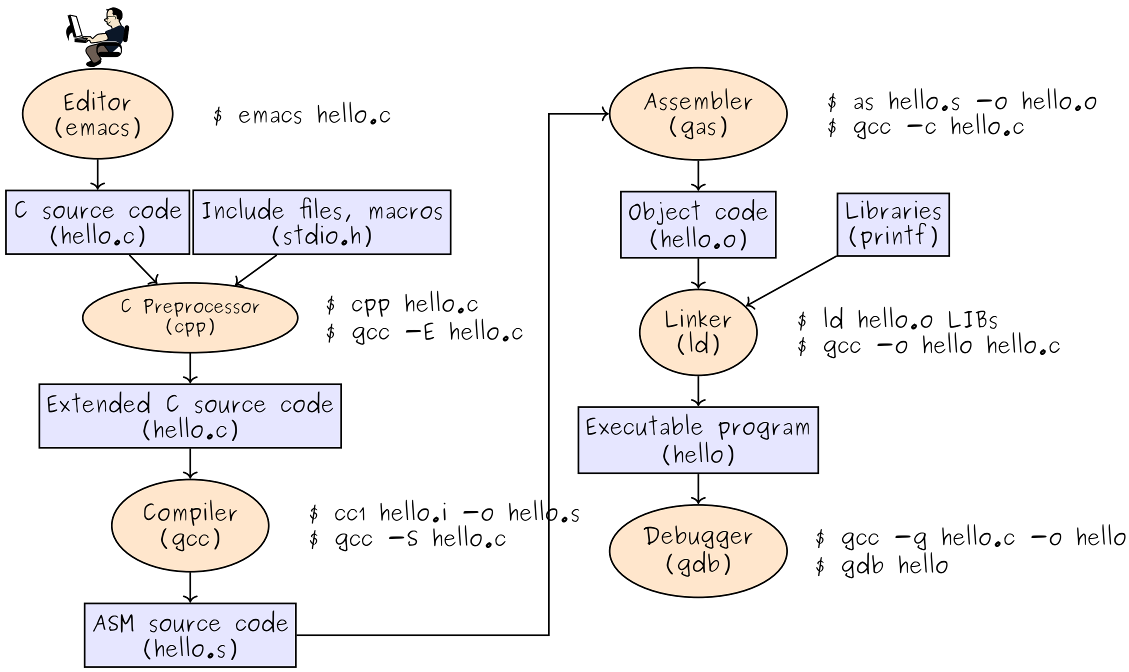
- C
- FORTRAN
- Java
- C++
- ...



Compilers do the translation work.

4.1.1 The Tool Chain

Compilation



Source code written by programmer in high-level language, in our case in `C`. We write c source code with a *text editor*, such as `emacs`, `vim`, etc.

Preprocessing is the first pass of any C compilation. It processes `include-files`, `conditional compilation instructions` and `macros`.

cpp The GNU C preprocessor

```
$ gcc -E hello.c
```

Compilation is the second pass. It takes the output of the preprocessor, and the `source code`, and generates `assembly source code`.

gcc/g++ GNU C/C++ compiler

```
$ gcc -S hello.c
```

Assembly is the third stage of compilation. It takes the assembly source code and produces an assembly listing with offsets. The assembler output is stored in an `object file`.

as the portable GNU assembler

```
$ gcc -c hello.c
```

Linking is the final stage of compilation. It combines object code with predefined routines from `libraries` and produces the `executable program`.

ld The GNU linker

```
$ gcc hello.c -lm
```

Wrapper The whole compilation process is usually not done ‘by hand’, but using a `wrapper` program that combines the functions of preprocessor(cpp), compiler(gcc/g++), assembler(as) and linker(ld).

```
$ gcc -Wall hello.c -lm -o hello
```

Compiler vs. Interpreter

hello.c

```
#include <stdio.h>
int main()
{
  printf("Hello, world!\n");
  return 0;
}
```

```
$ gcc -o hello hello.c
$ ./hello
```

hello.sh

```
#!/bin/bash
echo 'Hello, world!'
```

```
$ chmod +x hello.sh
$ ./hello.sh
```

hello.py

```
#!/usr/bin/python
print "Hello, world!"
```

```
$ chmod +x hello.py
$ ./hello.py
```

4.1.2 Header Files

Header Files

Why?

```
#include "add.h"

int triple(int x)
{
  return add(x, add(x,x));
}
```

Why not?

```
int add(int, int);

int triple(int x)
{
  return add(x, add(x, x));
}
```

- Ensure everyone use the same code
- Easy to share, upgrade, reuse

In the header files…

- function declarations
- macro definitions
- contants
- system wide global variables

```
$ ls /usr/include/
```

4.1.3 Library Files

Library Files

Static libraries *.a* files. Very old ones, but still alive.

```
$ find /usr/lib -name "*.a"
```

Shared libraries *.so* files. The preferred ones.

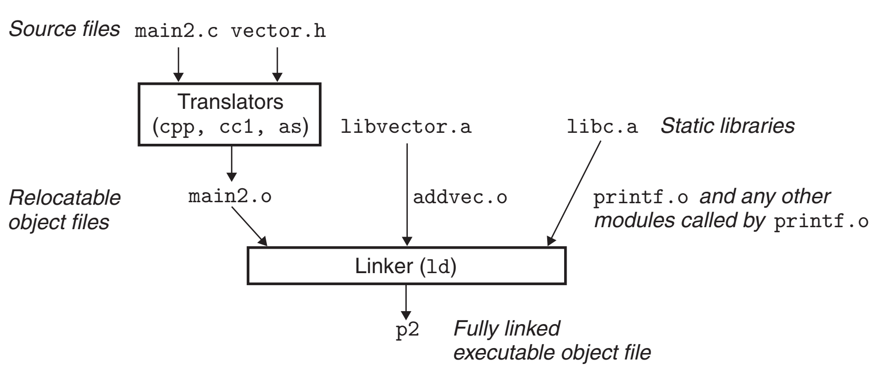
```
$ find /usr/lib -name "*.so.*"
```

Examples:

```
$ gcc -o hello hello.c /usr/lib/libm.a
$ gcc -o hello hello.c -lm
```

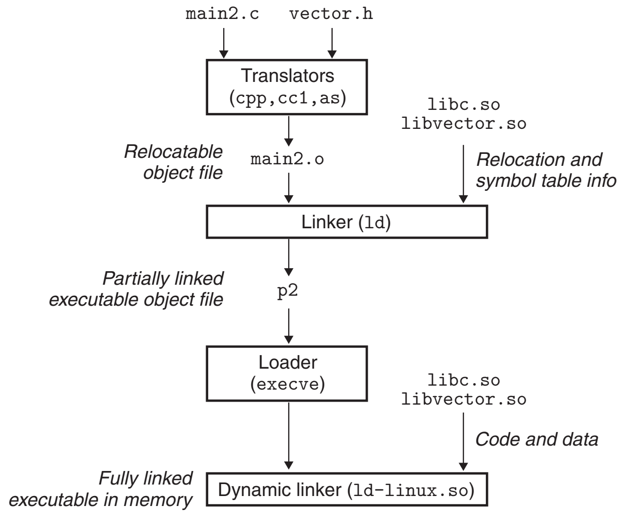
Static Linking

- The entire program and all data of a process must be in physical memory for the process to execute
- The size of a process is thus limited to the size of physical memory



Dynamic Linking

- Only one copy in memory
- Don't have to re-link after a library update



Build A Static Library
Source codes

main.c

```
#include "lib.h"

int main(int argc, char* argv[])
{
  int i=1;

  for (; i<argc; i++)
    {
      hello(argv[i]);
      hi(argv[i]);
    }
  return 0;
}
```

lib.h

```
#include <stdio.h>

void hello(char *);
void hi(char *);
```

hello.c

```
#include <stdio.h>

void hello(char *arg)
{
  printf("Hello, %s!\n", arg);
}
```

hi.c

```
#include <stdio.h>

void hi(char *arg)
{
  printf("Hi, %s!\n", arg);
}
```

Build A Static Library
Step by step

1. Get *hello.o* and *hi.o*
   `$ gcc -c hello.c hi.c`
2. Put **.o* into *libhi.a*
   `$ ar crv libhi.a hello.o hi.o`
3. Use *libhi.a*
   `$ gcc main.c libhi.a`

Build A Static Library
Makefile

```
main: main.c lib.h libhi.a
        gcc -Wall -o main main.c libhi.a

libhi.a: hello.o hi.o
        ar crv libhi.a hello.o hi.o

hello.o: hello.c
        gcc -Wall -c hello.c

hi.o: hi.c
        gcc -Wall -c hi.c

clean:
        rm -f *.o *.a main
```

Build A Shared Library
Source codes

hello.c

```c
#include "hello.h"

int main(int argc, char *argv[])
{
  if (argc != 2)
    printf ("Usage: %s needs an argument.\n", argv[0]);
  else
    hi(argv[1]);
  return 0;
}
```

hello.h

```c
#include <stdio.h>
#include <stdlib.h>

int hi(char*);
```

hi.c

```c
#include "hello.h"

int hi(char* s)
{
  printf ("Hi, %s\n",s);
  return 0;
}
```

Build A Shared Library
Step by step

1. Get *hi.o*
   `$ gcc -fPIC -c hi.c`
2. Get *libhi.so*
   `$ gcc -shared -o libhi.so hi.o`
3. Use *libhi.so*
   `$ gcc -L. -Wl,-rpath=. hello.c -lhi`
4. Check it
   `$ ldd a.out`

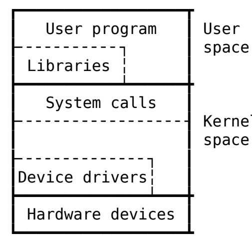
Build A Shared Library
Makefile

```
# http://www.cprogramming.com/tutorial/shared-libraries-linux-gcc.html
# http://tldp.org/HOWTO/Program-Library-HOWTO/shared-libraries.html
#
# gcc -fPIC -c hi.c
# gcc -shared -o libhi.so hi.o
# gcc -L/current/dir -Wl,option -Wall -o hello hello.c -lhi
#
# -L          - tells ld where to search libraries
# -Wl,option - pass option as an option to the linker (ld)
# -rpath=dir - Add a directory to the runtime library search path

hello: hello.c hello.h libhi.so
	gcc -L. -Wl,-rpath=. -Wall -o hello hello.c -lhi
libhi.so: hi.o hello.h
	gcc -shared -o libhi.so hi.o
hi.o: hi.c hello.h
	gcc -fPIC -c hi.c
clean:
	rm *.o *.so hello
```

GNU C Library

Linux API > POSIX API

```
$ man 7 libc
$ man 3 intro
$ man gcc
$ info gcc
sudo apt install gcc-doc
```



4.1.4 Error Handling

`errno.h`

```
#include <stdio.h>
#include <stdlib.h>
#include <sys/stat.h>
#include <fcntl.h>

int main(int argc, char *argv[])
{
  if ( open(argv[1], O_RDONLY) == -1 ){
    perror("open");
    exit(EXIT_FAILURE);
  }
  return 0;
}
```

```
$ man errno
$ man errno.h
$ man perror
```

- [*Advanced programming in the UNIX environment*, Sec. 1.7]
- https://stackoverflow.com/questions/30078281/raise-error-in-a-bash-script

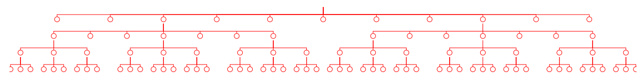
4.1.5 The Make Utility

The Make Utility

To compile a single C program:

`$ gcc hello.c -o hello` OK. But...

What if you have a large project with 1000+ files?



Linux 4.9 source tree: 3799 directories, 55877 files

make: help you maintain your programs.

Makefile

```
target: dependencies
	command
```

Example

```
hello: hello.c
	gcc -o hello hello.c
```

```
$ info make makefiles
```

Makefile

```
edit: main.o kbd.o command.o display.o \
                insert.o search.o files.o utils.o
        gcc -Wall -o edit main.o kbd.o command.o display.o \
                insert.o search.o files.o utils.o

main.o: main.c defs.h
        gcc -c -Wall main.c
kbd.o : kbd.c defs.h command.h
        gcc -c -Wall kbd.c
command.o: command.c defs.h command.h
        gcc -c -Wall command.c
display.o : display.c defs.h buffer.h
        gcc -c -Wall display.c
insert.o: insert.c defs.h buffer.h
        gcc -c -Wall insert.c
search.o: search.c defs.h buffer.h
        gcc -c -Wall search.c
files.o: files.c defs.h buffer.h command.h
        gcc -c -Wall files.c
utils.o: utils.c defs.h
        gcc -c -Wall utils.c

clean:
        rm edit main.o kbd.o command.o display.o \
           insert.o search.o files.o utils.o
```

```
./
├─ command.c
├─ display.c
├─ files.c
├─ insert.c
├─ kbd.c
├─ main.c
├─ search.c
├─ utils.c
├─ buffer.h
├─ command.h
├─ defs.h
└─ Makefile
```

4.1.6 Version Control

git

To create a new local git repo

In your source code directory, do:

```
$ git init
$ git add .
$ git commit -m "something to say…"
```

To clone a remote repo

Example:

```
$ git clone https://github.com/wx672/lecture-notes.git
$ git clone https://github.com/wx672/dotfile.git
```

Most commonly used git Commands

```
$ git add filename[s]
$ git rm filename[s]
$ git commit
```

```
$ git status
$ git log
$ git diff
$ git push
$ git pull
$ git help {add,rm,commit,…}
```

$ man gittutorial
$ man gittutorial-2

sudo apt install git
https://github.com

4.1.7 Manual Pages

Man page
Layout

```
NAME
    A one-line description of the command.
SYNOPSIS
    A formal description of how to run it and what
    command line options it takes.
DESCRIPTION
    A description of the functioning of the command.
EXAMPLES
    Some examples of common usage.
SEE ALSO
    A list of related commands or functions.
BUGS
    List known bugs.
AUTHOR
   Specify your contact information.
COPYRIGHT
    Specify your copyright information.
```

Man Page
Groff source code

```
.\" Text automatically generated by txt2man
.TH untitled  "06 August 2019" "" ""
.SH NAME
\fBA one-line description of the command.
.SH SYNOPSIS
.nf
.fam C
  \fBA formal description of how to run it and what command line options it takes.
.fam T
.fi
.fam T
.fi
.SH DESCRIPTION
\fBA description of the functioning of the command.
.SH EXAMPLES
Some examples of common usage.
.SH SEE ALSO
\fBA list of related commands or functions.
.SH BUGS
List known bugs.
.SH AUTHOR
Specify your contact information.
.SH COPYRIGHT
Specify your copyright information.
```

```
$ man 7 groff
$ man txt2man
$ man a2x
$ ls /usr/share/man
```

4.1.8 A Sample GNU Package

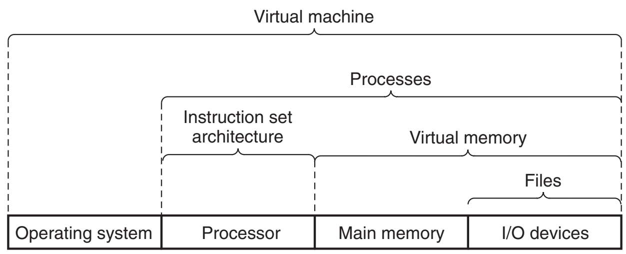
How to “Do one thing, and do it well”?

```
$ apt source hello
```

4.2 OS Basics

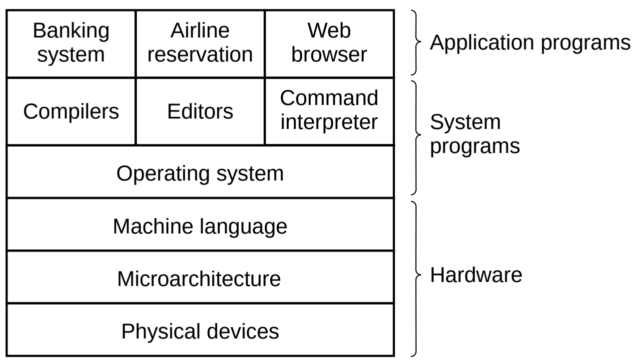
Abstractions

To hide the complexity of the actual implementations



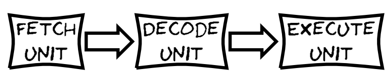
See also: [*Computer Systems: A Programmer's Perspective*, Sec. 1.9.2, *The Importance of Abstractions in Computer Systems*].

A Computer System



4.2.1 Hardware

CPU Working Cycle

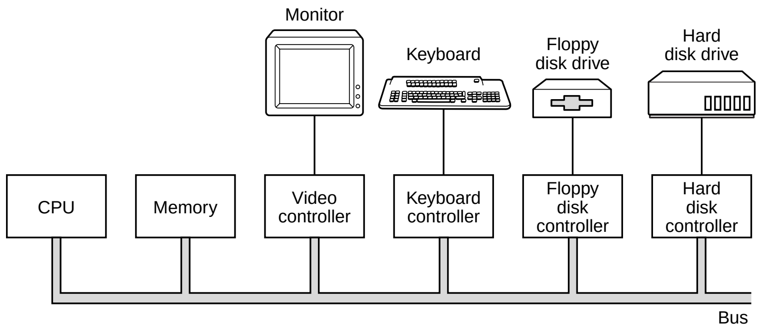


1. Fetch the first instruction from memory
2. Decode it to determine its type and operands
3. execute it

Special CPU Registers
Program counter (PC): keeps the memory address of the next instruction to be fetched
Stack pointer (SP): ☛ the top of the current stack in memory
Program status (PS): holds

- condition code bits
- processor state

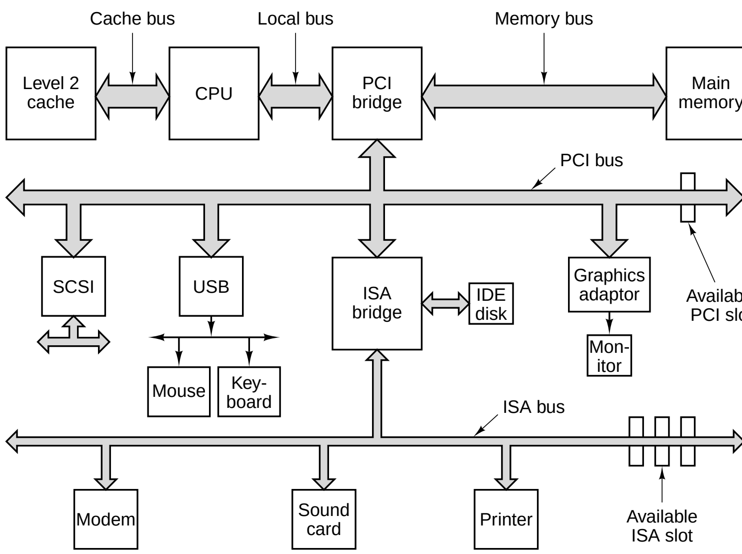
System Bus



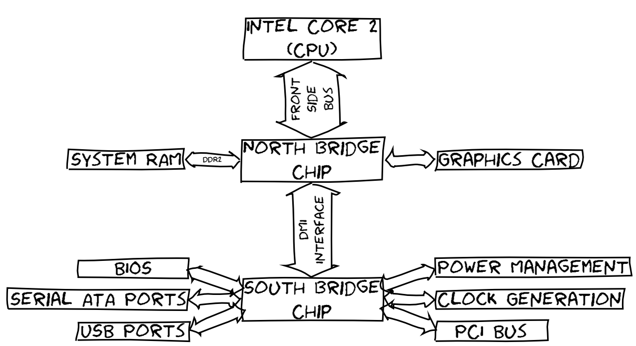
Address Bus: specifies the memory locations (addresses) for the data transfers
Data Bus: holds the data transfered. Bidirectional
Control Bus: contains various lines used to route timing and control signals throughout the system

Controllers and Peripherals

- Peripherals are real devices controlled by controller chips
- Controllers are processors like the CPU itself, have control registers
- Device driver writes to the registers, thus control it
- Controllers are connected to the CPU and to each other by a variety of buses



Motherboard Chipsets



See also: *Motherboard Chipsets And The Memory Map* [1].

- The CPU doesn't know what it's connected to

[1] http://duartes.org/gustavo/blog/post/motherboard-chipsets-memory-map

- CPU test bench? network router? toaster? brain implant?
- The CPU talks to the outside world through its pins
  - some pins to transmit the physical memory address
  - other pins to transmit the values
- The CPU's gateway to the world is the *front-side bus*

Intel Core 2 QX6600

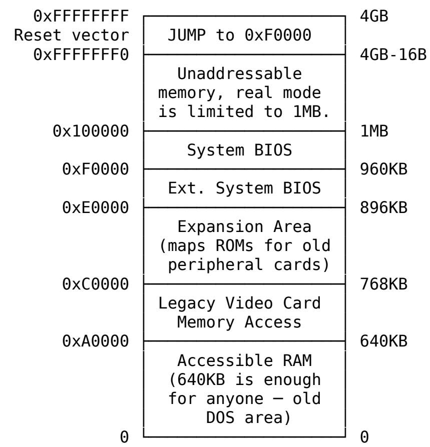
- 33 pins to transmit the physical memory address
  - so there are 2^{33} choices of memory locations
- 64 pins to send or receive data
  - so data path is 64-bit wide, or 8-byte chunks

This allows the CPU to physically address 64GB of memory ($2^{33} \times 8B$)

See also: *Datasheet for Intel Core 2 Quad-Core Q6000 Sequence* [2].

Some physical memory addresses are mapped away!

- only the addresses, not the spaces
- Memory holes
  - 640 KiB ~ 1 MiB
  - `/proc/iomem`



Memory-mapped I/O

- BIOS ROM
- video cards
- PCI cards
- …

This is why 32-bit OSes have problems using 4 GiB of RAM.

the northbridge

1. receives a physical memory request
2. decides where to route it
   - to RAM? to video card? to …?
   - decision made via the *memory address map*

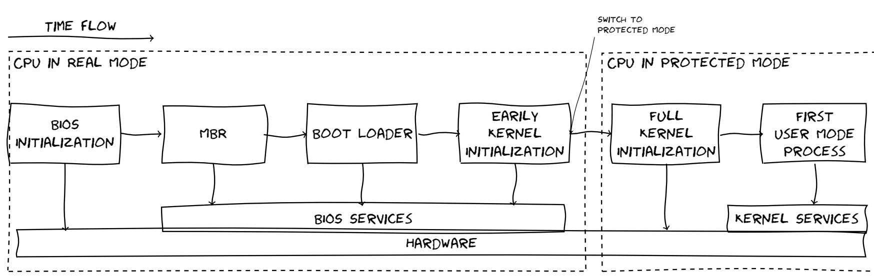
- When is the memory address map built? `setup()`.

4.2.2 Bootstrapping

Bootstrapping

Can you pull yourself up by your own bootstraps?

A computer cannot run without first loading software but must be running before any software can be loaded.



Intel x86 Bootstrapping

1. BIOS (`0xfffffff0`)
   ➠ POST ➠ HW init ➠ Find a boot device (FD,CD,HD…) ➠ Copy *sector zero (MBR)* to RAM (`0x00007c00`)
2. MBR – the first 512 bytes, contains
   - Small code ($< 446\,B$), e.g. GRUB stage 1, for loading GRUB stage 2
   - the primary partition table ($16 \times 4 = 64\,B$)

[2] http://download.intel.com/design/processor/datashts/31559205.pdf

- its job is to load the second-stage boot loader.

3. GRUB stage 2 — load the OS kernel into RAM
4. startup
5. init — the first user-space process

```
|<──────────── Master Boot Record (512 Bytes) ───────────>|
├────//────┬─────────┬──────┬──────────//────┬─────────┤
│ code area │ disk-sig │ null │ partition table │ MBR-sig │
│    440    │    4     │  2   │     16x4=64     │ 0xAA55  │
└────//────┴─────────┴──────┴──────────//────┴─────────┘
0          439       443    445              509       511
```

```
$ sudo hd -n512 /dev/sda
```

4.2.3 Interrupt

Why Interrupt?

While a process is reading a disk file, can we do...

```
while(!done_reading_a_file())
{
  let_CPU_wait();
  // or...
  lend_CPU_to_others();
}
operate_on_the_file();
```

Modern OS are Interrupt Driven

HW INT by sending a signal to CPU

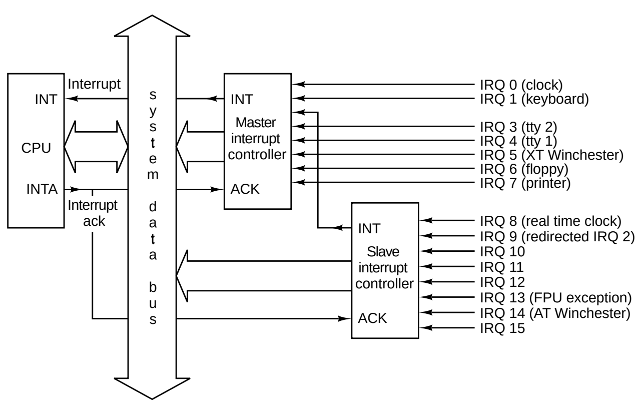
SW INT by executing a *system call*

Trap (exception) is a software-generated INT coursed by an error or by a specific request from an user program

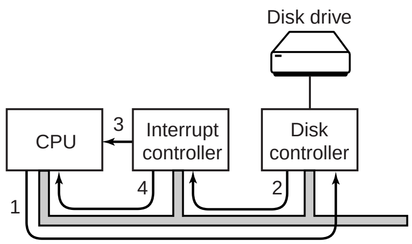
Interrupt vector is an array of pointers ☛ the memory addresses of *interrupt handlers*. This array is indexed by a unique device number

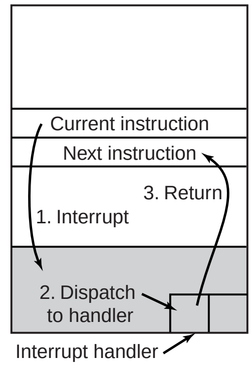
```
$ less /proc/devices
$ less /proc/interrupts
```

Programmable Interrupt Controllers



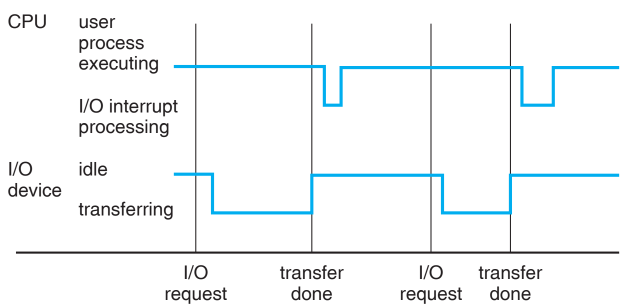
Interrupt Processing





Detailed explanation: in [*Modern Operating Systems*, Sec. 1.3.5, *I/O Devices*].

Interrupt Timeline



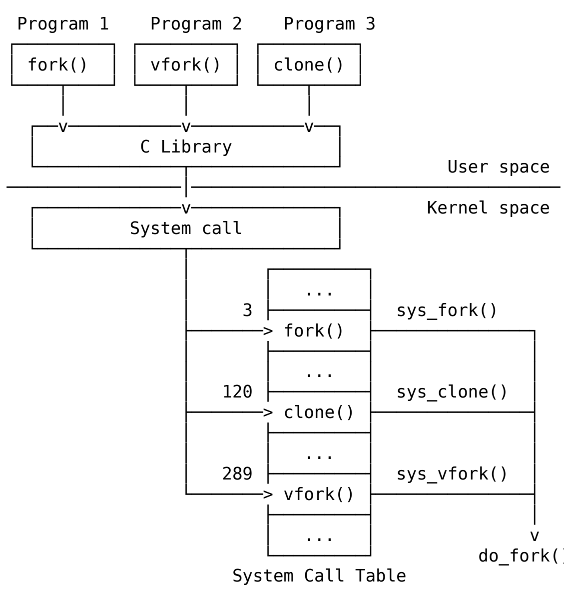
4.2.4 System Calls

System Calls

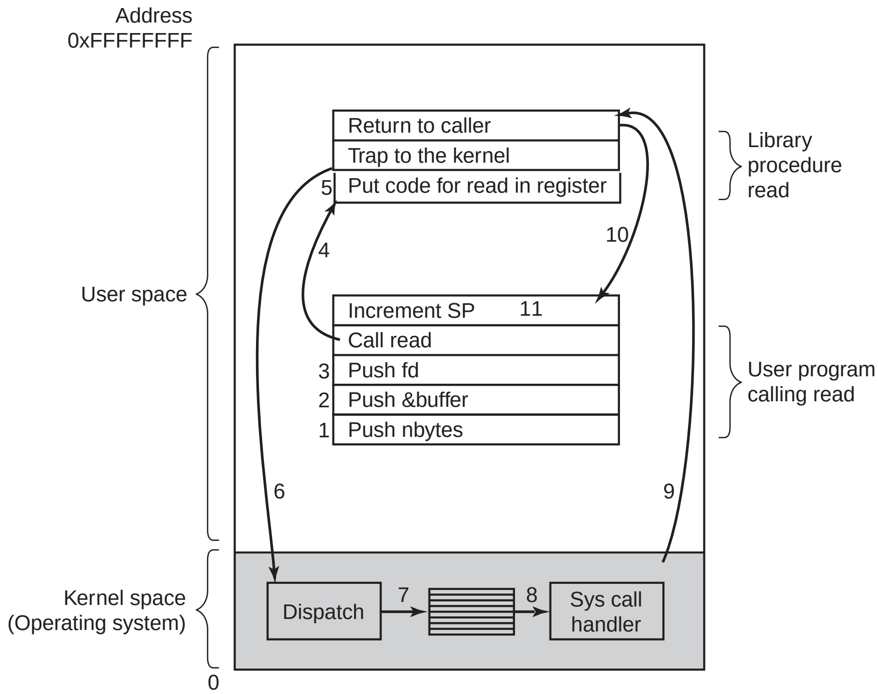
A System Call

- is how a program requests a service from an OS kernel
- provides the interface between a process and the OS

```
$ man 2 intro
$ man 2 syscalls
```



The 11 steps in making a system call
read(fd,buffer,nbytes)



Example
Linux INT 80h
Interrupt Vector Table: The very first 1KiB of x86 memory.

- 256 entries $\times$ 4B = 1KiB
- Each entry is a complete memory address (`segment:offset`)
- It's populated by Linux and BIOS
- Slot `80h`: address of the kernel services dispatcher (☛ sys-call table)

Example

```
Msg: db 'Hello, world'
MsgLen: equ $-Msg
mov eax,4      ; sys_write syscall = 4
mov ebx,1      ; 1 = STDOUT
mov ecx,Msg    ; offset of the message
mov edx,MsgLen ; length of string
int 80h        ; call the kernel
```

```
$ nasm -f elf64 hello.asm -o hello.o
$ ld hello.o -o hello
$ ./hello
```

Process management

Call	Description
pid = fork( )	Create a child process identical to the parent
pid = waitpid(pid, &statloc, options)	Wait for a child to terminate
s = execve(name, argv, environp)	Replace a process' core image
exit(status)	Terminate process execution and return status

File management

Call	Description
fd = open(file, how, ...)	Open a file for reading, writing or both
s = close(fd)	Close an open file
n = read(fd, buffer, nbytes)	Read data from a file into a buffer
n = write(fd, buffer, nbytes)	Write data from a buffer into a file
position = lseek(fd, offset, whence)	Move the file pointer
s = stat(name, &buf)	Get a file's status information

Directory and file system management

Call	Description
s = mkdir(name, mode)	Create a new directory
s = rmdir(name)	Remove an empty directory
s = link(name1, name2)	Create a new entry, name2, pointing to name1
s = unlink(name)	Remove a directory entry
s = mount(special, name, flag)	Mount a file system
s = umount(special)	Unmount a file system

Miscellaneous

Call	Description
s = chdir(dirname)	Change the working directory
s = chmod(name, mode)	Change a file's protection bits
s = kill(pid, signal)	Send a signal to a process
seconds = time(&seconds)	Get the elapsed time since Jan. 1, 1970

Fig. 1-18. Some of the major POSIX system calls. The return code *s* is −1 if an error has occurred. The return codes are as follows: *pid* is a process id, *fd* is a file descriptor, *n* is a byte count, *position* is an offset within the file, and *seconds* is the elapsed time. The parameters are explained in the text.

System Call Examples

`fork()`

```c
#include <stdio.h>
#include <unistd.h>

int main ()
{
  printf("Hello World!\n");
  fork();
  printf("Goodbye Cruel World!\n");
  return 0;
}
```

```
$ man 2 fork
```

`execve()`

```c
#include <stdio.h>
#include <unistd.h>

int main()
{
  printf("Hello World!\n");
  if( fork() != 0 )
    printf("I am the parent process.\n");
  else {
    printf("A child is listing the directory contents...\n");
    execl("/bin/ls", "ls", "-al", NULL);
  }
  return 0;
}
```

```
$ man 2 execve
$ man 3 exec
```

Quoted from stackoverflow: What is the difference between the functions of the *exec* family of system calls:

> There is no *exec* system call — this is usually used to refer to all the *execXX* calls as a group. They all do essentially the same thing: loading a new program into the current process, and provide it with arguments and environment variables. The differences are in how the program is found, how the arguments are specified, and where the environment comes from.
>
> - The calls with *v* in the name take an array parameter to specify the `argv[]` array (*vector*) of the new program.
> - The calls with *l* in the name take the arguments of the new program as a variable-length argument *list* to the function itself.
> - The calls with *e* in the name take an extra argument to provide the *environment* of the new program; otherwise, the program inherits the current process's environment.
> - The calls with *p* in the name search the *PATH* environment variable to find the program if it doesn't have a directory in it (i.e. it doesn't contain a / character). Otherwise, the program name is always treated as a path to the executable.

5 The Linux Environment

Command Line Options

getopt.c

```c
#include <stdio.h>
#include <unistd.h>

int main(int argc, char* argv[]) {
  int opt;

  while ((opt = getopt(argc, argv, "hf:l")) != -1) {
    switch (opt) {
    case 'h':
      printf("Usage: %s [-h] [-f file] [-l]\n", argv[0]);
      break;
    case 'l':
      printf("option: %c\n", opt);
      break;
    case 'f':
      printf("filename: %s\n", optarg);
      break;
    }
  }
  return 0;
}
```

```
$ man 3 getopt
```

Command Line Options

getopt.sh

```bash
#!/bin/bash

while getopts hf:l OPT; do
  case $OPT in
    h) echo "usage: `basename $0` [-h] [-f file] [-l]"
       exit 1 ;;
    l) echo "option: l" ;;
    f) echo "filename: $OPTARG" ;;
  esac
done
```

```
$ ./getopt.sh -h
$ ./getopt.sh -lf filename
$ ./getopt.sh -l -f filename
$ ./getopt.sh -f filename -l
```

Environment Variable

```c
#include <stdlib.h>
#include <stdio.h>

extern char** environ;

int main() {
  char** env = environ;

  while (*env) {
    printf("%s\n", *env);
    env++;
  }

  return 0;
}
```

```
$ env
$ man 3 getenv
$ man 3 putenv
```

[*Beginning linux programming*, p.147, Sec. The `environ` Variable]

Time and Date

```c
#include <time.h>
#include <stdio.h>

int main(void)
{
  time_t t = time(NULL); /* long int */

  printf("epoch time:\t%ld\n",t);
  printf("calendar time:\t%s", ctime(&t));

  return 0;
}
```

- January 1 1970 — start of the Unix epoch

```
$ man 3 time
$ man 3 ctime
```

Temporary Files

mkstemp.c

```c
#include <stdlib.h>
#include <unistd.h>
#define _GNU_SOURCE
#include <stdio.h>

int main(int argc, char *argv[])
{
  char c, *f;

  asprintf(&f, "%sXXXXXX", argv[1]);
  int tmp = mkstemp(f);

  while ( read(0, &c, 1) == 1)
    write(tmp, &c, 1);

  unlink(f);
  free(f);
  return 0;
}
```

mktemp.sh

```bash
#!/bin/bash

tmp=$(mktemp)

while read LINE; do
  echo $LINE >> $tmp
done


```

```
$ man 3 mkstemp
$ man 3 tmpfile
$ man 3 asprintf
```

Logging

syslog.c

```c
#include <syslog.h>
#include <sys/stat.h>
#include <fcntl.h>

int main(int argc, char *argv[])
{
  if ( open(argv[1], O_RDONLY) < 0 )
    syslog(LOG_ERR | LOG_USER, "%s - %m\n", argv[1]);
  else
    syslog(LOG_INFO | LOG_USER, "%s - %m\n", argv[1]);
  return 0;
}
```

logger.sh

```bash
#!/bin/bash

[[ -f "$1" ]] && logger "$1 exists." || logger "$1 not found."
```

6 Working With Files

6.1 File

File
A logical view of information storage

User's view
A file is the smallest storage unit on disk.

- Data cannot be written to disk unless they are within a file

UNIX view

Each file is a sequence of 8-bit bytes

- It's up to the application program to interpret this byte stream.

File

What is stored in a file?

Source code, object files, executable files, shell scripts, PostScript...

Different type of files have different structure

- UNIX looks at contents to determine type
  Shell scripts start with "`#!`"
  PDF start with "`%PDF...`"
  Executables start with *magic number*
- Windows uses file naming conventions
  executables end with "`.exe`" and "`.com`"
  MS-Word end with "`.doc`"
  MS-Excel end with "`.xls`"

File Types

Regular files: ASCII, binary

Directories: Maintaining the structure of the FS

In UNIX, everything is a file

Character special files: I/O related, such as terminals, printers ...

Block special files: Devices that can contain file systems, i.e. disks

Disks — logically, linear collections of blocks; disk driver translates them into physical block addresses

File Operations

POSIX file system calls

`creat(name, mode)`	`read(fd, buffer, byte_count)`
`open(name, flags)`	`write(fd, buffer, byte_count)`
`close(fd)`	`lseek(fd, offset, whence)`
`link(oldname, newname)`	`chown(name, owner, group`
`unlink(name)`	`fchown(fd, owner, group)`
`truncate(name, size)`	`chmod(name, mode`
`ftruncate(fd, size)`	`fchmod(fd, mode)`
`stat(name, buffer)`	`utimes(name, times)`
`fstat(fd, buffer)`	

File System Implementation

A typical file system layout

```
|<---------------------- Entire disk ---------------------->|
+-----+-------------+-------------+-------------+-------------+
| MBR | Partition 1 | Partition 2 | Partition 3 | Partition 4 |
+-----+-------------+-------------+-------------+-------------+
  ______________________________/              \____________
 /                                                          \
+----------------+-----------------+--------------------//--+
| Boot Ctrl Blk  | Volume Ctrl Blk |  Dir Structure    | Files
|  (MBR copy)    |   (Super Blk)   | (inodes, root dir)| dirs
+----------------+-----------------+--------------------//--+
```

```
|<------------ Master Boot Record (512 Bytes) ----------->|
+-----//------+-----------+------+-------//------+---------+
| code area   | disk-sig  | null | partition table | MBR-sig |
|    440      |     4     |  2   |    16x4=64      | 0xAA55  |
+-----//------+-----------+------+-------//------+---------+
0          439         443    445             509       511
```

On-Disk Information Structure
Boot block a MBR copy
Superblock Contains volume details

number of blocks	size of blocks
free-block count	free-block pointers
free FCB count	free FCB pointers

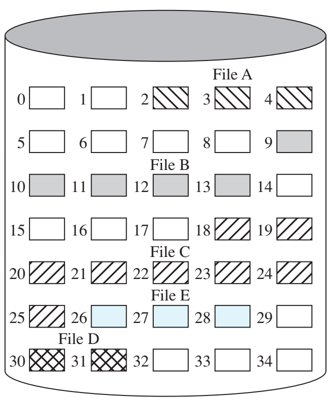
I-node Organizes the files *FCB (File Control Block)*, contains file details (metadata).

Superblock
Keeps information about the file system

- Type — ext2, ext3, ext4...
- Size
- Status — how it's mounted, free blocks, free inodes, ...
- Information about other metadata structures

```
$ sudo dumpe2fs /dev/sda1 | less
```

Implementing Files



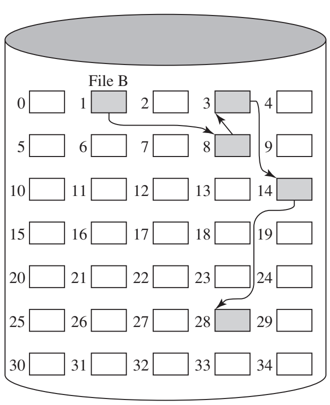
File Allocation Table

File Name	Start Block	Length
File A	2	3
File B	9	5
File C	18	8
File D	30	2
File E	26	3

Contiguous Allocation

☺ simple
☺ good for read only

☹ fragmentation



File Allocation Table

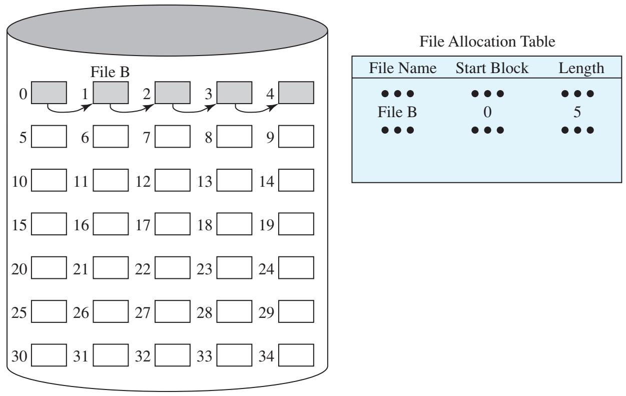
File Name	Start Block	Length
•••	•••	•••
File B	1	5
•••	•••	•••

Linked List (Chained) Allocation
A pointer in each disk block

☺ no waste block
☹ slow random access

☹ not 2^n

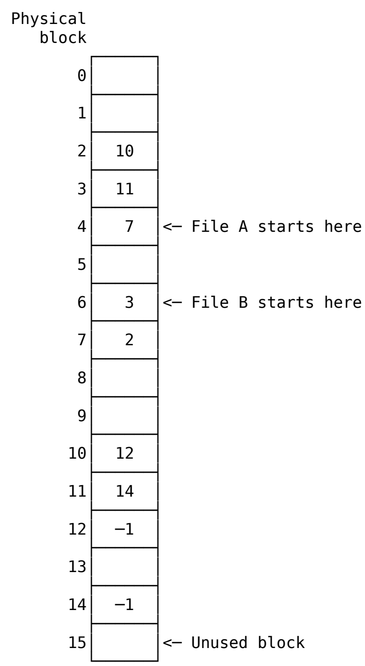
Linked List (Chained) Allocation Though there is no external fragmentation, consolidation is still preferred.



FAT: Linked list allocation with a table in RAM

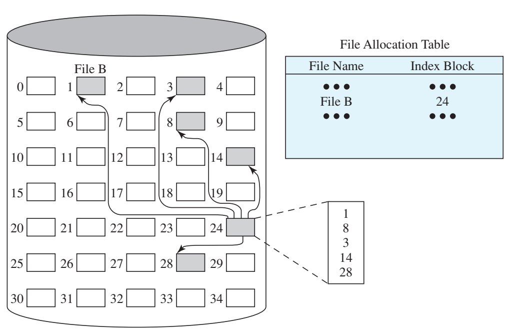
- Taking the pointer out of each disk block, and putting it into a table in memory
- fast random access (chain is in RAM)
- is 2^n
- the entire table must be in RAM

$$disk \nearrow \Rightarrow FAT \nearrow \Rightarrow RAM_{used} \nearrow$$



See also: [*File Allocation Table — Wikipedia, The Free Encyclopedia, Wikipedia:FAT*].

Indexed Allocation

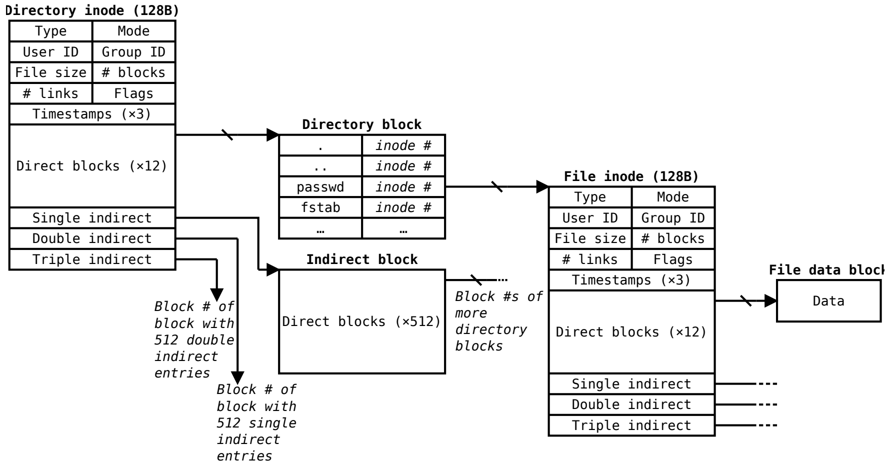


I-node A data structure for each file. An i-node is in memory *only if* the file is open

$$files_{opened} \nearrow \Rightarrow RAM_{used} \nearrow$$

See also: [*Inode — Wikipedia, The Free Encyclopedia, Wikipedia:inode*].

UNIX Treats a Directory as a File

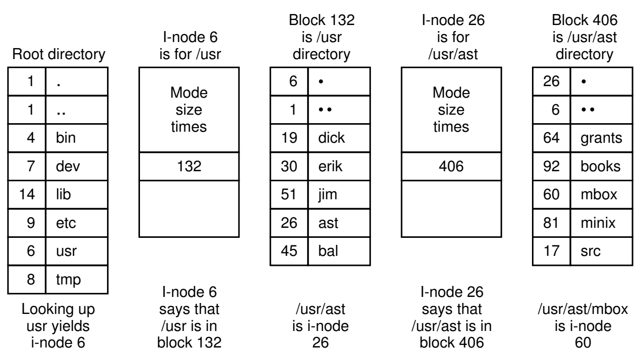


`open()`

Why? To avoid constant searching

- Without `open()`, every file operation involves searching the directory for the file.

The steps in looking up `/usr/ast/mbox`



`fd open(pathname, flags)`

A per-process *open-file table* is kept in the OS

- upon a successful `open()` syscall, a new entry is added into this table
- indexed by *file descriptor (fd)*
- `close()` to remove an entry from the table

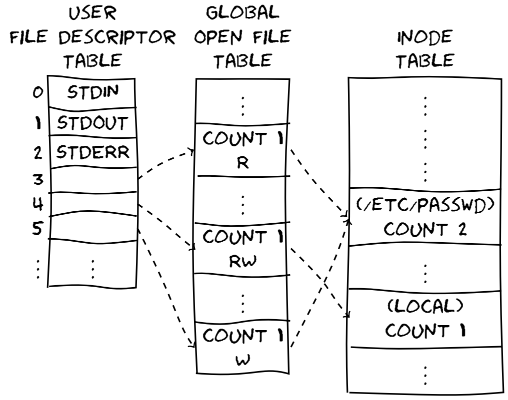
To see files opened by a process, e.g. `init`

```
$ lsof -p 1
```

```
$ man 2 open
```

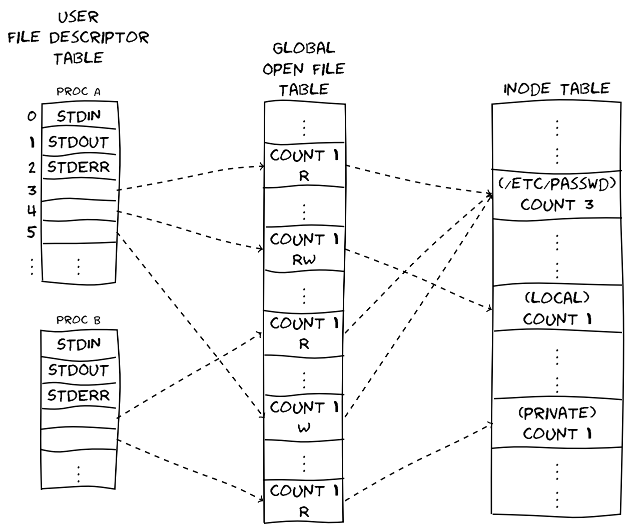
A process executes the following code:

```
fd1 = open("/etc/passwd", O_RDONLY);
fd2 = open("local", O_RDWR);
fd3 = open("/etc/passwd", O_WRONLY);
```



One more process B:

```
fd1 = open("/etc/passwd", O_RDONLY);
fd2 = open("private", O_RDONLY);
```



`write()`

```c
#include <unistd.h>

int main(void)
{
  write(1, "Hello, world!\n", 14);

  return 0;
}
```

```
$ man 2 write
$ man 3 write
```

`read()`

```c
#include <unistd.h>

int main(void)
{
  char buffer[10];

  read(0, buffer, 10);

  write(1, buffer, 10);

  return 0;
}
```

```
$ man 2 read
$ man 3 read
```

`cp`

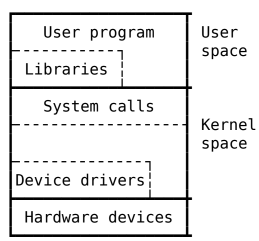
```c
#include <sys/types.h>   /* include necessary header files */
#include <fcntl.h>
#include <stdlib.h>
#include <unistd.h>

#define BUF_SIZE 4096    /* use a buffer size of 4096 bytes */
#define OUTPUT_MODE 0700 /* protection bits for output file */

int main(int argc, char *argv[])
{
  int in, out, rbytes, wbytes;
  char buf[BUF_SIZE];

  if (argc != 3) exit(1);

  if ( (in = open(argv[1], O_RDONLY)) < 0 ) exit(2); /* open source file */

  if ( (out = creat(argv[2], OUTPUT_MODE)) < 0 ) exit(3); /* create destination file */

  while (1) { /* Copy loop */
    if ( (rbytes = read(in, buf, BUF_SIZE)) <= 0 ) break;   /* read a block of data */
    if ( (wbytes = write(out, buf, rbytes)) <= 0 ) exit(4); /* write data */
  }

  close(in);
  close(out);
  if (rbytes == 0) exit(0); /* no error on last read */
  else exit(5);             /* error on last read */
}
```

`stdio` — The Standard I/O Library

System calls: `open()`, `read()`, `write()`, `close()`...

Library functions: `fopen()`, `fread()`, `fwrite`, `fclose()`...

Avoid calling syscalls directly as much as you can



- Portability
- Buffered I/O

`open()` vs. `fopen()`

`open()`

```c
#include <unistd.h>
#include <sys/stat.h>
#include <fcntl.h>
#include <stdio.h>

int main()
{
  char c;
  int in;
  in = open("/tmp/1m.test", O_RDONLY);

  while (read(in, &c, 1) == 1);

  return 0;
}
```

```
$ strace -c ./open
```

`fopen()` — Buffered I/O

```c
#include <stdio.h>

int main(void)
{
  FILE *stream;

  stream = fopen("/tmp/1m.test", "r");

  while ( fgetc(stream) != EOF );

  fclose(stream);

  return 0;
}
```

```
$ strace -c ./fopen
```

```
$ dd if=/dev/zero of=/tmp/1m.test bs=1k count=1024
```

|https://stackoverflow.com/questions/1658476/c-fopen-vs-open|

`cp` — With `stdio`

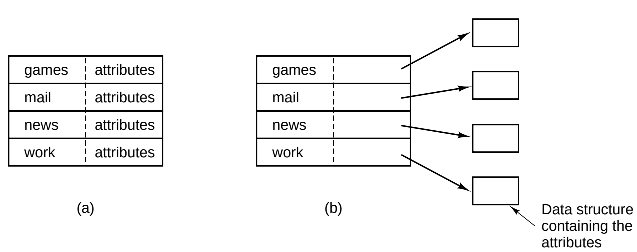
```c
#include <stdio.h>
#include <stdlib.h>

int main(int argc, char *argv[])
{
	FILE *in, *out;
	int c=0;

	if (argc != 3) exit(1);

	in = fopen(argv[1], "r");
	out = fopen(argv[2], "w");

	while ( (c = fgetc(in)) != EOF )
		fputc(c, out);

	return 0;
}
```

Homework: Try `fread()/fwrite()` instead.

|https://stackoverflow.com/questions/32742430/is-getc-a-macro-or-a-function| |https://stackoverflow.com/questions/9104568/macro-vs-function-in-c|

6.2 Directory

Implementing Directories



(a) A simple directory (Windows)
  - fixed size entries
  - disk addresses and attributes in directory entry

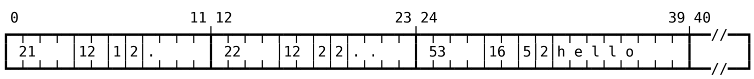
(b) Directory in which each entry just refers to an i-node (UNIX)

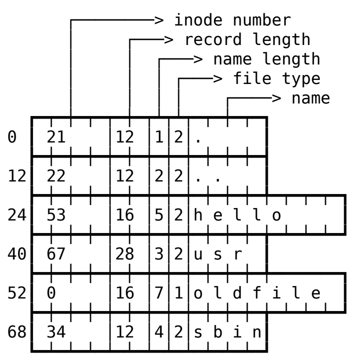
Directory entry in `glibc`

```
struct dirent {
  ino_t          d_ino;       /* Inode number */
  off_t          d_off;       /* Not an offset; see below */
  unsigned short d_reclen;    /* Length of this record */
  unsigned char  d_type;      /* Type of file; not supported
                                 by all filesystem types */
  char           d_name[256]; /* Null-terminated filename */
};
```

```
$ man readdir
$ view /usr/include/x86_64-linux-gnu/bits/dirent.h
```

Ext2 Directories





- Directories are special files
- "." and ".." first
- Padding to $4\times$
- inode number is 0 — deleted file

`ls`

```
#include <sys/types.h>
#include <dirent.h>
#include <stddef.h>
#include <stdio.h>

int main(int argc, char *argv[])
{
  DIR *dp;
  struct dirent *entry;

  dp = opendir(argv[1]);

  while ( (entry = readdir(dp)) != NULL ){
    printf("%s\n", entry->d_name);
  }

  closedir(dp);

  return 0;
}
```

The real `ls.c`?
- 116 A4 pages
- 5308 lines

Do one thing, and do it really well.

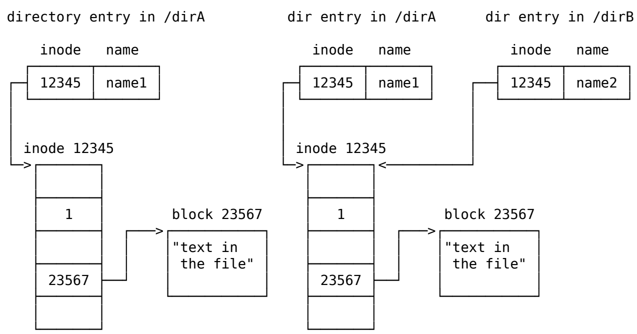
```
$ apt source coreutils
```

`mkdir()`, `chdir()`, `rmdir()`, `getcwd()`

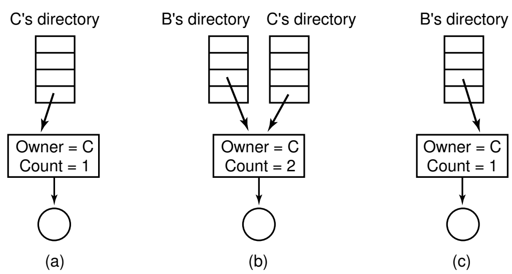
```c
#include <sys/stat.h>
#include <sys/types.h>
#include <unistd.h>
#include <stdio.h>

int main(int argc, char *argv[])
{
  char s[100];
  if ( mkdir(argv[1], S_IRUSR|S_IXUSR) == 0 )
    chdir(argv[1]);
  printf("PWD = %s\n", getcwd(s,100));
  rmdir(argv[1]);
  return 0;
}
```

Hard Links

Hard links ☛ the same inode

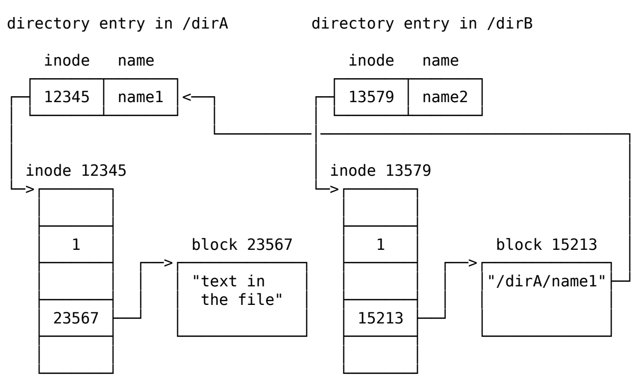


Drawback



Symbolic Links

A symbolic link has its own inode ☛ a directory entry



Fast symbolic link: Short path name ($< 60\, chars$) needs no data block. Can be stored in the 15 pointer fields

link(), unlink(), symlink()

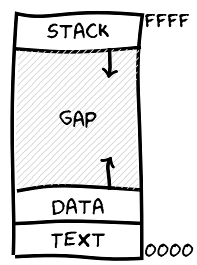
```c
#include <unistd.h>
#include <stdio.h>

int main(int argc, char *argv[])
{
  /* link(argv[1], argv[2]); */
  /* symlink(argv[1], argv[2]); */
  unlink(argv[1]);
  perror(argv[0]);
  return 0;
}
```

7 Processes and Threads

7.1 Process

Process

A process is an instance of a program in execution



Processes are like human beings:

- they are generated
- they have a life
- they optionally generate one or more child processes, and
- eventually they die

A small difference:

- sex is not really common among processes
- each process has just one parent

Process Control Block (PCB)

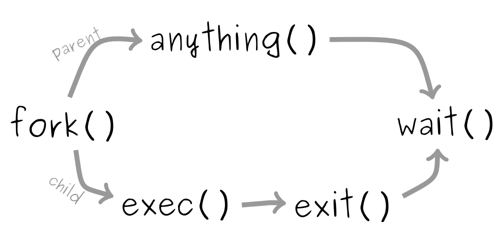
process state
PID
program counter
registers
memory limits
list of open files
...

Implementation

A process is *the collection of data structures* that fully describes how far the execution of the program has progressed.

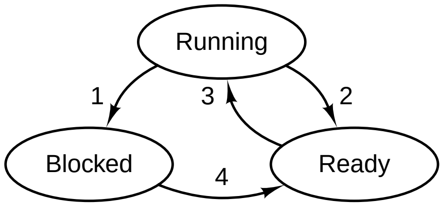
- Each process is represented by a *PCB*
- `task_struct` in 🐧

Process Creation



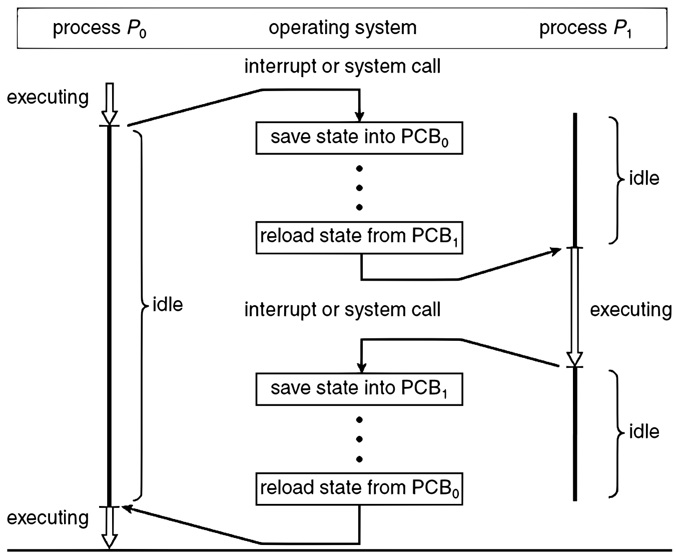
- When a process is created, it is almost identical to its parent
  - It receives a (logical) copy of the parent's address space, and
  - executes the same code as the parent
- The parent and child have separate copies of the data (stack and heap)

Process State Transition



1. Process blocks for input
2. Scheduler picks another process
3. Scheduler picks this process
4. Input becomes available

CPU Switch From Process To Process



Forking in C

```c
#include <stdio.h>
#include <unistd.h>

int main ()
{
  printf("Hello World!\n");
  fork();
  printf("Goodbye Cruel World!\n");
  return 0;
}
```

`exec()`

```c
#include <unistd.h>

int main(void) {
  char *argv[] = {NULL};
  char *envp[] = {NULL};
  execve("callee.out", argv, envp);
}
```

Fig. 1: `caller.c`

```c
#include <stdio.h>

int main(int argc, char **argv) {
  if (argc == 0 && argv[0] == NULL)
      puts("yup");
}
```

Fig. 2: `callee.c`

```
$ gcc -Wall caller.c -o caller.out
$ gcc -Wall callee.c -o callee.out
$ ./caller.out ./callee.out
```

Fig. 3: `argv[0]` can be NULL

```c
int main()
{
  pid_t pid;
  /* fork another process */
  pid = fork();
  if (pid < 0) { /* error occurred */
    fprintf(stderr, "Fork Failed");
    exit(-1);
  }
  else if (pid == 0) { /* child process */
    execlp("/bin/ls", "ls", NULL);
  }
  else { /* parent process */
    /* wait for the child to complete */
    wait(NULL);
    printf ("Child Complete");
    exit(0);
  }
  return 0;
}
```

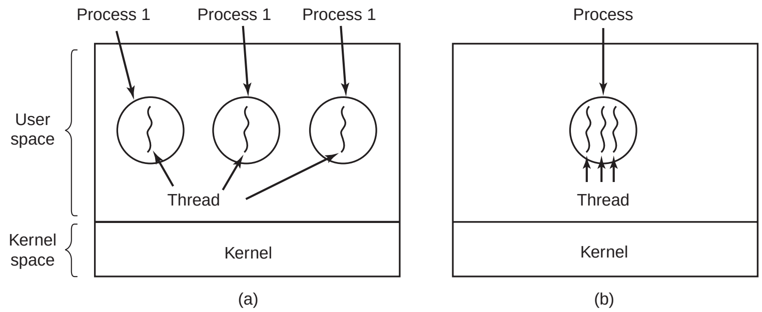
More about `argv[0]` `int execve(const char *pathname, char *const argv[], char *const envp[]);`

- `pathname` should be the binary image of a program. Or it can be a script (`man 2 execve`);
- `argv[0]` is the new process name, usually the same as the basename of `pathname`, though it can be any other string. It can even be NULL (see Figure 3 for example).
  The fact that `argv[0]` contains the name used to invoke the program can be employed to perform a useful trick. We can create multiple links to (i.e., names for) the same program, and then have the program look at `argv[0]` and take different actions depending on the name used to invoke it. An example of this technique is provided by the *gzip(1)*, *gunzip(1)*, and *zcat(1)* commands, all of which are links to the same executable file. [*The Linux Programming Interface: A Linux and UNIX System Programming Handbook*, Sec. 6.6]
- https://stackoverflow.com/questions/2794150/when-can-argv0-have-null
- https://stackoverflow.com/questions/36673765/why-can-the-execve-system-call-run-bin-sh-without-any-argv-arguments-but-not

7.2 Thread

Process vs. Thread

a single-threaded process	=	resource + execution
a multi-threaded process	=	resource + executions



A process = a unit of resource ownership, used to group resources together;
A thread = a unit of scheduling, scheduled for execution on the CPU.

Threads

code, data, open files, signals...		
thread ID	thread ID	thread ID
program counter	program counter	program counter
register set	register set	register set
stack	stack	stack

POSIX Threads

IEEE 1003.1c The standard for writing portable threaded programs. The threads package it defines is called *Pthreads*, including over 60 function calls, supported by most UNIX systems.

Some of the Pthreads function calls

Thread call	Description
`pthread_create`	Create a new thread
`pthread_exit`	Terminate the calling thread
`pthread_join`	Wait for a specific thread to exit
`pthread_yield`	Release the CPU to let another thread run
`pthread_attr_init`	Create and initialize a thread's attribute structure
`pthread_attr_destroy`	Remove a thread's attribute structure

Pthreads

Example 1

```
#include <pthread.h>
#include <stdlib.h>
#include <unistd.h>
#include <stdio.h>

void *thread_function(void *arg){
  int i;
  for( i=0; i<20; i++ ){
    printf("Thread says hi!\n");
    sleep(1);
  }
  return NULL;
}
```

```
int main(void){
  pthread_t mythread;
  if(pthread_create(&mythread, NULL, thread_function, NULL)){
    printf("error creating thread.");
    abort();
  }

  if(pthread_join(mythread, NULL)){
    printf("error joining thread.");
    abort();
  }
  exit(0);
}
```

Pthreads

pthread_t defined in pthread.h, is often called a ”thread id” (tid);
pthread_create() returns zero on success and a non-zero value on failure;
pthread_join() returns zero on success and a non-zero value on failure;

How to use pthread?

- #include<pthread.h>

$ gcc thread1.c -o thread1 -pthread
$ ./thread1

Pthreads

Example 2

```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>

#define NUMBER_OF_THREADS 10

void *print_hello_world(void *tid)
{
  /* prints the thread's identifier, then exits.*/
  printf ("Thread %d: Hello World!\n", tid);
  pthread_exit(NULL);
}

int main(int argc, char *argv[])
{
  pthread_t threads[NUMBER_OF_THREADS];
  int status, i;
  for (i=0; i<NUMBER_OF_THREADS; i++)
    {
      printf ("Main: creating thread %d\n",i);
      status = pthread_create(&threads[i], NULL, print_hello_world, (void *)i);

      if(status != 0){
        printf ("Oops. pthread_create returned error code %d\n",status);
        exit(-1);
      }
    }
  exit(NULL);
}
```

Linux Threads

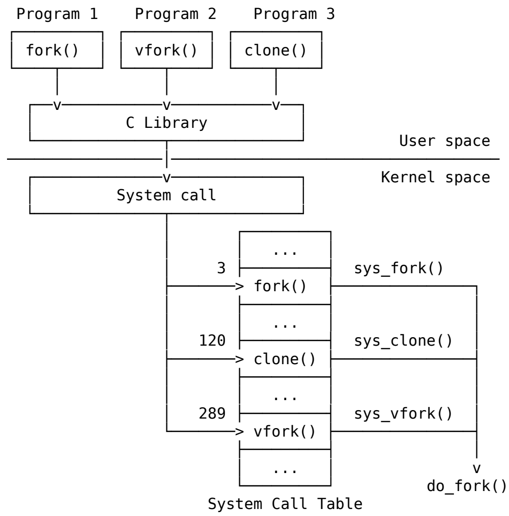
To the Linux kernel, there is no concept of a thread

- Linux implements all threads as standard processes
- To Linux, a thread is merely a process that shares certain resources with other processes
- Some OS (MS Windows, Sun Solaris) have cheap threads and expensive processes.
- Linux processes are already quite lightweight

On a 75MHz Pentium thread: $1.7\mu s$
fork: $1.8\mu s$

Linux Threads

clone() creates a separate process that shares the address space of the calling process. The cloned task behaves *much like* a separate thread.



`clone()`

```c
#include <sched.h>
int clone(int (*fn) (void *), void *child_stack,
          int flags, void *arg, ...);
```

arg 1 the function to be executed, i.e. `fn(arg)`, which returns an `int`;
arg 2 a pointer ☛ a (usually malloced) memory space to be used as the stack for the new thread;
arg 3 a set of flags used to indicate how much the calling process is to be shared. In fact,
`clone(0) == fork()`
arg 4 the arguments passed to the function.
It returns the PID of the child process or -1 on failure.

```
$ man clone
```

The `clone()` System Call

Some flags:

flag	Shared
`CLONE_FS`	File-system info
`CLONE_VM`	Same memory space
`CLONE_SIGHAND`	Signal handlers
`CLONE_FILES`	The set of open files

In practice, one should try to avoid calling `clone()` directly

Instead, use a threading library (such as pthreads) which use `clone()` when starting a thread (such as during a call to `pthread_create()`)

`clone()` Example

```c
#include <unistd.h>
#include <sched.h>
#include <sys/types.h>
#include <stdlib.h>
#include <string.h>
#include <stdio.h>
#include <fcntl.h>

int variable;

int do_something()
{
  variable = 42;
  _exit(0);
}

int main(void)
{
  void *child_stack;
  variable = 9;

  child_stack = (void *) malloc(16384);
  printf("The variable was %d\n", variable);

  clone(do_something, child_stack,
        CLONE_FS | CLONE_VM | CLONE_FILES, NULL);
  sleep(1);

  printf("The variable is now %d\n", variable);
  return 0;
}
```

Stack Grows Downwards

```c
child_stack = (void**)malloc(8192) + 8192/sizeof(*child_stack);
```

7.3 Signals

- Singals are software interrupts. Every signal has a name (SIGXXXX). Signals are classic examples of asynchronous events. They occur at what appear to be random times to the process. The process can't simply test a variable (such as `errno`) to see whether a signal has occurred; instead, the process has to tell the kernel "if and when this signal occurs, do the following." [*Advanced programming in the UNIX environment*, chap. 10]
- Signals are software interrupts sent to a program to indicate that an important event has occurred. The events can vary from user requests to illegal memory access errors. Some signals, such as the interrupt signal, indicate that a user has asked the program to do something that is not in the usual flow of control. (https://www.tutorialspoint.com/unix/unix-signals-traps)
- Signals are similar to interrupts, the difference being that interrupts are mediated by the processor and handled by the kernel while signals are mediated by the kernel (possibly via system calls) and handled by processes. The kernel may pass an interrupt as a signal to the process that caused it (typical examples are SIGSEGV, SIGBUS, SIGILL and SIGFPE). (https://en.wikipedia.org/wiki/Signal_(IPC))
- signal(7)

```
$ trap -l
```

Signals

- Singals are software interrupts
- Every signal has a name (SIGXXXX)
- One process can send a signal to another process

Sending signals

$ Ctrl+c, Ctrl+z, …

```
$ kill -signal <pid>
```

Trapping signals

```
#! trap <command> <signals>
```

Trap

```
#!/bin/bash

sigint(){
  echo -e "Why Ctrl-c?\n-> "
}

trap sigint SIGINT

echo -n "-> "

while read CMD; do
  $CMD
  echo -n "-> "
done
```

```
#! trap "rm -rf $tmpfiles" EXIT
```

Example
SIGINT

```c
#include <stdio.h>
#include <string.h>               /* for strlen() */
#include <stdlib.h>
#include <unistd.h>               /* for fork() */
#include <sys/wait.h>             /* for waitpid() */
#include <signal.h>

#define MAXLINE 4096

void sig_int(int signo)
{
    printf("Why Ctrl-c?\n  ");
}

int main(void)
{
    char  buf[MAXLINE];
    pid_t pid;
    int   status;

    if (signal(SIGINT, sig_int) == SIG_ERR)
        perror("signal");

    printf("  ");
    while (fgets(buf, MAXLINE, stdin) != NULL) {
        buf[strlen(buf) - 1] = '\0'; /* null */

        if ( (pid = fork()) == 0 ) { /* child */
            execlp(buf, buf, (char *)0);
            perror("execlp");
            exit(127);
        }

        if ((pid = waitpid(pid, &status, 0)) < 0)
            perror("waitpid");
        printf("  ");
    }
    exit(0);
}
```

- https://stackoverflow.com/questions/840501/how-do-function-pointers-in-c-work

Example
SIGUSR1

```
#include <signal.h>
#include <stdio.h>
#include <unistd.h>

void sig_usr(int);

int main(void)
{
  printf("PID = %d\n", getpid());

  if (signal(SIGUSR1, sig_usr) == SIG_ERR)
    perror("signal<SIGUSR1>");

  for ( ; ; )
    pause();
}

void sig_usr(int signo)
{
  if (signo == SIGUSR1)
    printf("received SIGUSR1\n");
  else
    perror("sig_usr");
}
```

```
$ kill -USR1 <PID>
```

Example
SIGALRM

```
#include <signal.h>
#include <stdio.h>
#include <unistd.h>
#include <stdlib.h>

void cry(int sig)
{
  puts("C: I'm crying...");
  kill(getppid(),sig);
}

void complain(int sig)
{
  puts("P: You're noisy.");
}

int main()
```

```

int main()
{
  if ( fork() == 0 ){
    signal(SIGALRM, cry);
    alarm(2);
    pause();
  }

  signal(SIGALRM, complain);
  pause();
  exit(0);
}
```

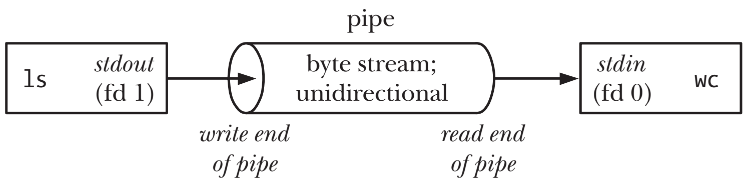
8 IPC

8.1 Pipes and FIFOs

- [*The Linux Programming Interface: A Linux and UNIX System Programming Handbook*, chap. 44]

Pipe

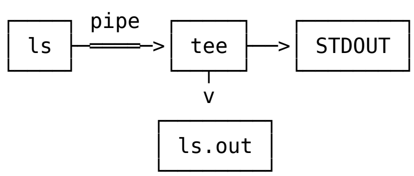
```
$ ls | wc -l
```



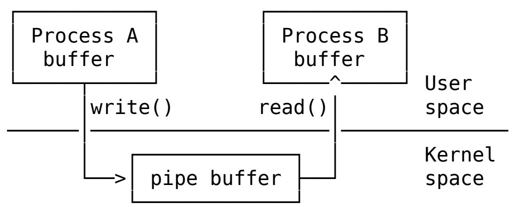
- A pipe is a byte stream
- Unidirectional
- `read()` would be blocked if nothing written at the other end

`tee`

```
$ ls | tee ls.out
```



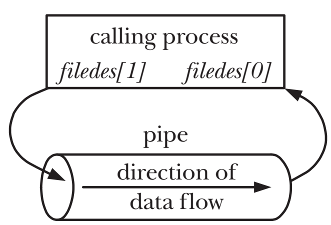
- When we say that a pipe is a byte stream, we mean that there is no concept of messages or message boundaries when using a pipe. The process reading from a pipe can read blocks of data of any size, regardless of the size of blocks written by the writing process. Furthermore, the data passes through the pipe sequentially — bytes are read from a pipe in exactly the order they were written. It is not possible to randomly access the data in a pipe using `lseek()`. [*The Linux Programming Interface: A Linux and UNIX System Programming Handbook*, chap. 44]



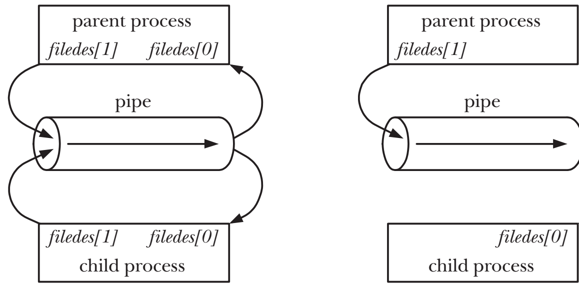
- No direct link between A and B
- A pipe is simply a buffer maintained in kernel memory
  `$ cat /proc/sys/fs/pipe-max-size`
- Need system calls

`pipe()`

```c
#include <unistd.h>

int pipe(int fd[2]);
```



`pipe()` + `fork()`



a) After *fork()* **b) After closing unused descriptors**

- Pipes must have a reader and a writer. If a process tries to write to a pipe that has no reader, it will be sent the SIGPIPE signal from the kernel. This is imperative when more than two processes are involved in a pipeline. (http://www.tldp.org/LDP/lpg/node20.html)
- While it is possible for the parent and child to both read from and write to the pipe, this is not usual. Therefore, immediately after the `fork()`, one process closes its descriptor for the write end of the pipe, and the other closes its descriptor for the read end. For example, if the parent is to send data to the child, then it would close its read descriptor for the pipe, `filedes[0]`, while the child would close its write descriptor for the pipe, `filedes[1]`. One reason that it is not usual to have both the parent and child reading from a single pipe is that if two processes try to simultaneously read from a pipe, we can't be sure which process will be the first to succeed—the two processes race for data. Preventing such races would require the use of some synchronization mechanism. However, if we require bidirectional communication, there is a simpler way: just create two pipes, one for sending data in each direction between the two processes. (If employing this technique, then we need to be wary of deadlocks that may occur if both processes block while trying to read from empty pipes or while trying to write to pipes that are already full.) [*The Linux Programming Interface: A Linux and UNIX System Programming Handbook*, chap. 44, p. 893]
- Pipes can be used for communication between any two (or more) related processes, as long as the pipe was created by a common ancestor before the series of `fork()` calls that led to the existence of the processes. For example, a pipe could be used for communication between a process and its grandchild. The first process creates the pipe, and then forks a child that in turn forks to yield the grandchild. A common scenario is that a pipe is used for communication between two siblings — their parent creates the pipe, and then creates the two children. This is what the shell does when building a pipeline.
- **Closing unused pipe file descriptors**. The process reading from the pipe closes its write descriptor for the pipe, so that, when the other process completes its output and closes its write descriptor, the reader sees end-of-file (once it has read any outstanding data in the pipe). If the reading process doesn't close the write end of the pipe, then, after the other process closes its write descriptor, the reader won't see end-of-file, even after it has read all data from the pipe. Instead, a `read()` would block waiting for data, because the kernel knows that there is still at least one write descriptor open for the pipe. That this descriptor is held open by the reading process itself is irrelevant; in theory, that process could still write to the pipe, even if it is blocked trying to read. For example, the `read()` might be interrupted by a signal handler that writes data to the pipe.
  The writing process closes its read descriptor for the pipe for a different reason. When a process tries to write to a pipe for which no process has an open read descriptor, the kernel sends the SIGPIPE signal to the writing process. By default, this signal kills a process. A process can instead arrange to catch or ignore this signal, in which case the `write()` on the pipe fails with the error EPIPE (broken pipe). Receiving the SIGPIPE signal or getting the EPIPE error is a useful indication about the status of the pipe, and this is why unused read descriptors for the pipe should be closed.
  If the writing process doesn't close the read end of the pipe, then, even after the other process closes the read end of the pipe, the writing process will still be able to write to the pipe. Eventually, the writing process will fill the pipe, and a further attempt to write will block indefinitely.
  One final reason for closing unused file descriptors is that it is only after all file descriptors in all processes that refer to a pipe are closed that the pipe is destroyed and its resources released for reuse by other processes. At this point, any unread data in the pipe is lost.

```c
#include <sys/wait.h>
#include <unistd.h>
#include <string.h>
#include <stdlib.h>
#include <stdio.h>

#define BUF_SIZE 10

int main(int argc, char *argv[]) /* Over-simplified! */
{
  int pfd[2]; /* Pipe file descriptors */
  char buf[BUF_SIZE];
  ssize_t numRead;

  pipe(pfd); /* Create the pipe */

  switch (fork()) {
  case 0: /* Child - reads from pipe */
    close(pfd[1]); /* Write end is unused */

    for (;;) { /* Read data from pipe, echo on stdout */
      if ( (numRead = read(pfd[0], buf, BUF_SIZE)) == 0)
        break;  /* End-of-file */
      if (write(1, buf, numRead) != numRead)
        perror("child - partial/failed write");
    }
    puts(""); /* newline */

    close(pfd[0]);

    _exit(EXIT_SUCCESS);

  default: /* Parent - writes to pipe */
    close(pfd[0]); /* Read end is unused */

    if (write(pfd[1], argv[1], strlen(argv[1])) != strlen(argv[1]))
      perror("parent - partial/failed write");

    close(pfd[1]); /* Child will see EOF */

    wait(NULL); /* Wait for child to finish */
    exit(EXIT_SUCCESS);
  }
}
```

- https://stackoverflow.com/questions/5422831/what-is-the-difference-between-using-exit-exit-in-a-conventional-linux-fo
- `_exit(2)`

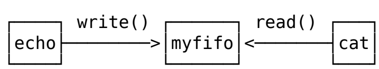
`popen()`

Named Pipe (FIFO)

PIPEs pass data between related processes.
FIFOs pass data between any processes.

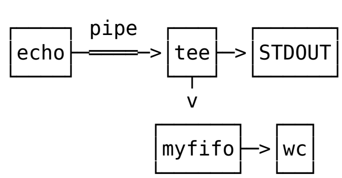
```
$ mkfifo myfifo
```

```
$ echo hello > myfifo
$ cat myfifo
```



`tee`

```
$ echo hello | tee myfifo
$ wc myfifo
```



- https://en.wikipedia.org/wiki/Named_pipe

IPC With FIFO

```c
#include <unistd.h>
#include <stdlib.h>
#include <stdio.h>
#include <string.h>
#include <fcntl.h>
#include <sys/types.h>
#include <sys/stat.h>

#define FIFO_NAME "/tmp/myfifo"

int main(int argc, char *argv[]) /* Oversimplified */
{
  int fd, i, mode = 0;
  char c;

  if (argc < 2) {
    fprintf(stderr, "Usage: %s <O_RDONLY | O_WRONLY | O_NONBLOCK>\n", argv[0]);
    exit(EXIT_FAILURE);
  }

  for(i = 1; i < argc; i++) {
    if (strncmp(*++argv, "O_RDONLY", 8) == 0)
        mode |= O_RDONLY;
    if (strncmp(*argv, "O_WRONLY", 8) == 0)
                mode |= O_WRONLY;
    if (strncmp(*argv, "O_NONBLOCK", 10) == 0)
                mode |= O_NONBLOCK;
  }

  if (access(FIFO_NAME, F_OK) == -1) mkfifo(FIFO_NAME, 0777);

  printf("Process %d: FIFO(fd %d, mode %d) opened.\n",
         getpid(), fd = open(FIFO_NAME, mode), mode);

  if( (mode == 0) | (mode == 2048) )
      while( read(fd,&c,1) == 1 ) putchar(c);

  if( (mode == 1) | (mode == 2049) )
      while( (c = getchar()) != EOF ) write(fd,&c,1);

  exit(EXIT_SUCCESS);
}
```

```
$ watch 'lsof -n.1 /tmp/myfifo'
$ ./a.out O_RDONLY
$ ./a.out O_WRONLY
$ ./a.out O_RDONLY O_NONBLOCK
$ ./a.out O_WRONLY O_NONBLOCK
```

`O_NONBLOCK`

- A `read()`/`write()` will wait on an empty blocking FIFO

- A `read()` on an empty nonblocking FIFO will return 0 bytes
- `open(const char *path, O_WRONLY | O_NONBLOCK);`
  - Returns an error (-1) if FIFO not open
  - Okay if someone's reading the FIFO

Opening a FIFO with `open()`

- If opened with `O_RDWR`, the result is undefined. If you do want to pass data in both directions, it's much better to use a pair of FIFOs or pipes, one for each direction.
- There are four legal combinations of `O_RDONLY`, `O_WRONLY`, and the `O_NONBLOCK` flag.

```
open(const char *path, O_RDONLY);
/* In this case, the open call will block; it will not return until a process opens the
   same FIFO for writing. */

open(const char *path, O_RDONLY | O_NONBLOCK);
/* The open call will now succeed and return immediately, even if the FIFO has not been
   opened for writing by any process. */

open(const char *path, O_WRONLY);
/* In this case, the open call will block until a process opens the same FIFO for
   reading. */

open(const char *path, O_WRONLY | O_NONBLOCK);
/* This will always return immediately, but if no process has the FIFO open for reading,
   open will return an error, -1, and the FIFO won't be opened. If a process does have the
   FIFO open for reading, the file descriptor returned can be used for writing to the
   FIFO. */
```

9 User Interface

9.1 Dialog, Zenity

9.2 Ncurses

9.3 GTK+

9.4 Qt

10 Terminal

- chap 62 of [*The Linux Programming Interface: A Linux and UNIX System Programming Handbook*]
- |http://tldp.org/HOWTO/Text-Terminal-HOWTO-16.html|
- http://pubs.opengroup.org/onlinepubs/9699919799/

```
$ man infocmp
```

11 IDE

Makefile, git