

# CS 3130 intro

# themes

automating building software

libraries, taking advantage of incremental compilation

sharing machines

multiple users/programs on one system

parallelism and concurrency

doing two+ things at once

under the hood of sockets

layered design on networks

under the hood of fast processors

caching and (hidden) parallelism

# themes

## automating building software

libraries, taking advantage of incremental compilation

## sharing machines

multiple users/programs on one system

## parallelism and concurrency

doing two+ things at once

## under the hood of sockets

layered design on networks

## under the hood of fast processors

caching and (hidden) parallelism

# make

```
$ ./foo.exe
```

```
...
```

```
...
```

```
$ edit readline.c
```

```
$ make
```

```
clang -g -O -Wall -c readline.c -o readline.o
```

```
ar rcs terminal.o readline.o libreadline.a
```

```
clang -o foo.exe foo.o foo-utility.o -L. -lreadline
```

```
$
```

# themes

automating building software

libraries, taking advantage of incremental compilation

sharing machines

multiple users/programs on one system

parallelism and concurrency

doing two+ things at once

under the hood of sockets

layered design on networks

under the hood of fast processors

caching and (hidden) parallelism

# address translation



# address translation



# address translation



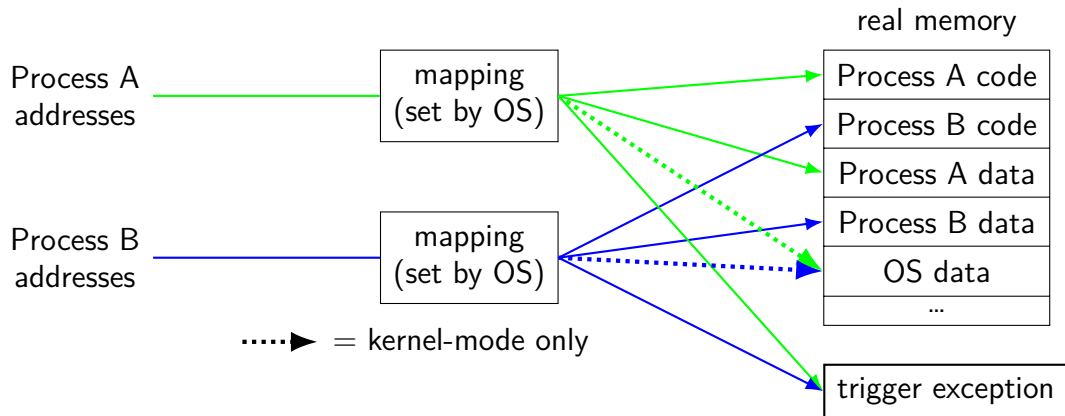


# address translation



# address spaces

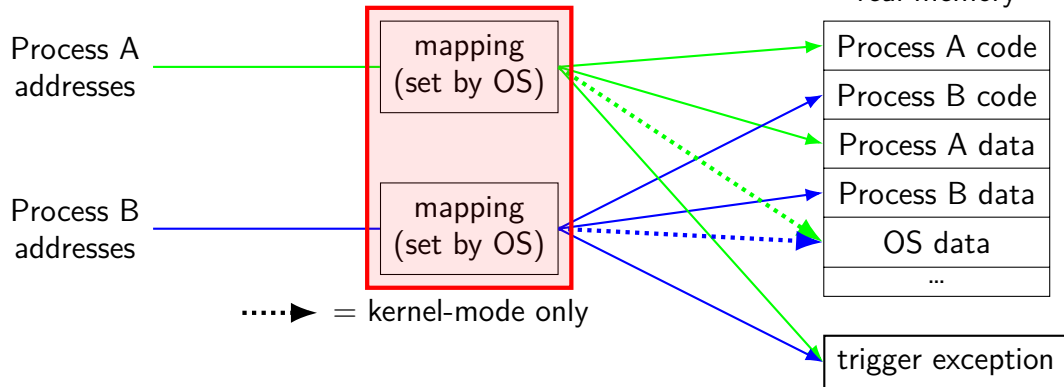
illusion of **dedicated memory**



# address spaces

illusion of **dedicated memory**

chose one during context switch



# themes

automating building software

libraries, taking advantage of incremental compilation

sharing machines

multiple users/programs on one system

parallelism and concurrency

doing two+ things at once

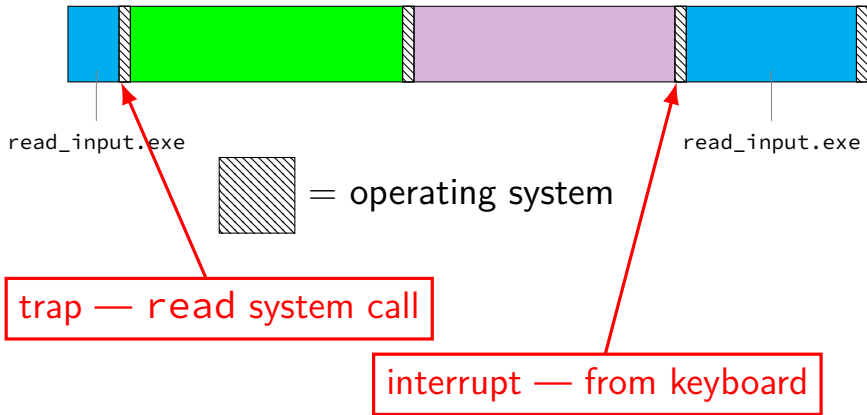
under the hood of sockets

layered design on networks

under the hood of fast processors

caching and (hidden) parallelism

# keyboard input timeline



# time multiplexing



# time multiplexing



...

```
call get_time
```

```
// whatever get_time does
```

```
movq %rax, %rbp
```

———— million cycle delay ————

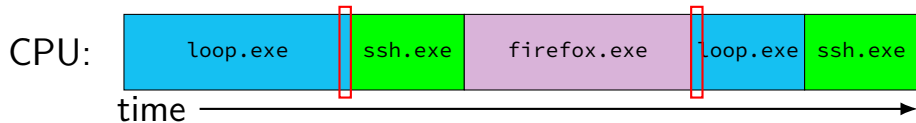
```
call get_time
```

```
// whatever get_time does
```

```
subq %rbp, %rax
```

...

# time multiplexing



...

```
call get_time
```

```
// whatever get_time does
```

```
movq %rax, %rbp
```

———— million cycle delay ————

```
call get_time
```

```
// whatever get_time does
```

```
subq %rbp, %rax
```

...



# themes

automating building software

libraries, taking advantage of incremental compilation

sharing machines

multiple users/programs on one system

parallelism and concurrency

doing two+ things at once

under the hood of sockets

layered design on networks

under the hood of fast processors

caching and (hidden) parallelism

# permissions

```
$ ls /u/other/secret
```

```
ls: cannot open directory '/u/other/secret': Permission denied
```

```
$ shutdown
```

```
shutdown: Permission denied
```

# themes

automating building software

libraries, taking advantage of incremental compilation

sharing machines

multiple users/programs on one system

parallelism and concurrency

doing two+ things at once

under the hood of sockets

layered design on networks

under the hood of fast processors

caching and (hidden) parallelism

# layers

application	HTTP, SSH, SMTP, ...	application-defined meanings
transport	TCP, UDP, ...	reach      correct      program, reliability/streams
network	IPv4, IPv6, ...	reach      correct      machine (across networks)
link	Ethernet, Wi-Fi, ...	coordinate shared wire/radio
physical	...	encode bits for wire/radio

# more than four layers?

sometimes more layers above 'application'

e.g. HTTPS:

HTTP (app layer) on TLS (another app layer) on TCP (network) on ...

e.g. DNS over HTTPS:

DNS (app layer) on HTTP on on TLS on TCP on ...

e.g. SFTP:

SFTP (app layer??) on SSH (another app layer) on TCP on ...

e.g. HTTP over OpenVPN:

HTTP on TCP on IP on OpenVPN on UDP on different IP on ...

# names and addresses

name	address
logical identifier	location/how to locate
variable counter	memory address 0x7FFF9430
DNS name www.virginia.edu	IPv4 address 128.143.22.36
DNS name mail.google.com	IPv4 address 216.58.217.69
DNS name mail.google.com	IPv6 address 2607:f8b0:4004:80b
DNS name reiss-t3620.cs.virginia.edu	IPv4 address 128.143.67.91
DNS name reiss-t3620.cs.virginia.edu	MAC address 18:66:da:2e:7f
service name https	port number 443
service name ssh	port number 22

# themes

automating building software

libraries, taking advantage of incremental compilation

sharing machines

multiple users/programs on one system

parallelism and concurrency

doing two+ things at once

under the hood of sockets

layered design on networks

under the hood of fast processors

caching and (hidden) parallelism

## recall: data/instruction memory

model in CPU: one cycle per access

but earlier — had to talk to memory on different chip

can't do that in one cycle

solution: keep copies of part of memory (“cache”)

- copy can be accessed quickly

- hope: almost always use copy?



# 2004 CPU

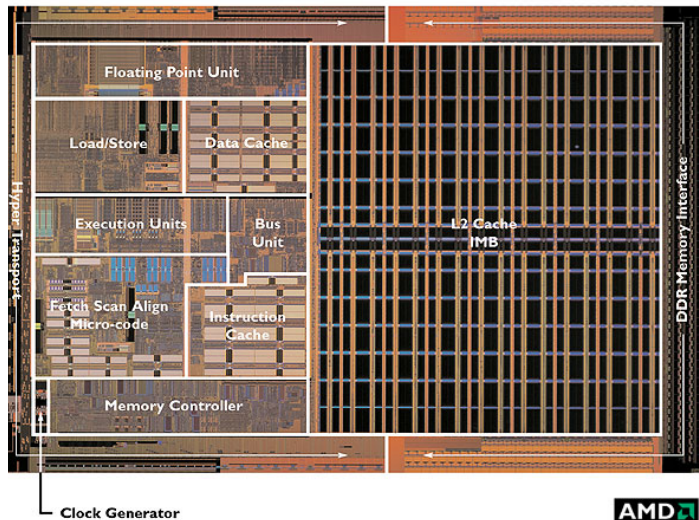


Image: approx 2004 AMD press image of Opteron die;  
approx register location via [chip-architect.org](http://chip-architect.org) (Hans de Vries)

# 2004 CPU

▲ Registers

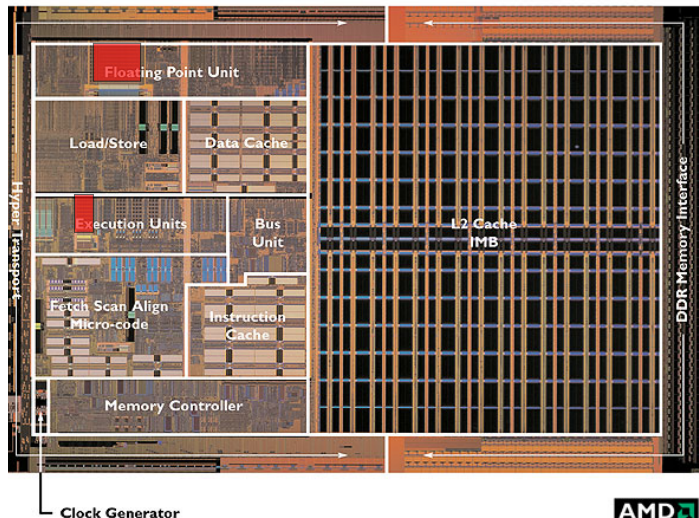


Image: approx 2004 AMD press image of Opteron die;  
approx register location via [chip-architect.org](http://chip-architect.org) (Hans de Vries)

# 2004 CPU

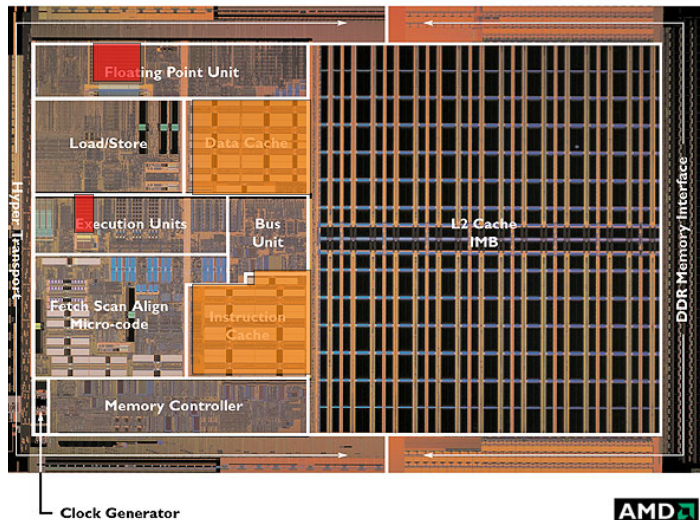


Image: approx 2004 AMD press image of Opteron die;  
approx register location via [chip-architect.org](http://chip-architect.org) (Hans de Vries)

# 2004 CPU

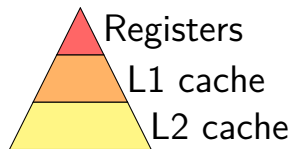
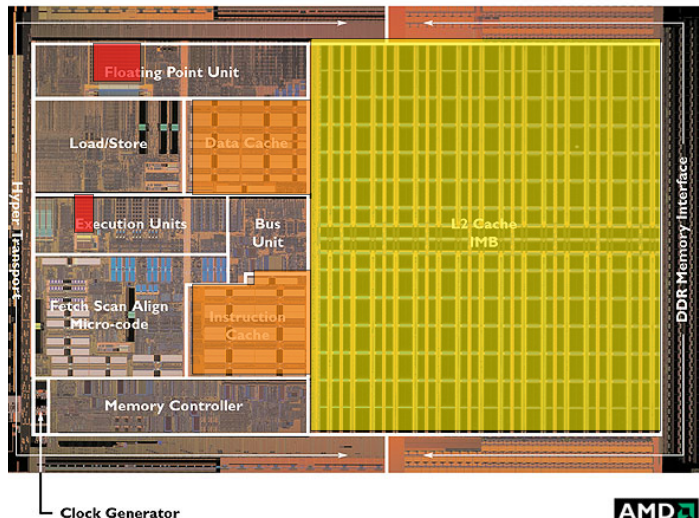


Image: approx 2004 AMD press image of Opteron die;  
approx register location via [chip-architect.org](http://chip-architect.org) (Hans de Vries)

# 2004 CPU

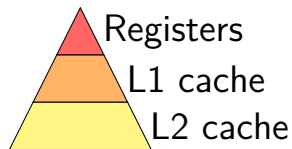
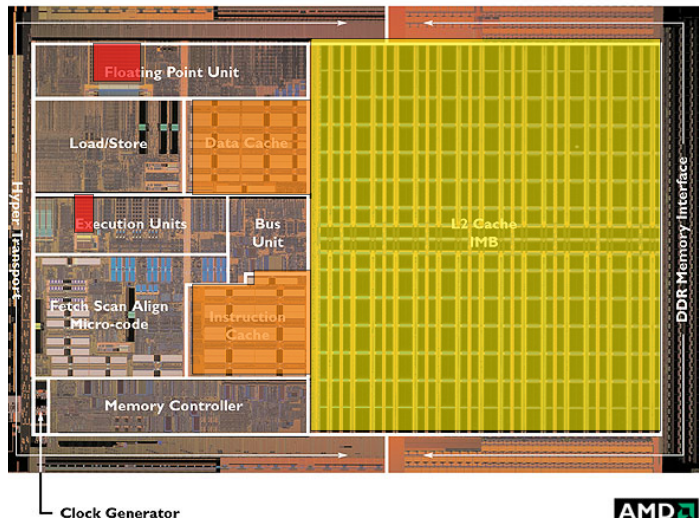


Image: approx 2004 AMD press image of Opteron die;  
approx register location via [chip-architect.org](http://chip-architect.org) (Hans de Vries)

# 2004 CPU

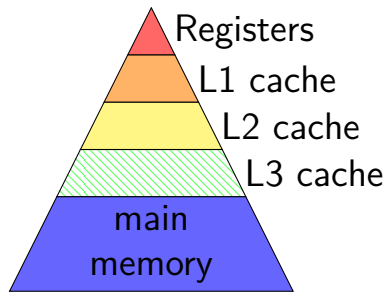
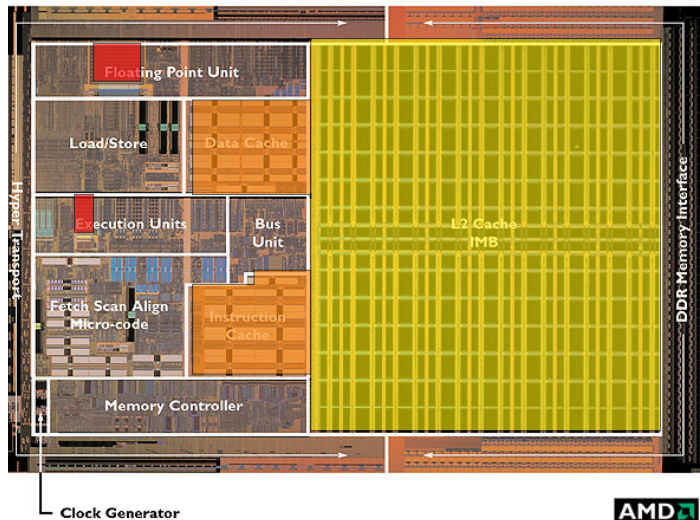
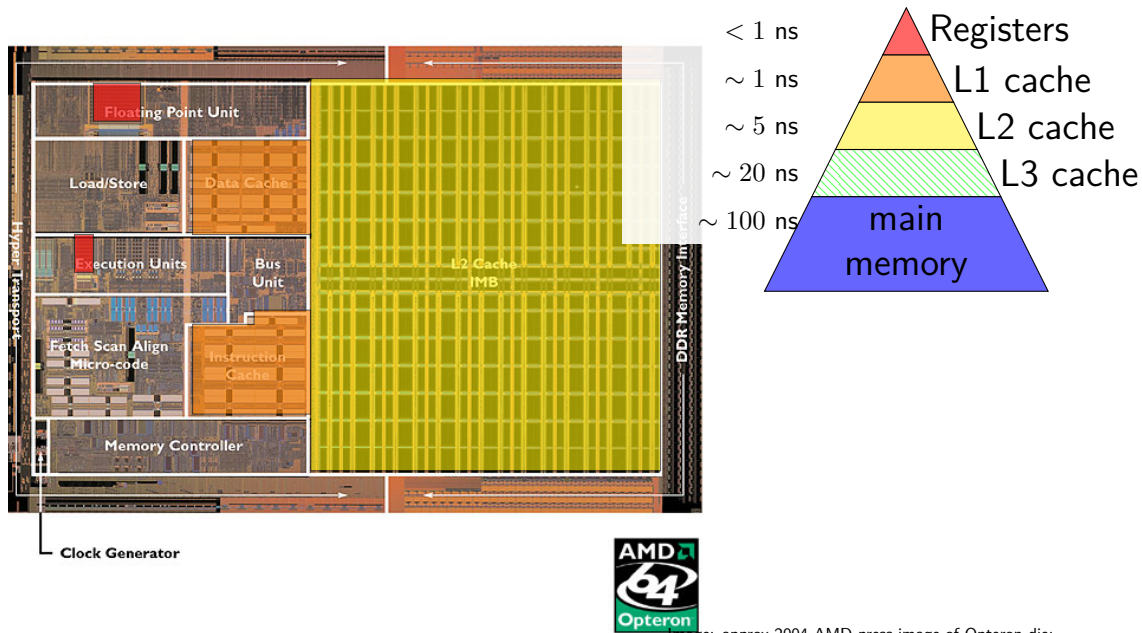


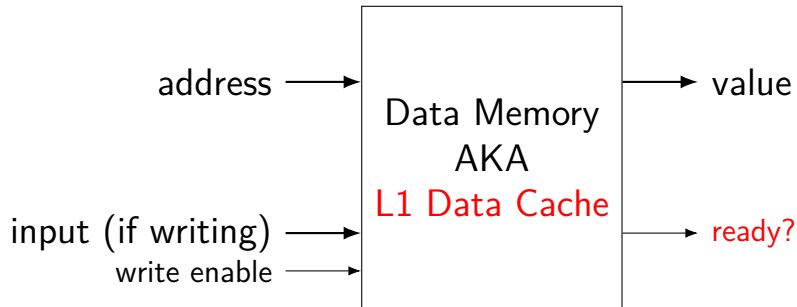
Image: approx 2004 AMD press image of Opteron die;  
approx register location via [chip-architect.org](http://chip-architect.org) (Hans de Vries)



# 2004 CPU

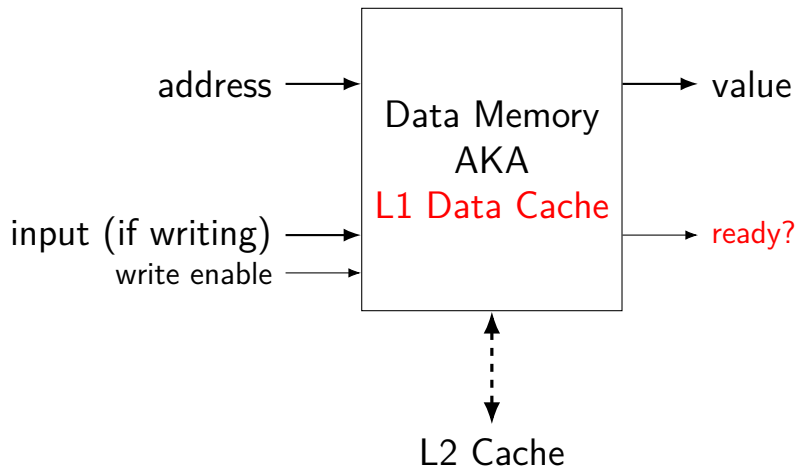


## cache: real memory

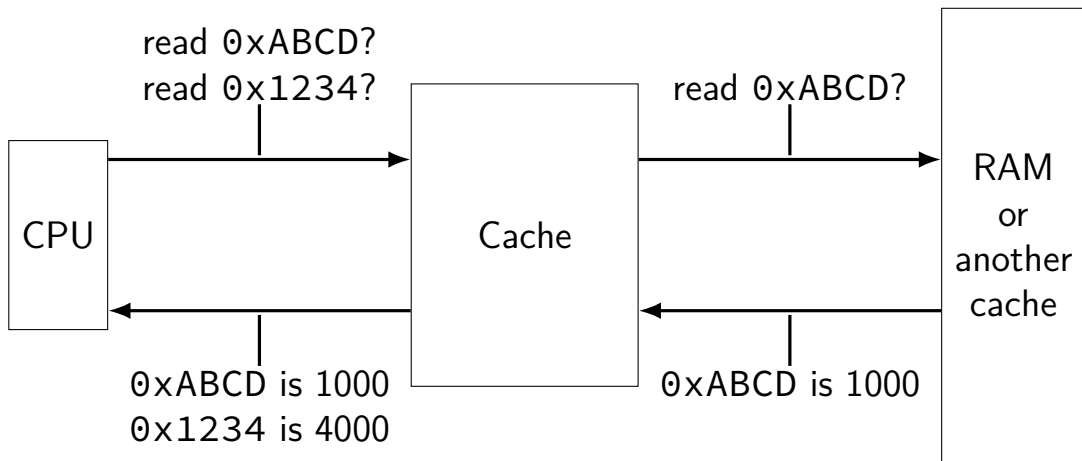




## cache: real memory



# the place of cache



# memory hierarchy goals

performance of the fastest (smallest) memory

hide 100x latency difference? 99+% hit (= value found in cache) rate

capacity of the largest (slowest) memory

# themes

automating building software

libraries, taking advantage of incremental compilation

sharing machines

multiple users/programs on one system

parallelism and concurrency

doing two+ things at once

under the hood of sockets

layered design on networks

under the hood of fast processors

caching and (hidden) parallelism

## some performance examples

example1:

```
    movq $1000000000000, %rax
loop1:
    addq %rbx, %rcx
    decq %rax
    jge loop1
    ret
```

about 30B instructions

my desktop: approx 2.65 sec

example2:

```
    movq $1000000000000, %rax
loop2:
    addq %rbx, %rcx
    addq %r8, %r9
    decq %rax
    jge loop2
    ret
```

about 40B instructions

my desktop: approx 2.65 sec

## some performance examples

example1:

```
    movq $1000000000000, %rax
loop1:
    addq %rbx, %rcx
    decq %rax
    jge loop1
    ret
```

about 30B instructions

my desktop: approx 2.65 sec

example2:

```
    movq $1000000000000, %rax
loop2:
    addq %rbx, %rcx
    addq %r8, %r9
    decq %rax
    jge loop2
    ret
```

about 40B instructions

my desktop: approx 2.65 sec

# logistics

# labs

attend lab in person and get checked off by TA, *or*

(most labs) submit something to submission site and we'll grade it

submit to submission site? don't care if you attend the lab

more strict about submissions without checkoffs being complete/correct

(can't tell how much time you actually spent)

in-person lab checkoff of incomplete lab at least 50% credit

some labs will basically require attendance

or contact me for other arrangements if you can't (sick, etc.)

logistically won't work otherwise — e.g. code review



# lab collaboration and submissions

please collaborate on labs!

when working with others on lab and submitting code files

please indicate who you worked with in those files  
via comment or similar

# quizzes

released evening after Thursday lecture  
starting *next* week

due 15 minutes before lecture on Tuesdays

about lecture and/or lab from the prior week

4–6 questions

*individual*, open book, open notes, open Internet

okay: looking up resources/tutorials/etc.

not okay: asking Stack Overflow the quiz question

not okay: IMing your friend the quiz question

# asking about quiz questions

I and the TAs won't answer quiz questions...

but we will answer questions about the lecture material, etc.

(and TAs (not you) are responsible for knowing  
what they can't answer

but we'd prefer you don't try to test those limits)

# homeworks

several homework assignments

done individually

due before a week's first lab

# exams

1 final exam

no midterms — instead:

- quizzes count a lot

- slightly more homework/lab than pilot

# development enviroment

official: department machines via SSH or NX (remote desktop)

you can also use your own machines, but...

we will test your code on x86-64 Linux

I haven't checked assignments on a Windows or OS X machine

# getting help

office hours — calendar will be posted on website

mix of in-person and remote, indicated on calendar

remote OH will use Discord + online queue

in-person OH may or may not — indicated on whiteboard, probably

## Piazza

use private questions if homework code, etc.

emailing me (preferably with '3130' in subject)

# late policy

no late quizzes

two quizzes dropped (unconditionally)

90% credit for 0–48 hours late homeworks

80% credit for 48–72 hours late homeworks

for labs that allow submission only, same policy as homeworks

lab submission due time is 11:59pm

for other labs, policy on a lab-by-lab basis



# excused lateness

special circumstances?

illness, emergency, etc.

contact me, we'll figure something out

please don't attend lab/etc. sick!

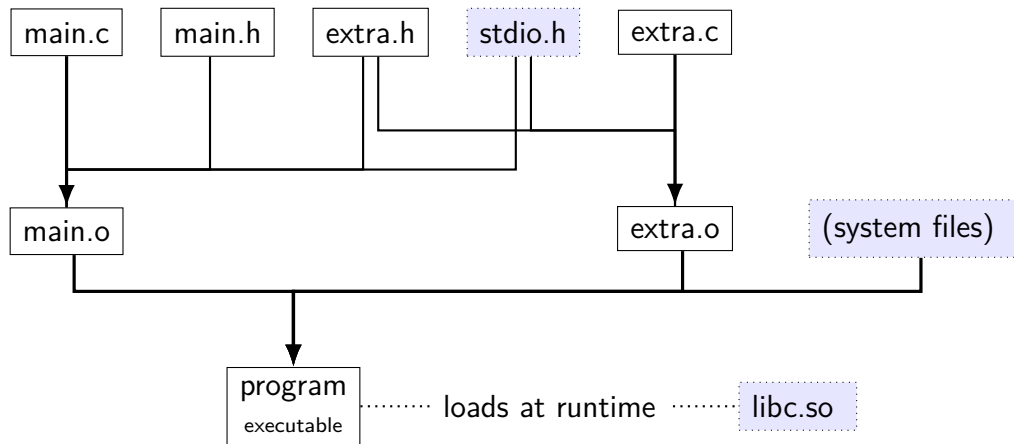
# attendance

I won't take attendance in lecture

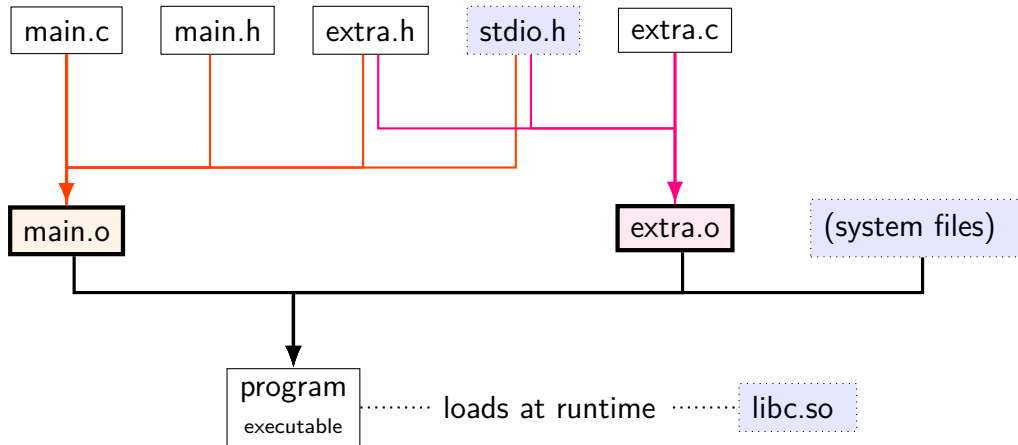
I will attempt to have lecture recordings

sometimes there may be issues with the recording

# files in building C programs [dynamic linking]

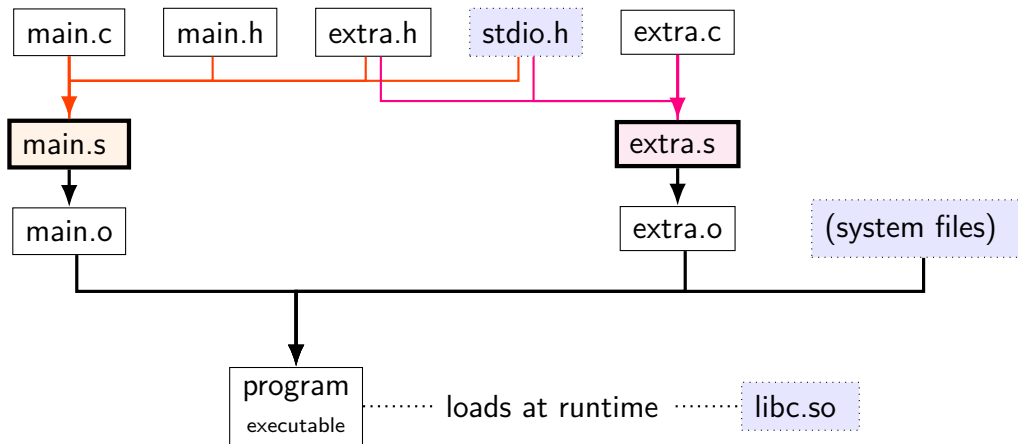


# files in building C programs [dynamic linking]



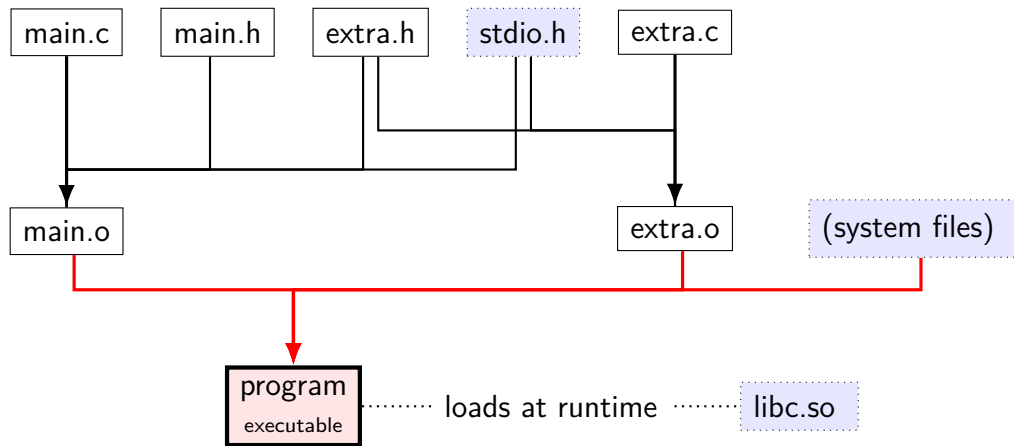
```
clang -c main.c  
clang -c extra.c
```

# files in building C programs [dynamic linking]



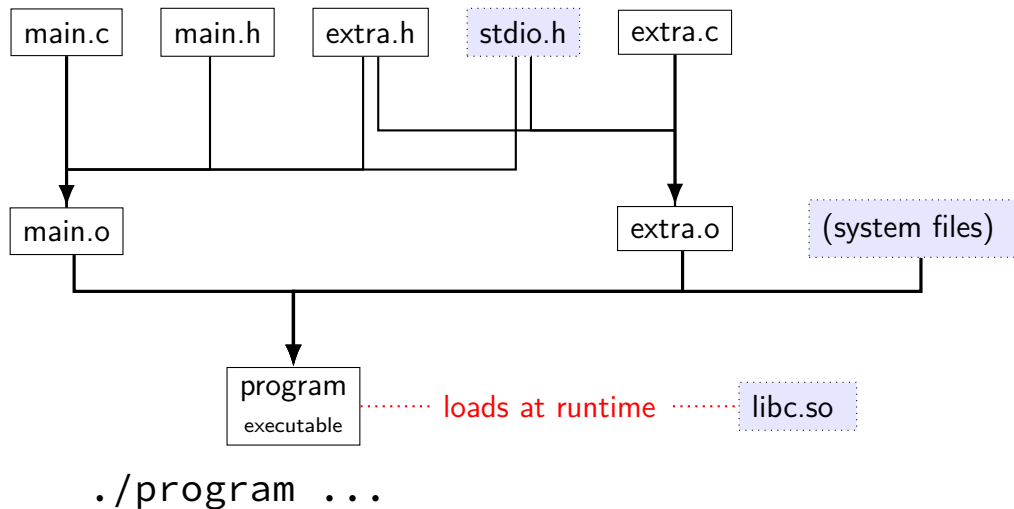
```
clang -S -c main.c  
clang -S -c extra.c
```

# files in building C programs [dynamic linking]

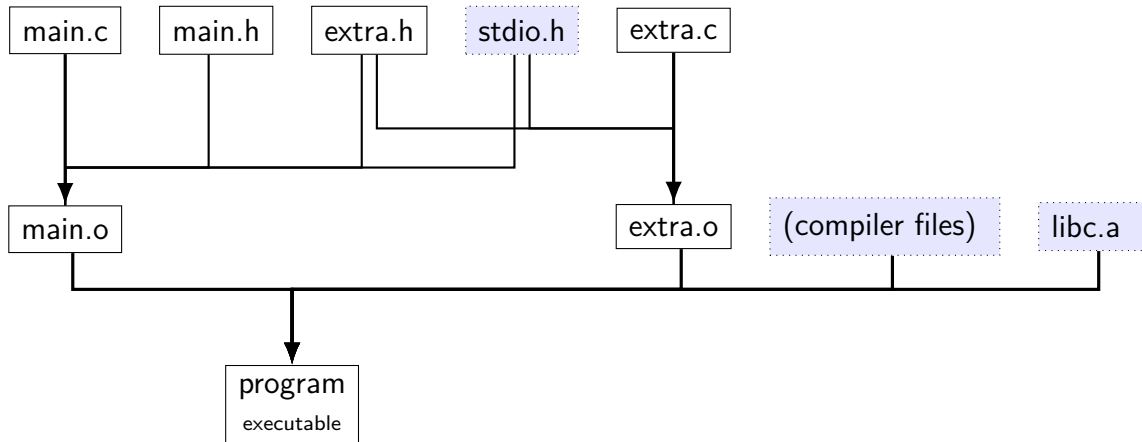


```
clang -o program main.o extra.o
```

# files in building C programs [dynamic linking]



# files in building C programs [static linking]





# file extensions

name		
.c		C source code
.h		C header file
.s	(or .asm)	assembly file
.o	(or .obj)	object file (binary of assembly)
(none)	(or .exe)	executable file
.a	(or .lib)	statically linked library [collection of .o files]
.so	(or .dll)	dynamically linked library ['shared object']

# static libraries

Unix-like *static* libraries: libfoo.a

internally: archive of .o files with index

create: `ar rcs file1.o file2.o ...`

use: `cc ... -o program -L/path/to/lib ...-lfoo`

`cc` could be `clang`, `gcc`, `clang++`, `g++`, etc.

`-L/path/to/lib` not needed if in standard location

# shared libraries

Linux *shared* libraries: libfoo.so

create:

compile .o files with `-fPIC` (position independent code)

then: `cc -shared ... -o libfoo.so`

use: `cc ...-o program -L/path/to/lib ...-lfoo`

## finding shared libraries

```
cc ...-o program -L/path/to/lib ...-lfoo
```

on Linux: `/path/to/lib` only used to create program  
program contains `libfoo.so` *without full path*

Linux default: `libfoo.so` expected to be in `/usr/lib`, `/lib`, and other 'standard' locations

possible overrides:

`LD_LIBRARY_PATH` environment variable  
paths specified with `-Wl,-rpath=/path/to/lib` when creating executable

# exercise (incremental compilation)

program built from main.c + extra.c

main.c, extra.c both include extra.h, stdio.h

```
clang -c main.c                # command 1
clang -c extra.c                # command 2
clang -o program main.o extra.o # command 3
```

What commands need to be rerun if...

Question A: ...main.c changes?

Question B: ...extra.h changes?

# make

make — Unix program for “making” things...

...by running commands based on what's changed

what commands? based on *rules* in *makefile*

## make rules

```
main.o: main.c main.h extra.h  
▶      clang -c main.c
```

before colon: target(s) (file(s) generated/updated)

after colon: prerequisite(s)

following lines prefixed by a tab character: command(s) to run

make will run the commands if any prerequisite is newer than the target

## make rules

```
main.o: main.c main.h extra.h  
▶      clang -c main.c
```

before colon: **target(s)** (file(s) generated/updated)

after colon: prerequisite(s)

following lines prefixed by a tab character: command(s) to run

make will run the commands if any prerequisite is newer than the target



## make rules

```
main.o: main.c main.h extra.h  
▶      clang -c main.c
```

before colon: target(s) (file(s) generated/updated)

after colon: prerequisite(s)

following lines prefixed by a tab character: command(s) to run

make will run the commands if any prerequisite is newer than the target

## make rules

```
main.o: main.c main.h extra.h  
▶      clang -c main.c
```

before colon: target(s) (file(s) generated/updated)

after colon: prerequisite(s)

following lines prefixed by a **tab** character: command(s) to run

make will run the commands if any prerequisite is newer than the target

## make rules

```
main.o: main.c main.h extra.h
```

```
▶          clang -c main.c
```

before colon: target(s) (file(s) generated/updated)

after colon: prerequisite(s)

following lines prefixed by a tab character: **command(s) to run**

make will run the commands if any prerequisite is newer than the target

## make rules

```
main.o: main.c main.h extra.h  
▶      clang -c main.c
```

before colon: target(s) (file(s) generated/updated)

after colon: prerequisite(s)

following lines prefixed by a tab character: command(s) to run

make will run the commands if any prerequisite is newer than the target

## make rules

```
main.o: main.c main.h extra.h  
▶      clang -c main.c
```

before colon: target(s) (file(s) generated/updated)

after colon: prerequisite(s)

following lines prefixed by a tab character: command(s) to run

make will run the commands if any prerequisite is newer than the target

...after making sure prerequisites up to date

## make rule chains

program: main.o extra.o

▶ clang -o program main.o extra.o

extra.o: extra.c extra.h

▶ clang -c extra.c

main.o: main.c main.h extra.h

▶ clang -c main.c

to *make* program, first...

update main.o and extra.o if they aren't

# running make

“make *target*”

- look in Makefile in current directory for rules

- check if *target* is up-to-date

- if not, rebuild it (and dependencies, if needed) so it is

“make *target1 target2*”

- check if both *target1* and *target2* are up-to-date

“make”

- if “*firstTarget*” is the first rule in Makefile,

- same as ‘make *firstTarget*’

## exercise: what will run?

W: X Y

► buildW

X: Q

► buildX

Y: X Z

► buildY

W modified 1 minute ago

X modified 2 hours ago

Y does not exist

Z modified 1 hour ago

Q modified 3 hours ago

exercise: “make W” will run what commands?

A. none

B. buildY only    C. buildW then buildY

D. buildY then buildW

E. buildX then buildY then buildW

F. buildX then buildW

G. something else



## ‘phony’ targets (1)

common to have Makefile targets that aren’t files

```
all: program1 program2 libfoo.a
```

“make all” effectively shorthand for “make program1  
program2 libfoo.a”

no actual file called “all”

## ‘phony’ targets (2)

sometimes want targets that don’t actually build file

example: “make clean” to remove generated files

clean:

► `rm --force main.o extra.o`

## but what if I create...

clean:

► `rm --force main.o extra.o`

`all: program1 program2 libfoo.a`

Q: if I make a file called “all” and then “make all” what happens?

Q: same with “clean” and “make clean”?

# marking phony targets

clean:

► `rm --force main.o extra.o`

`all: program1 program2 libfoo.a`

`.PHONY: all clean`

special .PHONY rule says “ ‘all’ and ‘clean’ not real files”

(not required by POSIX, but in every make version I know)

# conventional targets

common convention:

target name	purpose
(default), all	build everything
install	install to standard location
test	run tests
clean	remove generated files

## redundancy (1)

program: main.o extra.o

▶ clang -o program main.o extra.o

extra.o: extra.c extra.h

▶ clang -o extra.o -c extra.c

main.o: main.c main.h extra.h

▶ clang -o main.o -c main.c

what if I want to run clang with -Wall?

what if I want to change to gcc?

## variables (1)

CC = gcc

CFLAGS = -Wall -pedantic -std=c11 -fsanitize=address

LDFLAGS = -Wall -pedantic -fsanitize=address

program: main.o extra.o

► \$(CC) \$(LDFLAGS) -o program main.o extra.o

extra.o: extra.c extra.h

► \$(CC) \$(CFLAGS) -o extra.o -c extra.c

main.o: main.c main.h extra.h

► \$(CC) \$(CFLAGS) -o main.o -c main.c

## variables (2)

CC = gcc

CFLAGS = -Wall

LDFLAGS = -Wall

program: main.o extra.o

► \$(CC) \$(LDFLAGS) -o \$@ \$^

extra.o: extra.c extra.h

► \$(CC) \$(CFLAGS) -o \$@ -c \$<

main.o: main.c main.h extra.h

► \$(CC) \$(CFLAGS) -o \$@ -c \$<

aside: \$^ works on GNU make (usual on Linux), but not portable.



## suffix rules

CC = gcc

CFLAGS = -Wall

LDFLAGS = -Wall

program: main.o extra.o

► \$(CC) \$(LDFLAGS) -o \$@ \$^

.c.o:

► \$(CC) \$(CFLAGS) -o \$@ -c \$<

extra.o: extra.c extra.h

main.o: main.c main.h extra.h

aside: \$^ works on GNU make (usual on Linux), but not portable.

## pattern rules

CC = gcc

CFLAGS = -Wall

LDFLAGS = -Wall

program: main.o extra.o

▶ \$(CC) \$(LDFLAGS) -o \$@ \$^

**%.o: %.c**

▶ \$(CC) \$(CFLAGS) -o \$@ -c \$<

extra.o: extra.c extra.h

main.o: main.c main.h extra.h

aside: these rules work on GNU make (usual on Linux), but less portable than suffix rules.

## built-in rules

'make' has the 'make .o from .c' rule built-in already, so:

```
CC = gcc
```

```
CFLAGS = -Wall
```

```
LDFLAGS = -Wall
```

```
program: main.o extra.o
```

```
▶          $(CC) $(LDFLAGS) -o $@ $^
```

```
extra.o: extra.c extra.h
```

```
main.o: main.c main.h extra.h
```

(don't actually need to write supplied rule!)

# writing Makefiles?

error-prone to automatically all .h dependencies

-M option to gcc or clang

outputs Make rule

ways of having make run this

Makefile generators

other programs that write Makefiles

# other build systems

alternatives to writing Makefiles:

other make-ish build systems

ninja, scon, bazel, maven, xcodebuild, msbuild, ...

tools that generate inputs for make-ish build systems

cmake, autotools, qmake, ...

**backup slides**