

last time

topics / logistics

C and pointers

`pointer + number:`

advance by `number × sizeof(*pointer)`

`pointer[number]:`

`*(pointer + number);` treat pointer as beginning of array

* follows “one arrow”

no implicitly following pointer/taking address

function arguments copied, even if pointers

`func(pointer)` pattern in place of return

note on C exercise

highlighted compile/runtime error

```
for: int_array[1] = *pointer_to_pointer_to_int;
```

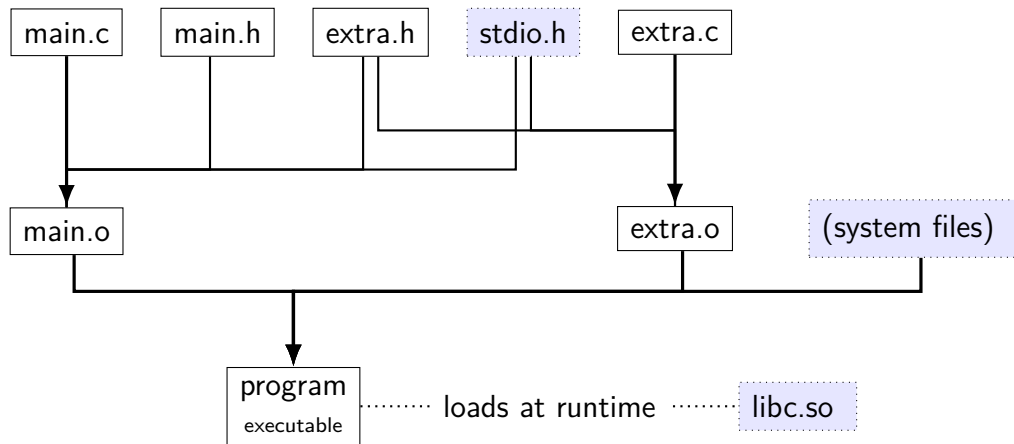
in GCC/clang: 'just' warning by default

does conversion from address to integer

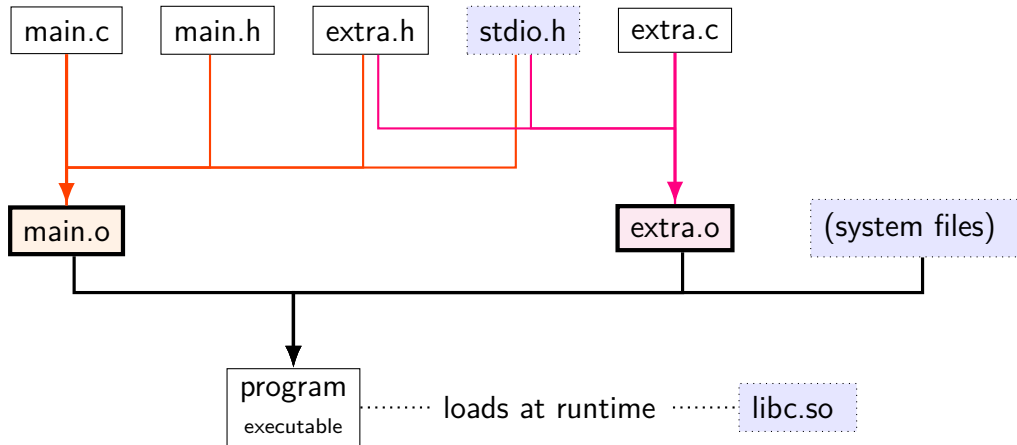
means `int_array[1]` gets 'junk' value

I usually compile with this set as error, not warning

files in building C programs [dynamic linking]

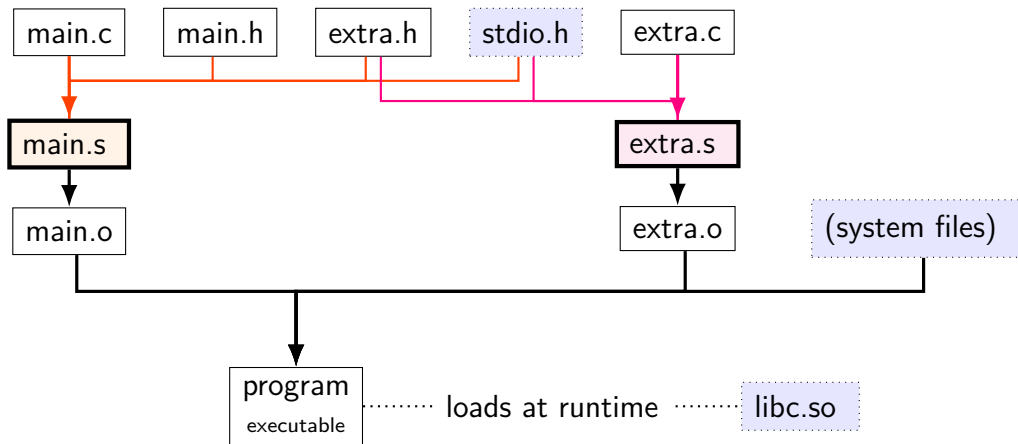


files in building C programs [dynamic linking]



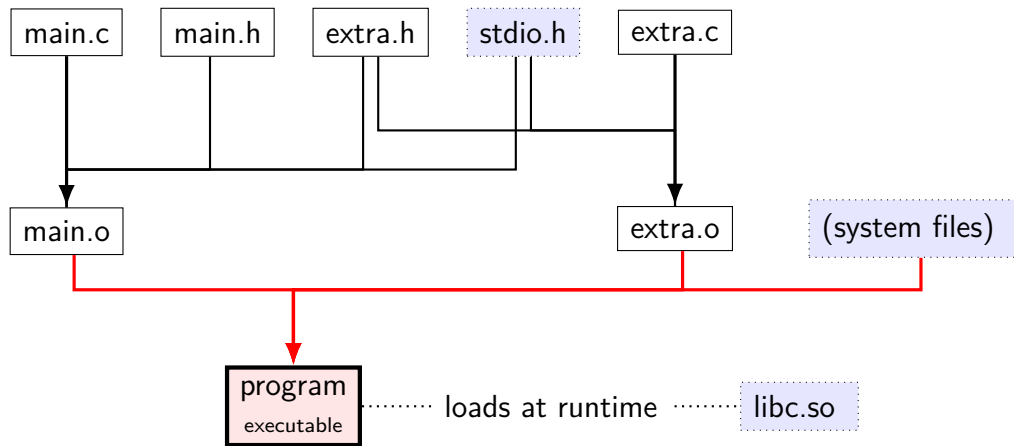
```
clang -c main.c  
clang -c extra.c
```

files in building C programs [dynamic linking]



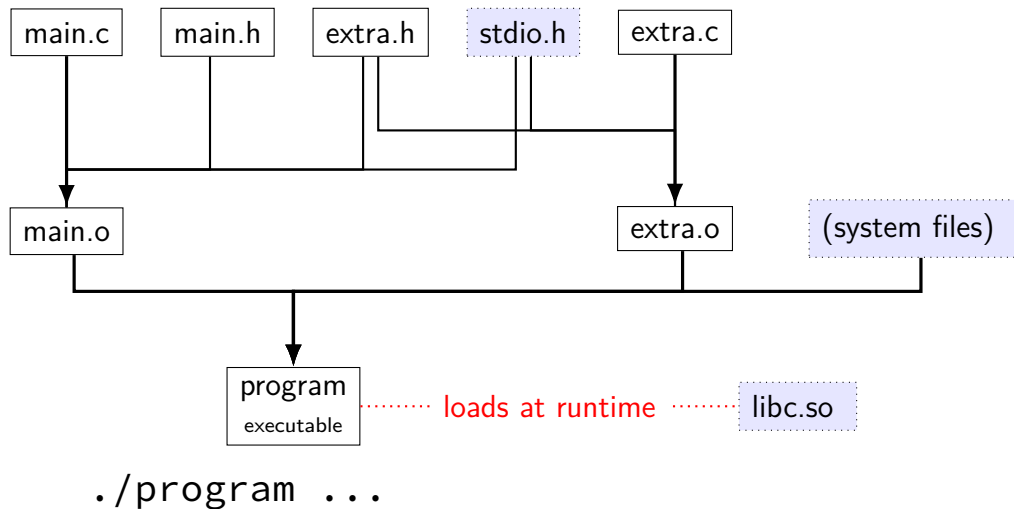
```
clang -S -c main.c  
clang -S -c extra.c
```

files in building C programs [dynamic linking]

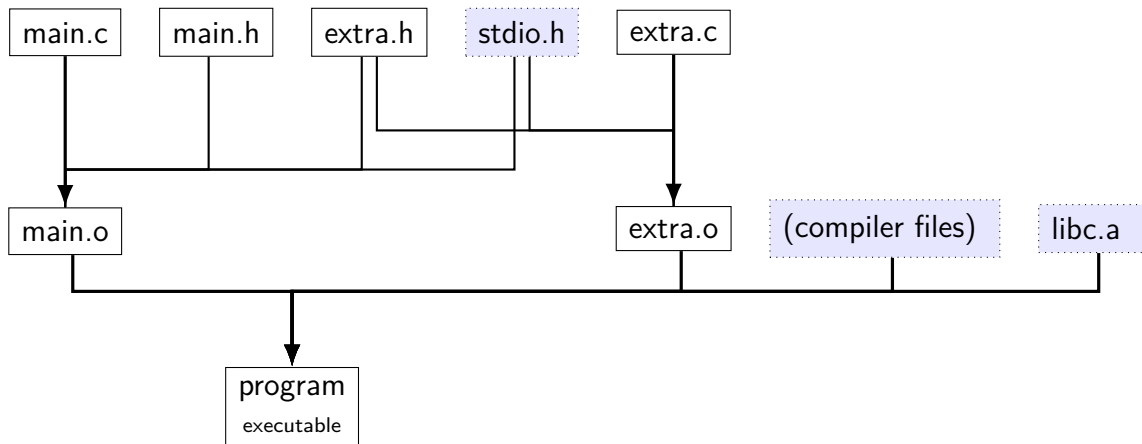


```
clang -o program main.o extra.o
```

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 or .dylib)	dynamically linked library ['shared object']

static libraries

Unix-like *static* libraries: libfoo.a

internally: archive of .o files with index

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

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

no space between `-l` and library name

`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 (1)

```
$ ls
libexample.so  main.c
$ clang -o main main.c -lexample
/usr/bin/ld: cannot find -lexample
clang: error: linker command failed with exit code 1 (use -v to see invocation)
$ clang -o main main.c -L. -lexample
$ ./main
./main: error while loading shared libraries:
  libexample.so: cannot open shared object file: No such file or directory
```

finding shared libraries (1)

```
$ ls
libexample.so  main.c
$ clang -o main main.c -lexample
/usr/bin/ld: cannot find -lexample
clang: error: linker command failed with exit code 1 (use -v to see invocation)
$ clang -o main main.c -L. -lexample
$ ./main
./main: error while loading shared libraries:
  libexample.so: cannot open shared object file: No such file or directory
```

```
$ LD_LIBRARY_PATH=. ./main

or

$ export LD_LIBRARY_PATH=.
$ ./main

or

$ clang -o main main.c -L. -lexample -Wl,-rpath .
$ ./main
```

finding shared libraries (1)

```
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 -Wall -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 runs commands if any prereq modified date after target

make rules

```
main.o: main.c main.h extra.h  
▶      clang -Wall -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 runs commands if any prereq modified date after target

make rules

```
main.o: main.c main.h extra.h  
▶      clang -Wall -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 runs commands if any prereq modified date after target

make rules

```
main.o: main.c main.h extra.h  
▶      clang -Wall -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 runs commands if any prereq modified date after target

make rules

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

```
►          clang -Wall -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 runs commands if any prereq modified date after target

make rules

```
main.o: main.c main.h extra.h  
▶      clang -Wall -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 runs commands if any prereq modified date after target

make rules

```
main.o: main.c main.h extra.h  
▶      clang -Wall -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 runs commands if any prereq modified date after target

...after making sure prerequisites up to date

make rule chains

program: main.o extra.o

▶ clang -Wall -o program main.o extra.o

extra.o: extra.c extra.h

▶ clang -Wall -c extra.c

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

▶ clang -Wall -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

- if not, rebuild it as needed so they are

“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 3 hours ago

Y does not exist

Z modified 1 hour ago

Q modified 2 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 -Wall -o program main.o extra.o

extra.o: extra.c extra.h

▶ clang -Wall -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 `-fsanitize=address` instead of `-Wall`?

what if I want to change clang to gcc?

variables/macros (1)

CC = gcc

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

LDFLAGS = -Wall -pedantic -fsanitize=address

LDLIBS = -lm

program: main.o extra.o

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

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

aside: conventional names

chose names CC, CFLAGS, LDFLAGS, etc.

not required, but conventional names (incomplete list follows)

CC	C compiler
CFLAGS	C compiler options
LDFLAGS	linking options
LIBS or LDLIBS	libraries

variables/macros (2)

```
CC = gcc
CFLAGS = -Wall
LDFLAGS = -Wall
LDLIBS = -lm
```

program: main.o extra.o

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

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.

aside: make versions

multiple implementations of make

for stuff we've talked about so far, no differences

most common on Linux: GNU make

will talk about 'pattern rules', which aren't supported by some other make versions

older, portable, (in my opinion less intuitive) alternative: suffix rules

pattern rules

CC = gcc

CFLAGS = -Wall

LDFLAGS = -Wall

LDLIBS = -lm

program: main.o extra.o

▶ \$(CC) \$(LDFLAGS) -o \$@ \$^ \$(LDLIBS)

%.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
LDLIBS = -lm
```

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

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

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

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

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

built-in rules

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

```
CC = gcc
CFLAGS = -Wall
LDFLAGS = -Wall
LDLIBS = -lm
```

```
program: main
```

```
▶ $(CC) $(CFLAGS) -o $@ $^ $(LDLIBS)
```

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

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

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

note: built-in rules not allowed on next week's lab

writing Makefiles?

error-prone to automatically all .h dependencies

-MM 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

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

.SUFFIXES: .c .o

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

backup slides