15-410

"Nobody reads these quotes anyway…"

Executables
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Some slides taken from 15-213 S'03 (Goldstein, Maggs).

Original slides authored by Randy Bryant and Dave O'Hallaron.

Pop Quiz

Q1. What does the Unix “ld” program do?

Q2. What does “ld” stand for?

Outline

Where addresses come from

Executable files vs. Memory Images

- Conversion by “program loader”
- You will write one for exec() in Project 3

Object file linking (answer to Q2)

- Loader bugs make programs execute *half*-right
- You will need to characterize what's broken
  - (*Not*: “every time I call printf() I get a triple fault”)
- You will need to how the parts *should* fit together

Who emits addresses?

Program linking, program loading

- ... means getting bits in memory at the right addresses

Who *uses* those addresses?

- (Where did that "wild access" come from?)

Code addresses: program counter (%cs:%eip)

- Straight-line code
- Loops, conditionals
- Procedure calls

Stack area: stack pointer (%ss:%esp, %ss:%ebp)

Data regions (data/bss/heap)

- Most pointers in general purpose registers (%ds:%ebx)

Initialized how?

Program counter

- Set to “entry point” by OS program loader

Stack pointer

- Set to “top of stack” by OS program loader

Registers

- How does my code know the address of `thread_table[]`?
- Some pointers are stored in the instruction stream

```
for (tp = thread_table,
  tp < &thread_table[n_threads], ++tp)
```

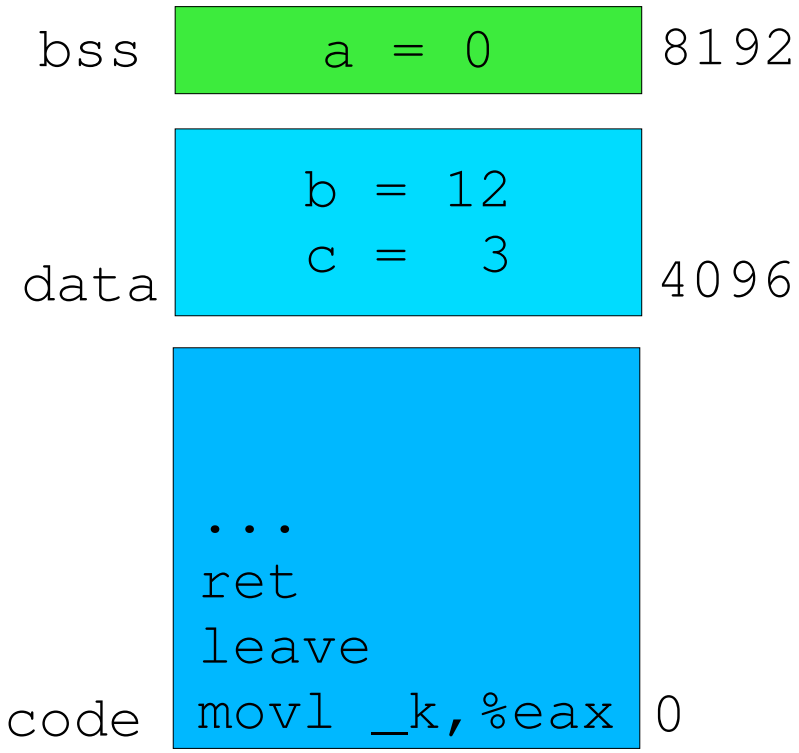
- Some pointers are stored in the data segment

```
struct thread *thr_base = &thread_table[0];
```

- How do these all point to the right places?

Where does an int live?

```
int k = 3;
int foo(void) {
  return (k);
}

int a = 0;
int b = 12;
int bar (void) {
  return (a + b);
}
```



Loader: Image File ⇒ Memory Image

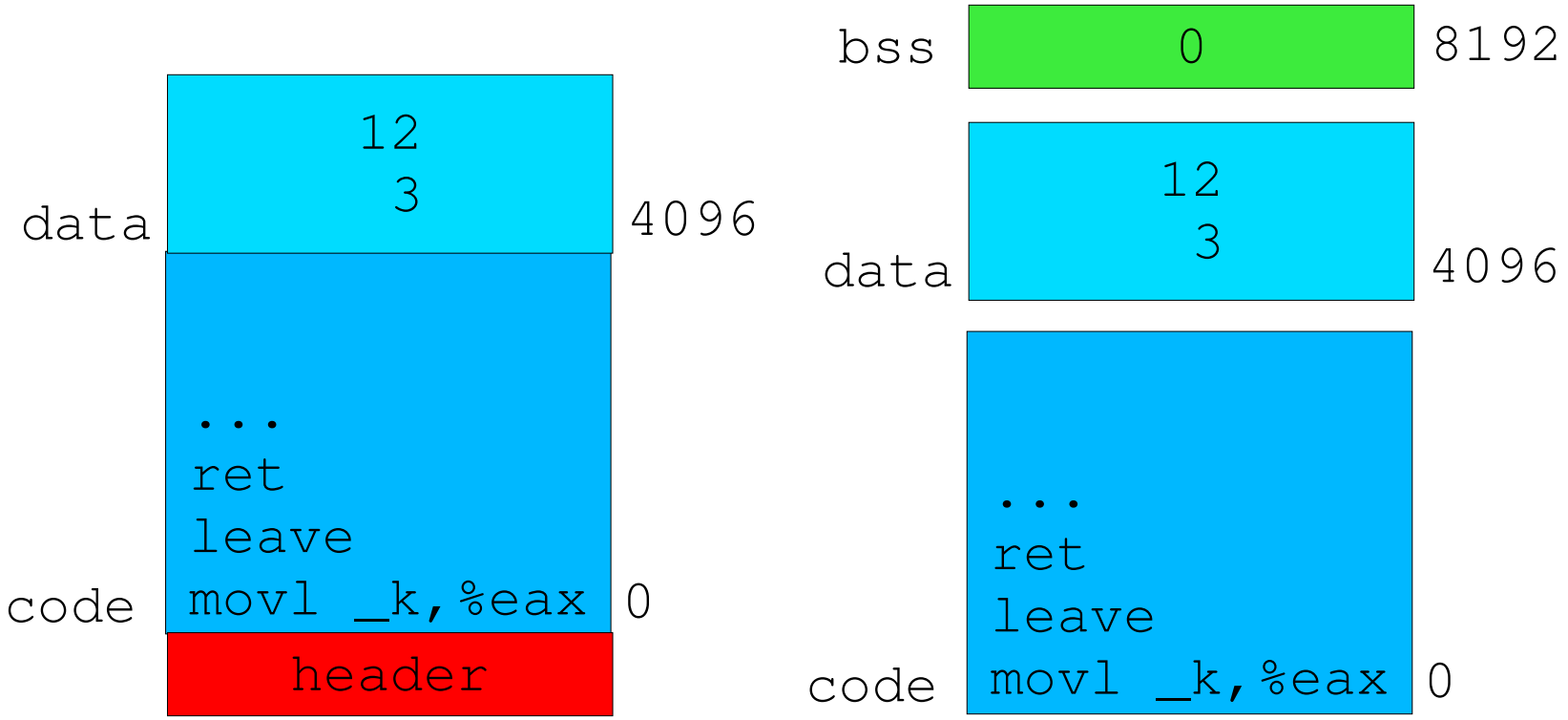


Image file has header (tells loader what to do)
Memory image has bss segment!

Programs are Multi-part

Modularity

- Program can be written as a collection of smaller source files, rather than one monolithic mass.
- Can build libraries of common functions (more on this later)
  - e.g., Math library, standard C library

Efficiency (time)

- Change one source file, compile, and then relink.
- No need to recompile other source files.

"Link editor" combines objects into one image file

- Unix "link editor" called "ld"

Linker Todo List

Merge object files

- Merges multiple relocatable (.o) object files into a single executable object file that can loaded and executed by the loader.

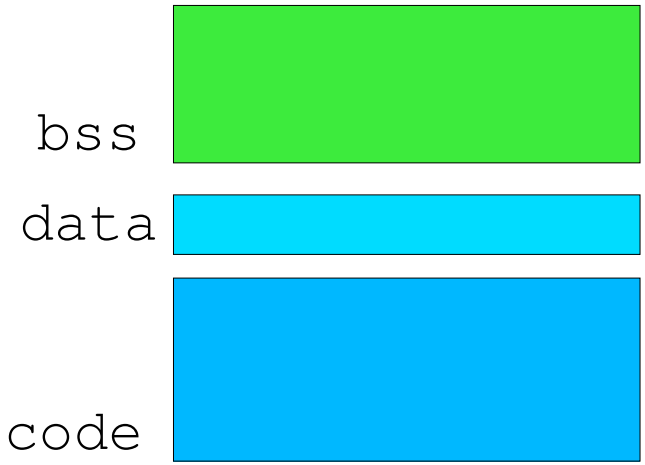
Resolve external references

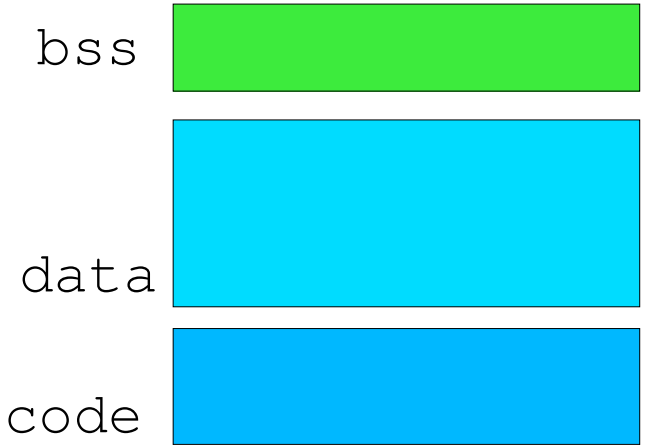
- As part of the merging process, resolves external references.
  - *External reference*: reference to a symbol defined in another object file.

Relocate symbols

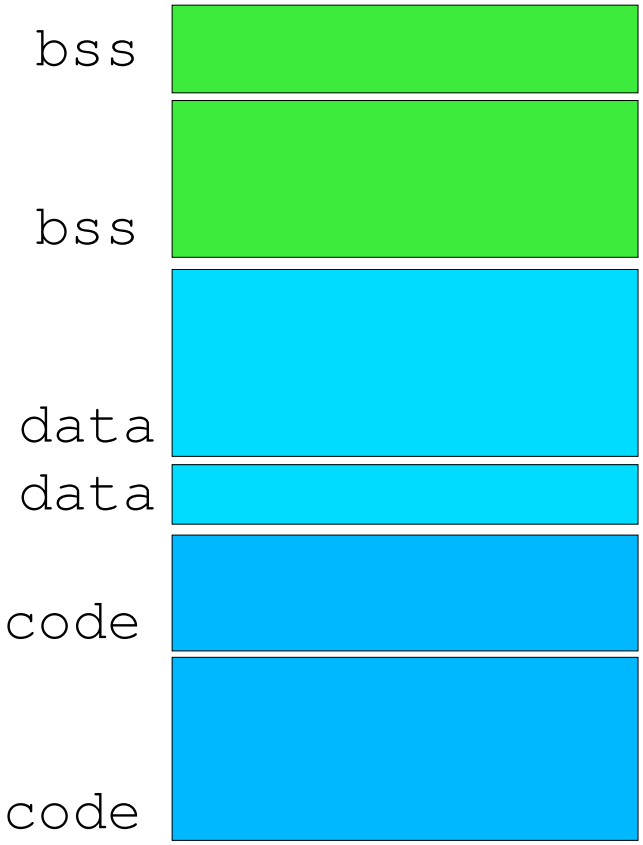
- Relocates symbols from their relative locations in the .o files to new absolute positions in the executable.
- Updates all references to these symbols to reflect their new positions.
- What does this mean??

Every .o uses same address space





Combining .o's Changes Addresses



Linker uses *relocation information*

Field

- address, bit field size

Field type

- relative, absolute

Field reference

- symbol name

Example

- “Bytes 1024..1027 of foo.o refer to absolute address of _main”

Example C Program

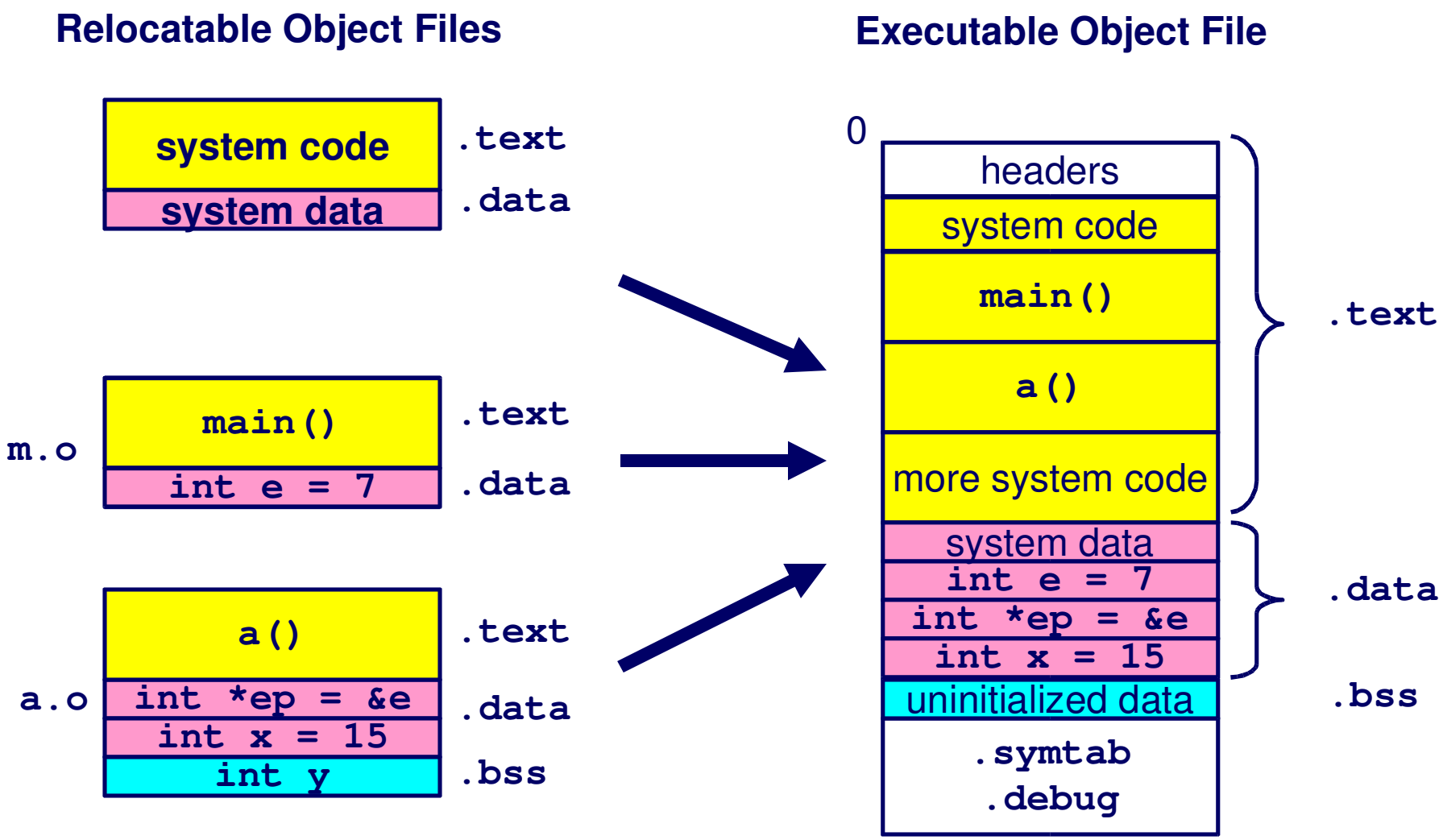
m.c

```
int e=7;

int main() {
  int r = a();
  exit(0);
}
```

a.c

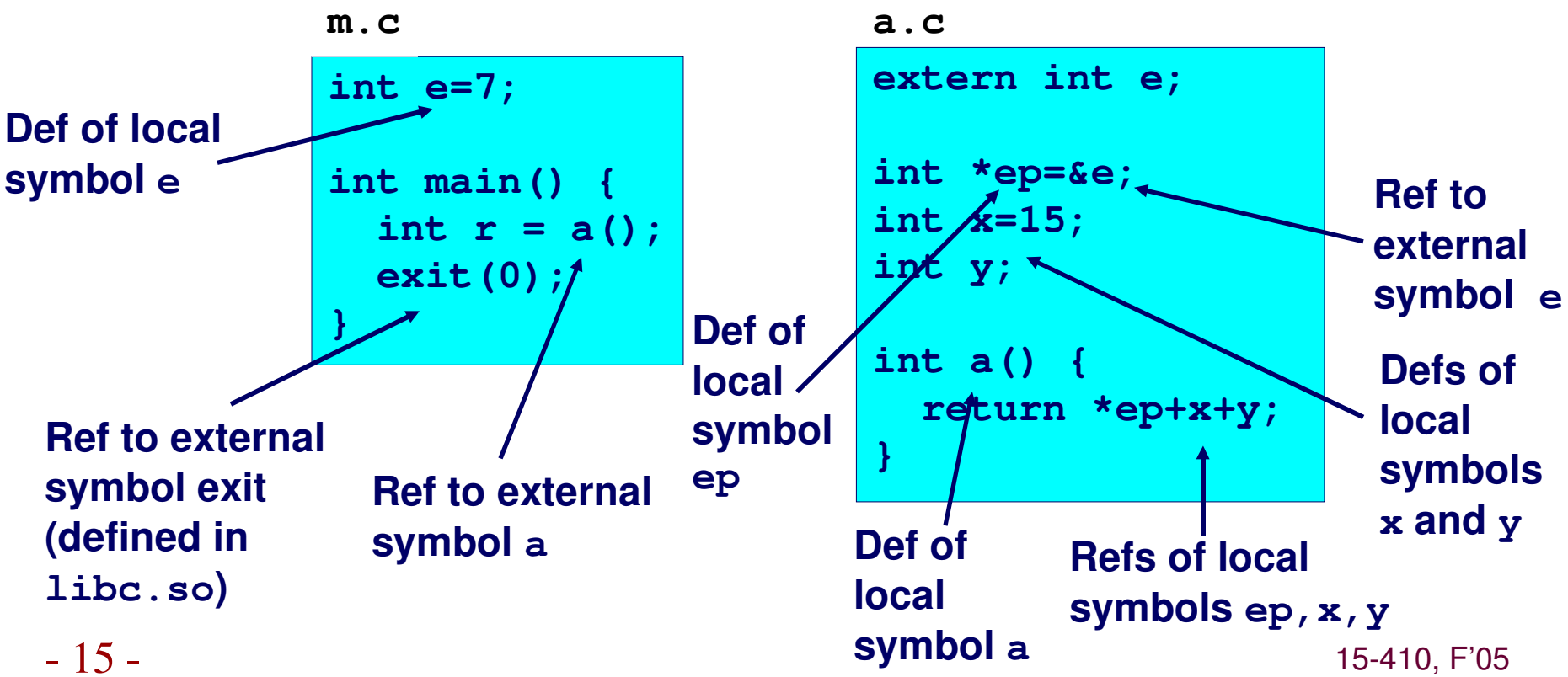
```
extern int e;

int *ep=&e;
int x=15;
int y;

int a() {
  return *ep+x+y;
}
```

Merging Relocatable Object Files into an Executable Object File



Relocating Symbols and Resolving External References

- *Symbols* are lexical entities that name functions and variables.
- Each symbol has a *value* (typically a memory address).
- Code consists of symbol *definitions* and *references*.
- References can be either *local* or *external*.



Executable File / Image File

Linked program consists of multiple “sections”

- Section properties
  - Type
  - Memory address

Common Executable File Formats

- a.out - “assembler output” (primeval Unix format: 70's, 80's)
- Mach-O – Mach Object (used by MacOS X)
- ELF – Executable and Linking Format
  - (includes “DWARF” - Debugging With Attribute Record Format)

Executable and Linkable Format (ELF)

Standard binary format for object files

Derives from AT&T System V Unix

- Later adopted by BSD Unix variants and Linux

One unified format for

- Relocatable object files (`.o`)
- Executable object files
- Shared object files (`.so`)

Generic name: ELF binaries

Better support for shared libraries than old `a.out` formats.

ELF Object File Format

Elf header

- Magic number, type (.o, exec, .so), machine, byte ordering, etc.

Program header table

- Page size, virtual addresses memory segments (sections), segment sizes.

`.text` section

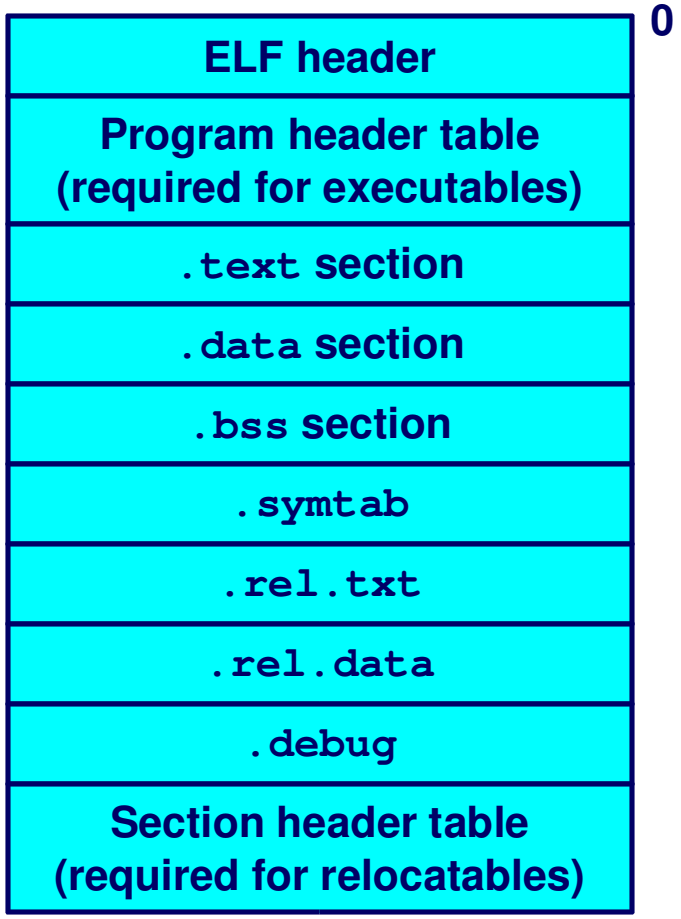
- Code

`.data` section

- Initialized (static) data

`.bss` section

- Uninitialized (static) data
- "Block Started by Symbol"
- "Better Save Space"
- Has section header but occupies no space



ELF Object File Format (cont)

`.symtab` section

- Symbol table
- Procedure and static variable names
- Section names and locations

`.rel.text` section

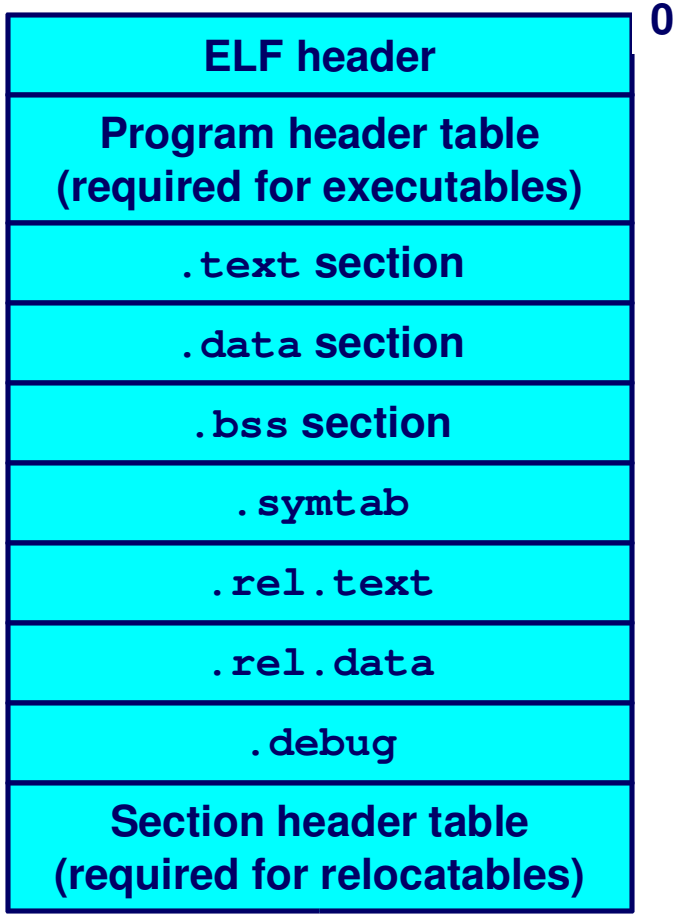
- Relocation info for `.text` section
- Addresses of instructions that will need to be modified in the executable
- Instructions for modifying.

`.rel.data` section

- Relocation info for `.data` section
- Addresses of pointer data that will need to be modified in the merged executable

`.debug` section

- Info for symbolic debugging (`gcc -g`)



“Not needed on voyage”

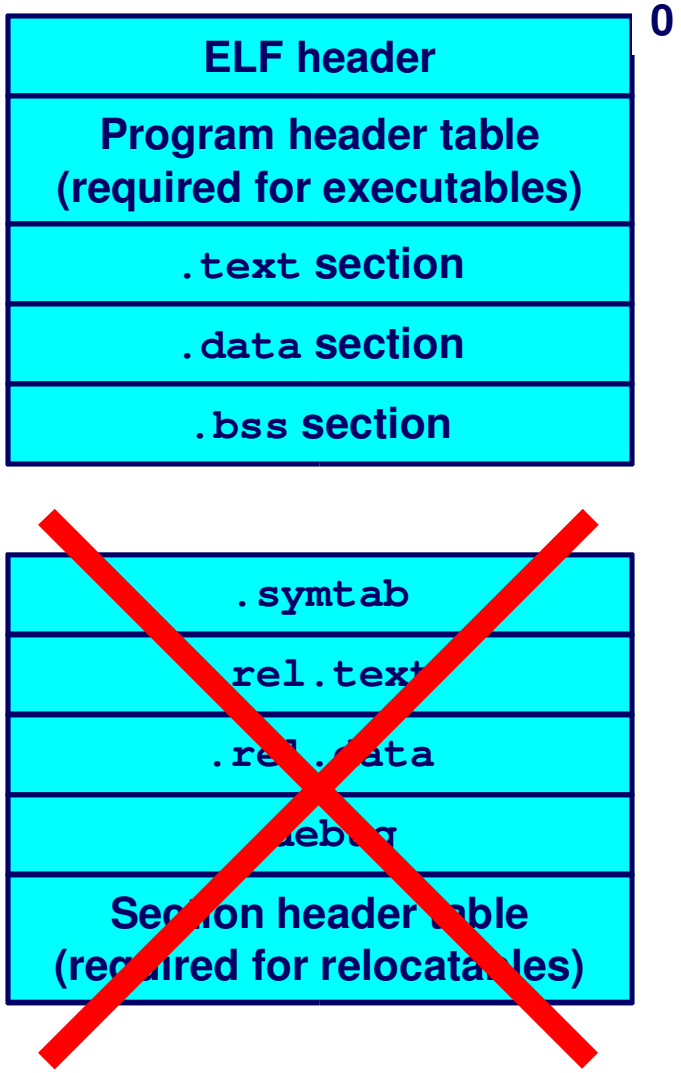
Some sections not needed for execution

- Symbol table
- Relocation information
- Symbolic debugging information

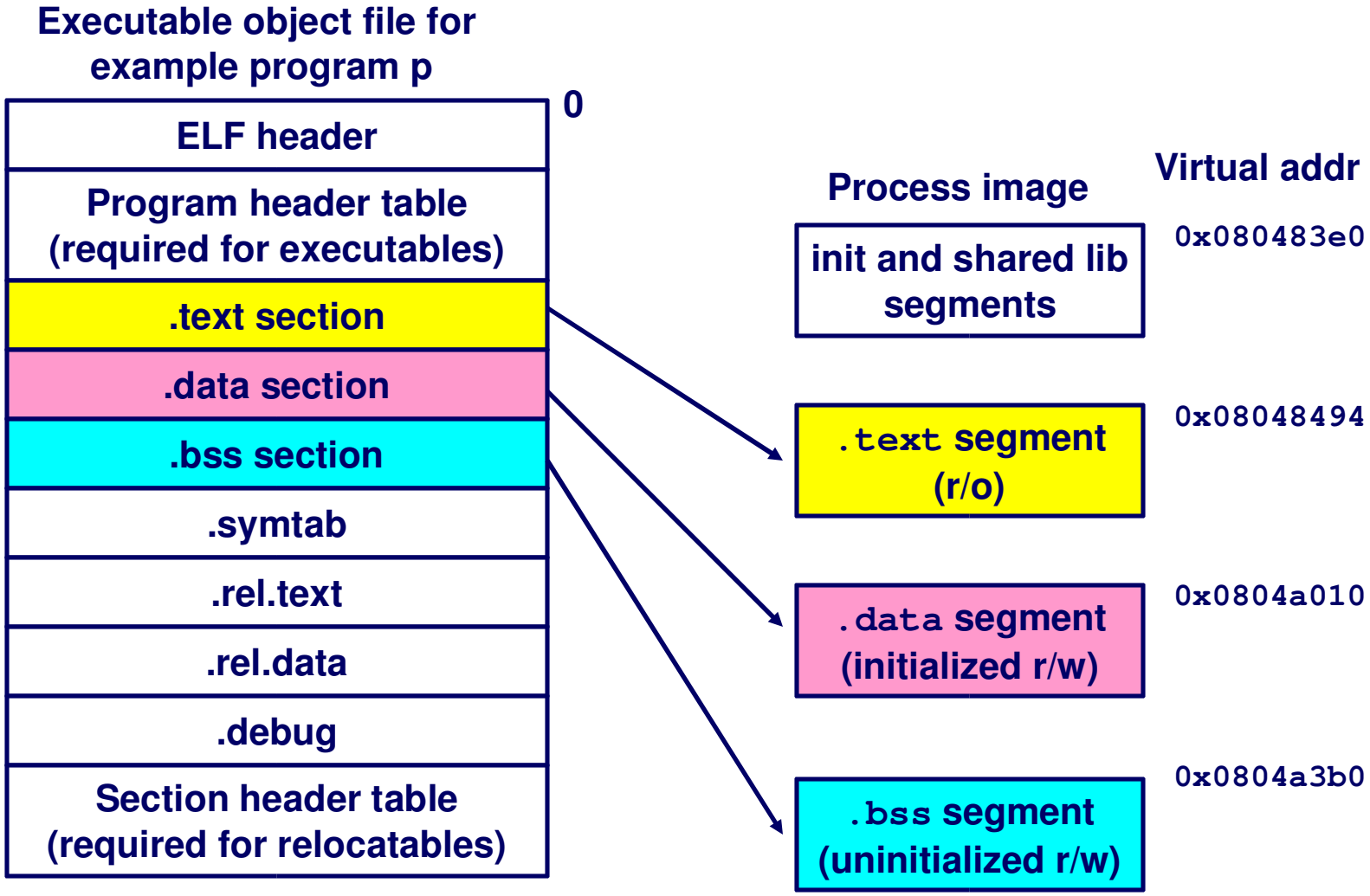
These sections not loaded into memory

May be removed with “strip” command

- Or retained for future debugging



Loading ELF Binaries



Summary

Where do addresses come from?

Where does an int live?

Image file vs. Memory image

Linker

- What, why
- Relocation

ELF structure

- The pieces which need to be loaded into memory by somebody
  - Somebody whose name is a lot like yours...