15-410

"Nobody reads these quotes anyway…"

Executables
February 29, 2008

Dave Eckhardt

Roger Dannenberg

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

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

Synchronization

Wednesday: Project 3 Checkpoint 1

- In cluster
- We will ask you to load and run a program released then

You need to *plan* how to get there

- Simple program loader
- Dummy VM (please write encapsulated bad code!!)
- Getting from kernel mode to user mode
- Getting from user mode to kernel mode
- Lots of faults
  - Solving them will require “story telling”
    - » Don't forget about intel-isr.pdf and intel-sys.pdf

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)
```

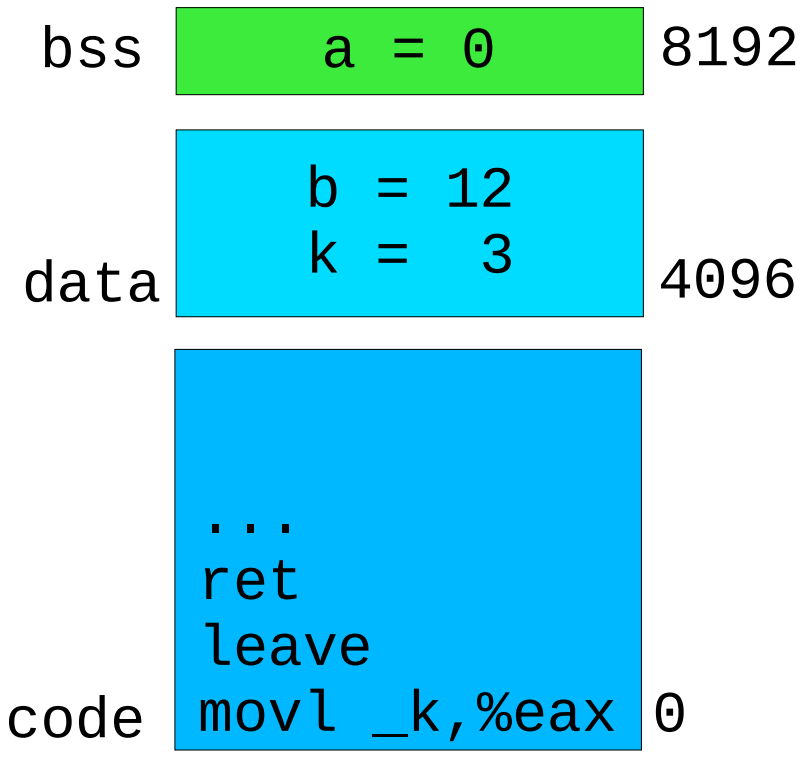
- Some pointers are stored in the data segment

```
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) {
  int shh = 99;
  return (k);
}

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



Loader: Image File ⇒ Memory Image

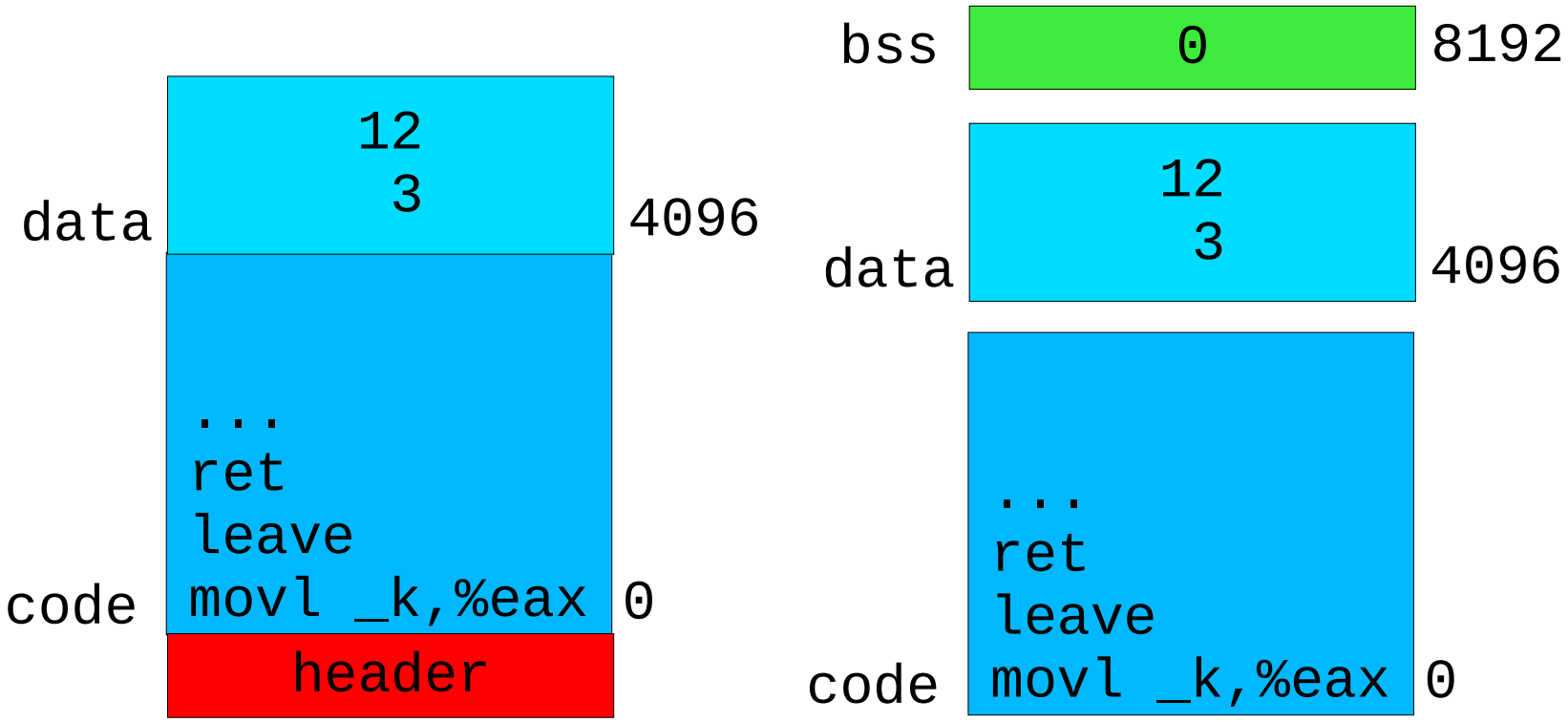


Image file has header (tells loader what to do)
Memory image has bss segment!

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.

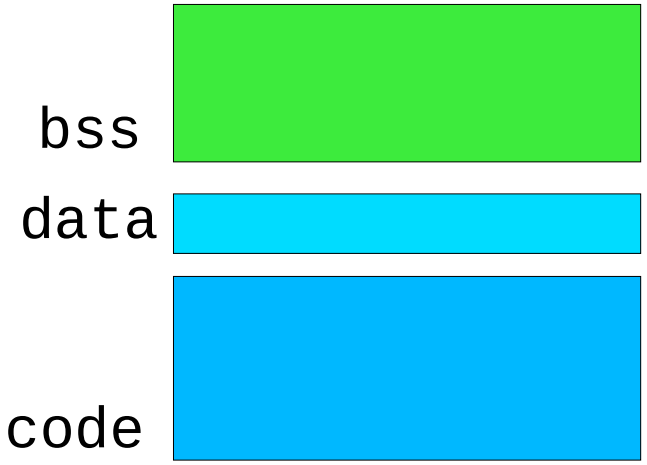
Resolve external references

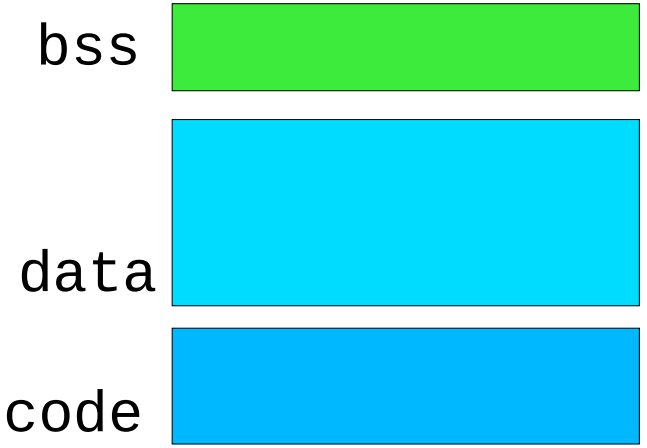
- As part of the merging process, resolves external references.
  - *External reference*: reference to a symbol defined in another object file.

Relocate symbols

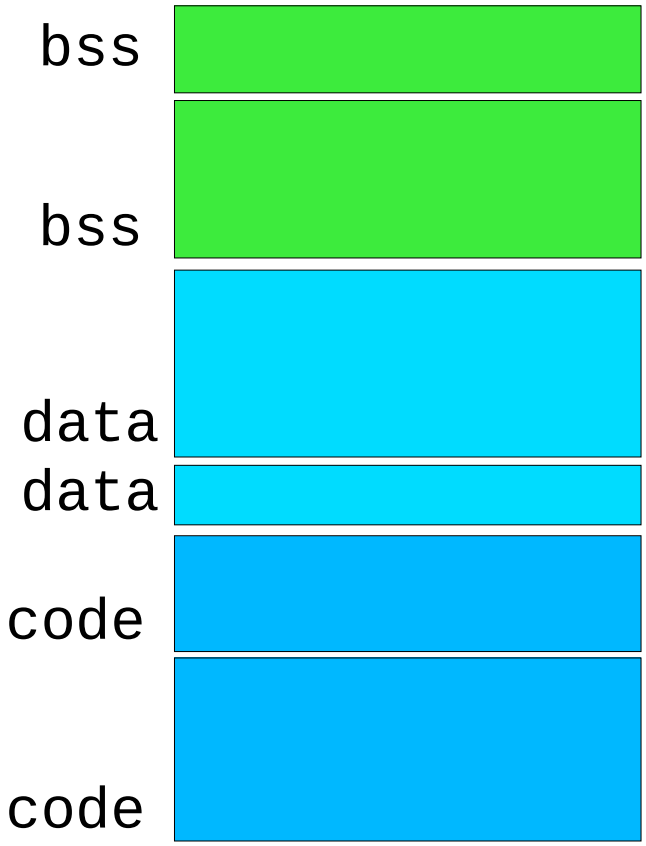
- Relocates symbols from their relative locations in the `.o` files to new absolute positions in the executable.
- Updates all references to these symbols to reflect their new positions.
- What does this mean??

Every .o uses same address space





Combining .o's Changes Addresses



Linker uses *relocation information*

Field location

- 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

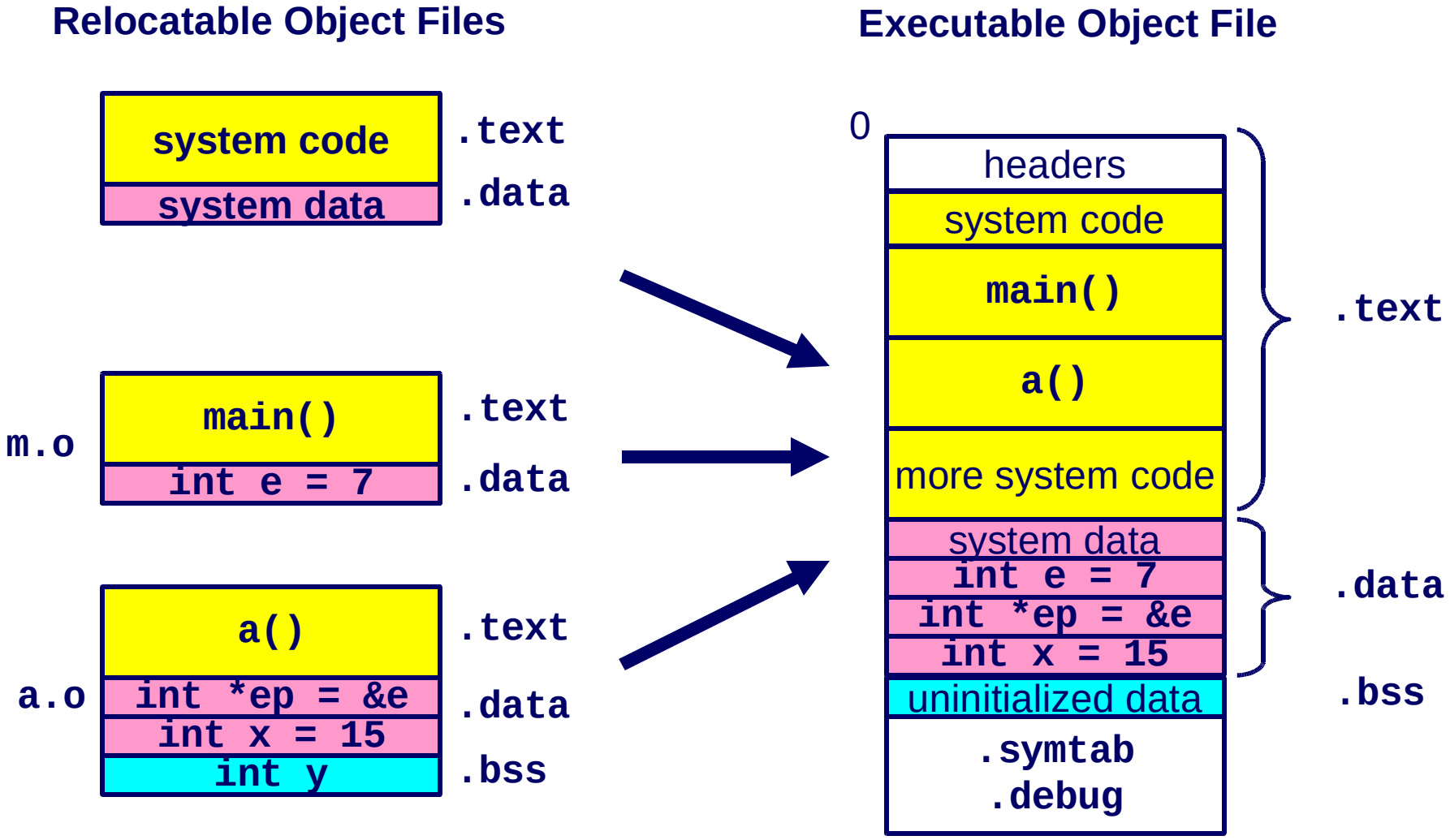
m.c

```
int e=7;

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

a.c

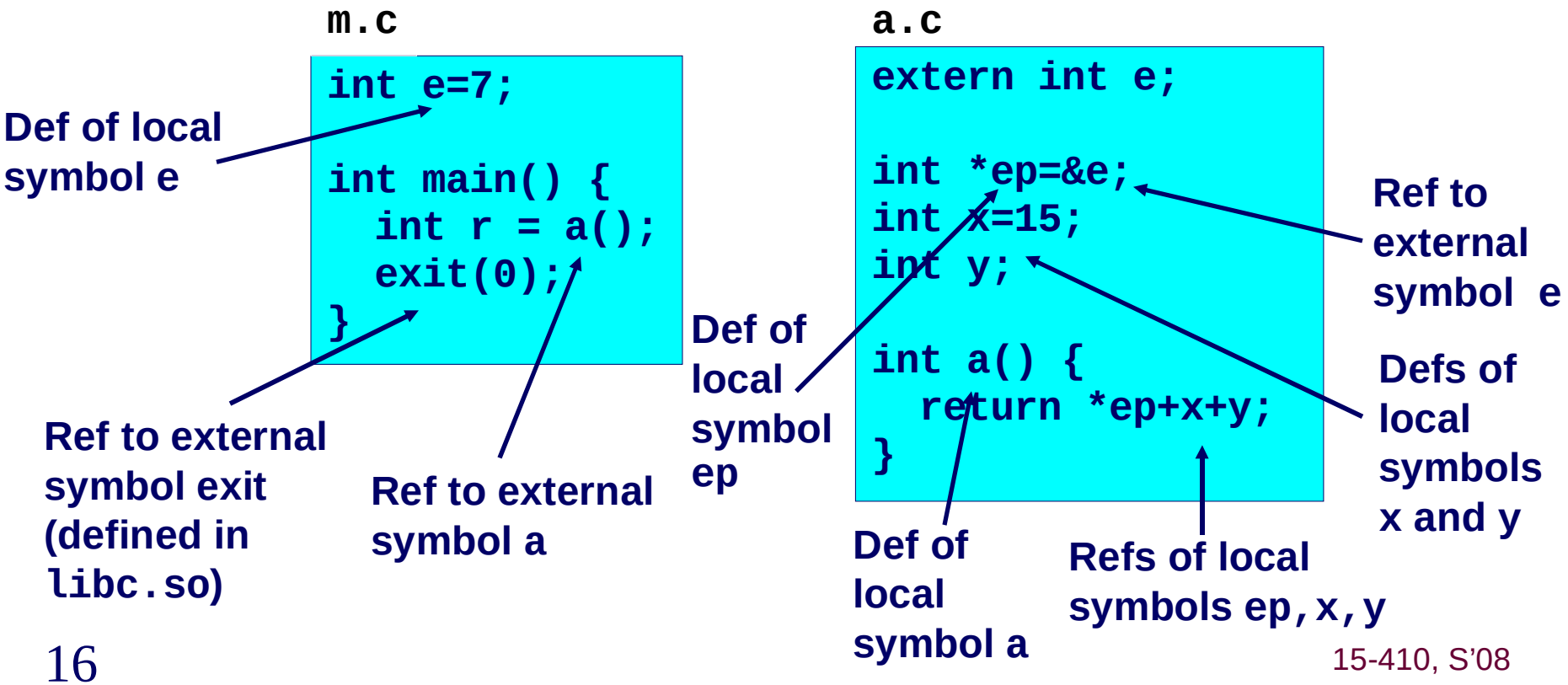
```
extern int e;

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

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

Merging Relocatable Object Files ⇒ 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

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

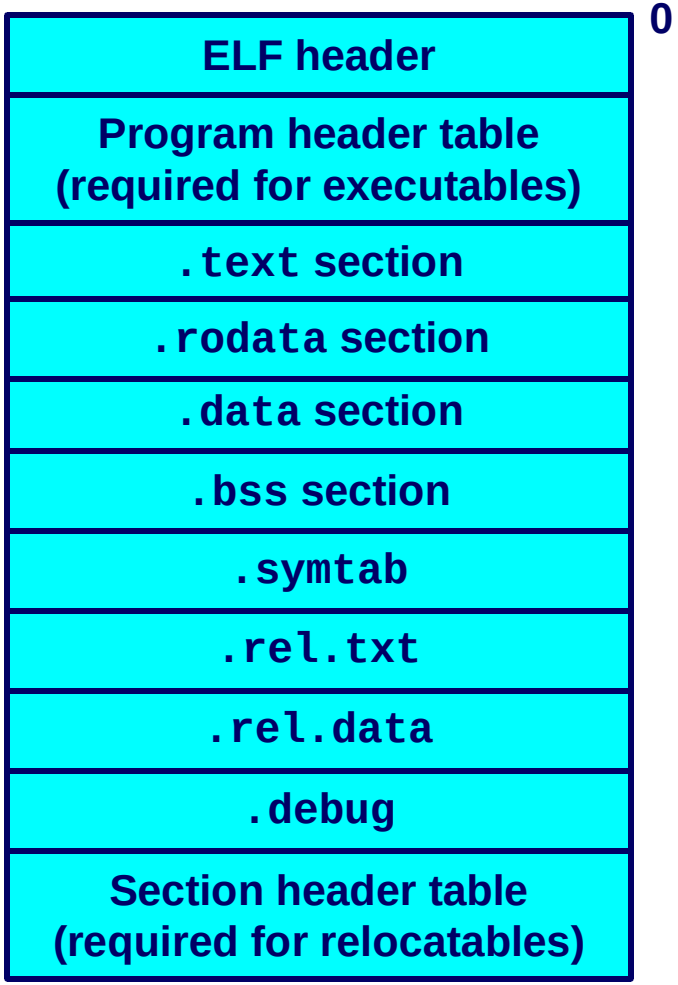
- Code

`.rodata`, `.data` section

- Initialized (static) data (ro = “read-only”)

`.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

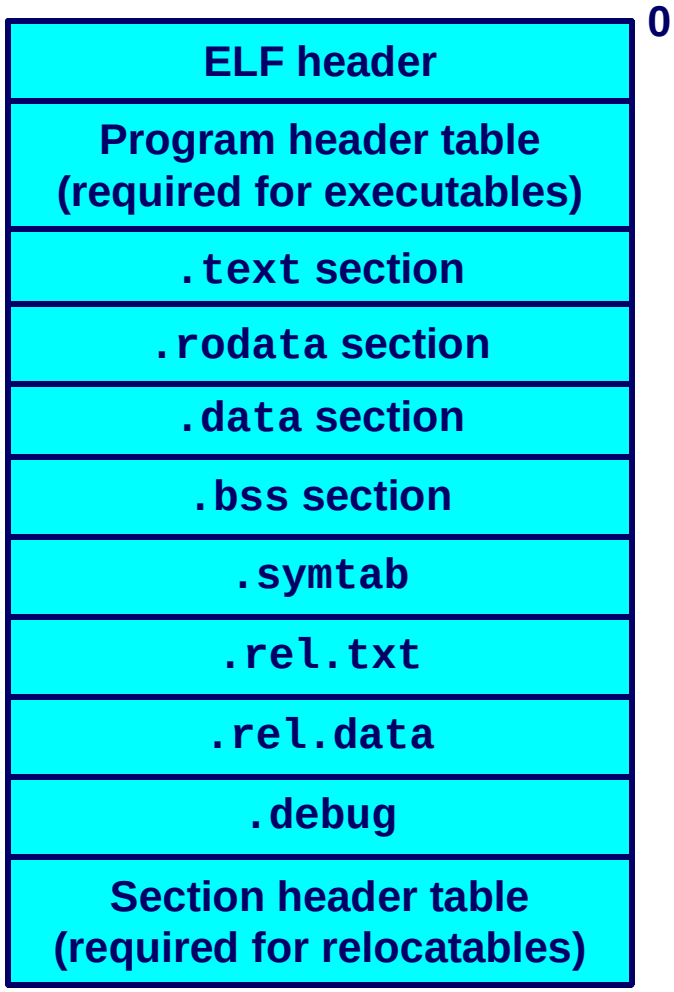
- Relocation info for `.text` section
- Addresses of instructions that will need to be modified in the executable
- Instructions for modifying.

`.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”

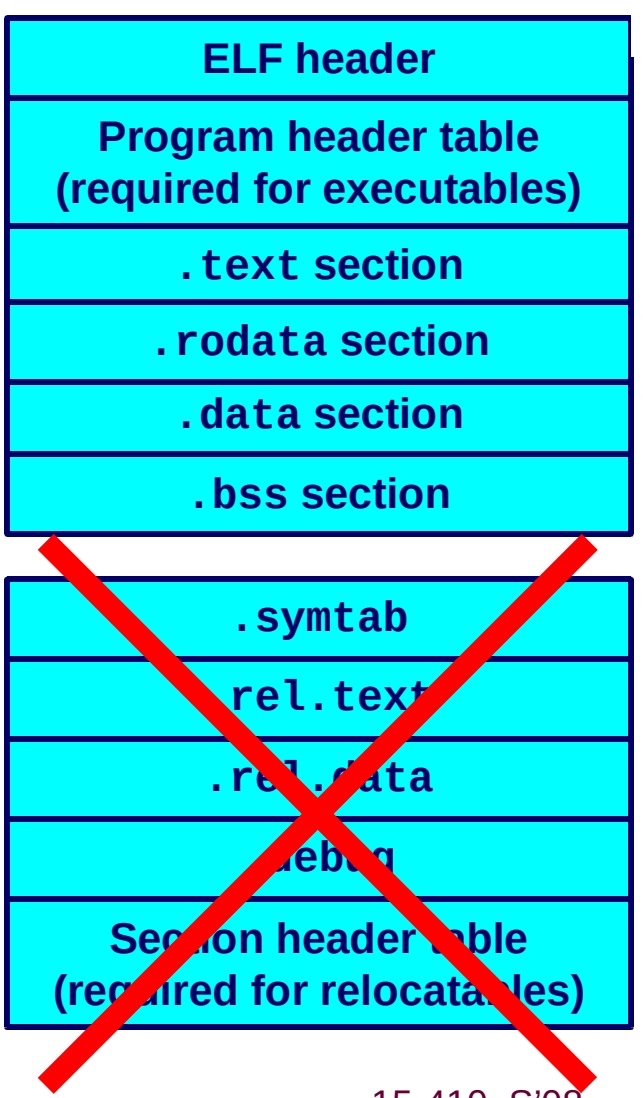
Some sections not needed for execution

- Symbol table
- Relocation information
- Symbolic debugging information

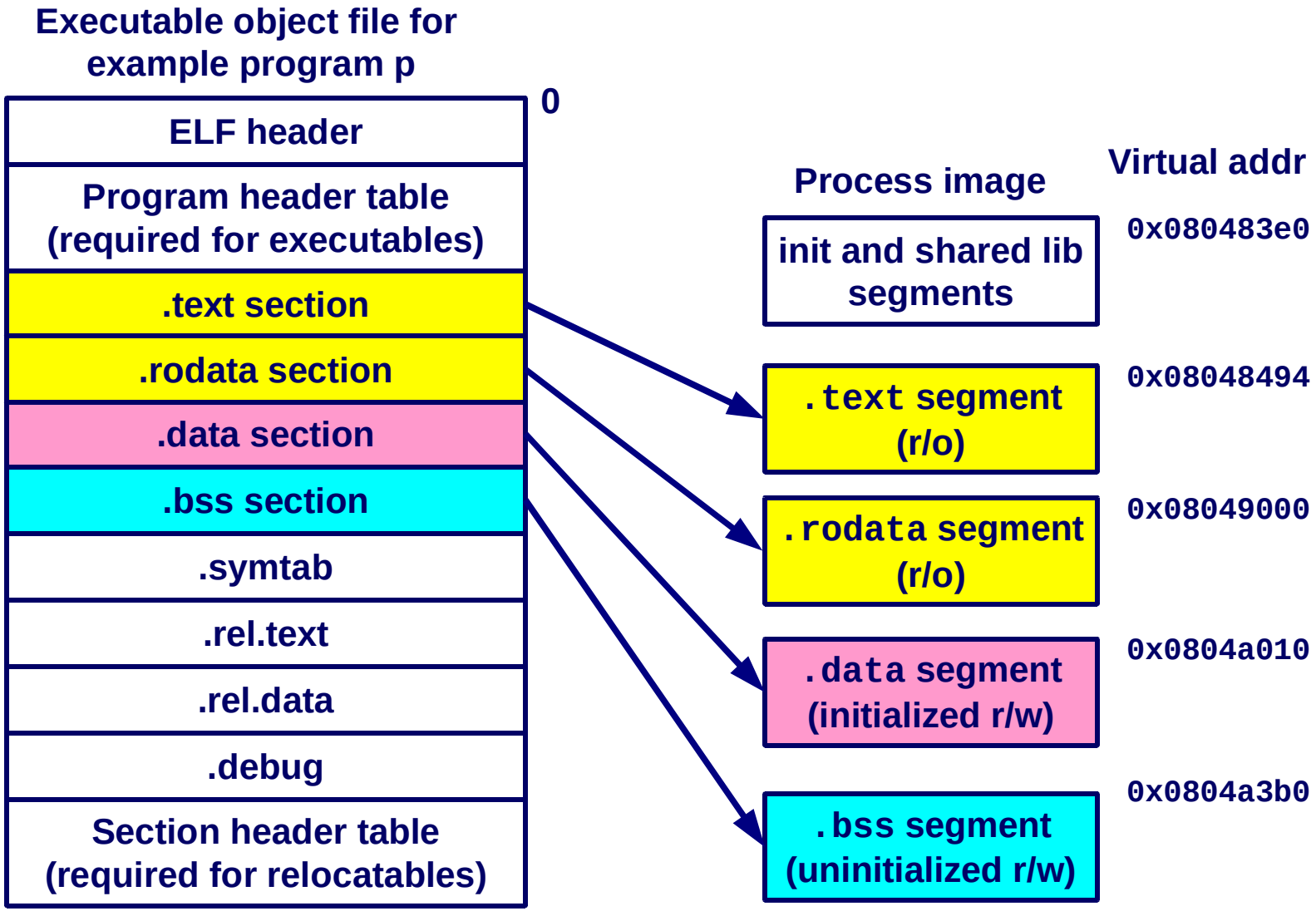
These sections not loaded into memory

May be removed with “strip” command

- Or retained for future debugging



Loading ELF Binaries



Getting Help

Writing your first loader should be fun

- But some parts might be “fun” instead

A tool you can use

- gdb

```
% gdb 410user/progs/init
(gdb) x/i main
0x1000020 <main>:      push   %ebp
(gdb) x/x main
0x1000020 <main>:      0x83e58955
```

- Ok, now you have a cross-check!

Other tools which tell you where executable parts belong

- nm
- objdump

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...**