

15-410

“Nobody reads these quotes anyway...”

Executables **Feb. 27, 2012**

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**Some slides taken from 15-213 S'03 (Goldstein, Maggs).
Original slides authored by Randy Bryant and Dave O'Hallaron.**

Synchronization

Project 3 Checkpoint 1

- In cluster (watch mail for coordinates)
- 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

Q0. What is “BSS”?

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);
}
```

| | | |
|------|---------------------------------------------------|------|
| bss | <div>a = 0</div> | 8192 |
| data | <div>b = 12 k = 3</div> | 4096 |
| code | <div>... ret leave movl _k,%eax</div> | 0 |

Loader: Image File \Rightarrow Memory Image

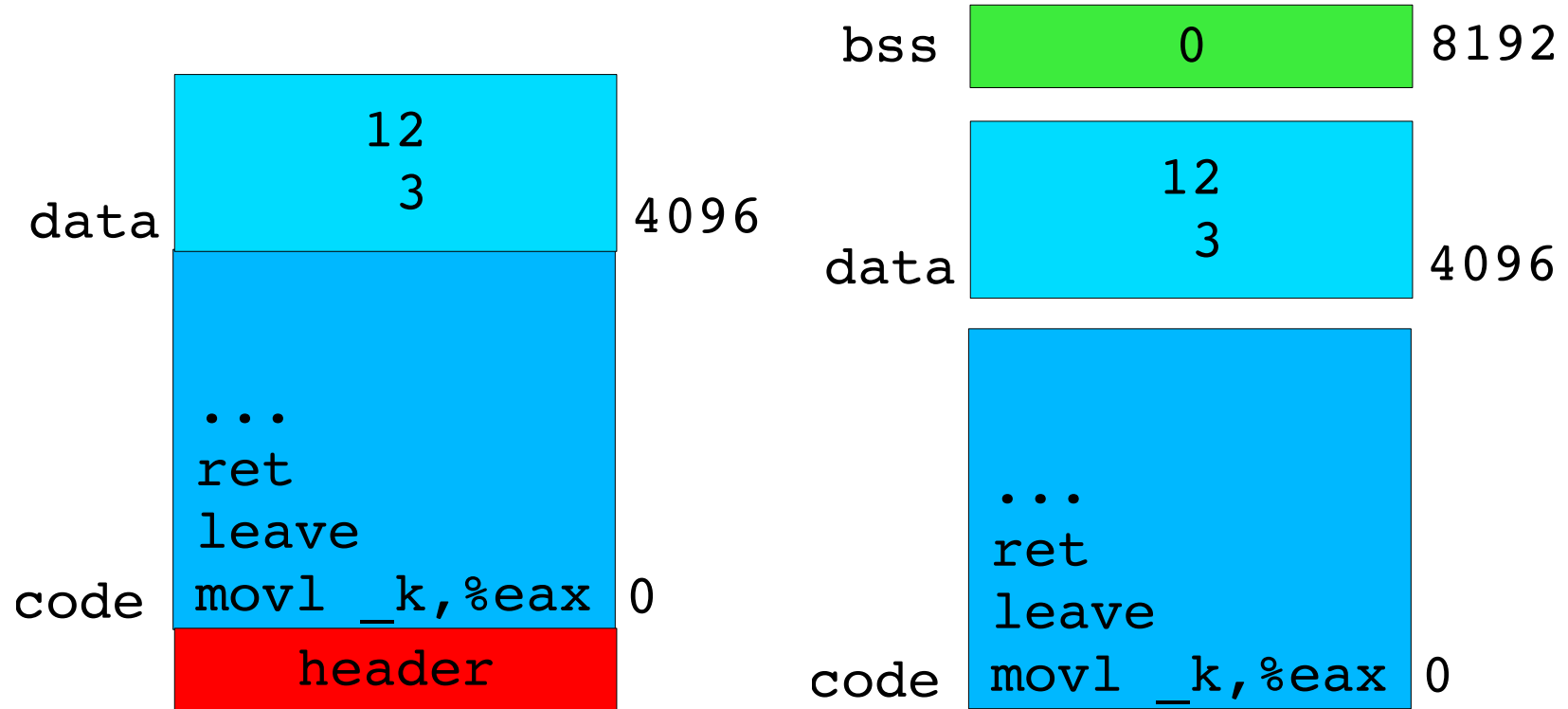


Image file has header (tells loader what to do)
Memory image has bss segment!

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 be loaded and executed by the loader.

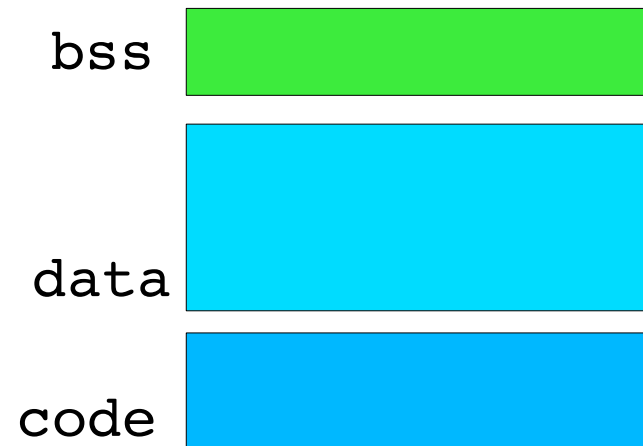
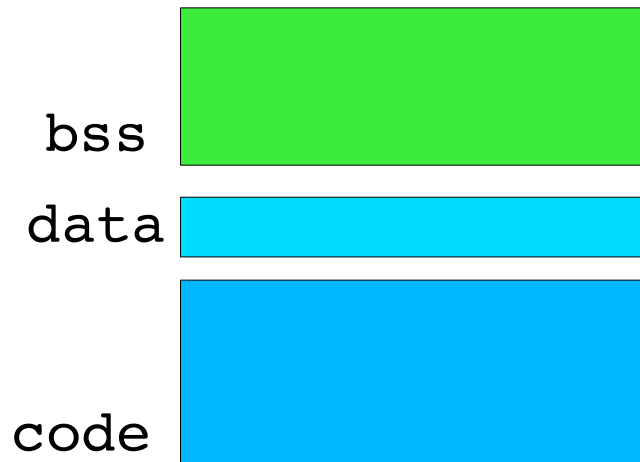
Resolve external references

- *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



Example C Program

m.c

```
int e=7;

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

a.c

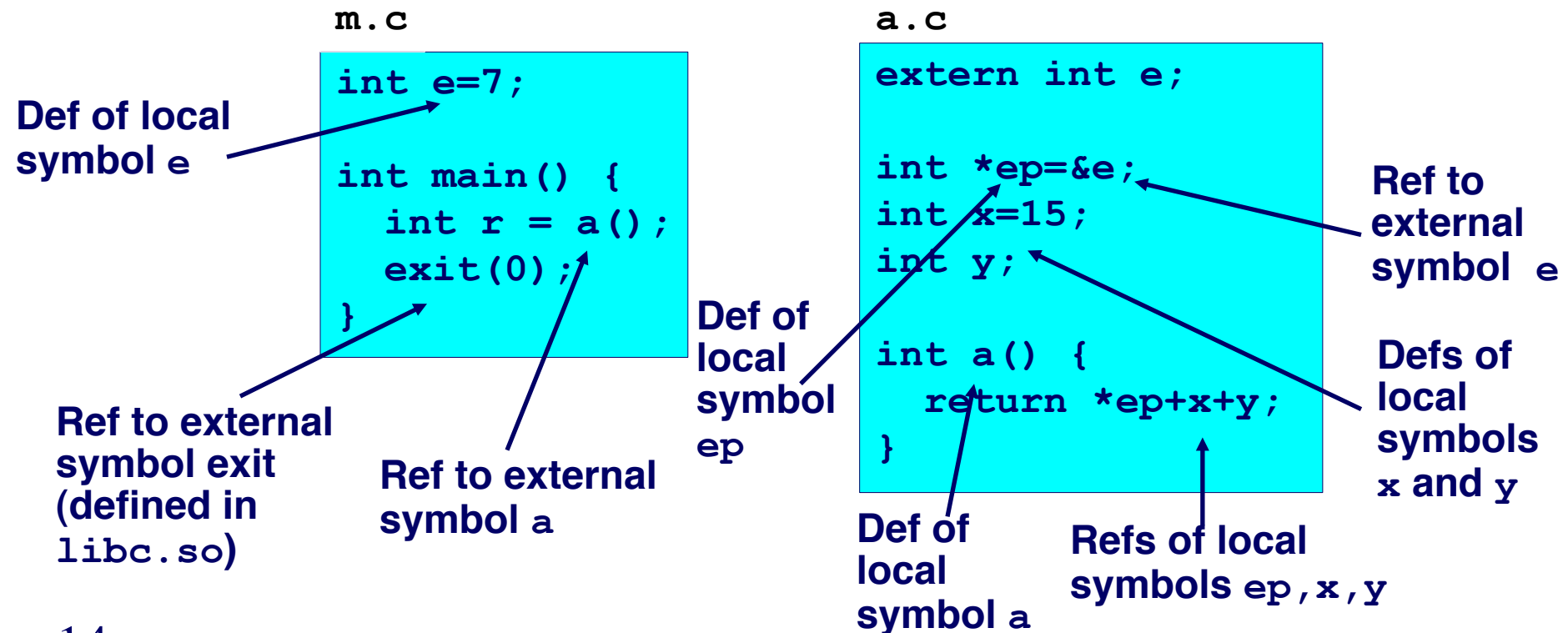
```
extern int e;

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

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

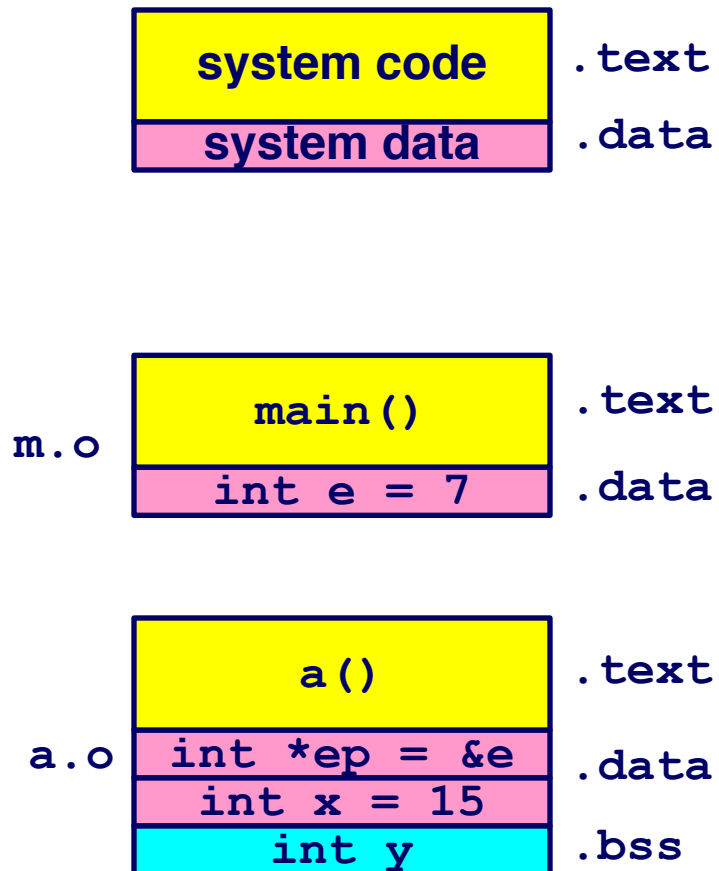
Relocating Symbols and Resolving External References

- **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**.

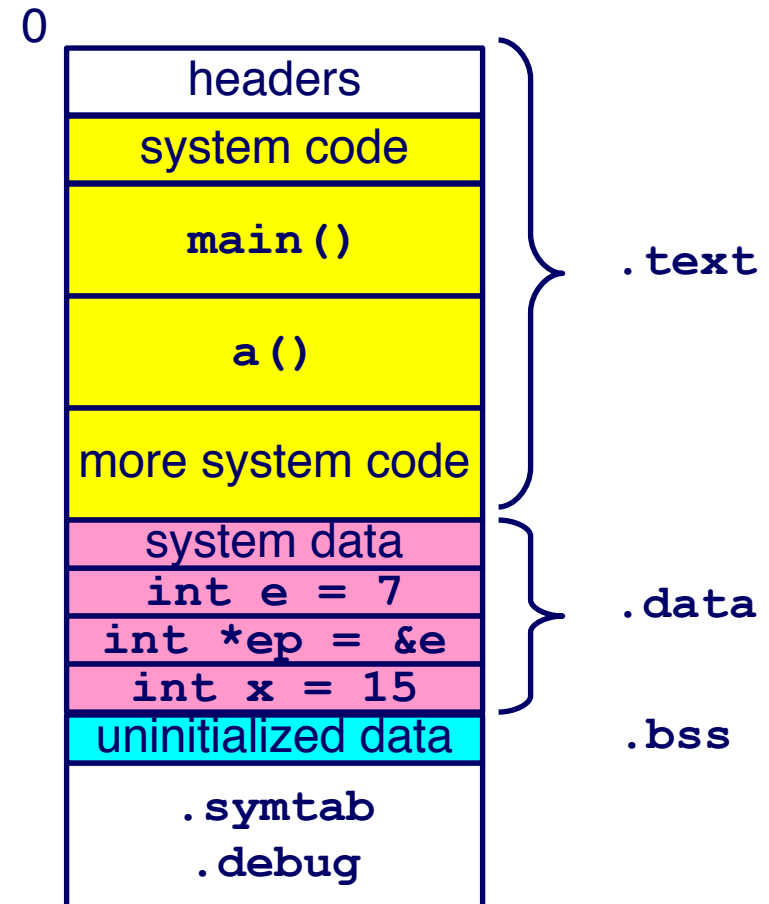


Merging Relocatable Object Files ⇒ Executable Object File

Relocatable Object Files



Executable Object File



Linker uses *relocation information*

Object file contains a “relocation table”

Each table entry specifies one “relocation field” in object

Example

- “Bytes 1024..1027 of foo.o refer to absolute address of `_main`”
 - `_main` may be a file-local symbol or an external symbol
- If `_main` moves, all fields referring to it must be patched

Field properties

Location

- offset, bit field size

Type

- relative, absolute

Reference

- symbol name (string)

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
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Common Executable File Formats

- a.out - “assembler output” (primeval Unix format: 70's, 80's)
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- 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 header |
| Program header table (required for executables) |
| .text section |
| .rodata section |
| .data section |
| .bss section |
| .symtab |
| .rel.txt |
| .rel.data |
| .debug |
| Section header table (required for relocatables) |

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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`)

| |
|-----------------------------------------------------|
| ELF header |
| Program header table (required for executables) |
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| .rodata section |
| .data section |
| .bss section |
| .symtab |
| .rel.txt |
| .rel.data |
| .debug |
| Section header table (required for relocatables) |

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“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

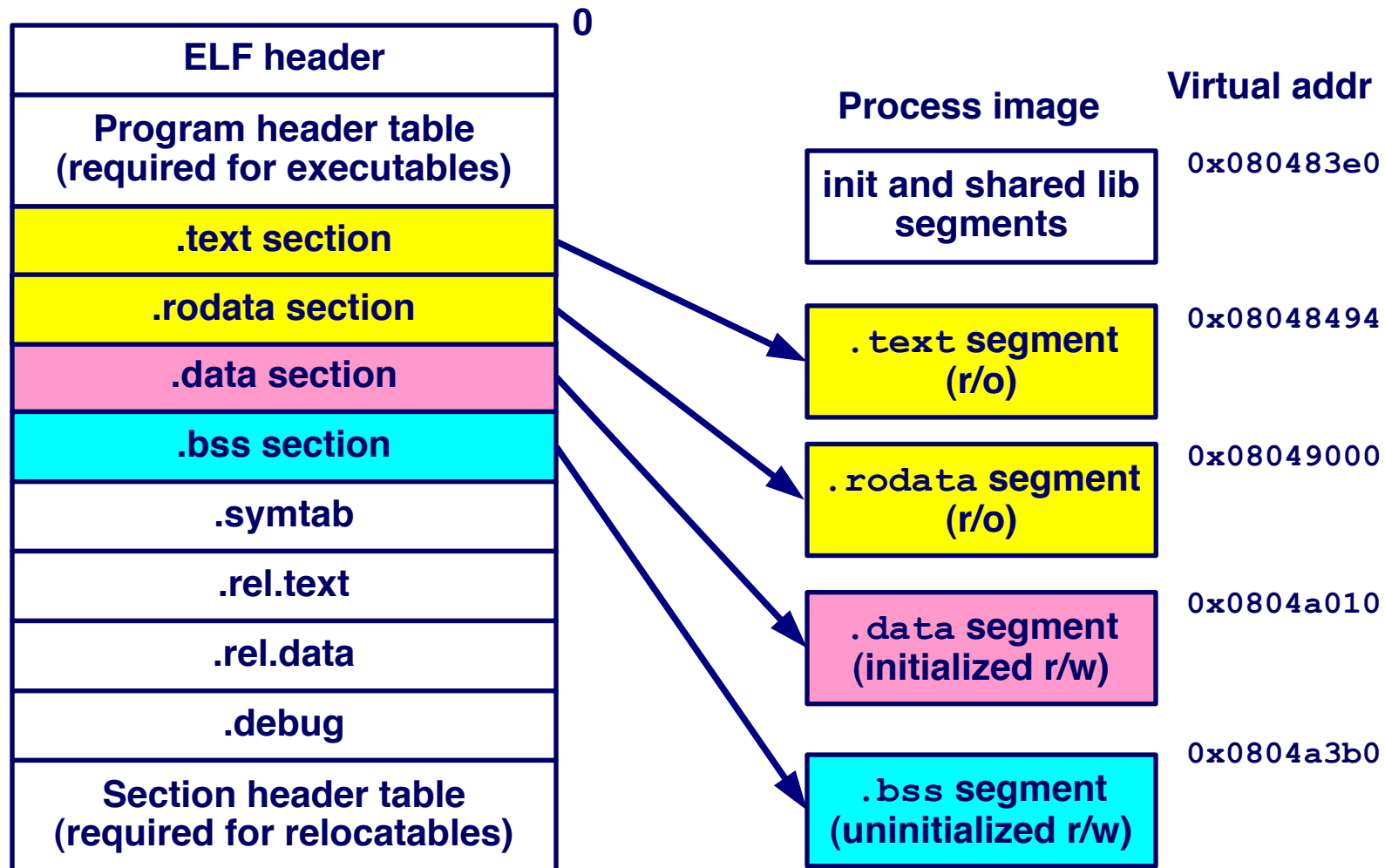
- Or retained for future debugging

| |
|----------------------------------------------------|
| ELF header |
| Program header table (required for executables) |
| .text section |
| .rodata section |
| .data section |
| .bss section |

| |
|-----------------------------------------------------|
| .symtab |
| .rel.text |
| .rel.data |
| .debug |
| Section header table (required for relocatables) |

Loading ELF Binaries

Executable object file for
example program p



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 -n
- 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...