Linking

- Topics
  - How do you transform a collection of object files into an executable?
  - How is an executable structured?
  - Why is an executable structured as it is?
- Learning Objectives:
  - Explain what ELF format is.
  - Explain what an executable is and how it got that way

With huge thanks to Steve Chong for his notes from CS61.

What is Linking?

- The process of merging all the code and data from multiple object files into a single file that is ready to be loaded into memory and executed.
- Two forms of linking:
  - Static: compile/link time – executable contains all the code and data needed to execute.
  - Dynamic: load time or run time – parts of the code and/or data are integrated after link time.
    - Think shared libraries.

What does the Linker do?

- Copy code and data from each object file into the executable.
- Resolve references between object files
- Relocate symbols to use absolute addresses rather than relative addresses.

Symbols

- Symbols are a convenience for the programmer, but the compiler, assembler, linker and loader have to deal with transforming symbols into something meaningful.
- Local variables: easy – compiler translates those into references into the stack.
- Local functions: relatively straight forward – place the functions somewhere and then translate references to the functions into addresses.
- Global variables: slightly more work
  - When a module allocates space for them, the compiler has to allocate space for them and translate references to the appropriate address.
  - When a module uses them, the compiler has to leave a note indicating that at link time, we will need to figure out where those global variables live and fix up references to them.
- External functions: similar to global variables
  - Defining module: place the code and remember that you have the definition of the symbol corresponding to the function name.
  - Using module: remember that you have to fill in calls to it later.

Example

- Consider the two files: main.c and swap.c:

main.c

```
int buf[2] = {1,2};

int main()
{
  swap();
  return 0;
}
```

swap.c

```
extern int buf[];

void swap()
{
  int temp;

  temp = buf[1];
  buf[1] = buf[0];
  buf[0] = temp;
}
```

Example: Local Variable

- Consider the two files: main.c and swap.c:

main.c

```
int buf[2] = {1,2};

int main()
{
  swap();
  return 0;
}
```

swap.c

Local variable

```
extern int buf[];

void swap()
{
  int temp;

  temp = buf[1];
  buf[1] = buf[0];
  buf[0] = temp;
}
```

Example: Define Global Variable

- Consider the two files: main.c and swap.c:

main.c

```
int buf[2] = {1,2};

int main()
{
  swap();
  return 0;
}
```

Global variable declared

swap.c

```
extern int buf[];

void swap()
{
  int temp;

  temp = buf[1];
  buf[1] = buf[0];
  buf[0] = temp;
}
```

Example: Use of Global Variable

- Consider the two files: main.c and swap.c:

main.c

```
int buf[2] = {1,2};

int main()
{
  swap();
  return 0;
}
```

swap.c

```
extern int buf[];

void swap()
{
  int temp;

  temp = buf[1];
  buf[1] = buf[0];
  buf[0] = temp;
}
```

Global variable referenced

Example: Define Function

- Consider the two files: main.c and swap.c:

main.c

```
int buf[2] = {1,2};

int main()
{
  swap();
  return 0;
}
```

swap.c

```
extern int buf[];

void swap()
{
  int temp;

  temp = buf[1];
  buf[1] = buf[0];
  buf[0] = temp;
}
```

External function defined

Example: Use External Function

- Consider the two files: main.c and swap.c:

main.c

```
int buf[2] = {1,2};

int main()
{
  swap();
  return 0;
}
```

swap.c

```
extern int buf[];

void swap()
{
  int temp;

  temp = buf[1];
  buf[1] = buf[0];
  buf[0] = temp;
}
```

External function used

.o files

main.o

.text section

code for main()

.data section

buf[]

symbol table

name	section	off
main	.text	0
buf	.data	0
swap	undefined	

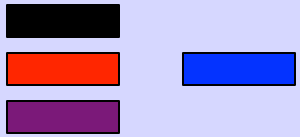
relocation info for .text

name	offset
swap	12

swap.o

.text section

code for swap()

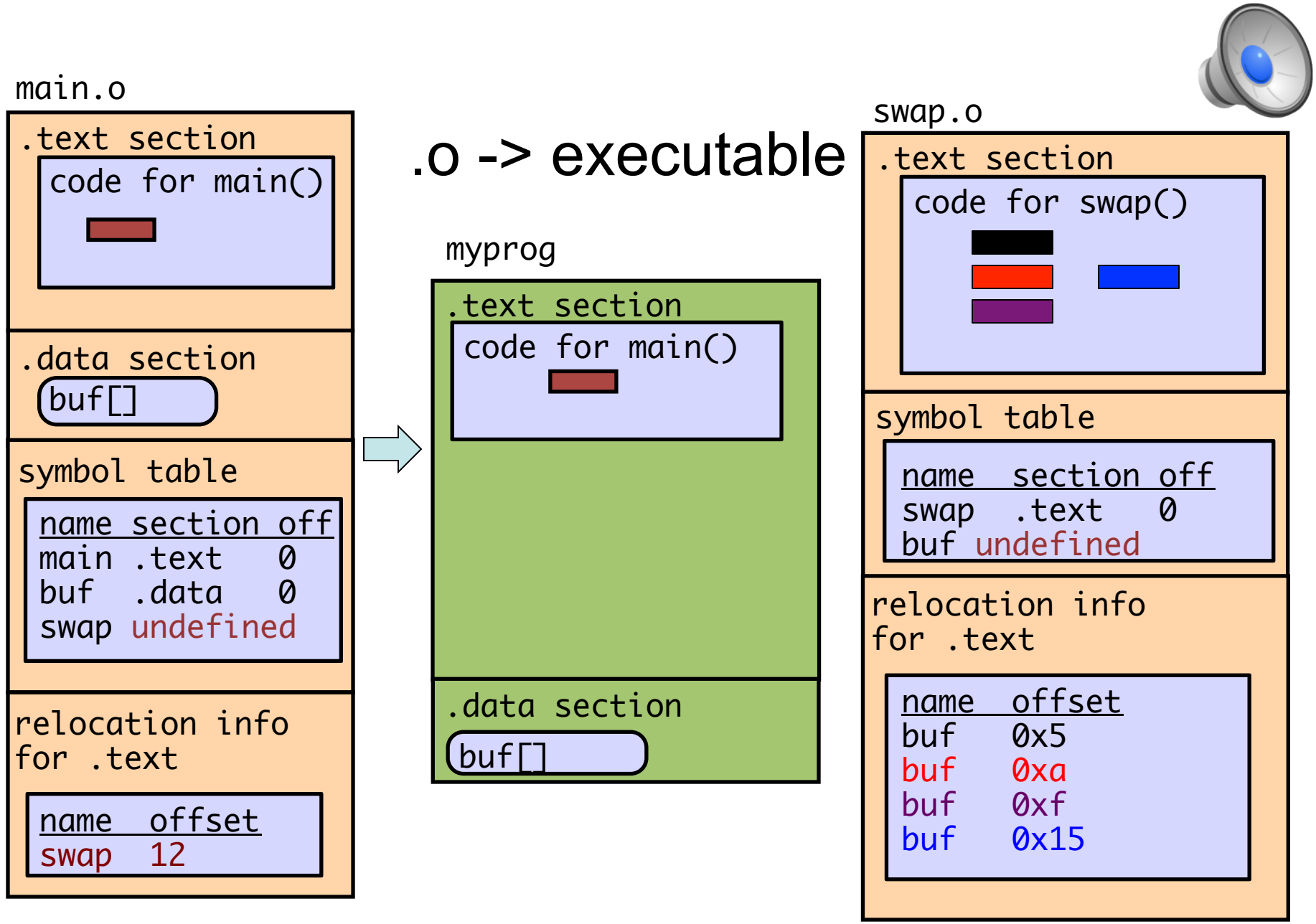


symbol table

name	section	off
swap	.text	0
buf	undefined	

relocation info for .text

name	offset
buf	0x5
buf	0xa
buf	0xf
buf	0x15


main.o
.text section
code for main()
.data section
buf[]
symbol table
name section off
main .text 0
buf .data 0
swap undefined
relocation info
for .text
name offset
swap 12
.o -> executable
myprog
.text section
code for main()
.data section
buf[]
swap.o
.text section
code for swap()
symbol table
name section off
swap .text 0
buf undefined
relocation info
for .text
name offset
buf 0x5
buf 0xa
buf 0xf
buf 0x15

.o -> executable

main.o

.text section

code for main()

.data section

buf[]

symbol table

name	section	off
main	.text	0
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myprog

.text section

code for main()

code for swap()

.data section

buf[]

swap.o

.text section

code for swap()

symbol table

name	section	off
swap	.text	0
buf	undefined	

relocation info for .text

name	offset
buf	0x5
buf	0xa
buf	0xf
buf	0x15

Can now resolve references to buf

.o -> executable

main.o

.text section

code for main()

.data section

buf[]

symbol table

name	section	off
main	.text	0
buf	.data	0
swap	undefined	

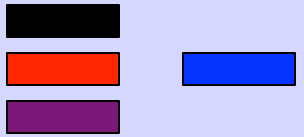
relocation info for .text

name	offset
swap	12

swap.o

.text section

code for swap()



symbol table

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swap	.text	0
buf	undefined	

relocation info for .text

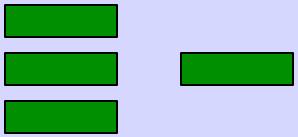
name	offset
buf	0x5
buf	0xa
buf	0xf
buf	0x15

myprog

.text section

code for main()

code for swap()



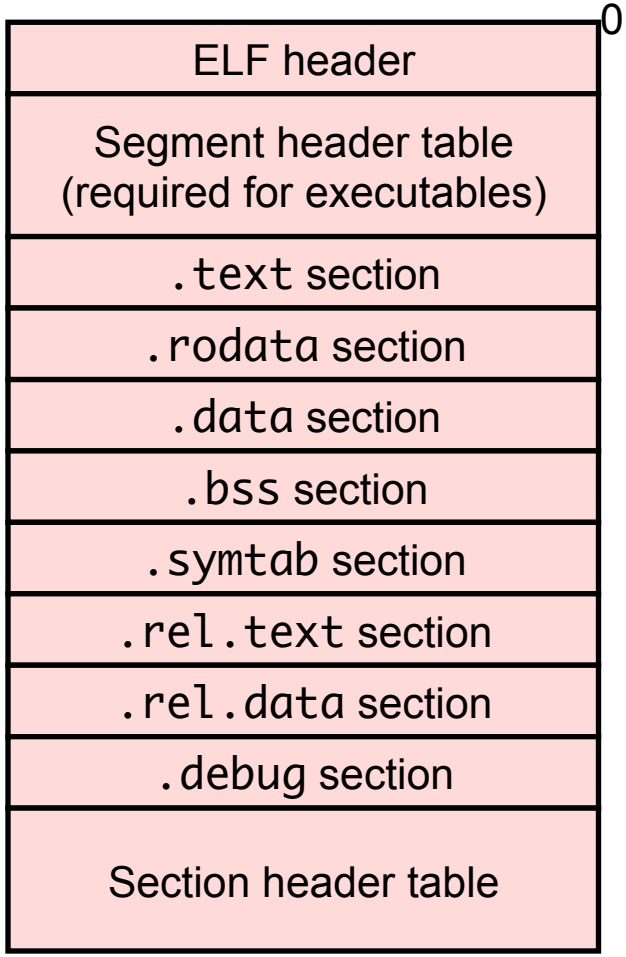
.data section

buf[]

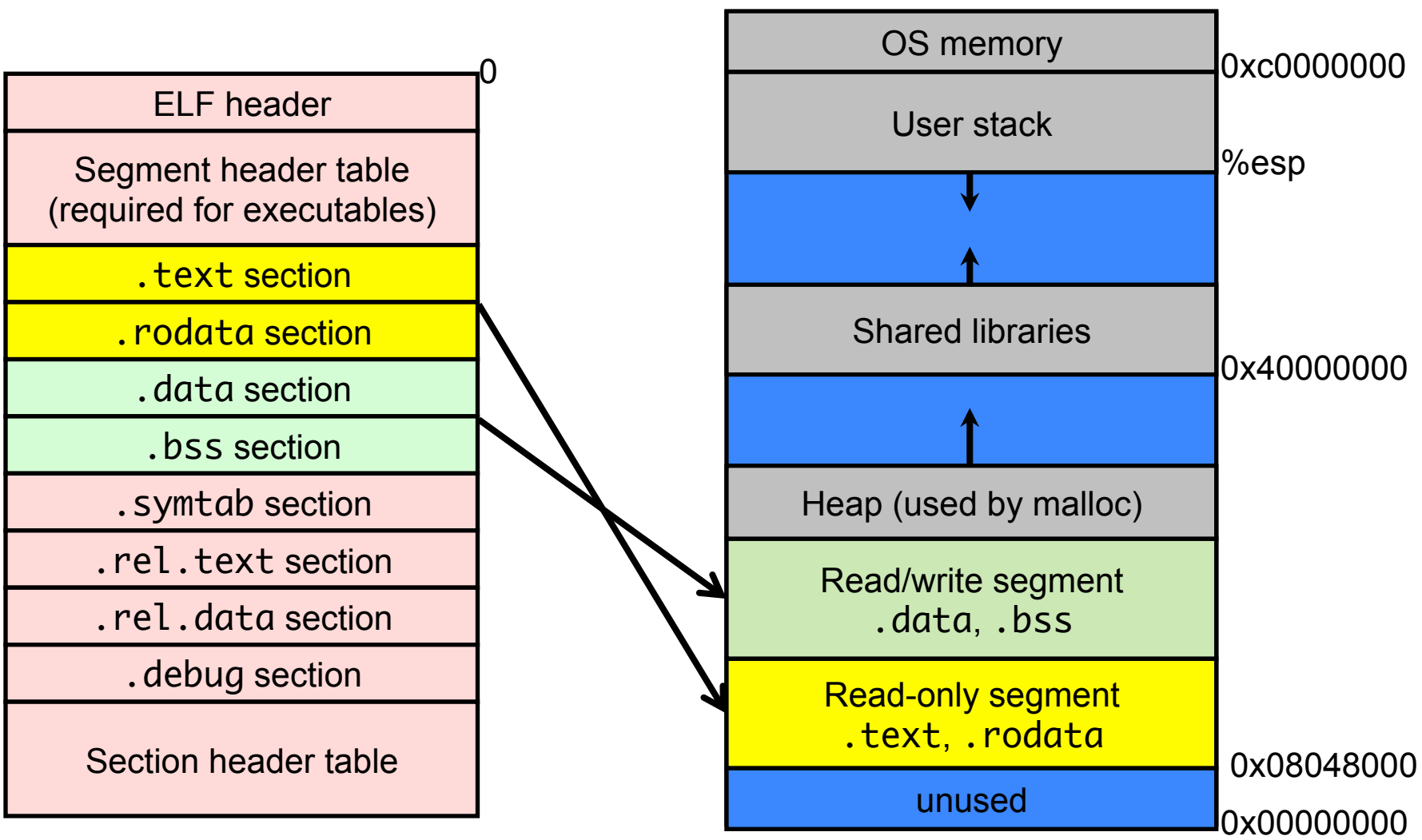
Can also resolve reference to swap

ELF: Executable and Linking Format

- A single format to represent object files, shared libraries (.so), and executables.
- Header: magic number, type, etc.
- Segment header: maps segments in file to (runtime) segments in memory.
- Text section: code
- Rodata: Read-only data
- Bss: Unitialized global variables
- Symtab: Symbol Table
- Rel.Text: Relocation for text
- Rel.Data: Relocation for data
- Debug: Debugging info (gcc –g)
- Section header table: offsets and sizes of each section



From ELF to Process



Populating the Address Space

- Until you have virtual memory, you will need to copy all the code and data from the executable into the address space.
- The heap and stack are not present in the executable, so what do you do?
  - When you need pages in the heap or stack, you produce zero-filled pages.