CS429: Computer Organization and Architecture

Linking I

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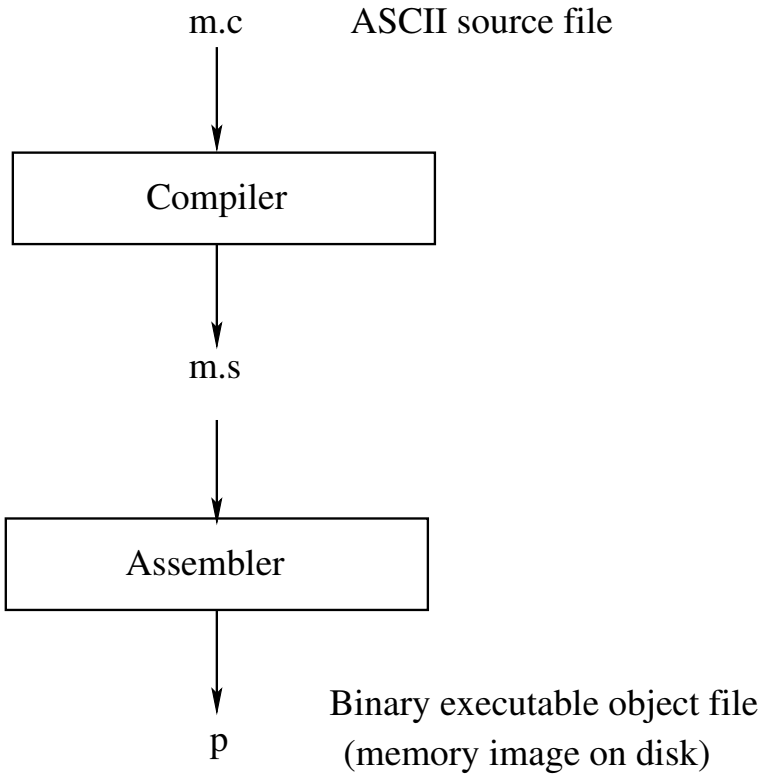
A Simplistic Translation Scheme

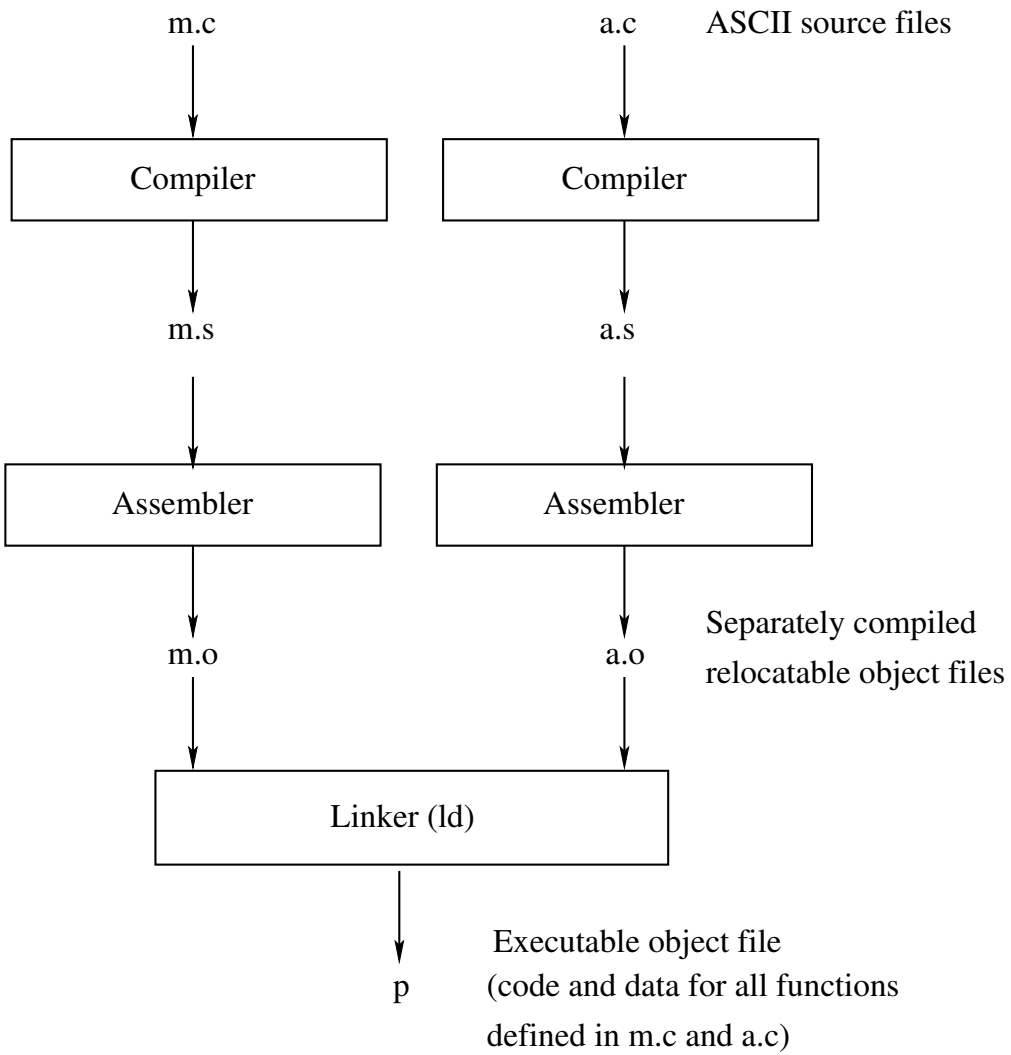


Problems:

- *Efficiency:* small change requires complete re-compilation.
- *Modularity:* hard to share common functions (e.g., printf).

Solution: Static linker (or linker).

Better Scheme Using a Linker



Linking is the process of combining various pieces of code and data into a single file that can be *loaded* (copied) into memory and executed.

Linking could happen at:

- compile time;
- load time;
- run time.

Must somehow tell a module about symbols from other modules.

Linking

A *linker* takes representations of separate program modules and combines them into a single *executable*.

This involves two primary steps:

1. *Symbol resolution:* associate each symbol reference throughout the set of modules with a single symbol definition.
2. *Relocation:* associate a memory location with each symbol definition, and modify each reference to point to that location.

Translating the Example Program

Compiler driver coordinates all steps in the translation and linking process.

- Typically included with each compilation system (e.g., gcc).
- Invokes the preprocessor (cpp), compiler (cc1), assembler (as), and linker (ld).
- Passes command line arguments to the appropriate phases

Example: Create an executable p from m.c and a.c:

```
> gcc -O2 -v -o p m.c a.c
cpp [args] m.c /tmp/cca07630.i
cc1 /tmp/cca07630.i m.c -O2 [args] -o /tmp/cca07630.s
as [args] -o /tmp/cca076301.o /tmp/cca07630.s
<similar process for a.c>
ld -o p [system obj files] /tmp/cca076301.o /tmp/
    cca076302.o
>
```

Compiling/Assembling

C Code

```
double sum(int val) {
  int sum = 0;
  double pi = 3.14;
  int i;

  for(i=3; i<=val; i++)
     sum += i;
  return sum + pi;
}
```

Obtain with command:

```
gcc -O -S sum.c
```

Produces file `code.s`

```
sum:
        pushl   %ebp
        movl    %esp, %ebp
        movl    8(%ebp), %ecx
        movl    $0, %edx
        cmpl    $2, %ecx
        jle     .L4
        movl    $0, %edx
        movl    $3, %eax
.L5:
        addl    %eax, %edx
        addl    $1, %eax
        cmpl    %eax, %ecx
        jge     .L5
.L4:
        pushl   %edx
        fildl   (%esp)
        leal    4(%esp), %esp
        faddl   .LC0
        popl    %ebp
        ret
.LC0:
        .long   1374389535
        .long   1074339512
```

Role of the Assembler

- Translate assembly code (compiled or hand generated) into machine code.
- Translate data into binary code (using directives).
- Resolve symbols—translate into relocatable offsets.
- Error checking:
  - Syntax checking;
  - Ensure that constants are not too large for fields.

Where Did the Labels Go?

Disassembled Object Code

```
08048334 <sum>:
 8048334:     55                          push   %ebp
 8048335:     89 e5                       mov    %esp, %ebp
 8048337:     8b 4d 08                    mov    8(%ebp), %ecx
 804833a:     ba 00 00 00 00              mov    $0x0, %edx
 804833f:     83 f9 02                    cmp    $0x2, %ecx
 8048342:     7e 13                       jle    8048357 <sum+0x23>
 8048344:     ba 00 00 00 00              mov    $0x0, %edx
 8048349:     b8 03 00 00 00              mov    $0x3, %eax
 804834e:     01 c2                       add    %eax, %edx
 8048350:     83 c3 01                    add    $0x1, %eax
 8048353:     39 c1                       cmp    %eax, %ecx
 8048355:     7d f7                       jge    804834e <sum+0x1a>
 8048357:     52                          push   %edx
 8048358:     db 04 24                    fildl  (%esp)
 804835b:     8d 64 24 04                 lea    4(%esp), %esp
 804835f:     dc 05 50 84 04 08           faddl  0x8048450
 8048365:     5d                          pop    %ebp
 8048366:     c3                          ret
```

Label Resolution

Disassembled Object Code

```
8048342:    7e 13                   jle    8048357 <sum+0x23>
    ...
8048355:    7d f7                   jge    804834e <sum+0x1a>
    ...
804835f:    dc 05 50 84 04 08       faddl  0x8048450
```

Byte relative offsets for jle and jge:

- jge: 13 bytes forward
- jge: 9 bytes backward (two's complement of 0xf7)

Relocatable absolute address:

- faddl: 0x8048450

How Does the Assembler Work?

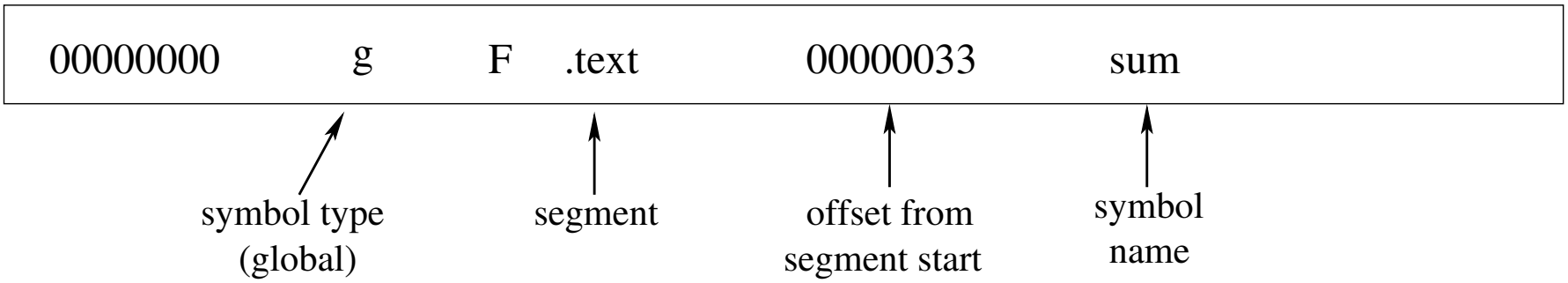
One Pass

- Record label definitions
- When use is found, compute offset

Two Pass

- Pass 1: scan for label instantiations—creates symbol table
- Pass 2: compute offsets from label use/def
- Can detect if computed offset is too large for assembly instruction.

Symbol Table



The symbol table tracks the location of symbols in the object file.

- Symbols that can be resolved need not be included.
- Symbols that may be needed during linking must be included.

What Does a Linker Do?

Merges object files

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

Resolves external references

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

Relocates 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.
- References can be in either code or data:
  - code: `a();` `/* reference to symbol a */`
  - data: `*xp = &x;` `/* reference to symbol x */`

Why Linkers?

Modularity

- Programs can be written as a collection of smaller source files, rather than one monolithic mass.
- Can build libraries of common functions shared by multiple programs (e.g., math library, standard C library)

Efficiency

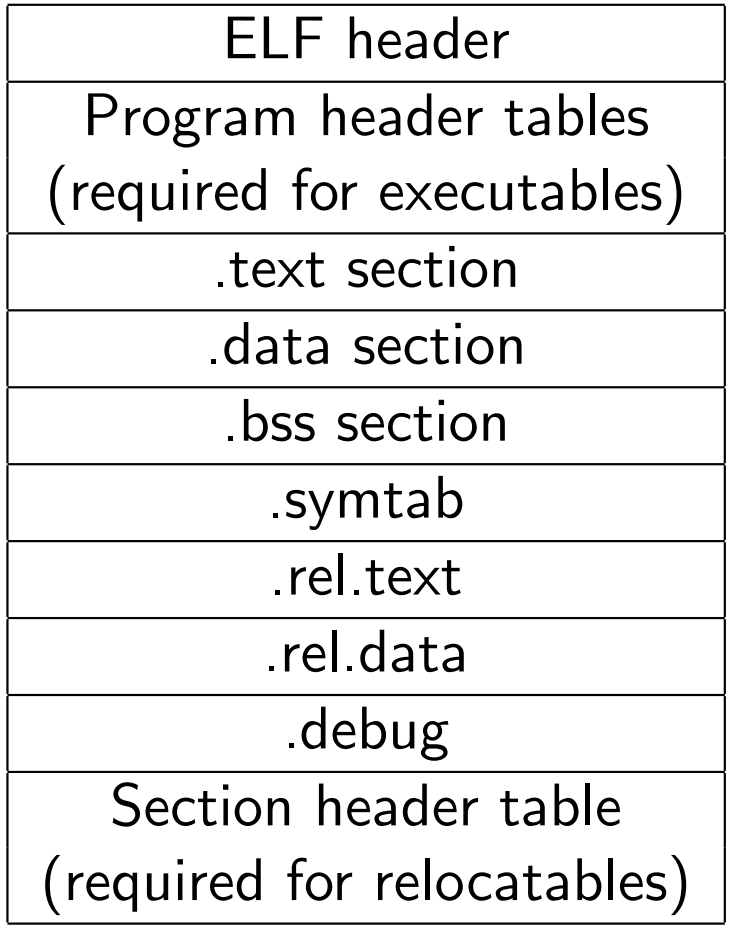
- Time:
  - Change one source file, recompile, and then relink.
  - No need to recompile other source files.
- Space:
  - Libraries of common functions can be aggregated into a single file.
  - Yet executable files and running machine images contain only code for the functions they actually use.

Executable and Linkable Format (ELF)

- Standard binary format for object files.
- Derives from AT&T System V Unix, and later adopted by BSD Unix variants and Linux.
- One unified format for:
  - Relocatable object files (.o),
  - Executable object files,
  - Shared object files (.so).
- The generic name is *ELF binaries*.
- Better support for shared libraries than the old a.out formats.

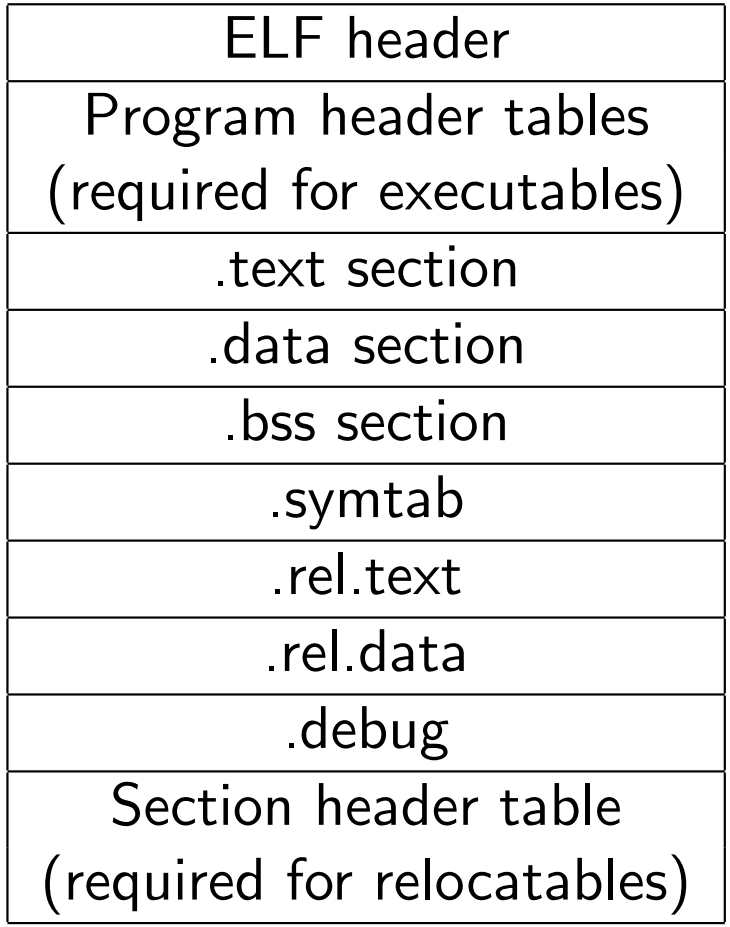
ELF Object File Format

- ELF header: magic number, type (.o, exec, .so), machine, byte ordering, etc.
- Program header table: page size, virtual addresses of 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 (continued)

- `.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 needing modification in the merged executable
- `.debug` section
  - Info for symbolic debugging (`gcc -g`)



Example C Program

m.c

```
int e = 7;

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

a.c

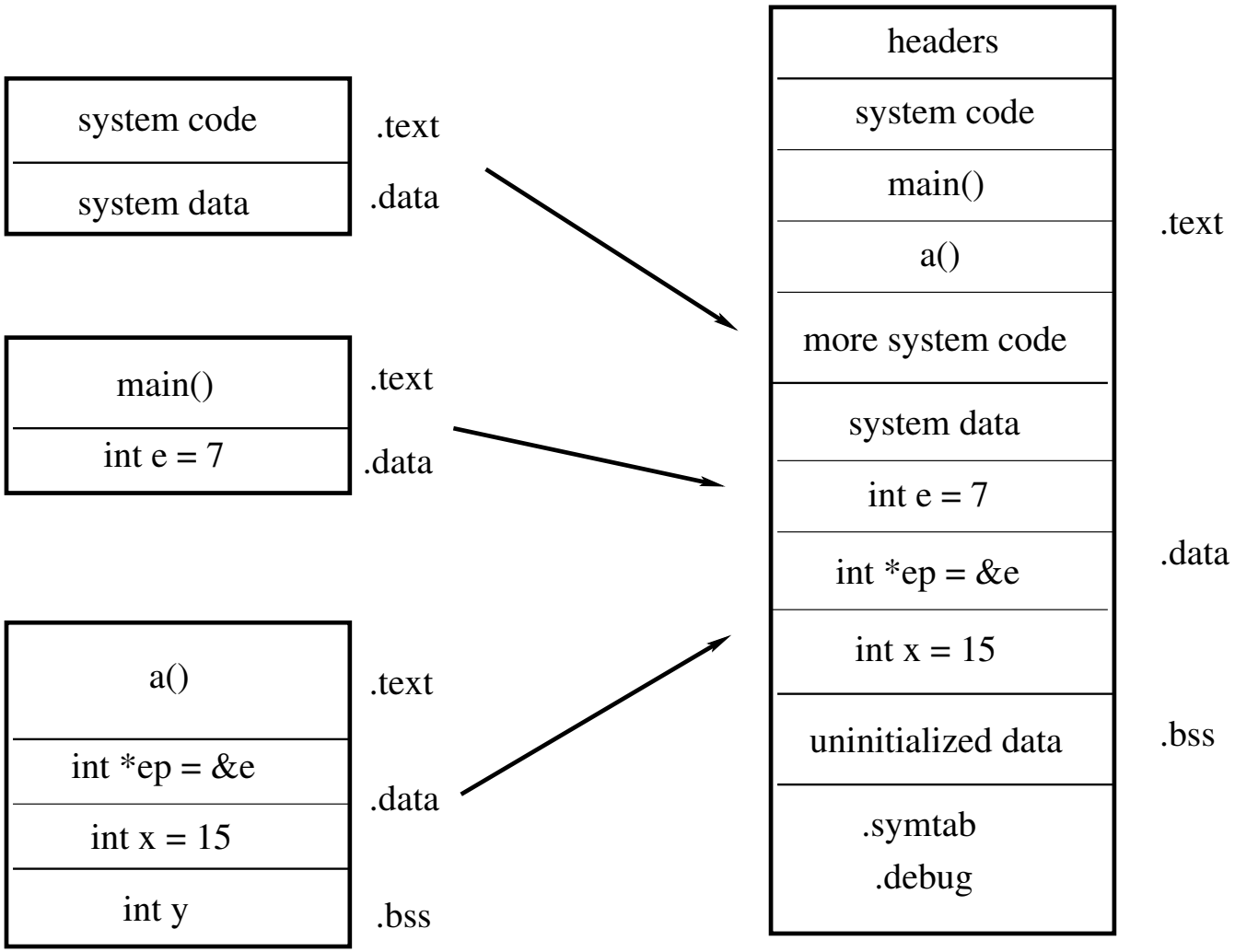
```
extern int e;

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

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

Merging Relocatable Object Files

Relocatable object files are merged into an executable by the Linker. Both are in ELF format.



Summary

This slideset:

- Compilation / Assembly / Linking
- Symbol resolution and symbol tables

Next time:

- Code and data relocation
- Loading
- Libraries
- Dynamically linked libraries