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CS61C : Machine Structures

Lecture 18 – Running a Program I
aka Compiling, Assembling, Linking, Loading (CALL)

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Cloak of invisibility?! ⇒

Researchers at U Penn have discovered a type of “invisibility shielding” to camouflage an object with a “plasmonic” screen that suppresses scattering of single-λ light. Star Trek?

www.nature.com/news/2005/050228/full/050228-1.html

Overview

- Interpretation vs Translation
- Translating C Programs
  - Compiler
  - Assembler
  - Linker (next time)
  - Loader (next time)
- An Example (next time)

Language Continuum

Scheme

Java

C++ C Assembly machine language

Java bytecode

Easy to program

Inefficient to interpret

Efficient

Difficult to program

- In general, we interpret a high level language if efficiency is not critical or translated to a lower level language to improve performance

Interpretation vs Translation

- How do we run a program written in a source language?
- Interpreter: Directly executes a program in the source language
- Translator: Converts a program from the source language to an equivalent program in another language
- For example, consider a Scheme program `foo.scm`

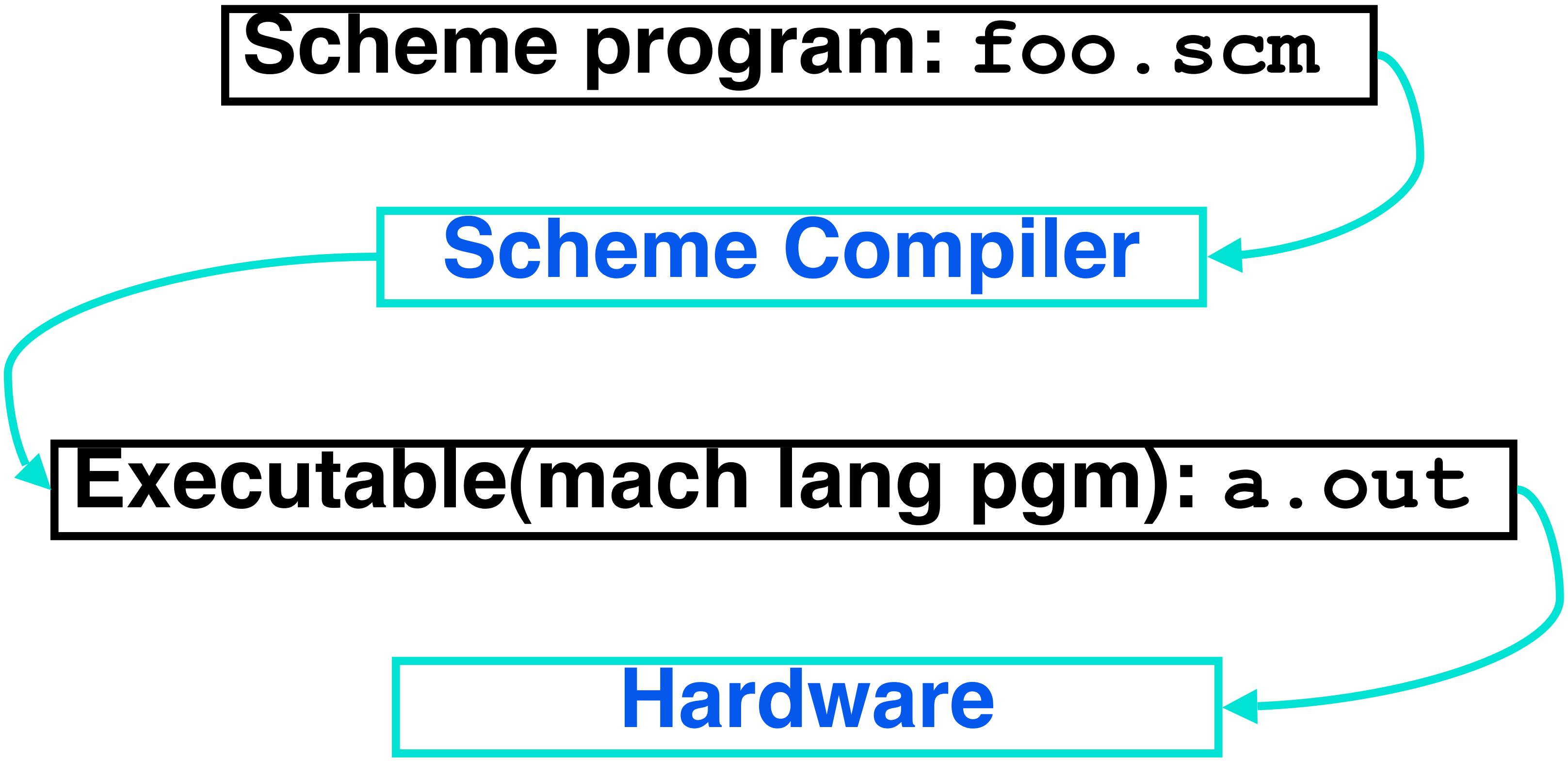
Interpretation

Scheme program: `foo.scm`

↓

Scheme Interpreter

Translation



- Scheme Compiler is a translator from Scheme to machine language.

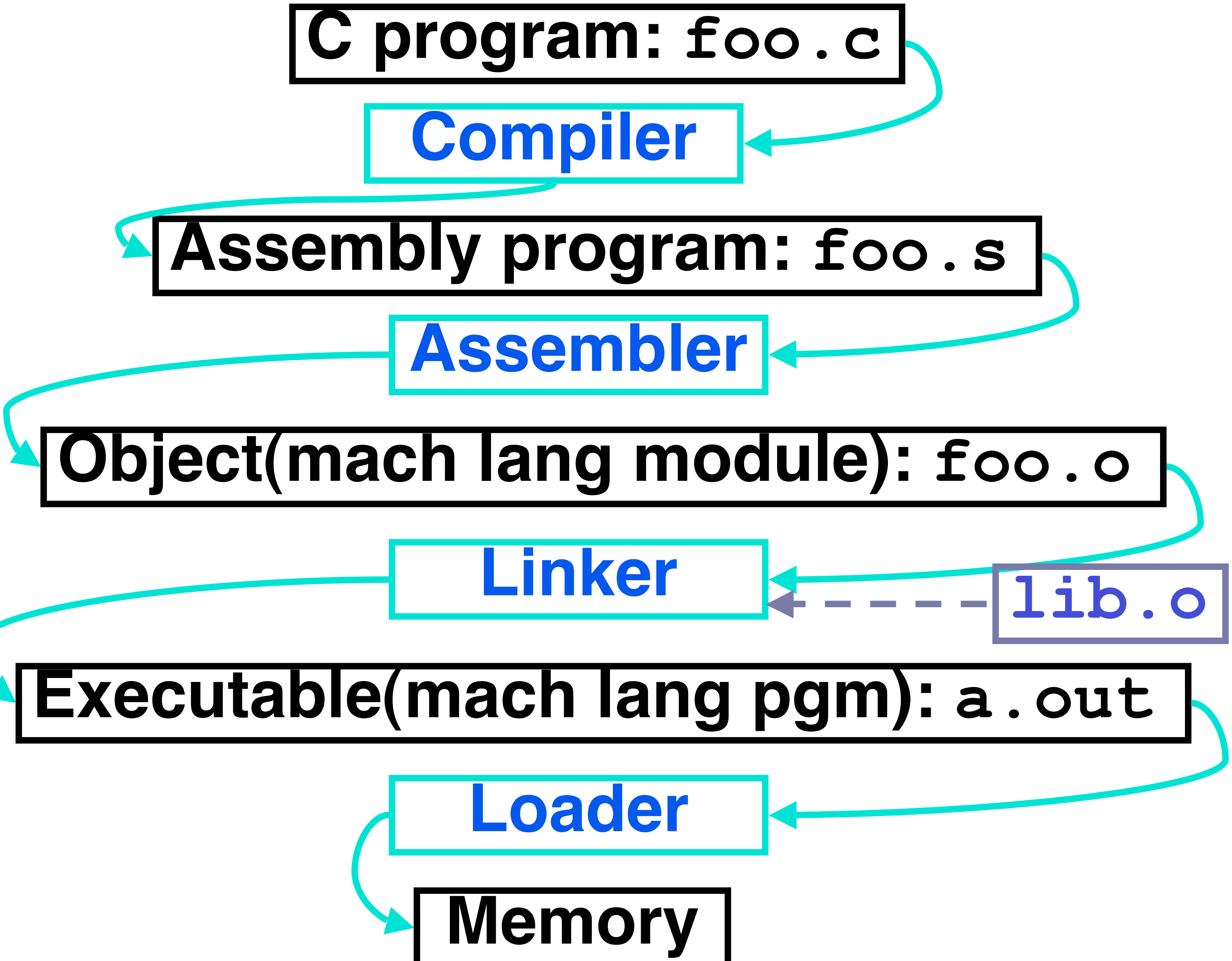
Interpretation

- Any good reason to interpret machine language in software?
- SPIM – useful for learning / debugging
- Apple Macintosh conversion
  - Switched from Motorola 680x0 instruction architecture to PowerPC.
  - Could require all programs to be re-translated from high level language
  - Instead, let executables contain old and/or new machine code, interpret old code in software if necessary

Interpretation vs. Translation?

- Easier to write interpreter
- Interpreter closer to high-level, so gives better error messages (e.g., SPIM)
  - Translator reaction: add extra information to help debugging (line numbers, names)
- Interpreter slower (10x?) but code is smaller (1.5X to 2X?)
- Interpreter provides instruction set independence: run on any machine
  - Apple switched to PowerPC. Instead of retranslating all SW, let executables contain old and/or new machine code, interpret old code in software if necessary

Steps to Starting a Program



Compiler

- **Input: High-Level Language Code (e.g., C, Java such as `foo.c`)**
- **Output: Assembly Language Code (e.g., `foo.s` for MIPS)**
- **Note: Output *may* contain pseudoinstructions**
- **<u>Pseudoinstructions</u>: instructions that assembler understands but not in machine (last lecture) For example:**
- `mov $s1,$s2` ⇒ `or $s1,$s2,$zero`

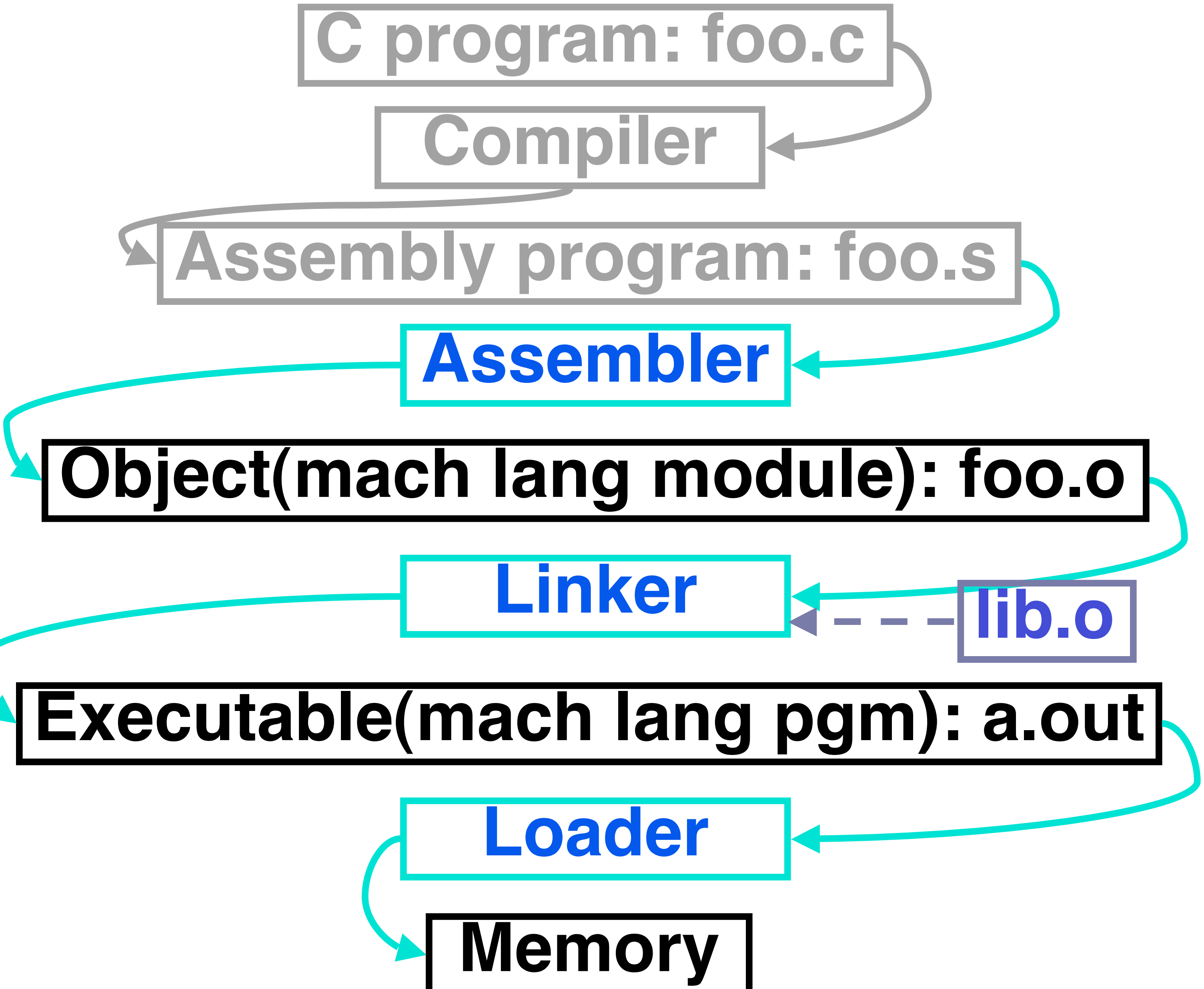
Upcoming Calendar

Week #	Mon	Wed	Thurs Lab	Fri
#7 This week	MIPS III	Running Program I	Running Program	Running Program II
#8 Midterm week (review Sun @ 2pm 10 Evans)	Intro to SDS I Midterm @ 7pm 1 Le Conte	Intro to SDS II	SDS	Intro to SDS III Midterm grades out

Administrivia…Midterm in 5 days!

- 2005-03-07 @ 7-10pm in 1 Piminitel
- Covers labs,hw,proj,lec up to SDS
- Last sem midterm + answers on www
- Bring…
  - NO backpacks, cells, calculators, pagers, PDAs
  - 2 Pens (we'll provide write-in exam booklets)
  - One handwritten (both sides) 8.5"x11" paper
  - One green sheet (corrections below to bugs from "Core Instruction Set")
    1) Opcode wrong for Load Word.
       It should say 23hex, not 0 / 23hex.
    2) `sll` and `srl` should shift values in `R[rt]`, not `R[rs]`
       i.e. `sll`/`srl`: `R[rd] = R[rt] << shamt`

Where Are We Now?



Assembler

- Input: Assembly Language Code (e.g., `foo.s` for MIPS)
- Output: Object Code, information tables (e.g., `foo.o` for MIPS)
- Reads and Uses Directives
- Replace Pseudoinstructions
- Produce Machine Language
- Creates Object File

Assembler Directives (p. A-51 to A-53)

- **Give directions to assembler, but do not produce machine instructions**
  - `.text`: **Subsequent items put in user text segment (machine code)**
  - `.data`: **Subsequent items put in user data segment (binary rep of data in source file)**
  - `.globl sym`: **declares `sym` global and can be referenced from other files**
  - `.asciiz str`: **Store the string `str` in memory and null-terminate it**
  - `.word w1…wn`: **Store the *n* 32-bit quantities in successive memory words**

Pseudoinstruction Replacement

- **Asm. treats convenient variations of machine language instructions as if real instructions**

Pseudo:	Real:
`subu $sp,$sp,32`	`addiu $sp,$sp,-32`
`sd $a0, 32($sp)`	`sw $a0, 32($sp)` `sw $a1, 36($sp)`
`mul $t7,$t6,$t5`	`mul $t6,$t5` `mflo $t7`
`addu $t0,$t6,1`	`addiu $t0,$t6,1`
`ble $t0,100,loop`	`slti $at,$t0,101` `bne $at,$0,loop`
`la $a0, str`	`lui $at,left(str)` `ori $a0,$at,right(str)`

Producing Machine Language (1/2)

- Simple Case
  - Arithmetic, Logical, Shifts, and so on.
  - All necessary info is within the instruction already.
- What about Branches?
  - PC-Relative
  - So once pseudoinstructions are replaced by real ones, we know by how many instructions to branch.
- So these can be handled easily.

Producing Machine Language (2/2)

- What about jumps (`j` and `jal`)?
  - Jumps require absolute address.
- What about references to data?
  - `la` gets broken up into `lui` and `ori`
  - These will require the full 32-bit address of the data.
- These can't be determined yet, so we create two tables…

Symbol Table

- List of "items" in this file that may be used by other files.
- What are they?
  - Labels: function calling
  - Data: anything in the `.data` section; variables which may be accessed across files
- First Pass: record label-address pairs
- Second Pass: produce machine code
  - Result: can jump to a later label without first declaring it

Relocation Table

- List of “items” for which this file needs the address.
- What are they?
  - Any label jumped to: `j` or `jal`
    - internal
    - external (including lib files)
  - Any piece of data
    - such as the `la` instruction

Object File Format

- <u>object file header</u>: size and position of the other pieces of the object file
- <u>text segment</u>: the machine code
- <u>data segment</u>: binary representation of the data in the source file
- <u>relocation information</u>: identifies lines of code that need to be "handled"
- <u>symbol table</u>: list of this file's labels and data that can be referenced
- <u>debugging information</u>

Peer Instruction

1. Assembler knows where a module's data & instructions are in relation to other modules.
2. Assembler will ignore the instruction `Loop:nop` because it does nothing.
3. Java designers used an interpreter (rather than a translater) mainly because of (at least one of): ease of writing, better error msgs, smaller object code.

	ABC
1:	FFF
2:	FFT
3:	FTF
4:	FTT
5:	TFF
6:	TFT
7:	TTF
8:	TTT

Peer Instruction Answer

smaller object code.

And in conclusion…