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CS61C : Machine Structures

Lecture #12 – MIPS Instruction Rep III, Running a Program I

aka Compiling, Assembling, Linking, Loading (CALL)

2005-0xA

There is one handout today at the front and back of the room!

Lecturer PSOE, new dad Dan Garcia

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SF: Tiger over Daly ⇒

In a treat for the Bay Area, the top golfers descended to Harding Park in SF and saw a treat: the two longest hitters battled in a playoff before Daly "choked".

sports.espn.go.com/golf/news/story?id=2185968

Review

- Reserve exponents, significands:

Exponent	Significand	Object
0	0	0
0	nonzero	Denorm
1-254	anything	+/- fl. pt. #
255	0	+/- ∞
255	nonzero	NaN

- Integer `mult`, `div` uses `hi`, `lo` regs
  - `mfhi` and `mflo` copies out.
- Four rounding modes (to even default)
- MIPS FL ops complicated, expensive

Clarification - IEEE Four Rounding Modes

- We gave examples in base 10 to show you the 4 modes (only apply to $.5_{10}$)
- What really happens is…

1) in binary, not decimal!
2) at the lowest bit of the mantissa with the guard bit(s) as our extra bit(s), and you need to decide how these extra bit(s) affect the result if the guard bits are "100…"
3) If so, you're half-way between the representable numbers.

E.g., 0.1010 is 5/8, halfway between our representable 4/8 [1/2] and 6/8 [3/4]. Which number do we round to? 4 modes!

Decoding Machine Language

- How do we convert 1s and 0s to C code?

  Machine language ⇒ C?

- For each 32 bits:
  - Look at `opcode`: 0 means R-Format, 2 or 3 mean J-Format, otherwise I-Format.
  - Use instruction type to determine which fields exist.
  - Write out MIPS assembly code, converting each field to name, register number/name, or decimal/hex number.
  - Logically convert this MIPS code into valid C code. Always possible? Unique?

Decoding Example (1/7)

- Here are six machine language instructions in hexadecimal:

  00001025_{hex}
  $0005402A_{hex}$
  11000003_{hex}
  00441020_{hex}
  $20A5FFFF_{hex}$
  08100001_{hex}

- Let the first instruction be at address $4{,}194{,}304_{ten}$ ($0x00400000_{hex}$).
- Next step: convert hex to binary

Decoding Example (2/7)

- **The six machine language instructions in binary:**

```
00000000000000000001000000100101
00000000000001010100000000101010
00010001000000000000000000000011
00000000010001000001000000100000
00100000101001011111111111111111
00001000000100000000000000000001
```

- **Next step: identify opcode and format**

R	0	rs	rt	rd	shamt	funct
I	1, 4-31	rs	rt	immediate		
J	2 or 3	target address				

Decoding Example (3/7)

- Select the opcode (first 6 bits) to determine the format:

Format:

```
R   00000000000000000001000000100101
R   00000000000001010100000000101010
I   00010001000000000000000000000011
R   00000000010001000001000000100000
I   00100000101001011111111111111111
J   00001000000100000000000000000001
```

- Look at opcode: 0 means R-Format, 2 or 3 mean J-Format, otherwise I-Format.

- Next step: separation of fields

Decoding Example (4/7)

- Fields separated based on format/opcode:

Format:

R	0	0	0	2	0	37
R	0	0	5	8	0	42
I	4	8	0	+3		
R	0	2	4	2	0	32
I	8	5	5	-1		
J	2	1,048,577				

- Next step: translate ("disassemble") to MIPS assembly instructions

Decoding Example (5/7)

- **MIPS Assembly (Part 1):**

Address:	Assembly instructions:	
`0x00400000`	`or`	`$2,$0,$0`
`0x00400004`	`slt`	`$8,$0,$5`
`0x00400008`	`beq`	`$8,$0,3`
`0x0040000c`	`add`	`$2,$2,$4`
`0x00400010`	`addi`	`$5,$5,-1`
`0x00400014`	`j`	`0x100001`

- **Better solution: translate to more meaningful MIPS instructions (fix the branch/jump and add labels, registers)**

Decoding Example (6/7)

- MIPS Assembly (Part 2):

```
        or    $v0,$0,$0
Loop:   slt   $t0,$0,$a1
        beq   $t0,$0,Exit
        add   $v0,$v0,$a0
        addi  $a1,$a1,-1
        j     Loop
Exit:
```

- Next step: translate to C code (be creative!)

Decoding Example (7/7)

Before Hex:

00001025_{hex}
$0005402A_{hex}$
11000003_{hex}
00441020_{hex}
$20A5FFFF_{hex}$
08100001_{hex}

- **After C code (Mapping below)**

  `$v0`: product
  `$a0`: multiplicand
  `$a1`: multiplier

```
product = 0;
while (multiplier > 0) {
    product += multiplicand;
    multiplier -= 1;
}
```

```
      or   $v0,$0,$0
Loop: slt  $t0,$0,$a1
      beq  $t0,$0,Exit
      add  $v0,$v0,$a0
      addi $a1,$a1,-1
      j    Loop
Exit:
```

Demonstrated Big 61C Idea: Instructions are just numbers, code is treated like data

Administrivia…Midterm in 7 days!

- Project 2 due Wednesday (ok, Friday)
- Midterm 2005-10-17 @ 5:30-8:30pm Here!
- Covers labs,hw,proj,lec up through 7th wk
- Prev sem midterm + answers on HKN
- Bring…
  - NO backpacks, cells, calculators, pagers, PDAs
  - 2 writing implements (we'll provide write-in exam booklets) – pencils ok!
  - 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`

Review from before: `lui`

- So how does `lui` help us?
  - Example:

```
addi   $t0,$t0, 0xABABCDCD
```

becomes:

```
lui    $at, 0xABAB
ori    $at, $at, 0xCDCD
add    $t0,$t0,$at
```

  - Now each I-format instruction has only a 16-bit immediate.

- **Wouldn't it be nice if the assembler would this for us automatically?**
  - If number too big, then just automatically replace `addi` with `lui`, `ori`, `add`

True Assembly Language (1/3)

- <u>Pseudoinstruction</u>: A MIPS instruction that doesn't turn directly into a machine language instruction, but into other MIPS instrucitons
- What happens with pseudoinstructions?
  - They're broken up by the assembler into several "real" MIPS instructions.
  - But what is a "real" MIPS instruction? Answer in a few slides
- First some examples

Example Pseudoinstructions

- Register Move

```
move   reg2,reg1
```

Expands to:

```
add    reg2,$zero,reg1
```

- Load Immediate

```
li     reg,value
```

If value fits in 16 bits:

```
addi   reg,$zero,value
```

else:

```
lui    reg,upper 16 bits of value
ori    reg,$zero,lower 16 bits
```

True Assembly Language (2/3)

- Problem:
  - When breaking up a pseudoinstruction, the assembler may need to use an extra reg.
  - If it uses any regular register, it'll overwrite whatever the program has put into it.
- Solution:
  - Reserve a register (`$1`, called `$at` for "assembler temporary") that assembler will use to break up pseudo-instructions.
  - Since the assembler may use this at any time, it's not safe to code with it.

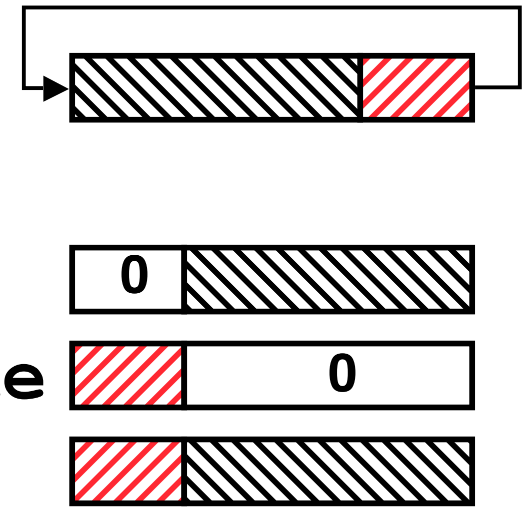
Example Pseudoinstructions

- Rotate Right Instruction

```
ror    reg, value
```

Expands to:

```
srl    $at, reg, value
sll    reg, reg, 32-value
or     reg, reg, $at
```



- "No OPeration" instruction

```
nop
```

Expands to instruction = 0_{ten},

```
sll    $0, $0, 0
```

Example Pseudoinstructions

- **Wrong operation for operand**

```
addu  reg,reg,value # should be addiu
```

If value fits in 16 bits, `addu` is changed to:

```
addiu reg,reg,value
```

else:

```
lui   $at,upper 16 bits of value
ori   $at,$at,lower 16 bits
addu  reg,reg,$at
```

- **How do we avoid confusion about whether we are talking about MIPS assembler with or without pseudoinstructions?**

True Assembly Language (3/3)

- **MAL** (MIPS Assembly Language): the set of instructions that a programmer may use to code in MIPS; this includes pseudoinstructions
- **TAL** (True Assembly Language): set of instructions that can actually get translated into a single machine language instruction (32-bit binary string)
- A program must be converted from MAL into TAL before translation into 1s & 0s.

Questions on Pseudoinstructions

- **Question:**
  - **How does MIPS recognize pseudo-instructions?**
- **Answer:**
  - **It looks for officially defined pseudo-instructions, such as `ror` and `move`**
  - **It looks for special cases where the operand is incorrect for the operation and tries to handle it gracefully**

Rewrite TAL as MAL

- TAL:

```
        or    $v0,$0,$0
Loop:   slt   $t0,$0,$a1
        beq   $t0,$0,Exit
        add   $v0,$v0,$a0
        addi  $a1,$a1,-1
        j     Loop
Exit:
```

- This time convert to MAL
- It's OK for this exercise to make up MAL instructions

Rewrite TAL as MAL (Answer)

- **TAL:**

```
        or    $v0,$0,$0
Loop:   slt   $t0,$0,$a1
        beq   $t0,$0,Exit
        add   $v0,$v0,$a0
        addi  $a1,$a1,-1
        j     Loop
Exit:
```

- **MAL:**

```
        li    $v0,0
Loop:   bge   $zero,$a1,Exit
        add   $v0,$v0,$a0
        decr  $a1, 1
        j     Loop
Exit:
```

Peer Instruction

1. Converting `float` -> `int` -> `float` produces same `float` number
2. Converting `int` -> `float` -> `int` produces same `int` number
3. FP `add` is associative: `(x+y)+z = x+(y+z)`

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

Peer Instruction Answer

Peer Instruction

Which of the instructions below are MAL and which are TAL?

```
A. addi $t0, $t1, 40000
B. beq  $s0, 10, Exit
C. sub  $t0, $t1, 1
```

	ABC
1:	MMM
2:	MMT
3:	MTM
4:	MTT
5:	TMM
6:	TMT
7:	TTM
8:	TTT

Peer Instruction Answer

;

Upcoming Calendar

Week #	Mon	Wed	Thurs Lab
#7 This week	MIPS III Running Program I	Running Program II	Running Program
#8 Midterm week (review Sun @ 2pm 10 Evans)	Midterm @ 5:30-8:30pm Here! (155 Dwin)	Intro to SDS I	SDS

In semi-conclusion…

- Disassembly is simple and starts by decoding `opcode` field.
  - Be creative, efficient when authoring C
- Assembler expands real instruction set (TAL) with pseudoinstructions (MAL)
  - Only TAL can be converted to raw binary
  - Assembler's job to do conversion
  - Assembler uses reserved register `$at`
  - MAL makes it <u>much</u> easier to write MIPS

Overview

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

Language Continuum

Scheme　　　　　　　　Java bytecode

Java

C++　　　C　　　Assembly　　　machine language

Easy to program ⟵⟶ Efficient

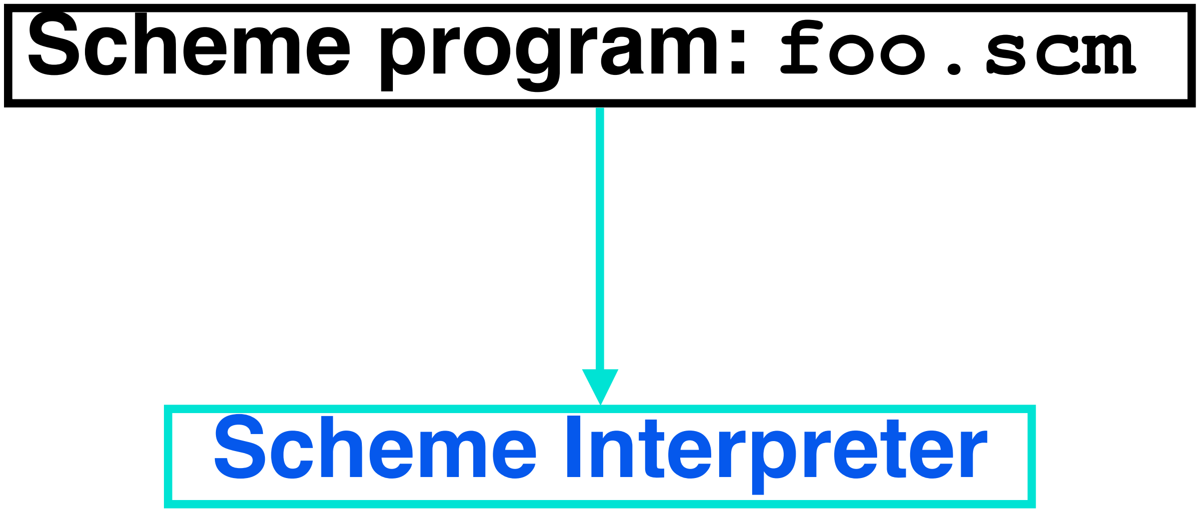
Inefficient to interpret　　　Difficult to program

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

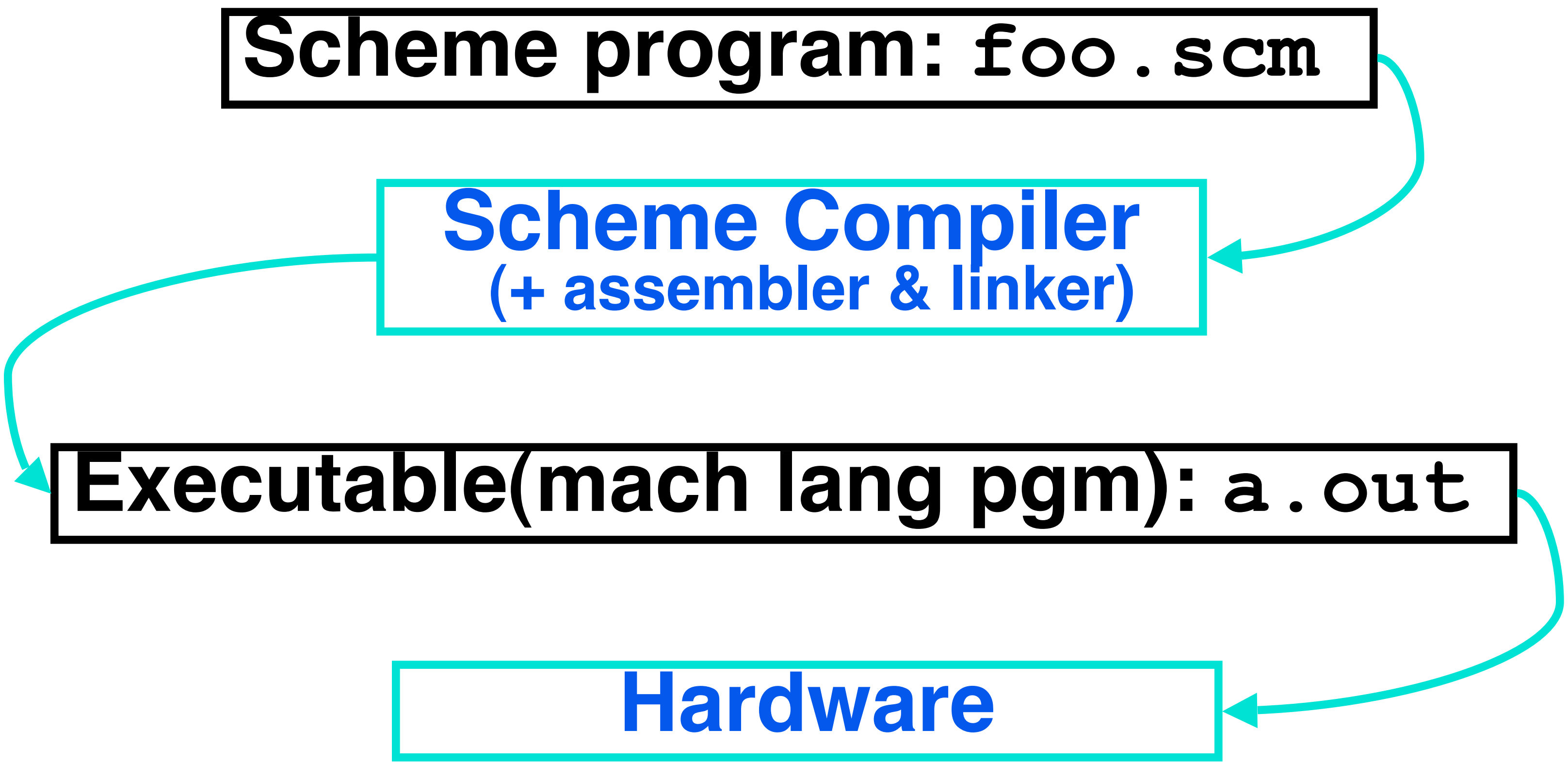
Interpretation vs Translation

- 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



Translation



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

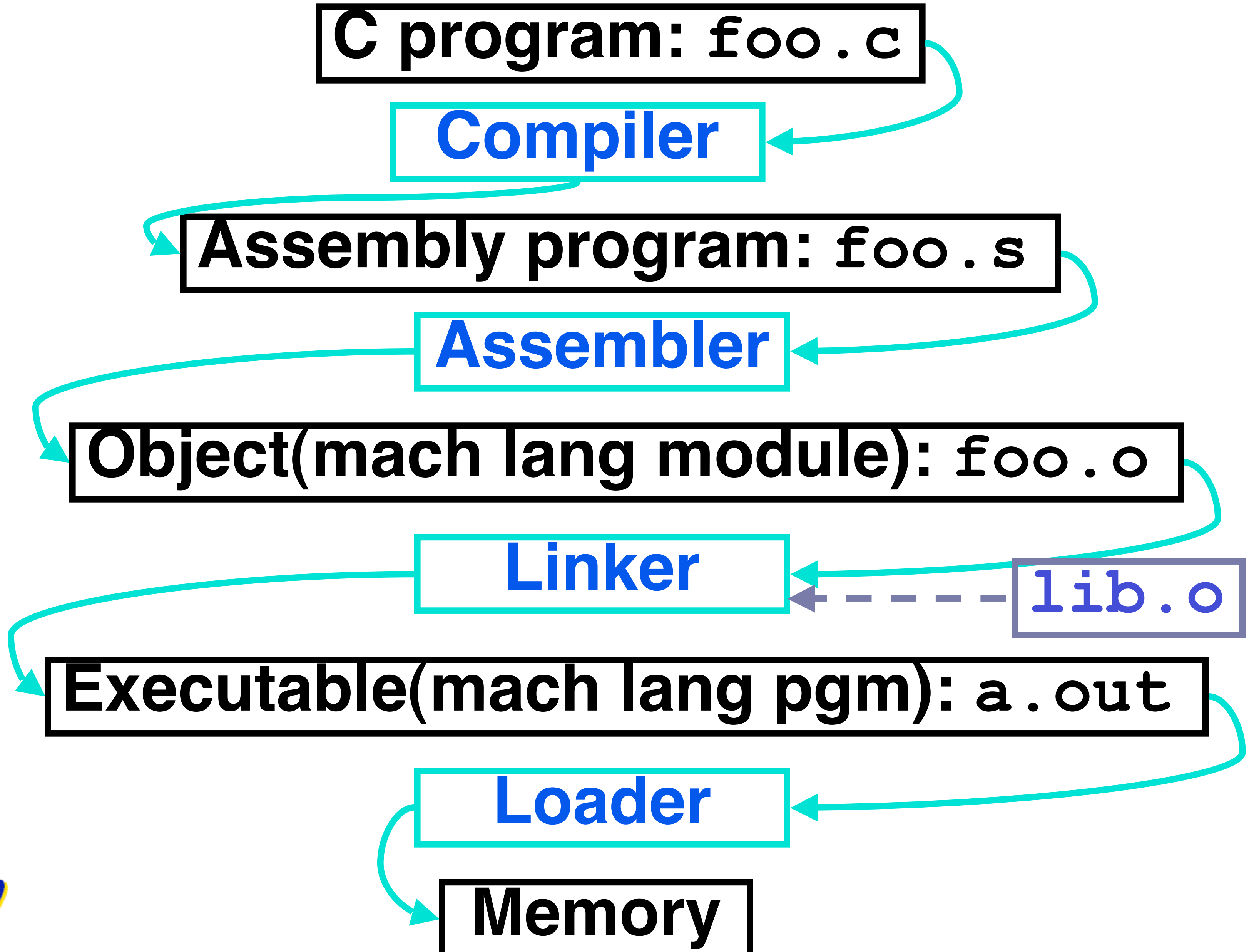
Interpretation

- 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
- Pseudoinstructions: instructions that assembler understands but not in machine. E.g.,
- `mov $s1,$s2` ⇒ `or $s1,$s2,$zero`

And in conclusion...