CS61C : Machine Structures

Lecture #12 – MIPS Instruction Rep III, Running a Program I
aka Compiling, Assembling, Linking, Loading (CALL)

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New Direction Service Announced

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Review of Floating Point

- 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 Unbiased Rounding

- Round to (nearest) even (default)
    - Normal rounding, almost: 2.5 ⇒ 2, 3.5 ⇒ 4
    - Insures fairness on calculation
    - Half the time we round up, other half down
    - Decimal gives a good initial intuition, but remember computers use binary
- Steps to Use it (in binary)
    - Determine place to be rounded to
    - Figure out the two possible outcomes (its binary so 1 or 0 in last place)
    - If one outcome is closer to current number than other, pick that outcome
    - If both outcomes are equidistant pick the outcome that ends in 0

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:

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 Friday @ 11:59pm
- Midterm 7/23 @ 7-10pm 60 Evans
- 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 (or copy of it)
- Review Session Friday @ …

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)

- Pseudoinstruction: A MIPS instruction that doesn't turn directly into a machine language instruction, but into other MIPS instructions
- 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:

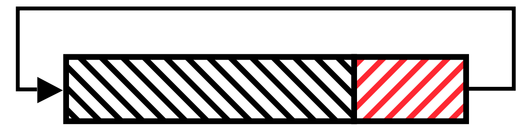
```
lui    reg,upper 16 bits of value
ori    reg,$zero,lower 16 bits
```

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

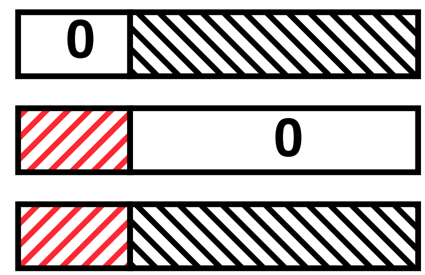
- Rotate Right Instruction



```
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

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

;

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
C++ C Assembly machine language
Java bytecode

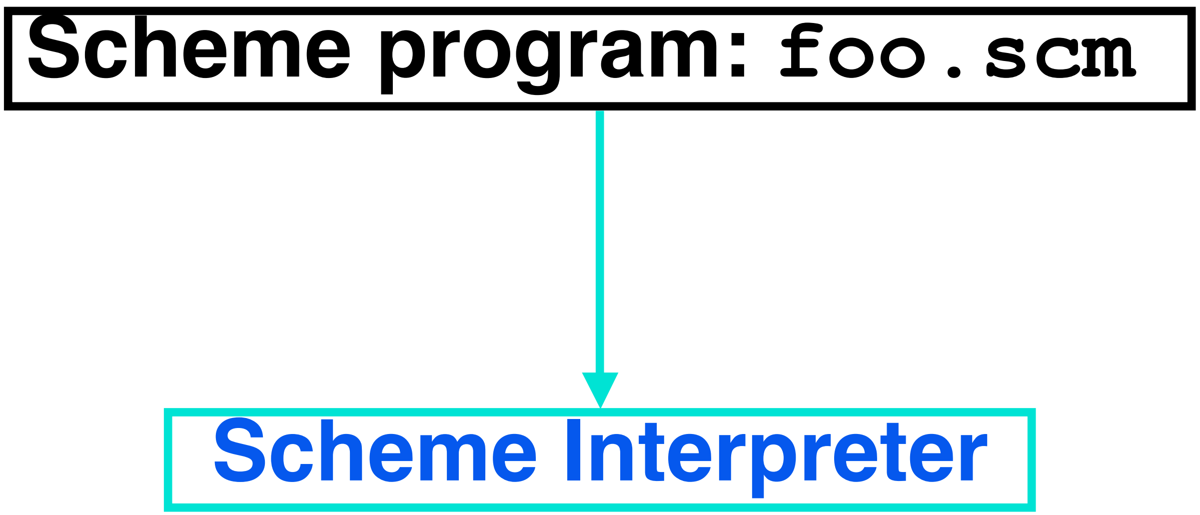
Easy to program ⟷ Efficient
Inefficient to interpret ⟷ Difficult to program

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

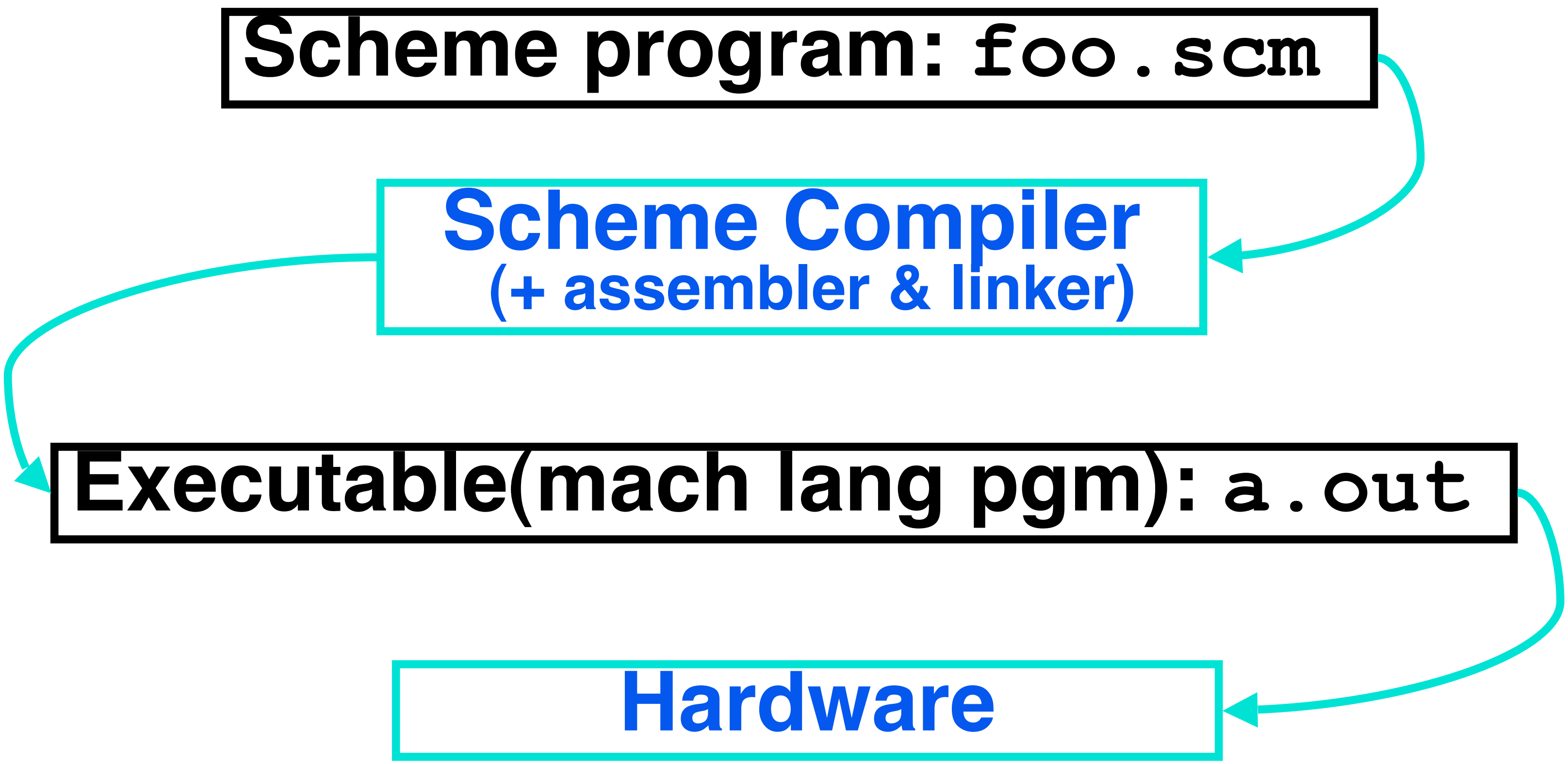
Interpretation vs Translation

- 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
- What if you want to run compiled programs (executables) from another ISA?
- Examples
  - VirtualPC let Windows (compiled to x86) run on old Macs (680x0 or PowerPC)
  - Run old video games on newer consoles

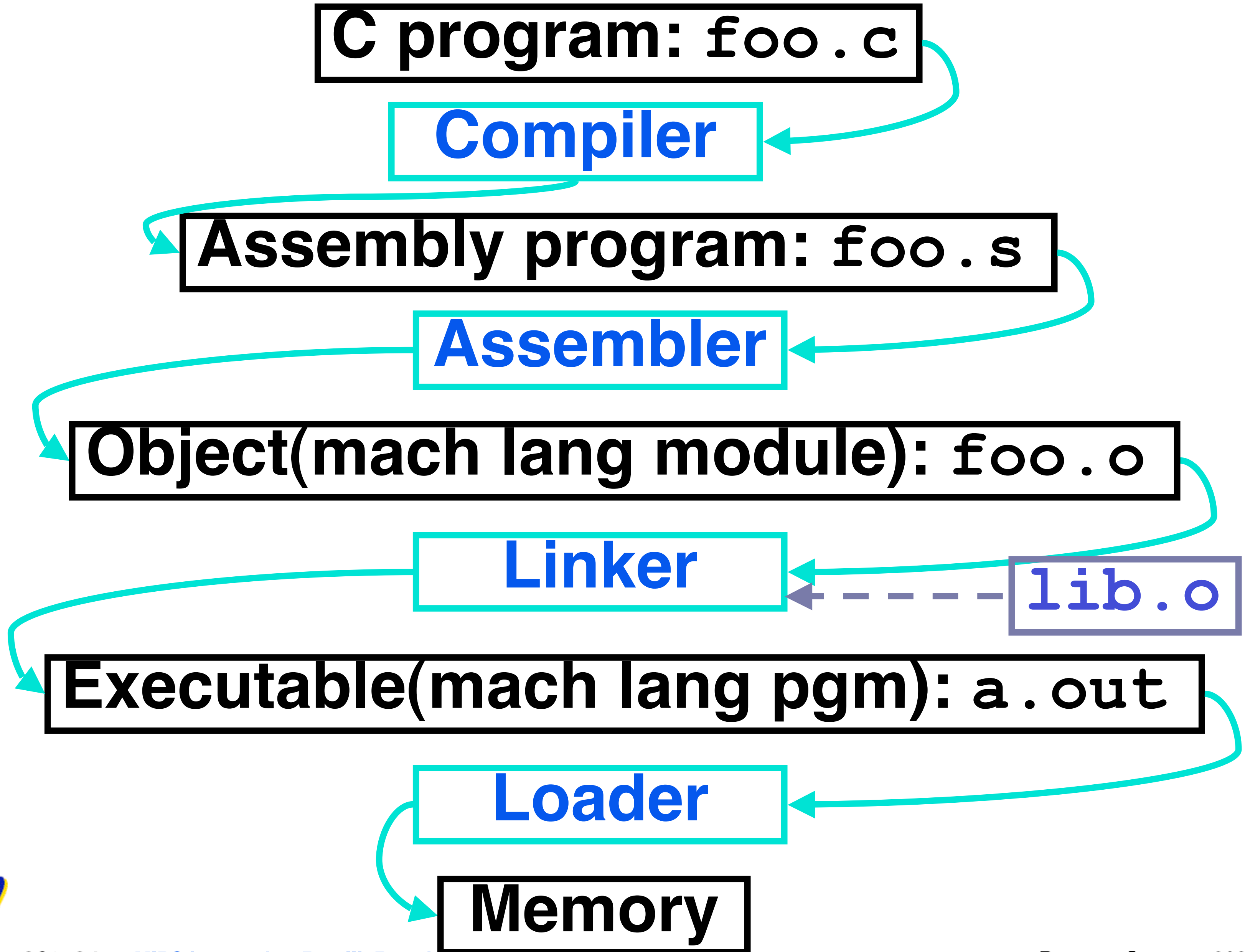
Machine Code Interpretation

- Apple's Two Conversions
  - In the last 2 years, switched to Intel's x86 from IBM's PowerPC
  - Could require all programs to be re-translated from high level language
  - Did so with minimal disruption to programmer, and especially the user
    - Rosetta allows old PowerPC programs to run on the new x86 systems by runtime translation
    - Universal Binaries contain the machine code for both platforms, so both systems can run at native speeds
  - Did a similar thing 13 years ago when they switched from Motorola 680x0 instruction architecture to PowerPC

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...