Grit

- Grit: “The power of passion and perseverance” (Educational researcher Angela Lee Duckworth).
- Calvin Coolidge, former U. S. president, referred to it as persistence:
  “Nothing in this world can take the place of persistence.
  “Talent will not: nothing is more common than unsuccessful men with talent.
  “Genius will not; unrewarded genius is almost a proverb.
  “Education will not: the world is full of educated derelicts.
  “Persistence and determination alone are omnipotent.
  “The slogan ‘press on’ has solved and always will solve the problems of the human race.”
Pseudo Instructions

- Pseudo instructions are instructions that exist in the SPIM assembler, but are not instructions designed into the MIPS computer. Most pseudo instructions are of the register-to-register type.
- Pseudo instructions make SPIM a bit more compiler-like. They are typically made up of two or more MIPS machine instructions, although a few are single instructions. Example—move is a pseudo instruction: move $t2,$t1 is converted by the assembler to: addu $t2,$0,$t1
- We will see a several pseudo instructions today.
Multiply as a Pseudo Instruction

- Since multiplying two 32-bit numbers can have a 64-bit result, the MIPS computer provides two 32-bit registers for a multiply result, LO and HI.
- Multiply sends the upper 32 bits to HI and the lower 32 bits to LO.
  - MIPS instruction: `mul $t1,$t2` means $[t1] \cdot [t2] \rightarrow \begin{cases} \text{HI (upper 32 bits)} \\ \text{LO (lower 32 bits)} \end{cases}$
  - In SPIM, `mul $t0, $t1, $t2` implies $[t1] \cdot [t2] \rightarrow [t0]$.
  - The assembler accomplishes this by adding a second instruction: `mul $t1, $t2; mflo $t0`. (mflo means $[LO] \rightarrow [t0]$)
  - SPIM recognizes `mul $t1,$t2`, with results left in LO and HI.
- Note: **You must check HI for a residual result** (product > 32 bits). SPIM does NOT do this!

Notes: 1. $[\ ]$ = “contents of;” 2. The second operand for multiply can be a constant, as for add.
Divide as a Pseudo Instruction

• Similarly, the MIPS divide is:
  – `div $t2,$t1`, which means \([\text{ LO}] \rightarrow \text{ HI (32 bit remainder)} \) \([\text{ HI}] \rightarrow \text{ LO (fixed point 32 bit quotient)} \)

• SPIM transfers the quotient from LO to the destination register, as it does the lower 32 bits in multiply.

• Thus the SPIM instruction `div $t0, $t2, $t1` becomes:*  
  – `div $t2,$t1; mflo $t0` (where `mflo` means \([\text{ LO}] \rightarrow \text{ [$t0]} \)).

• SPIM recognizes `div $t2,$t1`, which results in the quotient remaining in LO and the remainder in HI.

• In divide instructions, the 1\text{st} source is divided by the 2\text{nd}.
  – That is, `div $t0, $t2, $t1` means: \([\text{ LO}] \rightarrow [\text{ [$t0]} \). [\text{ HI}] \rightarrow \text{ [$t0]} \).

* The second operand (divisor) can be a number, as for `mul`, `add`, `sub`, etc.
Register-to-Register Instructions

A review of R-R instructions studied earlier:

- add $s1, $t2, $t6: \([t2] + [t6] \rightarrow [s1]\).
- addi $s1, $t2, 27: \([t2] + 27 \rightarrow [s1]\).
- sub $t3, $t4, $t5: \([t4] - [t5] \rightarrow [t3]\). Can also be immediate.
- mul $t0, $t1, $t2: \([t1] \cdot [t2] \rightarrow [t0]\).
- div $t0, $t2, $t1: \([t2]/[t1], \text{quotient} \rightarrow [\text{LO}] \rightarrow [t0]\).
- rem $t0, $t1, $t2: \([t1]/[t2], \text{remainder} \rightarrow [\text{HI}] \rightarrow [t0]\).
- and $t0, $t1, $t2: \([t1] \cdot [t2] \rightarrow [t0]\). Also OR, NOT, NOR, XOR.
- neg $t2, $s5: ([s5] + 1) \rightarrow [t2].
- abs $t1, $t0: \([t0] \rightarrow [t1]\).
- lui $t1, 23: 23 (0000 0000 0001 0111) \rightarrow \text{upper 16 bits of } t1.$
- li $t1, 78645329: 78645329 \rightarrow t1 \text{ (pseudo; uses $at).}$
- move $s5, $t3: \([t3] \rightarrow [s5]\)

Note: In R-R instructions, the source register contents are NOT changed.
Examples of R-R Instructions

<table>
<thead>
<tr>
<th>00 0000</th>
<th>1 1001</th>
<th>0 1110</th>
<th>0 1111</th>
<th>0 0000</th>
<th>10 0100</th>
</tr>
</thead>
<tbody>
<tr>
<td>OP = 0</td>
<td>Rs = $t9@</td>
<td>Rt = $t6</td>
<td>Rd = $t7</td>
<td>no shift</td>
<td>fn. code = 0x24*</td>
</tr>
<tr>
<td>and $t7,$t9,$t6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>00 0000</th>
<th>0 1001</th>
<th>0 1010</th>
<th>0 1000</th>
<th>0 0000</th>
<th>01 1000</th>
</tr>
</thead>
<tbody>
<tr>
<td>OP = 0</td>
<td>Rs = $t1</td>
<td>Rt = $t2</td>
<td>Rd = $t0</td>
<td>no shift</td>
<td>fn. code = 0x18+</td>
</tr>
<tr>
<td>mul $t0,$t1,$t2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

• Notes:
  – * 0x24 (=10 0100) is the function code for add with overflow indication.
  – + 0x18 (=01 1000) is the function code for multiply with overflow.
  – @ t registers 0-7 are register numbers 01000 to 01111.
Other Register-Register Instructions

- **lui $rd, #:** “load upper immediate.” The upper 16 bits of $rd are loaded with the immediate (“#”). **The lower half is cleared to 0.** Since lui is not a pseudo instruction, it is limited to a 16 bit immediate (convenient, since there are 16 bits in the upper half of a register). Example:
  - lui $t1, 23 – The number 23 (0000 0000 0001 0111) → upper 16 bits of $t1.

- **li $rd, #:** “load immediate.” Although this is a register-type instruction, **li is a pseudo instruction** (Pervin, Appendix D) which combines ori and lui to create the desired load. Example:
  - li $t0, 2405 (# < 16 bits): ori $t1, $at, (binary number [less than 16 bits])
  - li $t1, 78645329 (# > 16 bits): { lui $at, [upper 16 bits of binary number] ori $t1, $at, [lower 16 bits of binary number]
Other Register-Register Instructions (2)

• The “neg” instruction simply changes the mathematical sign of the number in the source register. Thus:
  – neg $t2, $s5: ([s5]+1) → [t2].

• “abs” is also a pseudo instruction. It takes the absolute value of the source register.
  – If the source is positive, the number → destination “as is.”
  – If the source is negative, the two’s complement → destination.
  – The destination always ends up with a positive number equaling the magnitude of the number in the source.
  – Example – abs $t1, $t0: ||$t0|| → [t1].
Other Register-Register Instructions (3)

- **move**: A pseudo instruction, as discussed earlier. The move instruction is a convenient way to transfer the contents of one register to another.*
  - `move $s5, $t3: [$t3] → [$s5]` ($t3 contents are not changed).
- **rem**: rem operates like divide, except that the contents of HI are moved to the destination register. I do not use it, as the sign of the numbers involved can cause the answer to be undefined in some cases. Example of use:
  - `rem $t0, $t1, $t2 – [$t1]/[$t2], remainder → [HI] → [$t0].`
  - That is, the instruction becomes two separate instructions, as in the case of divide: `div $t1, $t2; mfhi $t0`. Yes, the quotient of the divide → LO, but it is not used.

* li and lw or lb cannot be used to transfer data between registers!
Segments of a SPIM Program

• We started writing simple SPIM programs last class. What are all the parts of a SPIM program?
• There are three parts of a SPIM program in general:
  – Comments to introduce, comment on, or end the program.
  – The text section (actual program instructions).
  – The data section (identifying data elements).

• All data **must be labeled** (given an identifying acronym for the program [text] to refer to).
• Text statements (i.e., program instructions) **may also be labeled** for identification and reference in the program.
• “Text” and “data” directives must precede the text and data sections. We will discuss other directives later.
Typical SPIM Program Outline

• **Comments:** Title, any special notes on the program, explanation of instructions or instruction groups.
  – Comments always preceded by pound sign (#).

• **Text (the actual program):**
  – Started with the “.text” directive.
  – One SPIM instruction per line; can comment on the instruction line.
  – Any text line may contain a label (not required). The only required label is “main:” on the first line of text. **A label must be followed by a colon (:).**

• **Data:**
  – Starts with the “.data” directive.
  – Each data statement must include a definition and a label.
  – Data may be listed before or after text.
Program 1 from Last Lecture

• Write a program on your computer to do the following:
  – Enter 47 into $t0 ("x")
  – Put 253 into $t1 ("y")
  – Load 23 in $t2 ("z")
  – Compute $x^2 + 3y + 10z$
  – Store the result in $t3$
  – Stop the program by using system call 10.
  – What is the number in $t3$?
# EE 2310, Lecture 10 Example Program #1

## Format of a Simple Program

```assembly
.text
main:
  li $t0, 47
  li $t1, 253
  li $t2, 23
  mul $t0, $t0, $t0  # Square 47 (x^2)
  mul $t1, $t1, 3    # Mult. 3y (3 X 253)
  add $t3, $t1, $t0  # Compute x^2 +3y
  mul $t2, $t2, 10   # Compute 10z
  add $t3, $t3, $t2  # Compute x^2 +3y+10z
  li $v0, 10
  syscall
```

- **.“The Program Follows.”**
- **Only 1 instruction per line.**
- **Can look in $t3 to see answer.**
- **SySCALL 10**
  = “Stop!”
- **Can use # sign to comment on any line.**

### Notes:
- Any line may be made into a comment by starting with a # sign. Note that comments do not “wrap.” Each line must be started with a # sign.
- All labels followed by a colon (:).
- Margin kept clear for labels.
- “First Line of the Program.”
Program 1

- Load 23 into $t0 and 37 into $t1.
- Add $t0 and $t1, putting the sum in $t2
- Multiply $t2 times $t0, putting the results in $t3.
- Subtract $t1 from $t3, results going into $t4.
- AND $t4 and $t0, results into $t5.
- OR $t5 and $t3, placing results in $t6.
- MOVE $t6 to $t7.
- Find the answer to this series of manipulations in $t7, and write down or state that answer (in hex).
System Calls

- **System calls allow our simulated MIPS to communicate to the user and perform a few other functions.**
- Most system calls either initiate a print sequence to the system console, or read data from the keyboard.
- **Syscall 10** (as we learned last lecture) halts the program.
- Certain system calls use specific registers (primarily $v0 and $a0). The system calls will not execute unless the designated registers contain the correct information.
- **System calls are the user interface in SPIM.**
System Calls of Interest

1 - Print int., $a0 = int. $a0 contents printed as decimal #.
4 - Print string; $a0 = pointer to string. ASCII string is printed out.
5 - Read int; $v0 holds #. # from keyboard → $v0.*
8 - Read string; $a0 = buffer, $a1 = length. String is read from keyboard.*
10 - Exit program. Program ends.
11 - Print character, Lowest byte of $a0 → console as ASCII.
12 – Read character. One ASCII character from kbd → $v0

Note: System Calls 2, 3, 6, 7, 9 and 13-16 will not be used.

*Input system calls 5 and 8 are a little tricky; more about them later.
Mechanics of Writing a System Call

- Executing a system call requires two instructions:
  - (1) # of syscall → $v0;
  - (2) execute instruction “syscall.”
- For example, we have used syscall 10 (“stop the program”):
  ```
  li $v0, 10
  syscall
  ``
  “syscall 10”

- Sometimes $a0 or $a1 are used in syscalls. For example, system call 1 prints out the contents of $a0.
  ```
  li $a0, 0x ab67  (might also come from memory or via move)
  li $v0, 1
  syscall
  ```
  syscall 1 prints out a decimal value
More Example System Calls

- `la $a0, string`
- `li $v0, 4`
- `syscall`

In syscall 4, $a0 is loaded with the memory address of the first byte in the ASCII string to be output. Characters are output until a null (character = 0) is encountered.

- `lb $a0,num (or use li or move)`
- `li $v0,11`
- `syscall`

Syscall 11 prints out the lower 8 bits of $a0 as an ASCII character.

- `li $v0,12`
- `syscall`

In syscall 12, the 8 bits representing the ASCII character input from the keyboard → the lowest 8 bits of $v0 (erasing the 12!).
Directives give the SPIM assembler program information. The main ones of interest are shown here:*  
- `.text` -- “Program instructions follow.”
- `.data` -- “Data required by the program follows.”
- `.word [number]` -- “The data element that follows is a 32-bit number.”
- `.space [number]` -- “Reserve the number of bytes in memory shown and clear them to 0.”
- `.asciiz [character string]` -- “Store the following in memory as a byte string and null terminate.”
- `.ascii [character string]` -- Same as `.asciiz` but no null termination.
- `.frame` -- “Reserve the frame as shown on the stack.”

* See Pervin appendix D for full list. All directives are preceded by a period.
Labels

- **Labels** attach a name to data or to a text (program) line. Labels allow easy reference to a specific place in a program or to a specific piece of data.
  - Each data entry must be labeled with a unique name, or label.
  - The specific name “main:” MUST label the first line of text in a PCSPIM program.
  - Labels are always followed by a colon (:

- **Examples:**
  - `str: .asciiz "Hello, world!\n"` -- Characters are named “str”
  - `adder: add $t1,$t2,$t3` – This instruction is named “adder.”*
  - `calc: mul $t5,$t5,$t6` -- This instruction is named “calc.”

* Note: Do NOT use an instruction as a label. The assembler will reject it.
Comments

• Comments are VERY useful in describing a program. You may not think you need them, but you do. They help remind you (later) how the program works!
  – Comments are always preceded by a pound sign. The assembler ignores a line (or part of a line) after a #.
  – Comment lines do not wrap. A two or more line comment must have a # sign at the beginning of each line.
  – A comment may be appended on any instruction or data line. Simply enter a # and then the comment. Examples:
    – add $t1,$t1,$t6      # Computing the value K.
    – mul $s1,$t1,$t1      # Calculating the area of the square.
    – temp: .word 212     # Defining temperature constant.
    – .main: and $t1,$t7,$t8   # Start program with logical AND.
Reminder: Form of SPIM Program

- **Comments:** Title, any special notes on the program, explanation of instructions or instruction groups.
  - Comments always preceded by pound sign (#).
- **Text (the actual program):**
  - Started with the “.text” directive.
  - One instruction per line; can comment on the instruction line.
  - Any text line may contain a label (not required). The only required label is “main:” on the first line of text. **A label must be followed by a colon (:).**
- **Data:**
  - Starts with the “.data” directive. Data declarations covered later.
  - Each data statement must include a definition and a label.
  - Data may be listed before or after text.
The following instructions are convenient to mention at this point:

- **nop**: "No operation." The computer does nothing for one instruction cycle.
- The "set" instructions: These instructions (which are technically register-register instructions) generally put a 1 or 0 into a destination register, depending on the comparative values of two other registers. We will cover these later in the lecture on branch instructions, as they are decision-making (or more properly, decision-support) instructions.
- Shift, and rotate instructions (also R-R instructions) will also be covered in that lecture.
Program 2

• Let’s do a program to practice system call 4.
  – Declare an .asciiz data declaration of “Hello, world!\n”. *
  – Since all data declarations must be labeled, label your .asciiz character string as “str:”
  – Your program should set up and execute a system call 4 to output the greeting, “Hello, world!” to the console.
  – Stop the program using the appropriate syscall. (What is that syscall?)
  – Remember to use the directives for program(“.text”) and data (“.data”).
  – Remember to label the first line of your program properly.

• This is a 5-line program! (I.e., 5 lines after .text)
• The data declaration is also one line! (after .data)

*Note that \n is the symbol for the ASCII character CR/LF (carriage return/line feed).
Program 3

• Compose and run a program to calculate the formula $3x^2-897235$.
  – In this case, use $x = 2846$. Declare “$x$” in your data declaration.
  – Also a new requirement: a data declaration says “The answer is.”
  – This will require a second data declaration in your data section.
    (Remember to start the data section with “.data”).

• When you finish writing the program in NotePad, open it in SPIM
  and run it to make sure it operates properly.
  – If it executes properly on your SPIM emulator, the answer will be
    printed out. What is that answer?
  – Remember to do your data declaration so that so that “The answer is”
    is properly declared in the data section.
  – This program is a bit longer. You must do the calculation, output the
    answer header (“The answer is”), and then output the answer itself.
  – Remember, to output a decimal number, load it into $a0$, and execute
    a system call 1.
### MIPS INTEGER and GENERAL INSTRUCTIONS

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Arg1</th>
<th>Arg2</th>
<th>Arg3</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>* abs</td>
<td>rd</td>
<td>rs</td>
<td></td>
<td>put the absolute value of rs into rd</td>
</tr>
<tr>
<td>add</td>
<td>rd</td>
<td>rs</td>
<td>rt</td>
<td>rd = rs + rt (with overflow)</td>
</tr>
<tr>
<td>addu</td>
<td>rd</td>
<td>rs</td>
<td>rt</td>
<td>rd = rs + rt (without overflow)</td>
</tr>
<tr>
<td>addi</td>
<td>rt</td>
<td>rs</td>
<td>imm</td>
<td>rt = rs + imm (with overflow)</td>
</tr>
<tr>
<td>addiu</td>
<td>rt</td>
<td>rs</td>
<td>imm</td>
<td>rt = rs + imm (without overflow)</td>
</tr>
<tr>
<td>and/andi</td>
<td>rd</td>
<td>rs</td>
<td>rt</td>
<td>put rs AND rt into rd (imm, not rt in andi)</td>
</tr>
<tr>
<td>* b</td>
<td></td>
<td></td>
<td>label</td>
<td>branch to label</td>
</tr>
<tr>
<td>beq</td>
<td>rs</td>
<td>rt</td>
<td>label</td>
<td>branch to label if (rs==rt)</td>
</tr>
<tr>
<td>* beqz</td>
<td>rs</td>
<td>label</td>
<td></td>
<td>branch to label if (rs==0)</td>
</tr>
<tr>
<td>* bge</td>
<td>rs</td>
<td>rt</td>
<td>label</td>
<td>branch to label if (rs&gt;=rt)</td>
</tr>
<tr>
<td>bgez</td>
<td>rs</td>
<td>label</td>
<td></td>
<td>branch to label if (rs&gt;0)</td>
</tr>
<tr>
<td>bgt</td>
<td>rs</td>
<td>rt</td>
<td>label</td>
<td>branch to label if (rs&gt;rt)</td>
</tr>
<tr>
<td>bgtz</td>
<td>rs</td>
<td>label</td>
<td></td>
<td>branch to label if (rs&gt;0)</td>
</tr>
<tr>
<td>ble</td>
<td>rs</td>
<td>rt</td>
<td>label</td>
<td>branch to label if (rs&lt;=rt)</td>
</tr>
<tr>
<td>blez</td>
<td>rs</td>
<td>label</td>
<td></td>
<td>branch to label if (rs&lt;=0)</td>
</tr>
<tr>
<td>* blt</td>
<td>rs</td>
<td>rt</td>
<td>label</td>
<td>branch to label if (rs&lt;rt)</td>
</tr>
<tr>
<td>bltz</td>
<td>rs</td>
<td>label</td>
<td></td>
<td>branch to label if (rs&lt;0)</td>
</tr>
</tbody>
</table>

* Indicates a pseudo instruction (assembler generates a different instruction or more than one instruction to produce the same result; note that the pseudo instruction has no op code). 
MIPS INTEGER and GENERAL INSTRUCTIONS (Continued)

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>bne</td>
<td>rs, rt, label</td>
</tr>
<tr>
<td>* bnez</td>
<td>rs, label</td>
</tr>
<tr>
<td>div</td>
<td>rd, rs, rt</td>
</tr>
<tr>
<td>j</td>
<td>label</td>
</tr>
<tr>
<td>jal</td>
<td>[rd], label</td>
</tr>
<tr>
<td>jalr</td>
<td>[rd], rs</td>
</tr>
<tr>
<td>jr</td>
<td>rs</td>
</tr>
<tr>
<td>la</td>
<td>rd, label</td>
</tr>
<tr>
<td>lb</td>
<td>rt, address</td>
</tr>
<tr>
<td>lbu</td>
<td>rt, address</td>
</tr>
<tr>
<td>* li</td>
<td>rd, number</td>
</tr>
<tr>
<td>lui</td>
<td>rt, number</td>
</tr>
<tr>
<td>lw</td>
<td>rd, address</td>
</tr>
<tr>
<td>* move</td>
<td>rd, rs</td>
</tr>
<tr>
<td>* mul</td>
<td>rd, rs, rt</td>
</tr>
<tr>
<td>* neg</td>
<td>rd, rs</td>
</tr>
<tr>
<td>nop</td>
<td></td>
</tr>
<tr>
<td>nor</td>
<td>rd, rs, rt</td>
</tr>
<tr>
<td>* not</td>
<td>rd, rs</td>
</tr>
<tr>
<td>or</td>
<td>rd, rs, rt</td>
</tr>
<tr>
<td>ori</td>
<td>rt, rs, imm</td>
</tr>
</tbody>
</table>

* Indicates a pseudoinstruction (assembler generates a different instruction or more than one instruction to produce the same result; note that the pseudoinstruction has no opcode).
### MIPS INTEGER and GENERAL INSTRUCTIONS (Concluded)

<table>
<thead>
<tr>
<th>Instruction</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>* rem</td>
<td>( rd = rs \text{ MOD } rt )</td>
</tr>
<tr>
<td>* rol(ror)</td>
<td>( rd = rs \text{ rotated left(right) by } ra )</td>
</tr>
<tr>
<td>sb</td>
<td>Store byte in rt to address</td>
</tr>
<tr>
<td>* seq</td>
<td>if (rs==rt) ( rd=1 ); else ( rd=0 )</td>
</tr>
<tr>
<td>* sge</td>
<td>if (rs&gt;=rt) ( rd=1 ); else ( rd=0 )</td>
</tr>
<tr>
<td>* sgt</td>
<td>if (rs&gt;rt) ( rd=1 ); else ( rd=0 )</td>
</tr>
<tr>
<td>* sle</td>
<td>if (rs&lt;=rt) ( rd=1 ); else ( rd=0 )</td>
</tr>
<tr>
<td>sll</td>
<td>( rd = rt \text{ shifted left by distance } sa )</td>
</tr>
<tr>
<td>slt</td>
<td>if (rs&lt;rt) ( rd=1 ); else ( rd=0 )</td>
</tr>
<tr>
<td>* sne</td>
<td>if (rs!=rt) ( rd=1 ); else ( rd=0 )</td>
</tr>
<tr>
<td>sra</td>
<td>( rd = rt \text{ shifted right by } sa, sign-extended )</td>
</tr>
<tr>
<td>srl</td>
<td>( rd = rt \text{ shifted right by } sa, 0-extended )</td>
</tr>
<tr>
<td>sub</td>
<td>( rd = rs - rt )</td>
</tr>
<tr>
<td>sw</td>
<td>Store the word in rt to address</td>
</tr>
<tr>
<td>sw</td>
<td>Store word in rt to addr offset+base</td>
</tr>
<tr>
<td>syscall</td>
<td>Do a system call depending on contents of $v0</td>
</tr>
<tr>
<td>xor</td>
<td>( rd = rs \text{ XOR } rt )</td>
</tr>
</tbody>
</table>

* Indicates a pseudo instruction (assembler generates a different instruction or more than one instruction to produce the same result; note that the pseudo instruction has no op code).

**Note:** The above list is not complete, but contains all instructions of interest in EE 2310.
• The following material will not be covered in the lecture.
• Read and study it on your own, and you will have the opportunity (last slide) to earn a homework bonus.
Rationale for a Computer Instruction Set

- Another thing that writing programs in assembly language does for us is to give us visibility into the fundamentals of the computer instruction set.
- A great deal of research and development has gone into determining just what instructions a computer should embody in its repertoire, and why those instructions should exist.
- The study of what and how many instructions to include in a computer design is referred to as “Instruction Set Architecture.”
- The “Instruction Set Architecture,” or ISA, of a computer refers not only to what instructions a computer will execute, but how those instructions relate to each other, and why a certain set of instructions make the computer effective at executing certain types of programs.
Designing an Instruction Set

Many questions must be answered to determine the ISA. Some examples:

- What kinds of programs will be run (graphical or media, or extended accuracy for scientific applications)?
- Device basis (type of manufacturing technology – MOS, etc.)
- Integer unit size (bits) to support applications
- Instruction encoding (that is, how the bits in an instruction word will be put together to signify each instruction).
- Computational operations supported in hardware (for example, should there be a multiplier in hardware?).
- The types of data that will be manipulated and stored (fixed point or floating point, for example).
Kinds of Instruction Set Architectures

- Following are examples of some of the most pervasive ISAs over the last 30 years:
  - Accumulator Architecture:
    - CPU has 1 (and only 1) register, which is called the **Accumulator**. Operations always include memory reference.
    - Example -- Add X: X + [contents of Accumulator] → Accumulator, X the contents of a memory location
  - Memory-Based Computational Architecture:
    - No registers in CPU; operations always involve operands in memory.
    - Example -- Add X, Y, Z: Contents of memory locations Z and Y are added and stored in memory location X.
Kinds of Instruction Set Architectures (2)

- General-purpose register set: There are two classes:
  - Non-restrictive design (may allow multiple-word instructions):
    - Instructions may involve both register-to-register and register-to-memory operations.
    - Examples: `add r1,X,Y; rshift r3, 4, X, X and Y memory locations`.
  - RISC* Load/store architecture:
    - All arithmetic/logical operations use register operands only.
    - Data in memory accessible only via load and store instructions.

* Reduced Instruction Set Computer
Advantages and Disadvantages of Architectures

- **Accumulator:**
  + Minimizes CPU hardware and bus complexity.
  − Maximizes memory-to-CPU traffic (slow).

- **Memory:**
  + Simplest possible CPU design.
  − Very slow (was faster once upon a time, when memories were lots faster than CPUs).

- **General-purpose register set, non-restrictive design:**
  + Most general model for code generation, very flexible.
  − Very complex CPU and memory interface; also longer (i.e., multi-word) instructions may be necessary.

- **General-purpose register set, RISC load/store design:**
  + Single memory access mode simplifies design, ensures maximum speed.
  − Increases total instruction count, makes programming less flexible.
Why RISC Load-Store Architecture is Superior*

- Since 1980, logic circuits have become much faster than DRAM.
  - Registers are faster than main memory.
  - Frequent memory references (except cache) slow computational speeds.
- Load-store architecture offers many advantages.
  - Operand registers can be used in any order.
  - Do not have to go to memory to store data between computations (fast!).
  - Load-store architectures allow very straightforward (though less flexible) programming.
  - Fixed-length memory addresses → fixed-length instructions (fast!).
  - For a register machine, can optimize most frequently used instructions; also reduce the instructions complement to a minimum (fast!).
  - CPU is generally less complex (fast and cheap!).

* For the present, of course – things always change!
RISC Architecture is Effective

- Consider the following analysis of Intel X86 programs:

<table>
<thead>
<tr>
<th>Rank</th>
<th>80x86 Instruction</th>
<th>% Total executed</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>load</td>
<td>22%</td>
</tr>
<tr>
<td>2</td>
<td>conditional branch</td>
<td>20%</td>
</tr>
<tr>
<td>3</td>
<td>compare</td>
<td>16%</td>
</tr>
<tr>
<td>4</td>
<td>store</td>
<td>12%</td>
</tr>
<tr>
<td>5</td>
<td>add</td>
<td>8%</td>
</tr>
<tr>
<td>6</td>
<td>and</td>
<td>6%</td>
</tr>
<tr>
<td>7</td>
<td>sub</td>
<td>5%</td>
</tr>
<tr>
<td>8</td>
<td>move register-register</td>
<td>4%</td>
</tr>
<tr>
<td>9</td>
<td>call (procedure entry)</td>
<td>1%</td>
</tr>
<tr>
<td>10</td>
<td>return (procedure exit)</td>
<td>1%</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>96%</td>
</tr>
</tbody>
</table>
From the previous chart, we see that although the X86 has hundreds of instructions, with tens of thousands of variations (20,000+ add instructions), only ten instruction types made up 96% of all instructions in most programs.

Thus the general RISC load-store architecture (as embodied, in our case, by the MIPS architecture), further improves efficiency by restricting the instruction set to a few very valuable (and most-used) instructions.

Keeping the instruction set small further reduces complexity and cost and, additionally, increases operating speed.
We see that the choice of ISA heavily influences the overall design, or architecture, of the computer.

The clear winner is the RISC load-store architecture:
- Fixed-length instructions (increases speed)
- Reduction in overall instructions (increases speed)
- Minimization of memory references (increases speed)
- Reduction in size and complexity of processor (speed and cost)

The MIPS, our target processor/assembly language to study is based on this “victory” of this ISA.

The MIPS processor employs a RISC load/store ISA.
Bonus Homework Assignment

• This homework assignment is worth 100 points on your homework average. However, it will be “invisible” when calculating the average (thus you get an extra bundle of points, 100 maximum, without adding to the divisor when the average is calculated).
• Turn in your answers on a separate sheet of paper. The true/false questions may simply be marked T or F, along with the question number.
• This assignment is due at the beginning of the next class.
1. Provide a one-sentence definition of a computer ISA.

2. (T___/F___) Fixed/floating point choice is not an important ISA condition.

3. (T___/F___) The RISC architecture allows mathematical/logical operations directly on arguments in memory.

4. (T___/F___) The old-fashioned accumulator architecture is very simple.

5. (T___/F___) Computer memory is much faster than the CPU.

6. (T___/F___) Load and branch instructions combined occur much more often, on average, than a combination of add, and, sub, and move instructions.

7. What does “RISC” stand for?

8. (T___/F___) The fastest architecture is the accumulator architecture.