CMPE014 Fall 2002
MIPS Instruction Set Architectures (ISA)

- Definition and types of ISAs
- RISC principles
- MIPS ISA
- MIPS binary instruction format

Textbook: 3.15, 3.4
Instruction Set Architecture

Constant interface between the assembly language and the hw.

Permits many different hw implementations to run identical sw.
Architectural models for computational operations

• Stack architecture

• Accumulator architecture

• General Purpose Register (GPR) architectures
  – Register-memory
  – Memory-memory
  – Register-register (load/store)
**Instruction Set Architectures**

**Stack architecture**

Operands *specified* per *computational* instruction: 0

Operands are kept on a stack. Computational operations *remove* the operands from the stack and put the result onto the stack.

Example: $A = B \times (C + D \times B)$

1: \[
\begin{array}{c}
5 \\
4 \\
3 \\
2 \\
1 \\
\end{array}
\]

2: \[
\begin{array}{c}
5 \\
4 \\
3 \\
2 \\
1 \\
\end{array}
\]

3: \[
\begin{array}{c}
5 \\
4 \\
3 \\
2 \\
1 \\
\end{array}
\]

4: \[
\begin{array}{c}
5 \\
4 \\
3 \\
2 \\
1 \\
\end{array}
\]

5: \[
\begin{array}{c}
5 \\
4 \\
3 \\
2 \\
1 \\
\end{array}
\]

6: \[
\begin{array}{c}
5 \\
4 \\
3 \\
2 \\
1 \\
\end{array}
\]

7: \[
\begin{array}{c}
5 \\
4 \\
3 \\
2 \\
1 \\
\end{array}
\]

8: \[
\begin{array}{c}
5 \\
4 \\
3 \\
2 \\
1 \\
\end{array}
\]

9: \[
\begin{array}{c}
5 \\
4 \\
3 \\
2 \\
1 \\
\end{array}
\]
**Instruction Set Architectures**

**Accumulator architecture**

Operands per computational instruction: 1 (the other one is the accumulator by default). The result is put into the accumulator.

Example: \( A = B \times (C + D \times B) \)
GPR architecture: Register-memory

Operands per computational instruction: 2, a register and a memory location. The result is put back into the source register.

Example: \( A = B \times (C + D \times B) \)
**Instruction Set Architectures**

**GPR architecture: Memory-memory**

Operands per computational instruction: 3, all memory locations.

Example: \( A = B \times (C + D \times B) \)
**GPR architecture: Register-register (load/store)**

Operands per computational instruction: 2 or 3. Operands are loaded from memory into registers. The Arithmetic/Logic Unit (ALU) only operates on registers.

Example: $A = B \times (C + D \times B)$
Comparison of the three GPR ISAs

- memory–memory (VAX, PDP)
  - 2-3 memory accesses per typical ALU instruction

- register–memory (VAX, PDP, 68000, IBM 360, i80x86)
  - 1-2 memory accesses per typical ALU instruction
  - smaller size code
  - variable instruction length
  - easier hand-coding
  - memory bottleneck

- register–register (load/store)
  - 0 memory accesses per typical ALU instruction
  - simple instructions and code generation
  - higher instruction count
  - RISC (MIPS)
  - best for current compiler technology
Motivation for Reduced Instruction Set Computer (RISC)

Research in the early 1980s found that:

- most applications used a small set of simple instruction types, as many of the complex instructions of the earlier Complex Instruction Set Computer (CISC) architectures could not be effectively used by compilers. (example of CISC: Intel’s x86, Motorola’s 68K family and DEC’s VAX)

- in some cases, sequences of simpler instructions gave better performance and allowed better compiler optimizations than complex instructions
RISC design principles

- if hardware cannot implement a feature cheaply, it’s often better to implement the feature in software
- simplicity favors regularity (and makes debugging easier)
- smaller is faster
- make the common case fast
RISC architecture features

• fixed-size instructions (for easy decoding)
• memory transactions allowed only in separate load/store instructions (for easier pipelining)
• few and simple addressing modes
• large orthogonal register sets (no/few special registers)
• no/few *complicated* instructions

Common misconception: RISC = small number of instruction opcodes
MIPS

“Microprocessor without Interlocked Pipeline Stages”

- founded in 1984 by researchers from Stanford University (Hennessy), IBM and Motorola, **MIPS Computer Systems**, released in 1986 the the R2000, one of the earliest commercially-available RISC microprocessors


  (from MIPS home page: **ww.MIPS.com**)

- used by NEC, Sony, Nintendo, SGI, Philips, Siemens, Toshiba, TI, …
Our MIPS ISA

- 32-bit architecture — what does it mean?
- 32 registers
- Instruction set:
  - Computational: `and`, `andi`, `or`, `ori`, `add`, `addi`, `sub`, `slt`,
  - Load/store: `lw`, `sw`
  - Flow control: `j`, `beq`
Bits, bytes, and such

- BIT: one binary digit (1 or 0)
- NYBBLE: a 4-bit binary number
- BYTE: an 8-bit binary number
- WORD: an ordered set of $n$ bits, where $n$ is architecture-dependent
- DOUBLEWORD: an ordered set of 2 words
- QUADWORD: an ordered set of 4 words
How many different values...

...can be expressed with a:

- bit?
- nibble?
- byte?
- 16-bit word?
- 24-bit word?
- 32-bit word?
- 64-bit word?
- 79-bit word?
- 143-bit word?
MIPS binary instruction formats

- all instructions are 32 bits long
- all instructions have similar formats
- MAL and TAL

Example – assembly instruction:
add $t0, $s1, $s2

Binary instruction:

<table>
<thead>
<tr>
<th>MEANING</th>
<th>comp</th>
<th>$s1</th>
<th>$s2</th>
<th>$t0</th>
<th>-</th>
<th>add</th>
</tr>
</thead>
<tbody>
<tr>
<td>HEX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BIN</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

add is an \textit{R-type} (Register) instruction
**MIPS binary instruction formats**

**R-type (Register) instructions**

<table>
<thead>
<tr>
<th>op</th>
<th>rs</th>
<th>rt</th>
<th>rd</th>
<th>shamt</th>
<th>funct</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>26 25</td>
<td>21 20</td>
<td>16 15</td>
<td>11 10</td>
<td>6 5 0</td>
</tr>
</tbody>
</table>

- **op (opcode)**: the basic operation of instruction - also lets the CPU figure out the instruction format – op = 0 in all R-type instructions
- **rs**: first register source operand
- **rt**: second register source operand
- **rd**: register destination
- **shamt**: *shift amount*
- **funct**: *function* variant (e.g. *add* and *sub* both have op = 0 but *add* has funct = 32 and *sub* has funct = 34)
MIPS binary instruction formats

I-type (Immediate) instructions

<table>
<thead>
<tr>
<th></th>
<th>op</th>
<th>base/rs</th>
<th>rt</th>
<th>offset/immediate</th>
</tr>
</thead>
<tbody>
<tr>
<td>31-25</td>
<td>26</td>
<td>21-20</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>6 bits</td>
<td>5 bits</td>
<td>5 bits</td>
<td>16 bits</td>
</tr>
</tbody>
</table>

- **op (opcode):** the basic operation of instruction (e.g. **lw** opcode = 35, **addi** opcode = 8, **beq** opcode = 4)
- **rs/base:** register containing a source operand or base address
- **rt:** *destination* register in **addi** or **lw**, *source* register in **sw**, or second operand in **beq**
- **immediate/offset:** immediate field in computational instructions, *byte* address offset (wrt **rs**) in load/store instructions, *word* address offset (wrt **PC**) in branch instructions — always sign-extended to a 32-bit value
J-type (Jump) instructions

Format:

<table>
<thead>
<tr>
<th>op</th>
<th>target</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>26 25</td>
</tr>
<tr>
<td>6 bits</td>
<td>26 bits</td>
</tr>
</tbody>
</table>

Fields:

- **op (opcode):** the basic operation of instruction (e.g. j opcode = 2)
- **target:** the target word address of the instruction to jump to
### MIPS binary instruction formats

#### R-, I-, and J-type format comparison

**R-type:**

<table>
<thead>
<tr>
<th>op</th>
<th>rs</th>
<th>rt</th>
<th>rd</th>
<th>shamt</th>
<th>funct</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>26</td>
<td>25</td>
<td>21</td>
<td>16</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11</td>
<td>10</td>
</tr>
</tbody>
</table>

6 bits  5 bits  5 bits  5 bits  5 bits  6 bits

**I-type:**

<table>
<thead>
<tr>
<th>op</th>
<th>base/rs</th>
<th>rt</th>
<th>offset/immediate</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>26</td>
<td>25</td>
<td>21</td>
</tr>
<tr>
<td></td>
<td>6 bits</td>
<td>5 bits</td>
<td>5 bits</td>
</tr>
</tbody>
</table>

**J-type:**

<table>
<thead>
<tr>
<th>op</th>
<th>target</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>26</td>
</tr>
<tr>
<td>6 bits</td>
<td>26 bits</td>
</tr>
</tbody>
</table>
Recommended exercises

• Ex. 3.1 to 3.11