Architectural models for computational operations

- Stack architecture
- Accumulator architecture
- General Purpose Register (GPR) architectures
  - Register-memory
  - Memory-memory
  - Register-register (load/store)

MIPS Instruction Set Architectures (ISA)

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

Textbook: 3.15, 3.4

Stack architecture

Operands specified per computational instruction: 0
Operands are kept on a stack. Computational operations move the operands from the stack and put the result onto the stack.
Example: \( A = B \times (C + D \times B) \)

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Instruction Set Architecture

Constant interface between the assembly language and the hw,

\[
\text{Assembly language} \quad \xrightarrow{\text{Instruction Set Architecture}} \quad \text{Hardware}
\]

Permits many different hw implementations to run identical sw.
**Instruction Set Architectures**

GPR architecture: Memory-memory

Operands per computational instruction: 3, all memory locations.
Example: \( A = B \times (C + D \times B) \)

1:
2:
3:
4:
5:

Accumulator architecture

Operands per computational instruction: 1 (the other one is the accumulator by default). The result is put into the accumulator.
Example: \( A = B \times (C + D \times B) \)

1:
2:
3:
4:
5:

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

1:
2:
3:
4:
5:
6:
7:

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

1:
2:
3:
4:
5:
RISC design principles

- if hardware can not 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

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
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

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
- bought in 1992 by Silicon Graphics, changed its name. Now **MIPS Technologies, Inc.**, designs and licenses high performance, high value, embedded 32 and 64 bit intellectual property and core technology for digital consumer and embedded systems market,

(from MIPS home page: [www.MIPS.com](http://www.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`
MIPS binary instruction formats

I-type (Immediate) instructions

<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 25</td>
<td>21 20</td>
<td>16 15</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

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>
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<td></td>
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</tr>
<tr>
<td>BIN</td>
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<td></td>
</tr>
</tbody>
</table>

*add* is an **R-type (Register)** instruction

MIPS binary instruction formats

J-type (Jump) instructions

Format:
```

```

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-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 6 6 6 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

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

R-type:

<table>
<thead>
<tr>
<th>op</th>
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</table>

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

I-type:

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6 bits 5 bits 5 bits 16 bits

J type:

<table>
<thead>
<tr>
<th>op</th>
<th>target</th>
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<tbody>
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<td>31</td>
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</table>

6 bits 26 bits

Homework

Recommended exercises

- Ex. 3.1 to 3.11