Chapter 2: Assembly Language Fundamentals

Prof. Ben Lee
Oregon State University
School of Electrical Engineering and Computer Science

Chapter Goals

• Understand the importance of assembly language.
  ◦ The interface between hardware and software.

• Understand how assembly instructions are represented.
  ◦ What and how much information is encoded in the instructions.
  ◦ How these design choices affect the instruction format, and thus code density and power of the instructions.
2.1 Introduction

2.2 How Do We Speak the Language of the Machine?

2.3 Instruction Set Architecture

2.4 Instruction Format

2.5 A Pseudo-ISA
Assembly Language

I speak Spanish to God,
Italian to women,
French to men,
And German to my horse

Charles V, King of France (1337-1380)
(An excerpt from Computer Organization & Design: The Hardware/Software Interface by Patterson and Hennessy)

2.2 How Do We Speak the Language of the Machine
How Do We Speak the Language of the Machine?

- Instruction Set Architecture (ISA) is the portion of the machine visible to the programmer or compiler writer.
  - The basic operations of a computer are defined by its ISA.
  - Because instructions are the only information that the machine understands, an instruction set is also a machine language.
  - Sequences of instructions are called machine language programs, and the act of constructing such programs is machine language programming.

2.3 Instruction Set Architecture
Classification of ISA

- Four dimensions of instruction sets:
  - Operations provided in the instruction set.
  - Number of explicit operands named per instruction.
  - Location of the operands in the CPU and how operand locations are specified.
  - Type and size of operands.

Operations in the ISA

- Important criteria for designing an instruction set are
  - Functional completeness
  - Efficiency (power of the instruction)
  - Simplicity of hardware design and/or programming
Categories of Instructions

1. **Data transfer** - which cause information to be copied from one location to another either in the processor’s internal memory (registers) or in the external main memory.

2. **Arithmetic** - which perform operations on numeric data (e.g., add, subtract...).

3. **Logical** - which include Boolean and other non-numerical operations (e.g., and, not...)

4. **Control transfer** - which change the sequence in which program are executed (jump, conditional branch...)

5. **I/O** - which cause information to be transferred between the processor or its main memory and external I/O devices.

6. **System** - used for operating system call, virtual memory management instructions....

7. Floating point - used for floating point operations.

8. Decimal - decimal arithmetic, decimal-to-character conversions...

9. **String** - string move, compare, search....

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Number of Operands per Instruction

- The number of operands associated with each instruction can be considered in terms of the following issues:
  - Control circuit complexity (decoding).
  - Storage required for instructions (code density).
  - Power of instructions.
  - Number of instructions required to perform a given task.
Example

Let $x$ and $y$ represent memory locations or registers.

- 4-address instruction: No longer in use
  
  \[
  \text{ADD} \quad x + y \rightarrow z, \text{goto } q
  \]

- 3-address instruction: General Purpose Register (GPR) architecture
  
  \[
  \text{ADD} \quad x + y \rightarrow z \quad (q \text{ is implied})
  \]

  \[
  \text{ADD} \quad x + y \rightarrow x, \text{goto } q
  \]

- 2-address instruction: General Purpose Register (GPR) architecture
  
  \[
  \text{ADD} \quad x + y \rightarrow x
  \]

- 1-address instruction: Accumulator-based architecture
  
  \[
  \text{ADD} \quad x \quad (\text{accumulator based})
  \]

- 0-address instruction: Stack architecture
  
  \[
  \text{ADD} \quad \text{(use of a stack)}
  \]

2.4 Instruction Format
Instruction Format

Generic Instruction Format

<table>
<thead>
<tr>
<th>opcode</th>
<th>field₁</th>
<th>...</th>
<th>fieldₖ</th>
</tr>
</thead>
</table>

- **Operation Code**: Specifies the operation to be performed, e.g., add, subtract, shift, branch, etc.
- **Address Fields**: Specifies register identifier, memory addresses, and/or constants.

k bits => \(2^k\) operations

Number of bits in each field depends on the size of register file, memory, or constants.

Tradeoff among sizes of the various fields!

2.4 A Pseudo-ISA
A Pseudo-ISA

- **Data transfer Instructions**
  - **LDA** (Load Accumulator) – Loads a memory word to accumulator
    - LDA x; x is a location in memory
  - **STA** (Store Accumulator) – Stores the contents of accumulator to memory
- **Arithmetic and Logical Instructions**
  - **ADD** (Add to Accumulator) – Adds the content of memory word specified by the effective address to the value of the accumulator.
    - ADD x; x is a location in memory
  - **NAND** (NAND to Accumulator)
  - **SHFT** (Shift Accumulator) - Shifts the content of AC by one bit to the left. The bit shifted in is 0.
- **Control Transfer**
  - **J** (Jump to x) – Transfers the program control to the instruction specified by the address.
    - J x; jump to instruction in memory location x
  - **BNE** (Branch Conditionally to x) – Transfers the program control to the instruction specified by the address based on condition NE (not equal).
    - BNE x; branch to instruction in memory location x if content of AC is not zero

Instruction Format of Pseudo-ISA

1-address Instruction Format

- **Opcode**
- **Address**

\[2^3 = 8 \text{ instructions}\]
\[2^{13} = 8,192 \text{ or } 8K \text{ memory words}\]
Example Assembly Program

```c
:A simple C program
main()
{
    int A=83, B=-23, C=0;
    C = 4*A + B;
}
```

<table>
<thead>
<tr>
<th>Label</th>
<th>Instructions</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>ORG</td>
<td>0</td>
<td>/Origin of the program is location 0</td>
</tr>
<tr>
<td>LDA</td>
<td>A</td>
<td>/Load operand from location A</td>
</tr>
<tr>
<td>SHIFT</td>
<td></td>
<td>/Multiply A by 2</td>
</tr>
<tr>
<td>SHIFT</td>
<td></td>
<td>/Multiply 2*A by 2</td>
</tr>
<tr>
<td>ADD</td>
<td>B</td>
<td>/Add operand from location B</td>
</tr>
<tr>
<td>STA</td>
<td>C</td>
<td>/Store sum in location C</td>
</tr>
<tr>
<td>Loop:</td>
<td>J</td>
<td>/Loop forever</td>
</tr>
<tr>
<td>A:</td>
<td>DEC 83</td>
<td>/Decimal operand</td>
</tr>
<tr>
<td>B:</td>
<td>DEC -23</td>
<td>/Decimal operand</td>
</tr>
<tr>
<td>C:</td>
<td>DEC 0</td>
<td>/Sum stored in location C</td>
</tr>
<tr>
<td>END</td>
<td></td>
<td>/End of symbolic program</td>
</tr>
</tbody>
</table>

Why Program in Assembly?

- For many applications the speed and/or size a program is critically important, e.g., *embedded application*, such as ABS.
  - Need to respond rapidly and predictably to events, e.g., 1 ms after the sensor detects that a tire is skidding.
  - Compiler introduces uncertainty about the time cost of operations. For complex problems, HLL preferable.
Questions?