CS301 Computer Architecture

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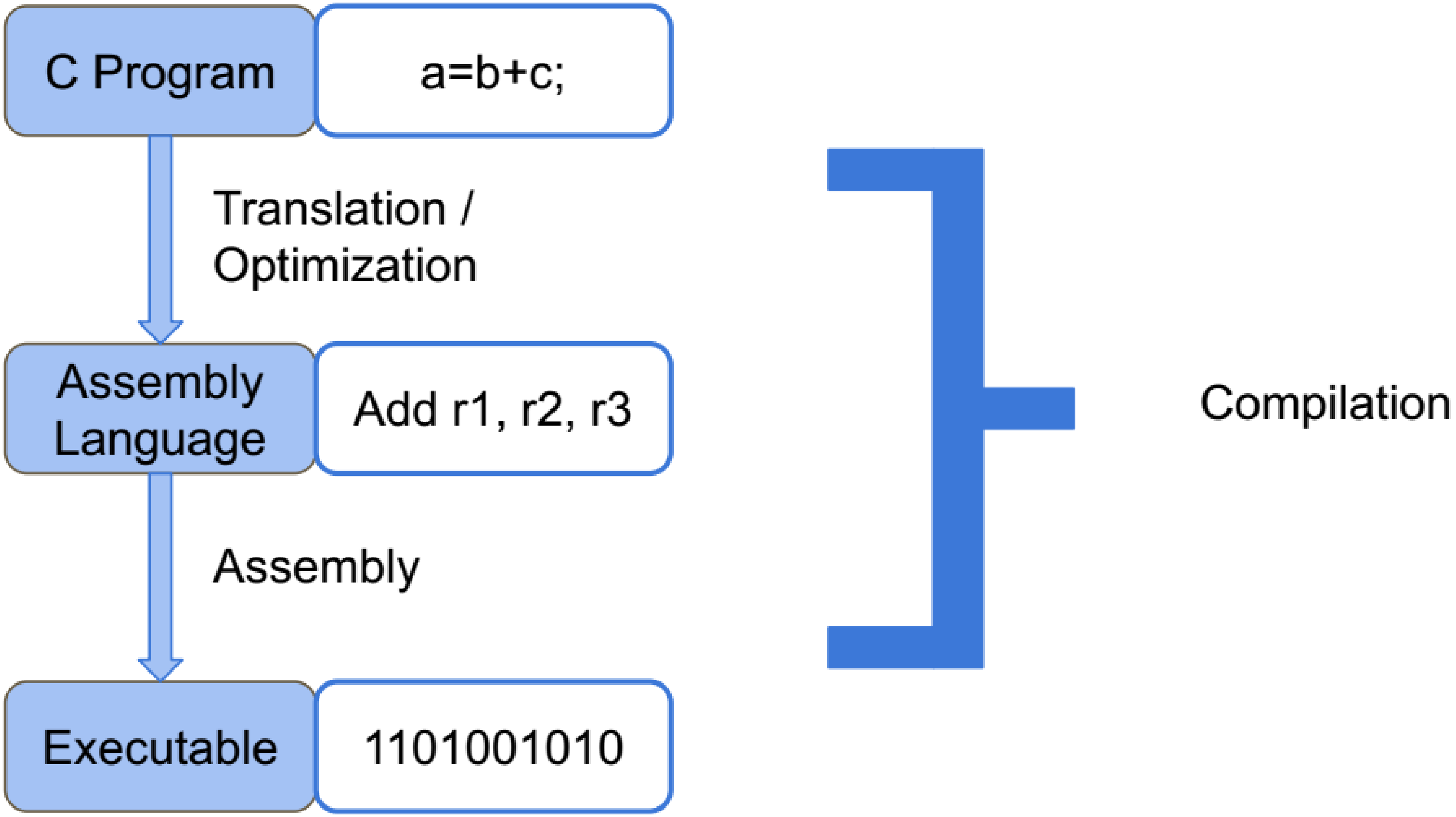
Materials in these slides are borrowed from textbooks and existing Architecture courses

The Language of Instructions

* Humans can understand
  * Complicated sentences
    * English, French, Spanish
* Computers can understand
  * Very simple instructions

The semantics of all the instructions supported by a processor is known as its instruction set architecture (ISA). This includes the semantics of the instructions themselves, along with their operands, and interfaces with peripheral devices.

Compilation and Assembly



Compilation and Assembly

- Write a simple program, and compile it using gcc
- The resultant *a.out* is in machine language, and in binary form
- Try *gcc -S test.c -o test.s* . *test.s* is the assembly program
- To get the binary from the assembly program, run *gcc test.s*

Popular Instruction Set Architectures (ISAs)

x86	Laptops, desktops, servers
ARM	Mobiles, Raspberry Pi
SPARC v8	Leon3 (open project!)
PowerPC	IBM machines
RISC-V	IITM's Shakti processors
SimpleRISC	CS301
ToyRISC	CS311

Features of an ISA

* Example of instructions in an ISA
  * Arithmetic instructions : add, sub, mul, div
  * Logical instructions : and, or, not
  * Data transfer/movement instructions
* Complete
  * It should be able to implement all the programs that users may write.

Features of an ISA – II

* Concise
  * The instruction set should have a limited size. Typically an ISA contains 32-1000 instructions.
* Generic
  * Instructions should not be too specialized, e.g. add14 (adds a number with 14) instruction is too specialized
* Simple
  * Should not be very complicated.

Designing an ISA

- Important questions that need to be answered :
  - How many instructions should we have ?
  - What should they do ?
  - How complicated should they be ?

Two different paradigms : RISC and CISC

RISC
(Reduced Instruction Set Computer)

CISC
(Complex Instruction Set Computer)

McGraw Hill Education

A ***reduced instruction set computer*** (RISC) implements simple instructions that have a simple and regular structure. The number of instructions is typically a small number (64 to 128). Examples: ARM, IBM PowerPC, HP PA-RISC

A ***complex instruction set computer*** (CISC) implements complex instructions that are highly irregular, take multiple operands, and implement complex functionalities. Secondly, the number of instructions is large (typically 500+). Examples: Intel x86, VAX

Summary Uptil Now ...

* Computers are dumb yet ultra-fast machines.
* Instructions are basic rudimentary commands used to communicate with the processor. A computer can execute billions of instructions per second.
* The compiler transforms a user program written in a high level language such as C to a program consisting of basic machine instructions.
* The instruction set architecture(ISA) refers to the semantics of all the instructions supported by a processor.
* The instruction set needs to be complete. It is desirable if it is also concise, generic, and simple.

Completeness of an ISA

How can we ensure that an ISA is complete ?

- Complete means :
  - Can implement all types of programs
  - For example, if we just have add instructions, we cannot subtract (NOT Complete)

McGraw Hill Education

* Single Instruction ISA
  * sbn – subtract and branch if negative

```
1: sbn a, b, 3    // a = a - b; if a < 0, jump to 3
2: sbn c, d, 3
3: sbn e, f, 1
...
```

Let us now design an ISA …

- Single Instruction ISA
  - sbn – subtract and branch if negative
- Add (a + b) (assume temp = 0)

```
1: sbn temp, b, 2
2: sbn a, temp, exit
```

Single Instruction ISA

*

```
Initialization:
        one  = 1
        index = 10
        sum = 0
```

```
1: sbn temp, temp, 2        // temp = 0
2: sbn temp, index, 3       // temp = -1 * index
3: sbn sum, temp, 4         // sum += index
4: sbn index, one, exit     // index -= 1
5: sbn temp, temp, 6        // temp = 0
6: sbn temp, one, 1         // (0 - 1 < 0), hence goto 1
```

exit

Single Instruction ISA - II

- Add the numbers – 1 … 10

```
Initialization:
        one  = 1
        index = 10
        sum = 0
```

```
1: sbn temp, temp, 2        // temp = 0
2: sbn temp, index, 3       // temp = -1 * index
3: sbn sum, temp, 4         // sum += index
4: sbn index, one, exit     // index -= 1
5: sbn temp, temp, 6        // temp = 0
6: sbn temp, one, 1         // (0 - 1 < 0), hence goto 1
```

exit

Single Instruction ISA - III

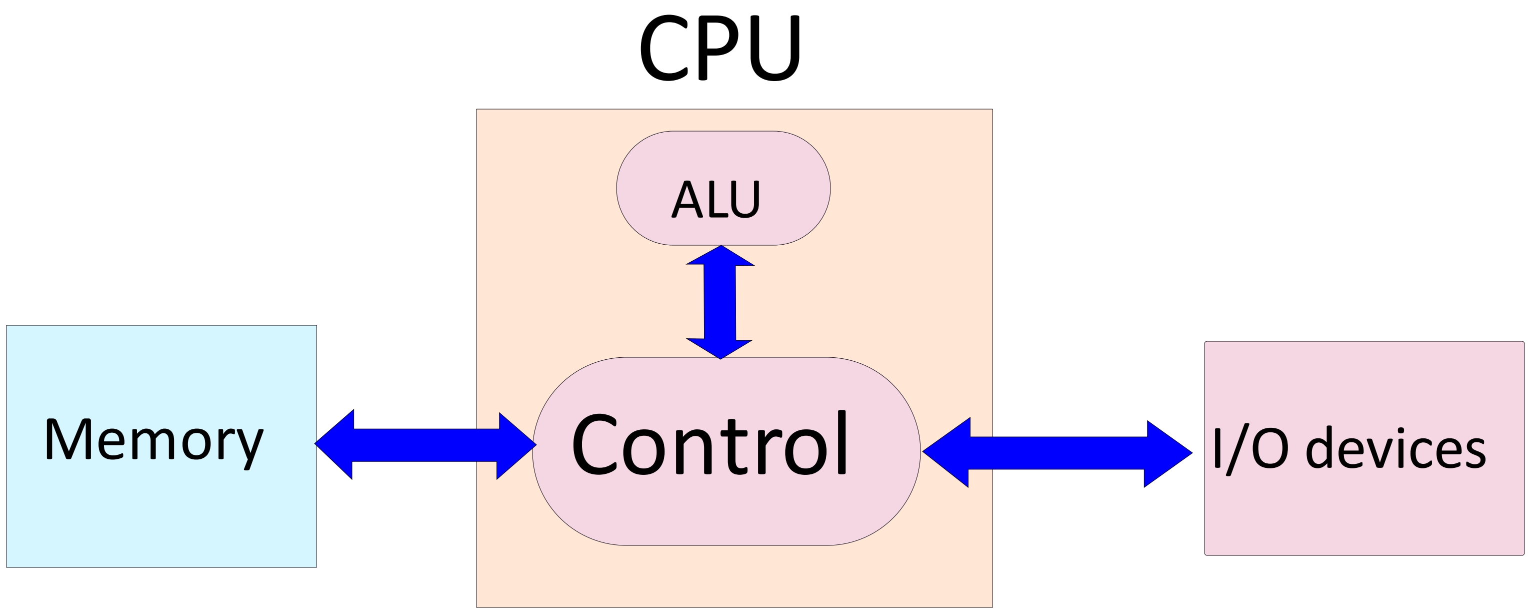
* Find whether a number is positive

- The given number is at address ‘number’
- If num is positive, write ‘0’ to address ‘result’; if negative, write ‘-1’
- Initialization: ‘one’ = 1

Multiple Instruction ISA

* Arithmetic and Logical Instructions
  * add, subtract, multiply, divide, or, and, not
* Move instructions
  * Transfer values between memory locations
* Branch instructions
  * Move to a new program location, based on the values of some memory locations

Von-Neumann Architecture



Problems with Harvard/ Von-Neumann Architectures

- The memory is assumed to be one large array of bytes
  - It is very very slow

General Rule: Larger is a structure, slower it is

- Solution:
  - Have a small array of named locations **(registers)** that can be used by instructions
  - This small array is very fast

Insight: Accesses exhibit locality (tend to use the same variables frequently in the same window of time)

Uses of Registers

* A CPU (Processor) contains set of registers (16-64)
* These are named storage locations.
* Typically values are loaded from memory to registers.
* Arithmetic/logical instructions use registers as input operands
* Finally, data is stored back into their memory locations.

Example of a Program in Machine Language with Registers

```
1: r1 = mem[b] // load b
2: r2 = mem[c] // load c
3: r3 = r1 + r2 // add b and c
4: mem[a] = r3 // save the result
```

- r1, r2, and r3, are registers
- mem → array of bytes representing memory

Machine with Registers