Computer Architecture

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The Von Neumann Model/Architecture

- Also called stored program computer (instructions in memory).
- Two key properties:
  - Stored program
    - Instructions stored in a linear memory array
    - Memory is unified between instructions and data
      - The interpretation of a stored value depends on the control signals
        - When is a value interpreted as an instruction?
  - Sequential instruction processing
    - One instruction processed (fetched, executed, and completed) at a time

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A computing System (Reminder)

- What is a computer?
  - in terms of what?
    - Functional
    - Structural

Functional definition

- Data processing
- Data storage
- Data movement
- Control

Structural definition

- Central processing unit
- Main memory
- Input/Output
- System interconnection

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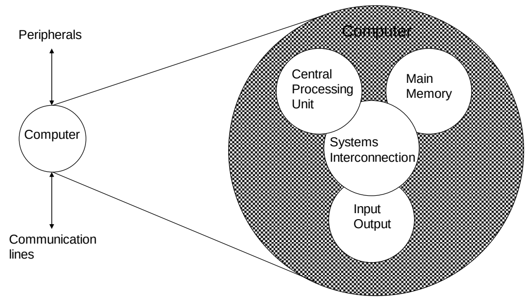
Structure - Top Level



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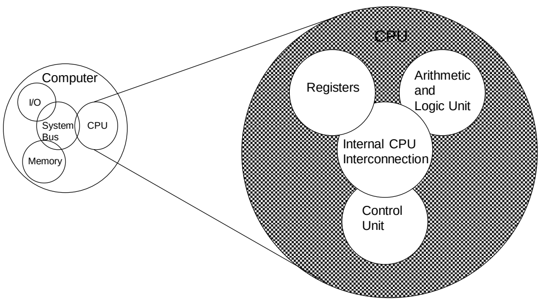
Structure - The CPU



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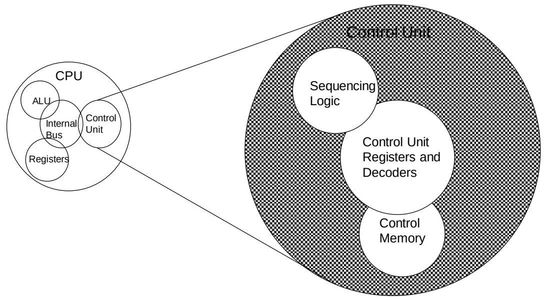
Structure - The Control Unit



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The Stored Program Computer

- 1943: ENIAC
  - Presper Eckert and John Mauchly -- first general electronic computer. **(or was it John V. Atanasoff in 1939?)**
  - Hard-wired program -- settings of dials and switches.
- 1944: Beginnings of EDVAC
  - among other improvements, includes program stored in memory
- 1945: John von Neumann
  - wrote a report on the stored program concept, known as the *First Draft of a Report on EDVAC*
- The basic structure proposed in the draft became known as the “von Neumann machine” (or model).
  - a *memory*, containing instructions and data
  - a *processing unit*, for performing arithmetic and logical operations
  - a *control unit*, for interpreting instructions

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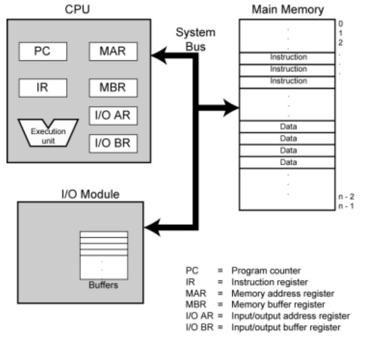
Von Neumann Model



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ENIAC - details

http://www.seas.upenn.edu/~museum/

- Decimal (not binary)
- 20 accumulators of 10 digits
- Programmed manually by switches
- 18,000 vacuum tubes
- 30 tons
- 15,000 square feet
- 140 kW power consumption
- 5,000 additions per second

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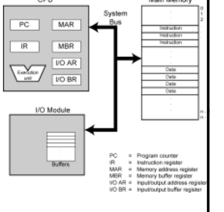
Interface to Memory

- How does processing unit get data to/from memory?
- MAR: Memory Address Register
- MBR (MDR): Memory Buffer (Data) Register



To LOAD a memory location (A):

1. Write the address (A) into the MAR.
2. Send a “read” signal to the memory.
3. Read the data from MBR.

To STORE a value (X) to a location (A):

1. Write the data (X) to the MBR.
2. Write the address (A) into the MAR.
3. Send a “write” signal to the memory.

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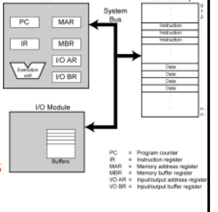
Processing Unit

- Functional Units (Execution unit)
  - ALU = Arithmetic and Logic Unit
  - could have many functional units. some of them special-purpose (multiply, square root, …)
- Registers
  - Small, temporary storage
  - Operands and results of functional units
- Word Size
  - number of bits normally processed by ALU in one instruction
  - also width of registers



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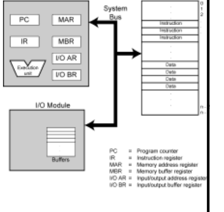
Input and Output

- Devices for getting data into and out of computer memory
- Each device has its own interface, usually a set of registers (I/OAR and I/OBR)
- Some devices provide both input and output
  - disk, network
- Program that controls access to a device is usually called a *driver*.



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Control Unit

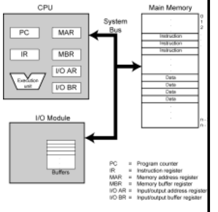
•Orchestrates execution of the program

•Instruction Register (IR) contains the *current instruction*.

•Program Counter (PC) contains the *address* of the next instruction to be executed.

•Control unit:

– reads an instruction from memory
  • the instruction's address is in the PC
– interprets the instruction, generating signals that tell the other components what to do
  • an instruction may take many *machine cycles* to complete



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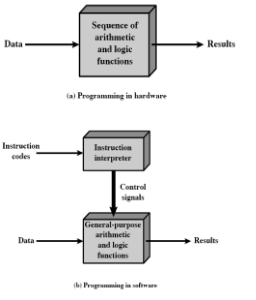
Program Concept

- Hardwired systems are inflexible
- General purpose hardware can do different tasks, given correct control signals
- Instead of re-wiring, supply a new set of control signals



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What is a program?

- A sequence of steps
- For each step, an arithmetic or logical operation is done
- For each operation, a different set of control signals is needed

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Instruction Processing

Fetch instruction from memory

Decode instruction

Evaluate Address

fetch OPerands from memory

EXecute operation

Store result

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Instruction

•The instruction is the fundamental unit of work.

•Specifies two things:

– opcode: operation to be performed
– operands: data/locations to be used for operation

•An instruction is encoded as a sequence of bits.
(*Just like data!*)

– **Often, but not always, instructions have a fixed length, such as 16 or 32 bits.**
– **Control unit interprets instruction: generates sequence of control signals to carry out operation.**
– **Operation is either executed completely, or not at all.**

•A computer's instructions and their formats is known as its ***Instruction Set Architecture (ISA)***.

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Instruction Processing: FETCH

•Load next instruction (at address stored in PC) from memory
into Instruction Register (IR).

– Copy contents of PC into MAR.
– Send "read" signal to memory.
– Copy contents of MBR into IR.

•Then increment PC, so that it points to the next instruction in sequence.

– PC becomes PC+1.

F → D → EA → OP → EX → S

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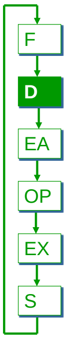
Instruction Processing: DECODE

- First identify the opcode.
  - A n-to-2^n decoder asserts a control line corresponding to the desired opcode.
- Depending on opcode, identify other operands from the remaining bits.



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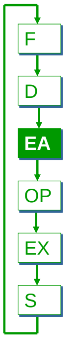
Instruction Processing: EVALUATE ADDRESS

- For instructions that require memory access, compute address used for access.
- Examples:
  - add offset to base register
  - add offset to PC
  - add offset to zero



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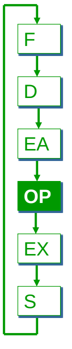
Instruction Processing: FETCH OPERANDS

- Obtain source operands needed to perform operation.
- Examples:
  - load data from memory (LDA)
  - read data from register file (ADD)



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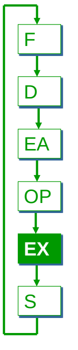
Instruction Processing: EXECUTE

- Perform the operation, using the source operands.
- Examples:
  - send operands to ALU and assert ADD signal
  - do nothing (e.g., for loads and stores)



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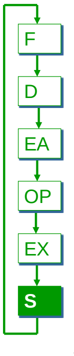
Instruction Processing: STORE RESULT

- Write results to destination. (register or memory)
- Examples:
  - result of ADD is placed in destination register
  - result of memory load is placed in destination register
  - for store instruction, data is stored to memory
    - write address to MAR, data to MBR
    - assert WRITE signal to memory



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Changing the Sequence of Instructions

- In the FETCH phase, we increment the Program Counter by 1.
- What if we don't want to always execute the instruction that follows this one?
  - examples: loop, if-then, function call
- Need special instructions that change the contents of the PC.
- These are called *control instructions*.
  - jumps are unconditional -- they always change the PC
  - branches are conditional -- they change the PC only if some condition is true (e.g., the result of an ADD is zero)

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Instruction Processing Summary

•Instructions look just like data -- it's all interpretation.

•Four basic kinds of instructions:
- Data processing instructions
  - Arithmetic and logic instructions (ADD, AND, …)
- Data storage instructions
  - Memory instructions (LDA, STA)
- Data movement instructions
  - I/O instructions (IN, OUT, …)
- Program flow control instructions
  - Test and branch instructions (JMP, BRP, …)

•Six basic phases of instruction processing:

F → D → EA → OP → EX → S

- not all phases are needed by every instruction
- phases may take variable number of machine cycles

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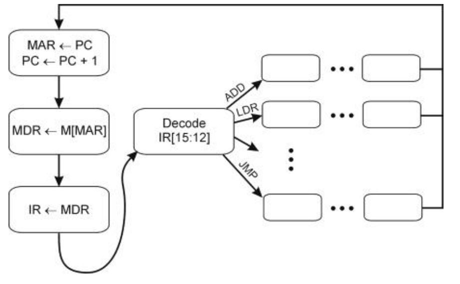
Control Unit State Diagram

•The control unit is a state machine.

•Here is part of a simplified state diagram:



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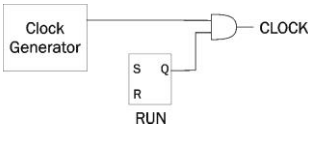
Stopping the Clock

•Control unit will repeat instruction processing sequence as long as clock is running.
- **If not processing instructions from your application, then it is processing instructions from the Operating System (OS).**
- **The OS is a special program that manages processor and other resources.**

•To stop the computer:
- **AND the clock generator signal with ZERO**
- **When control unit stops seeing the CLOCK signal, it stops processing.**



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Dataflow Model of a Computer

Von Neumann model
- An instruction is fetched and executed in control flow order
  - As specified by the instruction pointer
  - Sequential unless explicit control flow instructio

Dataflow model
- An instruction is fetched and executed in data flow order
  - i.e., when its operands are ready
  - i.e., there is no instruction pointer
  - Instruction ordering specified by data flow dependence
    - Each instruction specifies "who" should receive the result
    - An instruction can "fire" whenever all operands are received
  - Potentially many instructions can execute at the same time
  - Inherently more parallel

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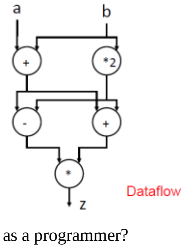
von Neumann vs Dataflow

- Consider a von Neumann program (sequential) vs dataflow execution

```
v <= a + b;
w <= b * 2;
x <= v - w
y <= v + w
z <= x * y
```

Sequential



Dataflow

- Which model is more natural to you as a programmer?
- All major instruction set architectures today use von Neumann
  - x86, ARM, MIPS, SPARC, Alpha, POWER PC

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