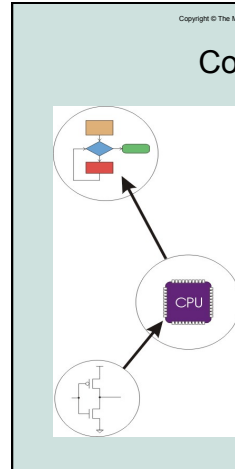


Chapter 4 The Von Neumann Model

Original slides from Gregory Byrd, North Carolina State University
Modified slides by Chris Wilcox, Colorado State University

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Computing Layers



- Problems
-
- Algorithms
-
- Language
-
- Instruction Set Architecture
-
- Microarchitecture ←
-
- Circuits
-
- Devices

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The Stored Program Computer

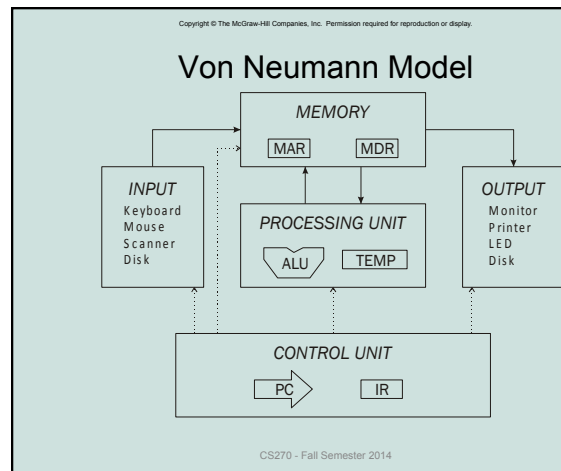
- ◆ 1943: ENIAC
 - Presper Eckert and John Mauchly -- first general electronic computer. (or was it John V. Atanasoff in 1939?)
 - Hard-wired program -- settings of dials and switches.
- ◆ 1944: Beginnings of EDVAC
 - among other improvements, includes program stored in memory
- ◆ 1945: John von Neumann
 - 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

For more history, see <http://www.maxmon.com/history.htm>

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Von Neumann Model



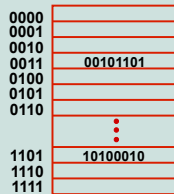
```

graph TD
    INPUT[INPUT  
Keyboard  
Mouse  
Scanner  
Disk] --> MEMORY
    MEMORY --> OUTPUT[OUTPUT  
Monitor  
Printer  
LED  
Disk]
    MEMORY <--> PU[PROCESSING UNIT]
    PU <--> CU[CONTROL UNIT]
    CU <--> INPUT
    CU <--> OUTPUT
  
```

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Memory

- ◆ **Organization**
 - $2^k \times m$ array of stored bits
- ◆ **Address**
 - unique (k -bit) identifier of location
- ◆ **Contents**
 - m -bit value stored in location
- ◆ **Basic Operations:**
 - **LOAD:** read a value from a memory location
 - **STORE:** write a value to a memory location



Interface to Memory

- ◆ How does CPU get data to/from memory?
 - **MAR:** Memory Address Register
 - **MDR:** Memory Data Register
- ◆ To **LOAD** a location (A):
 1. Write the address (A) into the MAR.
 2. Send a “read” signal to the memory.
 3. Read the data from MDR.
- ◆ To **STORE** a value (X) to a location (A):
 1. Write the data (X) to the MDR.
 2. Write the address (A) into the MAR.
 3. Send a “write” signal to the memory.



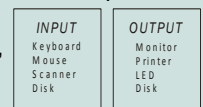
Processing Unit

- ◆ **Functional Units**
 - ALU = Arithmetic and Logic Unit
 - could have many functional units. (multiply, square root, ...)
 - LC-3 performs ADD, AND, NOT
- ◆ **Registers**
 - Small, temporary storage
 - Operands and results of functional units
 - LC-3 has eight registers (R0, ..., R7), each 16 bits wide
- ◆ **Word Size**
 - number of bits processed by ALU in one instruction
 - also width of registers
 - LC-3 is 16 bits



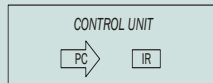
Input and Output

- ◆ Devices for getting data into and out of computer memory
- ◆ Each device has its own interface, usually a set of registers like the memory's MAR and MDR
 - LC-3 supports keyboard (input) and monitor (output)
 - keyboard: data (KBDR) and status (KBSR) registers
 - monitor: data register (DDR) and status register (DSR)
- ◆ Some devices provide both input and output
 - disk, network
- ◆ Program that controls access to a device is usually called a *driver*.

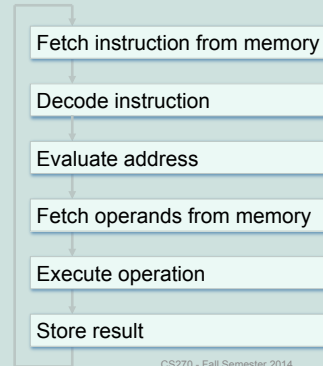


Control Unit

- 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



Instruction Processing



Instruction

- The instruction is the fundamental unit of work:
 - 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)**.

Example: LC-3 ADD Instruction

- LC-3 has 16-bit instructions.
 - Each instruction has a four-bit opcode, bits [15:12].
- LC-3 has eight *registers* (R0-R7) for temporary storage.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
ADD				Dst				Src1				0	0	0	Src2
0	0	0	1	1	1	0	0	1	0	0	0	0	1	1	0

"Add the contents of R2 to the contents of R6, and store the result in R6."

Example: LC-3 LDR Instruction

- ◆ Load instruction -- reads data from memory
- ◆ Base + offset mode:
 - add offset to base register -- result is memory address
 - load from memory address into destination register

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
LDR				Dst			Base			Offset					
0	1	1	0	0	1	0	0	1	1	0	0	0	1	1	0

"Add the value 6 to the contents of R3 to form a memory address. Load the contents of that memory location to R2."

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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 MDR into IR.
- ◆ Then increment PC, so that it points to the next instruction in sequence.
 - PC becomes PC+1.



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Instruction Processing: DECODE

- ◆ First identify the opcode.
 - In LC-3, this is always the first four bits of instruction.
 - A 4-to-16 decoder asserts a control line corresponding to the desired opcode.
- ◆ Depending on opcode, identify other operands from the remaining bits.
 - Example:
 - ◆ for LDR, last 6 bits is offset
 - ◆ for ADD, last 3 bits is source operand #2



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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 (as in LDR)
 - 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 (LDR)
 - 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 MDR
 - 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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Example: LC-3 JMP Instruction

- Set the PC to the value contained in a register. This becomes the address of the next instruction to fetch.

15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
JMP				0	0	0	Base			0	0	0	0	0	0
15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
1	1	0	0	0	0	0	0	1	1	0	0	0	0	0	0

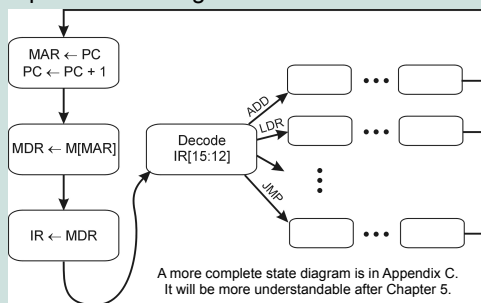
"Load the contents of R3 into the PC."

Instruction Processing Summary

- Instructions look just like data -- it's all interpretation.
- Three basic kinds of instructions:
 - computational instructions (ADD, AND, ...)
 - data movement instructions (LD, ST, ...)
 - control instructions (JMP, BRnz, ...)
- 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

Control Unit State Diagram

- The control unit is a state machine. Here is part of a simplified state diagram for the LC-3:



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.

