Introduction to Computer Systems

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Spring 2020

Week 4a: Data storage, the CPU and the Machine Cycle

Worksheet 3

- Show that NOT(A OR B) is equivalent to
  NOT(A) AND NOT(B)
- Use AND, OR and NOT to make an expression equivalent to A XOR B. Then use AND and NOT to replace OR
- Hex: A7+B9, 11-A, A4*12
- Two's complement , excess and floating point versions of the same number but which is which?
  10000010, 01101000, 00000010

Magnetic Disk or Hard Disk

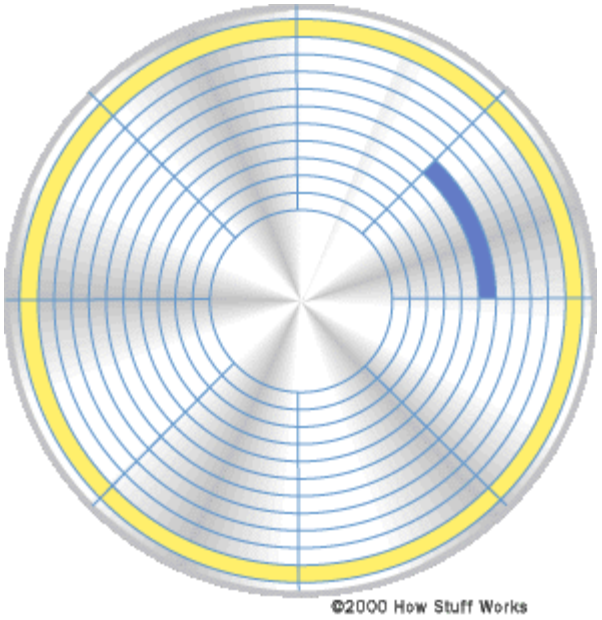
- Platter: brown disk (x3)
- Surfaces: highly polished magnetic recording material
- Arm with 6 read/write heads: one for each side of each platter
- Arm movement: swings between the outer rim and the inner boundary
- The read/write heads skim the platter but do not touch it

image: http://computer.howstuffworks.com/hard-disk.htm
text: adapted from "How Hard Disks Work"

Organisation of an MD

- Data is stored in concentric circular tracks on the disk
- Each track is divided into sectors.
- The tracks have the same number of sectors. The sectors have the same size, e.g. 512 Bytes or 1024 Bytes
- Each bit is stored by magnetizing a small region of the disk surface
- Formatting: creation of tracks and sectors on a disk. Any previous contents become inaccessible.

Tracks and Sectors



- Yellow: typical track
- Blue: typical sector
- Formatting: the start and end points of each sector are written onto the disk.

image and text:
http://computer.howstuffworks.com/hard-disk7.htm

Definitions

- Seek time: time to move head to the correct track
- Latency: time for correct sector to move to the head ≈ (1/2) time for 1 revolution
- Access time = seek time+latency
- Data transfer rate: rate at which bits can be read from or written to the disk

Typical Values for a Magnetic Disk

- Seek time: 9 ms
- Latency: 3 ms
- Data rate: 125 MBytes/sec
- Capacity: 15 TBytes
- Rotation rate: 10,000 rev/min
- Area for storing 1 bit: 200x25 sq nm
- Storage density: 200 Gbit/sq cm

https://en.wikipedia.org/wiki/Hard_disk_drive_performance_characteristics
https://en.wikipedia.org/wiki/Hard_disk_drive_platter
https://en.wikipedia.org/wiki/Hard_disk_drive

Question 1

- A magnetic disk turns at 6000 revs/min. Find the time in ms for a single revolution. When a request to read is received there is on average a delay of 14 ms before the reading of the data begins.

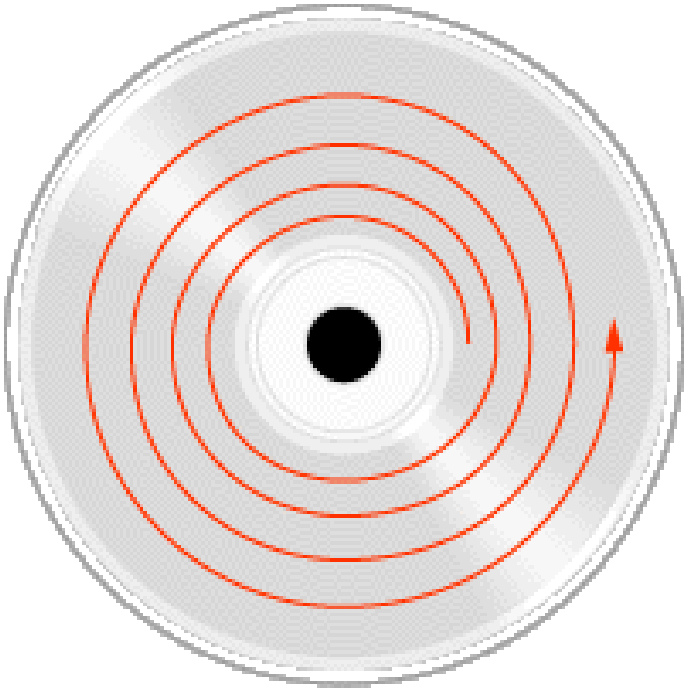
- Estimate the seek time and the latency in ms.

Question 2

- A magnetic disk turns at 6000 revs/min. It reads data at a rate of 125 MB/sec. Estimate the amount of data in bytes that can be read in one revolution of the disk. Assume that the read head is initially in the correct position.

- If each sector contains 2KB then how many sectors are there in a track?

Compact Disk

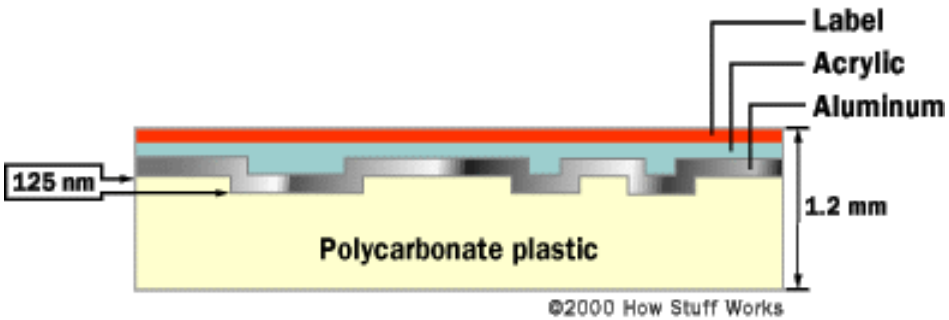


Spiral track:
spacing between turns:
1.6 microns (1.6x10^(-6)m)
width: 0.5 microns
total length: 5 km!

Disk read from below using near infra red laser, wavelength 780 nm.

http://electronics.howstuffworks.com/cd2.htm

Cross Section of CD-R Disk



Bumps. Width: 0.5 micron
Length: 0.83 micron
Ht: 0.126 micron

CD-RW: no bumps, but same spiral track.

Fabrication: injection moulding.

http://electronics.howstuffworks.com/cd1.htm

Organisation of a CD-R

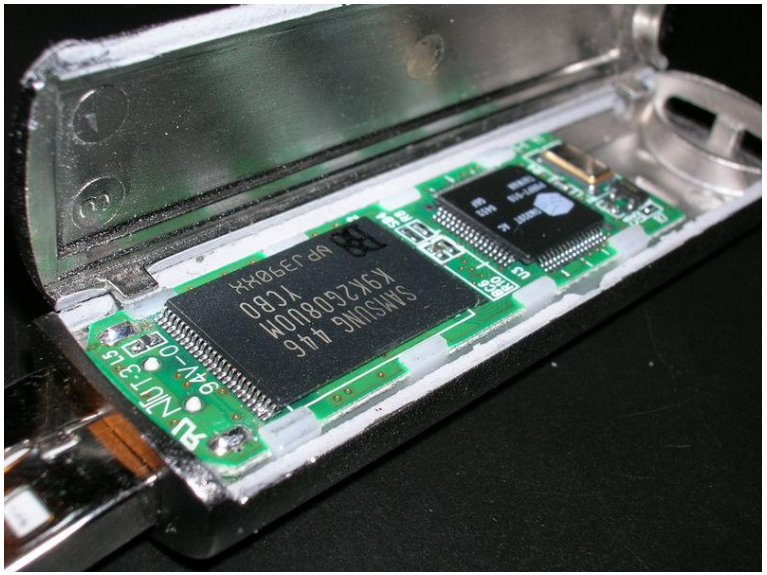
- Single spiral track read from the centre outwards
- Bit density along track is constant
- Track divided into sectors ~ 2 KB. Total capacity ~ 0.8 GB (Blu Ray 4 GB)
- Each bit stored as a mark or “bump” on the surface, and read using laser light.

Organisation of Magnetic Tape

- Each bit is stored by magnetising a small region of the tape surface.
- Reliable, cheap. Formerly the only way to store GBs of data
- Large access times, as tape is read sequentially.

Compact audio cassette
https://en.wikipedia.org/wiki/Magnetic_tape

Flash Memory



- Bits stored by accumulating charge in small chambers.
- Shock resistant: no moving parts
- Cost/bit > Hard drive cost/bit.
- Eventually damaged by repeated use (approx 10^5 write/erase cycles).

USB flash memory device
https://en.wikipedia.org/wiki/Flash_memory

Random Access Memory (RAM)

- Fast electronic memory.
- Used for computer main memory (primary storage).
- Holds data and programs during run time.
- Very fast read and write times.
- Usually volatile

Common RAM packages http://en.wikipedia.org/wiki/Random_access_memory

Definition of Random Access

- The cells in the memory can be accessed individually
- Read times and write times do not vary from cell to cell
- Example: main memory RAM
- The following are not random access: magnetic disk, CD, magnetic tape

Main Memory

- Mostly DRAM (dynamic RAM): electric power is needed to refresh the memory
- Small non-volatile part for booting (start up)
- The CPU reads from and writes to the main memory
- Very fast read and write (nano seconds)

Organisation of Main Memory (RAM)

- Physical: each bit is stored by a small electrical circuit.
- Logical: a list of cells or words addressed from 0 to 2^n-1, 8<=n<=30.
- All cells contain the same number of bytes, e.g. 1 byte.

…	19	28	43	21	0	7	56	84	21	21	23	11	…
	34	35	36	37	38	39	40	41	42	43	44	45	

Volatile and Non-Volatile Memory

- Volatile: memory contents lost if the power is switched off, e.g. main memory
- Non-volatile: memory contents retained if the power is switched off, e.g. magnetic disk.

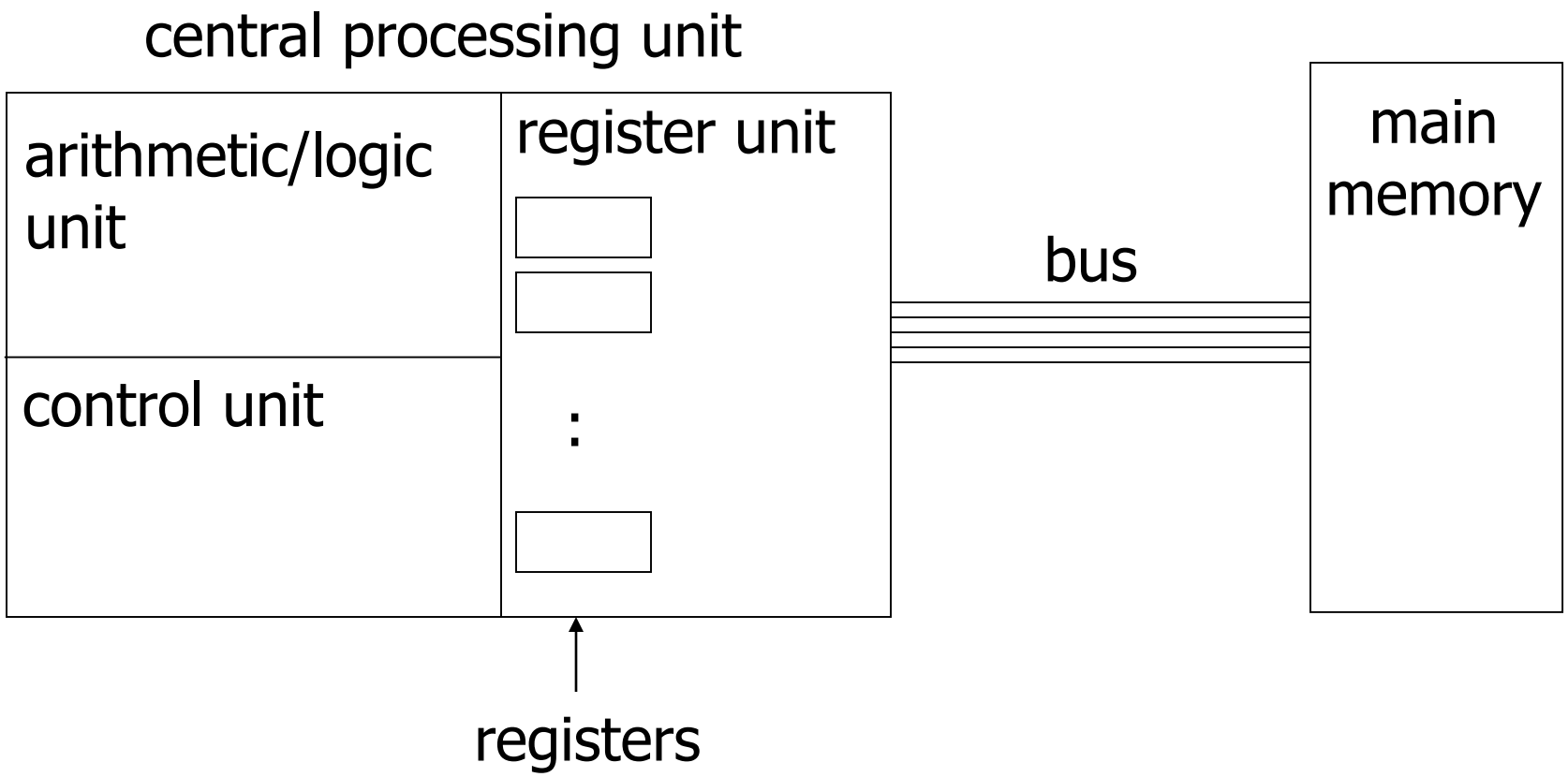
Devices For Storing Data

Device	**Physical Basis**	**Moving Parts?**	**Volatile?**
Hard Drive	Magnetic	Yes	No
CD	3D Shape	Yes	No
Tape	Magnetic	Yes	No
Integ. Circuit (Flash)	Electronic	No	No
Integ. Circuit (RAM)	Electronic	No	Yes

Memory Access Times

	Access Time	Size
CPU registers	2.5ns	256 bit
RAM	60 ns	~1 GB
Hard disk	15 ms	2 TB
Tape	10min	10 TB

Computer Architecture



Bus

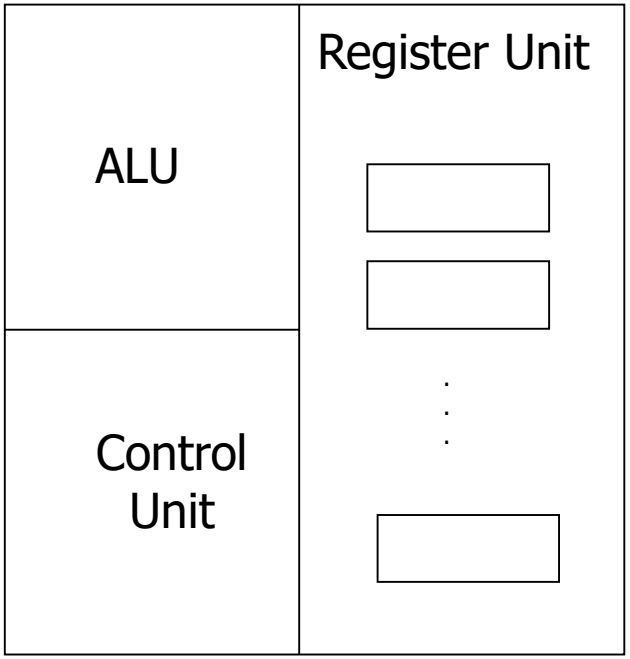
- Wires connecting CPU to main memory.
- Read: CPU sends read signal and address of memory cell.
- Write: CPU sends write signal, address, and data to be written.
- Length ~15cm. Speed of light = 30cm in 1 ns.

  Time for CPU to access a register ~ 2.5 ns.

  The bus should be short.

Central Processing Unit

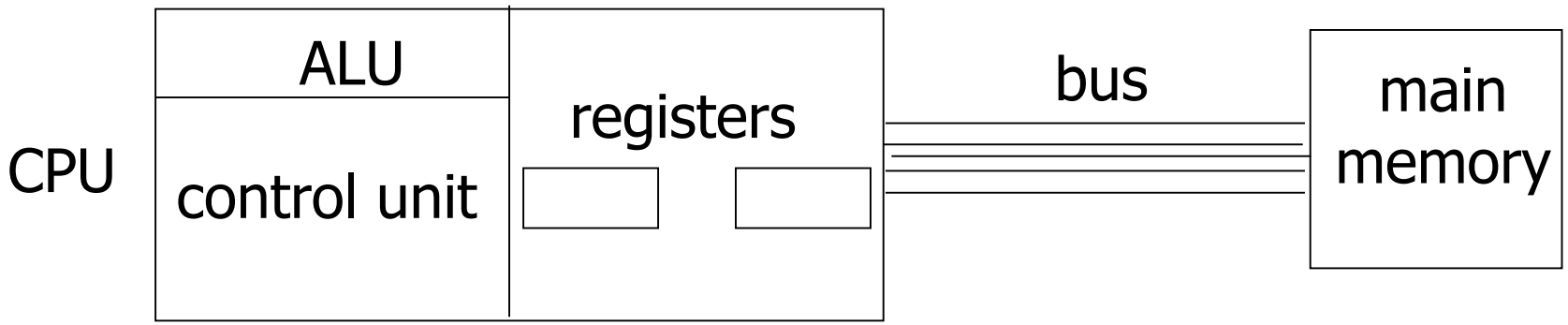
- Register: small amount of very fast read/write memory, e.g. enough to store one number.
- Arithmetic/Logic Unit: operates on data in registers, e.g. addition, subtraction.
- Control Unit: controls the ALU.



Summary of the Actions of the CPU

- Obtain an instruction from main memory
- Decode the instruction
- Carry out the instruction (calculate, transfer data …)
- The CPU uses registers to store data while carrying out instructions

Example Program



1. Take a bit string from main memory and load it in register 1
2. Take a bit string from main memory and load it in register 2
3. Add the contents of registers 1, 2. Put the result in reg. 3
4. Store the contents of register 3 in main memory

System Clock

- Circuit generating pulses at regular intervals
- The computer's activities are in step with the pulses, e.g. 5 pulses for an addition
- Current clock speeds ~ 2 GHz. (=2 pulses per nanosecond)
- Clock speed only a rough guide to performance, e.g. instructions per second

Stored Program Concept

- The program is stored in main memory along with the data. This is the von Neumann architecture
- The control unit loads both instructions and data from the main memory
- Advantage: the program can be changed easily
- Disadvantage: high traffic on the bus. This is the von Neumann bottleneck

Von Neumann Bottleneck

Faster CPUs +
Fixed data transfer rate
from memory

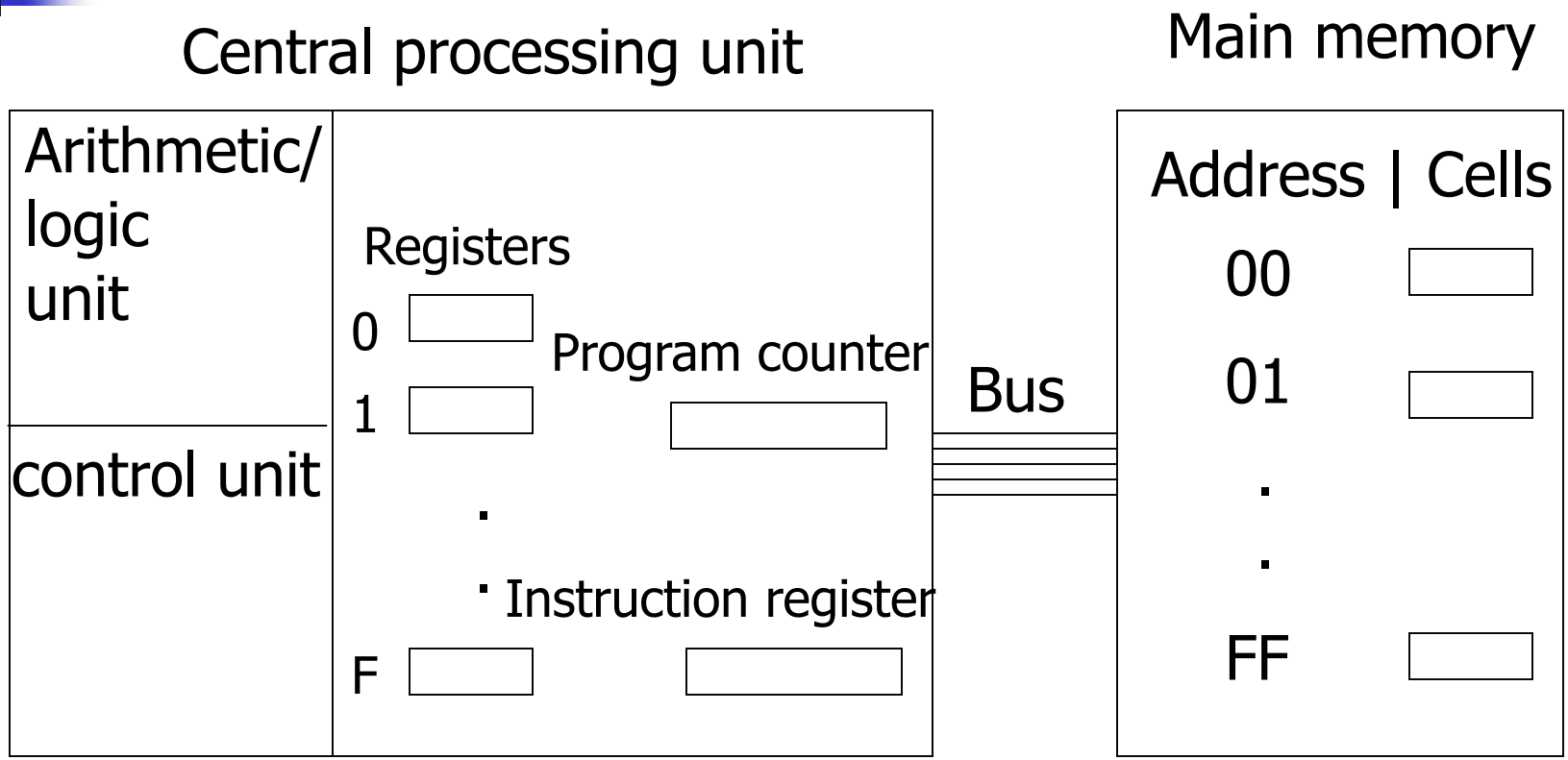
→

CPU idle
during data
transfer

- Possible solutions
  - Caching – additional fast memory in CPU
  - Prefetching – predict which data from memory will be required
  - Multithreading – parallel memory access

http://whatis.techtarget.com/definition/von-Neumann-bottleneck

CPU and Main Memory in More Detail



Special Registers

- Program counter: contains the address of the next instruction to be executed
- Instruction register: holds the instruction which is being executed

Example of an Instruction

- Hexadecimal code: 156C
- 1: Load data from a memory cell to a register
- 5: Register 5
- 6C: memory address

Data in the Machine for 156C

registers

⋮

5 | A7

program counter

03

instruction register

156C

main memory

01	15
02	6C
03	16
04	6D
⋮	
6C	A7

Bit Allocations

registers

4 bits | 8 bits

program counter

8 bits

instruction register

16 bits

main memory

8 bits | 8 bits

- Each memory address can be stored in a single cell
- Each instruction is stored in two memory cells
- Each register and each memory cell store the same number (8) of bits

Counting Bits

- Number of different types of instruction: 13
- Number of bits to specify a memory cell: 8
- Number of bits to specify a register: 4
- Data transfer:

  identify instruction/register/memory cell

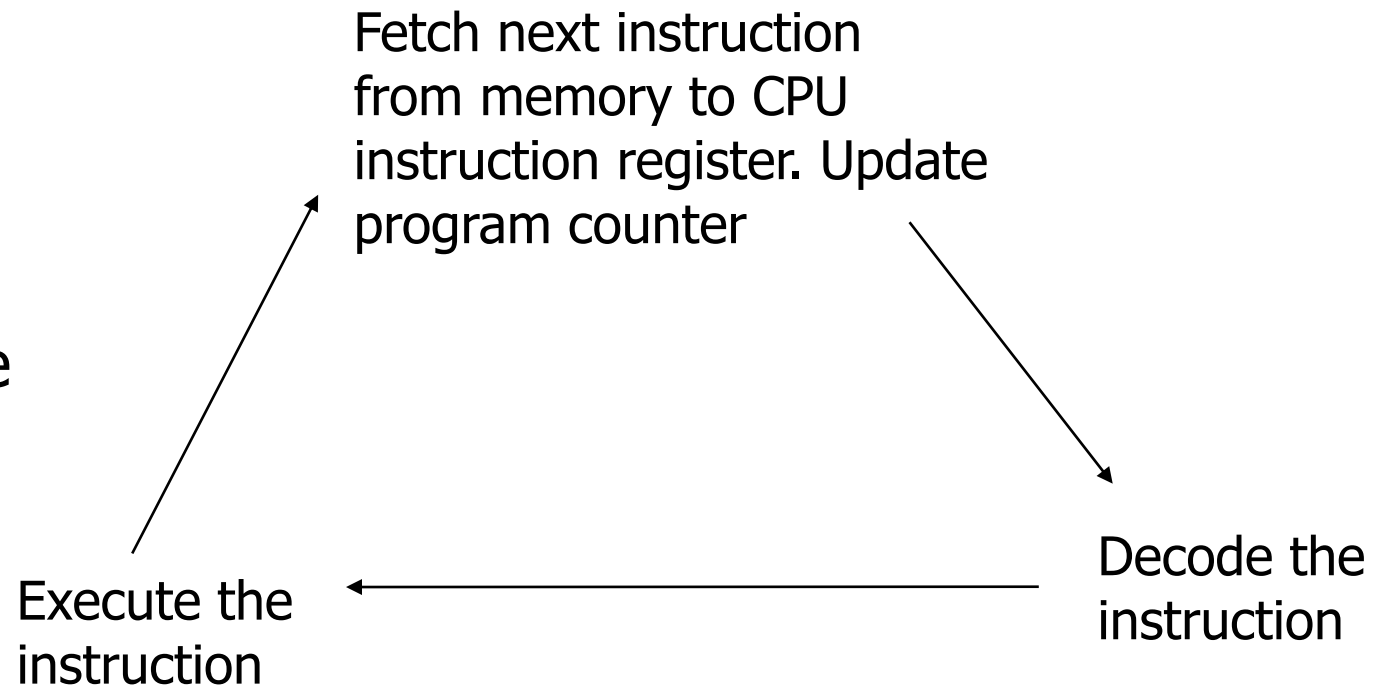
  = 4+4+8 = 16 bits
- Calculation:

  identify instruction/register1/register2/register3

  = 4+4+4+4 = 16 bits

The Machine Cycle

Fetch
Decode
Execute



Questions

- Write the instruction 156C as a string of bits

- A block of data is stored in memory from address 98 to A2 inclusive. How many memory cells are in the block? How many bits are stored?