Show how to connect three Full Adders to implement a 3-bit “ripple-carry” adder.
Reg. A

Reg. B

Reg. Sum
Chapter 5
Computing Components

Yet another layer of abstraction!

<table>
<thead>
<tr>
<th>Components</th>
<th>Circuits</th>
<th>Gates</th>
<th>Transistors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>
5.1 Individual Computer Components

Consider the following ad:

Insatavialion 640 Laptop

Exceptional Performance and Portability!

- Intel® Core™ 2 Duo (2.66GHz/1066Mhz FSB/6MB cache)
- 15.6” High Definition (1080p) LED Backlit LCD Display (1366 x 768)
- 512MB ATI Mobility Radeon Graphics
- Built-in 2.0MP Web Camera
- 4GB Shared Dual Channel DDR2 at 800MHz
- 500GB SATA Hard Drive at 5400RPM
- 8X Slot Load DL DVD+/- RW Drive
- 802.11 a/g/n and Bluetooth 3.0
- 85 WHr Lithium Ion Battery
- (2) USB 2.0, HDMI, 15-pin VGA, Ethernet 10/100/1000, IEEE 1394 Firewire, Express Card, Audio line-in, line-out, mic-in
- 14.8W X 1.2H X 10.1D, 5.6 lbs
- Microsoft® Windows 7® Professional
- Microsoft® Office Home and Student 2007
- 36-Month subscription to McAfee Security Center Anti-virus
What does all this jargon mean?

• Intel® Core™ 2 Duo (2.66GHz/1066Mhz FSB/6MB cache)
• 4GB Shared Dual Channel DDR2 at 800 MHz
• 500 GB SATA Hard Drive at 5400RPM
• 15.6” High Definition (1080p) LED Backlit LCD Display (1366 x 768)
• 8X Slot Load DL DVD+/- RW Drive
• 14.8” W X 1.2” H X10.1” D, 5.6 lbs.
• 512 MB ATI Mobility Radeon Graphics
• 85 WHr Lithium Ion Battery
• (2) USB 2.0, HDMI, 15-Pin VGA, Ethernet 10/100/1000 IEEE 1394 Firewire, Express Card, Audio line-in, line-out, mic-in

Be patient! You don't know them now, but you will get used to them.
When referring to computer memory, mega does not mean one million! (but it’s still close to that)
Decimal vs. binary multipliers

\[1000 = 10^3 \quad 1,000,000 = 10^6 \quad 1,000,000,000 = 10^9\]

\[1024 = 2^{10} \quad 1024\times1024 = 2^{20} \quad 1024\times1024\times1024 = 2^{30}\]

Rule:
For memory capacities, the multipliers are binary, for everything else (speed, frequency, pixels, etc.) they are decimal.
What is the meaning of:

- 1.5 TB hard-disk
- 54 Mbps wireless Ethernet
- 6 GB of RAM
- 8 Mega-pixel camera
- 3.2 GHz CPU
<table>
<thead>
<tr>
<th>Power of 10</th>
<th>Power of 2</th>
<th>Value of Power of 2</th>
<th>Prefix</th>
<th>Abbreviation</th>
<th>Derivation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{-12}$</td>
<td></td>
<td></td>
<td>pico</td>
<td>p</td>
<td>Spanish for little</td>
</tr>
<tr>
<td>$10^{-9}$</td>
<td></td>
<td></td>
<td>nano</td>
<td>n</td>
<td>Greek for dwarf</td>
</tr>
<tr>
<td>$10^{-6}$</td>
<td></td>
<td></td>
<td>micro</td>
<td>μ</td>
<td>Greek for small</td>
</tr>
<tr>
<td>$10^{-3}$</td>
<td></td>
<td></td>
<td>milli</td>
<td>m</td>
<td>Latin for thousand</td>
</tr>
<tr>
<td>$10^3$</td>
<td>$2^{10}$</td>
<td>1024</td>
<td>kilo</td>
<td>K</td>
<td>Greek for thousandth</td>
</tr>
<tr>
<td>$10^6$</td>
<td>$2^{20}$</td>
<td>1,048,576</td>
<td>mega</td>
<td>M</td>
<td>Greek for large</td>
</tr>
<tr>
<td>$10^9$</td>
<td>$2^{30}$</td>
<td>1,073,741,824</td>
<td>giga</td>
<td>G</td>
<td>Greek for giant</td>
</tr>
<tr>
<td>$10^{12}$</td>
<td>$2^{40}$</td>
<td>not enough room</td>
<td>tera</td>
<td>T</td>
<td>Greek for monster</td>
</tr>
<tr>
<td>$10^{15}$</td>
<td>$2^{50}$</td>
<td>not enough room</td>
<td>peta</td>
<td>P</td>
<td>Greek prefix for five</td>
</tr>
</tbody>
</table>

**Intel® Core™ 2 Duo**  
(2.66GHz/1066Mhz, FSB/6MB cache)
QUIZ: A CPU chip is rated 2.5 GHz.

What is the duration of one clock cycle? Use appropriate units!
QUIZ: A CPU chip is rated **3.44 GHz**.

What is the duration of one clock cycle? Use appropriate units!
5.2 Stored-Program Concept

The von Neumann (a.k.a. Princeton) architecture is based on two fundamental ideas:
1. Instructions and data are the same, so they are stored in the same circuit (memory)
2. Information processing is different from information storage, so they are performed in different circuits (CPU, memory)
The **Harvard** architecture is based on two fundamental ideas:

1. Instructions and data are not the same, so they are stored in separate circuits (memories)
2. Information processing is different from information storage, so they are performed in different circuits (CPU, memory)
QUIZ: Which of the diagrams depicts a von Neumann architecture?
QUIZ: Which of the diagrams depicts a von Neumann architecture?
QUIZ: Hardware layers

Connect each hardware item to the layer it belongs to:

- mouse
- XOR
- Intel 8008
- NTE 2996 MOSFET
- MUX
- motherboard
- full adder
- SR latch
QUIZ: A CPU chip is rated 3.33 GHz.

What is the duration of one clock cycle? Use appropriate units!
von Neumann architecture

1. Instructions and data are the same, so they are stored in the same circuit (memory)
2. Information processing is different from information storage, so they are performed in different circuits (CPU, memory)
Memory
Which hardware layer does memory belong to?

Image sources:  
http://www.mypcmobile.com/memory.php  
http://www.imagener.com/top-six-photo-enlargement-tips
### Memory

**Memory**

A collection of **cells**, each with a unique physical address.

Both addresses and contents are in **Binary** (or **hex**).

#### Cells can be bits, nibbles, **bytes**, words

<table>
<thead>
<tr>
<th>Address</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>00000000</td>
<td>11100011</td>
</tr>
<tr>
<td>00000001</td>
<td>10101001</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>.</td>
<td>.</td>
</tr>
<tr>
<td>11111100</td>
<td>00000000</td>
</tr>
<tr>
<td>11111101</td>
<td>11111111</td>
</tr>
<tr>
<td>11111110</td>
<td>10101010</td>
</tr>
<tr>
<td>11111111</td>
<td>00110011</td>
</tr>
</tbody>
</table>
QUIZ: Memory

The address and contents of a memory cell are the following, in hex:

89AB  FC

Translate them into decimal and binary.
**Memory**

**Addressability** = the # of bits in each cell

What is the addressability of the memory pictured?

Today, most computers’ memories are byte-addressable
QUIZ

1. How many **bytes** of memory are in the memory pictured?

2. Express the result using the appropriate multiplier.

| $10^3$ | $2^{10}$ | 1024 | kilo | K |
| $10^6$ | $2^{20}$ | 1,048,576 | mega | M |
| $10^9$ | $2^{30}$ | 1,073,741,824 | giga | G |
| $10^{12}$ | $2^{40}$ | not enough room | tera | T |
| $10^{15}$ | $2^{50}$ | not enough room | peta | P |

<table>
<thead>
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<th>Address</th>
<th>Contents</th>
</tr>
</thead>
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<tr>
<td>00000000</td>
<td>11100011</td>
</tr>
<tr>
<td>00000001</td>
<td>10101001</td>
</tr>
<tr>
<td>....</td>
<td>....</td>
</tr>
<tr>
<td>11111100</td>
<td>00000000</td>
</tr>
<tr>
<td>11111101</td>
<td>11111111</td>
</tr>
<tr>
<td>11111110</td>
<td>10101010</td>
</tr>
<tr>
<td>11111111</td>
<td>00110011</td>
</tr>
</tbody>
</table>
### QUIZ

How many **bits** does the address have in this memory?

What is the **addressability**?

<table>
<thead>
<tr>
<th>Address</th>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>0x789ABCDE</td>
<td></td>
</tr>
<tr>
<td>0x789A</td>
<td></td>
</tr>
</tbody>
</table>
The von Neumann architecture
ALU

- basic arithmetic operations such as add, subtract, increment, decrement, change sign, multiply, integer division
- logical operations such as AND, OR, XOR, NOT
The ALU also has a few very fast storage units called **registers**

- The information in a register can be processed quickly (in one CLK cycle), w/o waiting for a lengthy (~10 ns) memory transfer.

Figure source: http://www10.edacafe.com/book/
The von Neumann architecture
Input/Output devices

**Input device**
A device through which data and programs from the outside world are entered into the computer;

*Can you name three?*

**Output device**
A device through which results stored in the computer memory are made available to the outside world

*Can you name three?*
The von Neumann architecture
Control Unit

It is the organizing force in the computer

Implements the **fetch-execute cycle**

Includes two important registers:

- **Instruction register (IR)** → Contains the instruction that is being executed
- **Program counter (PC)** → Contains the address of the next instruction to be executed

\[ \text{ALU} + \text{Control Unit} = \text{CPU} \]
Flow of Information

**Bus** = A set of wires that connect all major units in a computer

Data flow through a von Neumann architecture
**Flow of Information**

**Bus** = A set of wires that connect all major units in a computer

Data flow through a von Neumann architecture

*How can we tell that it’s a vN architecture?*
Flow of Information

**Bus** = A set of wires that connect all major units in a computer

Is there another kind of memory?
FSB and BSB

Cache

Back-side Bus (BSB)

Front-side Bus (FSB)
To do in notebook for next time

Answer end-of-chapter questions 25 – 28
Find the info about bus and cache in the ad!

- Intel® Core™2 Duo (2.66GHz/1066Mhz FSB/6MB cache)
- 15.6” High Definition (1080p) LED Backlit LCD Display (1366 x 768)
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- 14.8W X 1.2H X 10.1D, 5.6 lbs
- Microsoft® Windows 7® Professional
- Microsoft® Office Home and Student 2007
- 36-Month subscription to McAfee Security Center Anti-virus
QUIZ: A CPU chip is rated 2.75 GHz.

What is the duration of one clock cycle? Use appropriate units!

<table>
<thead>
<tr>
<th>$10^{-12}$</th>
<th>$10^{-9}$</th>
<th>$10^{-6}$</th>
<th>$10^{-3}$</th>
<th>$10^3$</th>
<th>$2^{10}$</th>
<th>1024</th>
<th>kilo</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^6$</td>
<td>$2^{20}$</td>
<td>1,048,576</td>
<td>mega</td>
<td>M</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^9$</td>
<td>$2^{30}$</td>
<td>1,073,741,824</td>
<td>giga</td>
<td>G</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{12}$</td>
<td>$2^{40}$</td>
<td>not enough room</td>
<td>tera</td>
<td>T</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$10^{15}$</td>
<td>$2^{50}$</td>
<td>not enough room</td>
<td>peta</td>
<td>P</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
QUIZ: Computer Components

Explain in your own words the functions of the following components:

• ALU
• Control Unit
• Input device
• Memory
• Cache
What do the acronyms FSB and BSB stand for?

Compare and contrast them.
What do the acronyms FSB and BSB stand for?

Compare and contrast them.
The Fetch-Execute Cycle

**Fetch** the next instruction

**Decode** the instruction

**Get** data (if needed)

**Execute** the instruction

*Why is it called a *cycle*?*

**Remember:** In a vN machine, both instructions and data are stored in the same memory!
The Fetch-Execute Cycle

1. Fetch Instruction
2. Decode instruction
3. Get data
4. Execute the instruction

Main Memory

ALU

Registers

Control unit

FETCH CYCLE

EXECUTION CYCLE
RAM and ROM

The memory used for the (main) memory unit of a computer is of 2 types: RAM and ROM

- Both can be accessed directly, i.e. in constant time, by providing a memory address.
- Both can be read.

- However ...
RAM and ROM

**Random Access Memory** (RAM):
- can be changed (written)
- is volatile

**Read Only Memory** (ROM):
- cannot be changed (written)
- is not volatile

Take this with a grain of salt ...
Secondary Storage Devices

Name a few ...

Why is it necessary to have secondary storage devices?
Secondary Storage Devices

*Why is it necessary to have them?*

- Saving data when computer is off
- Volume ...
  - “Mass storage”
- Portability ...
- Reliability (backups) ...
- Modularity (add as you go) ...
Magnetic Tape

The first truly mass auxiliary storage device was the magnetic tape drive.

*Tape drives have a major problem; can you spot it?*

![Figure 5.4 A magnetic tape](image)
The first high-volume auxiliary storage device was the magnetic tape drive.

Image sources:
http://www.computerhistory.org/revolution/memory-storage/8/258/1025
http://wodumedia.com/large-hadron-collider-ready-to-restart/
Magnetic Disk - HDD

- Amount of information (bits, bytes) is the same on all tracks
- Disc rotates at the same angular velocity no matter which track is being read → **same transfer rate on all tracks**!
- Tracks near center are **more densely packed** with information
A HDD has 512 Bytes/sector, 256 sectors/track, and 10 platters. The diameter of each platter is 10 cm, and each track is 1 mm wide.

Calculate the total capacity of the drive in MB.

Use binary Mega!
A HDD has 512 Bytes/sector, 256 sectors/track, and 10 platters. The diameter of each platter is 100mm, and each track is 1mm wide.

Calculate the total capacity of the drive in MB.

Use binary Mega!

125 MB
Seek time
Time it takes for read/write head to be over right track

Latency
Time it takes for sector to be in position under R/W head

Access time = Seek time + latency

Transfer rate  (e.g. 100 MB/s)
QUIZ: HDD

Seek time
Time it takes for read/write head to be over right track

Latency
Time it takes for sector to be in position

Access time = Seek time + latency

Transfer rate (e.g. 100 MB/s)

The arm of a HDD moves at an average velocity of 40 m/s. The platter diameter is 100 mm.

What are the minimum and maximum possible seek times?

Calculate the average seek time.
QUIZ: HDD

Seek time
Time it takes for read/write head to be over right track

Latency
Time it takes for sector to be in position

Access time = Seek time + latency

Transfer rate (e.g. 100 MB/s)

The arm of a HDD moves at an average velocity of 40 m/s. The platter diameter is 100 mm.

What are the minimum and maximum possible seek times?

Calculate the average seek time. 1.25 ms
The spindle of a HDD rotates at **7200 RPM**. What are the **minimum** and **maximum** possible latencies? Calculate the **average latency**.
QUIZ: HDD

The spindle of a HDD rotates at 7200 RPM.
What are the minimum and maximum possible latencies?
Calculate the average latency.

4.16 ms
If the previous 2 quizzes refer to the same HDD, what is its average access time?
QUIZ: HDD

Seek time
Time it takes for read/write head to be over right track

Latency
Time it takes for sector to be in position

Access time = Seek time + latency

Transfer rate (e.g. 100 MB/s)

If the previous 2 quizzes refer to the same HDD, what is its average access time?

4.16 ms + 1.25 ms = 5.41 ms
A file is on the HDD, on **15 consecutive blocks** of the same track. Each block stores **4 KB**.
The average seek time is **10 ms**, and the average latency is **5 ms**. Once the first block is under the head, data is transferred at a rate of **50 MB/s**.
Calculate the total time needed to transfer the file.
A file is on the HDD, on **15 consecutive blocks** of the same track. Each block stores **4 KB**.
The average seek time is **10 ms**, and the average latency is **5 ms**.
Once the first block is under the head, data is transferred at a rate of **50 MB/s**.
Calculate the total time needed to transfer the file. **16.23 ms**
Magnetic Disks - Removable

Floppy disks (Why "floppy"?)

Year when they first became commercially available:
1969 (8-inch)
1976 (5¼-inch)
1982 (3½-inch)

- 80-500 KB
- 87 KB-1.2 MB
- 1.44 MB
Magnetic Disks - Removable

Zip disks
- Iomega, 1994
- 100 MB, 250 MB, 750 MB
Flash memory

• IBM 1998
• Nonvolatile!
• Can be erased and rewritten
  – But there’s a rub: Flash Endurance
• No moving parts!

Thumb drives

Solid State Drives (SSD)
Your turn! Calculate the cost per gigabyte for HDD and SDD

Source: www.newegg.com October 2013