**Hardware Outline**

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**What is a Computer?**

"... [A] programmable electronic device that can store, retrieve and process data."


**Components of a Computer System**

- COMPUTER SYSTEM
  - HARDWARE
    - Physical devices
  - SOFTWARE
    - Sets of instructions

**DON’T PANIC!**

This discussion may be confusing at the moment; it will make more sense after you’ve written a few programs.
Hardware That Computers Typically Have

- Central Processing Unit (CPU)
- Primary Storage
- Secondary Storage
- Input Devices
- Output Devices

Hardware Components

- **CENTRAL PROCESSING UNIT**
  - Control Unit
  - Arithmetic/Logic Unit
  - Registers

- **STORAGE**
  - Primary
    - Cache 8525 MB 104.857 MB/sec
  - Main Memory 80.12 MB 6.534 MB/sec
  - Secondary
    - Hard Disk $0.0006 MB 100 MB/sec
    - DVD−RW $0.0002 MB 5.3 MB/sec
    - CD−RW $0.0000 MB 7.6 MB/sec

- **INPUT/OUTPUT**
  - Basic I/O
  - Multimedia
  - Keyboard
  - Mouse
  - Monitor
  - Printer
  - Joystick
  - Networking
  - Modem
  - Internet Port
  - Modem
  - Internet Port

Note: storage costs and speeds are based on available PC systems, Jan 2004.

Prices, specs courtesy of:
bestbuy.com
cndyn.com
creativelabs.com
dell.com
pricewatch.com
storagetek.com
toshiba.com
## Central Processing Unit (CPU)

The Central Processing Unit (CPU), also called the *processor*, is the “brain” of the computer. It has three main parts: the Control Unit, the Arithmetic/Logic Unit and Registers.

- The **Control Unit** decides what to do next; for example:
  - load data from main memory into the *registers* (see below);
  - perform an arithmetic or logical operation (see below);
  - store data from the registers into main memory;
  - choose among several possible courses of action (*branch*).
- The **Arithmetic/Logic Unit** (ALU) performs arithmetic & logical operations.
  - *Arithmetic operations*: add, subtract, multiply, divide, etc.
  - *Logical operations*: compare two numbers to see which is greater, check whether a true-false statement is true, etc.
- **Registers** are memory-like locations where data reside when they’re being used right now; for example, the operands being used by the current arithmetic or logical operation, or the result of the arithmetic or logical operation that was just performed.

### CPU Examples:
- Intel Pentium 4/AMD Athlon XP (Windows PC)
- Intel Itanium (servers)
- Motorola PowerPC G5 (Macintosh)
- Hewlett-Packard Alpha EV68 (servers)

You can see a picture of the innards of a Pentium 4 at:


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### Control Unit

<table>
<thead>
<tr>
<th>Control Unit</th>
<th>Increment Instruction Pointer</th>
<th>Find Data Addresses in Memory</th>
</tr>
</thead>
<tbody>
<tr>
<td>Load Next Instruction</td>
<td>Load Data from Memory</td>
<td>Execute Instruction</td>
</tr>
<tr>
<td>Store Result in Memory</td>
<td>Find Data Addresses in Memory</td>
<td></td>
</tr>
</tbody>
</table>

### Arithmetic/Logic Unit

<table>
<thead>
<tr>
<th>Arithmetic/Logic Unit</th>
<th>Add</th>
<th>Multiply</th>
<th>Divide</th>
</tr>
</thead>
<tbody>
<tr>
<td>R03 = R03 + R63</td>
<td>R02 = R00 * R01</td>
<td>R02 = R00 / R01</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compare</th>
<th>Bit Shift</th>
<th>Bit Invert</th>
</tr>
</thead>
<tbody>
<tr>
<td>R00 &lt; R01</td>
<td>R00 &lt;&lt; R01</td>
<td>R03 = ~R01</td>
</tr>
</tbody>
</table>

### Registers

<table>
<thead>
<tr>
<th>Registers</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>R00</td>
<td></td>
</tr>
<tr>
<td>R01</td>
<td></td>
</tr>
<tr>
<td>R02</td>
<td></td>
</tr>
<tr>
<td>R03</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Control Unit makes decisions about what to do next; e.g., load data from memory, perform an arithmetic/logical operation, store data to memory, etc.

The Arithmetic/Logical Unit performs operations on data that are in registers.

The Registers are where operands must reside in order to be used in operations, and where the results of operations go before being stored in memory.

Registers are VERY expensive, because they are etched directly into the CPU.

Cache is also expensive, because it’s also etched into the CPU, but it isn’t directly connected to the Control Unit or Arithmetic/Logic Unit. Cache operates at speeds similar to registers, but cache is MUCH bigger (about 1,000 times as big).

Memory is cheap, because it isn’t part of the CPU, but it’s much slower than cache.
Storage (Primary & Secondary)

Primary Storage
- Primary storage is where data and instructions reside when they’re being used by a program that’s currently running.
- Primary storage typically is volatile: the data disappear when the power is turned off.
- Primary storage typically comes in two types:
  - Cache memory is where data reside when a currently running program is going to use them very very soon.
    - Cache is very fast (e.g., nearly the speed of the CPU).
    - Cache is very expensive (e.g., $525 per MB).
  - Main memory (RAM) is where data reside when a currently running program is going to use them at some point during the run (whether soon or not).
    - Main memory is slow compared to CPU speed (e.g., about 5-20% as fast as the CPU).
    - Main memory is much cheaper than cache (e.g., 12 cents per MB).

Secondary Storage
- Secondary storage is the place where data and instructions reside that will be used in the future.
- Secondary storage is not volatile: the data remain when the power is turned off.
- Secondary storage is much cheaper than primary storage (e.g., a fraction of a cent to several cents per MB).
- Examples: hard disk, CD, DVD, Zip disk, floppy, magnetic tape
- Most kinds are portable: you can pop the media (e.g., floppy disk, CD) out of the drive and carry it to another computer.

Main Memory

Memory is made up of locations (also called cells). Each location has a unique integer address that never changes. Each location has a value (also called the contents) that the CPU can get or change.

```
Address
0 1 2 3 4 5 6 7
8 9 10 11 12 13 14 15
16 17 18 19 20 21 22 23
24 25 26 27 28 29 30 31
      * * * -71

Location (Cell)       Highest Address
Lowest Address       e.g., 536,870,911 (512 MB)
```

We can think of memory as one contiguous line of cells.

RAM: Random Access Memory
Memory that the CPU can read from, write to and address arbitrarily (i.e., can read or write any location at any time, not just in a sequence). We often use ‘Main Memory,’ ‘Memory’ & ‘RAM’ interchangeably.

ROM: Read Only Memory
Memory that the CPU can read from but not write to, and can address arbitrarily.
Bits, Bytes, Words

- **Bit** (Binary digiT)
  - Tiniest possible piece of memory
  - Made of teeny tiny transistors wired together
  - Has 2 possible values that we can think of in several ways:
    - Low or High: Voltage into transistor
    - Off or On: Conceptual description of transistor state
    - False or True: “Boolean” value for symbolic logic
    - 0 or 1: Integer value
  - Bits aren’t individually addressable: the CPU can’t load from or store to an individual bit of memory.

- **Byte**: a package of 8 contiguous bits (typically)
  - On most platforms (kinds of computers), it’s the smallest addressable piece of memory: typically, the CPU can load from or store to an individual byte.
  - Possible integer values: 0..255 or -128..127 (to be explained later)
  - Can also represent a character (e.g., letter, digit, punctuation)

- **Word**: a package of 4 or 8 contiguous bytes (typically)
  - On a few platforms (e.g., Cray J90), the smallest possible addressable piece of memory
  - Standard size for storing a number (integer or real)
  - Standard size for storing an address (special kind of integer)

- **Kilobyte** (KB): approximately 1,000 bytes
- **Megabyte** (MB): approximately 1,000,000 bytes
- **Gigabyte** (GB): approximately 1,000,000,000 bytes
- **Terabyte** (TB): approximately 1,000,000,000,000 bytes
- **Petabyte** (PB): approximately 1,000,000,000,000,000 bytes

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How Data Travel Between Memory & CPU

The bus is the connection from the CPU to main memory; all data travel along it.

For now, we can think of the bus as a big wire connecting them.
Loading Data from Main Memory into the CPU

I want the contents of 09140980.

There you go!

I’ll put it in register R05.

Cache: Eliminating Speedbumps for the Bus

A 3.2 GHz CPU can perform 6.4 billion operations per sec (143 GB/s),
but its 800 MHz memory bus moves data at only 6.4 GB/sec,
so moving data between the CPU and main memory is a bottleneck.

Cache is a smaller memory that is nearly the same speed as the CPU.
If the data are in cache, then the CPU can access them more quickly.

Cache is typically about 128,000 to 2 million bytes,
while main memory is typically about 64 million to 4 billion bytes.
Secondary Storage

- Nonvolatile: data don’t disappear when power is turned off
- Much larger, much slower and much cheaper than main memory
- Most are portable: can be easily removed from your computer and taken to someone else’s

<table>
<thead>
<tr>
<th>Medium</th>
<th>Speed* (MB/sec)</th>
<th>Size* (GB)</th>
<th>Media Type</th>
<th>Can write to it?</th>
<th>Portable?</th>
<th>Popular?</th>
<th>Drive Cost ($)</th>
<th>Media Cost ($/MB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cache Memory</td>
<td>104,857</td>
<td>0.002</td>
<td>L2</td>
<td>Yes</td>
<td>No</td>
<td>Required</td>
<td>$525/MB</td>
<td>(for comparison only)</td>
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<tr>
<td>Main Memory</td>
<td>6,554</td>
<td>2</td>
<td>DDR 3200 RAM</td>
<td>Yes</td>
<td>No</td>
<td>Required</td>
<td>$0.012/MB</td>
<td>(for comparison only)</td>
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<tr>
<td>Hard Disk</td>
<td>100</td>
<td>320</td>
<td>Mag</td>
<td>Yes</td>
<td>No</td>
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<td>$15000/MB</td>
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<tr>
<td>Zip Disk</td>
<td>4.2</td>
<td>0.45</td>
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<td>Yes</td>
<td>Yes</td>
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<td>$0.036</td>
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<td>7.6</td>
<td>0.8</td>
<td>Optic</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>$35</td>
<td>$0.00035</td>
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<td>4.7</td>
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<td>Yes</td>
<td>No</td>
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<td>$0.0002</td>
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<tr>
<td>Mag Tape</td>
<td>15</td>
<td>100</td>
<td>Mag</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>$1830</td>
<td>$0.00065</td>
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<td>Floppy</td>
<td>0.03</td>
<td>0.0014</td>
<td>Mag</td>
<td>Yes</td>
<td>Yes</td>
<td>Very</td>
<td>$7</td>
<td>$0.007</td>
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<tr>
<td>Cassette</td>
<td>1 1</td>
<td>0.0014</td>
<td>Mag</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
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<td></td>
</tr>
<tr>
<td>Paper Tape</td>
<td>1 1</td>
<td>0.0014</td>
<td>Paper</td>
<td>Once</td>
<td>Yes</td>
<td>No</td>
<td>$25</td>
<td></td>
</tr>
<tr>
<td>Punch Card</td>
<td>1 1</td>
<td>0.0014</td>
<td>Paper</td>
<td>Once</td>
<td>Yes</td>
<td>No</td>
<td>$25</td>
<td></td>
</tr>
<tr>
<td>DVD-ROM</td>
<td>21.6</td>
<td>17</td>
<td>Optic</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>$25</td>
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<tr>
<td>CD-ROM</td>
<td>7.8</td>
<td>0.8</td>
<td>Optic</td>
<td>No</td>
<td>Yes</td>
<td>Very</td>
<td>$19</td>
<td></td>
</tr>
</tbody>
</table>

* Maximum among models commonly available for PCs

**Media Types**

- Magnetic: always can be read; always can be written and rewritten multiple times; contents degrade relatively rapidly over time; can be erased by magnets
- Optical: always can be read; some can be written only once; some can be rewritten multiple times; contents degrade more slowly than magnetic media; can’t be erased by magnets
- Paper: forget about it!

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CDROM/DVDROM

When a CD or DVD holds data instead of music or a movie, it acts very much like Read Only Memory (ROM):

- it can only be read from, but not written to;
- it’s nonvolatile;
- it can be addressed essentially arbitrarily (it’s not actually arbitrary, but it’s so fast that it might as well be).

Disadvantages of CDROM/DVDROM compared to ROM:

- CDROM and DVDROM are much slower than ROM.
  - CDROM is 7.8 MB/sec (peak); DVDROM is 21.6 MB/sec.
  - ROM is 6,554 MB/sec.

Advantages of CDROM/DVDROM compared to ROM:

- CDROM and DVDROM are much cheaper than ROM.
  - Blank CDs and blank DVDs are less than $0.0005 per MB.
  - ROM is even more expensive than RAM (which is $0.12 per MB), because it has to be made special.
- CDROM and DVDROM can have arbitrary amount of storage (on many CDs or DVDs); ROM is limited to a few GB.

Why Are Floppies So Expensive Per MB?

CD-RWs cost less than $0.0005 per MB, but floppy disks cost about $0.07 per MB. Why?

Well, CDs have much greater capacity than floppies (800 MB vs. 1.44 MB), and the costs of manufacturing the actual physical objects are similar.

So, the cost of a floppy per MB is much higher.
**Input & Output Devices**

- *Input Devices* transfer data into computer (e.g., from a user into memory); for example:
  - Keyboard
  - Mouse
  - Scanner
  - Microphone
  - Touchpad
  - Joystick

- *Output Devices* transfer data out of computer (e.g., from memory to a user); for example:
  - Monitor
  - Printer
  - Speakers

We often say *I/O* as a shorthand for “Input/Output.”