What is a microprocessor?
- The ‘brain’ of the computer
- Central Processing Unit (CPU)  
  *aka, Microprocessor*

Microprocessor History
- The First Microprocessor
  - Intel 4004
  - 1971
  - First microprocessor
  - Just over 2,300 transistors
- Today’s Microprocessors
  - Over one billion processors

Moore’s Law
- The number of transistors on a single chip doubles every 24 months
- This rule of thumb has held true since 1965
- Putting it in perspective
  - Applying Moore’s Law to 10 cents put aside in 1965 would yield $6,710,886.40 in 2015

An Overview of the Computer
- The Four Major Components of a Computer
  - Processor
  - Memory
  - Input
  - Output
  - The processor is sometimes classified as two components
    - Datapath
    - Control
- A More Detailed View
● What Connects the Various Components Together?

● The Bus
  • Definition
    - A collection of wires which transfer electrical signals
    - Parallel vs. Serial
  • Speed determined by
    - Clock Bus Speed
    - Bus Width
  • Local Bus
    - Exists between CPU & memory
  • Expansion Bus
    - Connects to peripherals
      - Video Card
      - Audio Card

● A More Detailed View

Motherboard
- *aka, System Board*
- **Printed Circuit Board (PCB)** containing the microprocessor, memory, and I/O interfaces
- Contains
  - Memory Slots
    - Accept RAM
  - CPU Socket
Expansion Slots

- Accept
  - Sound Card
  - Video Card
    - Contain Graphics Processing Unit (GPU)
  - Network Interface Card (NIC)
- On a tablet or laptop, these cards are integrated into the motherboard

Ports

Processor

- What is the CPU?
  - The brain of the computer
  - Performs the calculations
  - Processes the data

- CPU Characteristics
  - Clock Speed
    - Measured in Hz
    - A 1 GHz clock can execute 1 billion instructions per second

- Number of Cores

- Amount of Cache Memory

- Main Players Producing Microprocessors for PCs
  - Advanced Micro Devices (AMD)
    - FX Series
    - A Series (AMD A10, A8, A6, A4)
  - Intel
    - i Series (Intel i3, i5, i7)

- Processors used to be denoted by a number
  - Similar to a model number
  - Example
    - Intel’s 80486

- Today, names are used

- Why?

- Measuring Performance
  - Benchmarks
    - Software specifically designed to measure performance
    - Example
      - cpubenchmark.net

- The ARM Microprocessor
  - Paradigm Shift
  - ARM licenses their design
    - Intellectual Property (IP)
    - Users pay
      - an upfront license fee
      - royalty for every chip produced
Motivation
- Embedded Systems
  - Energy efficient
  - Small
- SOC

System On Chip (SOC)
- The technology exists to place an entire system on a single chip!
- Some systems are already implemented in this fashion
- What are the advantages of SOC?
- Do our desktop and laptop computers use SOC technology?

Microsoft Surface vs. Microsoft Surface Pro
- Tablets
- Surface (Surface 2)
  - ARM Based
- Surface Pro (Surface Pro 2)
  - Intel Based
- Surface 3 & Surface Pro 3

Discussion on History & Ramifications

Ports
- Attachment Points for Peripherals
  - Thunderbolt
    - Speeds up to 10 GB/Second
  - Universal Serial Bus (USB)
    - Most common
    - USB 2.0, 3.0, 3.1, Type-C
    - USB Hubs
      - Can expand the number of USB ports on your machine
      - Powered/NonPowered
  - FireWire 800
    - Apple
- Monitors/Multimedia
  - High-Definition Multimedia Interface (HDMI)
  - Video Graphics Array (VGA)
    - Analog
  - Digital Video Interface (DVI)
  - Mini Display Port
    - Apple
**Memory**

- When you purchase a new computer, what characteristics do you look for in terms of memory?
- Example
  - What did you bring to UB today?
    - Did you bring things from high school?
    - Did you bring your 8th grade English notebook?
  - What did you pull out of your bag for class today?

- Your books/notebooks spanning your entire academic career provide a similar example to the memory hierarchy

**The Memory Hierarchy**

- **Goal**
  - Large Capacity
  - High Perform
  - Inexpensive

![Memory Hierarchy Diagram]

- How does it work?
  - Copy what we need from large, slow memory into the fast, small memory
  - Most of the time, you are using the fast memory

- What if you need something from slower memory?
  - Go get it!
  - Penalty (time) associated with doing so

- **Fast Memory**
  - Small
  - Expensive

- **Large Capacity Memory**
  - Slow
  - Inexpensive
Memory Hierarchy Implementation

- Registers
  - Volatile
  - Very limited amount of space
    - Typically 64 to 128 bytes
  - Implemented as part of microprocessor

- Cache
  - Pronounced cash
  - Volatile
  - **Static RAM (SRAM)**

- RAM (Random Access Memory)
  - Volatile
  - **Dynamic RAM (DRAM)**
    - Needs to be refreshed periodically
    - Cell
      - Stores one bit
    - Each cell (which stores a 1 or a 0) is relatively large compared to DRAM, but is faster
  - Variations of DRAM (from slowest to fastest)
    - Double Data Rate Three Synchronous DRAM (DDR 3 SDRAM)
    - Double Data Rate Five Synchronous DRAM (DDR 5 SDRAM)

- ROM (Read Only Memory)
  - Nonvolatile
  - Used on Boot
    - **BIOS (Basic Input/Output System)**

- RAM/ROM Capacities
  - Kilobyte (KB)
    - $2^{10}$ bytes = 1,024 bytes
  - Megabyte (MB)
    - $2^{20}$ bytes = 1,048,576 bytes
  - Gigabyte (GB)
    - $2^{30}$ bytes = 1,073,741,824 bytes
  - Terabyte (KB)
    - $2^{40}$ bytes = 1,099,511,627,776 bytes
  - Petabyte (PB)
    - $2^{50}$ bytes = 1,125,899,906,842,624 bytes

- Secondary Storage
  - Nonvolatile
  - Hard Drives
    - Types
      - **Mechanical**
        - Disk(s) Spin
          - 5400 RPM
          - 7200 RPM
        - Read/Write Head Moves Along the Radius
- **Solid State (SSD)**
  - No Moving Parts
- **Hybrid Drives**
  - Best of both worlds
  - Combines mechanical & solid state drives
  - Apple refers to them as **Fusion Drives**

✓ **Internal vs. External**
  - Internal
  - Drive resides in drive bay
  - External
  - Most commonly USB

筢 **Cloud Storage**
  ✓ Network (Internet) Based

筢 **Portable Storage**
  ✓ Flash Drive
    - *aka*, Jump Drive, USB Drive, or Thumb Drive
  ✓ Flash Memory Cards
    - SD Card

筢 **Optical Storage**
  ✓ Compact Disks (CD)
    - 700 MB
  ✓ Digital Video (or Versatile) Disks (DVD)
    - 4.7 GB (Dual Layer, 8.5 GB)
  ✓ Blu-ray
    - 25 GB (Dual Layer, 50 GB)

筢 **Legacy**
  ✓ Floppy, ZIP, Jaz

● **Access Times**

 евр **RAM**
  ✓ Nanoseconds (ns)

 евр **Hard Drives**
  ✓ Mechanical
    ✓ Milliseconds (ms)
  ✓ Solid State
    ✓ Fractions of Milliseconds (ms)

● **Adding RAM**

 евр **Memory Modules**
  ✓ **DIMMs (Dual Inline Memory Modules)**
    ✓ Replaces older **SIMMs (Single Inline Memory Modules)**

 евр **Be sure to add the correct type of memory**
  - System Dependent

 евр **Proper grounding is important as well**
  - Protects your system from static electricity

 евр **The amount of RAM a system can support is dictated by the OS & motherboard**
Too little RAM degrades performance

**Why?**

- **Thrashing**
  - Consider opening Microsoft Word, Microsoft Excel, Mozilla FireFox, and Adobe Acrobat Reader
  - Multitasking through these applications requires memory being allocated for each one in RAM
  - Too little RAM requires the system to make room in RAM. Data in RAM must be temporarily stored on the hard disk drive to do so.
    - Hard disk drives are on the order of thousands to millions of times slower than RAM
    - Doing this too frequently causes you to spend a lot of time waiting for the swap to complete!

- Increasing the amount of RAM in your system is the best way to increase system performance for the least amount of money

**Most bang for your buck!**

### What happens when a computer is booted?

- **BIOS**
  
  - **Basic Input/Output System**
  
    - Very small section of primary memory that is nonvolatile
  
  - BIOS contains initial instructions that computer executes when it is started
  
  - Performs most basic setup
  
  - Loads operating system from secondary storage to primary memory (RAM)
  
  - Transfers control to operating system

### Machine Language

- The language the computer understands
- Consists of 1’s and 0’s
- When you purchase a program, this is what you are actually purchasing
- Unique to the processor

  - **Why?**
    - Based on the design of the processor itself

  - **Example**
    - Second generation Apple Macintosh not compatible with a PC
      - PowerPC® vs. Intel® Pentium® Series
      - How about today’s Macintosh & PC?

  - **Example**
    
    111000100100110110100000101000
    11100101100111010010000000000000
    11100011101000000000000000000000
    11100111100111010001000100000000
    11100001010100010000000000000011
Imagine a program represented in machine language
- Millions of lines of 1’s and 0’s
- Your program does not work
  ➥ A single 1 or 0 is wrong
  ✔️ Fix it!

Assembly Language
- A more readable form of machine language
- Each line in the machine language program describes a specific instruction
  ➥ ADD
  ➥ SUBTRACT
  ➥ LOAD
  ➥ STORE
  ➥ COMPARE
- Mnemonics to describe primitive tasks
  ➥ Increases readability of program
  ➥ Simplifies writing and debugging programs
- Unique to the processor
  ➥ Based on processor’s machine language
- Example

```
sub    r13,r13,#0x28
ldr    r2,[r13,#0]
ldr    r3,[r13,#0]
mov    r0,#0
ldr    r1,[r13,r0,lsl #2]
cmp    r1,r2
bge    0x80c8 ; (main + 0x20)
mov    r2,r1
cmp    r1,r3
ble    0x80d4 ; (main + 0x2c)
mov    r3,r1
add    r0,r0,#1
cmp    r0,#0xa
blt    0x80b8 ; (main + 0x10)
mov    r0,#0
add    r13,r13,#0x28
```

High-Level Languages
- Used for most programs
- Closer to a natural language than machine language/assembly language
  ➥ Programming is simpler and faster
  ➥ Programs brought to market faster
Compiler
- Program that translates a high-level language program to machine language

Source Code
- The high level program
- Example

```c
int main()
{
    int temp[10];
    int i, sum, min, max;

    sum=0;
    min=temp[0];
    max=temp[0];

    for (i=0; i<10; i++)
    {
        if (temp[i] < min) {min = temp[i];};
        if (temp[i] > max) {max = temp[i];};
        sum = temp[i] + sum;
    }
}
```

High-Level Languages vs. Machine Language
- Why do you get the machine language program when you purchase a program instead of the source code?

Compatibility
- Software
  - Operating Systems are not compatible
    - Example
      - MacOS not compatible with Microsoft Windows
      - Linux not compatible with Microsoft Windows
  - Operating system families are often backward compatible
    - Example
      - MacOS X is compatible with MacOS 9
      - Microsoft Windows 8 is compatible with Microsoft Windows 7

How a Microprocessor Works
- When an instruction is executed, the process is divided into individual tasks
  - Fetch
    - Load the instruction from memory into the microprocessor
Decide
- Determine what the instruction is
- What tasks need to be performed?
- Load the data that will be needed

Execute
- Actually perform the task defined by the instruction

Store
- Store the results of the instruction for future use

- Consider executing two instructions

<table>
<thead>
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<th>Instruction #1</th>
<th>Instruction #2</th>
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<tbody>
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<td>Fetch</td>
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<tr>
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<tr>
<td>Execute</td>
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<tr>
<td>Store</td>
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Clock Ticks

If different portions of the microprocessor are allocated for each task (fetch, decode, execute, store) then the sequential execution shown above is inefficient.

More efficient to have every part of the processor always be busy.

Pipelining
- Overlapping instructions increases the efficiency of the microprocessor
- Today’s microprocessors are pipelined
- It not only increases efficiency, but significantly increases performance

Consider extending the above example to 100,000 instructions. How much faster is it than 100,000 instructions executed without pipelining?

The theoretical speedup can approach the number of stages in the pipeline

Drawback
- Dependencies

System Clock
- How long does each cycle take?
- Measured in Hertz (Hz)
  - Clock ticks per second
- The clock period is the inverse of the rate
- Example
  - A 1.5 GHz clock ticks every 0.667 billionth of a second
Overclocking

What is overclocking?
- Pushing the CPU faster than the recommended clock speed

Advantages
- Increases Performance
  - Common among gamers

Disadvantages
- Shortens life of processor
- Increases power consumption

What happens if the clock speed is increase too much?

Multi-Core Microprocessors
- Dual Core
- Quad Core

Dual Core vs. Dual Processor

Hyperthreading
- Two non-related sets of instructions are woven together into a single instruction stream on a CPU

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