Microprocessors

Chapter 6
Overview

- In this chapter, you will learn how to
  - Identify the core components of a CPU
  - Describe the relationship of CPUs and memory
  - Explain the varieties of modern CPUs
  - Select and install a CPU
  - Troubleshoot CPUs
Central Processing Unit (CPU)
Core Components
Concepts

- The **CPU (central processing unit)** works as a very powerful calculator.
- CPUs are not very smart ... just very fast at manipulating zeros and ones.
• Visualize the CPU as a man in a box.
  – He will gladly perform anything you want him to do, but he can't see or hear anything outside the box.
  – How can you communicate with him?
Figure 2: How do we talk to the man in the box?
Talking to the Man

- **Imagine 16 lights**
  - 8 on the inside and 8 on the outside
  - When an inside light is on, the corresponding outside light is on. You can switch these lights on and off
  - We call this communication system the **external data bus**

Figure 3: Cutaway of the external data bus—note that one light bulb pair is on
• The CPU communicates with the outside world using the external data bus (EDB)
  - Uses binary (1 is on, and 0 is off) to communicate
  - Data lines on the bus can be switched (turned on or off) from inside or outside.

• There is a problem: The man in the box has no memory! He needs help to save information he's working on.
External Data Bus (continued)

Figure 4: Close-up of the underside of a CPU
• **In reality, a lot of little wires flash on or off**
  - Voltage is applied or not
  - Represented not as on, off, on, off...
    but as 1, 0, 1, 0...

**Figure 5:** Here "1" means on, "0" means off.
• Inside the box are **registers** (worktables or temporary storage locations).

• The four general-purpose registers found in all CPUs are AX, BX, CX, and DX.

**Figure 6: The four general-purpose registers**
The man in the box needs one more tool: the codebook or instruction set.

- This codebook is called machine language.
- One command is a line of code.
- The complete set of commands for a processor is its instruction set.
Here are some examples of real machine language for the Intel 8088:

<table>
<thead>
<tr>
<th>Code</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1011010</td>
<td>The next line of code is a number. Put that number into the DX register.</td>
</tr>
<tr>
<td>01000001</td>
<td>Add 1 to the number already in the CX register.</td>
</tr>
<tr>
<td>00111100</td>
<td>Compare the value in the AX register with the next line of code.</td>
</tr>
</tbody>
</table>
The CPU so Far

Figure 8: The CPU so far
Clock

• The CPU does no work until told to—even though data may be on the EDB.

• You need a buzzer to tell the man in the box to start.
  – This is referred to as a clock.
  – A clock is actually a stream of pulses.

Figure 9: The CPU does nothing until activated by the clock.

Figure 10: The CPU often needs more than one clock cycle to get a result.
Clock (continued)

• Clock speed is the CPU’s maximum speed, not the speed at which the CPU must run.
  – Used to synchronize eternal and external activity
  – One cycle per second = 1 hertz (Hz); 1 million cycles per second = 1 megahertz (MHz)
  – Every command requires at least two clock cycles.

• Clock speed is the maximum clock cycles per second.
Clock (continued)

• A clock cycle is the time taken by the special wire to charge.
  – The CPU needs at least two clock cycles to act on each command.
  – A cycle is one complete up-and-down segment of the sine wave.

• Clock Speeds
  – 1 hertz (1 Hz) = 1 cycle per second
  – 1 megahertz (1 MHz) = 1 million cycles per second
  – 1 gigahertz (1 GHz) = 1 billion cycles per second
  – Intel 8088 ran at 4.77 MHz
  – Modern CPUs run at 3+ GHz
Figure 11: Where is the clock speed?
System Crystal

• **System crystal governs CPU running speed**

• **Modern motherboards use jumpers to select crystal speed**

Figure 12: One of many types of system crystals
System Crystal (continued)

- Crystal can clock a CPU with a rated speed higher than the crystal, but the CPU will operate at the slower speed of the crystal.
  - In other words, a 1 GHz crystal can clock a 2 GHz CPU, but the CPU will operate only as fast as the crystal clock—1 GHz.
  - Underclocking means running a CPU slower than its rated clock speed—it does not take advantage of all the power of the CPU.
  - Overclocking means to run a CPU faster than its maximum clock speed—it can fry the CPU.
Back to the External Data Bus

Figure 13: Diagram of an Intel 8088 showing the external data bus and clock wires
Memory

- Memory is the computer's workspace.
- Programs and data are stored on storage media (hard drives, etc.).
- Media are not fast enough to provide data to CPU.
- Memory takes programs and data and sends them to the CPU MUCH faster.
Random access memory (RAM) is organized like a spreadsheet, with each row holding eight bits (one byte).

Transfers and stores data to and from CPU in byte-sized chunks.

Number of bytes of RAM varies from PC to PC, with today's PCs holding billions of bytes of RAM.

Figure 14: RAM as a spreadsheet
Computers use **dynamic random access memory (DRAM)**

- Dynamic rather than static
- Random rather than sequential
- Circuits need power and to be refreshed to maintain data.

Figure 15: Typical RAM
• CPU and RAM need a method to communicate, so they use the EDB.
• The CPU doesn't know how to talk to memory, so it needs a helper chip—the MCC.
• The memory controller chip (MCC) is a device that facilitates the flow of data from the RAM to the CPU.
• The **address bus** enables the CPU to control the MCC.
  
  – Another set of wires in addition to the external data bus
  – Used by the CPU to tell the MCC which line of code it wants from RAM

**Figure 18: Address bus**
• The number of wires in the address bus determines the maximum amount of RAM the CPU can handle.
  – An 8088 had 20 wires, which provided $2^{20}$ combinations (1,048,576, or 1 MB).
  – Many current CPUs use 36 wires, which provide $2^{36}$ combinations (68,718,476,736, or 64 GB).
  – Today's CPUs have many more wires, allowing them to address several GB of RAM.
Bits and Bytes

- Any individual 1 or 0 = a bit
- 4 bits = a nibble
- 8 bits = a byte
- 16 bits = a word
- 32 bits = a double word
- 64 bits = a paragraph or quad word
• **Bits are represented as** $b$ (e.g., Kb)
• **Bytes are represented as** $B$ (e.g., KB)

<table>
<thead>
<tr>
<th>K</th>
<th>Kilo</th>
<th>$2^{10}$</th>
<th>1024</th>
<th>$2^{10}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>M</td>
<td>Mega</td>
<td>$2^{20}$</td>
<td>1,048,576</td>
<td>$2^{20}$</td>
</tr>
<tr>
<td>G</td>
<td>Giga</td>
<td>$2^{30}$</td>
<td>1,073,741,824</td>
<td>$2^{30}$</td>
</tr>
<tr>
<td>T</td>
<td>Tera</td>
<td>$2^{40}$</td>
<td>1,099,511,627,776</td>
<td>$2^{40}$</td>
</tr>
</tbody>
</table>
Modern CPUs
Manufacturers

- Two main CPU makers
  - Intel
  - AMD
- CPUs might look similar, but they are not interchangeable.

Figure 19: Identical Intel and AMD 486 CPUs from the early 1990s
Manufacturers (continued)

• **Intel**: Intel has dominated the industry with its CPU and motherboard support chips.
  – Modern Intel processors include Pentium, Core 2 Duo, Celeron, Core i5, Core i7, Xeon, and more.

• **AMD**: Advanced Micro Devices has kept competition in the CPU market.
  – While Intel holds the most market share, AMD often provides quality CPUs at competitive prices.
Intel and AMD differentiate product lines by using different product names, based on the target market.

<table>
<thead>
<tr>
<th>Market</th>
<th>Intel</th>
<th>AMD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainstream and enthusiast desktop</td>
<td>Core i7/i5/i3, Core 2 Duo</td>
<td>Phenom II, A-Series, Phenom, Athlon X2</td>
</tr>
<tr>
<td>Budget desktop</td>
<td>Pentium, Celeron</td>
<td>Sempron, Athlon II</td>
</tr>
<tr>
<td>Mobile</td>
<td>Core i7/i5/i3 (mobile), Core 2 Duo (mobile), Atom</td>
<td>Turion</td>
</tr>
<tr>
<td>Server</td>
<td>Xeon/Itanium</td>
<td>Opteron</td>
</tr>
</tbody>
</table>

Table 1: Current Intel and AMD Product Lines and Names
Code Names

- Both companies use code names to keep track of different variations within models—CPUs labeled as the same model may have CPUs inside that are very different from earlier versions of that model.

**Figure 20: Same branding, different capabilities**
Desktop Versus Mobile

• Desktop Versus Mobile:
  – Mobile devices have needs that differ from those of desktop computers:
  – They need to consume as little electricity as possible.
  – Less electricity consumption extends the battery charge and creates less heat.

• Both manufactures have created both mobile and desktop versions of their CPUs.

Figure 21: Desktop vs. mobile, fight!
Technology

- Clock multipliers
- 64-bit processing
- Virtualization support
- Parallel execution
- Multicore processing
- Integrated memory controller (IMC)
- Integrated graphics processing unit (GPU)
Clock Multipliers

- All modern CPUs run at some multiple of the system clock speed.
- In early computers, the CPU ran at the same speed as the motherboard.
  - Designers discovered that the CPU could run faster than the rest of the chips on the motherboard.
Clock Multipliers (continued)

Figure 22: CPU-Z showing the clock speed, multiplier, and bus speed of a Core i7 processor at rest
Clock Multipliers (continued)

- Technicians had to set jumpers on older motherboards to configure the multiplier
  - Now the motherboard is automatically configured through a function called CPUID

![Dip switches on a motherboard](image)

Figure 23: Dip switches on a motherboard
64-bit Processing

• Increases in EDB and address-bus size
• New technologies such as MMX and SSE were added, causing shift to 64-bit technology
• Most new CPUs support 64-bit processing
  – Can run a compatible 64-bit operating system, such as Windows 7, and 64-bit applications
• CPUs also still support 32-bit processing for 32-bit operating systems, such as Windows XP, and 32-bit applications
• Primary benefit to moving to 64-bit is support for more than 4 GB of memory—up to 16 EB
Virtualization Support

- Modern CPUs have built-in support for running more than one operating system at a time
- Enables hardware-based virtualization support, making virtualization easier and more resource efficient
Parallel Execution

- Modern CPUs can process multiple commands and parts of commands in parallel
  - Older CPUs processed in a linear fashion
- Works through multiple pipelines, dedicated cache, and the capability to work with multiple threads or programs at one time
Pipelining

- Pipelining—CPU takes at least four steps (called stages):
  - Fetch: Get the data from the EDB
  - Decode: Figure out what type of command needs to be executed
  - Execute: Perform the calculation
  - Write: Send the data back onto the EDB

Figure 24: Simple pipeline
Pipelining (continued)

- Some newer CPUs have many stages in pipeline
- Makes a CPU run more efficiently without increasing the clock speed
- Some processors use multiple decode stages to reduce pipeline stalls
- Some CPUs offer multiple pipelines, allowing the arithmetic logic unit (ALU) and the floating point unit to work at the same time
Pipelining (continued)

Figure 25: Bored integer unit

Figure 26: Multiple pipelines
Cache

- Cache—reduces wait states by using built-in, very high-speed RAM called static RAM (SRAM).
  - SRAM preloads as many instructions as possible.
  - Cache on the CPU was called the L1 cache because it was used first.
  - Cache on the motherboard was called the L2 cache, and used second; later added to CPU package.
  - The address bus and external data bus (connecting the CPU, MCC, and RAM) were lumped into a single term called the frontside bus.
  - Connection between the CPU and the L2 cache became known as the backside bus.
Cache (continued)

Figure 27: RAM cache

Figure 28: CPU-Z displaying the cache information for a Core i7 processor
Cache (continued)

Figure 29: Frontside and backside buses
Multithreading

- CPU simulates the actions of a second processor and enhances efficiency, but does not increase processing power (also known as simultaneous or Hyper-Threading)

Figure 30: Windows Task Manager with the Performance tab displayed for a system running a Hyper-Threaded Pentium 4
Multicore processing

- Combines multiple CPUs (or cores) into a single chip, creating a multicore architecture and executing multiple threads at once
- Differs from Hyper-Threading, where the OS and applications have to be written specifically to handle the multiple threads
Figure 31: CPU-Z showing the cache details of a Sandy Bridge Core i7
Almost all current CPUs have an integrated memory controller (IMC)

- Moved from the motherboard chip into the CPU to optimize the flow of information into and out from the CPU
- Causes different CPUs to require different types and capacities of RAM
Integrated Graphics Processing Unit (GPU)

• Video processing portion of the computer traditionally has a discrete microprocessor unique to video capabilities, known as the GPU.

• Graphics processors can handle certain tasks much more efficiently than the standard CPU, so are sometimes integrated.

• Enhances the overall performance of the computer while reducing energy use, size, and cost—ideal for mobile devices.
Integrated Graphics Processing Unit (GPU) (continued)

Figure 32: Dedicated and shared cache
Selecting, Installing, and Troubleshooting CPUs

- Selecting a CPU
- Installation issues
- Overclocking
- Troubleshooting CPUs
Selecting a CPU

• Get the right CPU for the right purpose.
• Determine if the motherboard supports Intel or AMD processors.
• Determine what type of socket the motherboard has.
  – The motherboard documentation or manufacturer's web site can give you this information.
• Learn which processors go with which socket types.

Figure 33: Supported processors and socket type
# Intel-Based Sockets

## Table 2: Intel-based sockets

<table>
<thead>
<tr>
<th>Socket</th>
<th>CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>LGA 775¹</td>
<td>Pentium 4, Celeron, Pentium 4 Extreme Edition, Core 2 Duo, Core 2 Quad, Xeon, and many others</td>
</tr>
<tr>
<td>LGA 1155²</td>
<td>Core i3/i5/i7, Pentium, Celeron, Xeon</td>
</tr>
<tr>
<td>LGA 1156³</td>
<td>Core i3/i5/i7, Pentium, Celeron, Xeon</td>
</tr>
<tr>
<td>LGA 1366⁴</td>
<td>Core i7, Xeon, Celeron</td>
</tr>
</tbody>
</table>

### Notes

1. The LGA 775 socket was the only desktop or server socket used for many years by Intel and thus just about every branded Intel CPU used it at one time or another.
2. Socket LGA 1155 CPUs are based on Sandy Bridge or Ivy Bridge architecture.
3. Socket LGA 1156 CPUs are based on the pre-Sandy Bridge architecture.
4. The very first Core i7 processors used LGA 1366.
# AMD-Based Sockets

<table>
<thead>
<tr>
<th>Socket</th>
<th>Pins</th>
<th>CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>940¹</td>
<td>940</td>
<td>Opteron, Athlon 64 FX</td>
</tr>
<tr>
<td>AM2²</td>
<td>940</td>
<td>Athlon 64, Athlon 64 X2, Athlon 64 FX, Opteron, Sempron, Phenom</td>
</tr>
<tr>
<td>AM2⁺²</td>
<td>940</td>
<td>Athlon 64, Athlon 64 X2, Athlon II, Opteron, Phenom, Phenom II</td>
</tr>
<tr>
<td>AM3³</td>
<td>941</td>
<td>Phenom II, Athlon II, Sempron, Opteron</td>
</tr>
<tr>
<td>AM3⁺⁴</td>
<td>942</td>
<td>FX</td>
</tr>
<tr>
<td>FM1</td>
<td>905</td>
<td>A⁵</td>
</tr>
<tr>
<td>F</td>
<td>1207</td>
<td>Opteron, Athlon FX</td>
</tr>
</tbody>
</table>

Table 3: AMD-based sockets
AMD-Based Sockets (continued)

Notes

1. You would usually find only an Opteron server-based CPU in a socket 940. The Athlon 64 FX was a super high-end CPU for the day and is very unlikely to be on the exams.

2. AMD says that CPUs designed for AM2 sockets will work in a Socket AM2+ and vice versa, though at the slower memory movement speeds of the AM2 component (socket or CPU). Many manufacturers have not released motherboard updates that would enable support for a Socket AM2+ CPU on a Socket AM2 motherboard, thus making it impossible to upgrade just the CPU.

3. Though the names of some of the processors designed for Socket AM3 match the names of CPUs designed for earlier sockets, they're not the same CPUs. They are specific to AM3 because they support different types of RAM (see Chapter 7). Just to make things even crazier, though, AM3 CPUs work just fine in Socket AM2/2+ motherboards.

4. AMD had only released the FX-branded CPUs that use the Bulldozer core at the time of this writing. Motherboards with AM3+ sockets already tout support for Phenom II, Athlon II, and Sempron CPUs, in addition to the FX series.

5. The A series features integrated GPUs and other chips.
Installation issues

• Pay careful attention to
  – CPU pins
  – Power supply
  – Adequate cooling

• Consider whether to leave CPU at standard settings or overclocking
Socket Types

• **Socket types**
  - Intel processors use a land grid array (LGA) package
  - AMD CPU pins align with socket holes—a pin grid array (PGA)
  - CPUs and sockets are keyed to help prevent misalignment and incorrect insertion (Zero Insertion Force, or ZIF sockets)
Socket Types (continued)

Figure 35: AMD-based socket without pins

Figure 34: Intel-based socket with pins

Figure 36: Underside and top of a CPU
Socket Types (continued)

Figure 37: Moving the release arm

Figure 38: Fully opened socket
Cooling

- CPUs can heat up due to electrical power usage (wattage).
- Most CPUs use a combination of heat-sink and cooling-fan assembly to keep them within normal operating temperatures.

Figure 39: Intel OEM heat-sink and fan assembly
Cooling (continued)

• OEM CPU coolers are heat-sink and fan assemblies that are included with a retail-boxed CPU.

• Specialized CPU coolers are third-party heat-sink and fan assemblies for a variety of CPUs, and usually exceed the OEM heat sinks in the amount of heat they dissipate.
Cooling (continued)

Figure 40: Cool retail heat sink
• Liquid cooling works by running some liquid—usually water—through a metal block that sits on top of your CPU, absorbing heat.

• Apply a small amount of thermal compound (or heat dope) to the CPU before attaching the heat sink—applying too much or too little can cause the CPU to overheat and fail.
Cooling (continued)

Figure 41: Liquid-cooled CPU
Cooling (continued)

Figure 42: CPU fan power standout on motherboard
Cooling (continued)

Figure 43: Applying thermal compound

Figure 44: AMD OEM heat-sink and fan assembly
Cooling (continued)

Figure 45: Heat-sink and fan assembly mounted to motherboard with screws
Overclocking

• For the CPU to work, the motherboard speed, multiplier, and voltage must be set properly.
• Motherboard uses the CPUID functions to set these options automatically.
• Some motherboards enable you to adjust these settings.
• Some people intentionally run their systems at clock speeds higher than the CPU was rated, a process called overclocking, to enhance performance.
Overclocking (continued)

- Intentional overclocking of a CPU immediately voids most warranties.
- Can cause system instability, lockups, frequent reboots, or damage, and may destroy CPU.
- Overclocking is done through jumpers, CMOS settings, or software configuration.
- Usually involves increasing the bus speed for the system and increasing the voltage going into the CPU.
Overclocking (continued)

Figure 46: Manually overriding CPU settings in the system setup utility
Overclocking (continued)

- In case you need to go back to CMOS defaults, use the CMOS clear jumper setting from the motherboard manual

Figure 47: CMOS-clear jumper
Troubleshooting CPUs

• Overheating—can cause system to not start or to lockup. Newer CPUs will usually shut themselves down before overheating.
  - Too much heat dope (thermal paste) can impede the flow of heat from the CPU to the heat sink and cause the CPU to heat up rapidly.
  - Not enough thermal paste can cause the CPU to heat up and shut down.
  - Faulty fan power connection can cause CPU to heat up and shut down.
  - Heating may take longer and cause problems after boot and OS load.
Troubleshooting CPUs (continued)

- Environmental heat / lack of adequate ventilation can cause CPU heat-up and shutdown

- **Catastrophic Failure**
  - May cause Windows Stop error (Blue Screen of Death)
  - May cause PC to shut down or go black
  - May burn up components
A problem has been detected and Windows has been shut down to prevent damage to your computer.

PAGE_FAULT_IN_NONPAGED_AREA

If this is the first time you've seen this stop error screen, restart your computer. If this screen appears again, follow these steps:

Check to make sure that any new hardware or software is properly installed. If this is a new installation, ask your hardware or software manufacturer for any Windows updates you might need.

If problems continue, disable or remove any newly installed hardware or software. Disable BIOS memory options such as caching or shadowing. If you need to use Safe Mode to remove or disable components, restart your computer, press F8 to select Advanced Startup Options, and then select Safe Mode.

Technical information:

*** STOP: 0x00000050 (0x00000000,0xF866C51E,0x00000008,0xC0000000)

*** cddrom.sys - Address F866C51E base at F866A000, DateStamp 36B027B2

Figure 48: Blue Screen of Death
• **Intel Atom processors**
  - Small, relatively low-powered, but also low-power-consumption CPUs.
  - Used in netbooks and nettop computers where battery life and quietness are more important than raw power.

Figure 49: Intel Atom processor