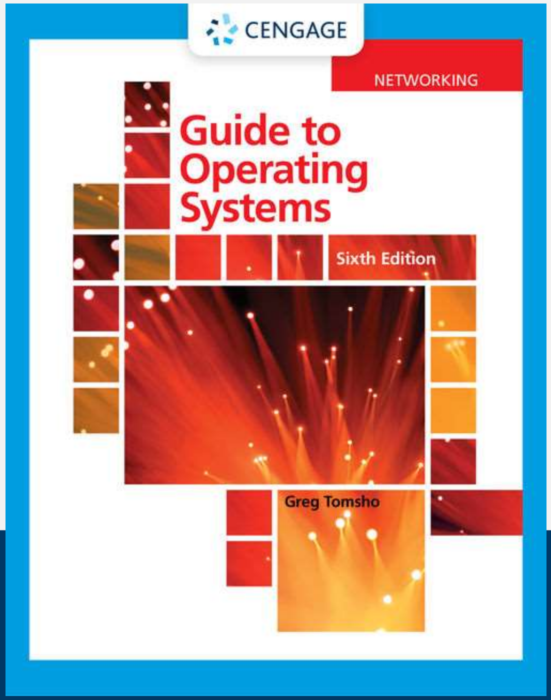


Guide to Operating Systems, 6th Edition

Module 3: The Central Processing Unit (CPU)

Learning Objectives

By the end of this module, you should be able to:

- Describe the function and features of CPUs
- Describe CPU design characteristics
- Identify features of modern CPUs

CPU Fundamentals (1 of 2)

- The **system architecture** of the computer is built around the CPU
  - Includes the number and type of CPUs in the hardware; the communications routes (buses) between CPUs; and other hardware components, such as memory and disk storage
  - A bus is a path or channel between a computer's CPU and the devices it manages, such as memory and I/O devices
- The CPU is the chip that performs the actual computational and logic work
- Most client computers have one chip and are referred to as **single-processor computers**

CPU Fundamentals (2 of 2)

- A processor **core** is the part of a CPU that reads and executes machine code
  - A multicore processor has two or more cores
- CPUs are manufactured on a silicon wafer, called a **die**
- **Multiprocessor computers** have multiple physical CPU chips
  - Many server computers and high-end client computers are multiprocessor computers

CPU Startup Operation

- When power is applied to the CPU, it begins reading data from a memory address called the reset vector
  - The **reset vector** is an address that a CPU begins reading from whenever the CPU receives a reset signal
- On many processors, the data found at the address of the reset vector is loaded into the CPU's program counter and is used as the address where the CPU will begin program execution
  - The **program counter** is a register on a CPU that contains the address of the next instruction the CPU will execute

Knowledge Check 1

- What part of the CPU is responsible for reading and executing machine code?
  - A) bus
  - B) control unit
  - C) core
  - D) register

QUESTION

Knowledge Check 1: Answer

- What part of the CPU is responsible for reading and executing machine code?

- C) core

CPU Design (1 of 4)

- Most CPUs are composed of the following elements:
  - *Control unit* – the control unit (CU) provides timing and coordination between other parts of the CPU
  - *Arithmetic logic unit (ALU)* – the ALU performs the primary task of executing instructions
  - *Registers* – a register is a temporary holding location where data must be placed before the CPU can use it
  - *Memory/cache controller* – the cache controller intercepts accesses to memory for data or code and checks if the requested data is in cache first

CPU Design (2 of 4)

- Most CPUs are composed of the following elements (continued):
  - *System bus* – A series of lanes used to communicate between the CPU and other major parts of the computer
- There are three types of buses:
  - **Control bus** – carries status signals between the CPU and other devices
  - **Address bus** – carries address signals to indicate where data should be read or written to in the system’s memory
  - **Data bus** – carries the actual data that is being read from or written to system memory

CPU Design (3 of 4)

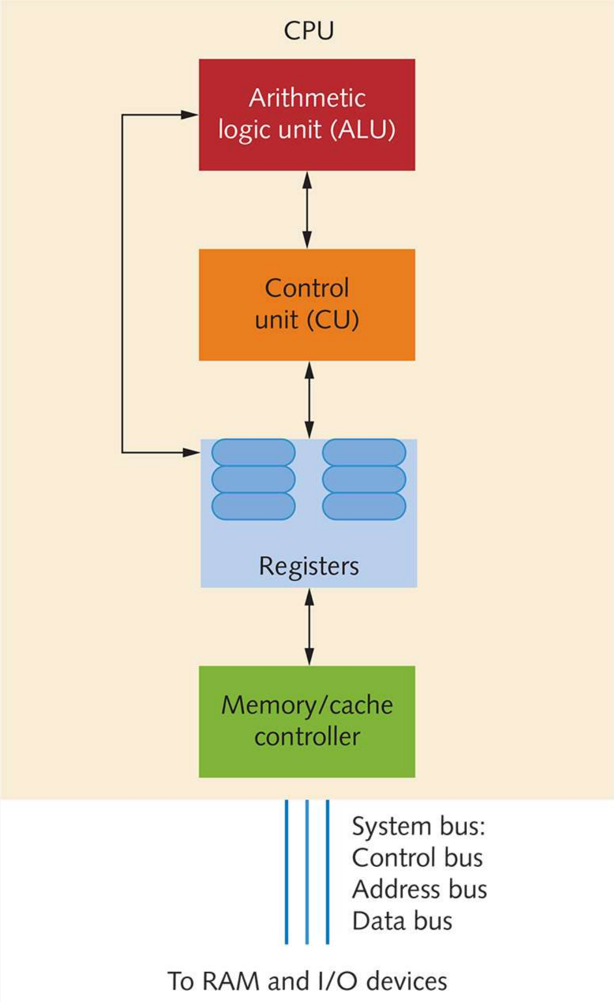
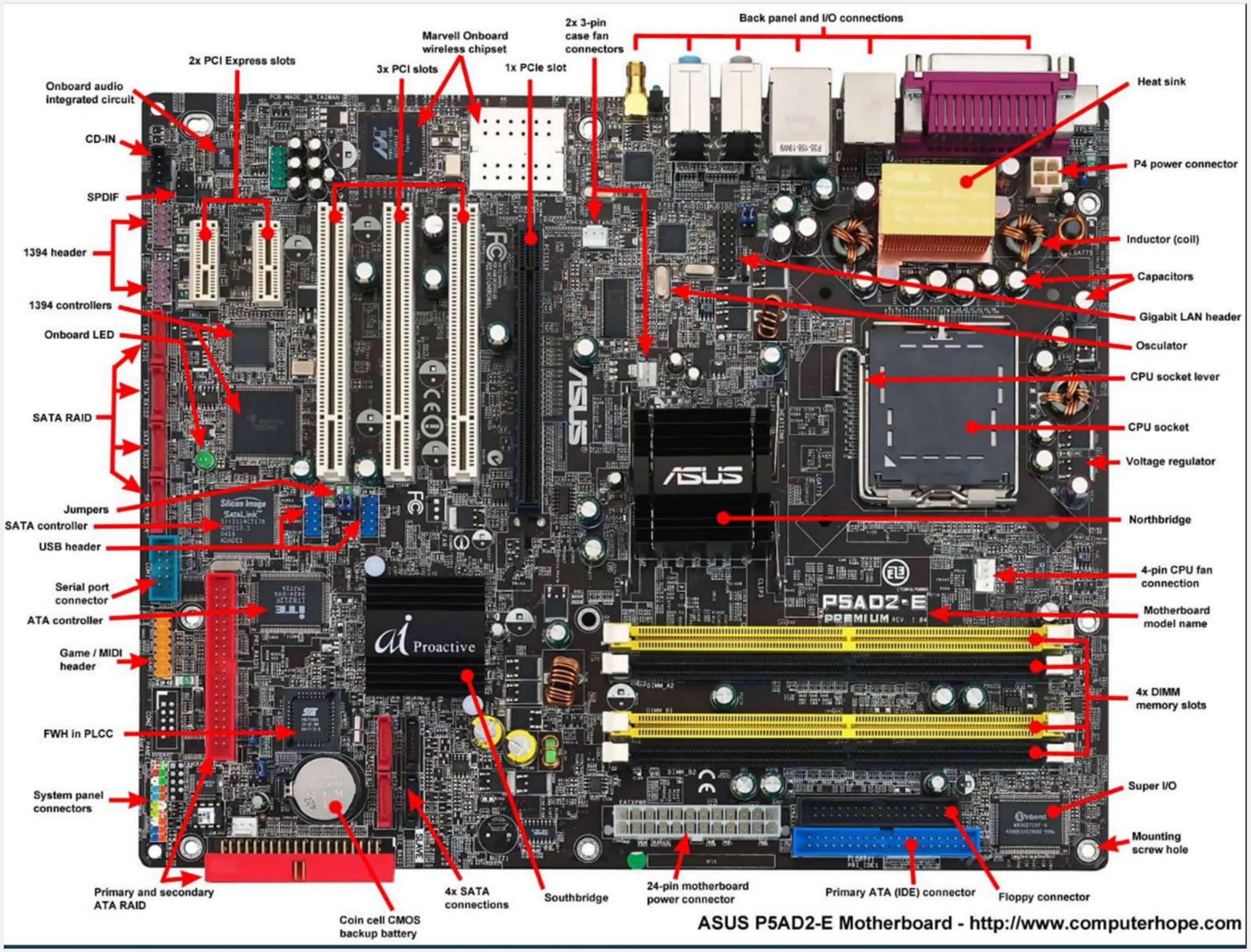
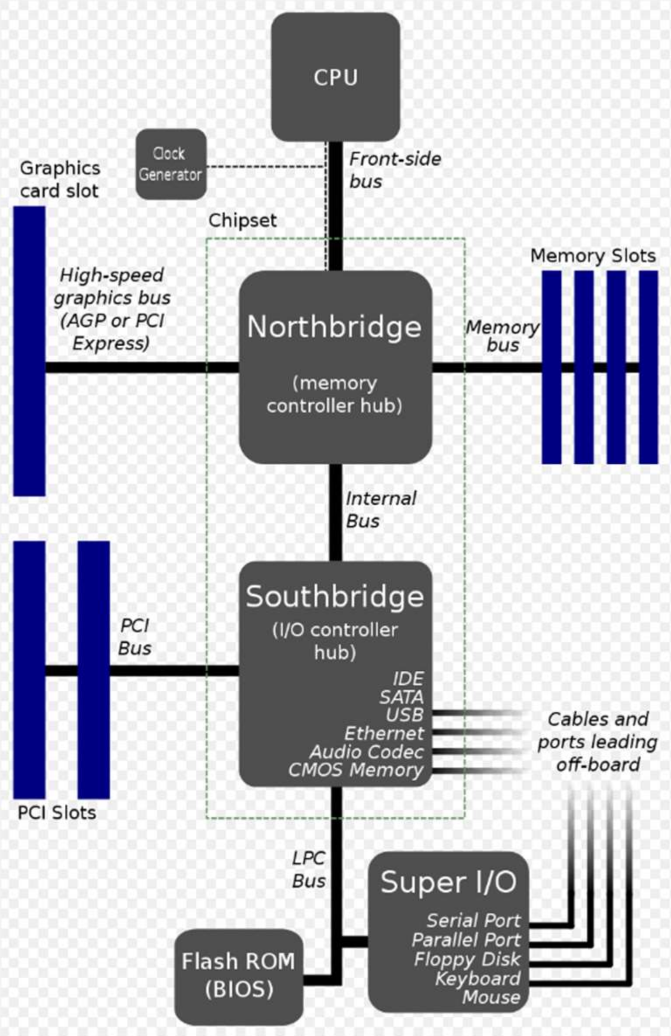


Figure 3-2 Basic architecture of a CPU

Asus Motherboard



North/South Bridge



CPU Design (4 of 4)

- CPUs can be classified by hardware elements:
  - Architecture
  - Clock speed
  - Cache
  - Address bus
  - Data bus
  - Control bus
  - CPU scheduling
- Each of these elements is described in more detail on the following slides

Architecture (1 of 5)

- Two general CPU designs are used today:
  - **Complex Instruction Set Computing (CISC)**
  - **Reduced Instruction Set Computing (RISC)**
- The main difference between the two design types is the number of different instructions the chip can process
- CPUs can process as many as several billion operations per second, depending on the architecture
- An **instruction set** is a list of commands the CPU can understand and carry out

Architecture (2 of 5)

- CISC and RISC CPUs differ in the following ways:
  - *Complex versus simple instructions*
    - CISC CPUs are generally more complex
  - *Clock cycles*
  - *Pipelining*
    - Pipelining is the ability of the CPU to perform more than one task on a single clock cycle
  - *Hardware versus microcode*
    - **Microcode** is a small program inside the chip that interprets and executes each instruction

Architecture (3 of 5)

```
add X, Y
```

CISC CPU

Three additions in 12 clock cycles

Clock cycles											
1	2	3	4	5	6	7	8	9	10	11	12
add (1st addition)				add (2nd addition)				add (3rd addition)			

```
load R1, X
load R2, Y
add R1, R2
stor R1, X
```

RISC CPU

Three additions in 6 clock cycles

Clock cycles						
1	2	3	4	5	6	
load	load	add	stor			1st addition
	load	load	add	stor		2nd addition
		load	load	add	stor	3rd addition

Figure 3-3 CISC processing versus RISC processing using pipelining

Architecture (4 of 5)

- CISC and RISC CPUs differ in the following ways (continued):
  - *Compiler*
    - A **compiler** is a computer program that takes a high-level language and turns it into assembly code that is executed by the CPU
    - An **assembler** turns those instructions into numeric values, called opcodes
  - *Number and usage of registers*
    - CISC CPUs have fewer registers than a RISC CPU

```
X = X + Y;
```

```
add X, Y
```

```
load R1, X
load R2, Y
add R1, R2
stor R1, X
```

Architecture (5 of 5)

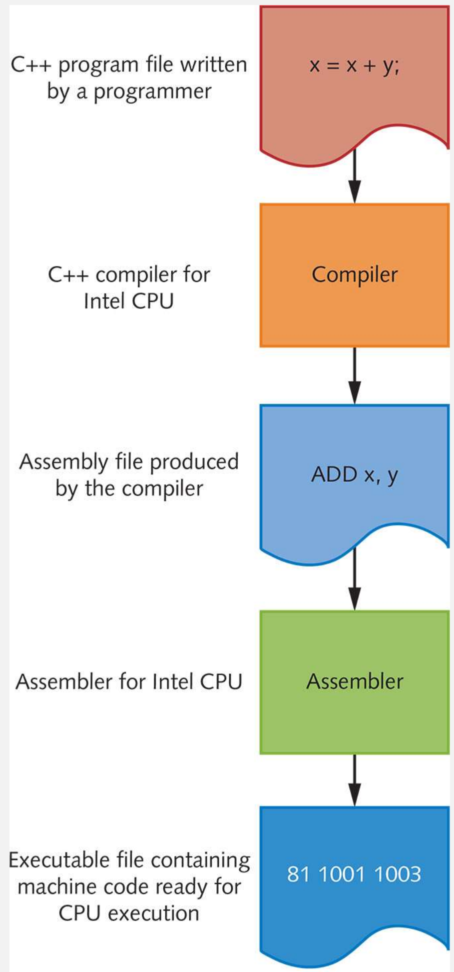


Figure 3-4 From high-level language to machine code

Clock Speed (1 of 2)

- The speed of a CPU defines how fast it can perform operations
- The most frequently used indicator is the **internal clock speed**
  - The internal clock speed is the speed at which a CPU executes an instruction or part of an instruction
  - The faster the clock speed, the faster the CPU
- As more components are needed to make a CPU, the chip uses more energy, which is converted to heat.
  - CPUs require fans to keep cool

Clock Speed (2 of 2)

- The CPU must be able to communicate with other chips in the computer
  - It uses an **external clock speed** to communicate with the rest of the computer
  - The external clock speed runs slower than the internal clock speed
    - The external clock speed is typically one-half, one-third, one-fourth, or one-eighth the speed of the internal CPU clock

Operating Point	Clock	Ratio	Bus	VID
CPU Minimum	550.0 MHz	x5.50	100.0 MHz	-
CPU Base	3600.0 MHz	x36.00	100.0 MHz	-
CPU Boost Max	4200.0 MHz	x42.00	100.0 MHz	-
CPU PBO Max	4200.0 MHz	x42.00	100.0 MHz	-
CPU Status	4058.9 MHz	x40.67	99.8 MHz	1.4375 V

Cache (1 of 2)

- Because the internal clock is faster than the external clock, the CPU has to wait on information to arrive from other parts of the computer
- Most modern CPUs have **cache memory** built into the chip
- While the CPU is executing program code, instructions or data that are most likely to be used next are fetched from main memory and placed in cache memory

Cache (2 of 2)

Base Clock: 3.6GHz	**L1 Cache:** 384KB
L2 Cache: 3MB	**L3 Cache:** 32MB

- There are different levels of cache
  - **Level 1 (L1) cache** is the fastest and usually runs at the same speed as the CPU
  - **Level 2 (L2) cache** is slower than L1, but much larger
  - **Level 3 (L3) cache,** until the last several years, was not part of the CPU chip, but part of the motherboard
  - **Level 4 (L4) cache** will usually be found on the motherboard (if it exists)
- The **cache controller** predicts what data will be needed and makes the data available in cache before it is needed

Address Bus

- The address bus is an internal communications pathway that specifies the source and target addresses for memory reads and writes
  - The address bus typically runs at the external clock speed of the CPU
  - The width of the address bus is the number of bits that can be used to address memory
    - A wider bus means the computer can address more memory and store more data
- Modern processors have a 64-bit address bus
  - Allows them to address 16 terabytes (TB) of memory

CENGAGE

Data Bus

- The data bus allows computer components, such as the CPU, display adapter, and main memory, to share information
- The number of bits in the data bus indicates how many bits of data can be transferred from memory to the CPU in one clock tick
  - A CPU with an external clock speed of 1 GHz and a 64-bit data bus could transfer as much as 8 GB per second
- A CPU with a 64-bit data bus typically can perform operations on 64 bits of data at a time

Control Bus

- Information is transported on the control bus to keep the CPU informed about the status of resources and devices connected to the computer
- Memory read and write status is transported on this bus, as well as **interrupt requests (IRQ)**
  - An interrupt request is a request to the processor to “interrupt” whatever it is doing to take care of a process, which in turn might be interrupted by another process

CPU Scheduling (1 of 2)

- CPU scheduling determines which process to start given the multiple processes waiting to run
- Modern OSs support multithreading
  - **Multithreading** is the ability to run two or more processes (known as threads) at the same time
  - A **thread** is the smallest piece of computer code that can be independently scheduled for execution
  - **Hyper-threading (HT)** allows two threads to run on each CPU core simultaneously

CPU Scheduling (2 of 2)

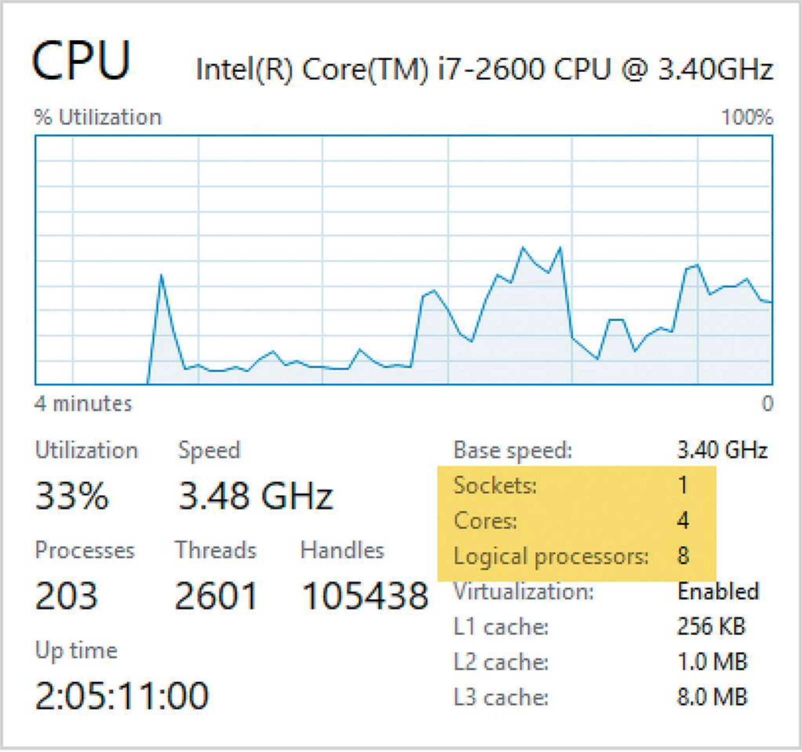


Figure 3-5 Task Manager showing a quad-core hyper-threaded CPU

Knowledge Check 2

- The ability of the CPU to perform more than one task on a single clock cycle is known as which of the following?
  - A) multiprocessor
  - B) multithreading
  - C) caching
  - D) pipelining

QUESTION

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Knowledge Check 2: Answer

- The ability of the CPU to perform more than one task on a single clock cycle is known as which of the following?

- D) pipelining

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Modern Processors for PCs and Servers

- This section provides an overview of CPUs found in modern client and server systems running general-purpose OSs
  - Modern systems today typically have two or more cores and 64-bit architecture

Intel Processors (1 of 3)

- The most popular CPU manufacturer today is Intel
  - 8086 architecture is the CPU found in the original IBM PC
  - All processors introduced by Intel that are intended to run Windows and other PC OSs have been based on the 8086 architecture
- Modern processors are multicore, with as many as 72 or more cores
- **Microarchitecture** is the description of a CPU's internal circuitry, defining characteristics such as the technology used to create the chip, the supported instruction set, and the bit size

Intel Processors (2 of 3)

- The most current microarchitecture is called Cascade Lake-AP
  - It supports up to 56 cores running at 2.6 GHz with an L3 cache up to 77 MB
- Table 3-2, on the following slide, lists only the base processor, but Intel has released a number of editions for each processor

Intel Processors (3 of 3)

CPU	Year Introduced	Cores	Speed	Bus Speed	L3 Cache	AMD Comparable
Intel Core i5	2009	2-4	1.06-3.76 GHz	2.5 GT/s	3-8 MB	AMD Ryzen 5
Intel Core i7	2008	2-6	1.06-3.33 GHz	2.5 GT/s-4.8 GT/s	4-15 MB	AMD Ryzen 7
Intel Core i3	2010	2	1.20-3.06 GHz	2.5 GT/s	3-4 MB	AMD Ryzen 3
Intel Core i9	2017	10-18	2.6-4 GHz	8GT/s	13-25 MB	AMD Ryzen 9

AMD Processors

- Advanced Micro Devices, Inc. (AMD) manufactures processors that compete with Intel's line of processors
- AMD processors are compatible with software written for the Intel x86-based processors
- AMD processors tend to cost less for similar performance and are easier to overclock
  - Overclocking is the ability to run a processor faster than its stated clock speed

ARM-Based Processors

- Advanced RISC Machines (ARM) processors are RISC processors that are commonly used in mobile devices such as smartphones and tablets
  - They are also used in embedded systems and are starting to be used in notebook computers
- They are multicore, 32-bit and 64-bit processors with low power consumption
- ARM processors are not produced by a single company
  - Companies license the architecture and sell their own version of an ARM processor

Summary (1 of 2)

- Central to understanding computer hardware is the system architecture of the computer, which is built around the CPU, or processor
- When power is applied to a CPU, it begins reading data from a memory address called the reset vector
- Most CPUs are composed of a control unit, arithmetic logic unit, registers, and a system bus, which is composed of a control bus, address bus, and data bus
- CPUs can be classified by several elements, including design type, speed, cache, address bus, data bus, control bus, and CPU scheduling

Summary (2 of 2)

- CPU architectures include CISC and RISC
- The amount of cache is critical to a CPU’s overall speed because it is much faster than RAM
- CPU scheduling allows an OS to schedule multiple processes or threads
- Intel processors are the most popular CPUs today, but AMD processors are frequently used
- ARM processors are RISC-based and are the most commonly used processor in the world due to their extensive use in mobile devices