Computer Organization & Architecture

Chapter 1 – Basic Structure of Computers

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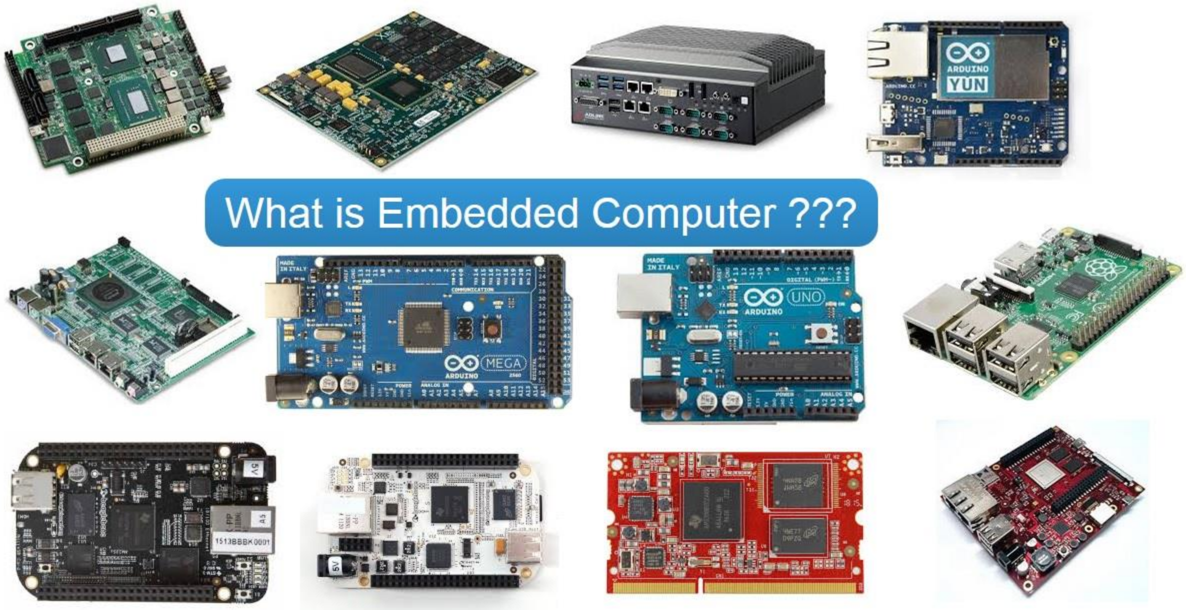
Content of this lecture

- 1.1 Computer Types
- 1.2 Functional Units
- 1.3 Basic Operational Concepts
- 1.6 Performance
- 1.7 Historical Perspective
- Summary

Embedded Computers (1)

- An embedded computer is a microcontroller or microprocessor based system devised for specific function.
- Integrated into a larger device or system.



Embedded Computers (2)

- Characteristics
  - Small Form-factor: generally single high-density PCB
  - Lower power components
  - Minimal upgradeability/expansions
  - Low hardware cost
- Examples
  - Calculators
  - Digital Cameras
  - Vending Machines
  - Elevators
  - Copiers
  - Printers
  - GPS
  - …

Personal Computers (1)

- A small, general purpose computer that is created to be utilized by one person at a time.
- General computation, document preparation, computer-aided design, audiovisual entertainment, …
- Types
  - Workstation
    - High-end personal computer
    - Used for tasks such as computer-aided design, drafting and modeling, computation-intensive scientific and engineering calculations, image processing, architectural modeling, and computer graphics for animation and motion picture visual effects.

Personal Computers (2)

- Types (ctd.)
  - Desktop computers
    - Gaming computers
    - Single-unit PC(all-in-one PC)
  - Portable computers
    - Notebook (Laptop) computers
    - Netbook computers
      - Small, lightweight and inexpensive laptop computers suited for general computing tasks and accessing web-based applications.
    - Tablet

Servers and Enterprise Systems

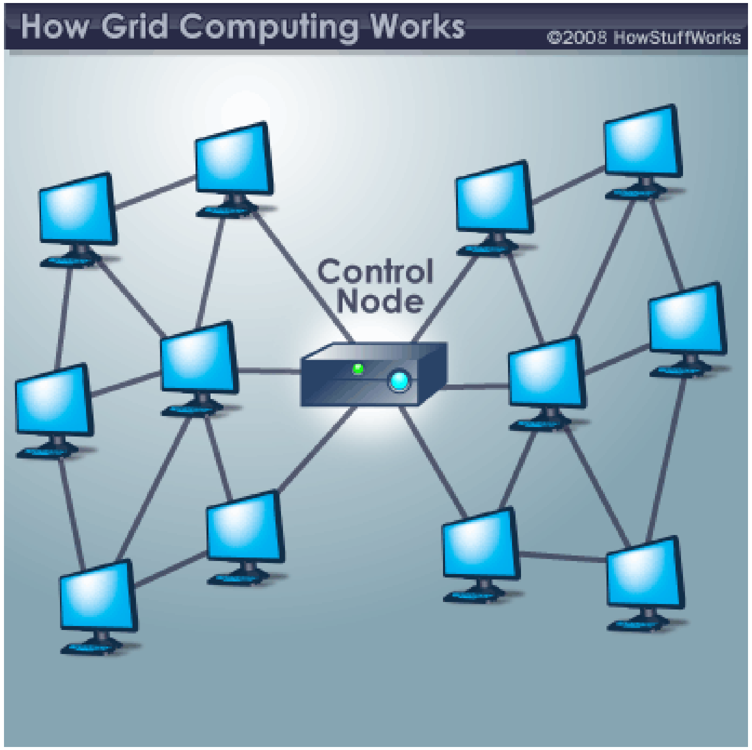
- Servers
  - A server is a computer that provides data to other computers.
  - Shared by a potentially large number of users
  - Contain sizable database storage units
  - Capable of handling large volumes of requests to access the data
  - Business data processing in medium to large corporations, information processing for a government agency,…

Supercomputers and Grid Computers (1)

- Supercomputers
  - A supercomputer is a type of computer that has the architecture, resources and components to achieve massive computing power.
  - FLOPS
    - Floating-point operations per second
    - Measurement of computing performance of a supercomputer.
  - Used in large-scale numerical calculations required in applications weather forecasting, aircraft design and simulation.

Supercomputers and Grid Computers (2)

- Grid Computers
  - Grid computers combine a large number of personal computers and disk storage units in a physically distributed high-speed network.



A group of computers that coordinate to solve a problem together.

Cloud Computing

- Cloud Computing is nothing but the delivery of computing services such as a database, networking, software, storage, servers, and many more.

- Question: Grid Computing vs. Cloud Computing

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Basic Functions of a Computer

- Data Processing
  - Data means any digital information
- Control
- Data Storage
- Data Movement

Basic Functional Units of a Computer (1)

- Arithmetic and Logic Unit (ALU)
- Control Unit

} Processor

- Memory
- Input Unit
- Output Unit

} I/O Unit

Basic Functional Units of a Computer (2)

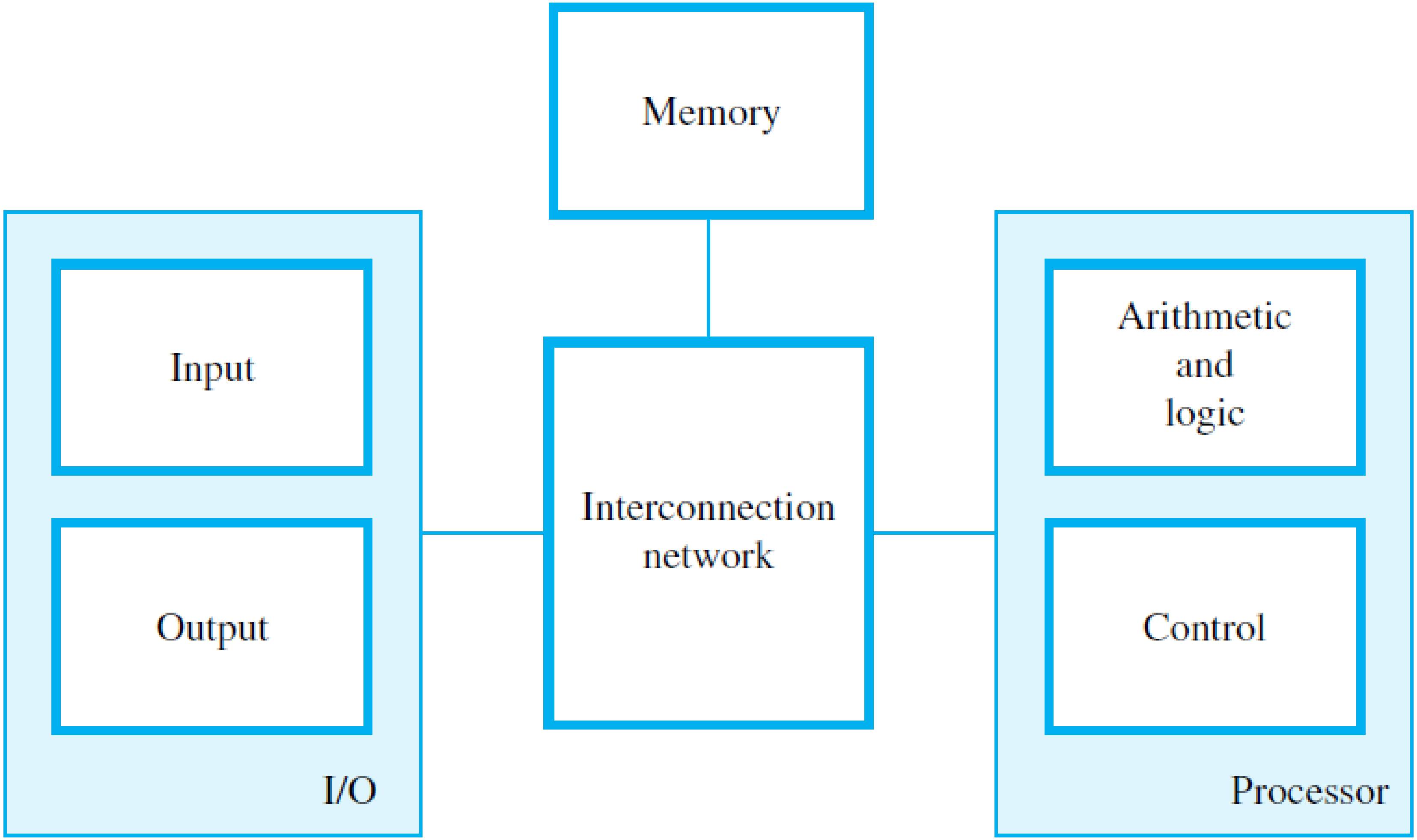


Figure 1.1 Basic functional units of a computer.

Information Handled by a Computer

- Instructions/Machine Instructions
  - Govern the transfer of information within a computer as well as between the computer and its I/O devices
  - Specify the arithmetic and logic operations to be performed
  - Program: a list of instructions which performs a task
- Data
  - Numbers and characters used as operands by the instructions
- Encoded in binary code – 0 and 1

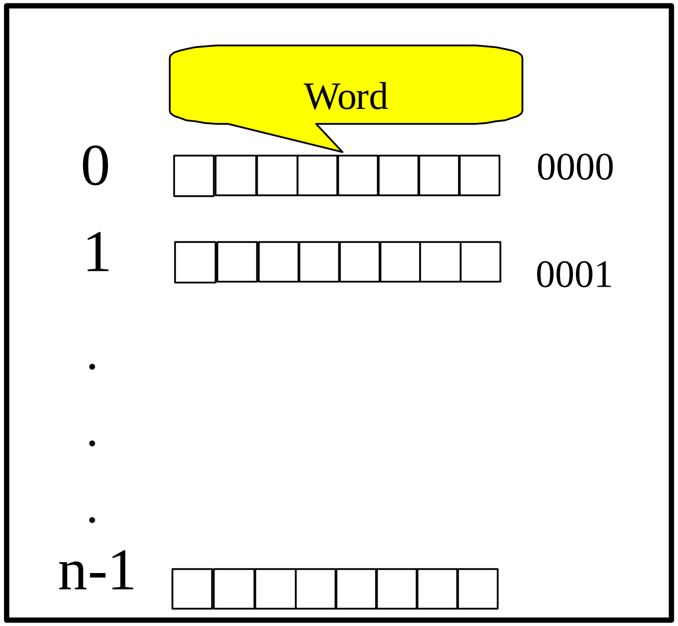
Input Units

- Function
  - Make computer accept coded information
- Input Devices
  - Keyboard
  - Mouse
  - Digital camera
  - Joystick
  - Touchpad
  - Scanner
  - Microphone
  - …

Output Units

- Function
  - Send processed results to the outside world
- Output Devices
  - Video display
  - Printer
  - …

Memory Unit (1)

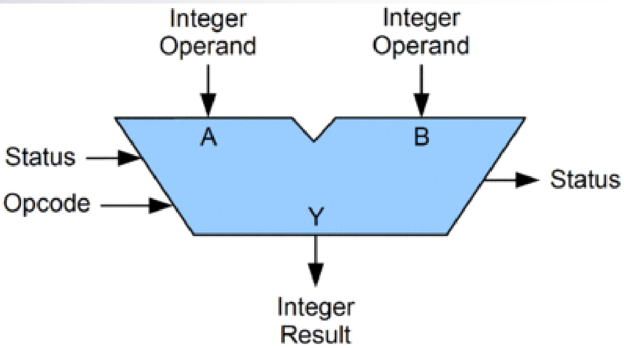


- Function
  - Store instructions and data
- Classification of Storage
  - Primary Storage
    - Store programs when they are being executed
    - Related terms
      - Word
      - Word length
      - Address
      - Memory access time
      - Random access memory

Memory Unit (2)

- Classification of Storage
  - Secondary Storage
    - Store many programs and large amounts of data, particularly for information that is accessed infrequently.
    - Magnetic Disks and Tapes
      - Hard disks
      - Floppy disks
    - Optical Disks
      - CD-ROMs

Arithmetic and Logic Unit



- Function
  - Execute arithmetic or logic operations
- Most computer operations are executed in ALU of the processor.
- Load the operands into memory – bring them to the processor – perform operation in ALU – store the result back to memory or retain in the processor.
- Registers in ALU: high speed storage elements

Control Unit

- Functions
  - Controls sequential instruction execution
  - Interprets instructions
  - Guides data flow through different computer areas
  - Regulates and controls processor timing
  - Sends and receives control signals from other computer devices
  - Handles multiple tasks, such as fetching, decoding, execution handling and storing results

Operations of a Computer

- The computer accepts information in the form of programs and data through an input unit and stores it in the memory.
- Information stored in the memory is fetched, under program control, into an arithmetic and logic unit where it is processed.
- Processed information leaves the computer through an output unit.
- All activities inside the machine are directed by the control unit.

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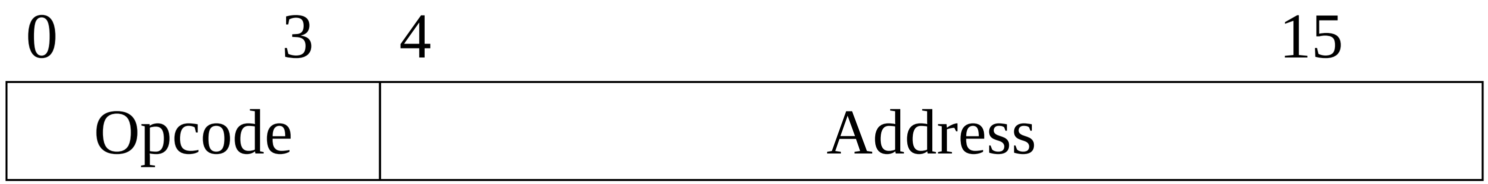
Program Execution (1)

- Execute instructions specified in the program.
  - 1.The processor reads (fetch) instructions from memory one at a time, and executes each instruction.
  - 2.Program execution consists of repeating the process of instruction fetch and instruction execution.

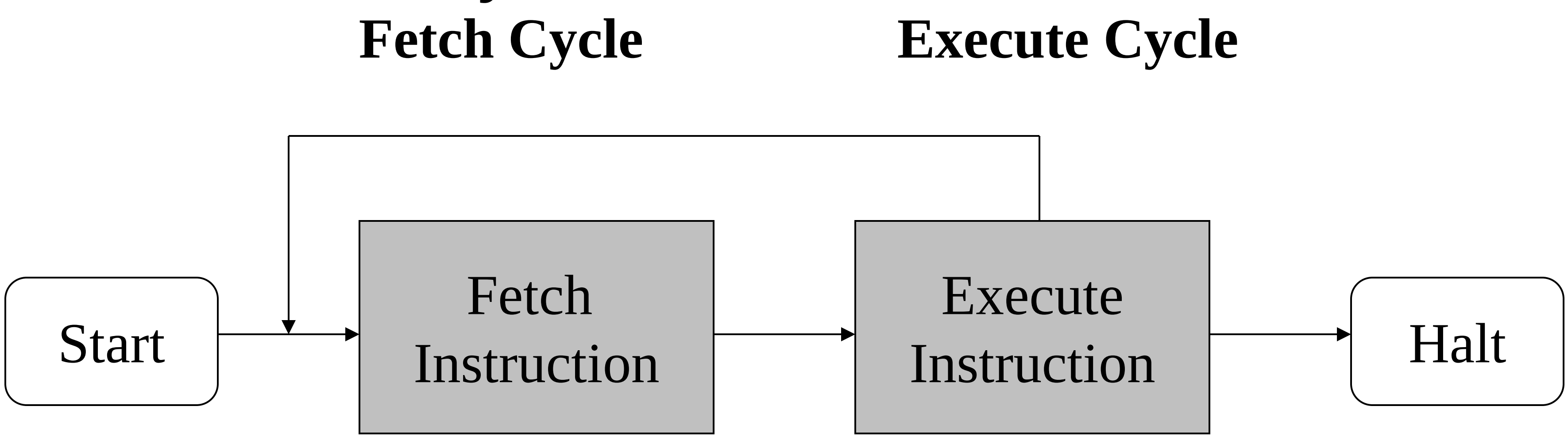
Program Execution (2)

- Example of an Instruction



An Example Instruction Format

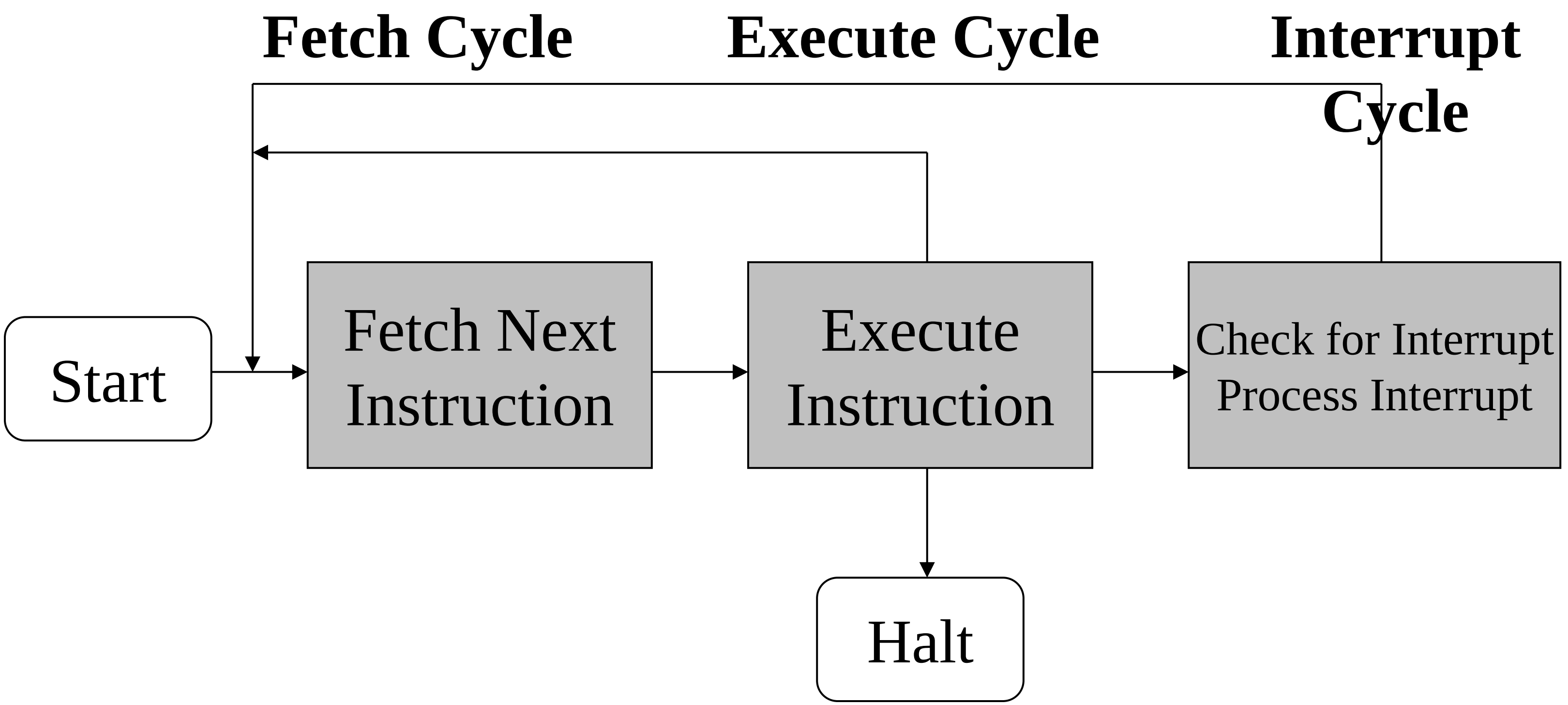
- Instruction Cycle



Instruction Cycle

Program Execution (3)

- Instruction Cycle with Interrupt
  - Interrupt: An interrupt is a request from an I/O device for service by the processor.



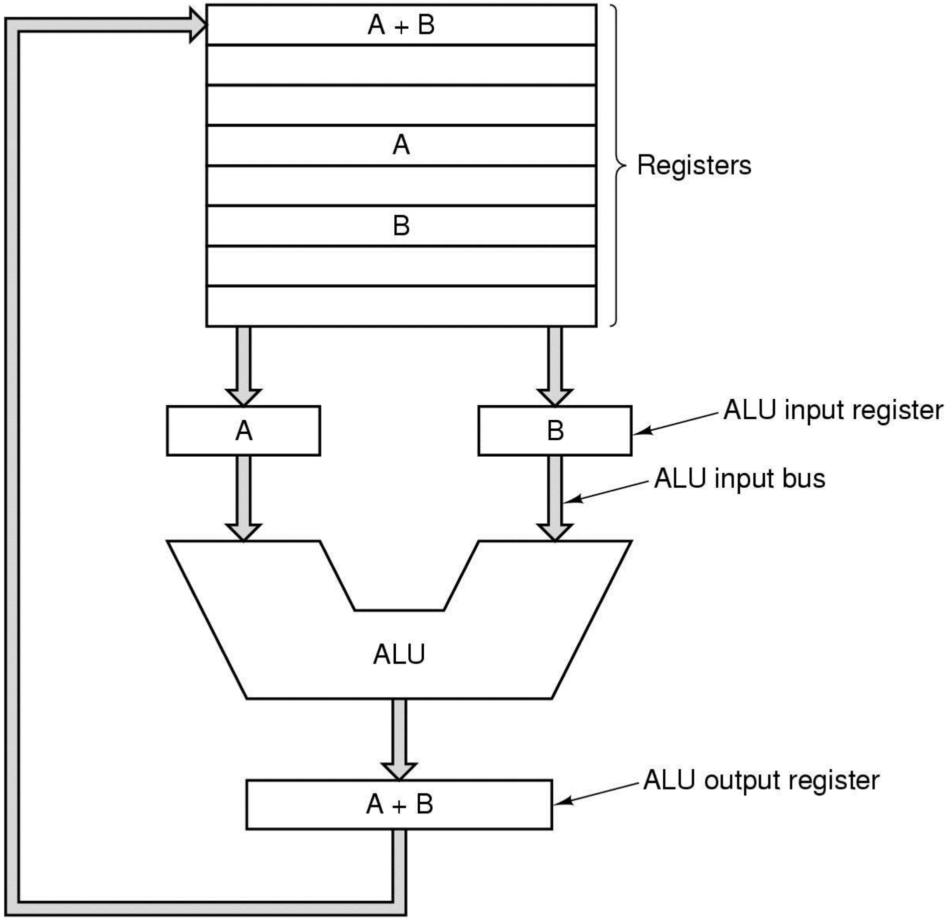
Program Execution (4)

- Instruction Execution
  - Example: *Add LOCA, R0*
    - Fetch the instruction from the memory into the processor(IR)
    - The operand at LOCA is fetched and added to the contents of R0 (combines a memory access operation with an ALU operation)
    - The resulting sum is stored in register R0
  - *Load LOCA, R1*

    Add R1, R0

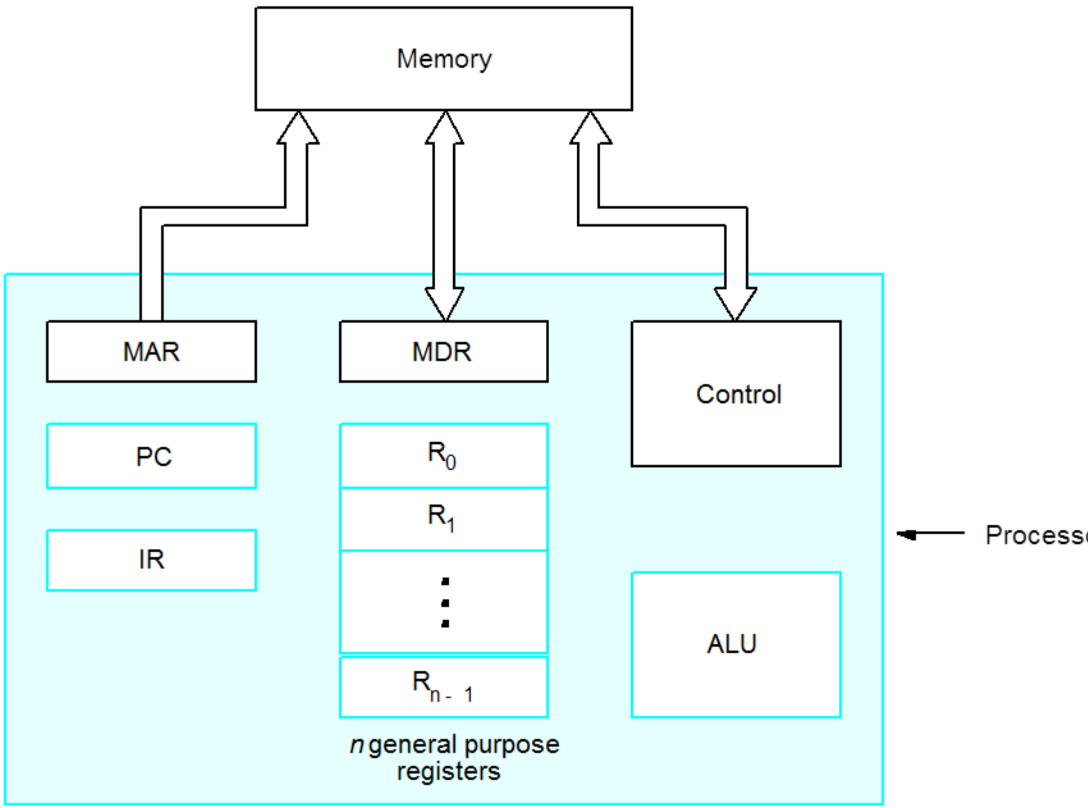
Program Execution (5)

- Instruction Execution (ctd.)



Program Execution (6)

- Instruction Execution (ctd.)



Program Execution (7)

- Instruction Execution (ctd.)
  - Normal steps of an instruction execution

(1) MAR← [PC], Read

(2) WMFC, MDR← [MAR], PC← [PC]+1

(3) IR← [MDR]

If an operand resides in the memory, then (4) to (7), else (7)

(4) MAR← LOCA, Read

(5) WMFC, MDR← [MAR]

(6) Ri← [MDR]

(7) ALU performs operation

If the result is to be stored in the memory, then (8)

(8) MDR← result

(9) MAR← address, Write

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Measuring Performance

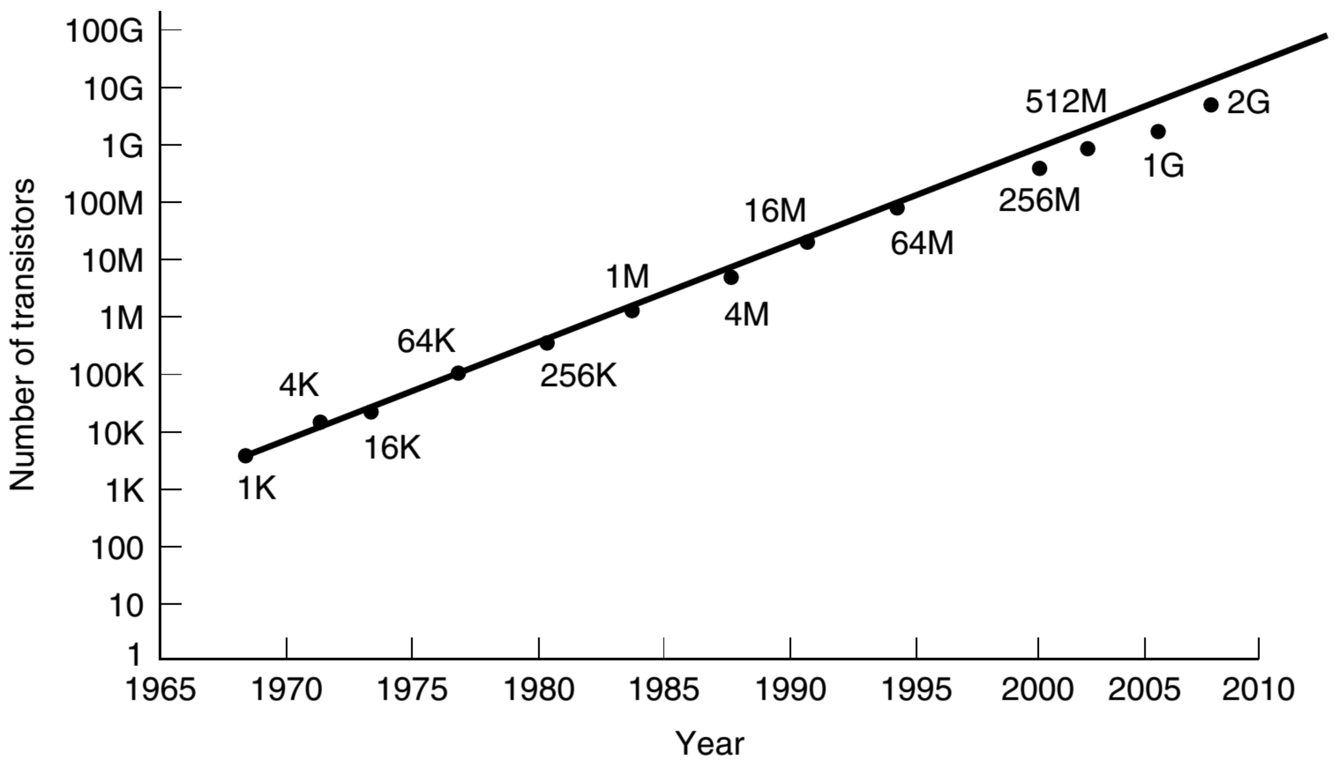
- Measuring Performance
  - How quickly a computer can execute programs
    - Design of instruction set
    - Hardware, including hardware fabrication technology
    - Software, including OS
    - Compiler
  - MIPS
    - Millions of Instructions per second
    - Measurement of how many machine instructions a processor execute per second.

Technology (1)

- Chip manufacturers pack more and more transistors per chip every year.
- Moore's Law (1965)
  - Integrated circuit density-doubling would occur every 24 months, integrated circuits would double in performance every 18 months.
- Moore's law has long been associated with the number of bits in a memory, it applies equally well to CPU chips.

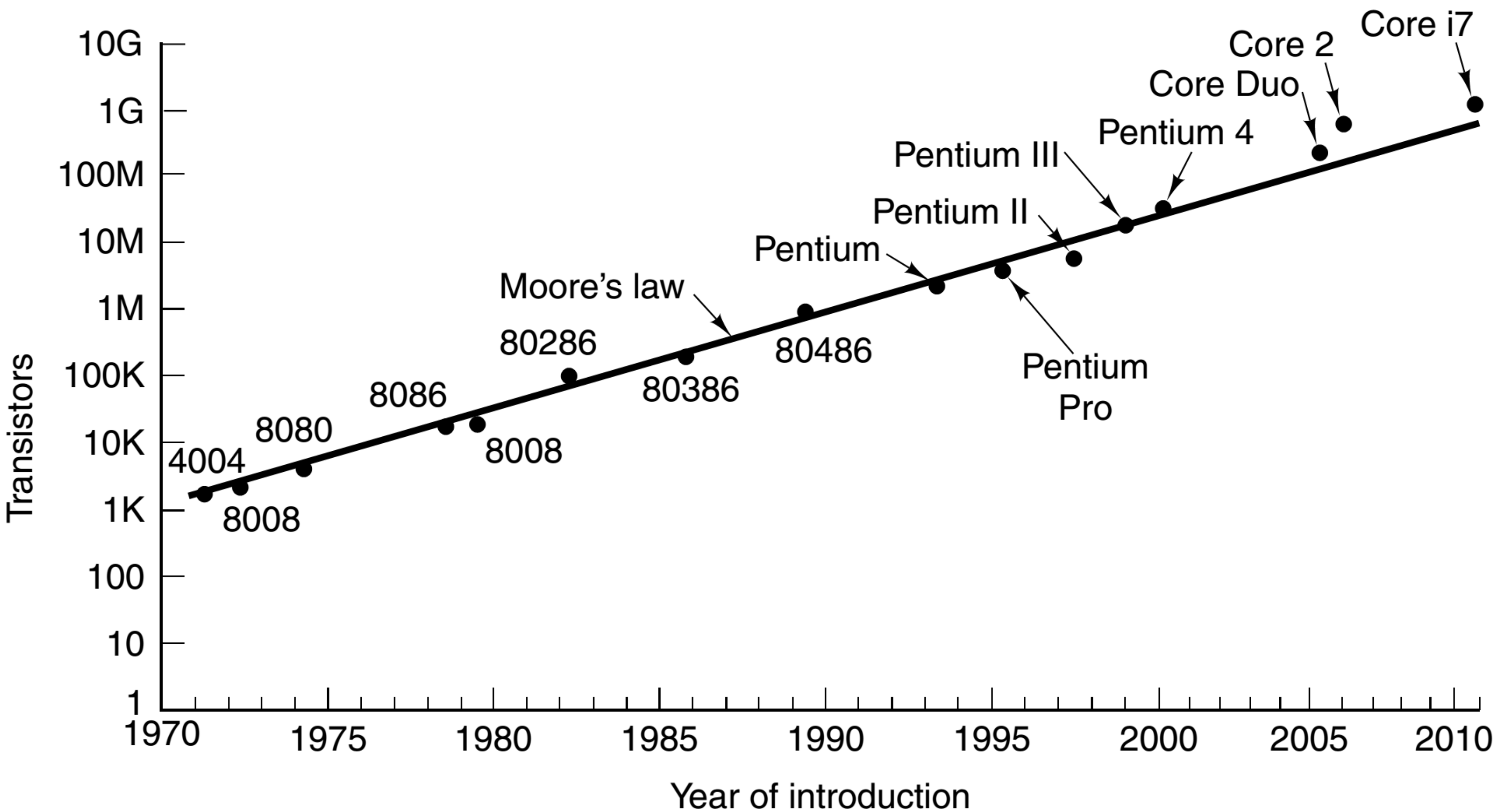
Technology (2)

- Moore's Law for Memory Chips



Technology (3)

- Moore's Law for CPU(Intel) Chips



Technology (4)

- Tick-Tock Model (2007)
  - An aggressive development model introduced by Intel for their mainstream microprocessors.
  - Tick 芯片工艺提升，晶体管变小
    - With each tick, Intel advances their manufacturing process technology in line with Moore's Law.
  - Tock 工艺不变，芯片核心架构的升级
    - With each tock, Intel uses the their latest manufacturing process technology from their "tick" to manufacture a newly designed microarchitecture.

Technology (5)

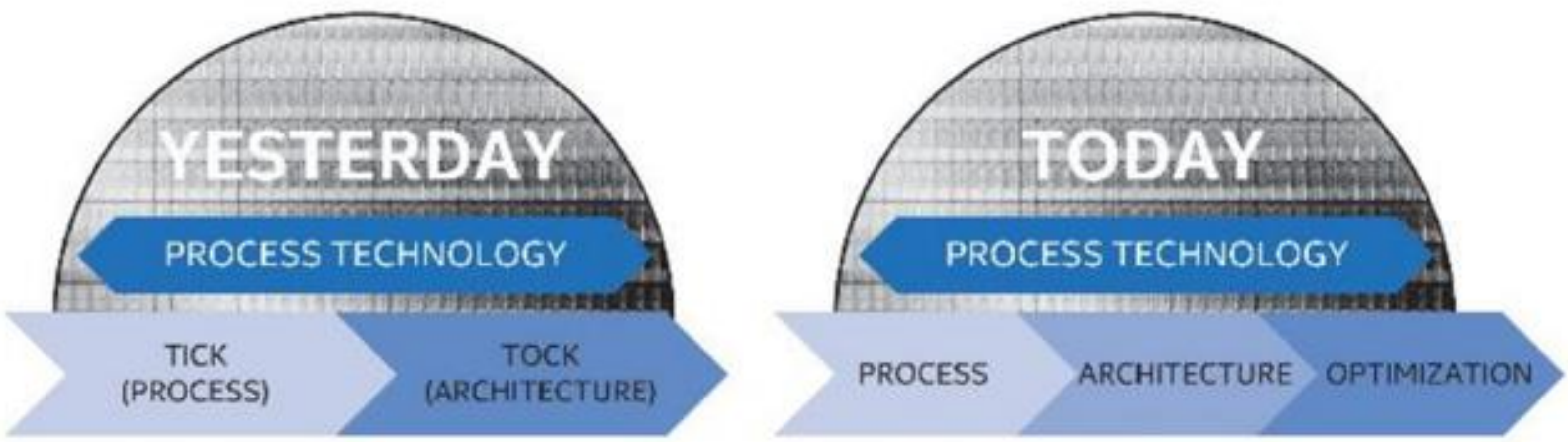
- Tick-Tock Roadmap

Intel Tick-Tock Roadmap			
Cycle	Process	Introduction	Microarchitecture
Tick	65 nm	2005	Pentium D
Tock	65 nm	2006	Core
Tick	45 nm	2007	Penryn
Tock	45 nm	2008	Nehalem
Tick	32 nm	2009	Westmere
Tock	32 nm	2010	Sandy Bridge
Tick	22 nm	2011	Ivy Bridge
Tock	22 nm	2013	Haswell
Tick	14 nm	2014	Broadwell
Tock	14 nm	2015	Skylake

Tock 14nm 2016 Kaby Lake

Technology (6)

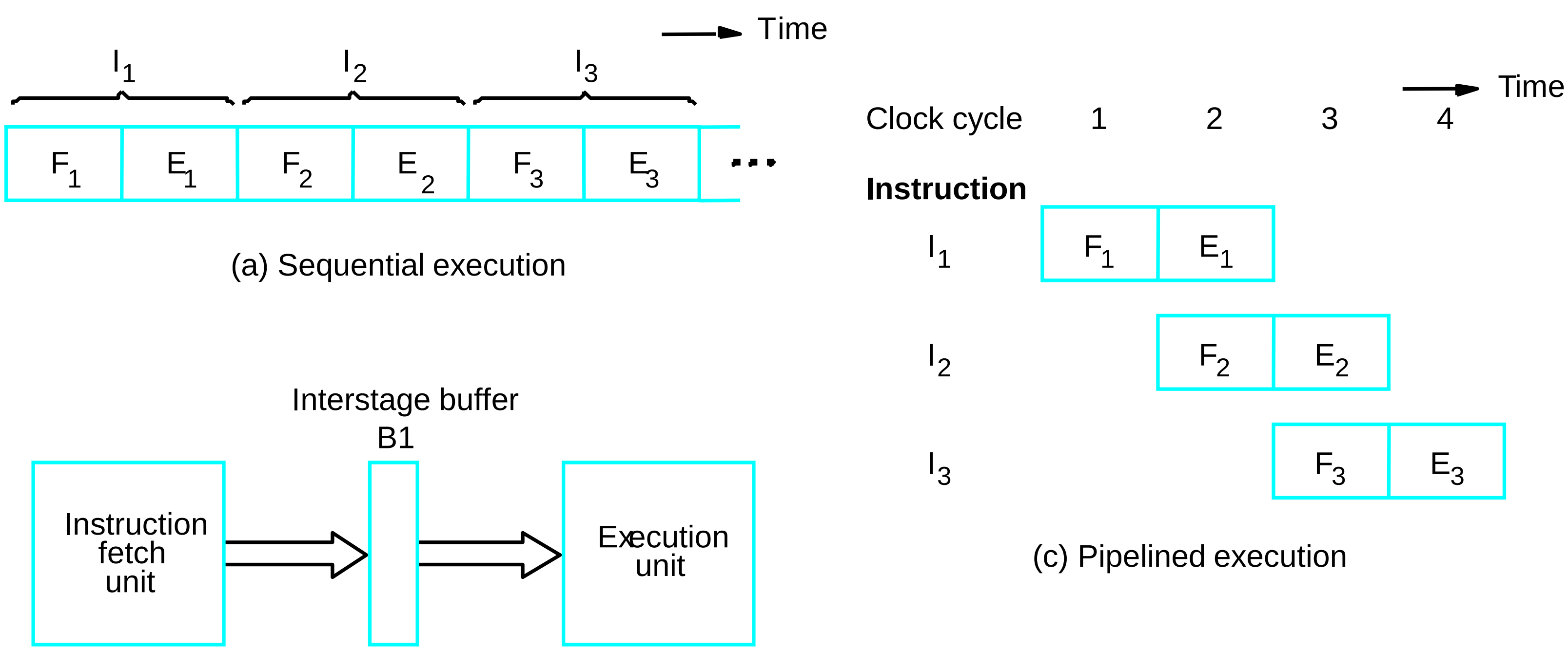
- Process-Architecture-Optimization
  - 10nm工艺被认为硅基半导体的转折点，再往后是7nm工艺，已经进入量子学范畴，半导体特性都有变化了，所以研发难度更大，需要更多黑科技材料加入，也需要EUV等新一代光刻设备。



Parallelism (1)

- Instruction-level Parallelism
  - Pipelining: beginning other waiting instructions before the first finishes

Fetch + Execution



(a) Sequential execution

(b) Hardware organization

(c) Pipelined execution

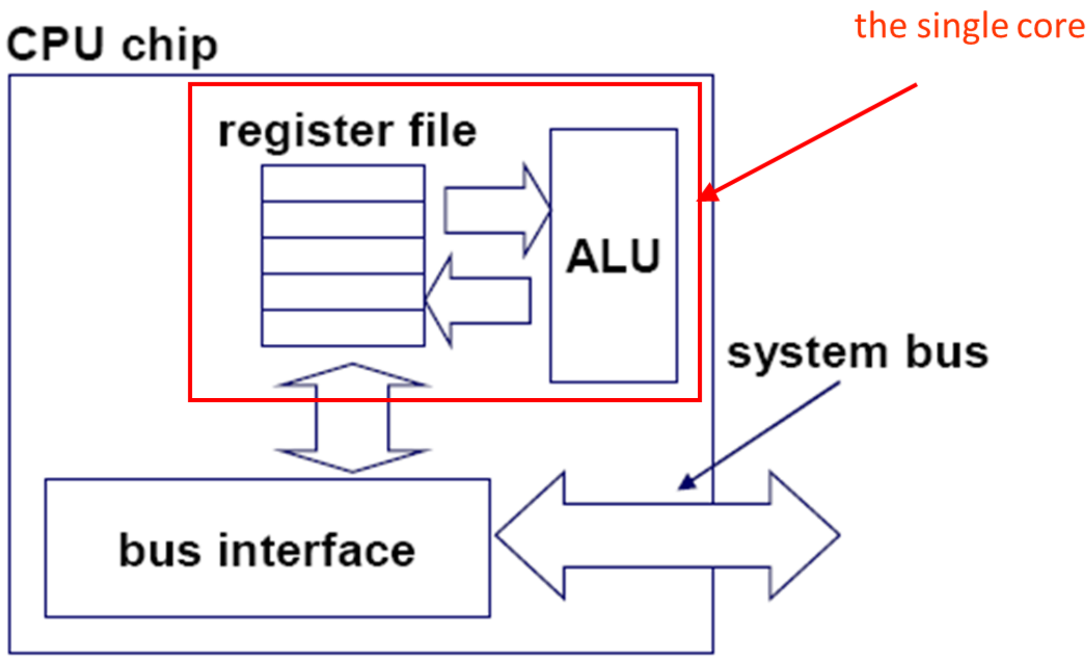
Basic idea of instruction pipelining.

Parallelism (2)

- Multicore Processors
  - Problems in Single Core
    - To execute the tasks faster you must increase the clock time.
    - Increasing clock times too high drastically increases power consumption(higher voltage) and heat dissipation to extremely high levels, making the processor inefficient.
    - Power consumed and heat dissipated is proportional to the square of the voltage.
    - E.g. At 3.6 GHz, the Pentium 4 consumes 115 watts of power. That means it gets about as hot as a 100-watt light bulb.

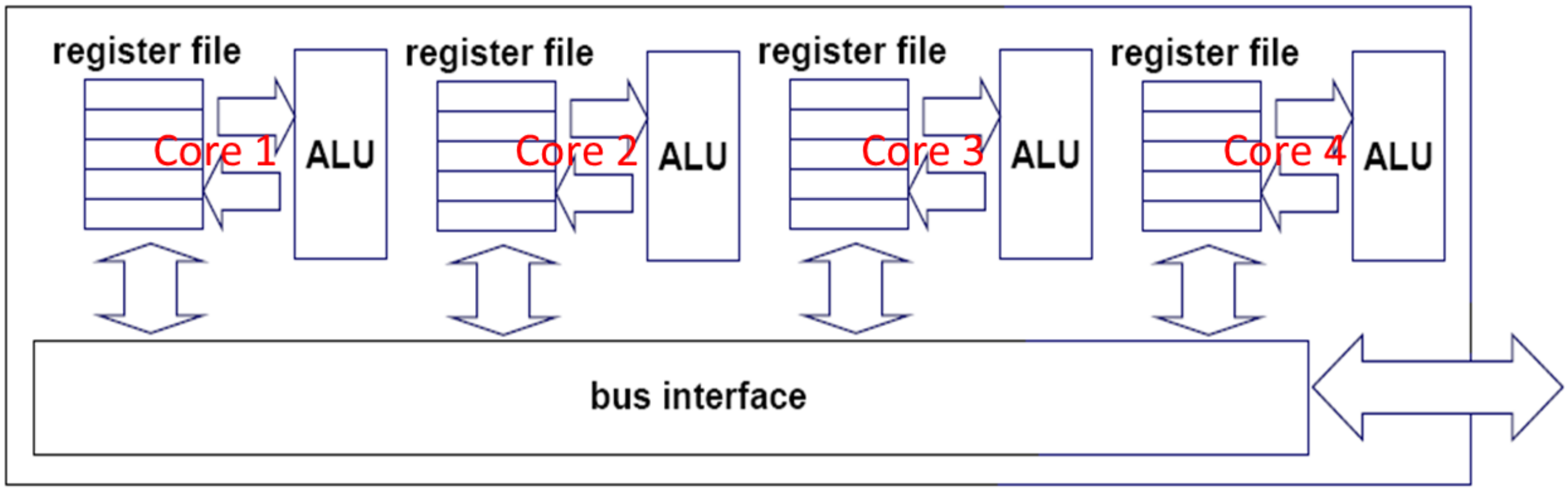
Parallelism (3)

- Multicore Processors (ctd.)
  - Single-core CPU Chip



Parallelism (4)

- Multicore Processors (ctd.)
  - Multi-core CPU Chip

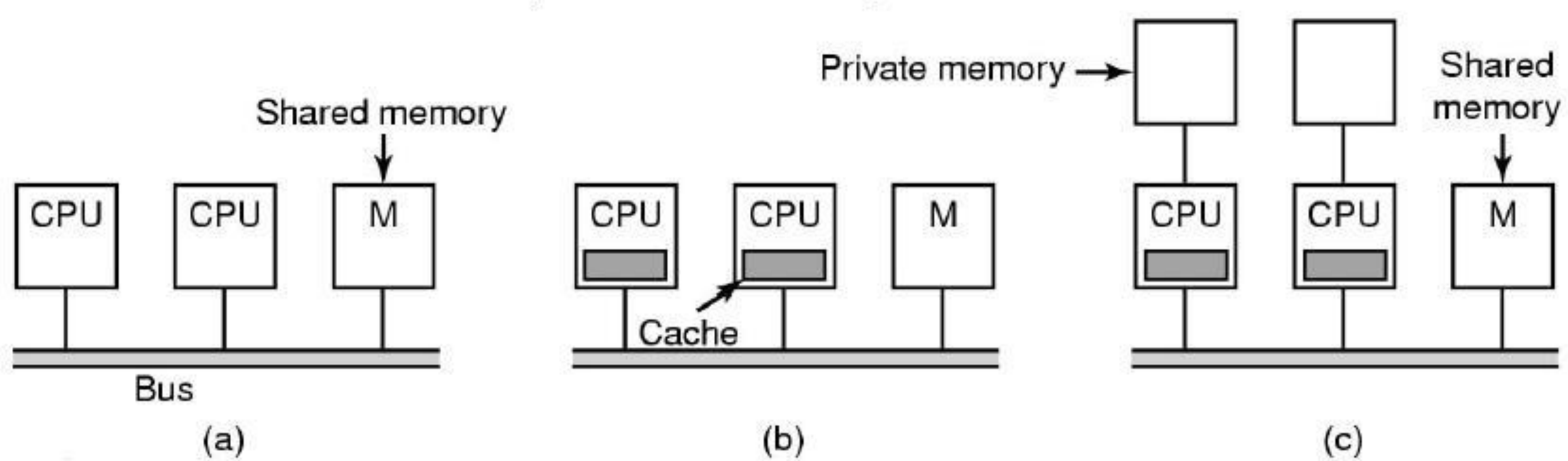


Parallelism (5)

- Multiprocessors
  - A shared-memory multiprocessor (or just multiprocessor henceforth) is a computer system in which two or more CPUs share full access to a common RAM.
  - Why Multiprocessors?
    - For improved latency: e.g. Meteorologist running weather analysis program
    - For improved throughput: e.g. Transaction processing systems at banks, Google search engine
    - For improved reliability: e.g. Computer system in a spacecraft; it should continue working correctly even when some CPUs go wrong

Parallelism (6)

- Shared-Memory Multiprocessor
  - (a) Simplest MP: More than one processor on a single bus connect to memory, bus bandwidth becomes a bottleneck.
  - (b) Each processor has a cache to reduce the need to access to memory.
  - (c) To further scale the number of processors, each processor is given private local memory.



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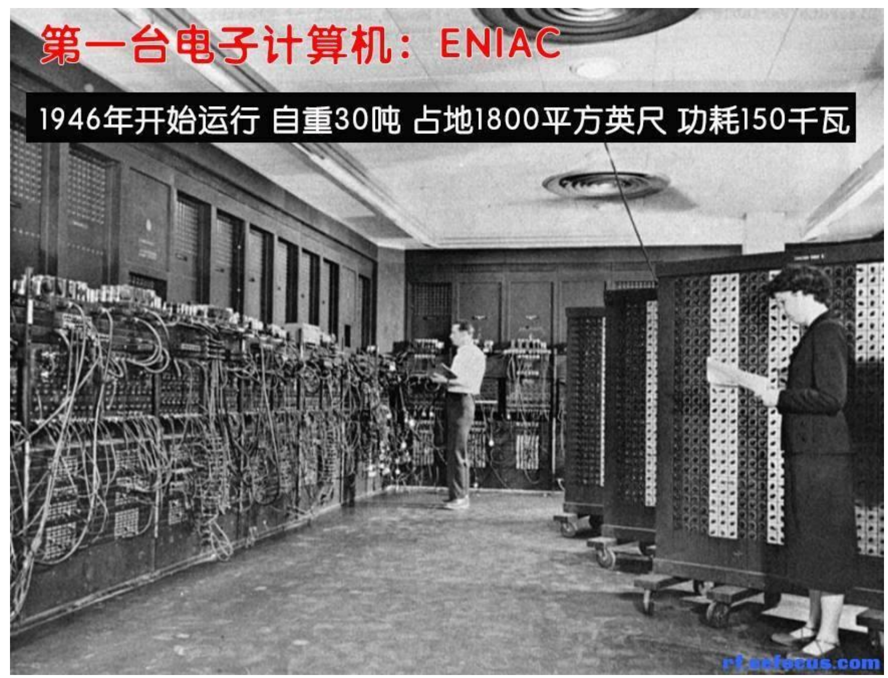
Computer Generations (1)

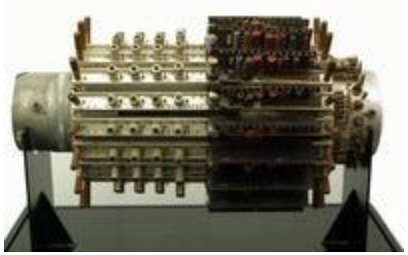
- The First Generation : Vacuum Tubes (1945-1955)
  - ENIAC(Electronic Numerical Integrator And Computer)
    - The world’s first general-purpose electronic digital computer
    - The Moore school of the University of Pennsylvania

Consisted of 18,000 vacuum tubes and 1500 relays



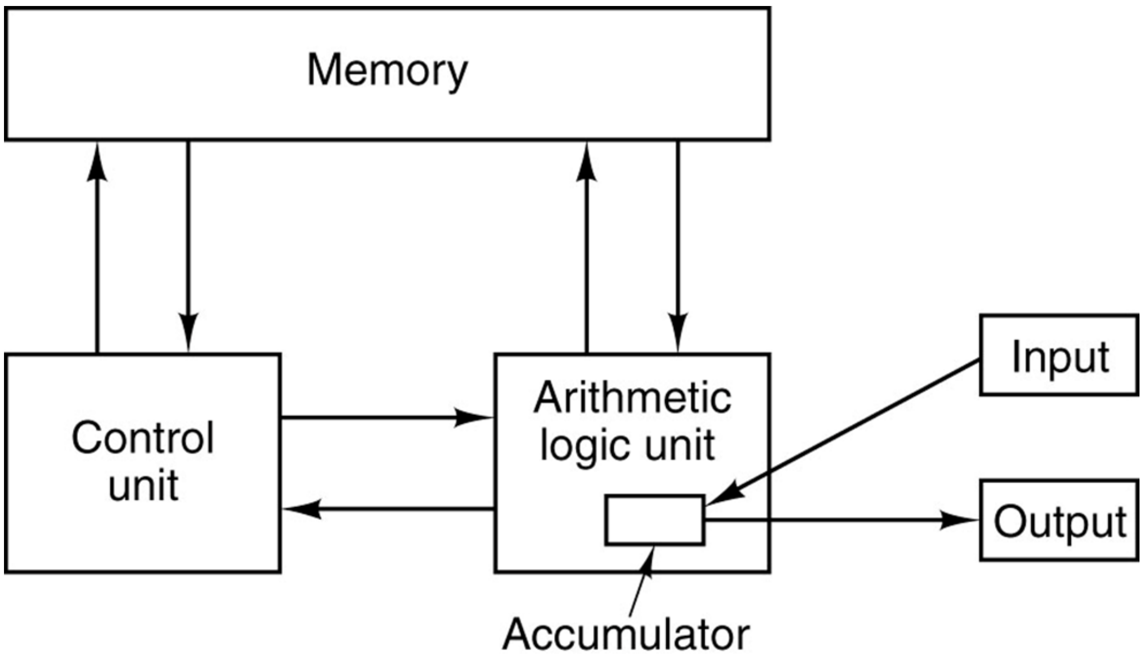
Computer Generations (2)

- The First Generation : Vacuum Tubes (1945-1955) (ctd.)
  - Stored-program concept (John von Neumann)
    - Data and instructions are stored in a single read-write memory.
    - The contents of this memory are addressable by location , without regard to the type of data contained there.
    - Execution occurs in a sequential fashion (unless explicitly modified) from one instruction to the next.
  - Assembly Language
  - Mercury delay-line memory



Computer Generations (3)

- The First Generation : Vacuum Tubes (1945-1955) (ctd.)
  - The Original Von Neumann Machine



Computer Generations (4)

- The Second Generation : Transistors (1955-1965)
  - Magnetic core memories and magnetic drum storage devices
  - High-level languages, e.g. Fortran
  - Compiler
  - Separate I/O processors
  - PDP-8, IBM7094, CDC6600…

Computer Generations (5)

- The Third Generation : Integrated Circuits (1965-1975)
  - An IC comprises a number of circuit components. They are interconnected in a single small package to perform the desired electronic function.
  - Small Scale Integration: transistors <100
  - Medium Scale Integration: transistors101~1k
  - Integrated-circuit memories
  - Microprogramming
  - Parallelism
  - Pipelining
  - Cache
  - Virtual memories
  - IBM360 Computer family, PDP-11, …

Computer Generations (6)

- The Fourth Generation : LSI & VLSI (1975-1990)
  - Complete processors and large sections of the main memory of small computers could be implemented on single chips.
  - LSI: Large Scale Integration
    - Transistors 1,001~10k
  - VLSI: Very Large Scale Integration
    - Transistors 10,001~100k
  - RISC takes place of CISC
  - FPGA
  - Multicore and Parallel Programming

Computer Generations (7)

- Beyond the Generation (1991-   )
  - Some computer system that have a dominant organizational or application-driven feature.
  - ULSI: Ultra Large Scale Integration
    - Transistors 100,001~10M
  - GLSI: Giga Scale Integration
    - Transistors>10,000,001

Computer Generations (8)

- Beyond the Generation (1991-) (ctd.)
  - 三大主流厂商晶体管密度比较
    - 单位：百万个晶体管每平方毫米

排名	工艺技术	近似晶体管密度（MTr/mm²）
1	英特尔 10nm	100.8
2	台积电 7nm FF/FF+	96.5
3	三星 7nm	95.3
4	台积电 7nm HPC	66.7
5	三星 8nm	61.2
6	台积电 10nm	60.3
7	三星 10nm	51.8
8	英特尔 14nm	43.5
9	GlobalFoundries 12nm	36.7
10	台积电 12nm	33.8
11	三星/GlobalFoundries 14nm	32.5
12	台积电 16nm	28.2

Summary (1)

- Computer Types
- Five basic functional units of computers
  - Arithmetic and logic unit
  - Control unit
  - Memory
  - Input unit
  - Output unit

Summary (2)

- Computer Generations
  - The first generation: vacuum tubes
  - The second generation: transistors
  - The third generation: integrated circuits
  - The fourth generation: LSI&VLSI