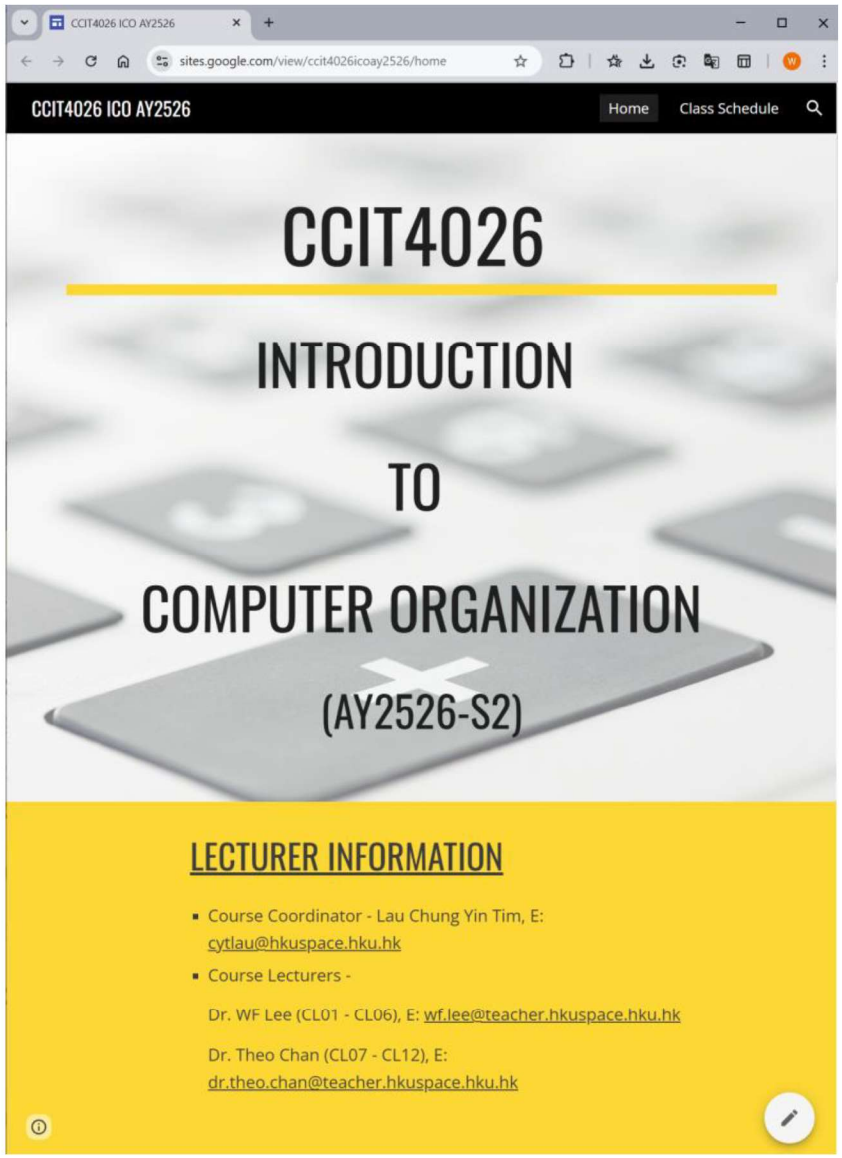
INTRODUCTION TO COMPUTER ORGANIZATION

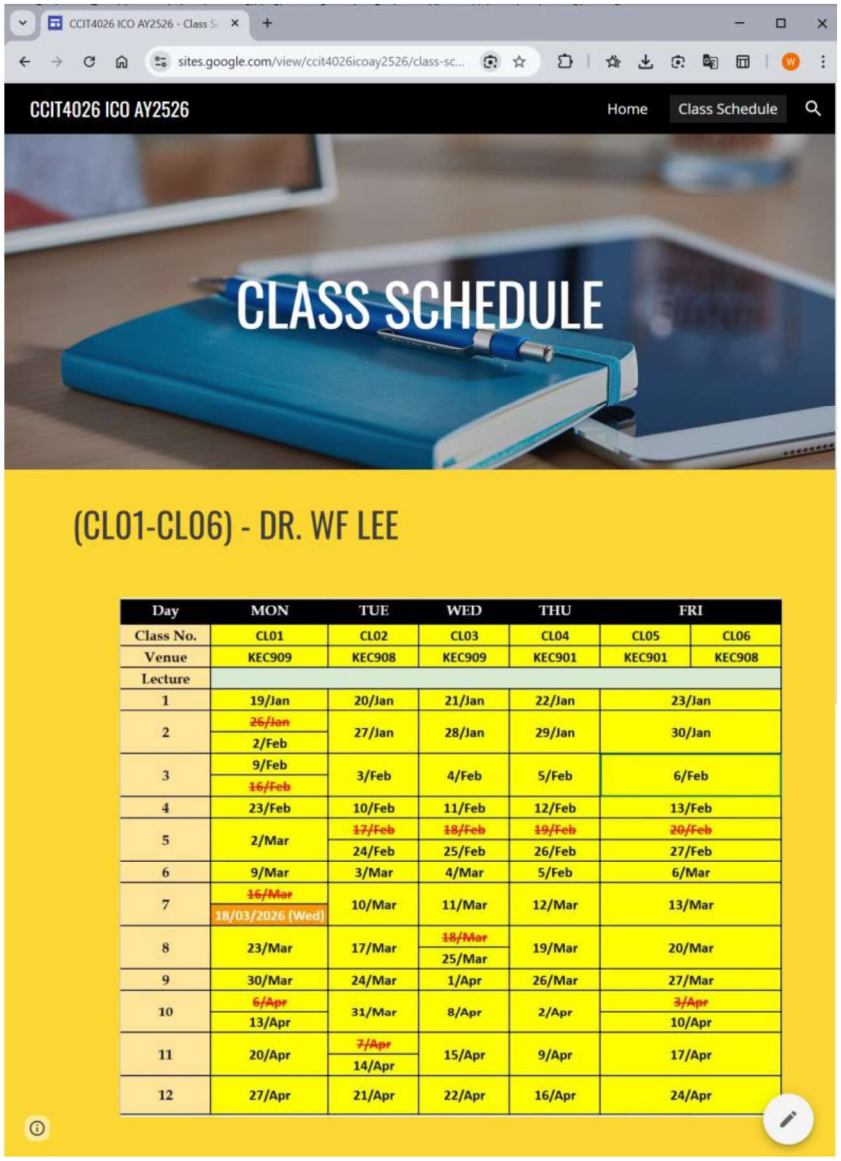
CCIT4026

Chapter 1 : Introduction

Course Information

- https://sites.google.com/view/ccit4026icoay2526/home





Day	MON	TUE	WED	THU	FRI	
Class No.	CL01	CL02	CL03	CL04	CL05	CL06
Venue	KEC909	KEC908	KEC909	KEC901	KEC901	KEC908
Lecture						
1	19/Jan	20/Jan	21/Jan	22/Jan	23/Jan	
2	~~26/Jan~~ 2/Feb	27/Jan	28/Jan	29/Jan	30/Jan	
3	9/Feb ~~16/Feb~~	3/Feb	4/Feb	5/Feb	6/Feb	
4	23/Feb	10/Feb	11/Feb	12/Feb	13/Feb	
5	2/Mar	~~17/Feb~~ 24/Feb	~~18/Feb~~ 25/Feb	~~19/Feb~~ 26/Feb	~~20/Feb~~ 27/Feb	
6	9/Mar	3/Mar	4/Mar	5/Feb	6/Mar	
7	~~16/Mar~~ 18/03/2026 (Wed)	10/Mar	11/Mar	12/Mar	13/Mar	
8	23/Mar	17/Mar	~~18/Mar~~ 25/Mar	19/Mar	20/Mar	
9	30/Mar	24/Mar	1/Apr	26/Mar	27/Mar	
10	~~6/Apr~~ 13/Apr	31/Mar	8/Apr	2/Apr	~~3/Apr~~ 10/Apr	
11	20/Apr	~~7/Apr~~ 14/Apr	15/Apr	9/Apr	17/Apr	
12	27/Apr	21/Apr	22/Apr	16/Apr	24/Apr	

Course Intended Learning Outcomes (ILOs)

- ILO1. describe various data representations and explain how arithmetic and logical operations are performed by computers;
- ILO2. describe organization of digital computers and explain the basic principles and operations of components such as data path and control of CPU, memory, and I/O;
- ILO3. describe the measurements of performance of computer components and evaluate the performance of the components;
- ILO4. analyze simple program in machine language and develop simple program with assembly language.

Pre-requisites

- CCIT4020 ICP (Introduction to Computer Programming)
  - Skillful in computer programming and Python programming language.
- CCIT4082 DLS (Digital Logic and Systems)
  - Knowledge on sequential logics and
  - Concept of State Machine logic design.

Assessment

(a) Laboratory Exercises (x 5) -- 25%

Written Assignments (x 4) -- 15%

40%

(b) Midterm Test (1.5 hrs) 20%

- Tentative: TBC (Mid-Apr on Sat/Sun)

(c) Written Exam (2 hrs) 40%

Lab. Exercises

Totally 5 Labs (Using MARS – MIPS Software Simulator)

- BOTH Lab. Report (.pdf) **AND** Source Code (.asm) submission on SOUL.

  (!!!!!! NO mark would be given if missing either one)

-
- Similar to other programming courses.
- Mainly focus on Assembly Language.
- This is a very important language for us to understand the computer organization.

Written Assignments

- Will be released according to the schedule
- Normally ONE week after release
- Simple questions for you to prepare the tests and final examination

Email Policy

- We adopt the college email as the primary communication channel beyond class time.
- Students seeking help from lecturers shall use their @learner.hkuspace.hku.hk address to prevent from being spammed.
- Improperly compiled messages, such as untitled and unaddressed ones, would be ignored.
- Emails written in languages other than English would be ignored.
- Include your student ID and class number in closing your message. Normally speaking, students may expect a reply in two days time. Unattended messages may be assumed to have been lost and students may consider resending so.

Academic Honesty

- We encourage discussion to be made amongst students. But once you have finished your conversation, write down your answers in your ***own wordings and understandings***.

- Similar expression, wordings, or equations may invite our investigation on suspected cases of plagiarism. Serious offenses will be passed to the Guidance Committee.

- "***Purchase answers***" from paid/registered online consultation website would be considered as cheating.

Outline (Chapter 1)

- What is a Computer?
- Computer Components
- Use of different technology
- Performance

Computer Organization

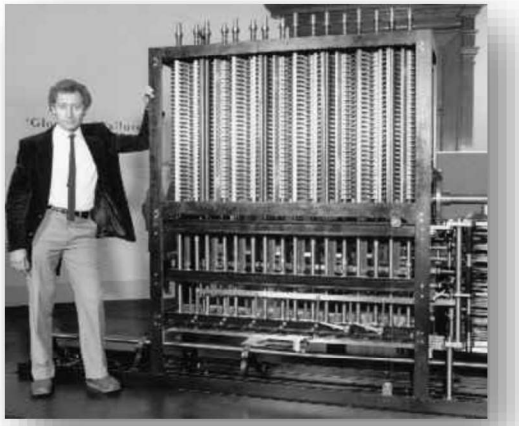
- This is an introductory course to computer organization.

- The topics covered include:
  - Instruction-Set-Architecture (ISA) design and assembly language programming,
  - Digital design and computer arithmetic,
  - Performance analysis,
  - Controller and datapath design,
  - Pipelining,
  - More ..... (If time allow)

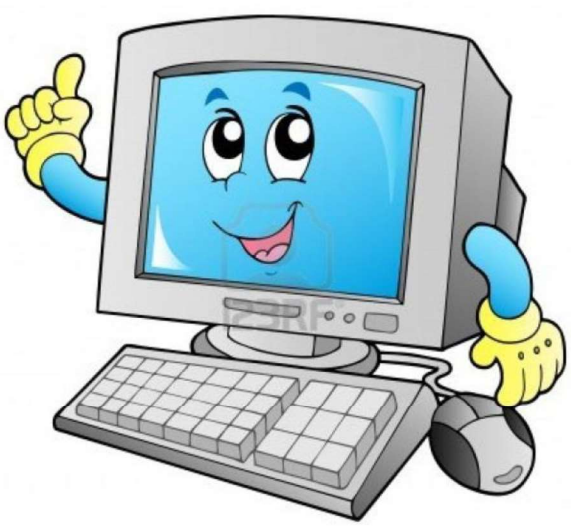
What is a Computer?

A computer <u>can</u>

- process data
- store data
- move data between the computer and outside world
- control the operation of the above



What is a Computer?



Computers take many forms:

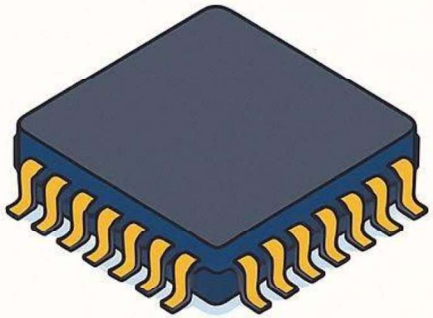
1. Desktop computers
   - Single user personal computers
   - Laptops

2. Servers
   - Mainframes, supercomputers
   - Usually access via network

3. Embedded computers
   - Application processors in cell phones, microcontroller in car, plane, cargo ship, video games, even your air conditioner, etc.
   - Designed to perform one or one set of related applications

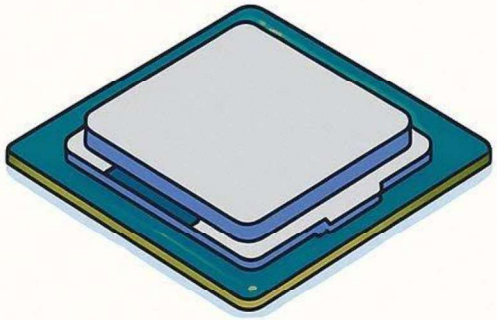
MCU VS MPU

(Microcontroller)



- All-in-one control chip
- On-chip integration
- Control & real-time operation
- Low power consumption
- Bare metal or RTOS

(Microprocessor)

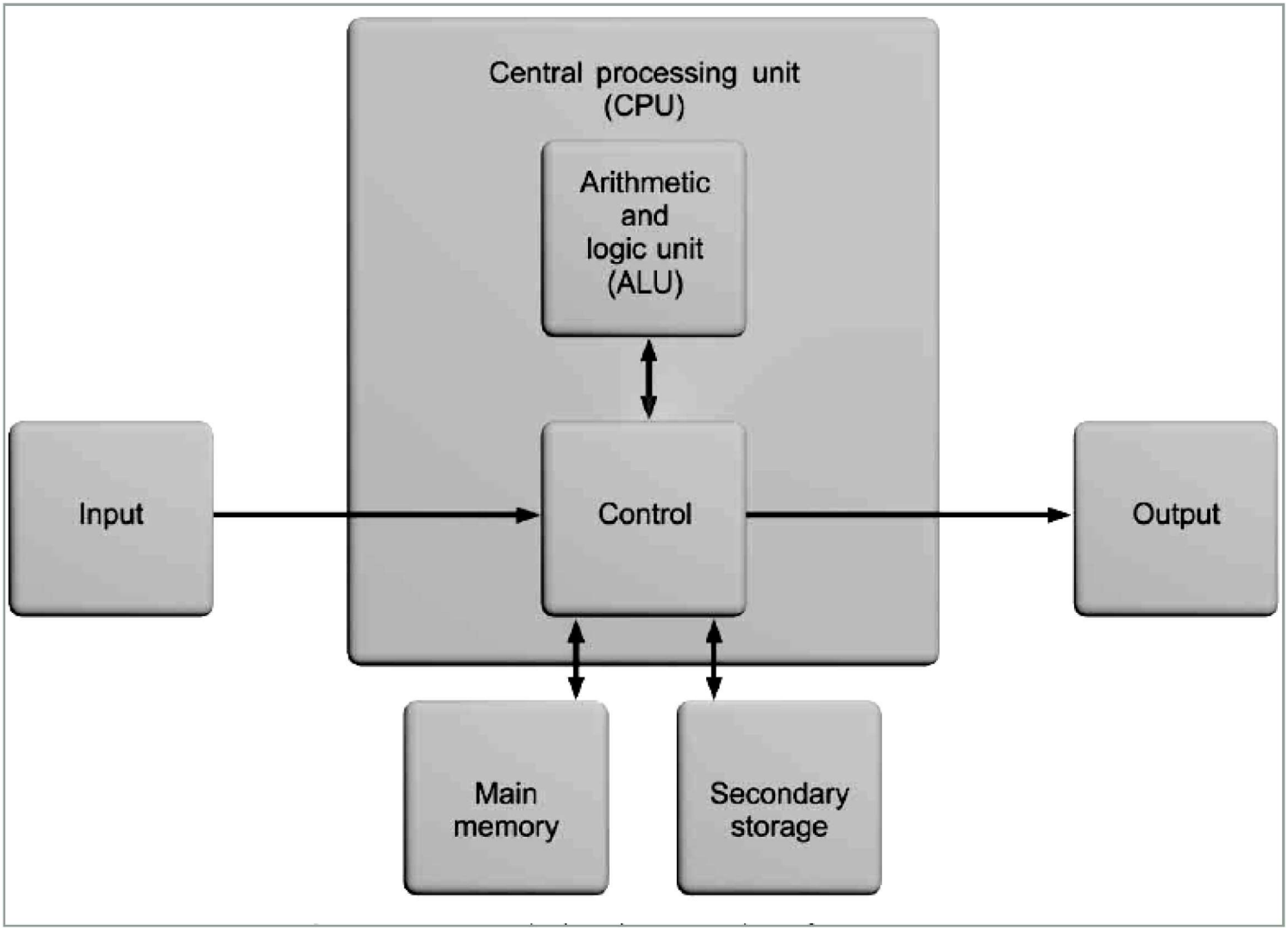


- Central processing unit
- External components required
- Data processing & high performance
- High power consumption
- Full General-Purpose OS

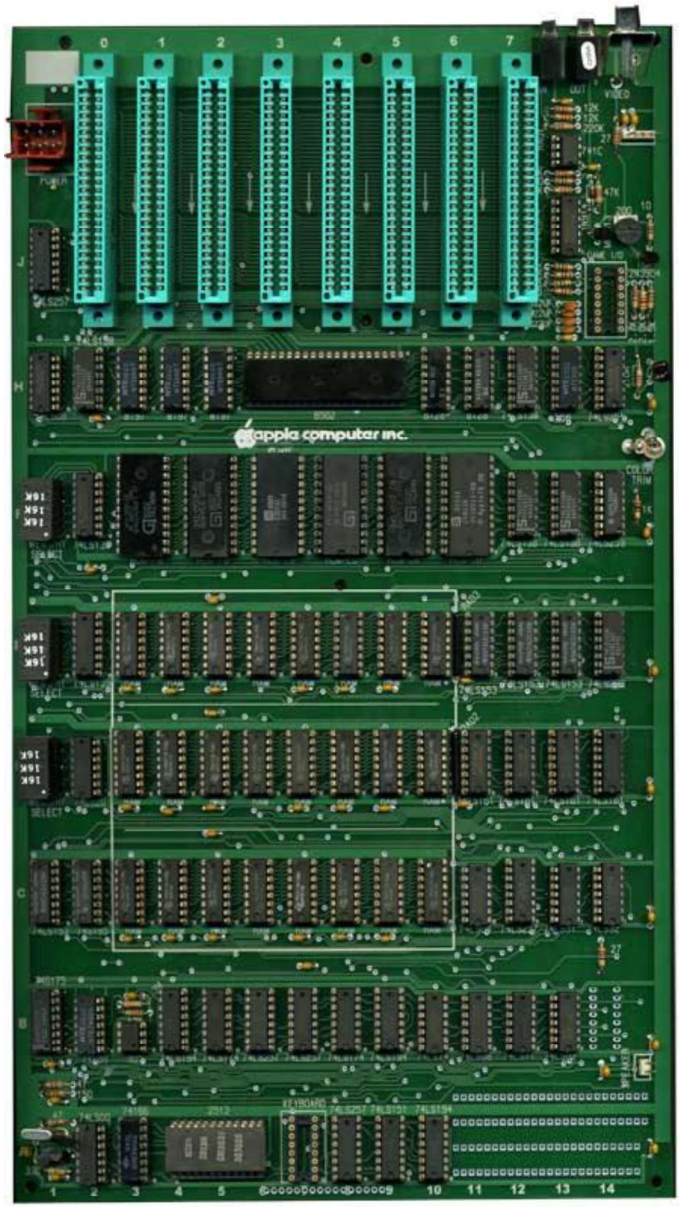
What is Computer?

- A **computer** is a general purpose device which *can be programmed* to carry out a sequence of arithmetic or logical operations, for solving specific problems.
- Computer **hardware** is the collection of physical elements that construct a computer system.
- Behavior of the computer system is computer **software** (or simply program).
- A program or set of programs is called software.
- Computer **program** contains data and instructions used to operate a computer and produce a specific result.

Computer components

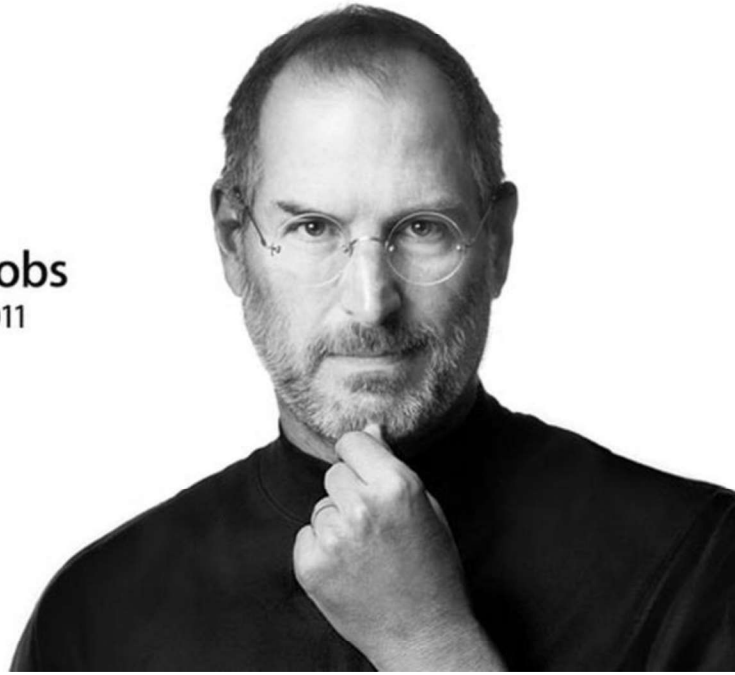


Computer made out of off-the-shelf TTL



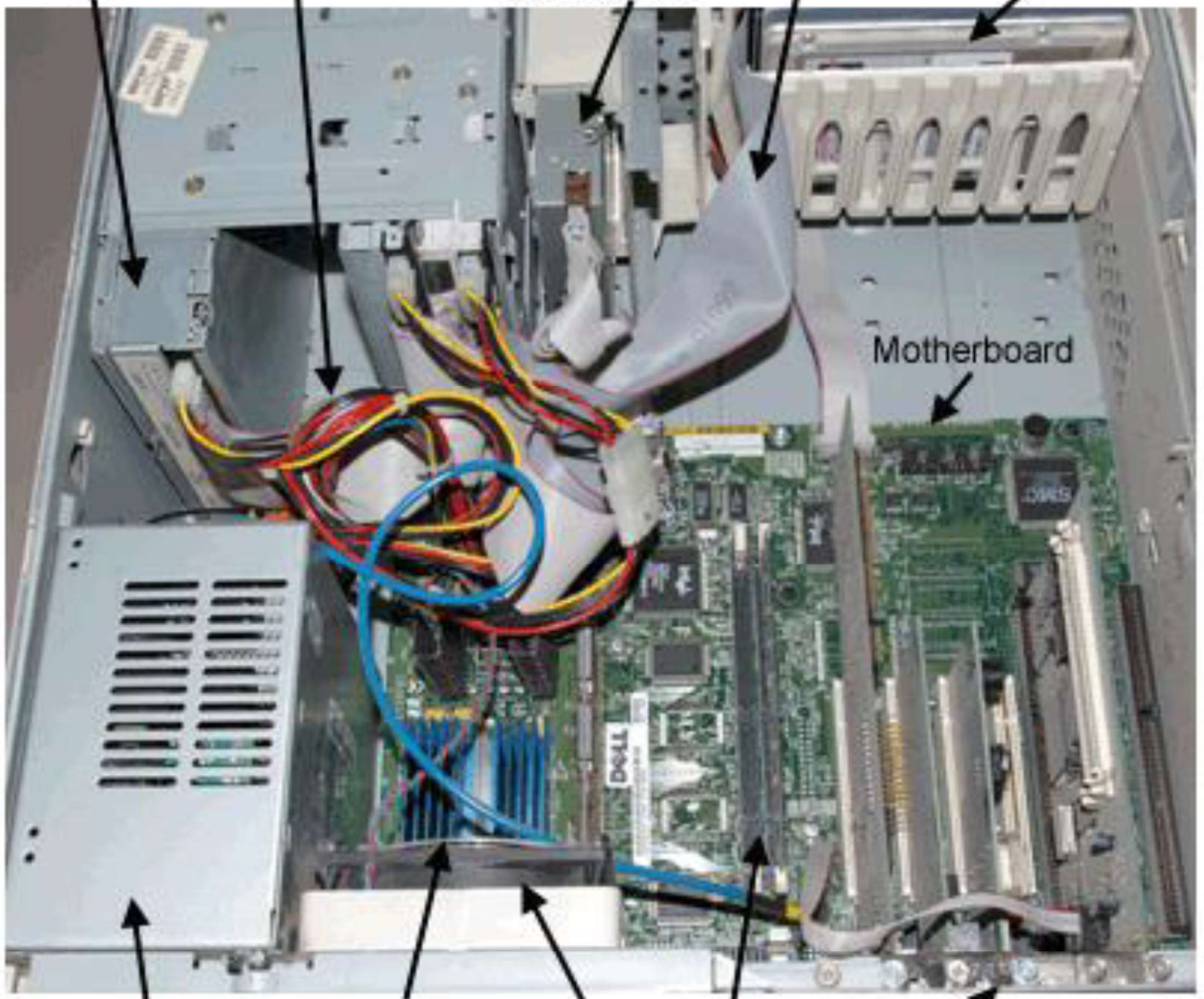
The huge PCB holding lots of TTL logic gates (remember those we learnt in IDC)

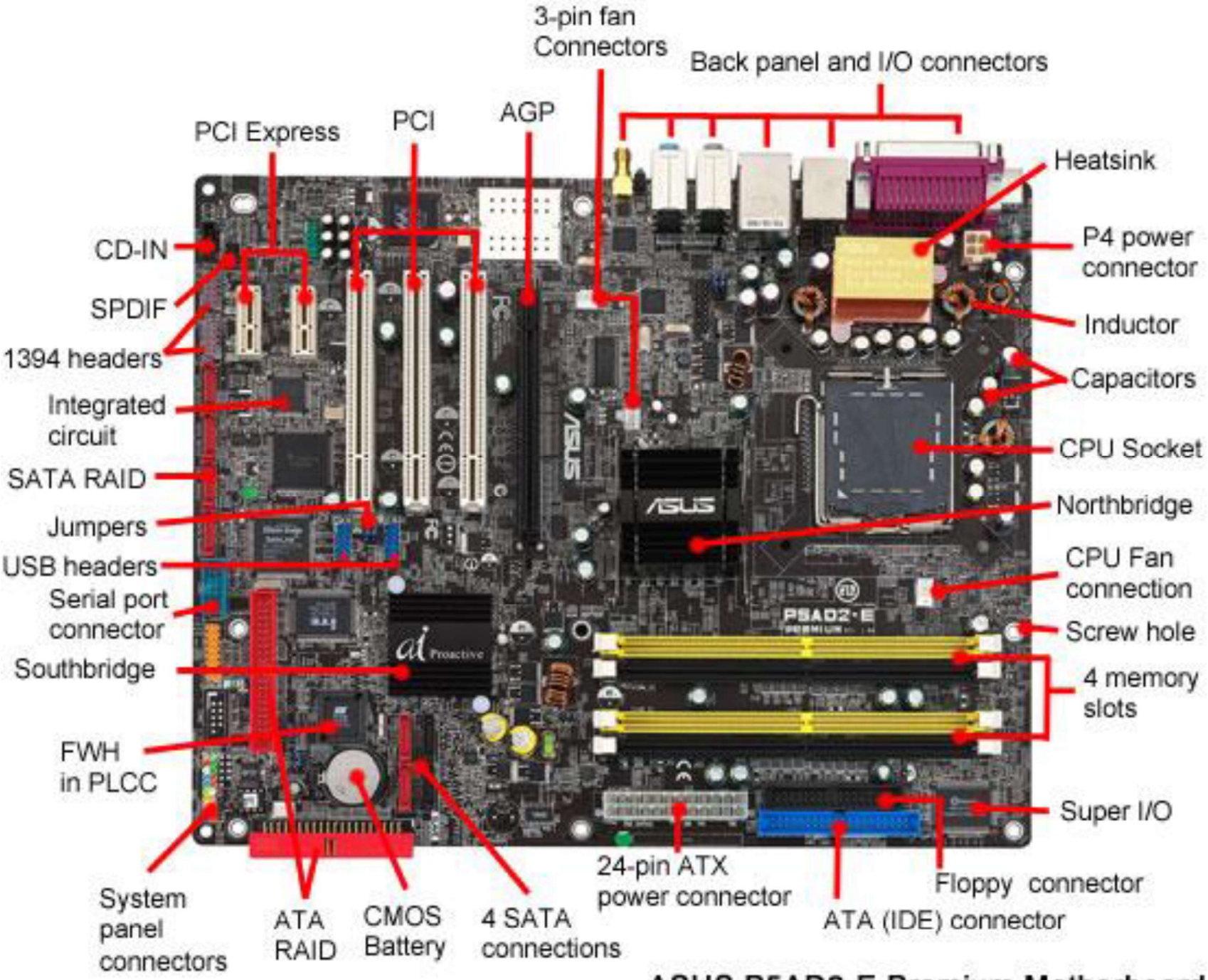
CPU: 6502
Speed: 1MHz
RAM: 48K Bytes



Steve Jobs
1955-2011

Inside of a computer case





ASUS P5AD2-E Premium Motherboard

http://www.computerhope.com

Traditional Northbridge and Southbridge

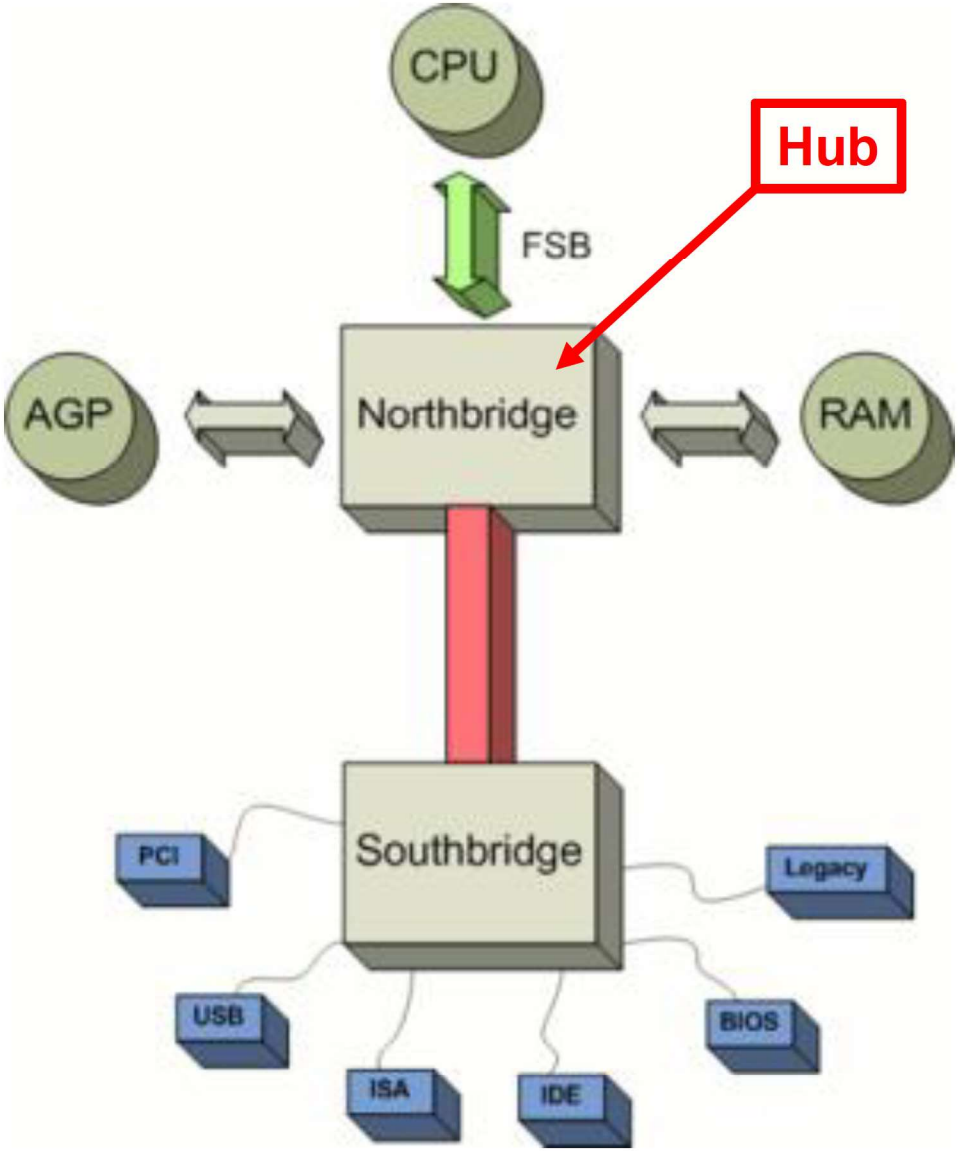
Northbridge

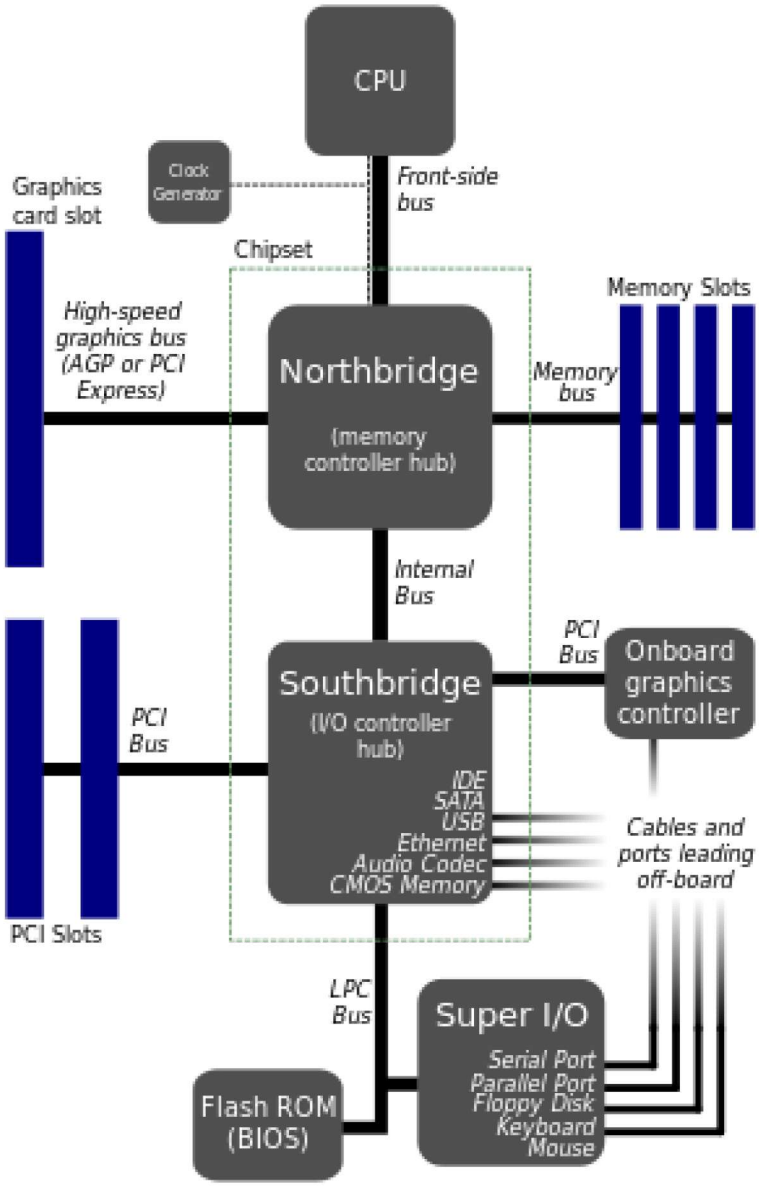
- A **chipset** on a PC motherboard.
- Handles communications among the **CPU**, **RAM**, PCI Express **graphic cards**, and the **southbridge**.
- CPU is connected to the northbridge via a fast bridge (Front Side Bus, FSB).

Southbridge

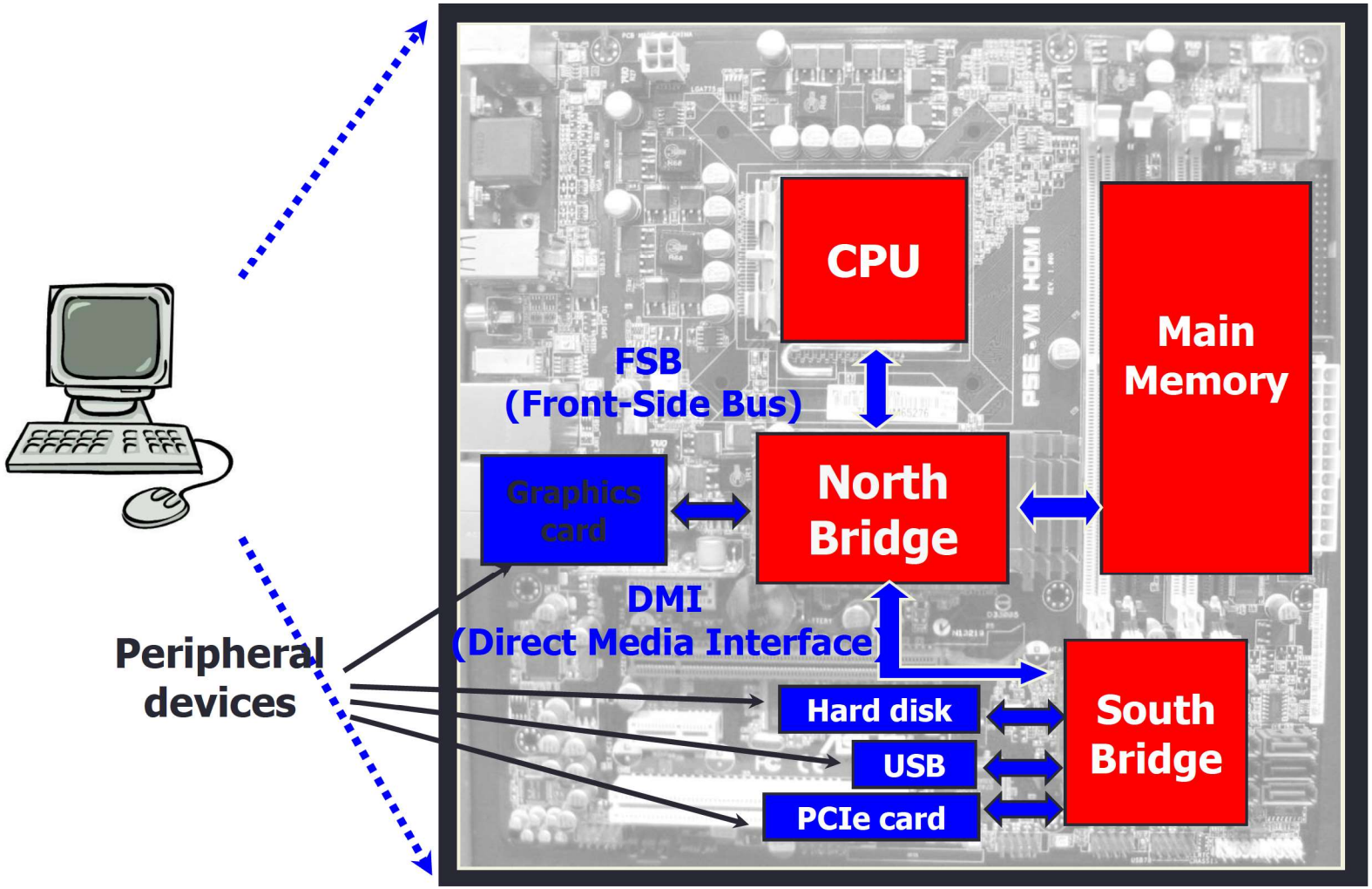
- Another chipset on a PC motherboard.
- Handles the slower processes and all I/O functions, e.g. USB, audio, serial and IDE channels such as hard drives and DVD drives.

Traditional Northbridge and Southbridge





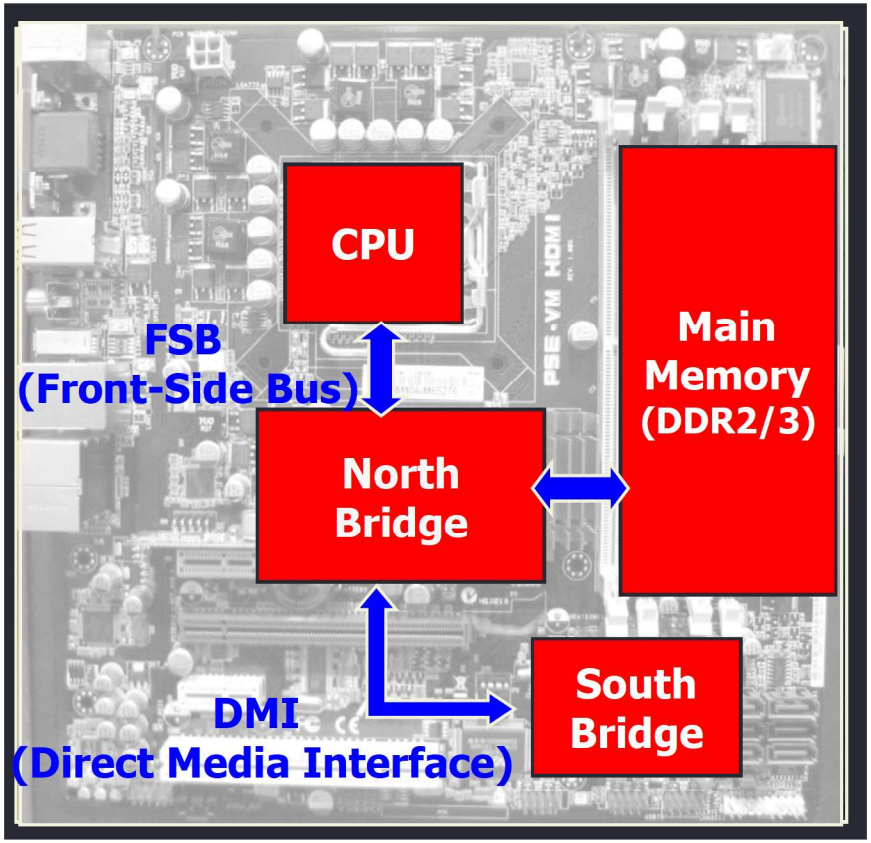
A Computer System (till 2008)



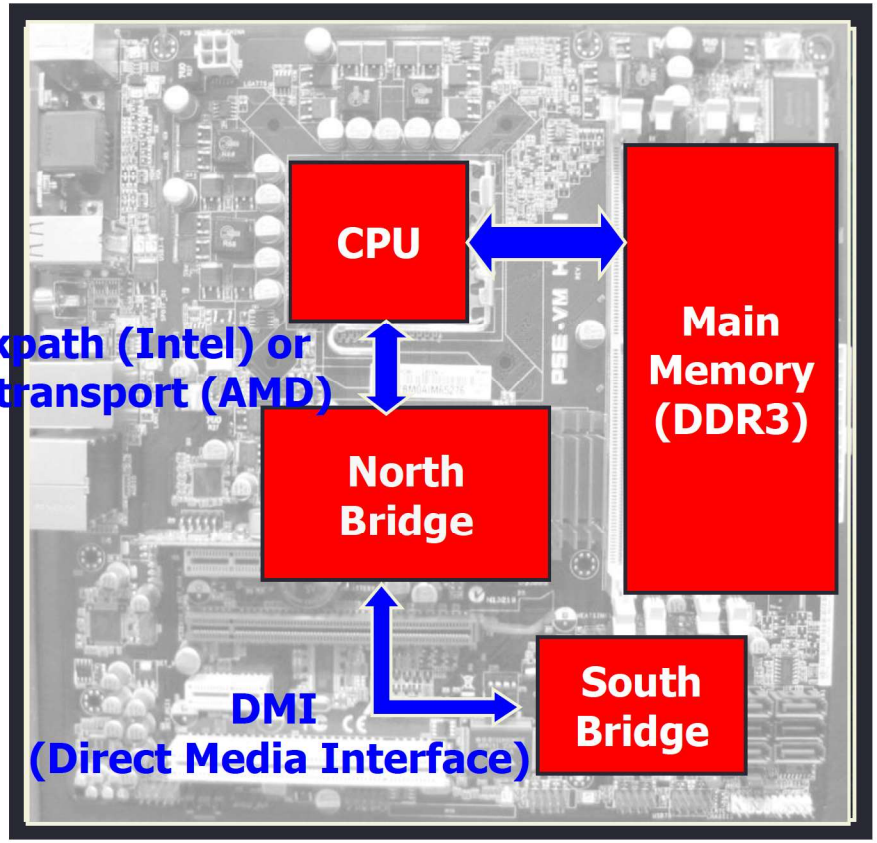
But, don't forget the big picture!

A Computer System

- Core 2 Duo – based Systems



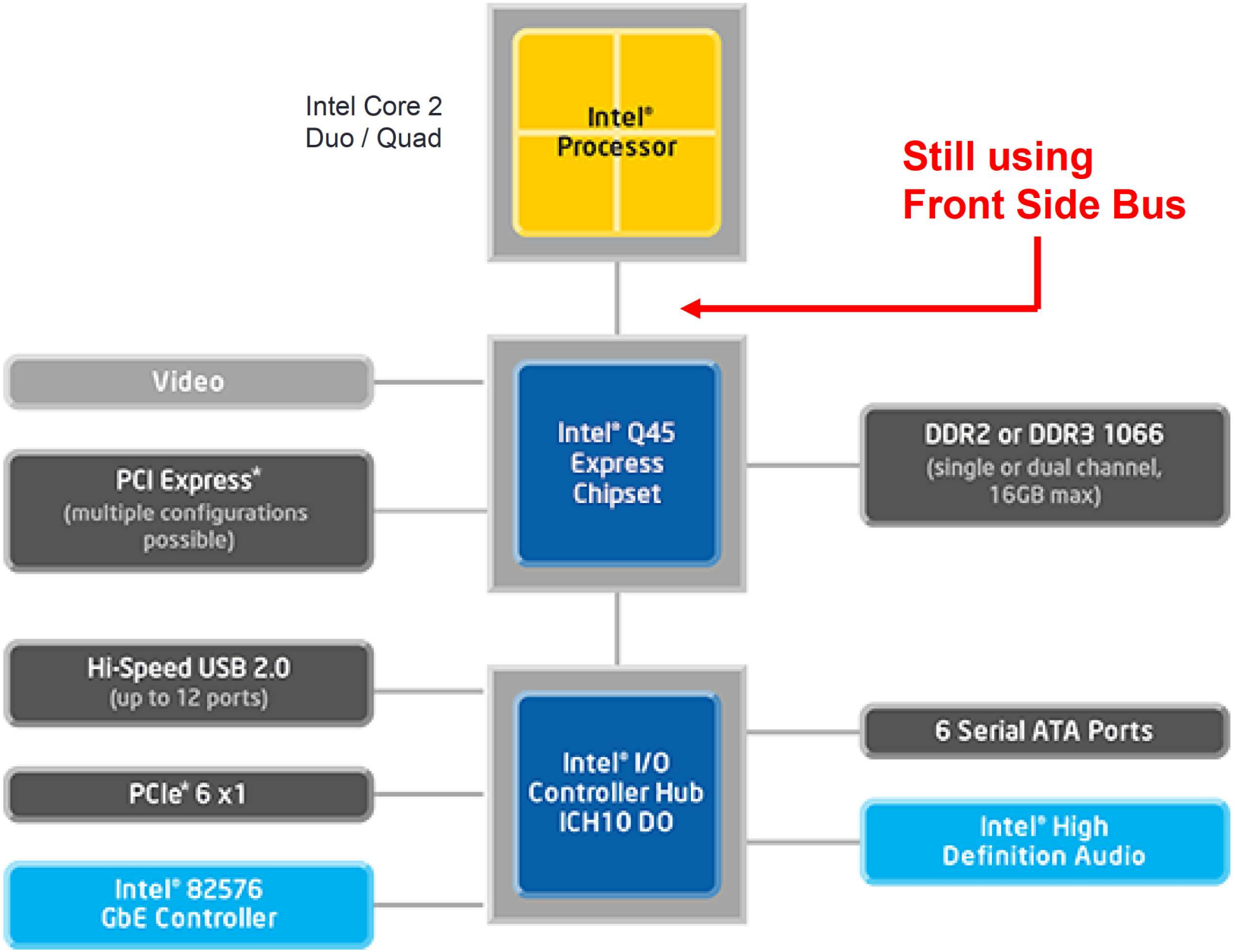
- Core i7– based Systems



Keep in mind that CPU and computer systems are evolving at a fast pace

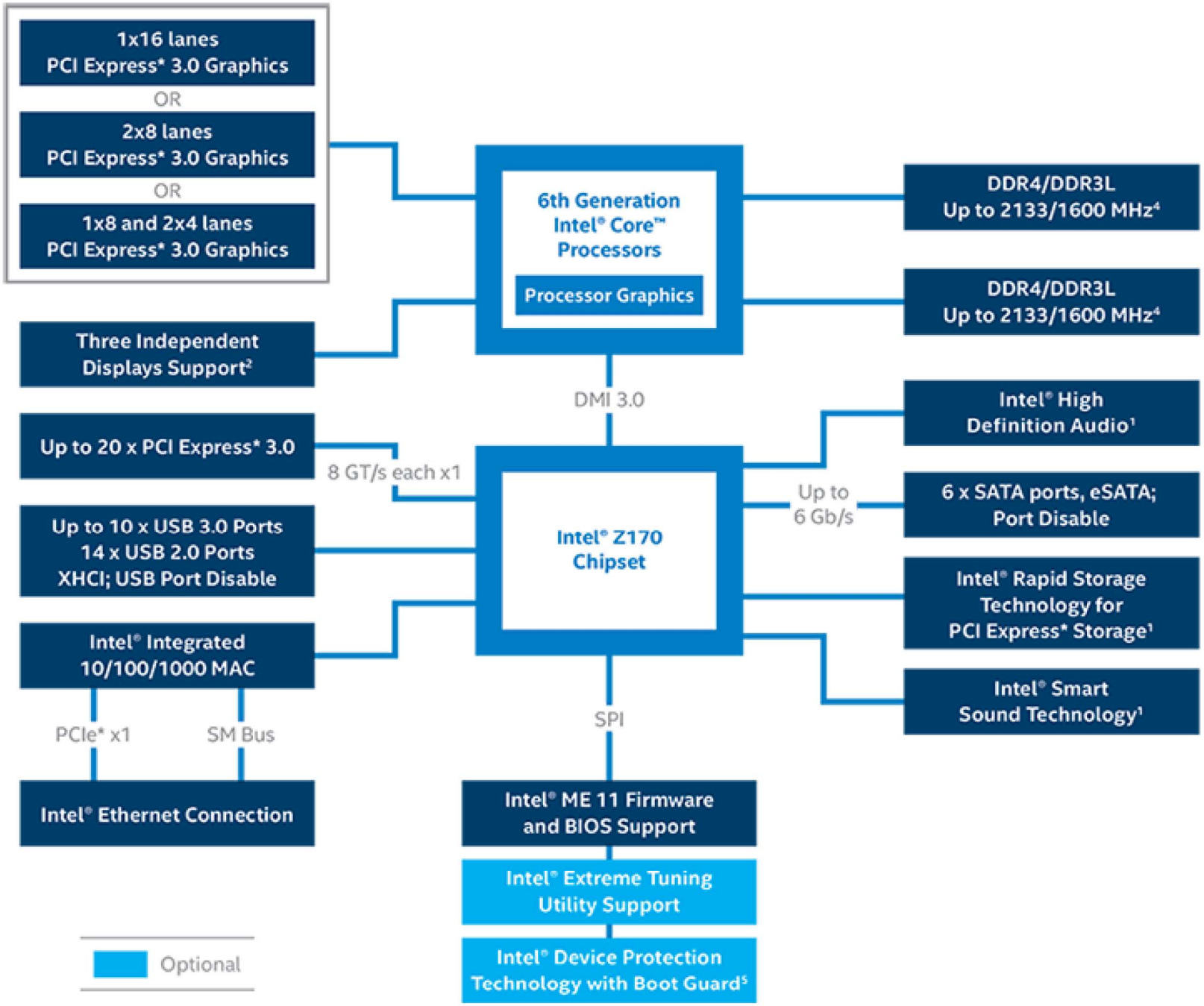
Intel Q45 Chipset

Release date: Aug 2008



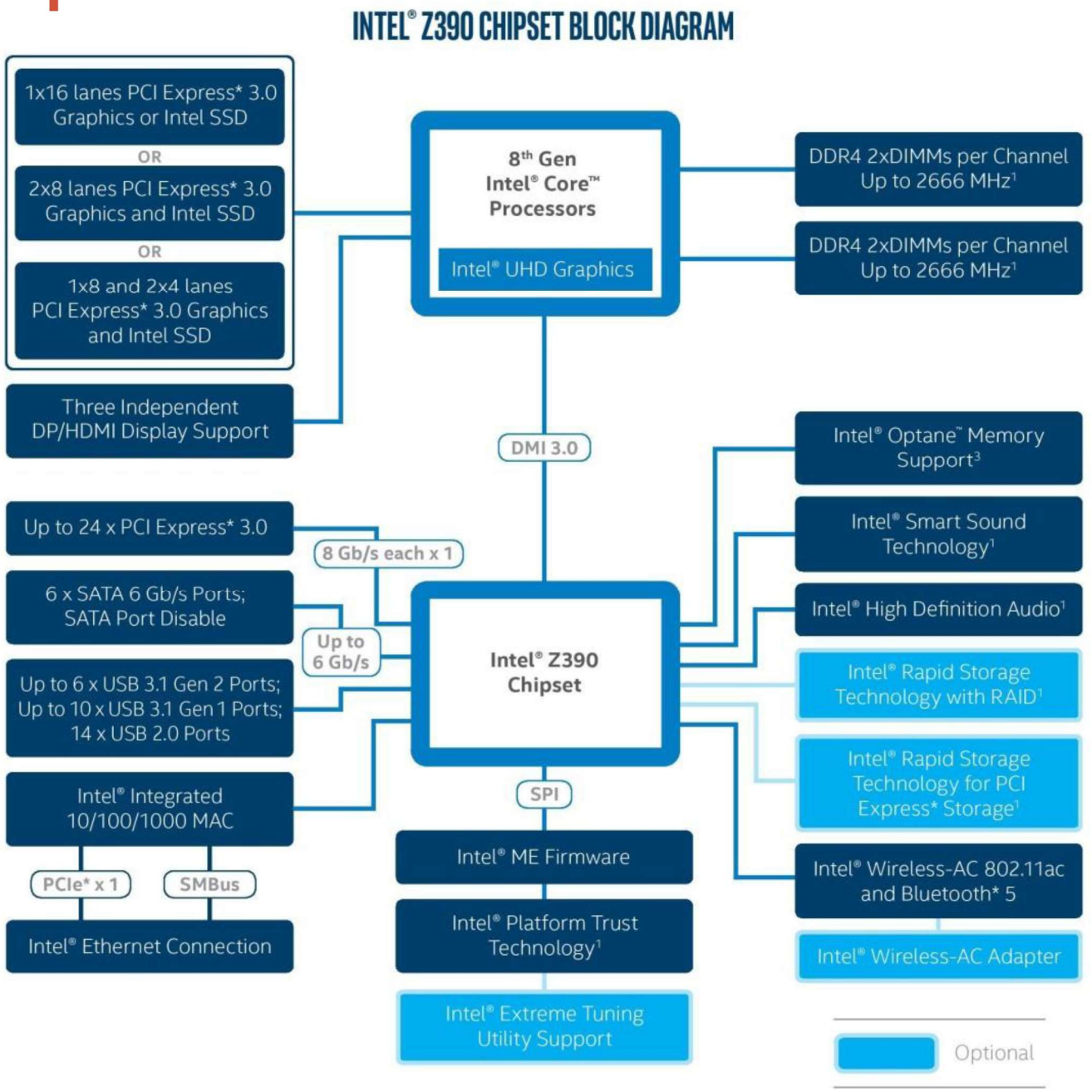
Intel Z170 Chipset

Release date: Aug 2015



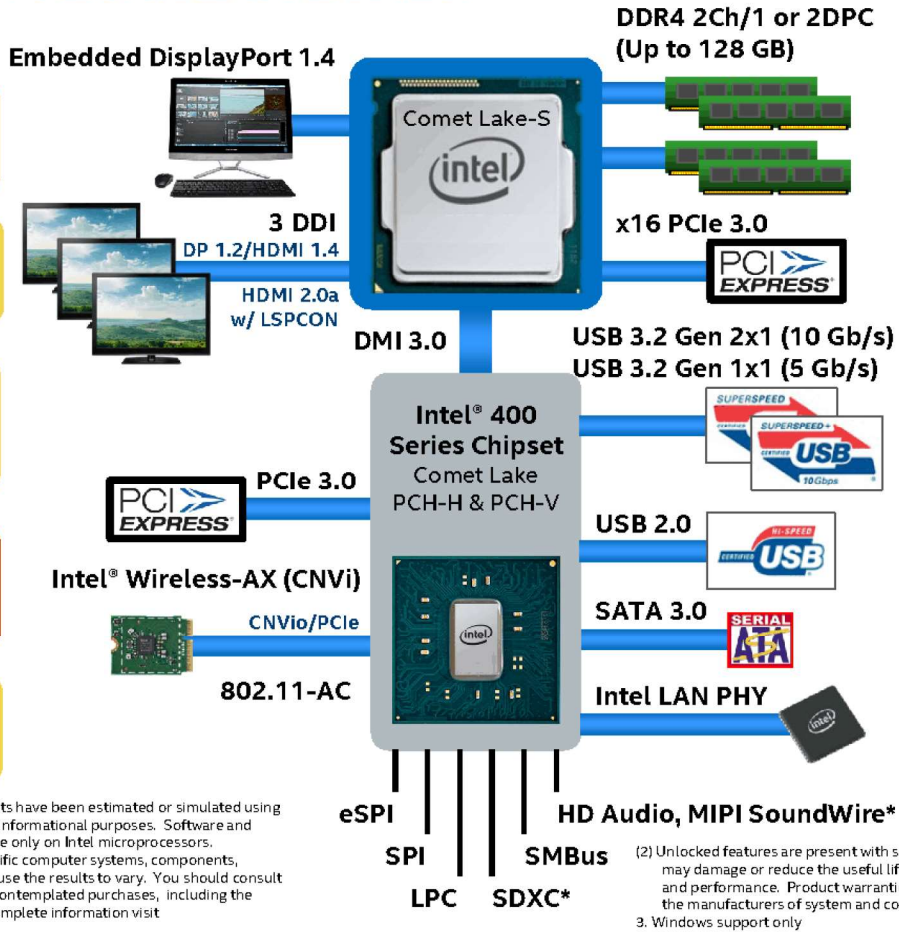
Intel Z390 Chipset

Release date: 2018Q2



COMET LAKE S PLATFORM FEATURE OVERVIEW

- Up to 10 Processor Cores for Enhanced Performance[1]
- Media & Display Features for Premium 4K Content Support
- Integrated + Discrete Intel® Wireless-AC (Wi-Fi/BT CNVi) Support (not available for long life support)
- Intel® Wi-Fi 6 (Gig+) Support (CNVi & Discrete Wireless-AX) Under Evaluation
- Enhanced Core & Memory Overclocking[2]



- Up to 30 PCH-H High-Speed I/O Lanes with Port Flexibility
- Up to 40 PCIe 3.0 Lanes (16 CPU, up to 24 PCH).
- Integrated USB 3.2 Gen 2x1 (10 Gb/s) Support
- Intel® Rapid Storage Technology (Intel® RST) 17.x[3]
- Programmable (Open FW SDK) Quad-Core Audio DSP
- C10 & S0ix Support for Modern Standby*

New with Comet Lake-S Platform

(1) Compared to top bin of 9th Gen Intel® Core™ desktop processor platform. Results have been estimated or simulated using internal Intel analysis or architecture simulation or modeling, and provided for informational purposes. Software and workloads used in performance tests may have been optimized for performance only on Intel microprocessors. Performance tests, such as SYSmark and MobileMark, are measured using specific computer systems, components, software, operations and functions. Any change to any of those factors may cause the results to vary. You should consult other information and performance tests to assist you in fully evaluating your contemplated purchases, including the performance of that product when combined with other products. For more complete information visit http://www.intel.com/benchmarks.

(2) Unlocked features are present with select chipsets and processor combinations. Altering clock frequency or voltage may damage or reduce the useful life of the processor and other system components, and may reduce system stability and performance. Product warranties may not apply if the processor is operated beyond its specifications. Check with the manufacturers of system and components for additional details.

3. Windows support only

CPU buyers' guide?

Some decisive factors about CPU power:

1. Number of Cores
2. Clock
3. Cache

More to that

4. Power consumption
5. Coprocessor
6. Over-clocking

Specifications	Core-i3	Core-i5	Core-i7
Application processor	Entry level	Mid range	High end
Number of cores	2	2 to 4	2 to 4
Frequency rane	2.93 to 3.06 GHz	3.2 to 3.46 GHz	2.8 to 4 GHz
Turbo boost	Not Supported	Supported	Supported
Hyper threading	Supported	Not Supported	Supported
Cache	3 to 4 MB	3 to 8 MB	4 to 8 MB
Number of threads	4	4	8
Size	32 nm silicon	32 to 45 nm silicon	32 to 45 nm silicon
Graphics	Low	Mid-range	Best
Price	Low	Mid-range	Expensive
Example	i3-540	i5-660, i5-750	i7-920

What is x86?

- Generic term referring to processors from Intel, AMD and VIA
- Derived from the model numbers of the first few generations of processors:
  - 80**86**, 802**86**, 803**86**, 804**86** → **x86**
- Now it generally refers to processors from Intel, AMD, and VIA
  - x86-16: 16-bit processor
  - x86-32 (aka IA32): 32-bit processor
  - x86-64: 64-bit processor

* IA: Intel Architecture

- Intel takes about 80% of the PC market and AMD takes about 20%
  - Apple also have been introducing Intel-based Mac from Nov 2006

Power under the hood.

Inside the MacBook is a powerful 2.13GHz Intel Core 2 Duo processor based on advanced Core microarchitecture. MacBook provides a fast 1066MHz frontside bus and 3MB of shared L2 cache, so you'll have more than enough horsepower to get the job done.

x86 History

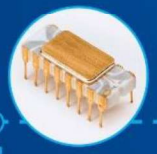
A HISTORY OF PC INNOVATION

Ever since Morris Tanenbaum launched the Silicon Age with the fabrication of the first silicon transistor at Bell Labs in 1954, the PC has undergone a transformative evolution. From the revolutionary Intel 4004 release to game-changing Ultrabook™ and 2 in 1, Intel has been at the center of PC innovation throughout its 50-year history, and through ongoing collaboration with the ecosystem, Intel will continue to redefine the PC experience.

1968

THE DAWN OF THE MOUSE

The first mouse makes its debut, changing the way people would interact with computers forever.



1971

HONEY... I SHRUNK THE COMPUTER

Intel launches the first ever commercial microprocessor, the Intel 4004, enabling computers to finally get smaller.

1975

COMPUTING GETS PERSONAL

The first personal computer hits the market in 1975. The Altair 8880, based on the Intel® 8080 CPU, finally brings computing to the masses.

1978

THE 8086 REVOLUTION

The 8086 gives rise to the x86 architecture, which will eventually become Intel's most successful line of processors.

1980'S

LUGGABLE

The first truly portable PCs and laptops hit the market with the Osborne 1.

2003

A WIRELESS WORLD

The Intel® Centrino® processor launches, bringing integrated wireless to laptops.

1996

GET ON THE BUS!

Intel leads a group of 7 tech giants to develop USB (Universal Serial Bus), changing connectivity forever and paving the way for Thunderbolt™ (2011), which would offer even more flexible and versatile connection options.

1993

THE NAME GAME

The Intel® Pentium® line of processors launches, ditching the traditionally used numeric naming system for good.

1991

INTEL INSIDE

Intel becomes a household name with the launch of Intel Inside® campaign, changing the way consumers think about PCs, as they begin to consider power as a key purchase point.

2006

BUSINESS BAKED IN

The Intel® vPro™ platform launches, with features specifically for business PC users from the silicon up.

2007

BRINGING THE INTERNET TO EVERYONE

As computer companies compete to deliver smaller, more user-friendly laptops, the Netbook is born, bringing easy access to the internet to everyone and everywhere.

2011

LAPTOPS SLIM DOWN AND BEEF UP

Intel introduces a new category of PC called the Ultrabook,™ using low-power processors and drives to reduce bulk without compromising battery life.

2012

ERA OF THE 2-IN-1 PC BEGINS

PCs are revolutionized again with 2 in 1 hitting the market in late 2012.

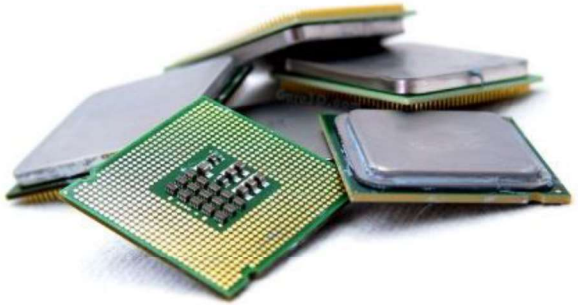
2018

THE NEXT GENERATION

Intel's first processor to package a GPU directly onto the CPU along with dedicated High Bandwidth Memory. EMIB technology reduces the silicon footprint making the 8th Gen Intel® Core™ processor with Radeon™ RX Vega M Graphics perfect for small form factors—an indication of more innovation to come.

CPU

- Central Processing Unit (CPU) is one of the most important components of a computer.
- It carries out the **instructions** of a computer program by performing arithmetic, logical, control, input/output, and other operations of the computer system
- It is in charge of the **clock**, which refers to the frequency that the CPU is running at. For every time the clock completes one **cycle**, an **instruction** has been carried out.



CPU

- **Central Processing Unit (CPU)** carries out the instructions of a computer program by performing arithmetical, logical, input/output, and other operations of the computer system

- The CPU plays a role somewhat analogous to the “brain” in the computer

- The CPU consists of four major units:
  - Control unit
  - Arithmetic and Logic Unit
  - Cache
  - Register

CPU

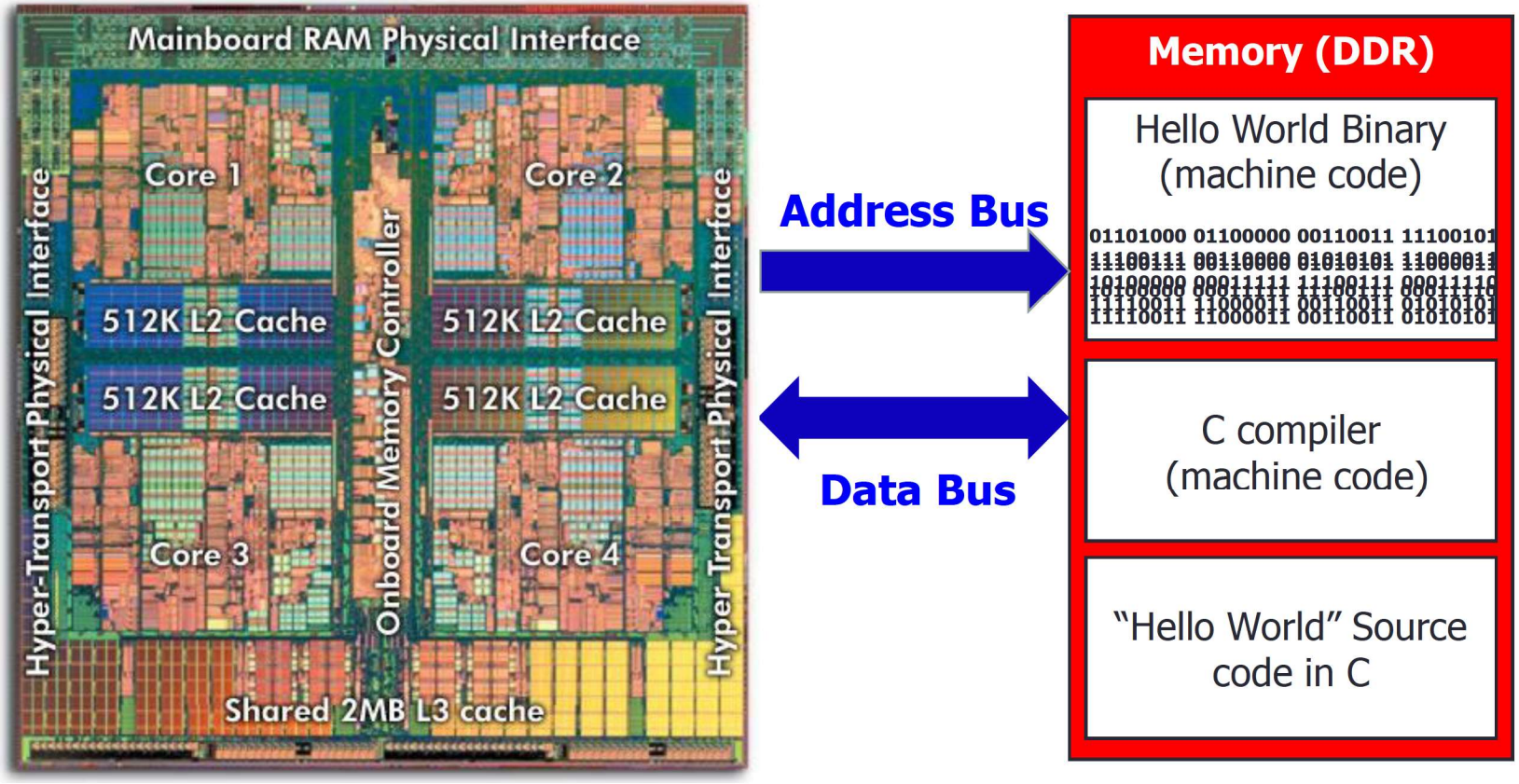
- **Control unit:** directs and monitors the overall operation of the computer. It is the “brain” within the “brain” (CPU). It tells the memory, ALU, I/O devices how to respond to program instructions.

- **Arithmetic and Logic Unit (ALU):** performs all of the computations, such as addition, subtraction, comparisons, and so on, that a computer provides

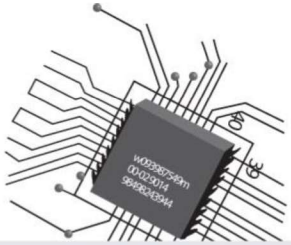
- **Cache**: is a smaller and faster memory which stores copies of the data from frequently used main memory locations.

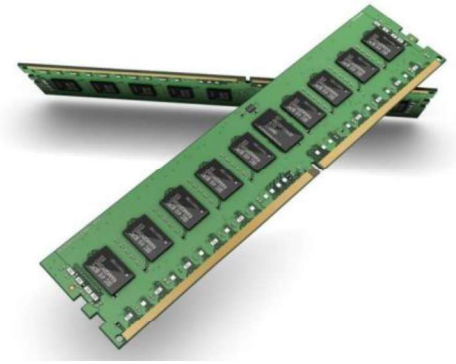
- **Register**: is a special high-speed storage area within the CPU. All data must be represented in a register before it can be processed. The number of registers is limited.

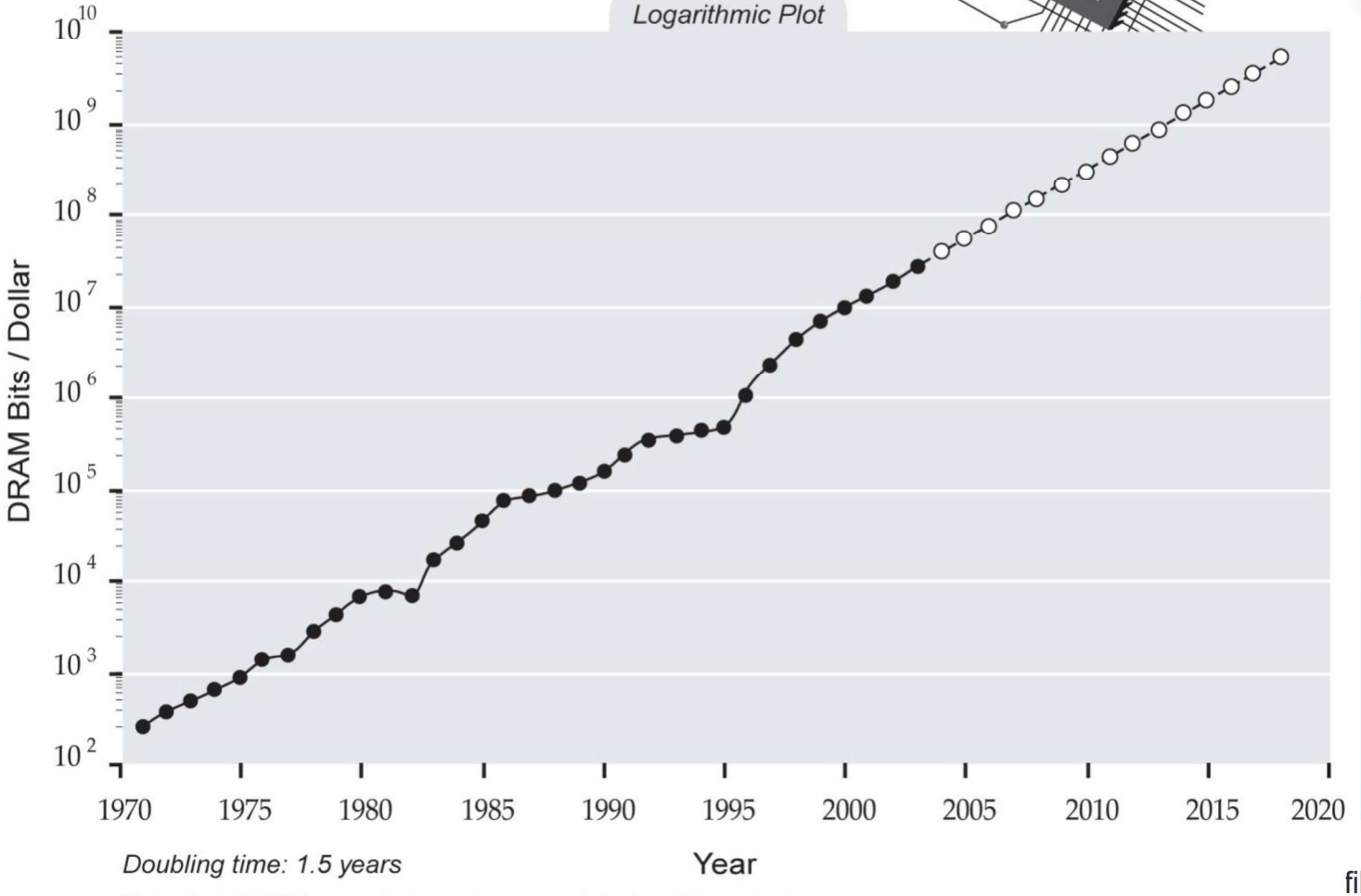
Inside a CPU


Mainboard RAM Physical Interface
Core 1
Core 2
512K L2 Cache
512K L2 Cache
512K L2 Cache
512K L2 Cache
Core 3
Core 4
Shared 2MB L3 cache
Hyper-Transport Physical Interface
Onboard Memory Controller
Hyper-Transport Physical Interface
Address Bus
Data Bus
Memory (DDR)
Hello World Binary (machine code)
01101000 01100000 00110011 11100101
11100111 00110000 01010101 11000011
10100000 00011111 11100111 00011110
11110011 11000011 00110011 01010101
11110011 11000011 00110011 01010101
C compiler (machine code)
"Hello World" Source code in C

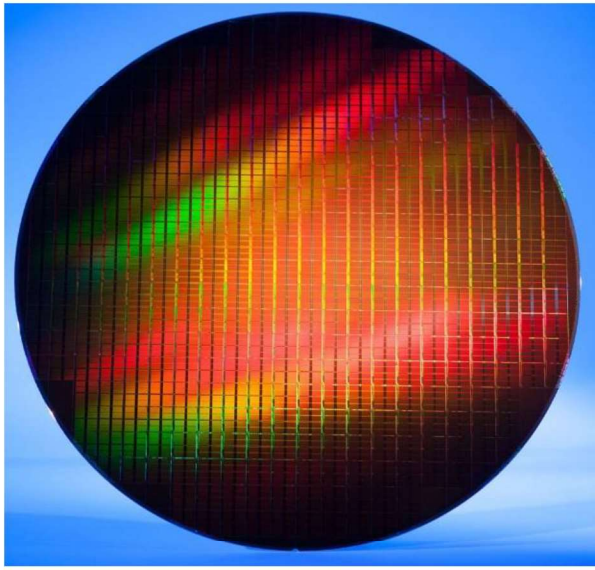
DRAM Chip Capacity Growth







Micron NAND wafer



files.com/2020/04/13/dram-is-stuck-in-a-
ap/

Dramatic Technological Advances

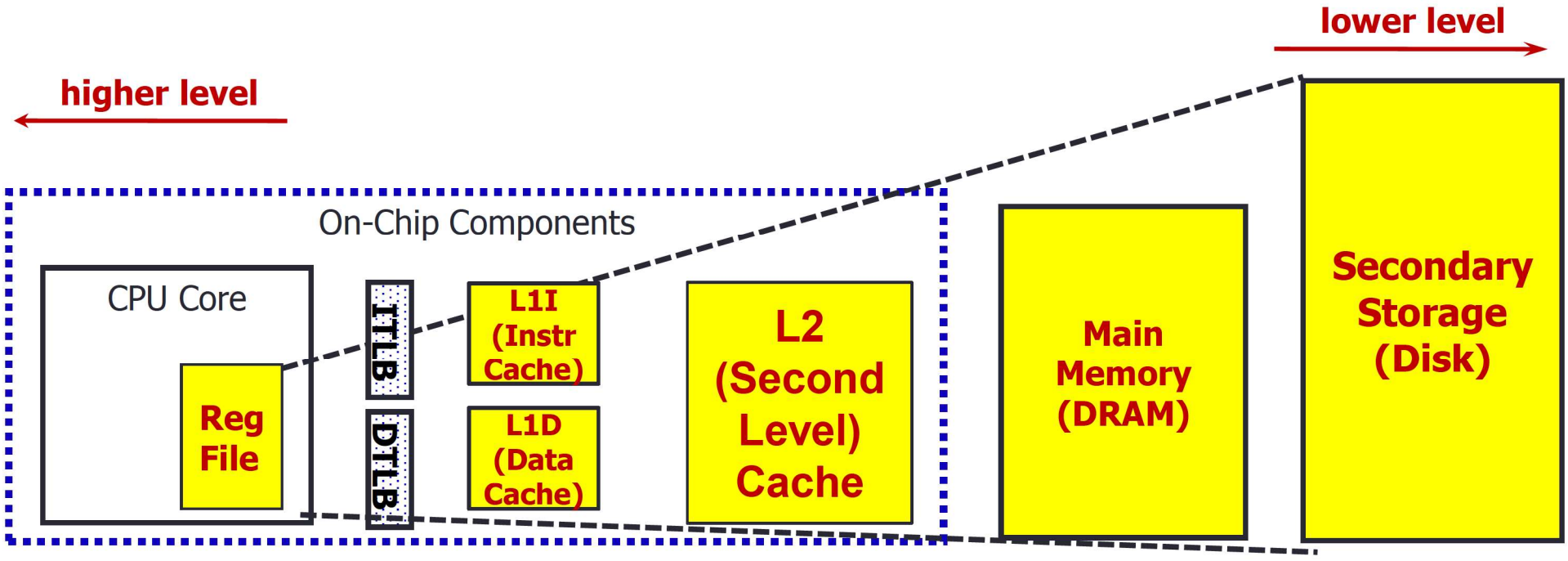
- **Processor**:
  - **Logic capacity**: increase ~30% per year
  - **Clock rate**: increase ~20% per year
- **Memory**:
  - **DRAM capacity**: increase ~60% per year (or ~4X every 3 years)
  - **Memory speed**: increase ~10% per year
  - **Cost per bit**: decrease ~25% per year
- **Disk**:
  - **Capacity**: increase ~60% per year
  - **Size**: 3.5in -> 2.5in -> 1.8 in -> 1.0 in -> 0.85 in
  - Is replacing by flash memory (such as SSD)

5 MB hard drive in 1956

128 GB pen drive in 2017

A Typical Memory Hierarchy

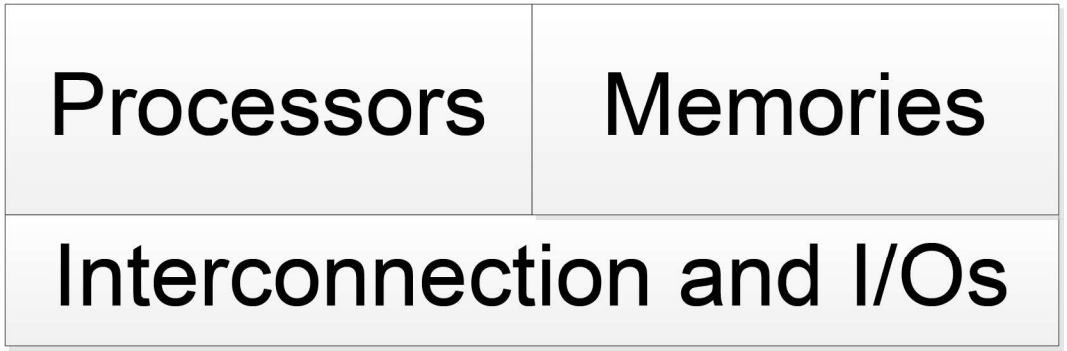
- Take advantage of the **principle of locality** to present the user with as much memory as is available in the cheapest technology at the speed offered by the fastest technology



Speed (cycles):	½'s	1's	10's	100's	10,000's
Size (bytes):	100's	10K's	M's	G's	T's
Cost:	highest				lowest

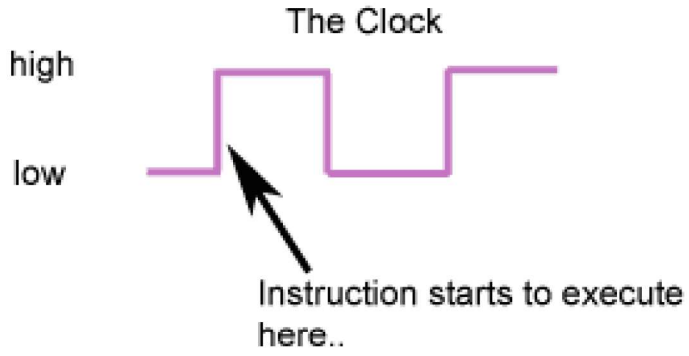
Computer Organization

- Despite different looks in different computer type, their organizations are similar
  - Processors and memories are connected by interconnection and I/Os
- Implemented by multiple IC chips
- While interconnection and I/Os are very different, processors and memories have more similarities



CPU Performance

- Every *tick* of the clock, CPU can process one piece of data or execute one instruction.



- *Tick* is also called *clock cycle*, *clock tick* or *clock period*.
- CPU performance refers to *CPU execution time*
  - *Execution time = clock cycles* x *clock cycle time*
  - $Clock\ rate = \frac{1}{clock\ cycle\ time}$

$$\Longrightarrow \textbf{\textit{Execution time (in second)}} = \frac{\textbf{\textit{clock cycles}}}{\textbf{\textit{clock rate}}}$$

CPU Performance

- Maximize performance means minimize response time (execution time)
- The performance of computer X is:

$$\text{Performance}_X = \frac{1}{\text{Execution time}_X}$$

- If the performance of computer X is greater than Y,

$$\text{Performance}_X > \text{Performance}_Y$$

$$\frac{1}{\text{Execution time}_X} > \frac{1}{\text{Execution time}_Y}$$

$$\text{Execution time}_Y > \text{Execution time}_X$$

CPU Performance

- CPU clock rate is measured in Hz (Hz: number of cycles per second)
- Example:

Computer A's clock rate is 2GHz, a program needs to run 10 seconds. If we want to run the same program in computer B in 6 seconds, computer B needs 1.2 times as many clock cycles as computer A. What should be the clock rate of computer B?

$$\text{CPU execution time}_A = \frac{\text{CPU Clock Cycle}_A}{\text{Clock Rate}_A}$$

$$\text{CPU clock cycle}_A = 10 \times (2 \times 10^9) \text{ cycles}$$

$$\text{Clock rate}_B = \frac{1.2 \left(10 \times \left(2 \times 10^9\right)\right) \text{ cycles}}{6 \text{ seconds}} = 4 \text{ GHz}$$

CPU Performance

- Performance of executing a program

  CPU time = *Instruction count* x *CPI* x *clock cycle time*

  where CPI refers to clock cycles per instruction

Example: Code sequence 1 or 2 has a lower CPI?

	A	**B**	**C**
CPI	1	2	3

	instructions
Code sequence 1	AABCC
Code sequence 2	AAAABC

CPU Performance

	A	B	C
CPI	1 clock	2 clocks	3 clocks

	instructions
Code sequence 1	AABCC
Code sequence 2	AAAABC

CPU clock cycle$_1$ = 1 + 1 + 2 + 3 + 3 = 10 cycles

CPU clock cycle$_2$ = 1 + 1 + 1 + 1 + 2 + 3 = 9 cycles

CPI_1 = (CPU clock cycle$_1$)/(No. of instructions) = 10/5 = 2

CPI_2 = (CPU clock cycle$_2$)/(No. of instructions) = 9/6 = 1.5

$\Longrightarrow$ Code sequence 2 has a lower CPI.