Digital microsystems design

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2020

Outline

- Subject
  - Prerequisites
  - Overview
  - Goal
  - Specific objectives
- Introduction
  - Terms
  - History
  - Technology
- Administrative
  - Evaluation
  - Contact

Subject

- Design, build, usage and program a digital system
  - Microprocessors (single, multiple)
  - Mainboard
  - Buses
  - Memories
  - I/O interfaces

Prerequisites

- Programming languages

- Computer architecture
- Digital logic
- Digital circuits and signals

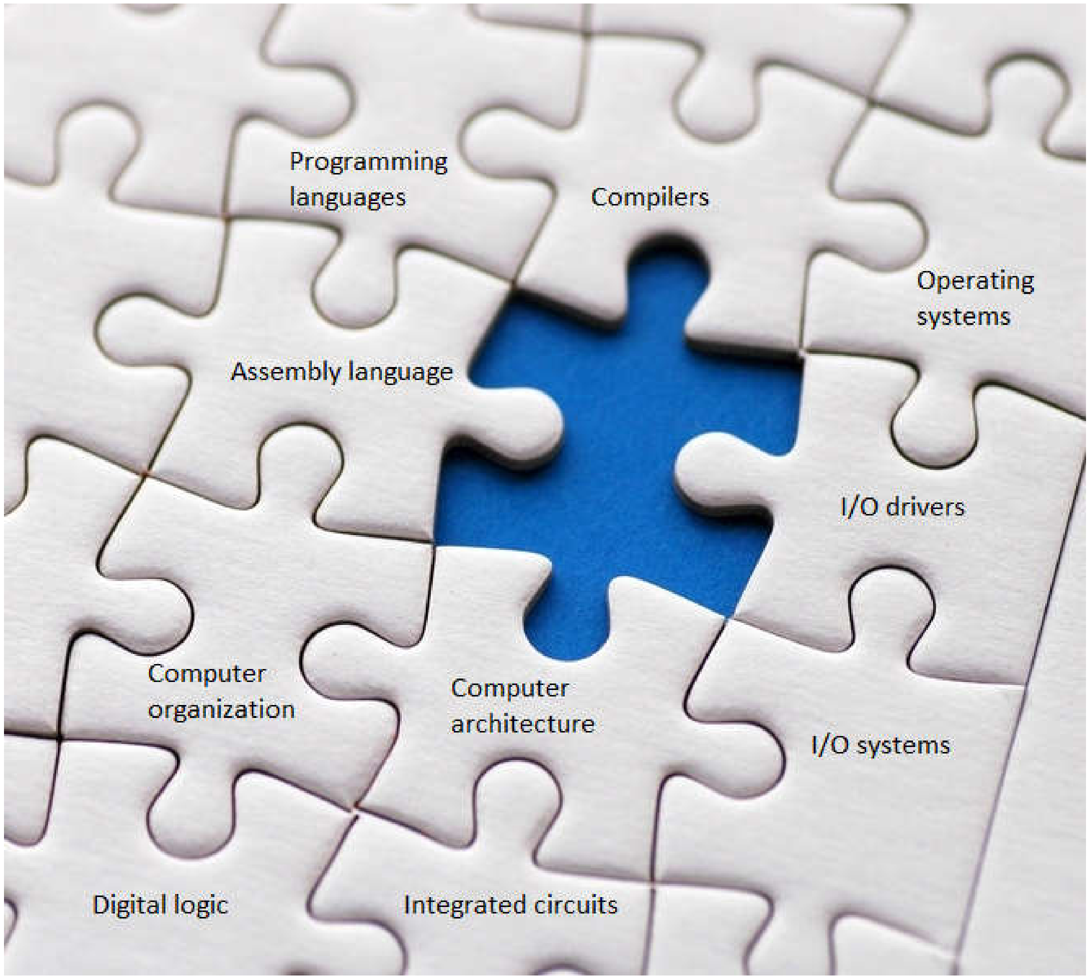
Prerequisites

- C programming language

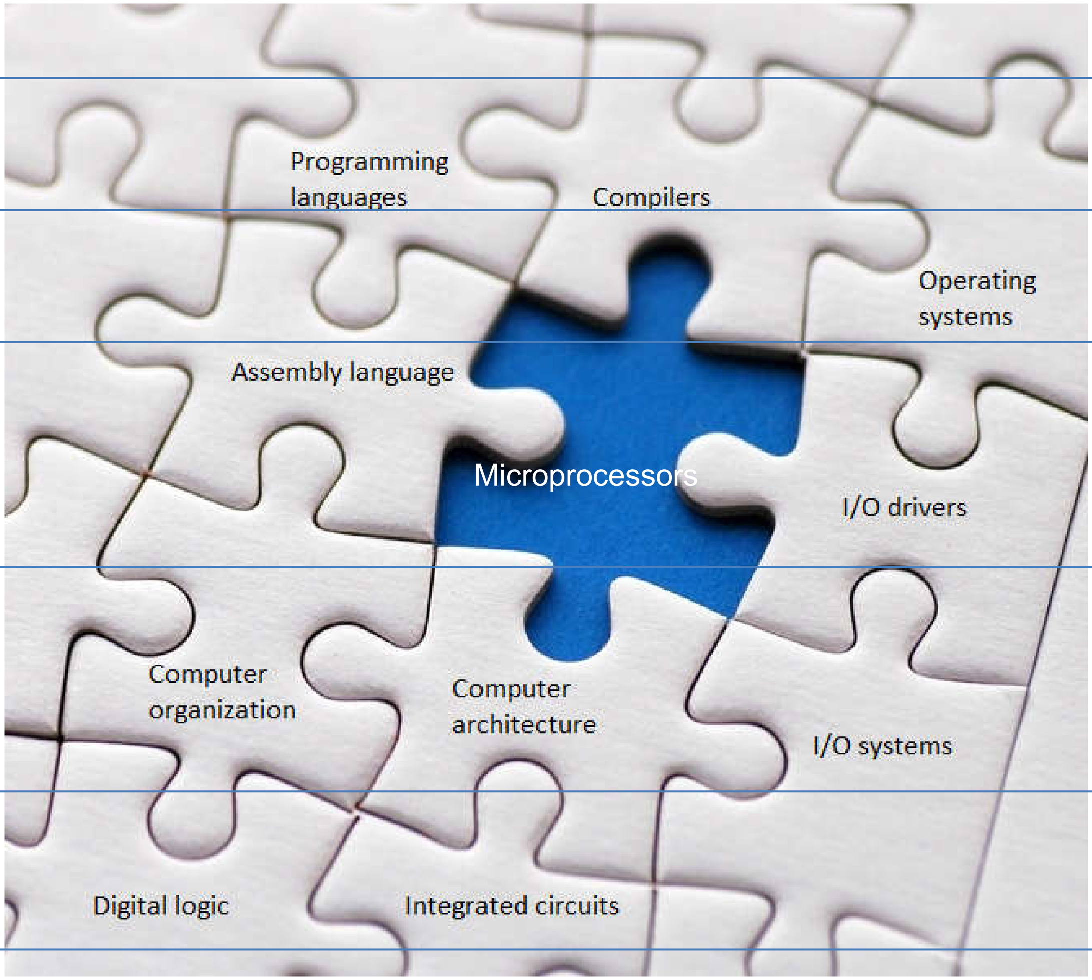
- Logic gates
- Registers, buffers, memories, decoders, multiplexers, buses

- Pipelines, caches

Overview


Programming languages
Compilers
Operating systems
Assembly language
I/O drivers
Computer organization
Computer architecture
I/O systems
Digital logic
Integrated circuits

Overview



Programming languages
Compilers
Operating systems
Assembly language
Microprocessors
I/O drivers
Computer organization
Computer architecture
I/O systems
Digital logic
Integrated circuits

Overview

- Three classes this year will fill the gap
  - Digital microsystems design
    - Microprocessors and microprocessor-based systems
    - Intel IA32 processors architectures (x86,x64)
  - Embedded systems
    - Microcontrollers and microcontroller-based systems
  - Microprocessor systems
    - ARM processors architectures
    - Applications oriented (IoT, SmartCity, SmartHouse)

Overview

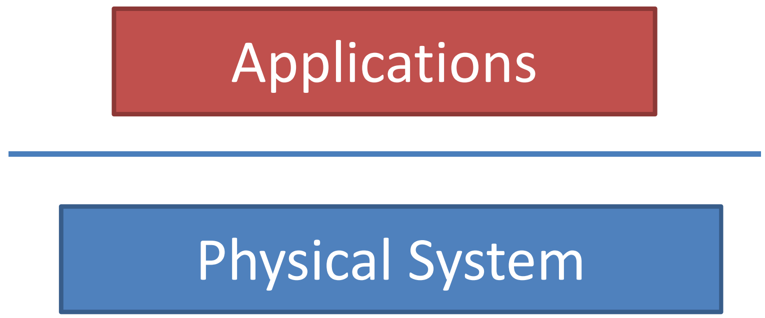
- Complementary with Large Scale Integrated Circuits
  - Digital Microsystem Design - targets mainly usage and programming of Digital Systems
  - Large Scale Integrated Circuit - low level design of Digital Systems

Overview

- How a computer program is executed by hardware?
  - How a C program is executed by a desktop computer or a mobile device?
  - How a Java program is executed by a server or by a mobile device?
  - ...
  - Is there any difference between them?

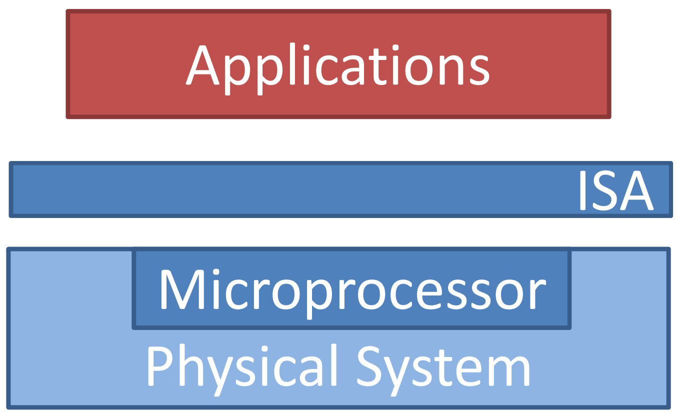
Overview

- What is the interface between software code and hardware components?



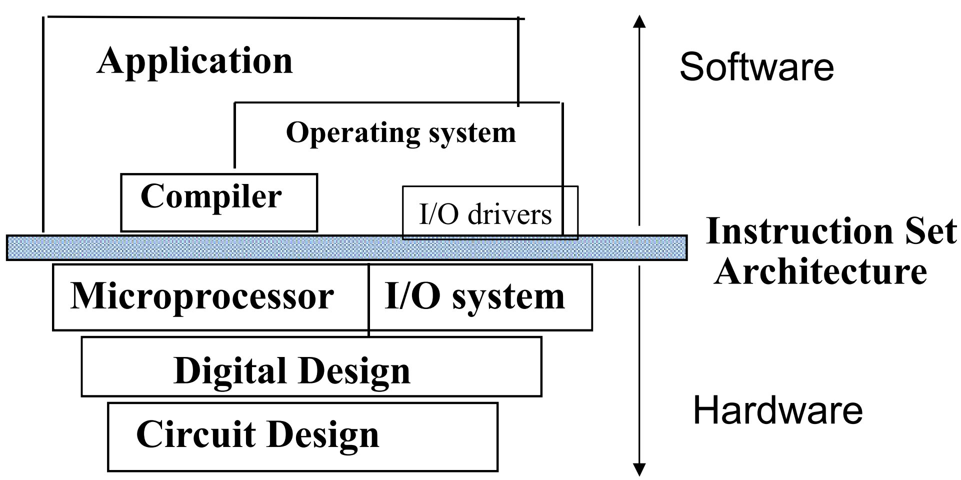
Overview

- What is the interface between software code and hardware components?



Overview

- What is the glue (interface) between software code and hardware components?

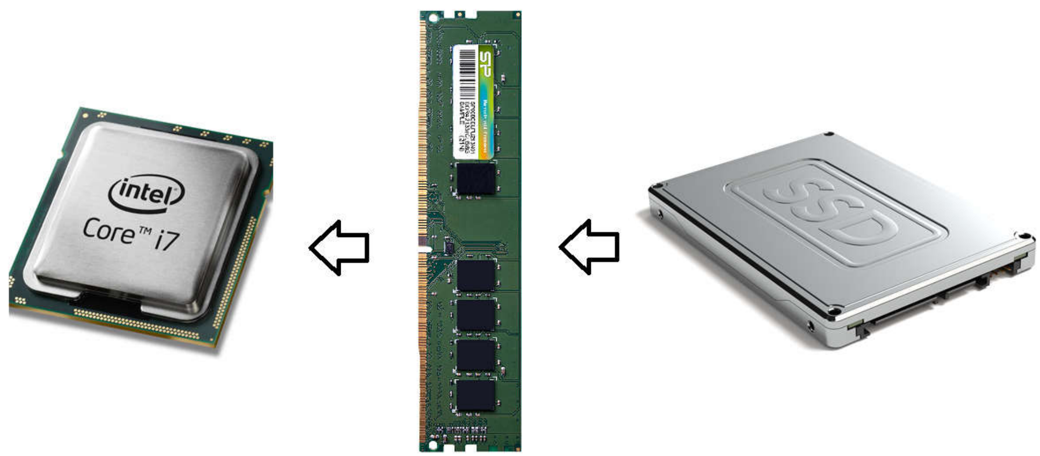


Overview

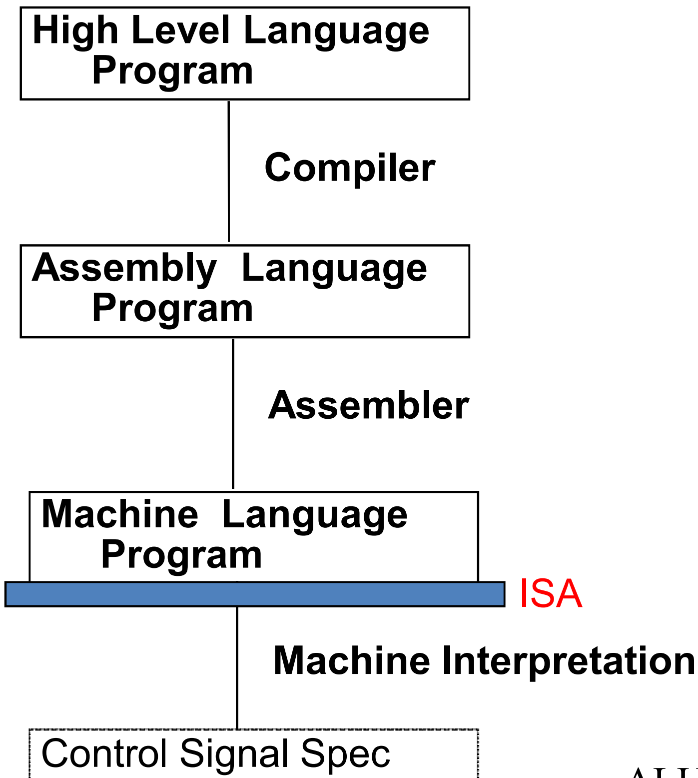
- How a computer program is executed by the processor?
  - Where exactly the application is stored before execution?
  - Where exactly the application is executed from?
  - What exactly contains an application file (EXE file)?

Overview

- Microprocessor <- Main memory <- Storage
  - Machine cycles
  - Machine code
  - Memory hierarchies



Overview




```
temp = v[k];
v[k] = v[k+1];
v[k+1] = temp;
```

```
mov     ax, [bx+si]
mov     dx, [bx+si+4]
mov     [bx+si], dx
mov     [bx+si+4], ax
```

```
1000: 8B 4F
1002: 8B 57 04
1005: 89 8F
1007: 89 87 04
100A: ….
```

ALUOP[0:3] <= InstReg[9:11] & MASK

Overview

- How would you describe to a friend, the role of the microprocessor in a computer system?

Overview

- How would you describe to a friend, the role of the microprocessor in a computer system?
  - The processor is similar to the human brain of a person, being able to take decisions or control the behavior of the system (HW)

Goal

- The discipline aims at providing students with knowledge needed to design a microprocessor based system (both HW and low-level SW) and to understand how different systems' components are interconnected and application software are implemented and executed

Objectives

- Specific objectives
  - Acquiring the overview over the microprocessor internal components and their behavior and their external interfaces to the system
  - Acquiring the capacity to analyze and design microprocessor based systems
  - Acquiring the ability to implement and test low level applications for x86 ISA and how they will impact the efficiency of high level algorithms

Objectives

- x86, IA32, AMD64 processor architectures
- Specialized circuits
- Buses
- Memories

- Assembly language
- C language constraints and optimization

Terms

- Microprocessor architecture, microarchitecture
  - Internal structure of a microprocessor
- Instruction set architecture
  - Programming interface of a microprocessor

Introduction

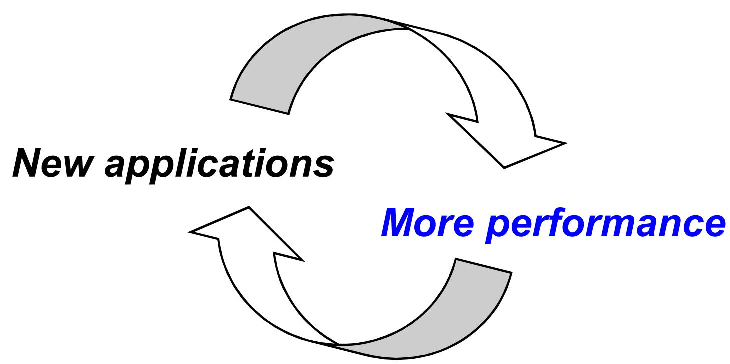
- Microprocessors and microcontrollers are part of every type of modern electronic and computing devices: computers, mobile devices, TV sets, multimedia, automotive, etc.
  - Microprocessors – general purpose
  - Microcontrollers – application specific, application oriented, embedded

Introduction

- What are the main requirements of modern computer systems?

Introduction

- Requirements of modern computer systems:
  - Computing power and speed
  - Memory and storage capacity
  - Communication bandwidth and response time
  - Reliability and availability
  - Low power



Introduction

- Reliability – The likelihood that the system has no defect / error
- Availability – the likelihood that the system will be available and respond correctly to input when used

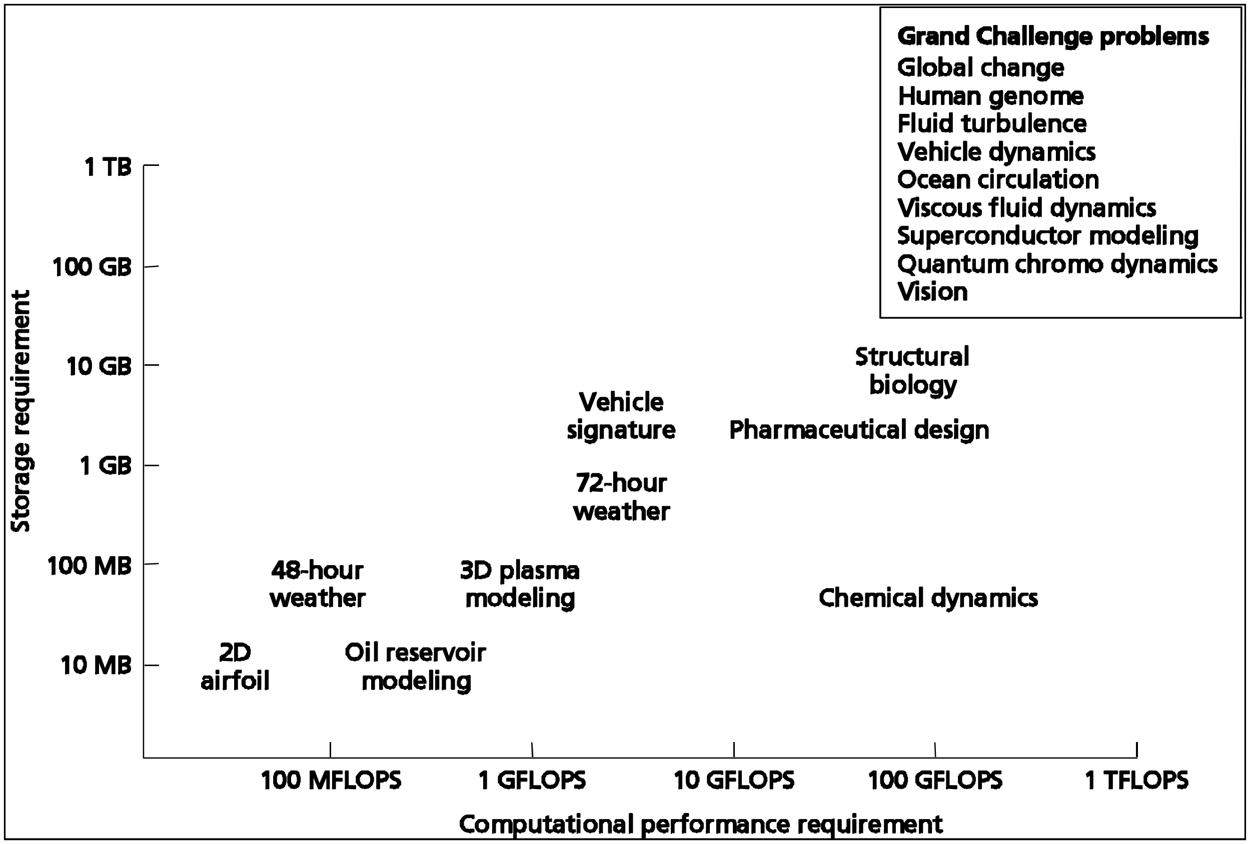
Introduction

- Characteristics of high performance applications:
  - Large number of computations
  - Big data – large volume of data
  - Fine granularity – high accuracy of data processing

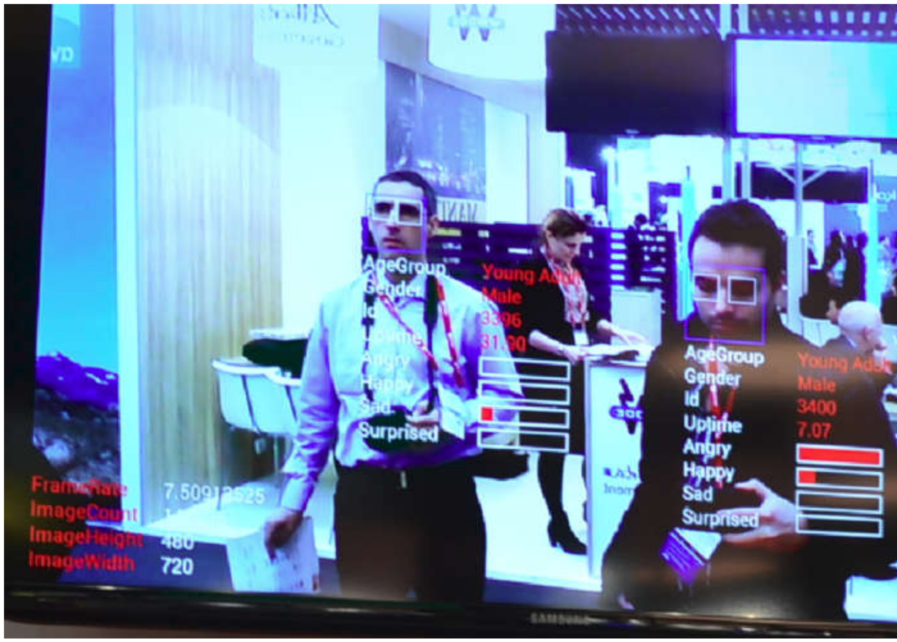
Introduction

- Applications:
  - Automotive (collisions, combustion efficiency)
  - Aeronautics (engine efficiency, air flow analysis, mechanical structures, electromagnetism)
  - Weather prediction
  - Pharmaceutics (molecular modeling)
  - Mining industry (natural deposits analysis)
  - Financial analysis (currency exchange rates)
  - Multimedia (image and voice processing and recognition, gaming, movies)
  - Military

Introduction



Introduction



History

- Computer generations
  - First generation: mechanical and electromechanical
  - Second generation: vacuum tubes
  - Third generation: transistors and integrated circuits (SSI, MSI, LSI)
  - Fourth generation: microprocessors and VLSI
  - Fifth generation: experimental (quantum, chemical, DNA, optical)

Source: http://en.wikipedia.org/wiki/Computer/

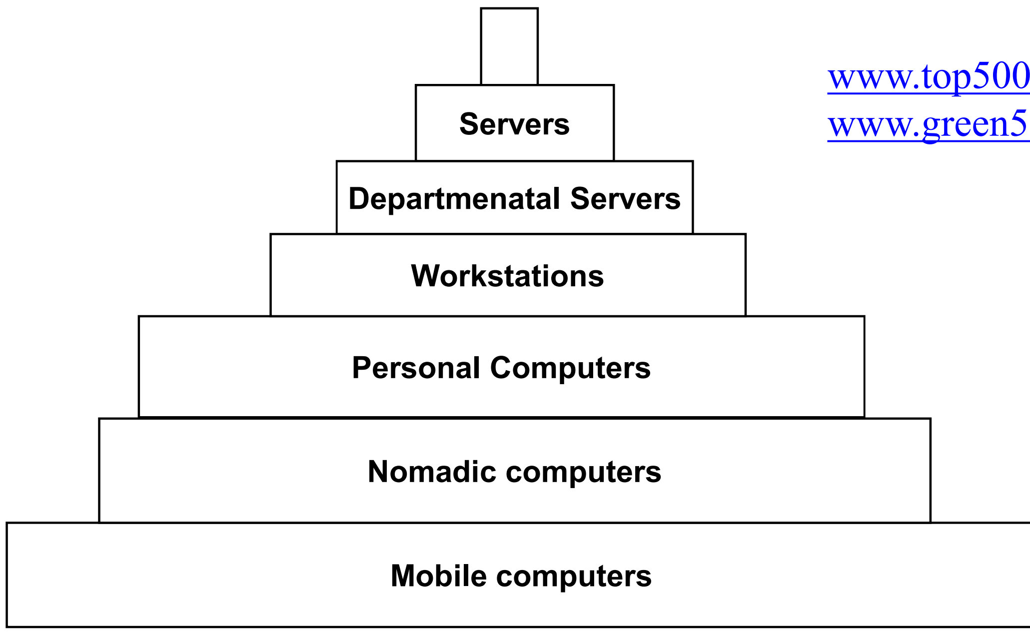
History

- Computer eras

	Early	Mainframes	Minicomputers	Personal computers	Network	Mobile	Smart
Decade	-1960	1960-1970	1970-1980	1980-1990	1990-2000	2000-2010	2010-
Location	few	computer centers	terminal rooms	desktop	nomadic	mobile	ubiquitous
End users	researchers	experts	specialists	individuals	groups	anyone	everyone
Data	physical	binary	text	graphical	multimedia	intelligent	big
User interfaces	switches	punched cards	keyboard, screen	mouse	voice	sensors	context and IoT
Connectivity	-	-	input / output	LAN	Internet	wireless	cloud
Technology	relays and vacuum tubes	transistors	integrated circuits	microprocessors	chipsets and controllers	accelerators	Multi- and many cores

History

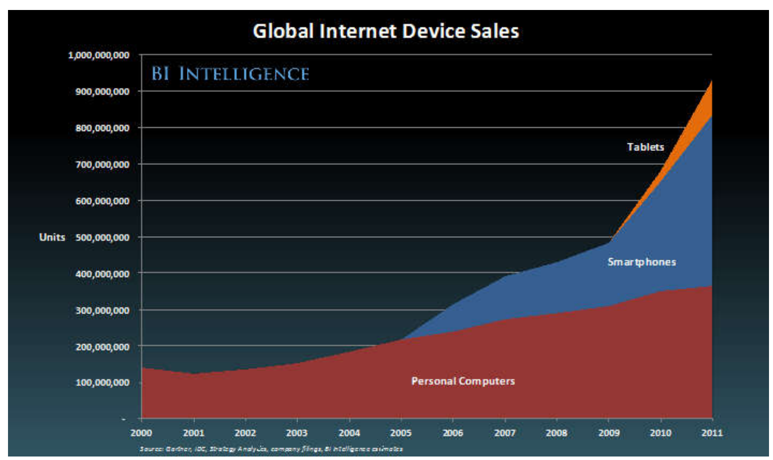
- Each era put its mark on today computer systems:
  - supercomputers



www.top500.org
www.green500.org

History

- The number of laptops sold worldwide in 2008 overtook the number of desktop computers
- The number of smartphones sales in 2011 exceeded the number of personal computers
- The number of smartphone sales in 2013 surpassed the number of featured phones



History

- Technological advances
  - Servers / nano-servers
  - Cloud
  - Tablets
  - Smartphones
  - IoT

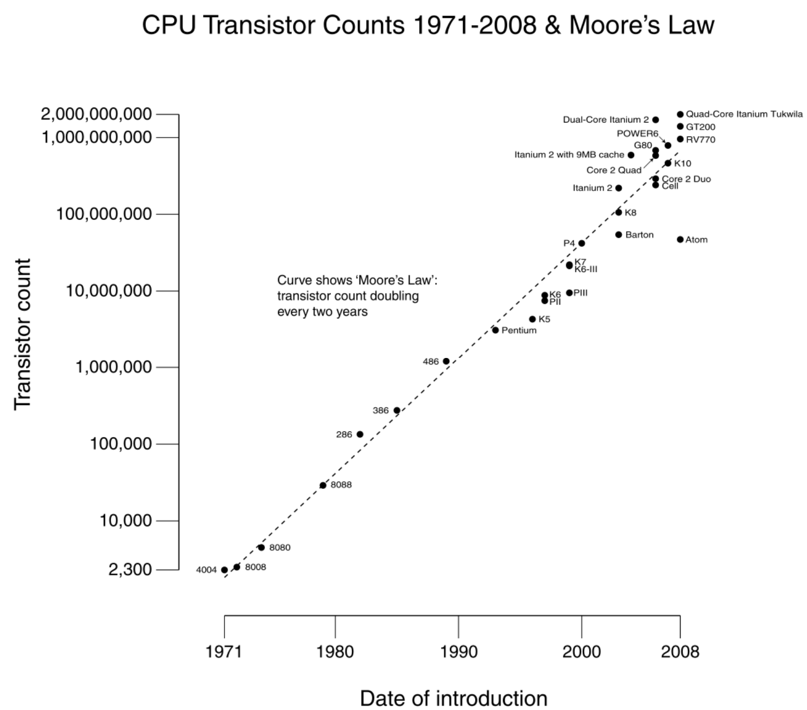
- Multi-core/Many-core/Heterogeneous
- Virtualization

History

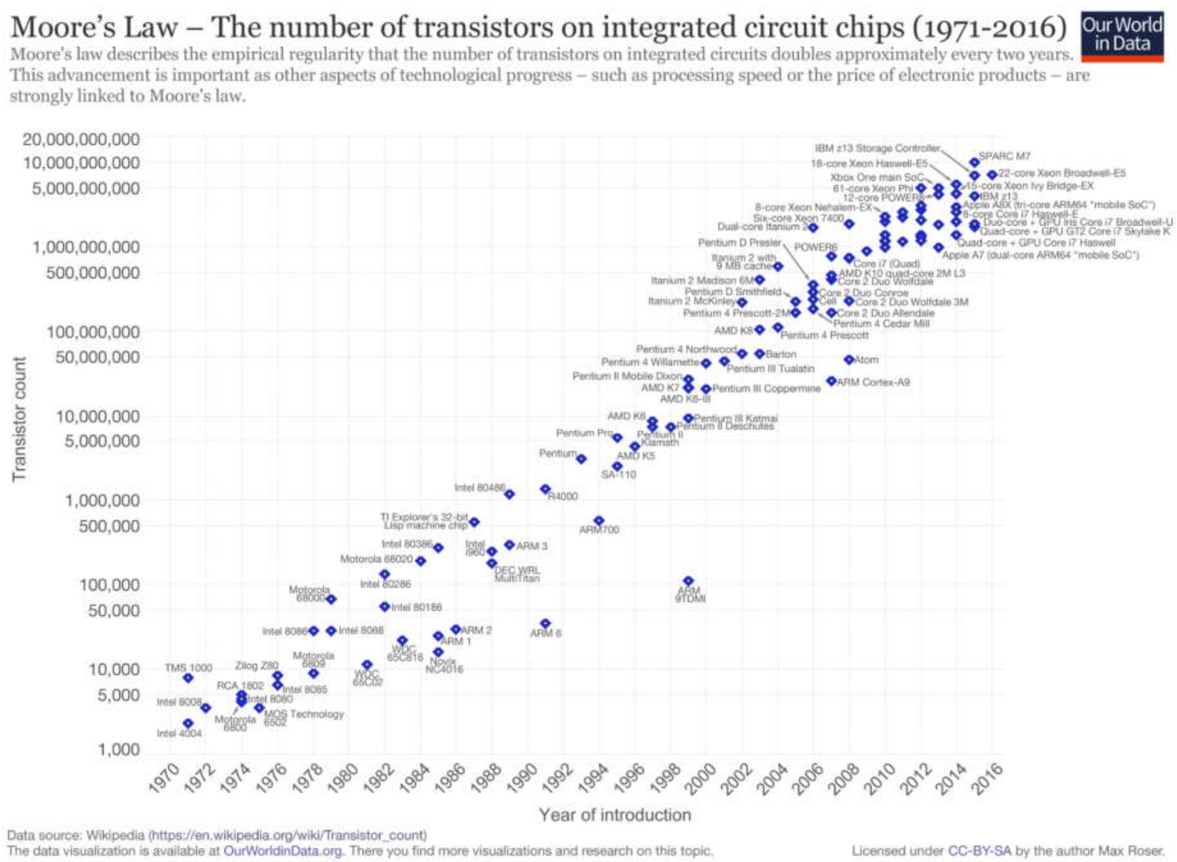
- Intel company
- 1971: Intel 4004 – the first programmable circuit
  - Microprocessor
  - 4 bits
- 1972: Intel 8008 – the first 8 bits microprocessor

Technology

- Moore’s law
  - The number of transistors on a given piece of silicon would double every 18 months (1965)
  - 24 months (1975)



Technology


Moore's Law – The number of transistors on integrated circuit chips (1971-2016)
Our World in Data
Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are strongly linked to Moore's law.
Transistor count
20,000,000,000
10,000,000,000
5,000,000,000
1,000,000,000
500,000,000
100,000,000
50,000,000
10,000,000
5,000,000
1,000,000
500,000
100,000
50,000
10,000
5,000
1,000
Year of introduction
1970 1972 1974 1976 1978 1980 1982 1984 1986 1988 1990 1992 1994 1996 1998 2000 2002 2004 2006 2008 2010 2012 2014 2016
Data source: Wikipedia (https://en.wikipedia.org/wiki/Transistor_count)
The data visualization is available at OurWorldinData.org. There you find more visualizations and research on this topic.
Licensed under CC-BY-SA by the author Max Roser.

Technology

- What is the main factor that supported microprocessor advances?

Technology

Processor	**Year**	**Transistors count**	**Pins count**	**Technology [μm]**	**V_{DD} [V]**	**F_{max} [MHz]**	**P_{max} [W]**
4004	1971	2250	16	10	12	0.1	
8080	1974	4500	40	6	5	3	
8086	1978	29000	40	2	5	12	
80286	1982	134000	68	1.5	5	20	
80386	1985	275000	132	1	5	33	1.9
80486	1989	1200000	168	0.8	5 - 3.3	66	6
Pentium	1994	3100000	320	0.6 - 0.35	5 - 3.3	200	15
Pentium Pro	1997	5500000	387	0.35	3.3 - 2.9	300	47
Pentium 2	1998	7500000	242	0.25	3.3 - 2.1	500	27
Pentium 3	1999	9500000	242	0.18	3.3 - 1.3	1200	37
Pentium 4	2000	55000000	478	0.13	1.75 - 1.5	1500	57
Pentium 4	2001	55000000	478	0.13	1.75 - 1.5	2000	75
Itanium	2001	25000000		0.18	3.3	800	116
Pentium 4	2002	55000000	478	0.13	1.75 - 1.5	3000	81
Itanium 2	2002	220000000		0.18	3.3	1000	130

Technology

- Processor description on emag.ro

PROCESOR

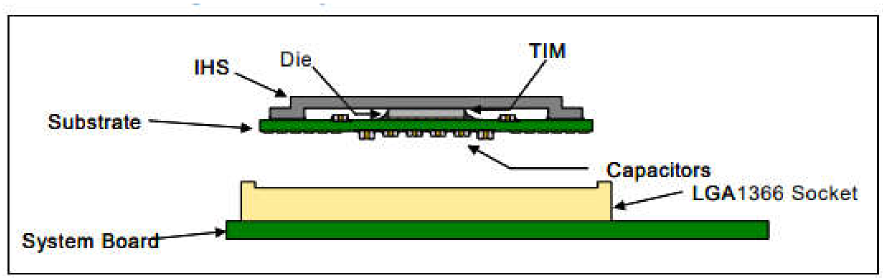
Producator procesor	Intel®
Tip procesor	i5
Model procesor	7400
Numar nuclee	4
Numar thread-uri	4
Arhitectura	Kaby Lake
Frecventa nominala	3000 MHz
Frecventa Turbo Boost	3500 MHz
Cache	6144 KB
Tehnologie procesor	14 nm

Technology

- What is the smallest physical component used to design a circuit?

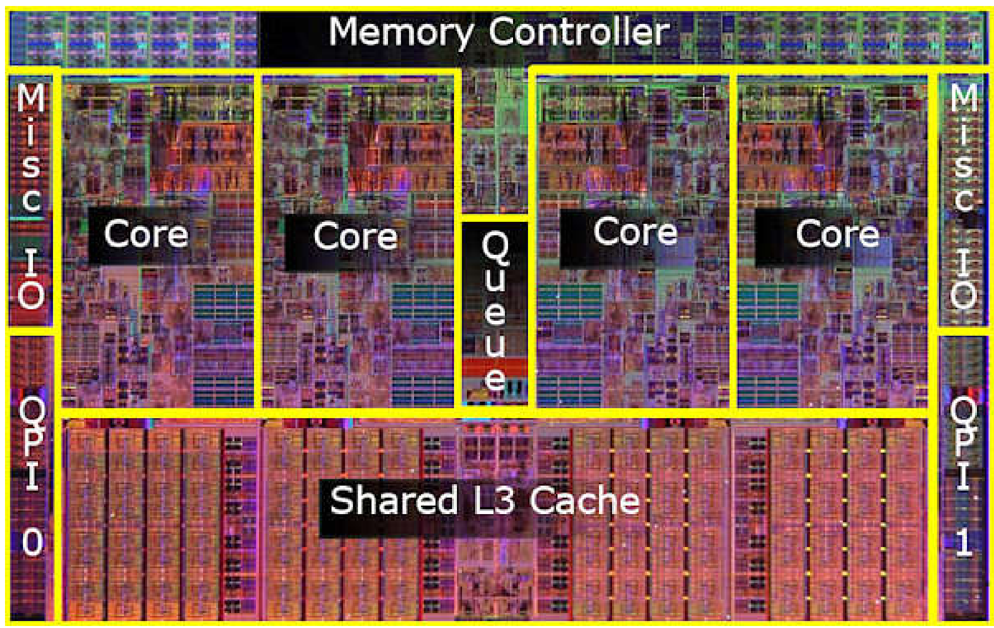
Technology

- Manufacturing technology of VLSI circuits
  - Packaging
    - IHS – integrated heat spreader
    - TIM – thermal interface material
    - Socket – connector for placing the processor on the main system board



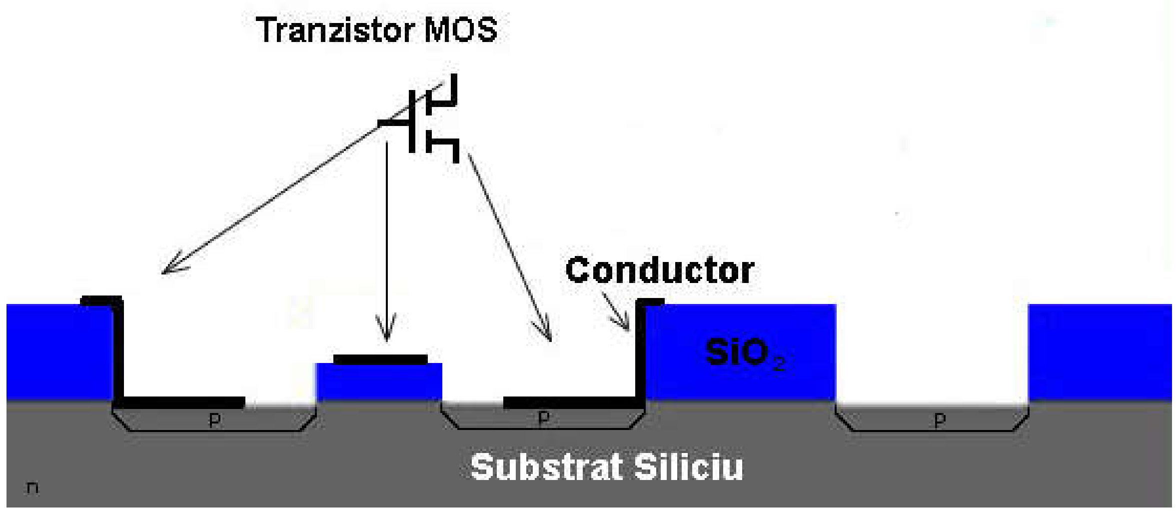
Technology

- Manufacturing technology of VLSI



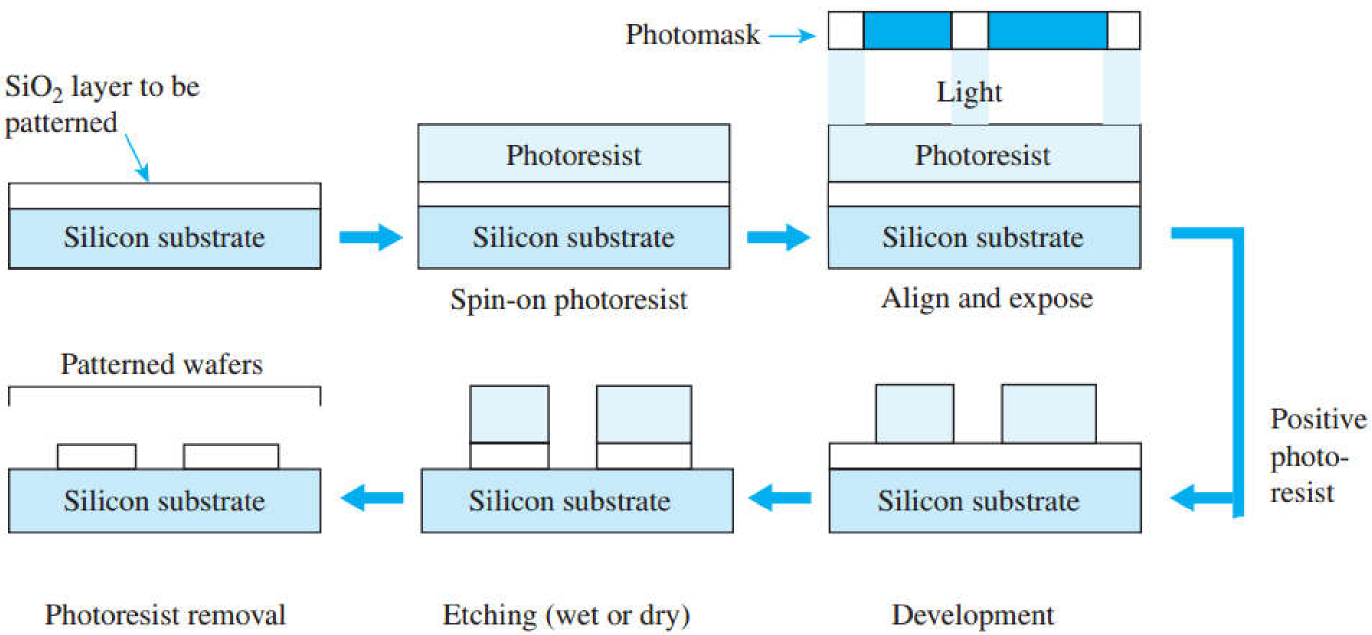
Technology

- Manufacturing technology of VLSI circuits
  - Cross section of a MOS transistor



Technology

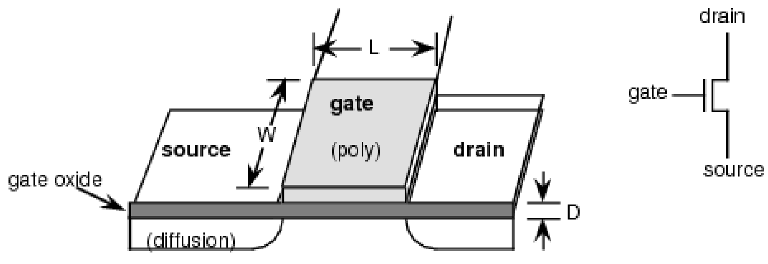
- Fabrication process

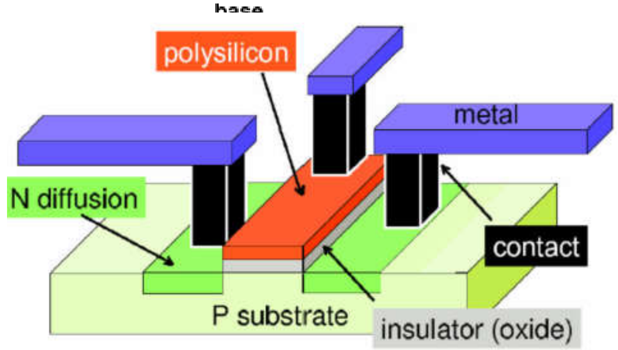


Technology

- Manufacturing technology of VLSI circuits
  - 3D view of a MOS transistor

nMOS Transistor



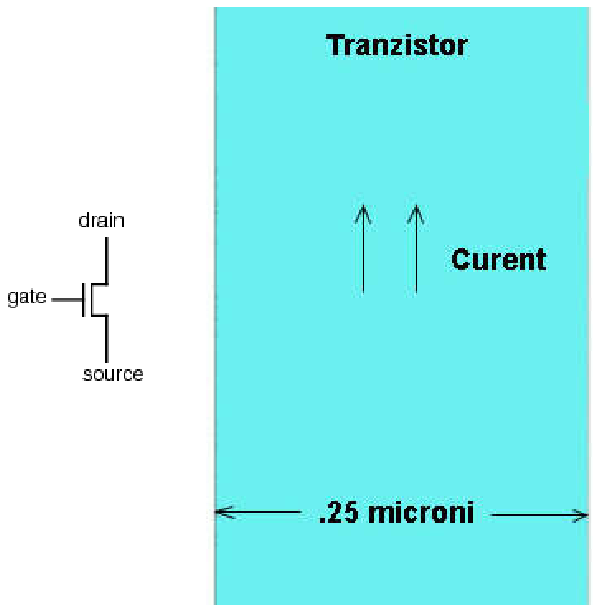


Semiconductor manufacturing processes

10 µm – 1971
6 µm – 1974
3 µm – 1977
1.5 µm – 1982
1 µm – 1985
800 nm – 1989
600 nm – 1994
350 nm – 1995
250 nm – 1997
180 nm – 1999
130 nm – 2001
90 nm – 2004
65 nm – 2006
45 nm – 2008
32 nm – 2010
22 nm – 2012
14 nm – 2014
10 nm – 2017
7 nm – 2018
5 nm – *~2020*

Technology

- Manufacturing technology of VLSI circuits
  - Top-down view over a MOS transistor



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Technology

- Moore’s law was a prediction of VLSI circuits development using the semiconductor scaling process
- Scaling is the process of shrinking the physical basic units of an integrated circuit – the transistors

Technology

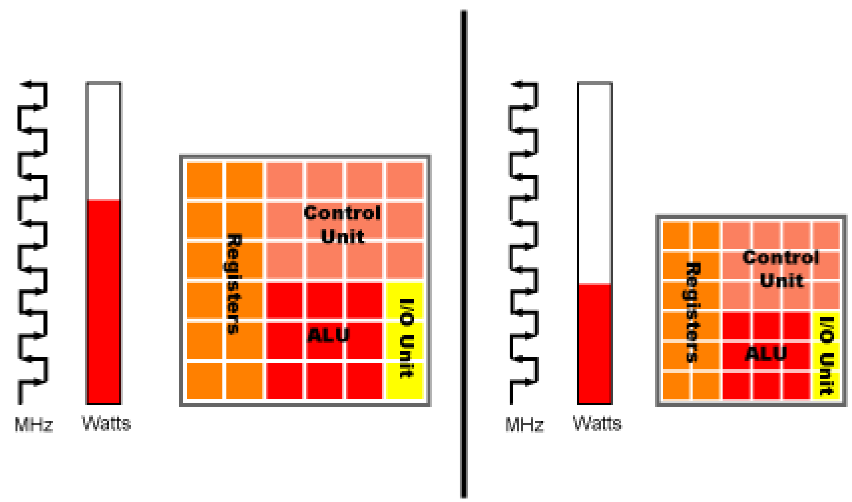
- Scaling objectives
  - Decrease the sizes of the transistors
  - Increase the frequency
  - Increase the number of transistors
- Consequence of increasing the number of transistors
  - Increase the power consumption
- As a solution to increasing power consumption
  - Decrease the circuit voltages
  - Decrease the threshold voltages

Technology

- Scaling benefits
  - Increase the number of transistors on the same area of the die
  - Decrease the power consumption of the circuit
  - Increase the operation frequency
- Technology scaling has been the means by which Moore's Law was possible

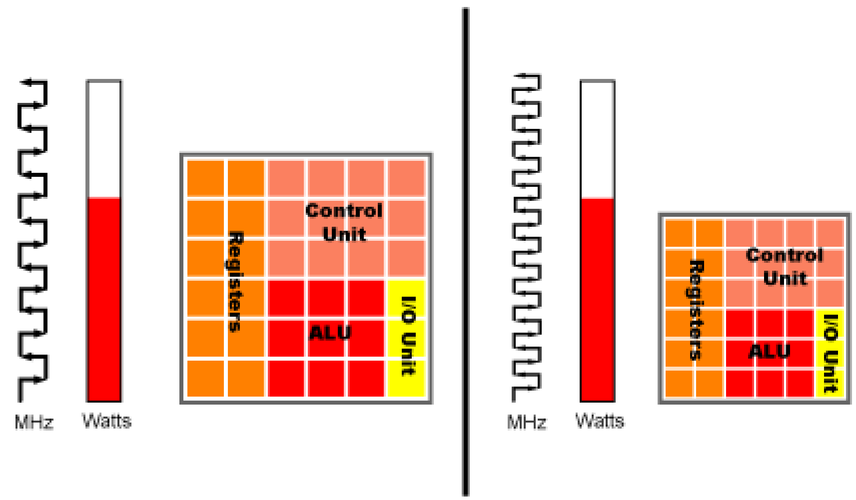
Technology

- Scaling benefits:
  - The same features at lower power consumption



Technology

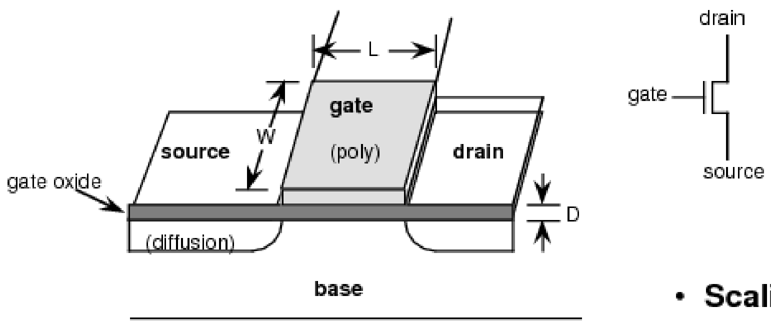
- Scaling benefits:
  - Increasing processing speed at the same power consumption



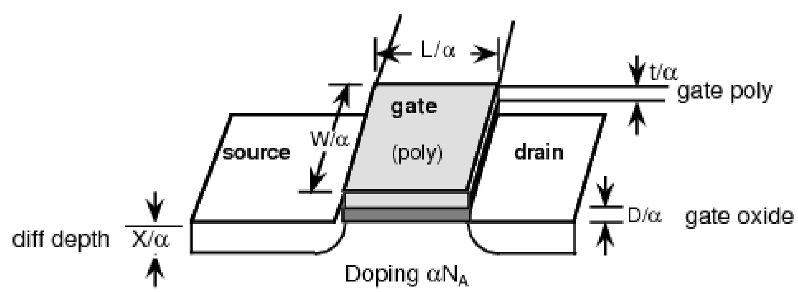
Technology

- Scaling process

nMOS Transistor

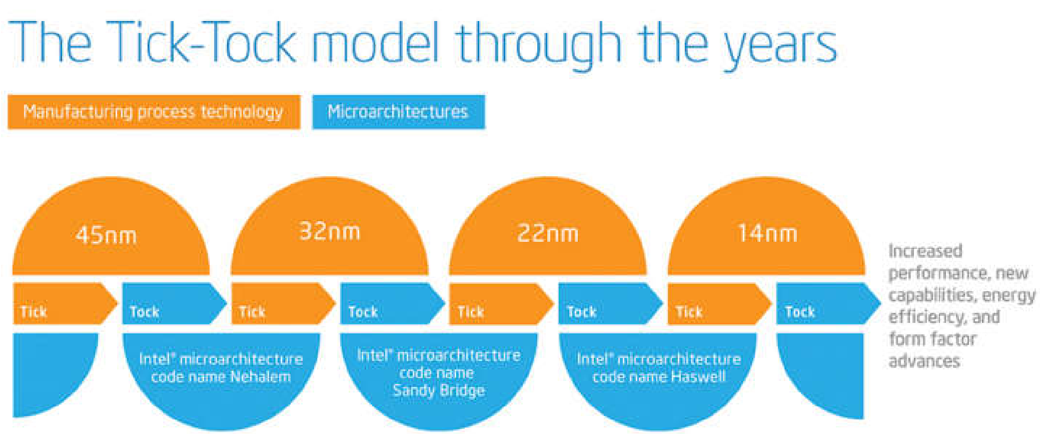


- **Scaling factor α:**



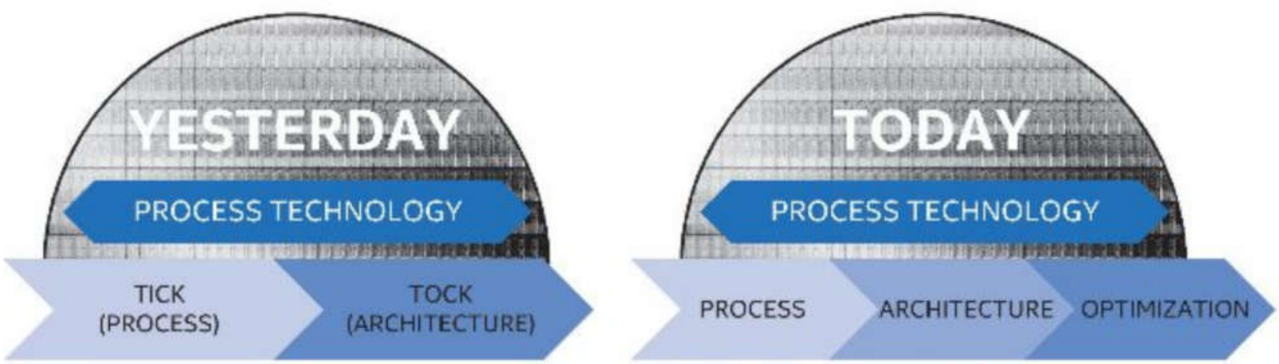
Tehnology

- Alternation of processor development steps
  - Scaling/technology changing (~1year)
  - Architectural advances (~1year)



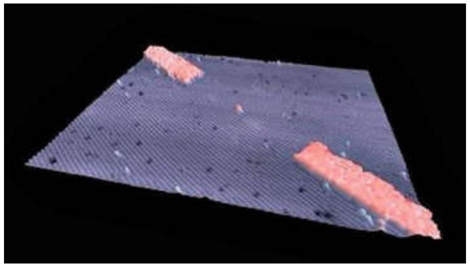
Tehnology

- Moore’s law limits
  - Prolongation of development cycle
    - Process
    - Architecture
    - Optimization



Technology

- Moore's law limits
  - 2010 – frequency
  - 2025 – size
    - Single atom transistor (University of New South Wales)
    - Validation of theoretical models



Technology

- Moore's law risks
  – Companies took the prediction as a law to be competitive on the market
  – Push innovation in one direction – increase the performance
  – Intel Israel – Centrino technology – optimize for low power

Start-up Nation: The Story of Israel's Economic Miracle,
by Dan Senor, Saul Singer

Exam subjects

- Technology scaling
- Moore's Law
- Terms
  - Microarchitecture
  - ISA
- Definition of microprocessor

Administrative

- Evaluation
- Laboratories
  - B414
- Students counseling
  - B412
- cv.upt.ro

Evaluation

- Minimal performance standards
  - Overall microprocessor architecture and behavior;
  - Memory decoding, I/O decoding
  - Data types and memory variables
  - ISA

Digital microsystem design fundaments	Written exam	25%
Digital microsystem design applications	Written exam	25%
Solving the topics proposed during the laboratory	Laboratory deliverables presentation and questions	25%
Semester project development and presentation	Project deliverables presentation and questions	25%

Contact

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- B412/B414/B413

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