Digital microsystems design

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Outline

- Introduction
  - Prerequisites
  - Overview
  - Goal
  - Specific objectives
- Terms and definitions
- Technology
- Classification

Introduction

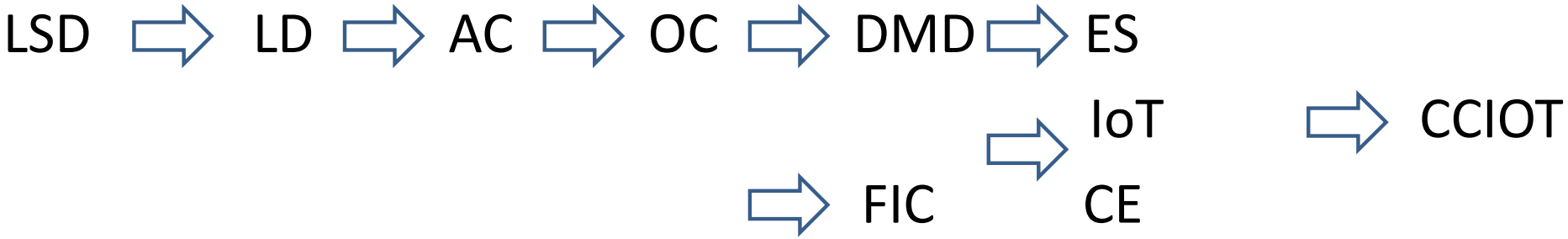
- Design, build, use and program a digital system
  - Microprocessors (single, multiple)
    - Cores and threads
  - Mainboard
  - Buses
  - Memories
  - I/O interfaces

Introduction

- Prerequisites
  - Programming languages
    - Native, not managed
  - Computer architecture
  - Digital logic
  - Digital circuits and signals

Introduction

- Hardware design track



Introduction

- Prerequisites
  - C programming language
  - Registers, buffers, memories, decoders, multiplexers, buses
  - Logic gates
  - Pipelines, caches

Introduction

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

Introduction

- Understand the terms

used by computers and processors manufacturers

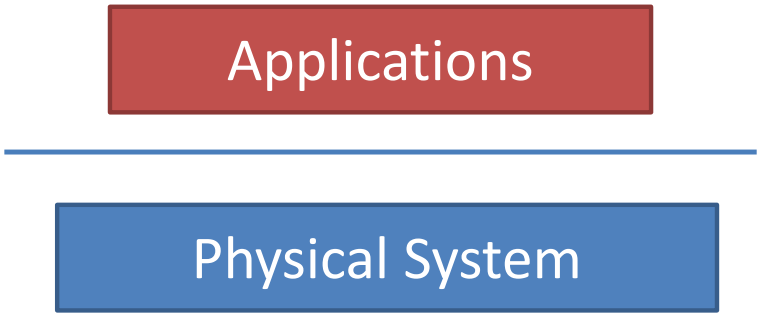
Product Collection	7th Generation Intel® Core™ i5 Processors
Code Name	Products formerly Kaby Lake
Vertical Segment	Mobile
Processor Number	i5-7200U
Status	Launched
Launch Date	Q3'16
Lithography	14 nm
Recommended Customer Price	$281.00

Performance

# of Cores	2
# of Threads	4
Processor Base Frequency	2.50 GHz
Max Turbo Frequency	3.10 GHz
Cache	3 MB SmartCache
Bus Speed	4 GT/s OPI
TDP	15 W
Configurable TDP-up Frequency	2.70 GHz
Configurable TDP-up	25 W
Configurable TDP-down Frequency	800 MHz
Configurable TDP-down	7.5 W

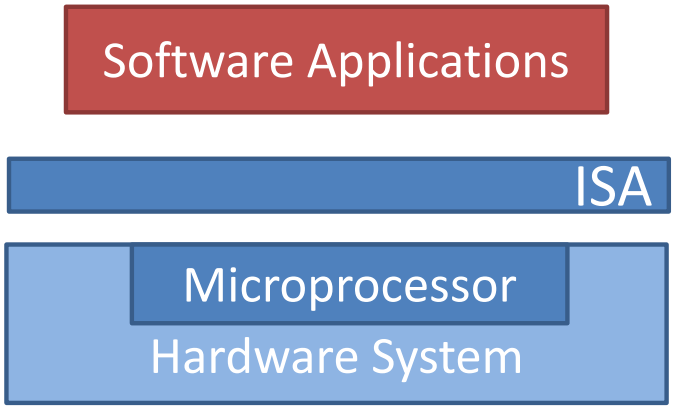
Overview

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



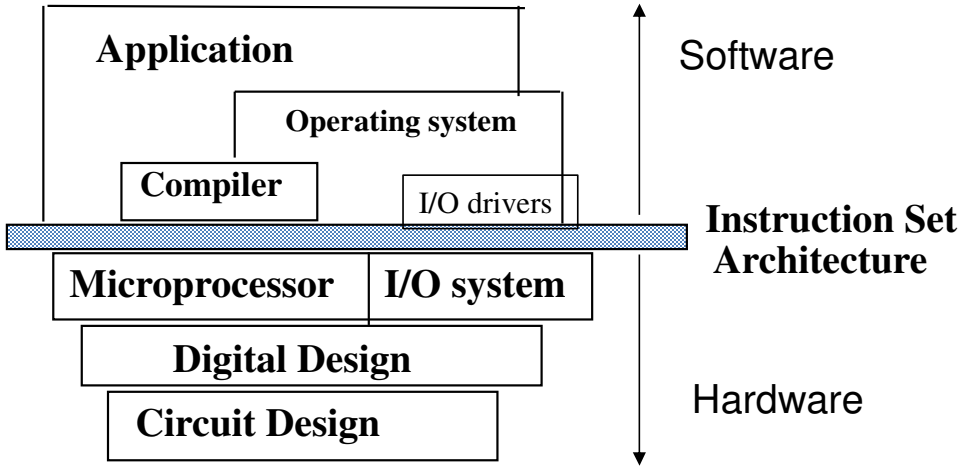
Overview

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



Overview

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



Overview

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

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

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

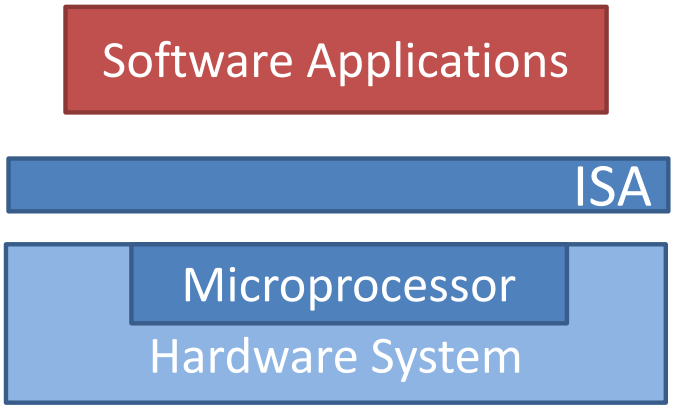
Objectives

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

- Assembly language
- C language constraints and optimization

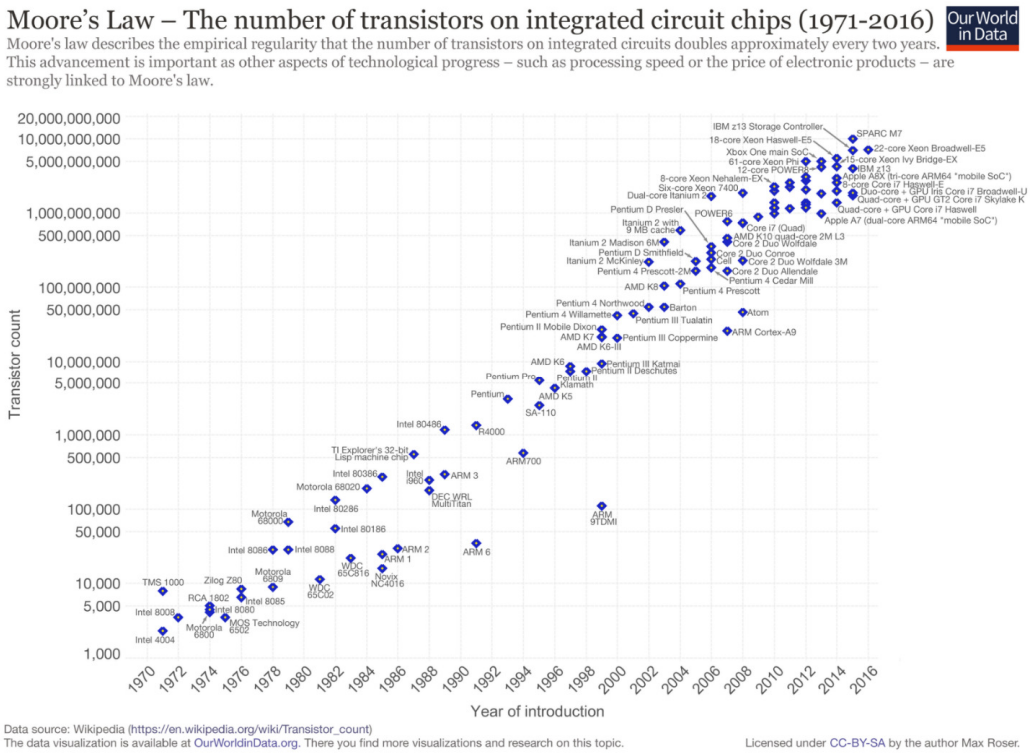
Terms

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



Technology

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



Technology

- Which 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

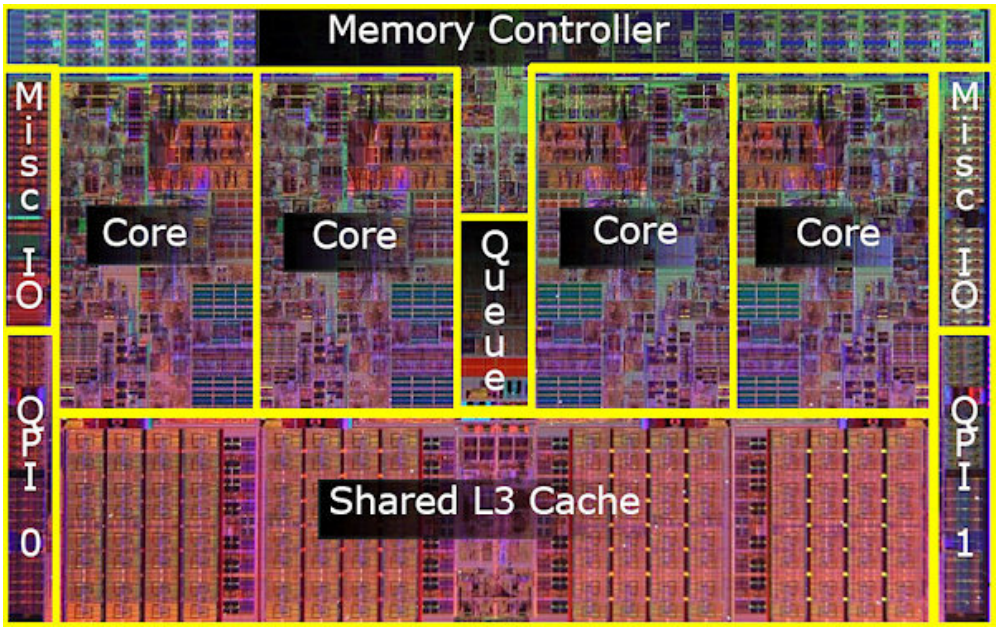
- Processor description on emag.ro

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

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

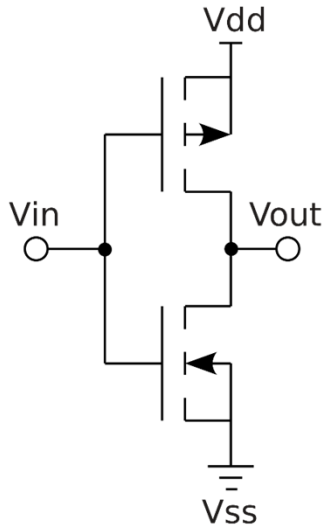


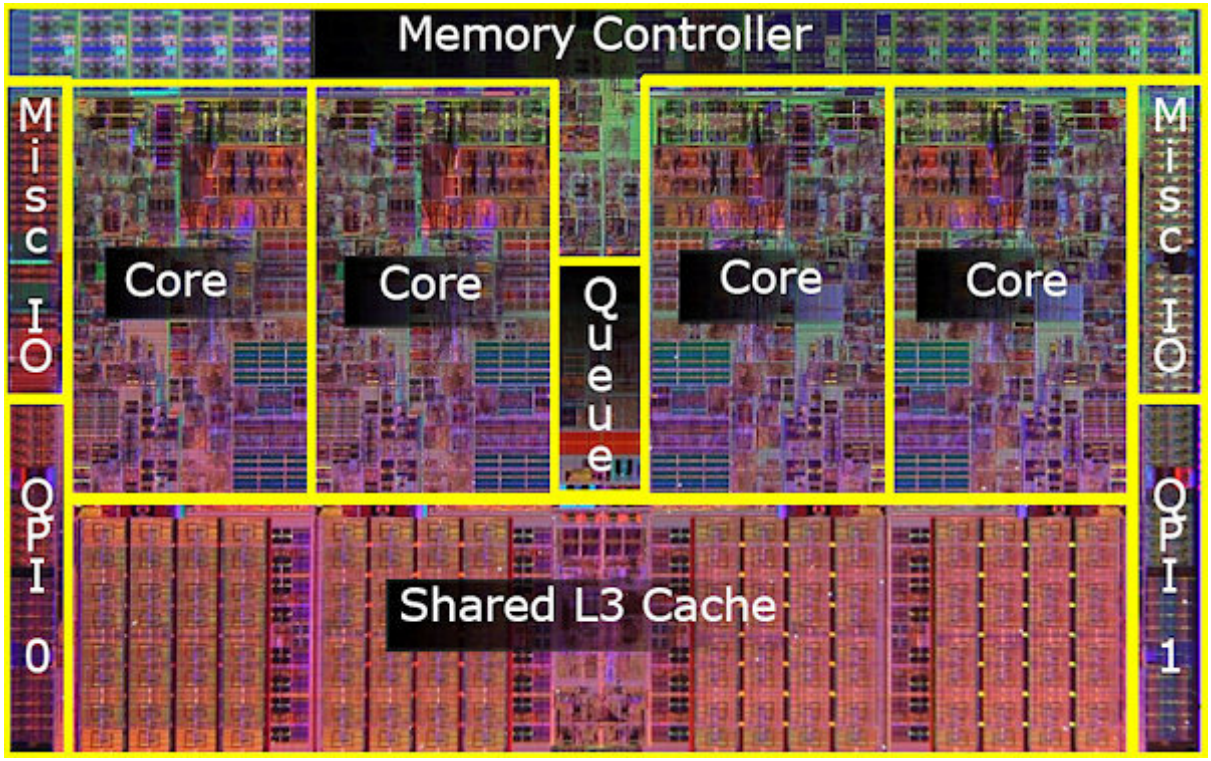
Caches
Registers
ALUs
Decoders
Buffers

→ Logical gates → Transistors

Technology

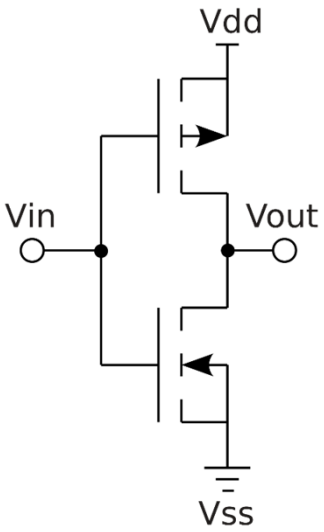
- Manufacturing technology of VLSI

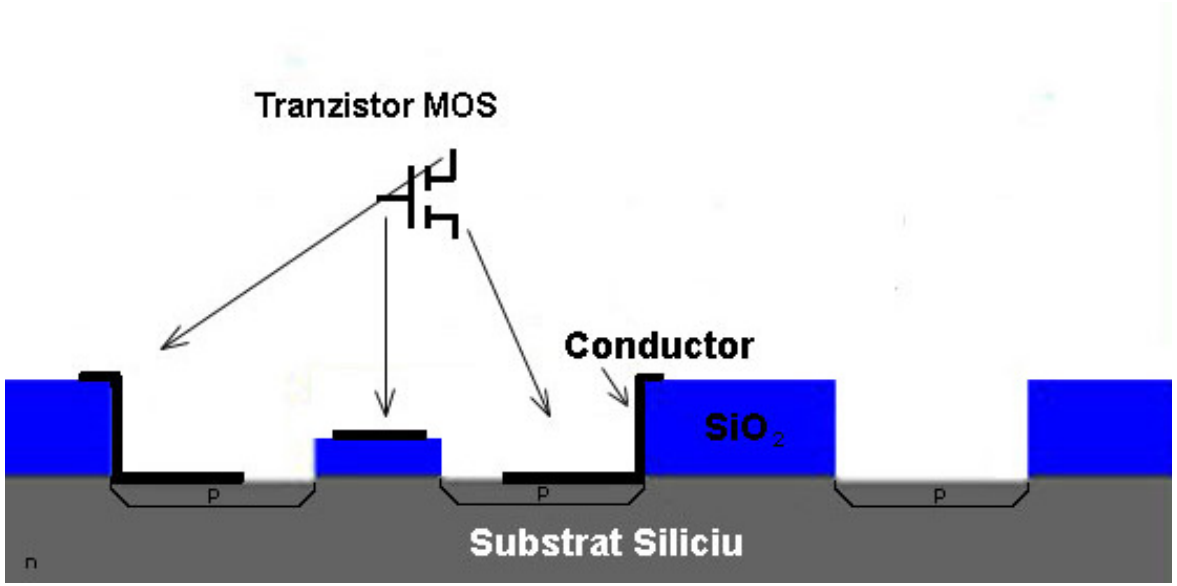




Technology

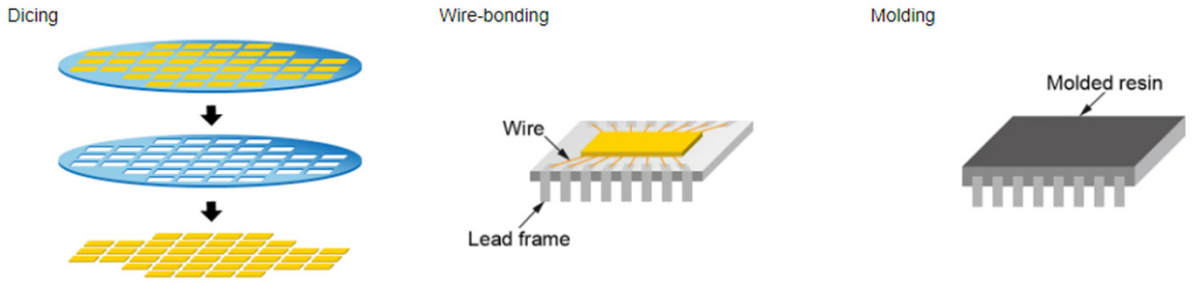
- Manufacturing technology of VLSI circuits
  - Cross section of a MOS transistor





Technology

- Fabrication process



Technology

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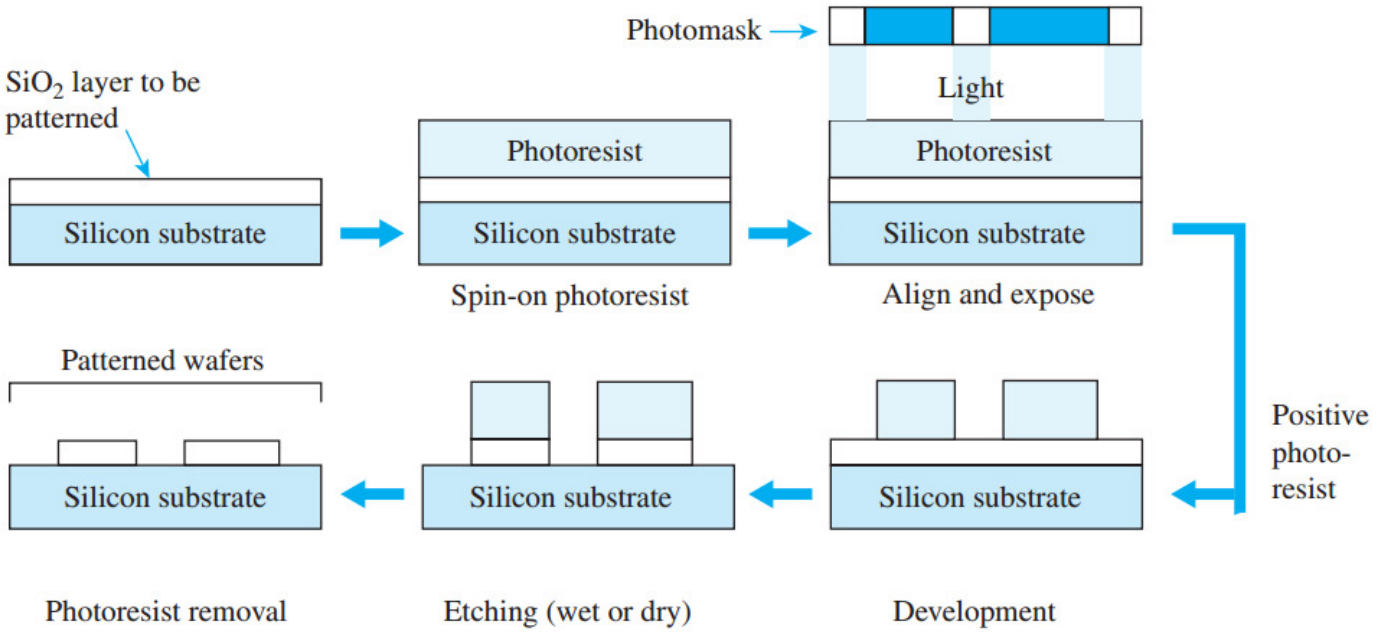
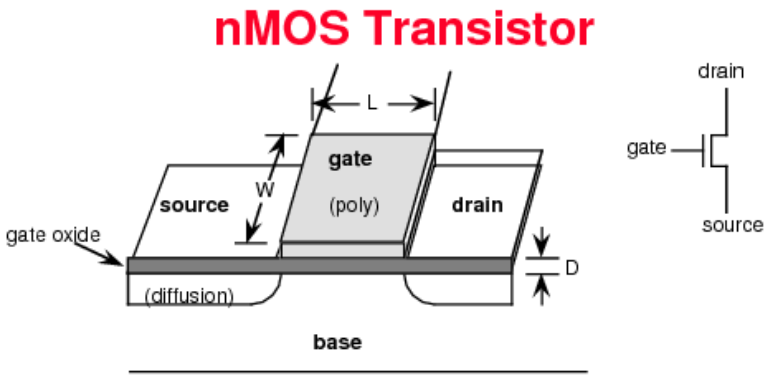


Technology

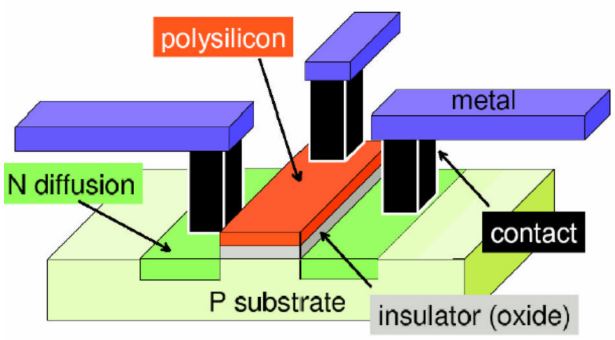
- Manufacturing technology of VLSI circuits
  - 3D view of a MOS transistor



Semiconductor manufacturing processes
10 µm – 1971
6 µm – 1974
3 µm – 1977
1.5 µm – 1981
1 µm – 1984
800 nm – 1987
600 nm – 1990
350 nm – 1993
250 nm – 1996
180 nm – 1999
130 nm – 2001
90 nm – 2003
65 nm – 2005
45 nm – 2007
32 nm – 2009
22 nm – 2012
14 nm – 2014
10 nm – 2016
7 nm – 2018
5 nm – 2020
Future
3 nm ~ 2022
2 nm ~ 2024

Technology

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



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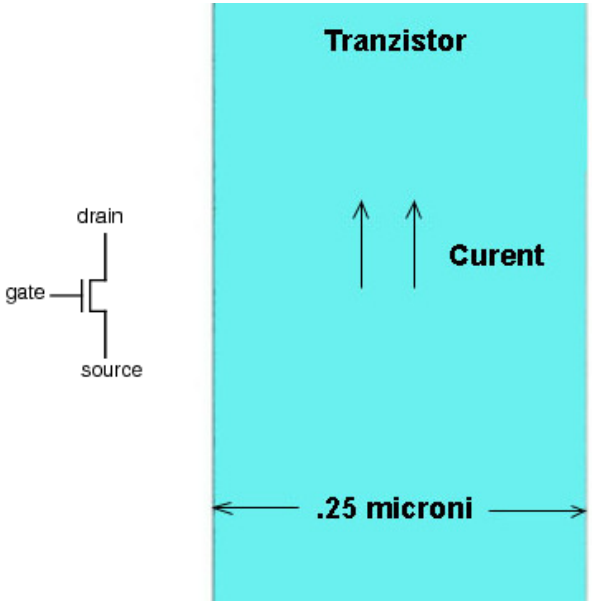
7 nm – 2018
5 nm – 2020
Future
3 nm ~ 2022
2 nm ~ 2024

Technology

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



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Future
3 nm ~ 2022
2 nm ~ 2024

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

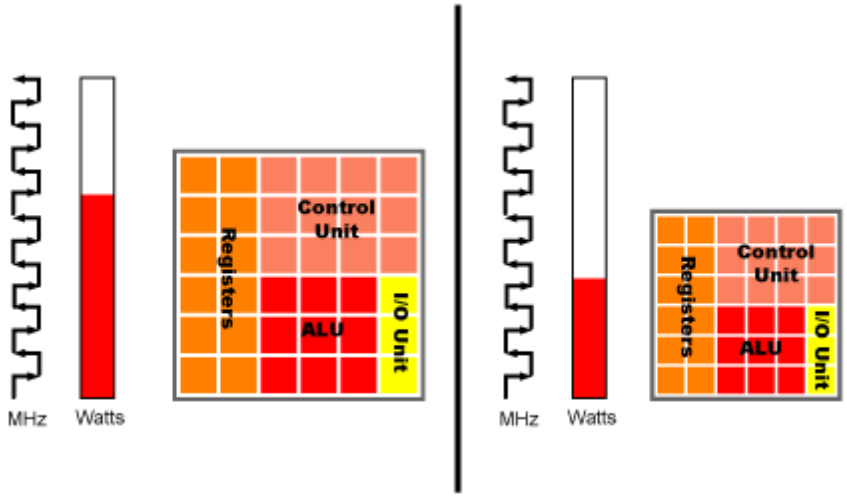
- Scaling objectives
  - Decrease the sizes of the transistors
  - Increase the frequency
  - Increase the number of transistors
- Consequence of increasing the number of transistors
  - Increase the power consumption
- As a solution to increasing power consumption
  - Decrease the circuit voltages
  - 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 mean by which Moore's Law was possible

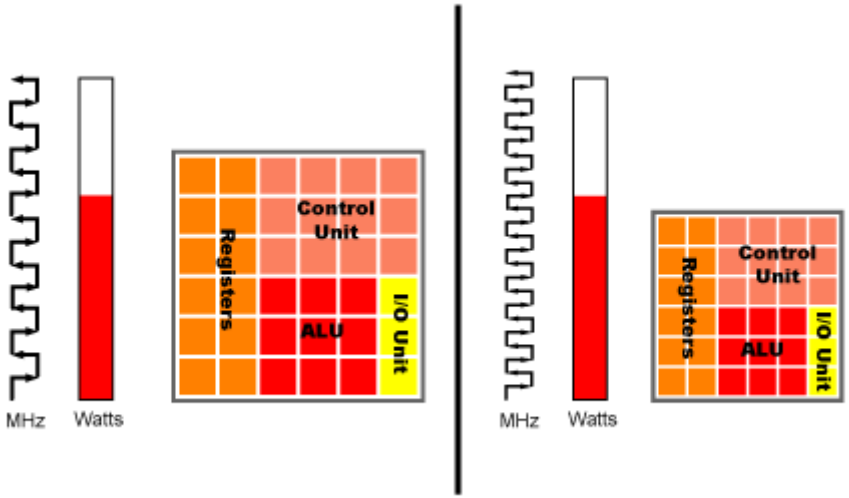
Technology

- Scaling benefits
  - The same features at lower power consumption



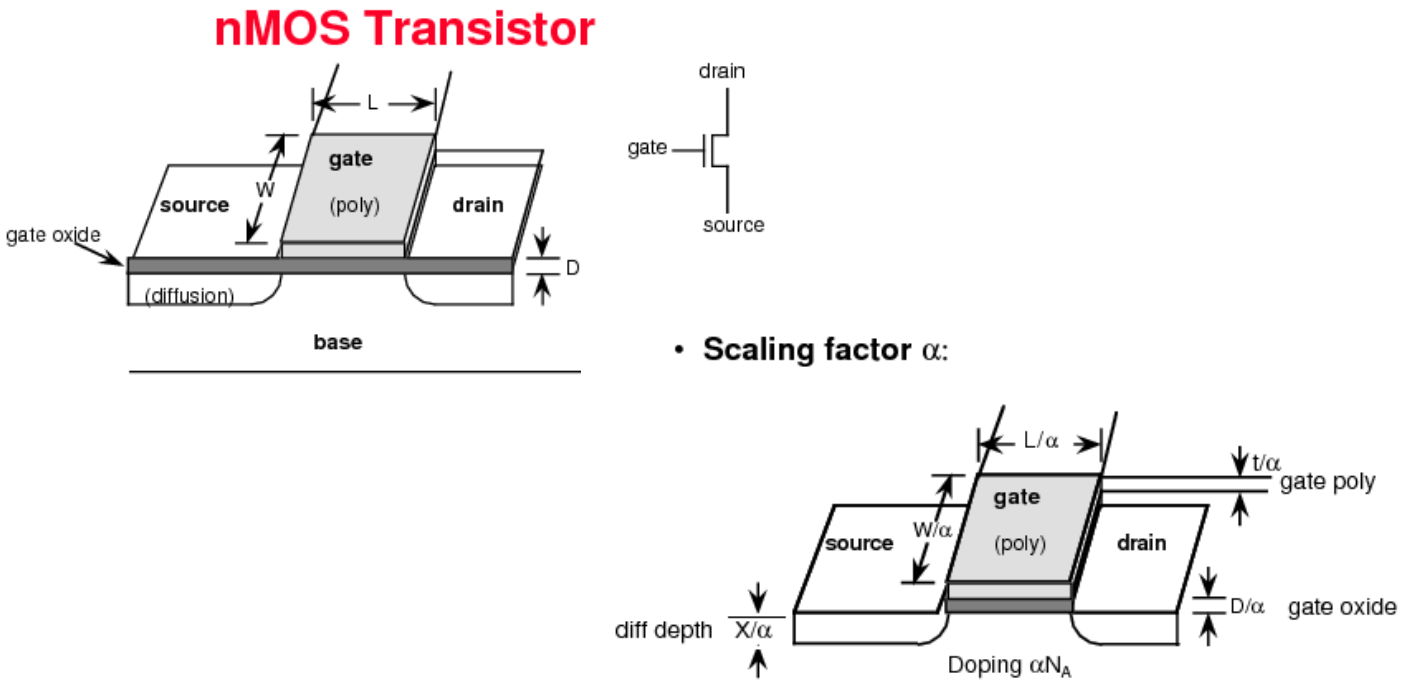
Technology

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



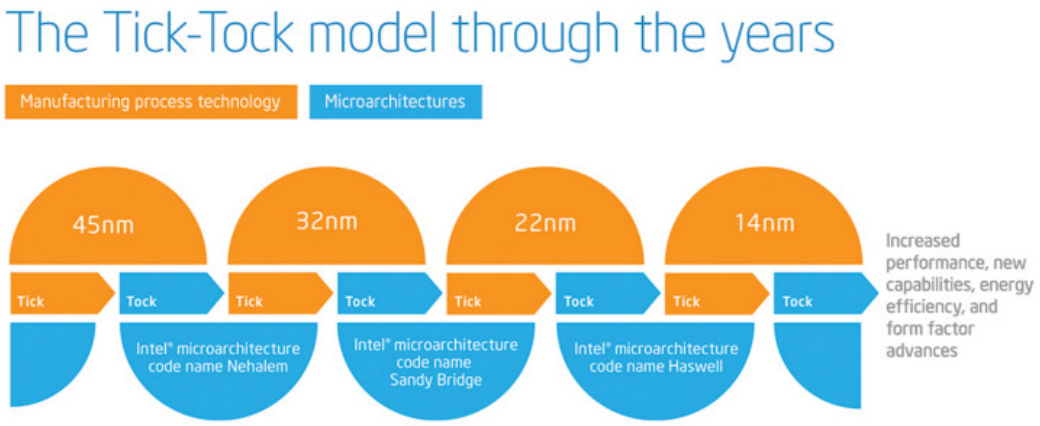
Technology

- Scaling process



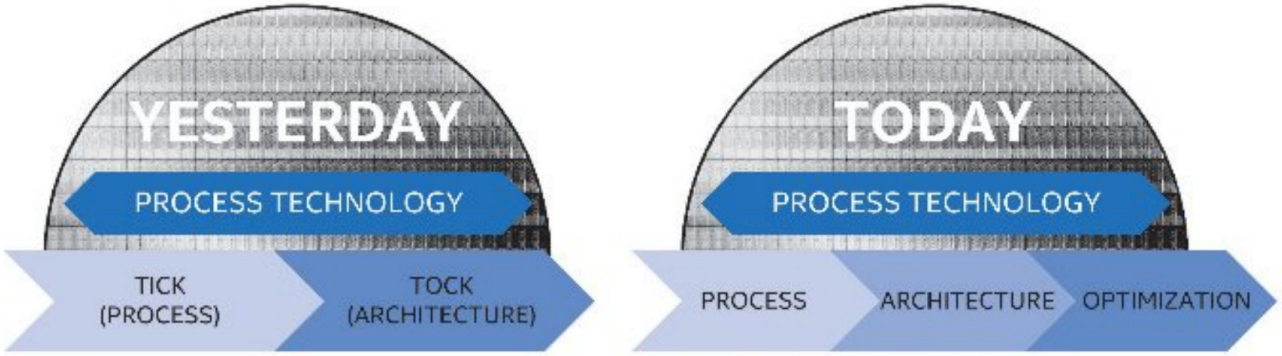
Technology

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



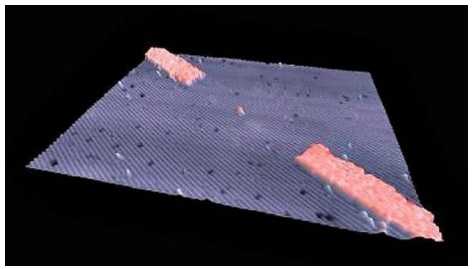
Technology

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



Technology

- Moore's law limits
  - 2010 – frequency
  - 2020 – costs
  - 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

Definitions

- A digital microsystem is a microprocessor or microcontroller-based computing system.
  - Computer systems
  - Embedded systems
  - Mobile systems

Definitions

- A **microprocessor** is a general purpose programmable logical circuit
  - Can be used in general purpose computing devices
  - Can be programmed to run any type of application
- A **microcontroller** is an application specific programmable logical circuit dedicated to real-time, embedded applications
  - Application oriented processor
  - Domain specific processor

Definitions

- Mobile processors are low power processors used in mobile systems
  - General purpose, simple processors
  - Low power, energy efficient

Definitions

- Other types of processors
  - DSP – Digital Signal Processor
  - GPU – Graphics Processing Unit
  - FPU – Floating Point Unit
  - TPU – Tensor Processing Unit

  - ASIC – Application Specific Integrated Circuit
- Soft-processors (soft cores)
  - FPGA synthetized

Classification

- What are the main parameters used to compare different systems?

Classification

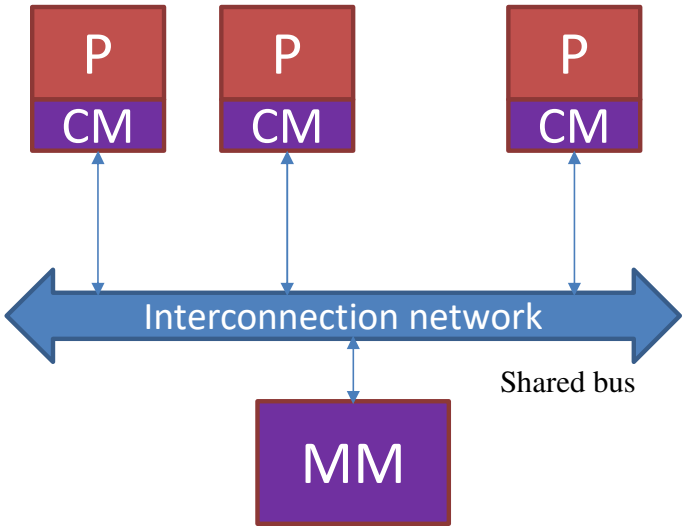
- Parameters
  - Performance
  - Number of processors
  - Number of cores
  - Interconnection network
  - Memory hierarchies
  - Granularity
    - Fine grain – simple operations on large amount of data
    - Coarse grain – complex operations on small amount of data

Classification

- Memory organization
  - UMA (Uniform Memory Access Model)
  - NORMA (No Remote Memory Access Model)
  - NUMA (Non-Uniform Memory Access Model)
  - COMA (Cache-Only Memory Access Model)

Classification

- UMA - Uniform Memory Access Model



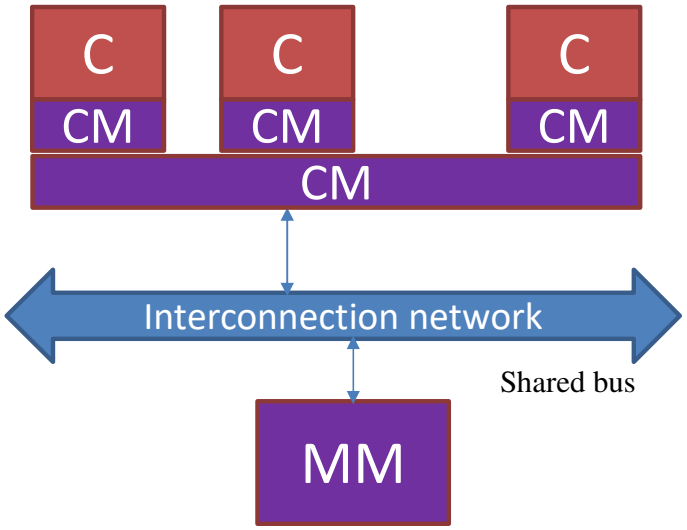
P – CPU or CPU core
CM – Cache memory
MM – Main memory

Classification

- UMA (Uniform Memory Access)
  - Shared memory / global memory
    - Shared variables
  - Uniform access
    - Equal access to memory
    - The same access time
    - No mater which processor
  - Unique physical address space
  - Symmetric multi-processors (SMP)

Classification

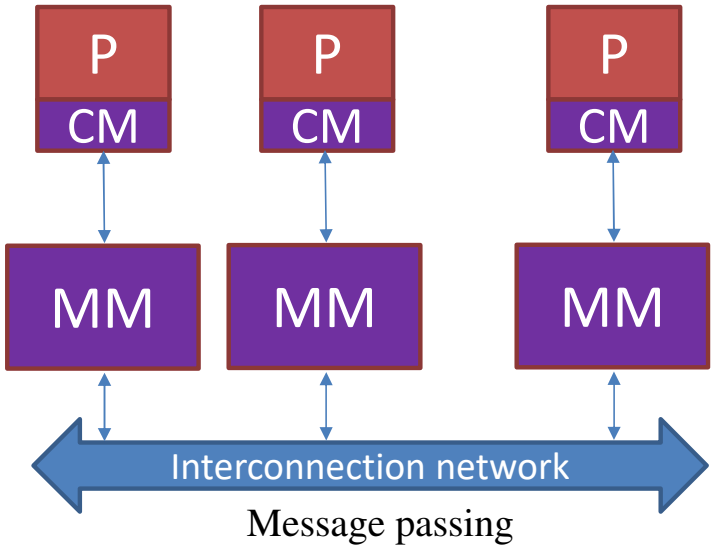
- UMA - Uniform Memory Access Model



C – CPU core
CM – Cache memory
MM – Main memory

Classification

- NORMA - No Remote Memory Access Model



P – CPU or CPU core
CM – Cache memory
MM – Main memory

Classification

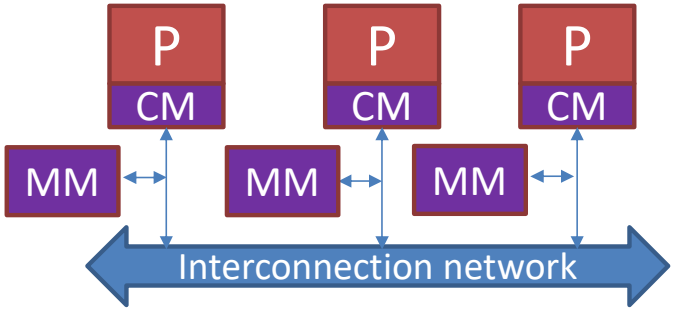
- NORMA (No Remote Memory Access)
  - Distributed memory
  - Access to local memory only
  - No access to remote memory
  - Distinct address spaces for every processor
  - Inter-processors communication using messages (network, I/O)

Classification

- NUMA (Non-Uniform Memory Access)
  - Distributed-shared memory
  - Each processor has access to both local memory and remote memory
  - Non-uniform access to memory
    - Local memory low access times
    - Remote memory high access times
  - Unique virtual address space

Classification

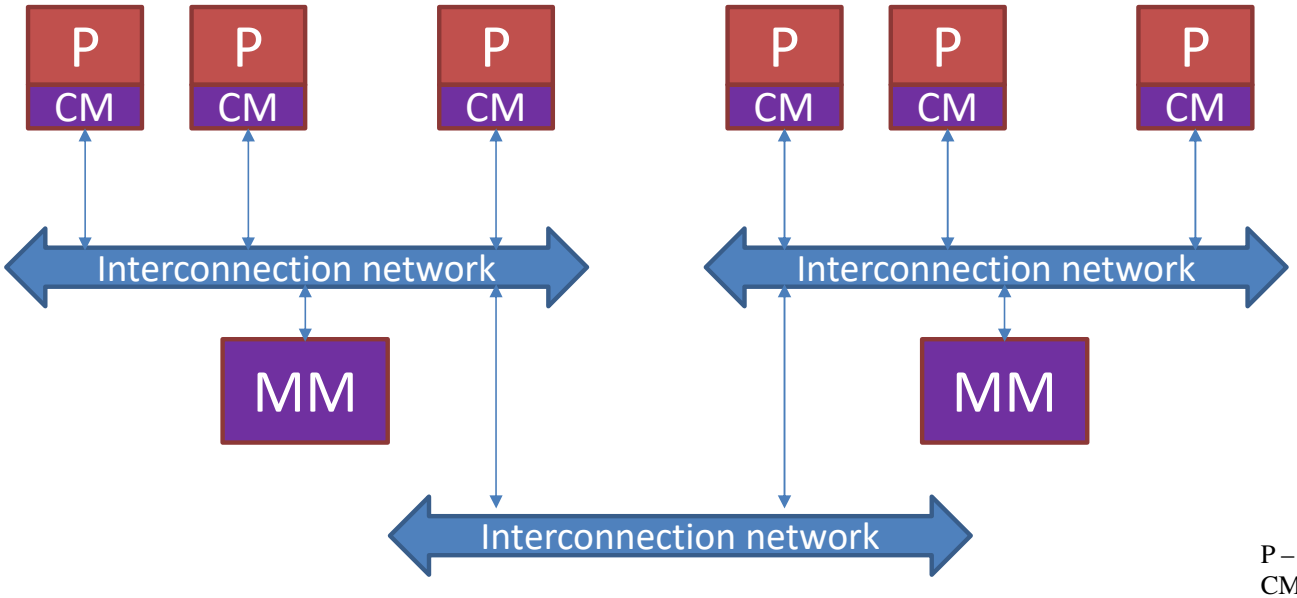
- NUMA



P – CPU or CPU core
CM – Cache memory
MM – Main memory

Classification

- Hybrid UMA/NUMA - general



P – CPU or CPU core
CM – Cache memory
MM – Main memory

Classification

- Flynn
  - Instructions stream
  - Data stream
- Flynn taxonomy:
  - SISD (Single Instruction stream Single Data stream)
  - **SIMD** (Single Instruction stream Multiple Data stream)
  - MISD (Multiple Instruction stream Single Data stream)
  - **MIMD** (Multiple Instruction stream Multiple Data stream)

Classification

- SISD
  - Instructions are executed sequentially
  - Micro-operations parallelism allowed (pipeline)
  - Multiple functional units (math-coprocesor, graphic processor, I/O processor)

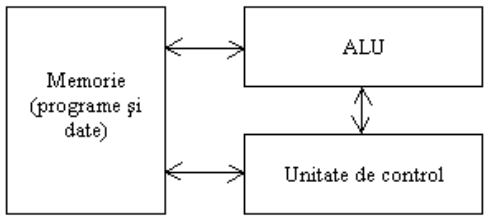


Figura 1.1 – Arhitectura von Neumann

Classification

- SISD
  - UC – command unit
  - UE – execution unit
  - MM – memory module
  - SI – instruction stream
  - SD – data stream

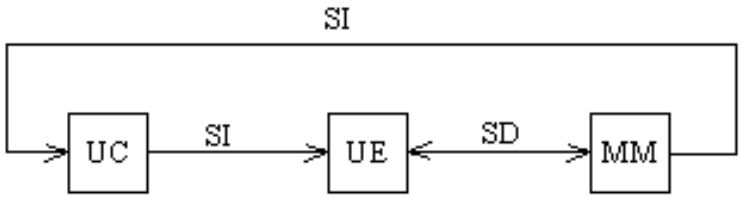


Figura 1.2 Arhitectura SISD

Classification

- SIMD
  - One UC controls many UEs
  - UEs execute simultaneously the same instruction on distinct data
  - Large number of UEs (thousands)
  - Applications having fine grain data processing

Classification

- SIMD
  - Processors arrays
  - Vector processors
  - Graphical processors

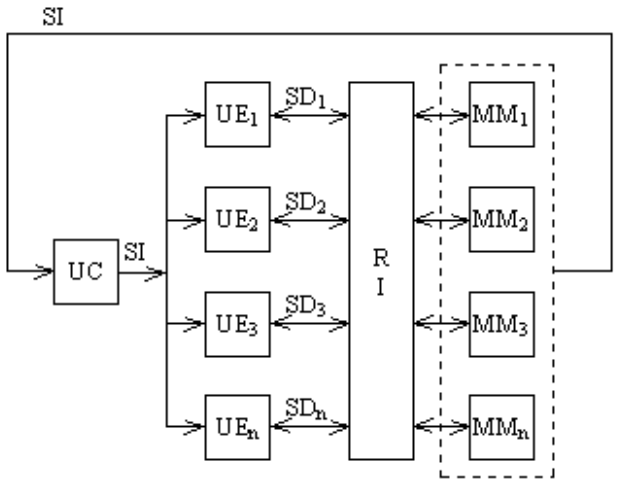


Figura 1.3 Arhitectura SIMD

Classification

- MISD
  - The same data is processed by different UEs
  - Macro-pipeline
- Systolic arrays

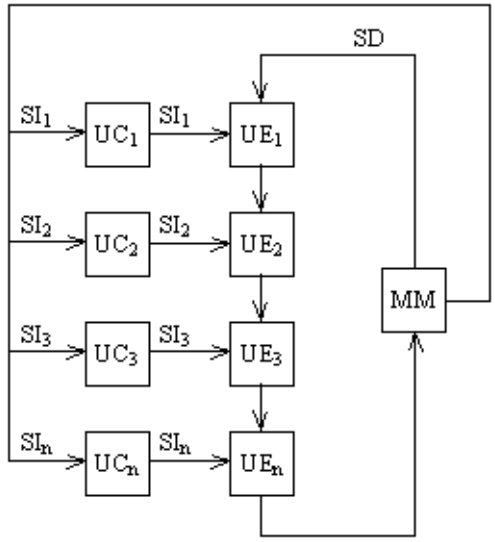


Figura 1.4 Arhitectura MISD

Classification

- MIMD
  - Each UE has its own UC
  - Every UE executes instructions on local data

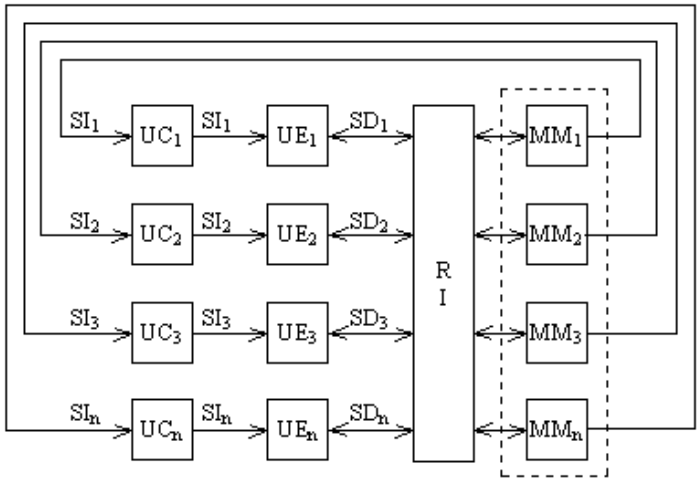


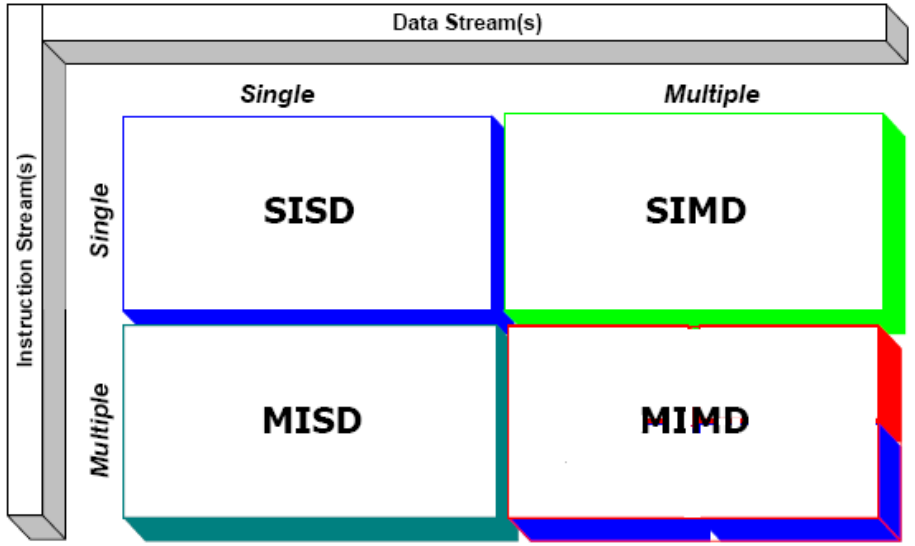
Figura 1.5 Arhitectura MIMD

Classification

- MIMD
  - Multi-processor servers
  - Multi-core processors
  - Computer networks
- Rack based servers
  - Blades
  - Hundreds of cores
  - Hundreds of GB of memory

Classification

- Extension of Flynn taxonomy
  - MIMD

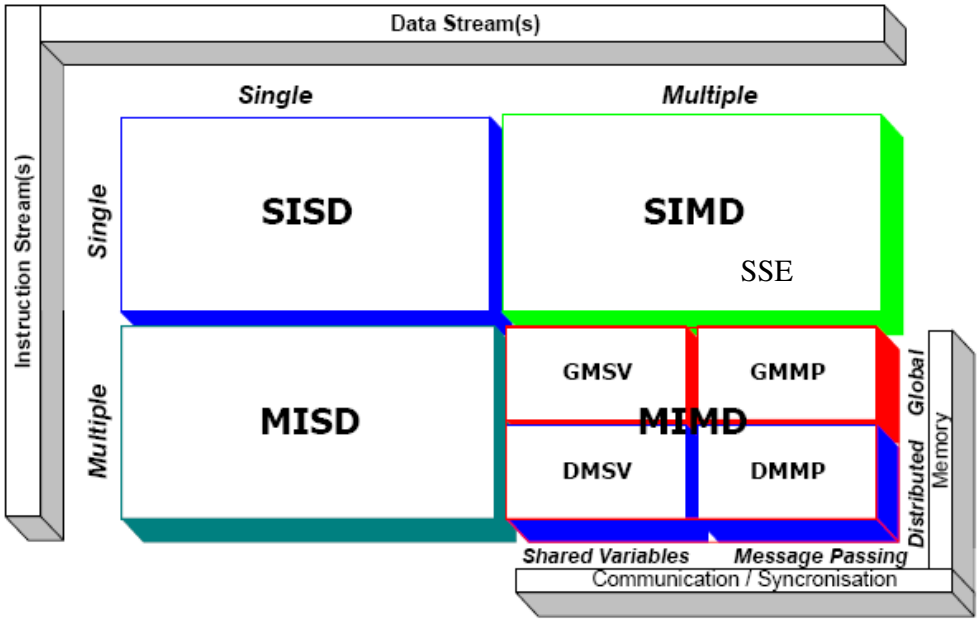


Classification

- MIMD architectures can be further classified based on:
  - Inter-processor communication:
    - Shared memory or messages
  - Interconnection network
    - Bus or crossbar
  - Memory organization:
    - Shared or distributed
  - Coupling level between the nodes
    - Loosely or tightly

Classification

- Flynn-Johnson taxonomy

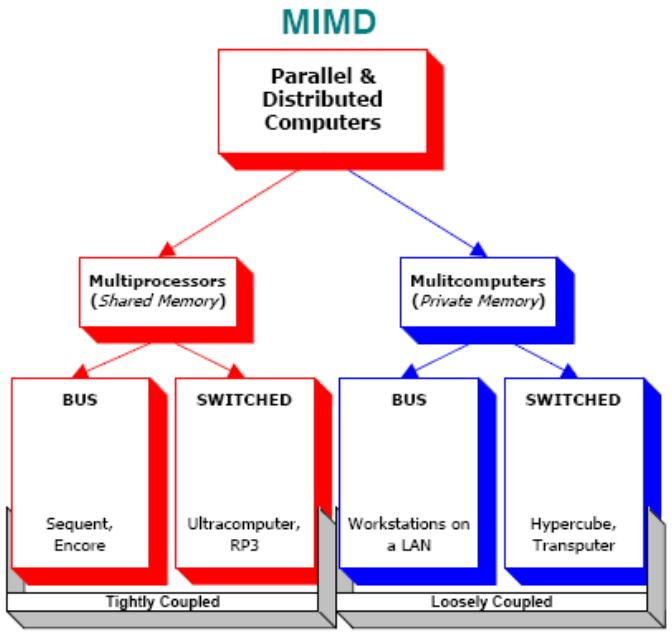


Classification

- GMSV – Global Memory / Shared Variables.
  - Multi-core/ multi-processor
- GMMP – Global Memory / Message Passing
  - virtualization
- DMSV – Distributed Memory / Shared Variables.
  - Distributed-shared memory/ middleware
- DMMP – Distributed Memory / Message Passing.
  - Computer networks, distributed computing, grid

Classification

- Tanenbaum taxonomy



Classification

- Interconnection network topologies
  - Static (ring, tree, hypercube, mesh)
  - Dynamic (bus, switches/crossbar)
- Coupling
  - Tightly coupled systems
  - Loosely coupled systems

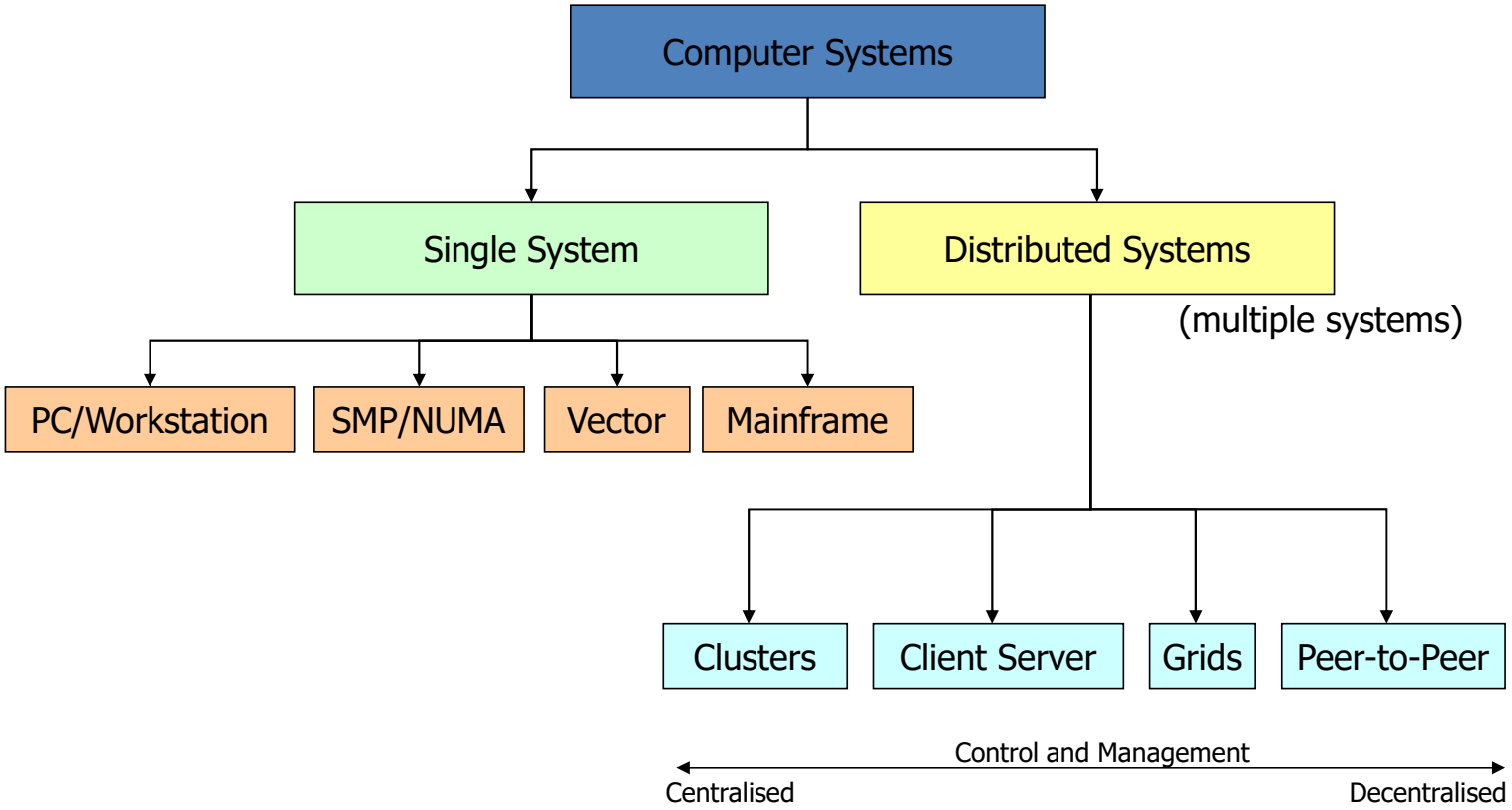
Administrative

- Lab – B414/B413 2h / week
  - Iasmina Gruicin, Marius Marcu
- Project – B414 1h / week
  - Marius Marcu

10. Assessment

Activity type	10.1 Assessment criteria	10.2 Assessment methods	10.3 Weight in final mark
10.4 Lecture	Digital microsystem design fundaments	Written exam	25%
	Digital microsystem design applications	Written exam	25%
10.5 Seminar /labs	Solving the topics proposed during the laboratory	Laboratory deliverables presentation and questions	25%
	Semester project development and presentation	Project deliverables presentation and questions	25%
10.6 Minimal performance standards (minimal specific knowledge required for passing the exam, the means to assess mastering the specific knowledge)			
• Overall microprocessor architecture and behavior; overall microprocessor system architecture and behavior • Memory decoding, I/O decoding • Connecting memory to CPU • Connecting I/O to CPU			

Summary


Computer Systems
Single System
Distributed Systems
(multiple systems)
PC/Workstation
SMP/NUMA
Vector
Mainframe
Clusters
Client Server
Grids
Peer-to-Peer
Control and Management
Centralised
Decentralised

Summary

- Memory organization
  - UMA
  - NUMA
  - NORMA

Summary

- Flynn taxonomy
  - SISD
    - Harvard architecture
    - Princeton architecture
  - SIMD
  - MISD
  - MIMD
    - GMSV
    - DMSV
    - GMMP
    - DMMP