Introduction

University of South Carolina

Introduction to Computer Architecture
Fall, 2024
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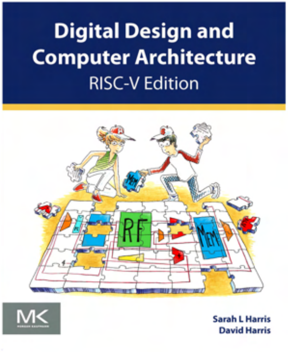
Molinaroli College of Engineering and Computing
UNIVERSITY OF SOUTH CAROLINA

Textbook



Digital Design and Computer Architecture (RISC-V Edition)
Sarah L Harris, David Harris

- Further Reading/Exercises:
  Computer Organization and Design RISC-V Edition: The Hardware Software Interface
  David A. Patterson, John L. Hennessy

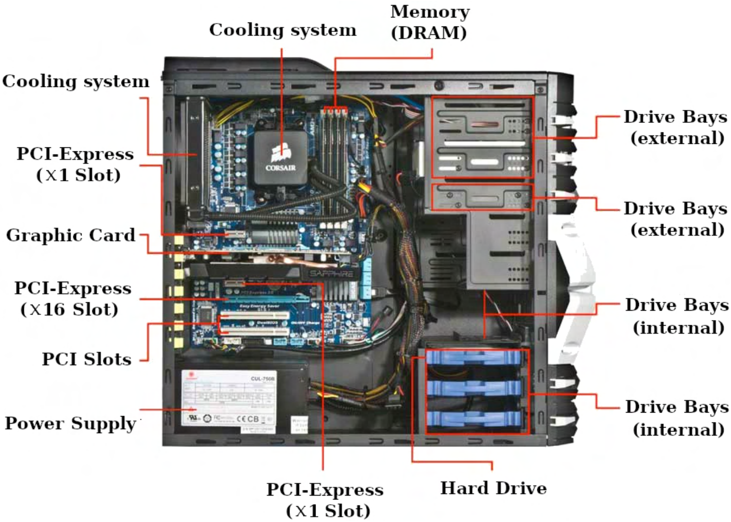
Assessment

- Grading:

Assessment Component	**Weight**
Assignments	Mandatory
Quiz 1 (Chapter 5 + Review)	30%
Quiz 2 (Chapter 6)	40%
Final (Chapter 7)	30%
Optional Projects	Extra Bonus

An everyday experience!

Inside the box

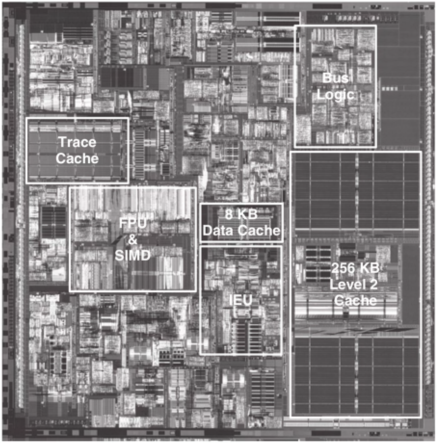


The main components

- Mainboard
- CPU
- Off-chip memory (DRAM)
- Storage devices
- I/O Cards

Central Processing Unit

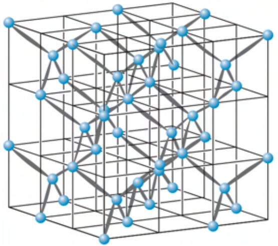
- Arithmetic and Logic Unit
- Control Logic
- Internal Memory
- Data path



Pentium 4 Die shot

From sand to CPU!

- Silicon is abundant in nature
- Primarily found as (SiO_2) in sand
- Silicon is a semiconductor



From sand to CPU!

- Silicon is a semiconductor
- Manufacturing process
    - Silicon ingot

From sand to CPU!

- Silicon is a semiconductor
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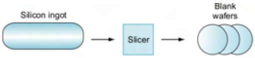
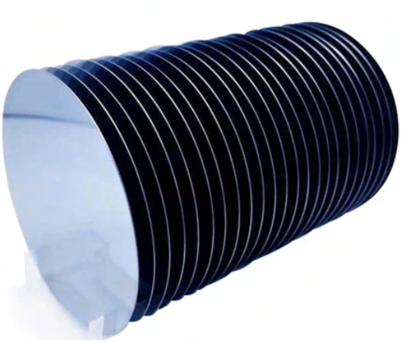
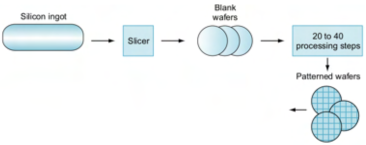
  - Sliced into wafers ($\leq$ 0.1 inches)

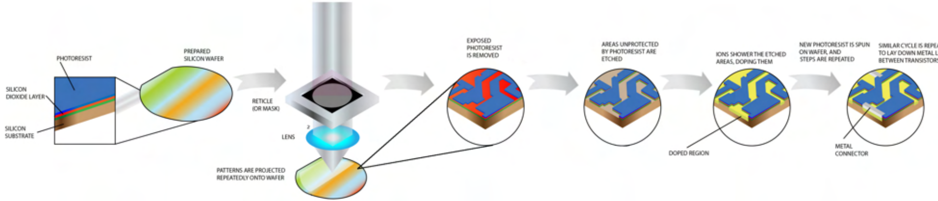




From sand to CPU!

- Silicon is a semiconductor
- Manufacturing process
  - Silicon ingot
  - Sliced into wafers ($\leq$ 0.1 inches)
  - Oxidation,Photolithography,...
  - Conductivity is altered selectively





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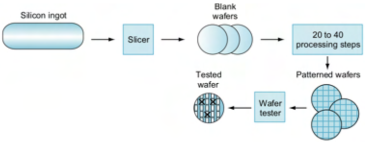

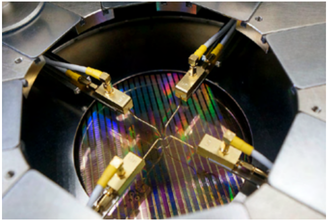

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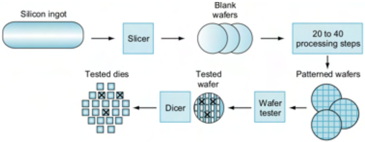
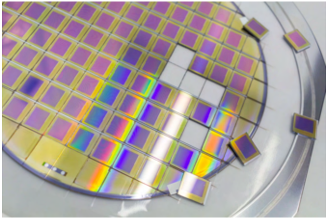
- Silicon is a semiconductor
- Manufacturing process
  - Silicon ingot
  - Sliced into wafers ($\leq$ 0.1 inches)
  - Oxidation,Photolithography,...
  - Conductivity is altered selectively
  - Testing
  - Dicing





From sand to CPU!

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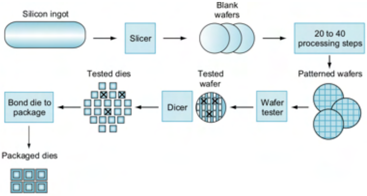
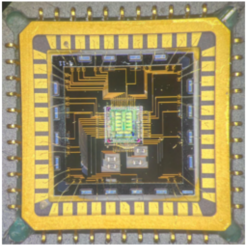
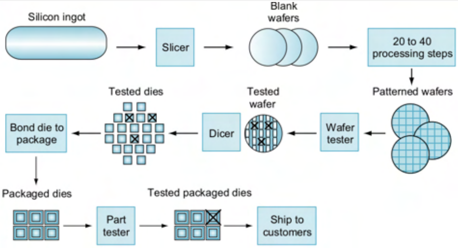
- Manufacturing process
    - Silicon ingot
    - Sliced into wafers ($\leq$ 0.1 inches)
    - Oxidation,Photolithography,...
    - Conductivity is altered selectively
    - Testing
    - Dicing
    - Packaging

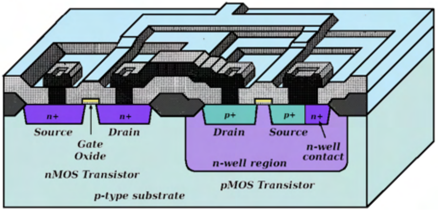




From sand to CPU!

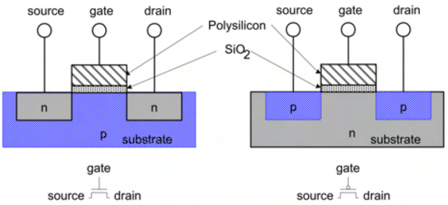
- Starts with Silicon ingot
- Silicon is a semiconductor
- Ingot sliced into wafers ($\leq$ 0.1 inches)
- Oxidation,Photolithography,Doping...
- Conductivity is altered selectively
- More complex CPUs higher density
- SSI,MSI,LSI form $\sim 1 - 10^4$ transistors
- VLSI form $\sim 10^4 - 10^6$ transistors
- ULSI more than millions
- Current feature size $\sim 9nm - 5nm$

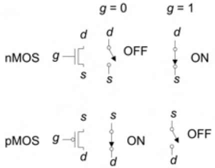




MOSFETs

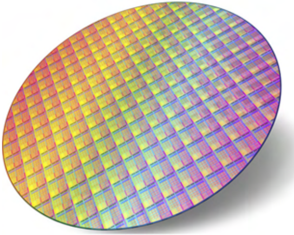
- MOSFETs are predominantly the building blocks of almost all digital systems
- Each MOSFET is a sandwich of a few semiconductor layers
- There are two types of MOS, pMOS and nMOS
- In digital circuits, a MOSFET behaves as a voltage-controlled switch
- The gate voltage needed to turn on the transistor is called threshold voltage
- The threshold voltage is typically about 0.3 to 0.7 V
- The size of transistors are a fraction of a micron nowadays





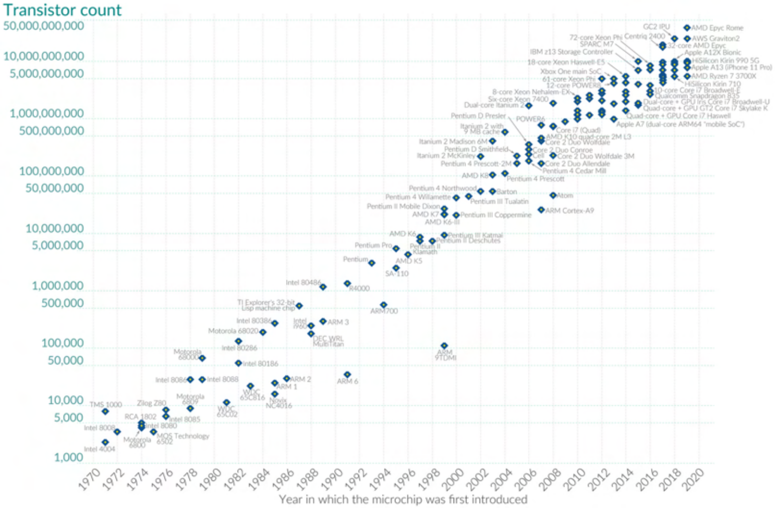
Moore's Trend

- More complex digital systems needs more transistors
- Increasing die size decreases yield, so it is costly!
- Smaller transistors are faster and more power-efficient
- Moore described in 1965 a long-term trend:
  "Transistor counts double every two years"
- The trend can't last forever
- It has already slowed down for couple of reasons



The Shrinking Business

- Technological advancements continually shrinks the size of transistors



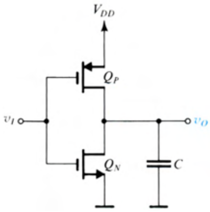
Performance

- Performance is a multi-facets measure
- Computer performance can be limited by
  - Memory
  - Hard Disk
  - Graphic system
  - Network connection
- Almost all CPUs are synchronous digital circuits
- Changes occur at clock transitions
- Clock rate is a main factor in CPU performance
- CPU performance

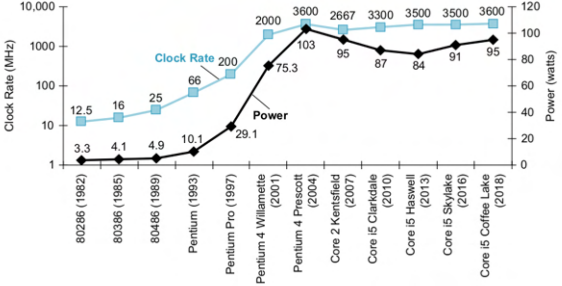
$$ExecutionTime = (\#Inst.) \times (CPI) \times \frac{1}{F_{clock}}$$

Power Wall

- Power is energy per unit time
- Power consumption limits the battery life
- Digital systems draws Dynamic and Static powers
- Dynamic power is drawn for charging capacitive loads
- Charging power of a capacitor $C\,V_{DD}^2$
- Power Consumption

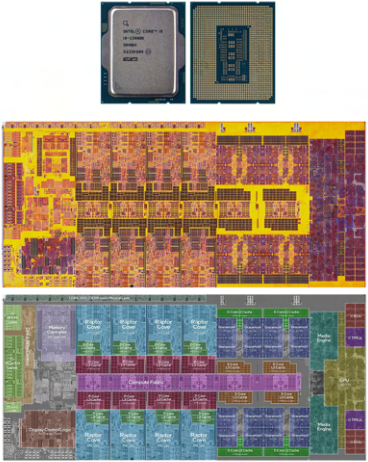


$$P_{dynamic} \propto \alpha\, C\, V_{DD}^2\, F_{clock}$$



Multi-Core Processors

- Power puts strict constraints on clock rate
- Power consumption limits the battery life
- Power is dissipated as heat
- Cooling chips can become costly
- Since 2006, the industry shifted toward multi-core processors

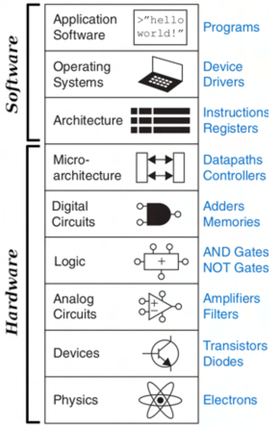


Multidimensional trade-off

- **Complexity:** A CPU is a highly intricate system involving millions of transistors, intricate circuits, and numerous subsystems.
- **Cost vs. Speed**: Faster designs usually come with higher costs due to advanced components and technologies.
- **Power vs. Speed**: High-speed processors often consume more power, impacting energy efficiency.
- **Complexity vs. Cost**: More complex designs enhances performance at the cost of increase development and manufacturing costs.
- **Complexity vs. Power**: Increased complexity can lead to higher power consumption and cooling requirements

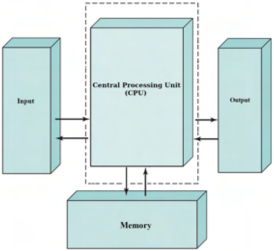
Abstraction to the rescue

- **Abstraction:** The art of hiding complexity by focusing on high-level concepts and simplifying interactions
- **Principles:**
  - **Modularity**: Breaking down systems into manageable, reusable modules
  - **Hierarchy**: Organizes components in a structured manner, from high-level to detailed
  - **Regularity**: Applies consistent design patterns to maintain order and predictability
  - **Discipline**: Restricting the design space in favor of simplification



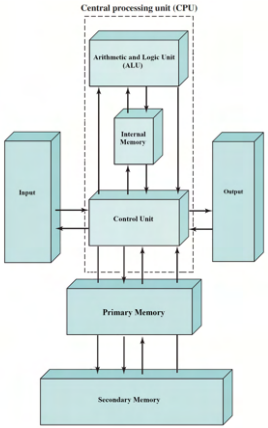
Abstracted View of a Computer System

- **Von Neumann's computer key components**
  - **Central Processing Unit**
  - **Memory**
  - **Input Devices**
  - **Output Devices**
  - **Data path**



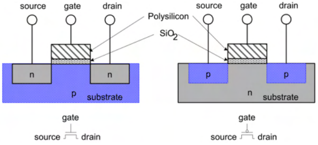
Abstracted View of a Computer System

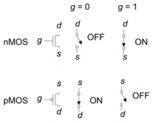
- **Von Neumann's computer Key Components**
  - **Central Processing Unit**
    - Arithmetic Logic Unit (ALU)
    - Internal Memory
    - Control Unit
    - Datapath
  - **Memory**
    - Primary Memory
    - Secondary Memory
  - **Input Devices**
  - **Output Devices**
  - **Data path**



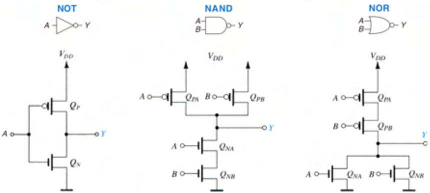
Digital Abstraction

- Modeling the transistors as switches is an example of abstraction

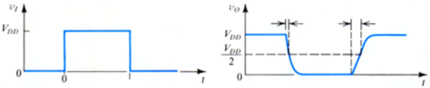




- Logic gates are an abstraction of transistor circuits



- Binary signals are an abstraction of continuous voltages

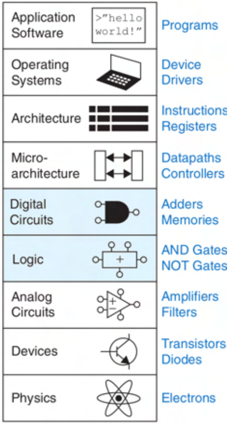


Course Objectives

- How a program written in a high-level language (like C) will be translated to the assembly language?
- How a program written in assembly language will be represented as binary codes in machine language?
- How the architecture and micro-architecture are related?
- How a CPU executes the machine codes?
- How the micro-architecture of a CPU affects its performance?

Road Map

- **Chapter 2,3 (Review)**
  - Reviewing the necessary digital design concepts
  - Combinational Circuits
  - Sequential Circuits
- **Chapter 5**
  - Reviewing the necessary digital design concepts
  - Introducing Arithmetic and Logical Components
  - Introducing Memory Components
- **Chapter 6**
  - Computer Architecture
  - Assembly Language Programming
- **Chapter 7**
  - Micro-Architecture
  - Performance Analysis
- **Miscellaneous Topics**
  - As much as time permits



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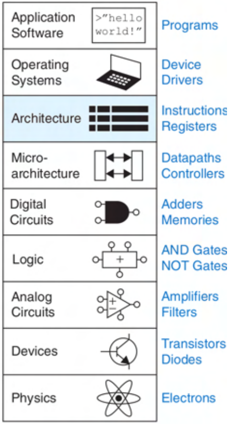

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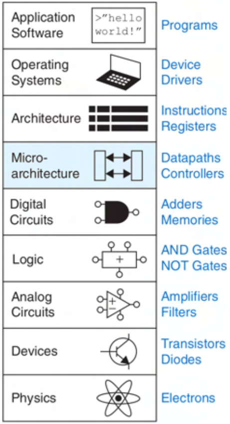

Contact info

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