
Digital Systems

Dae Hyun Kim

EECS

Washington State University

Central Processing Unit (CPU)

- CPU (Microprocessor)
 - General-purpose
 - Input: instructions, data
 - Output: the results of the instructions
 - Metrics
 - Performance
 - Power
 - Area (these three metrics are called “PPA”)
 - Cost

Chip



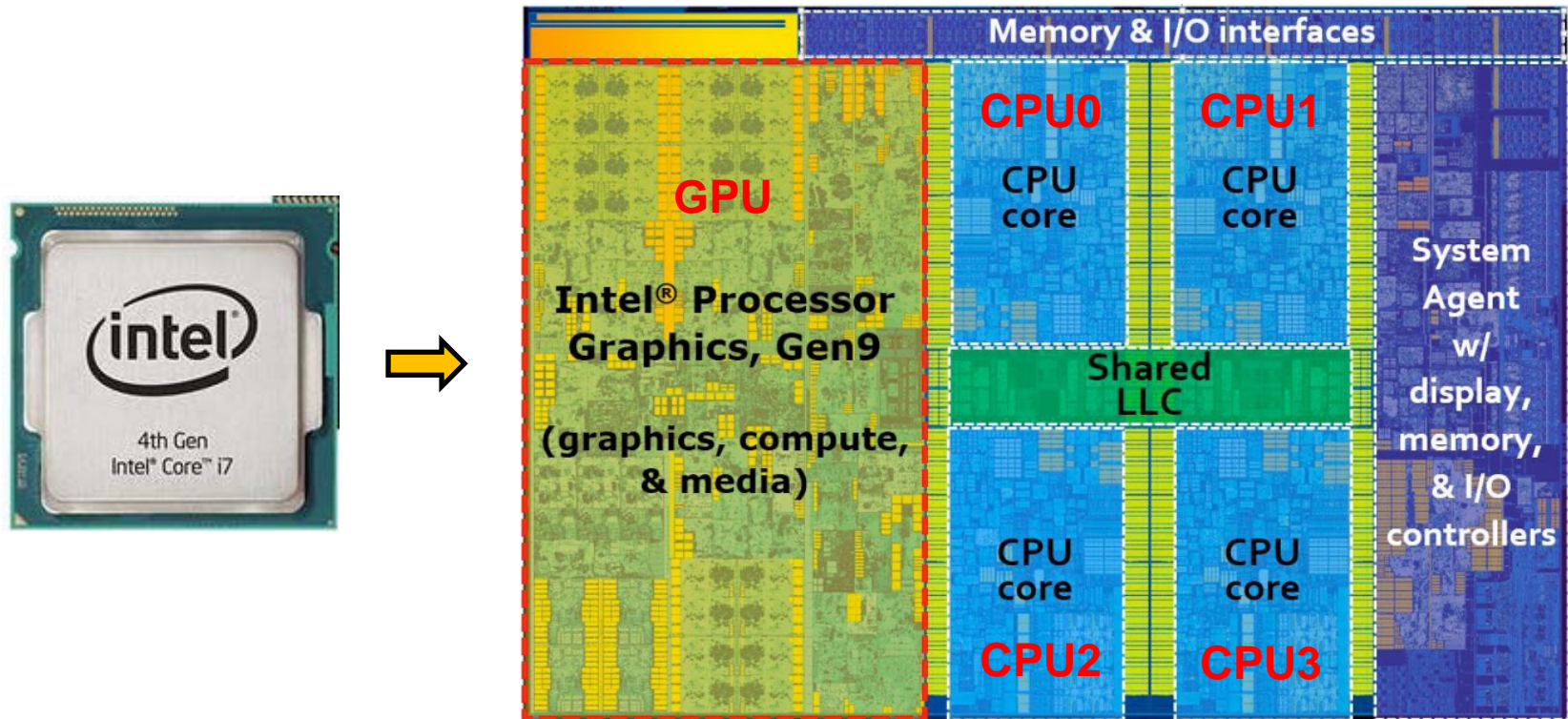
Intel i7



AMD Ryzen

Inside a CPU

- A CPU chip generally has multiple cores (CPU# shown below) and a GPU (graphics processing unit).

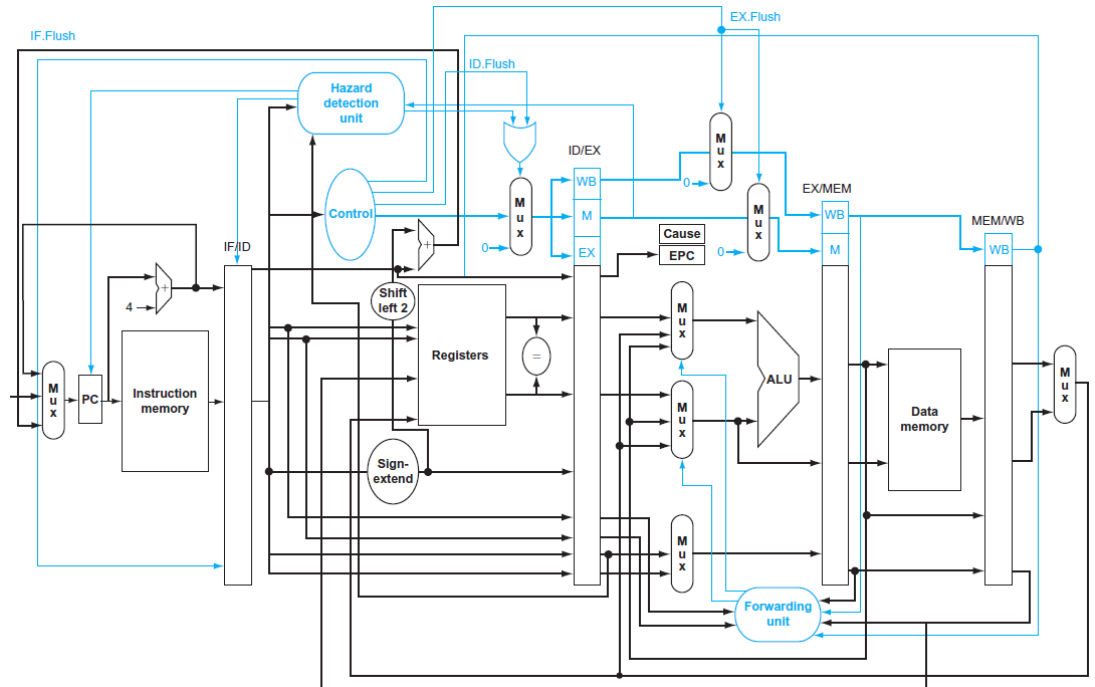
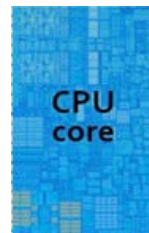


Computer (CPU) Architecture

- Logical view (block diagram)
 - EE334
 - Intel, AMD, Apple, Qualcomm, TI, ...

Chip

Computer architecture



Arithmetic Logic Architecture

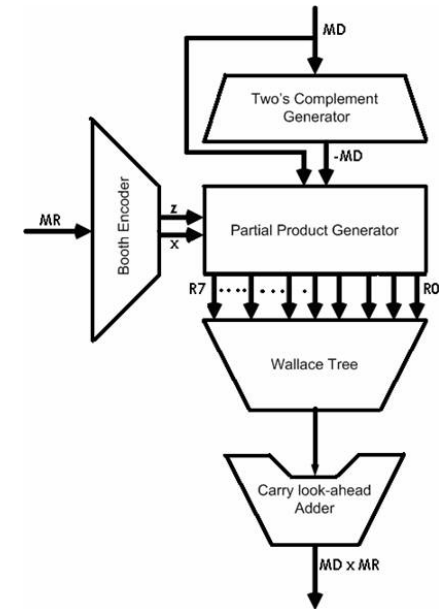
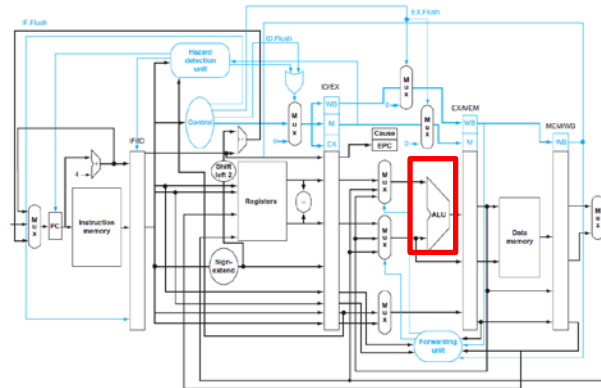
- Arithmetic logic

- Integer adder/multiplier/divider
- Floating-point adder/multiplier/divider
- Vector units, ...
- **EE466**
- (You have already studied how to design basic digital logic units in **EE214**)

Chip

Computer architecture

Digital design



Multiplier

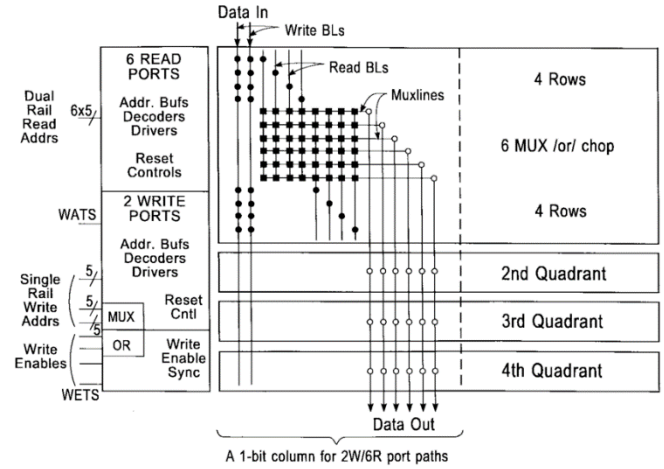
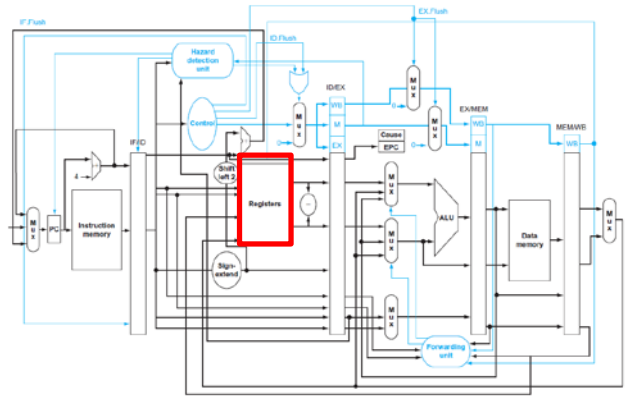
Static Memory Architecture

- Static memory
 - Used for register files, cache memory, ...
 - EE466

Chip

Computer architecture

Digital design

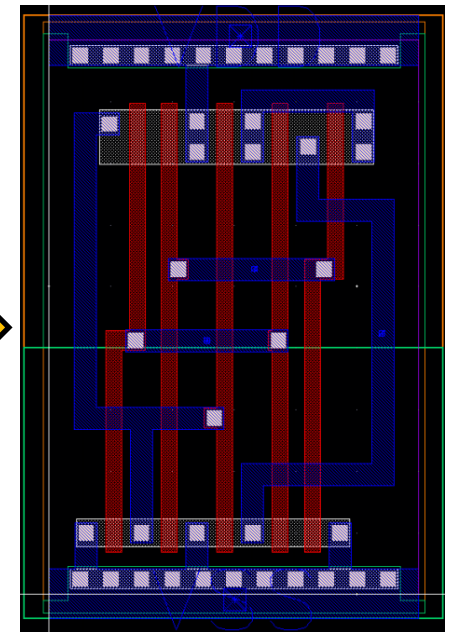
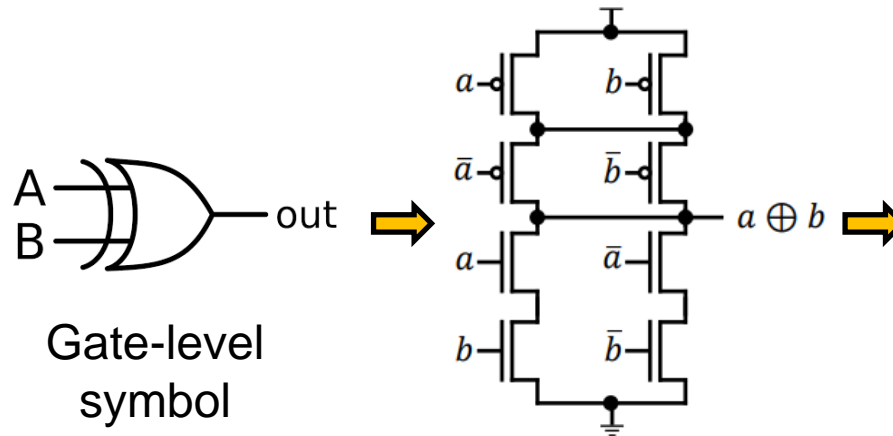
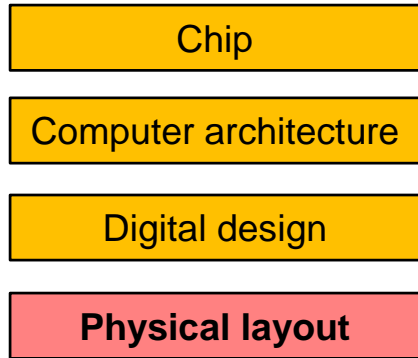


Register file

Physical Layout Design

- A physical layout has drawings of transistors (TRs) and interconnects.

- EE434



TR-Level Design, Layout, and Detailed Analysis

- Design of a gate using transistors
- Analysis of a gate
 - Timing
 - Power
 - Energy
 - Parasitic resistance and capacitance
- Design of a layout
- Analysis of a layout
 - Timing (static timing analysis)
 - Power (statistical, vector-based)
 - Power integrity
 - Signal integrity
 - Interconnects
- EE434, EE466

Chip

Computer architecture

Digital design

Physical layout

Transistors and Semiconductor

- Operation principles of a transistor
- Device physics
- EE496

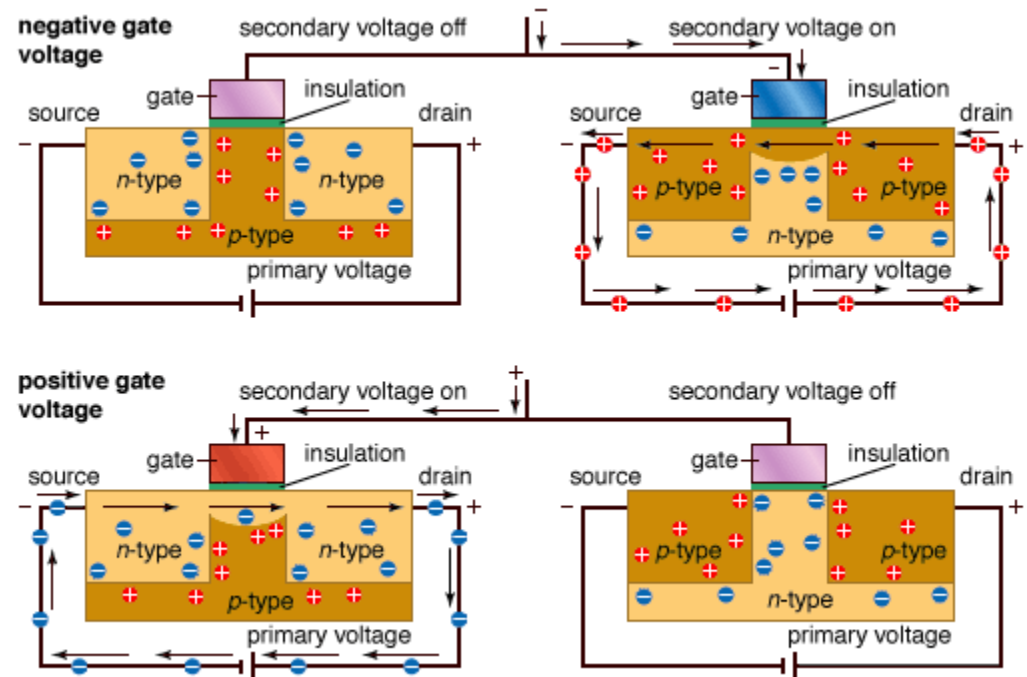
Chip

Computer architecture

Digital design

Physical layout

Device physics



© 2004 Encyclopædia Britannica, Inc.

Beyond Semiconductor

- Physics
 - Quantum mechanics
 - Solid-state physics
 - ...
- Mathematics
 - Linear algebra
 - Probability and statistics
 - Ordinary and partial differential equations
 - ...

Chip

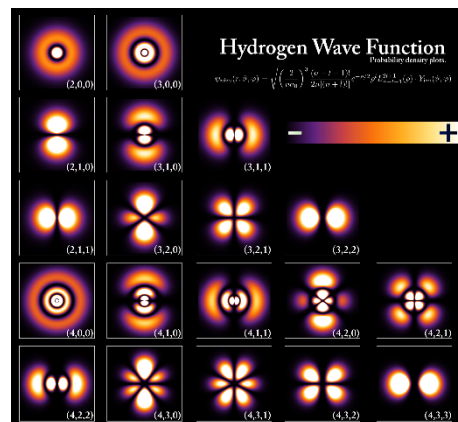
Computer architecture

Digital design

Physical layout

Device physics

Physics & Math



$$\hat{H} = \sum_{n=1}^N \frac{\hat{\mathbf{p}}_n \cdot \hat{\mathbf{p}}_n}{2m_n} + V(\mathbf{r}_1, \mathbf{r}_2, \dots, \mathbf{r}_N, t)$$
$$= -\frac{\hbar^2}{2} \sum_{n=1}^N \frac{1}{m_n} \nabla_n^2 + V(\mathbf{r}_1, \mathbf{r}_2, \dots, \mathbf{r}_N, t)$$

$$i\hbar \frac{\partial}{\partial t} \Psi = -\frac{\hbar^2}{2} \sum_{n=1}^N \frac{1}{m_n} \nabla_n^2 \Psi + V\Psi$$

Systems (Applications)

- Desktop, laptop, server, smartphone, ...



- Embedded system

- Any computer system with processors, memory, I/O, etc. (sensors, ...) for some dedicated functions.



Calculator

Digital camera

Line tracer

Unmanned vehicle

In-flight entertainment

Systems

○ Embedded system

- In general, an embedded system needs the following software
 - Operating system (Linux, ...)
 - CPTS 460 (Operating Systems and Computer Architecture)
 - Compiler (assembly, C/C++, ...)
 - CPTS 355 (Programming Language Design)
 - CPTS 452 (Compiler Design)
 - Applications
 - CPTS 122 (Data Structures), 223 (Advanced Data Structures)
 - CPTS 350 (Design and Analysis of Algorithms)
 - CPTS 360 (Systems Programming)
 - CPTS 411 (Parallel Programming)
 - CPTS 415 (Big Data), 427 (Computer Security), 434 (Neural Network), 437 (Machine Learning), 440 (Artificial Intelligence), 442 (Computer Graphics), 451 (DB Systems), 455 (Computer Networks), 464 (Distributed Systems), 466 (Embedded Systems)

Operating System

- Computer system management
 - Processes
 - Threads
 - CPU scheduling
 - Synchronization
 - Main memory
 - Virtual memory
 - Storage (HDD, SSD, ...), file system
 - I/O (USB, speaker, keyboard, mouse, printer, ...)
 - Network
 - Security
 - ...

Operating system

Chip

Computer architecture

Digital design

Physical layout

Device physics

Physics & Math

Compiler

- From a source code to an executable (or a library, etc.)
 - Lexical analysis
 - “a =b +c * 60”: a is <identifier, 1>, = is a symbol, ...
 - Syntax analysis
 - $a = (b + (c * (60)))$
 - Semantic analysis
 - If a, b, c are floating-point, 60 becomes 60.0.
 - Intermediate code generation
 - Machine-independent code
 - Machine-independent code optimization
 - For runtime reduction, code size minimization, ...
 - Machine-dependent code generation
 - Assembly code
 - Machine-dependent code optimization
 - Symbol tables
 - ...

Compiler

Operating system

Chip

Computer architecture

Digital design

Physical layout

Device physics

Physics & Math

Application

Application

Compiler

Operating system

Chip

Computer architecture

Digital design

Physical layout

Device physics

Physics & Math

○ Study

- Programming languages (C/C++, Java, Swift, Kotlin, ...)
- Data structures and algorithms
- Low-level features (device drivers, memory management, ...)
- OS-dependent features (DirectX for Windows, Metal for MacOS, ...)
- Cross-platform libraries (OpenGL, ...)
- Database (SQL, ...)
- Network
- Security
- Artificial intelligence, machine learning
- ...

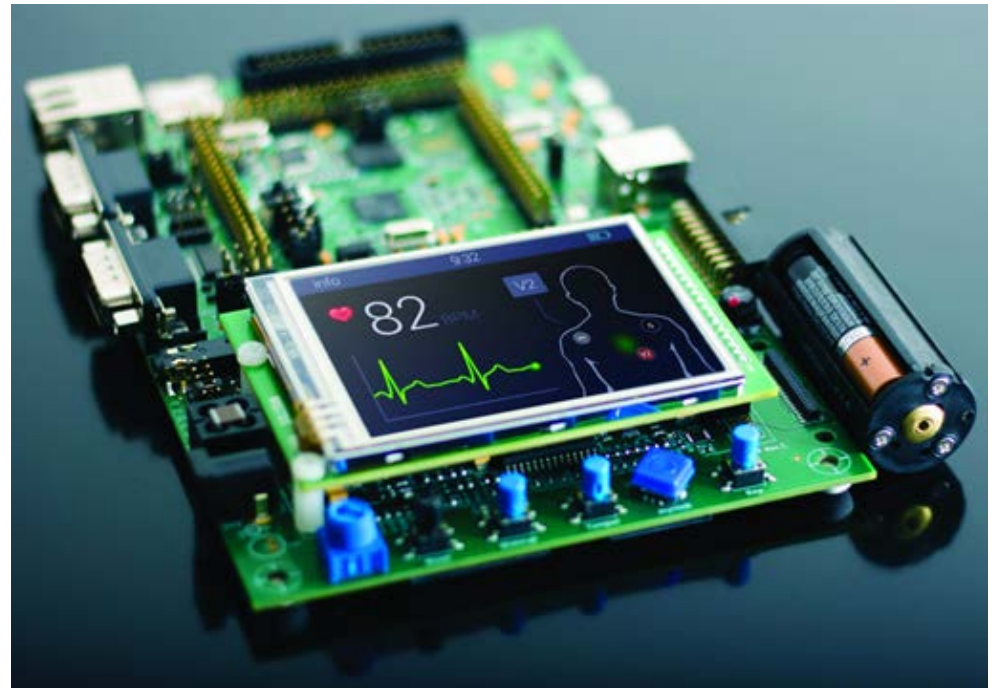
Embedded Systems

○ Hardware

- PCB
- Analog parts (ADC, DAC, sensors, power management ICs, wireless, ...)
- Digital parts (CPU, memory, LCD, digital I/O, ...)
- ...

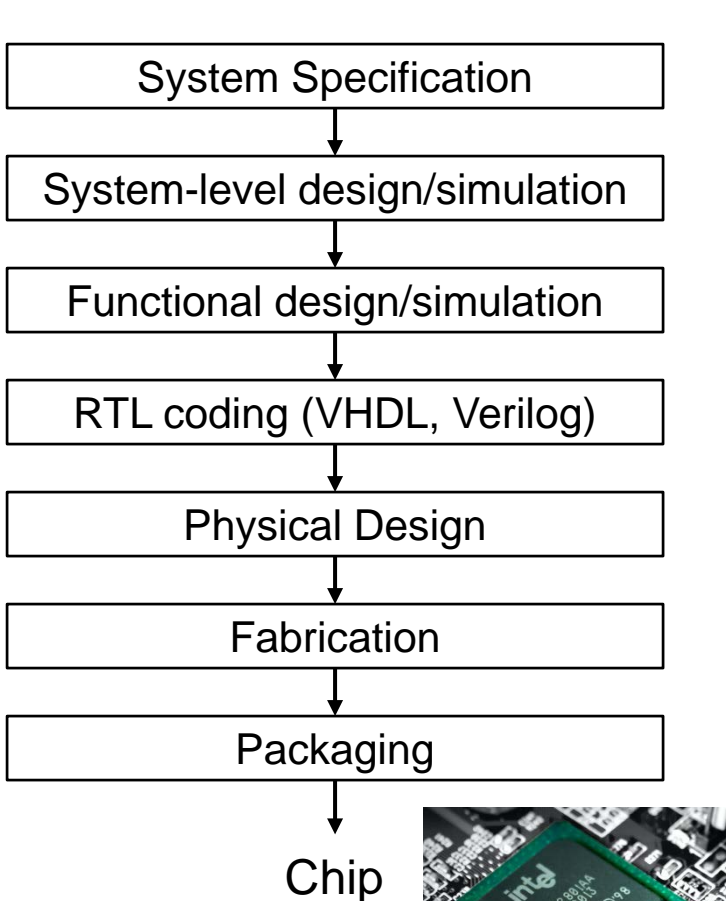
○ Software

- OS
- (Compiler)
- Applications
- ...



VLSI/ASIC Design

- VLSI: Very-Large-Scale Integration
- ASIC: Application-Specific Integrated Circuit



Freq Area Power
64-bit microprocessor / 3GHz / 100mm² / 40W

(C/C++) Pipelining, CPU-DRAM, ...

(C/C++/HDL) ALU, FPU, BPred, ...

module imul64 (a, b, clk, out);

Layout 

Bare die 

