Computer Architecture

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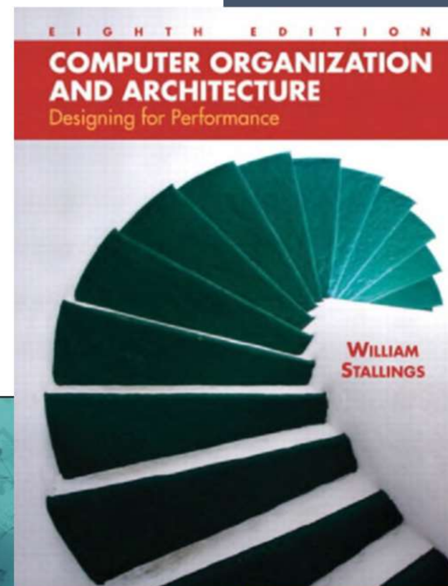
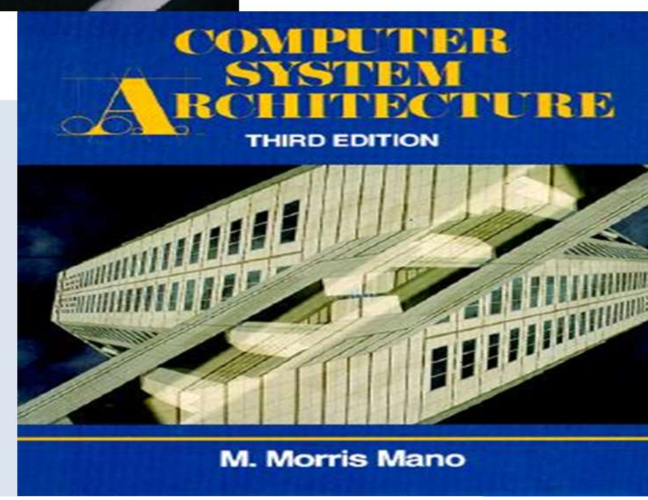
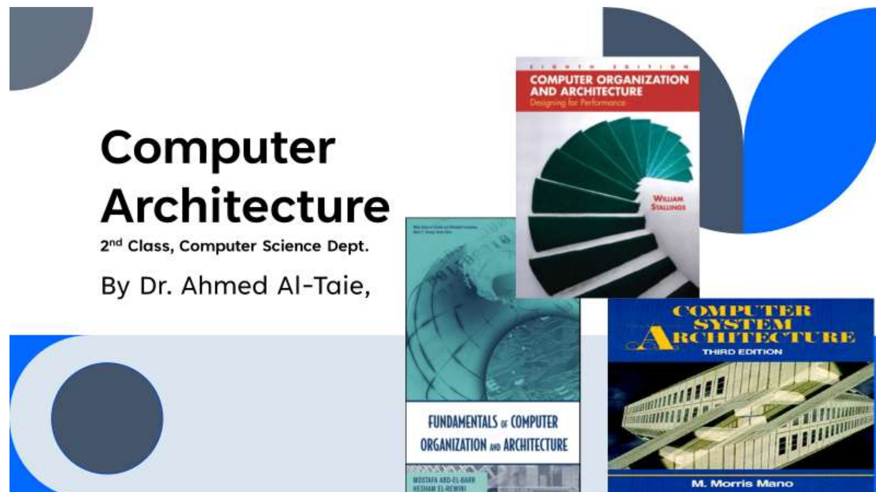




Chapter 1
Introduction to Computer Systems
Outline

- Historical Background
- Architectural Development and Styles
- Technological Development
- Performance Measures



Introduction to Computer Systems

The technological advances

witnessed in the computer industry are the result of a long chain of immense and successful efforts made by two major forces.

These are the ***academia***, represented by university research centers, and the ***industry,*** represented by computer companies.

The objective

of such historical review is to understand the **factors affecting computing** as we know it today and **hopefully to forecast the future of computation**.

A great majority of the computers of our daily use are known as ***general purpose machines***.

These are

machines that are built with no specific application in mind, but rather are capable of performing computation needed by a diversity of applications.

These machines are to be **distinguished** from those built to serve specific applications.

The latter are known as **special purpose machines.**

Introduction to Computer Systems

Computer systems

have conventionally been defined through their interfaces at a number of **layered abstraction levels**, each providing **functional support** to its predecessor.

Included

among the levels are the **application programs**, the **high-level languages**, and the **set of machine instructions**.

Based on the interface between

different levels of the system, **a number of computer architectures** can be defined.

The interface between

the **application programs** and a **high-level language** is

referred to as a ***language architecture***.

The ***instruction set architecture*** defines the interface between the basic machine instruction set and the runtime and I/O control.

Introduction to Computer Systems

A different definition of ***computer architecture*** is built on four basic viewpoints.

These are ***the structure***, ***the organization***, ***the implementation***, and ***the performance.***

In this definition,

the ***structure*** defines the interconnection of various hardware components,

the ***organization*** defines the dynamic interplay and management of the various components,

the ***implementation*** defines the detailed design of hardware components, and the **performance specifies** the behavior of the computer system.

Historical Background

We should emphasize at

- the outset that **the effort to build computers** has **not originated at one single place**.
- We also firmly believe that **building a computer requires teamwork**.

Historical Background

- It is probably fair to say that the **first program-controlled (mechanical) computer** ever build was the **Z1 (1938).**
- This was followed in **1939** by the **Z2** as **the first operational** program-controlled computer **with fixed-point arithmetic.**

However,

- the **first recorded university-based attempt** to build a computer originated on **Iowa State University campus** in the **early 1940s.**
- Researchers on that campus were able to build **a small-scale special-purpose electronic computer.** However, that computer was **never completely operational**.

Historical Background

Just about the same time

- a **complete design** of a fully functional programmable special-purpose machine, the **Z3**, was reported in **Germany in 1941**.
- It appears that the **lack of funding prevented** such design from **being implemented.**

General-purpose machines

- the University of Pennsylvania is recorded to have hosted the building of the **Electronic Numerical Integrator and Calculator (ENIAC)** machine in **1944**.
- It was the **first operational general-purpose machine built** using **vacuum tubes**.
- The machine was primarily built to help **compute** artillery firing tables during **World War II**.

The improved version

- of the **ENIAC**, called the **Electronic Discrete Variable Automatic Computer (EDVAC),** was an attempt to improve the way programs are entered and explore the concept of stored programs.
- Inspired by the **ENIAC's** ideas, researchers at the Institute for Advanced Study (IAS) at Princeton built (**in 1946**) the **IAS machine**, which was about **10 times faster** than the **ENIAC**.

Historical Background

In 1946 and while the EDVAC

- project was in progress, a similar project was initiated at **Cambridge University**.
- The project was to build a stored-program computer, known as the **Electronic Delay Storage Automatic Calculator (EDSAC)**.
- It was in **1949** that the **EDSAC** became the **world's first full-scale, stored-program**, fully operational computer.

A spin-off of the EDSAC

- resulted in a series of machines introduced at **Harvard**. The series consisted of **MARK I, II, III, and IV**.
- The **latter two machines** introduced the concept of **separate memories for instructions and data**.
- The term **Harvard Architecture** was given to such machines to indicate the use of **separate memories** and it is used today to describe machines with **separate cache memories.**

The first general-purpose

- commercial computer, the **UNIVersal Automatic Computer (UNIVAC I),** was on the market by the middle of 1951.
- It represented an improvement over the **BINAC**, which was built in **1949**.
- **IBM** announced its first computer, the **IBM701**, in **1952**.
- The early **1950s** witnessed a **slowdown** in the computer industry.
- In **1964 IBM** announced a line of products under the name **IBM 360 series**.

Historical Background

This led Digital Equipment Corporation (DEC)

- to introduce the **first minicomputer, the PDP-8**. It was considered a remarkably low-cost machine.
- **Intel** introduced the **first microprocessor**, the **Intel 4004**, in **1971**.
- The world witnessed the **birth** of the **first personal computer (PC) in 1977** when **Apple computer series** were first introduced.

In 1977 the world also witnessed

- the introduction of the **VAX-11/780 by DEC**.
- **Intel** followed suit by introducing the first of the **most popular microprocessor**, the **80 86 series**.
- Personal computers, which were introduced in **1977** by **Altair, Processor Technology, North Star, Tandy, Commodore, Apple**, and many others, **enhanced the productivity** of end-users in numerous departments.

Personal computers from

- **Compaq, Apple, IBM, Dell, and many others**, soon became pervasive, and changed the face of computing.
- In parallel with small-scale machines, **supercomputers** were coming into play.
- The **first such supercomputer**, the **CDC 6600**, was introduced in **1961** by **Control Data Corporation**.
- **Cray Research Corporation** introduced the **best cost/performance supercomputer,** the **Cray-1, in 1976**.

Historical Background

The 1980s and 1990s witnessed the introduction

- of many **commercial parallel computers** with **multiple processors.**
- They can generally be classified into two main categories: (1) shared memory and (2) distributed memory systems.
- The **number of processors** in a **single** machine ranged from several in a shared memory computer to hundreds of thousands in a massively parallel system.

Examples of parallel computers during

- this era include **Sequent Symmetry, Intel iPSC, nCUBE, Intel Paragon, Thinking Machines (CM-2, CM-5), MsPar MP), Fujitsu (VPP500),** and others.
- One of the clear trends in computing is the **substitution of centralized servers** by **networks of computers**.
- These **networks connect inexpensive, powerful desktop machines** to form unequaled computing power.

Local area networks (LAN)

- of **powerful personal computers** and **workstations** began to **replace mainframes and minis** by 1990.
- These individual desktop computers were soon to be connected into larger complexes of computing by **wide area networks (WAN).**

Summary of Historical Background

- The pervasiveness of the Internet created interest in network computing and more recently in grid computing. Grids are geographically distributed platforms of computation.
- They should provide dependable, consistent, and inexpensive access to high-end computational facilities.
- In Table 1.1, major characteristics of the different computing paradigms are associated with each decade of computing, starting from 1960.

TABLE 1.1 Four Decades of Computing

Feature	Batch	Time-sharing	Desktop	Network
Decade	1960s	1970s	1980s	1990s
Location	Computer room	Terminal room	Desktop	Mobile
Users	Experts	Specialists	Individuals	Groups
Data	Alphanumeric	Text, numbers	Fonts, graphs	Multimedia
Objective	Calculate	Access	Present	Communicate
Interface	Punched card	Keyboard & CRT	See & point	Ask & tell
Operation	Process	Edit	Layout	Orchestrate
Connectivity	None	Peripheral cable	LAN	Internet
Owners	Corporate computer centers	Divisional IS shops	Departmental **end User**	Everyone

ARCHITECTURAL DEVELOPMENT AND STYLES

- Increasing the performance of the architectures, has taken a number of forms.
- Among these is the philosophy that by doing more in a single instruction, **one can use a smaller number of instructions** to perform the same job.
- The immediate consequence of this is the need for fewer memory read/write operations and an eventual **speedup** of operations.
- It was also argued that **increasing the complexity of instructions and the number of addressing modes** has the theoretical advantage of **reducing the "semantic gap" between the instructions** in a **high-level** language and those in the **low-level** (machine) language.
- A **single (machine) instruction** to **convert several** binary coded decimal **(BCD)** numbers to binary is an **example** for **how complex some instructions** were intended to be.

ARCHITECTURAL DEVELOPMENT AND STYLES

- The huge number of **addressing modes** considered (more than **20** in the **VAX** machine) further adds to the **complexity** of instructions.
- Machines following **this philosophy** have been referred to as **complex instructions set computers (CISCs)**.
- **Examples** of **CISC** machines **include** the **Intel Pentium™, the Motorola MC68000™, and the IBM & Macintosh PowerPC™**.
- It should be noted that **as more capabilities were added to their processors**, manufacturers realized that it was increasingly **difficult to support higher clock rates** that would have been possible otherwise.
- This is because of the **increased complexity** of computations within **a single clock period**.

ARCHITECTURAL DEVELOPMENT AND STYLES

- A number of studies (from the mid-1970s and early-1980s) also identified that in **typical programs** more than **80%** of the instructions executed are those using **assignment statements, conditional branching** and **procedure calls.**
- It was also surprising to find out that simple **assignment statements** constitute almost **50%** of those operations. These findings caused a **different philosophy to emerge**.
- This philosophy promotes the **optimization** of **architectures** by **speeding up those operations** that are **most frequently used** while **reducing** the **instruction complexities** and the **number** of **addressing modes**.
- Machines **following this philosophy** have been referred to as **reduced instructions set computers (RISCs)**.
- Examples of RISCs include the **Sun SPARC™** and **MIPS™** machines.

TECHNOLOGICAL DEVELOPMENT

- **Computer technology** has shown an **unprecedented** rate of **improvement**.
- This **includes** the **development** of **processors** and **memories**.
- The **integration of numbers of transistors** (a transistor is a controlled on/off switch) into **a single chip** has **increased** from a **few hundred** to **millions**.
- This impressive increase has been **made possible** by the **advances** in the **fabrication technology of transistors**.

TECHNOLOGICAL DEVELOPMENT

- The **scale of integration** has **grown** from **small-scale (SSI)** to **medium-scale (MSI)** to **large-scale (LSI)** to very **large-scale integration (VLSI)**, and currently to **wafer scale integration (WSI)**.
- Table 1.2 shows the typical numbers of devices per chip in each of these technologies.

TABLE 1.2 Numbers of Devices per Chip

Integration	Technology	Typical number of devices	Typical functions
SSI	Bipolar	10–20	Gates and flip-flops
MSI	Bipolar & MOS	50–100	Adders & counters
LSI	Bipolar & MOS	100–10,000	ROM & RAM
VLSI	CMOS (mostly)	10,000–5,000,000	Processors
WSI	CMOS	>5,000,000	DSP & special purposes

SSI, small-scale integration; MSI, medium-scale integration; LSI, large-scale integration; VLSI, very large-scale integration; WSI, wafer-scale integration.

TECHNOLOGICAL DEVELOPMENT

- The **continuous decrease** in the minimum devices **feature size** has led to a **continuous increase** in the **number of devices per chip**, which **in turn** has led to **a number of developments**.
- **Among these** is the **increase in the number of devices** in **RAM memories**, which in turn **helps designers** to **trade off memory size** for **speed**.
- The **improvement** in the **feature size** provides **golden opportunities** for **introducing improved design styles**.