Structured computer organization

by Andrew Tanenbaum · Language: EN

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Overview

Structured Computer Organization" by Andrew S. Tanenbaum is a foundational textbook that introduces the fundamental principles of computer architecture and organization through a layered, hierarchical approach. The book systematically dissects a computer system into distinct levels of abstraction, starting from the lowest level of digital logic gates and progressing upwards through microarchitecture, instruction set architecture (ISA), operating system machine, and assembly language levels. This structured perspective helps readers understand how complex computer systems are built from simpler components and how each layer interacts with and builds upon the one below it.

Tanenbaum's work emphasizes the importance of understanding the hardware-software interface and the various transformations that occur as a program executes. It explains concepts such as data representation, CPU design, memory hierarchies, input/output mechanisms, and the role of operating systems in managing resources. The book is renowned for its clarity, comprehensive coverage, and pedagogical effectiveness, making complex topics accessible to students. It often uses a hypothetical machine (like the "Mic-1") to illustrate concepts, providing concrete examples without being tied to a single, quickly obsolete commercial processor.

The book matters significantly because it provides a robust conceptual framework for understanding how computers work from the ground up. It equips students with the knowledge necessary to design, analyze, and program computer systems effectively, fostering a deep appreciation for the intricate interplay between hardware and software. Its enduring relevance lies in its focus on fundamental principles that transcend specific technological advancements, making it a cornerstone text for computer science and computer engineering curricula worldwide.

Key Takeaways

- Computer systems are best understood as a hierarchy of distinct, interacting levels of abstraction, from digital logic to high-level programming.
- Understanding the instruction set architecture (ISA) is crucial for bridging the gap between hardware capabilities and software execution.
- Microarchitecture implements the ISA, demonstrating how complex instructions are broken down into simpler micro-operations.

• Operating systems provide an essential layer of abstraction, managing hardware resources and presenting a more user-friendly virtual machine to applications.

• Performance optimization often involves understanding trade-offs across different levels of the computer organization hierarchy.

• The fundamental principles of digital logic and data representation underpin all higher-level computer operations.

• Effective system design requires a holistic view of how hardware and software components interact and influence each other's behavior.

Chapter Summaries

Chapter 1: Introduction

This chapter introduces the fundamental concept of a computer system as a hierarchy of levels, each built upon the one below it. It discusses the historical evolution of computers, from early mechanical devices to modern electronic machines, highlighting key figures like Babbage and Von Neumann. The chapter establishes the Von Neumann architecture as a foundational model, detailing its components: CPU, memory, and I/O. It also provides an overview of the different layers of abstraction that will be explored throughout the book, such as the digital logic level, microarchitecture level, and instruction set architecture level, setting the stage for a structured understanding of computer organization.

Chapter 2: The Digital Logic Level

This chapter delves into the lowest hardware level, explaining how computers are built from basic electronic components. It begins with Boolean algebra and logic gates (AND, OR, NOT, XOR, NAND, NOR), showing how these form the building blocks of digital circuits. Combinational circuits like adders, multiplexers, decoders, and shifters are discussed, illustrating how they perform operations without memory. The chapter then introduces sequential circuits, including flip-flops (SR, D, JK, T), registers, and counters, which incorporate memory and state. Finally, it covers the organization of memory, distinguishing between RAM (SRAM, DRAM) and ROM, and explaining how these components store and retrieve data.

Chapter 3: The Microarchitecture Level

This chapter explores the microarchitecture level, which implements the instruction set architecture using microprograms. It introduces the concept of a data path, comprising registers, ALUs, and internal buses, which are controlled by microinstructions. The control store, a special memory holding these microprograms, is detailed, explaining how microinstructions fetch, decode, and execute machine instructions. The chapter often presents a concrete example, such as the Mic-1 or a similar simplified CPU, to illustrate how a complex instruction like ADD or MOV is broken down into a sequence of simpler micro-operations, demonstrating the execution cycle and the role of the microprogrammer.

Chapter 4: The Instruction Set Architecture Level

This chapter focuses on the Instruction Set Architecture (ISA), which defines the interface between software and hardware. It covers the design principles of instruction sets, including instruction formats (e.g., fixed vs. variable length), addressing modes (e.g., immediate, direct, indirect, register, indexed), and the types of instructions (data movement, arithmetic/logic, control flow like branches and jumps). The chapter often uses a generic or simplified ISA to demonstrate how machine language programs are structured and executed. It also discusses the differences between CISC (Complex Instruction Set Computer) and RISC (Reduced Instruction Set Computer) architectures, highlighting their respective advantages and disadvantages in terms of performance and complexity.

Chapter 5: The Operating System Machine Level

This chapter examines the layer provided by the operating system, which manages hardware resources and provides a more convenient interface for application programs. Key topics include memory management techniques such as virtual memory, paging, and segmentation, explaining how the OS translates virtual addresses to physical addresses and protects processes from each other. It also covers input/output (I/O) programming, discussing different I/O methods like programmed I/O, interrupt-driven I/O, and Direct Memory Access (DMA). The chapter elaborates on interrupts and traps, their handling, and their role in enabling the OS to respond to events and enforce system policies, thus creating a virtual machine for each process.

Chapter 6: The Assembly Language Level

This chapter bridges the gap between the ISA level and high-level programming by focusing on assembly language. It explains how assembly language instructions directly correspond to machine instructions, providing a symbolic representation that is more human-readable than raw binary. Topics include the structure of assembly programs, the use of registers, data types, and control flow constructs (loops, conditionals) implemented with jumps. The chapter also covers the role of assemblers, linkers, and loaders in translating assembly code into executable programs, and how system calls are made from assembly to interact with the operating system, demonstrating practical low-level programming concepts.

Chapter 7: Parallel Computer Architectures

This chapter introduces the concepts of parallel computing, addressing the limitations of single-processor performance. It begins with Flynn's taxonomy (SISD, SIMD, MISD, MIMD) to classify different parallel architectures. The chapter then delves into multiprocessor systems, discussing shared-memory architectures, cache coherence problems, and solutions like snooping and directory-based protocols. It also covers multicomputer systems, which use message passing for communication, and explores various interconnection networks (e.g., meshes, hypercubes). The goal is to explain how multiple processors can work together to solve problems faster, detailing the hardware and software challenges involved in designing and

programming parallel systems.

Themes

- Layered Abstraction
- Hardware-Software Interface
- Digital Logic
- System Architecture
- Performance Optimization
- Virtual Machines

Frequently Asked Questions

What is Structured computer organization about?

This book provides a comprehensive introduction to computer architecture and organization, explaining how computer systems are structured into a hierarchy of distinct levels, from digital logic gates to operating systems and assembly language. It details the interplay between hardware and software, offering a fundamental understanding of how computers function.

Is Structured computer organization worth reading?

Yes, it is highly recommended for anyone studying computer science or engineering. It offers a foundational understanding of how computers work, presented with exceptional clarity and a structured approach that remains relevant despite technological advancements. It's a classic text for a reason.

How does Structured computer organization end?

Spoiler: The book typically concludes with discussions on advanced topics like parallel computer architectures, including pipelining, superscalar processors, and multiprocessors. It demonstrates how the fundamental layered principles extend to complex modern systems, reinforcing the scalability and evolution of computer design.

Who should read Structured computer organization?

It is primarily intended for undergraduate students in computer science, computer engineering, and electrical engineering. Professionals seeking to deepen their understanding of computer fundamentals, system architects, and software developers interested in low-level system interactions would also find it highly valuable.

How long does it take to read Structured computer organization?

Given its depth and typical length (around 800-1000 pages), reading it thoroughly could take approximately 2000 minutes (about 33-34 hours) for a focused reader, or longer if engaging with exercises and supplementary materials for full comprehension.

Questions & Answers

What is the central organizing principle Tanenbaum uses to describe computer systems?

Tanenbaum's central organizing principle is the concept of hierarchical levels of abstraction, often referred to as 'virtual machines.' He describes a computer system as a series of layers, each built upon the one below it. Each level provides a more abstract interface, hiding the complexities of the lower levels, making the system easier to understand, design, and program. This layered approach is fundamental to understanding modern computer architecture.

What are the main levels of a computer system discussed in the book?

The book typically describes several levels: the Digital Logic Level (gates, flip-flops), the Microarchitecture Level (microprogram, datapath), the Instruction Set Architecture (ISA) Level (machine language instructions), the Operating System Machine Level (system calls, virtual memory), and sometimes the Assembly Language Level. Each level represents a different abstraction, from the physical hardware up to the software interface seen by application programmers.

How does Tanenbaum differentiate between computer architecture and computer organization?

While often used interchangeably, Tanenbaum implicitly or explicitly distinguishes them. Computer architecture refers to the attributes of a system visible to a programmer, such as the instruction set, number of registers, and memory addressing techniques. Computer organization, which is the focus of the book, deals with how these architectural attributes are implemented, including the control signals, memory technology, and physical interconnections. It's the 'how' versus the 'what'.

What is the significance of the Instruction Set Architecture (ISA) level?

The ISA level is crucial because it defines the interface between hardware and software. It specifies the set of instructions a processor can execute, the data types it can handle, the registers available, and the memory addressing modes. This level acts as a contract: any program written in the ISA will run on any machine that implements that ISA, regardless of its underlying microarchitecture, ensuring software compatibility and portability.

Explain the concept of microprogramming as presented in the book.

Microprogramming is a technique for implementing the control unit of a CPU. Instead of hardwiring the control logic, a microprogrammed control unit uses a small, fast memory (control

store) to hold a sequence of microinstructions. Each machine language instruction is executed by fetching and executing a sequence of these microinstructions. This approach offers flexibility, allowing for easier design changes, bug fixes, and even emulation of different ISAs.

What role does the datapath play in a CPU, according to Tanenbaum?

The datapath is the part of the CPU that performs data processing operations. It consists of functional units like the Arithmetic Logic Unit (ALU), registers, and internal buses that connect them. The datapath is responsible for fetching instructions, decoding them, fetching operands, executing operations, and storing results. Its design directly impacts the CPU's performance and the types of operations it can efficiently execute.

How does the book explain the memory hierarchy?

The book explains the memory hierarchy as a multi-level structure designed to balance speed, cost, and capacity. It typically includes fast, small, and expensive cache memory at the top, followed by slower, larger, and cheaper main memory, and finally, even slower, larger, and cheaper secondary storage (like hard drives). The goal is to make the system appear to have the speed of the fastest memory and the capacity of the slowest.

What are the primary methods for handling I/O operations discussed?

The book covers several methods for handling I/O. Programmed I/O involves the CPU constantly polling the I/O device to check its status or transfer data, which is inefficient. Interrupt-driven I/O allows the device to signal the CPU when it needs attention, freeing the CPU for other tasks. Direct Memory Access (DMA) is the most efficient, allowing I/O devices to transfer data directly to and from main memory without CPU intervention, except for setup.

What is pipelining, and why is it important in CPU design?

Pipelining is a technique used to improve CPU performance by allowing multiple instructions to be processed concurrently in different stages of execution. Instead of waiting for one instruction to complete before starting the next, a pipeline breaks down instruction execution into stages (e.g., fetch, decode, execute, write-back) and processes different instructions in different stages simultaneously. This increases instruction throughput, making the CPU faster.

What is the difference between RISC and CISC architectures as presented?

RISC (Reduced Instruction Set Computer) architectures feature a small, simple, and fixed-length instruction set, with most operations performed on registers, and memory access limited to load/store instructions. CISC (Complex Instruction Set Computer) architectures have a large, complex, and variable-length instruction set, often with instructions that perform multiple operations and directly access memory. RISC aims for faster execution of simple instructions, while CISC aims for fewer instructions per program.

How does the book address the concept of parallelism in computer systems?

The book introduces parallelism as a way to achieve higher performance by performing multiple operations simultaneously. It discusses various forms, including instruction-level parallelism (e.g., pipelining, superscalar execution), data-level parallelism (e.g., vector processors), and thread-level parallelism (e.g., multi-core processors). The goal is to exploit concurrency inherent in tasks to speed up computation, though it introduces challenges in design and programming.

What is the role of the operating system machine level?

The operating system machine level is a virtual machine created by the operating system. It provides a more convenient and powerful interface for application programmers than the raw ISA. This level includes concepts like processes, virtual memory, files, and system calls. It manages resources, protects programs from each other, and handles I/O, abstracting away many hardware details and providing a stable environment for applications.

Why does Tanenbaum emphasize the importance of understanding multiple levels of abstraction?

Tanenbaum emphasizes this because a deep understanding of computer systems requires appreciating how each level contributes to the overall functionality and how they interact. Problems at one level can manifest at another, and optimizing performance often involves making informed decisions across different layers. This multi-level perspective helps designers and programmers create more efficient, reliable, and robust systems.

What is the purpose of a bus in computer organization?

A bus is a collection of parallel wires or optical fibers used to connect various components within a computer system, such as the CPU, memory, and I/O devices. It serves as a shared communication pathway, allowing data, addresses, and control signals to be transmitted between these components. Buses are critical for system integration and performance, though they can become a bottleneck if not designed efficiently.

How does the book explain the concept of virtual memory?

Virtual memory is a memory management technique that gives each program the illusion of having its own large, contiguous address space, even if the physical memory is fragmented or smaller. It achieves this by using a combination of RAM and disk space, translating virtual addresses generated by programs into physical addresses. This allows programs larger than physical memory to run and provides memory protection between processes.