Systems Architecture

Chapter 1 – Computer Technology, You're Need to Know

Technology and Knowledge

Acquiring and Configuring Technology Devices

Information Systems Development

- **Systems Development Life Cycle (SDLC):** series of steps for developing an information system
- **Unified Process (UP):** an iterative SDLC with 4-6 week cycles
- **Disciplines:** groupings of associated activities in the SDLC
    - **Business Modeling and Requirements:** building models of the processes to understand the system as it will be built.
    - **Design:** activities that determine the structure of the system as defined in the requirements.
        - **Architectural Design:** select and determine configurations for hardware, networking, system software, and applications development tools. These affect all design that follows.
        - **Information Architecture:** requirements and constraints defining information resources and how they interact with one another.
        - Detailed Design: narrowed in scope, constrained by architecture
    - **Implementation and Testing:** build, aquire, and integrate software components. Verification of correct functioning components and that they meet requirements.
    - **Deployment:** install, configure, and bring solution into operation.
    - **Systems Evaluation and Maintenance:** handling and solving errors that occur in the system over time.

Managing Computer Resources

Need to manage hundreds of systems. Pay attention to compatibility and future trends. Broad understanding of current technology and future trends.

Roles and Job Titles

- **Application Developers:** people who develop software for specific processing needs. Developers of scientific or technical applications have degrees in computer science.
    - **Systems Analyst:** business modeling and requirements.
    - **Systems Designer:** design and deployment
    - **Applications Programmer:** writes and tests software
- **Systems Programmers:** develops operating systems, DBMSes, Network Security, etc.
- **Hardware Personnel:** design, install, and maintain hardware.
- **Systems Managers:** variety of IT management positions

- **Computer Operations Manager:** oversees large Information Processing facility.
- **Network Administrator:** network infrastructure, local area network
- **Database Administrator:** databases, data resources
- **Chief Information Officer (CIO):** strategic planning and use of IT resources

Computer Technology Information Resources

- **Periodical Literature**
  - **ACM Computing Surveys:** latest research and trends
  - **Computerworld:** weekly magazine of computer news items
  - **Communications of the ACM:** research topic in CS
  - **Computer:** research-oriented information
- **Technology-oriented websites:**
  - **C/net:** consumer oriented
  - **Earthweb:** broad info for IS professionals
  - **Gartner Group:** consulting agency, CIO news
  - **Internet.com:** internet technology and business
  - **Itworld:** IS professionals news
  - **TechWeb:** IS professionals news
- Beware bias in news sources, such as omitting news about companies that don't pay advertising or news about companies that pay advertising.
- **Vendor and Manufacturer Web Sites:** sales-driven, but also good resources for technical data.
- Professional Societies
  - **Association for Information Technology Professionals (AITP):** IS managers and application developers
  - **Association for Computing Machinery (ACM):** computer science emphasis
  - **Institute for Electrical and Electronics Engineers Computer Society (IEEE):** engineers with emphasis on computer hardware

Chapter 2- Introduction to Systems Architecture

Automated Computation

- **Mechanical Implementation:** Charles Babbage Difference Engine: used moving gears to perform algorithms
  - Complex, prone to wear down, operating speed limits
- **Electronic Implementation:** Movement of electrons instead of gears
  - Faster, more reliable.
- **Optical Implementation:** Photons through fiber optic cables
  - Common in computer systems covering large distances
- **Quantum Computing:** Experimental use of quantum mechanics in computing
  - Qubit: stores data in multiple simultaneous quantum states

Computer Capabilities

- **Distinguish Computer from other Computational Devices:** general-purpose processor, data storage capacity, flexible communications capacity.

- **Processor:** performs data manipulation and transformation. Computation, Comparison, and data movement.
    - **Instruction:** signal for command to a processor to perform function.
    - **Executing:** processor performs a function in response to an instruction
    - **General-Purpose Processor:** may execute many different instructions in different sequences or combinations.
    - **Special-Purpose Processor:** designed for one specific task.
    - Formulas and Algorithms
        - **Formula:** a specific equation
        - **Algorithm:** a set of instructions
    - Comparisons and Branching
        - **Jumps / Branches:** moving to specific instructions based on state
        - **Logic instructions:** comparisons, evaluations
- **Storage Capacity:** immediate memory is faster, but lost when powered down. Secondary storage is long-term, but slower to access.
- **Input / Output Capability:** the ability of the system to interface with other systems and users and exchange data.

Computer Hardware

- **Four Components that Parallel Computer Capabilities**
    - **Processing:** computation, comparison, and instructions to transform data
    - **Storage:** temporary, short-term, and long-term use.
    - **External Communication:** users, administrators, other computers
    - **Internal Communication:** transport data among components.
- **Central Processing Unit (CPU):** general-purpose processor, executes instructions, controls data movement.
    - **Arithmetic Logic Unit (ALU):** electrical circuits that perform math (addition, subtraction) and logic (comparisons).
    - **Control Unit:** accesses program instructions, controls data movement among other components.
- Primary Storage: for information need for immediate programs
    - **Main memory / memory:** programming instructions currently being executed.
    - **Random Access Memory (RAM):** costly, but very fast type of main memory. Is also volatile.
    - **Volatility:** storage devices that cannot keep information without power.
- **Secondary Storage:** holds programs not currently being executed.
    - Holds data not needed by running programs.
    - Serves as a backup to primary storage, when it becomes overfilled
- **Input Output (I/O)** Units: external communications functions
    - **Human-oriented:** video displays, printers, keyboards,
    - **Computer-oriented:** modems, network interfaces.
- **System Bus:** Internal communications, provides the pathway for communications. A powerful CPU can be crippled without a high-capacity bus.

Computer System Classes

- **Microcomputer:** designed to meet the information needs of a single user
    - Also called a **Personal Computer (PC)** or **Workstation**
    - **Network Computer:** microcomputer with limited secondary storage and software. Connects to a server for applications.
- **Midrange Computer / Minicomputer:** information processing for multiple users, execute many applications simultaneously (multitasking).
- **Mainframe:** handles a large number of users and applications. Accessed with display terminals.
- **Supercomputer:** one purpose, rapid mathematical computations (billions to trillions per second). Used for computationally intensive applications, such as simulations and 3-D modeling.
- **Server:** (subset of micro to supercomputers) used for managing file systems, databases, websites, printers for a variety of users on a network.
- **Multicomputer Configurations:** organization of multiple computers to support specific services or applications.
    - **Cluster:** group of similar computers networked to provide a service or execute an application (Server Farm).
    - **Blade:** a circuit board containing most of computer server components, installed in a cabinet.
    - **Grid:** group of dissimilar computers networked all over the world or in a room that perform a task for a central machine when not performing other tasks.
- Bigger Isn't Always Better
    - **Grosch's Law:** larger more powerful computers will always be more cost-effective than smaller ones
    - Doesn't Take into account multiple classes of computers, computers for specific purposes, increased software costs in comparison to hardware, computer databases, adoption of GUIs, multicomputer configurations
    - "The Cost of CPU power actually increases on a per-unit basis as computer class increases."

The Role of Software

- Software bridges the gap of human language to machine language and high-level abstraction to low-level detail.
- Software Types
    - **Application Program / Application Software:** stored set of instructions for responding to specific requests.
    - **Utility Programs:** instructions for basic tasks that are necessary to applications.
    - **System Software:** collection of programs implement utility functions, allocate resources, and manage resources.
    - **Machine Independence / Hardware Independence:** shielding of machine's physical details from users and application programmers.
- System Software Layers

    - **System Management:** utility programs for users and administrators to control resources
    - **System Services:** utility programs for system management and applications to perform functions
    - **Resource Allocation:** utility programs that allocate hardware and other resources among users and programs
    - **Hardware Interface:** utility programs that control and interact with individual hardware devices
- **Operating System:** windows, UNIX, Linux, Mac OSX. Includes programs that meet the needs of most users, administrators, and application programs.
    - Program storage, loading, execution
    - File Manipulation and access
    - Secondary storage management
    - Network and interactive user interfaces
- **Applications Development Software:** programs used to develop programs
    - **Program Translator:** translates programming language into CPU instructions.
    - **Programming Language:** allow programmers to express complex processing tasks in a single statement or instruction.
    - **Program Editors:** writing tools for programs
    - **Debugging Tools:** simulate program execution for tracing errors
    - **System Development Tools:** create models of entire systems for developing software

Economics of System and Application Development Software
- System software consumes hardware resources
- Cost per unit of computing power has rapidly decreased
- Reusable software is more cost-effective.
- Hardware is getting cheaper, software is getting more expensive.

Computer Networks
- Set of hardware and software components enabling users to share information
- **External Resources:** accessing external devices on a network
- **Network Software:** finds requested resources on a network, negotiate resources, receive and deliver resources.
    - For Computers Offering Resources: listen for requests, validate requests, deliver resources.
- **Network Communication and Physical Network:** simple because they do not transform data, but they must offer high-speed transfer of data.

Chapter 3 – Data Representation

Data Representation and Processing
- Data Information Processor must be capable of recognizing external data and converting it to internal format, store and retrieve data internally, transport data among internal storage and processing components, manipulate data.

Automated Data Processing

- Data is processed electronically with electrical switches. Relies on laws of electricity, optics and quantum mechanics, which are described by mathematical formulas, which may, in turn, be used to manipulate math.
- Shortcoming of this is that humans need processing of more complex, abstract concepts like "love" or "hate" or "friend."

Binary Data Representation

- **Binary Number:** number with only two possible values, 0 or 1.
    - May be represented as electrical signals.
    - May be processed by two-state electrical devices.
- **Boolean Logic:** George Boole, methods of reasoning and logical proof using sequences of statements evaluated as true or false.
- **Base / Radix:** multiplier that describes the difference between on position and the next in a number
- **Decimal Point:** period or comma distinguishing between the whole number and fractional part of a number
- **Radix Point:** term for Decimal Point in other Base number systems.
- **Bit:** a digit in a binary number
- **Bit String:** collection of bits describing a single data value
- **Most Significant Digit / High-Order Bit:** leftmost digit, which carries the most weight.
- **Least Significant Digit / Low-Order Bit:** rightmost digit, carrying least weight.
- **Byte:** string of eight bits.
- **Hexadecimal Notation:** base 16, more compact, large number values require less digits to express
- **Octal Notation:** base 8

Goals of Computer Data Representation

- Compactness, Accuracy, Range, Ease of Manipulation, Standardization
- **Compactness:** using fewer bits to represent values
- **Accuracy:** trade off with compactness. 1/3 is 0.333333… but this cannot be represented compactly.
- **Ease of Manipulation:** efficiently perform functions with data. Less components means better efficiency.
- **Standardization:** data formats suitable to a wide variety of devices

CPU Data Types

- **Integers:** a whole number
    - **Signed Integer:** uses on bit to represent positive or negative values, reduces the highest and lowest number available for representation by one factor.
    - **UnSigned Integer:** lowest number is zero, but highest number is one factor higher

- **Excess Notation:** fixed number of bits, with the leftmost bits representing the sign. 0 requires same amount of space as -99999
- **Two's Complement Notation:** positive numbers are represented normally, with 0 as the leftmost digit to signify their being positive. Negative numbers are the opposite number in complement plus one (ie. 0101 positive is (1010 + 1) negative).
    - Confusing for humans, but popular for needing only two logic circuits to perform addtion on single-bit values, and subtraction can be performed as addition of a negative value.
- **Range and Overflow:** 32 or 64 bits
    - Numeric Range: range of two's complement value is –2^n-1 to 2^n-1-1, with –1 to the exponent for the sign digit.
    - Overflow: numbers too large to be stored in available bits.
- **Double Precision Data Formats / Long Integers:** use two adjacent fixed-length data items to hold one value.
- **Real Numbers:** whole and fractional components. Need a bit for the radix point.
- **Floating Point Notation:** moving the radix point depending on the number. Computers use this.
    - **IEEE 32-bit format:** standard for floating points.
    - **Mantissa:** part of a floating point number that contains its significant digits, depending on the interpretation of the exponent.
- Range, Overflow and Underflow
    - **Range:** range of numbers that can fit in a data type
    - **Overflow:** numbers too big to fit in a data type
    - **Underflow:** numbers too small to fit in a data type
- Precision and Truncation
    - **Truncation:** 1/3 is stored in mantissa to the extent that all bits are filled.
    - Programmers avoid truncation by avoiding floating point numbers. For instance, storing all monetary values in pennies rather than dollars with cents.
- **Processing Complexity:** Floating point numbers require more time than integers to process. Programmers use integers whenever possible.

Character Data

- **Character:** special-purpose symbols such as alphabet letters, numerals, punctuation
- **String:** sequence of characters that form a meaningful word.
- Character data cannot be directly represented by computer, must be turned into bits.
- **Coding Methods:** users must use same coding and decoding method, coded values must be storable and transmitable, coding methods represent tradeoffs of compactness, ease of manipulation, accuracy, range, and standardization.
- **EBCDIC (Extended Binary Coded Decimal Interchange Code):** 1960s IBM character coding method. Only S/390 mainframe still uses it. 8-bit strings.
- **ASCII (American Standard Code for Information Interchange):** widely used coding method, adopted in US.
    - **International Alphabet Number 5 (IA5):** international equivalent of ASCII, promulgated by the International Standards Organization (ISO).
    - Uses 7-bits, with one bit used for parity check.

- **Device Control:** ASCII control codes for formatting data, line feeds, ding bells, etc.
- **Software and Hardware Support:** ASCII characters are handled as numbers, so not much of an issue.
    - **Collating Sequence:** when comparing characters (ie. 'a' is greater than 'z') their numerical equivalents are compared. Numerical values should match character orders.
    - There is not widely accepted standard for collating symbols.
- **ASCII Limitations:** lacks range to provide commands and symbols for its expanded use, such as Chinese, Japanese, or Korean
    - **Latin-1:** lower 128 entries for Western European languages.
    - **Multinational Characters:** upper 128 entries
- **Unicode:** (Unicode.org) multilinguale character encoding standard. Incorporates ASCII.
- **Boolean Data:** data must be stored in binary formats. 0 is false, 1 is true.
- **Memory Addresses:** serial numbers identifying memory bytes
- **Flat Memory Model:** nonnegative integers to identify memory locations, uses two's complement or unsigned binary for simplicity.
- **Segmented Memory Model:** memory divided into pages, with bytes contained within them. Requires two-part addresses.

Data Structures

- **Primitive / Machine Data Types:** data types directly supported by the CPU.
- **Data Structure:** related group of primitive data elements organized for some type of common processing.
- Pointers and Addresses
    - **Pointer:** data element that contains address of another data element
    - **Address:** location of an element on a data storage device
- **Arrays and Lists:** types of data put into groups
    - **Array:** ordered list where each element can be referenced by and index to its position.
    - **Linked List:** uses pointers so list elements may be scattered among nonsequential storage locations.
    - **Singly Linked List:** each list element occupies two storage location, one for the value of the list element, the other the address to the next element.
    - **Contiguous VS NonContiguous** memory locations. Arrays are contiguous. Linked lists are noncontiguous.
    - Noncontiguous are easier to expand. Inserting into arrays means reallocating all the elements in the array.
- **Record:** data structure composed of other data structures or primitive data elements.
- **Index:** array of pointers to records, efficient record insertion, deletion, and retrieval.
- **Classes:** data structure that contain both traditional data elements and programs to manipulate the data.
    - **Methods:** programs in a class.
    - **Object:** one instance of a class

Chapter 4 – Processor Technology and Architecture

CPU Operation

- **Fetch Cycle / Instruction Cycle (control unit):** data inputs are prepared for transformation into outputs
    - Fetches instruction from primary storage
    - Increments pointer to location of next instructions
    - Separates instructions into components
    - Stores components to registers
- **Execution Cycle (ALU):** transformation takes place and data output is stored.
    - Retrieves instruction code from register
    - Retrieves data inputs from registers
    - Passes data inputs through internal circuits to perform data transformation
    - Stores result in register.

Instructions and Instruction Sets

- **Instruction:** command to CPU to perform primitive processing functions on specific data inputs. Lowest level command processor can perform.
- **Op Code:** first group of bits representing unique binary number of instruction.
- **Operands:** subsequent groups of bits to hold input values for instructions.
- **Instruction Set:** collection of instructions a CPU can process.
    - Varies by: Number of Instructions, size of instructions, op codes, operands, supported data types, number and complexity of operations performed
- **Data Movement**
    - **MOVE Instruction:** copies data bits to storage locations.
    - **Load operation:** data transferred from main memory into register.
    - **Store operation:** register to primary storage.
- **Data Transformations:** based on Boolean logic
    - **NOT:** transforms Boolean value true to false, false to true.
    - **AND:** generates true if both data inputs are true.
    - **OR:** generates true if either data input is true.
    - **XOR:** exclusive OR, generates true if only one data input is true, but not the other.
    - **ADD:** arithmetic sum
    - **SHIFT:** shift bit string to right or left.
    - **Logical SHIFT:** extract a sing bit from a bit string and shift it.
    - **Arithmetic SHIFT:** multiplication or division by shifting bit strings
- **Sequence Control:** alter the flow of instruction execution in a program
    - **Branch / Jump Operations:** causes processor to depart from sequential instruction order
    - **Unconditional BRANCH:** processor always departs from normal sequence
    - **Conditional BRANCH:** branch occurs if specified condition is met.
    - **HALT:** suspends normal flow of instruction execution in current program.
- **Complex Processing Operations:** can be performed by combining simpler operations.

- **Instruction Set Extensions:** CPUs provide a much larger set of instructions, including advanced computation operations such as multiplication, division, two's complement negation.
    - **Complex Instructions:** represent combinations of primitive processing operations.
    - Represent a tradeoff between CPU complexity and program execution speed.

Instruction Format

- **Instruction Format:** template that specifies the number of operands and the position and length of op code and operands.
- **Fixed Length Instructions:** simplify instruction-fetching process within control unit, pointer increments a constant amount with each fetch.
- **Variable Length Instruction:** incremented the length of the most recently fetched instruction. Control unit must check the op code of each fetched instruction to determine increment.
- **Reduced Instruction Set Computing (RISC):** philosophy of processor and computer system design that lacks complex instructions.
- **Complex Instruction Set Computing (CISC):** alternate philosophy, used to overcome limited memory of early computers.
- RISC and CISC result in tradeoffs of power and efficiency. RISC requires more memory, but is more efficient. CISC requires less memory, but is less efficient. Most Intel processors are CISC for backwards compatibility.

Clock Rate

- **Clock Rate:** frequency at which the system clock generates timing pulses.
- **Clock Cycle:** each tick in the timing cycle.
- **Hertz (Hz):** unit of measurement for clock rates.
- **Megahertz (MHz):** millions of cycles per second.
- **Gigahertz (GHz):** billions of cycles per second.
- **CPU Cycle Time:** inverse of the clock rate.
- **Millions of Instructions per Second (MIPS):** rate at which instructions are executed, most important metric in determining processor performance, single-precision integers
- **Millions of Floating Point Operations per Second (MFLOPS):** rate at which instructions are executed fro floating-point numbers.
- **Wait State:** clock cycle CPU spends waiting for a slower device
- **Benchmark:** measure of CPU performance when executing specific tasks.

CPU Registers

- Provide a "scratch-pad" for currently executing program, and store information about current program and status of CPU.
- **General-Purpose Register:** used only by the currently executing program, hold intermediate results or data values frequently used.
- **Special-Purpose Registers**
    - **Instruction Register:** stores instructions for extraction by control unit

        - **Instruction Decoding:** process of extracting the op code and operands, loading data inputs, and signaling the ALU
    - **Instruction Pointer / Program Counter:** stores address of instruction to retrieve
    - **Program Status Word (PSW):** contains data that describes the status of the CPU and currently executing program
        - Flag: represents one data item, stores result of comparison operation, control conditional branch execution, or indicate actual or potential error conditions

Word Size

- **Word:** unit of data that contains a fixed number of bytes or bits.
- CPUs with larger word sizes can perform more work.
- Bus width must be large enough to handle CPU word size.
- Diminishing Returns: past 64 bits, additional word size returns many unnecessary, unused bits.

Enhancing Processor Performance

- **Memory Caching:** see Chapter 5.
- **Pipelining:** method of organizing CPU circuitry to enable multiple instructions to be in different stages of execution at the same time. Uses overlapping. Reduced efficiency if some stages must wait on others.
- **Branch Prediction:** CPU guesses whether a branch will evaluate to true or false based on past experience
- **Speculative Execution:** instructions executed after the guess, but before the final result is known with certainty.
- **Multiprocessing:** an CPU architecture in which duplicate CPUs or processor stages can execute in parallel. Includes duplicate circuitry for some processing stages in CPU, duplicate CPUs sharing memory and system bus, duplicate CPUs on a singl microprocessor that also contains main memory caches and a special bus to connect the CPUs.

The Physical CPU

- CPU is a complex system of interconnected electrical switches
- **Gate:** circuit that can perform a processing function on an individual binary electrical signal or bit. Peforms AND, OR, XOR, NOT, and others.
- **Electrical Properties:** speed and reliability of CPUs speeds is affected by materials I CPU, conductivity, resistance, and heat.
- **Electrical Current:** flow of electrons from one place to another
- **Wires / Traces:** conductive molecules arranged in straight lines, molecules serve as stepping stones for electrons.
- **Conductivity:** the ability of an element or substance to enable electron flow
- **Conductor:** substance that electrons can flow through
- **Resistance:** loss of electrical power that occurs within a conductor.
- **Heat:** increases resistance of conductor, and destroys components.

- **Heat Sink:** absorbs heat and dissipates it via air or water movement.
- **Speed and Circuit Length:** reduce circuit length, increase speed.
- **Processor Fabrication:** original computers used copper wiring and were subject to heat damage. Modern methods are much improved.
- **Semiconductors:** materials that vary in response to electrical inputs applied.
- **Transistors:** semiconductor material treated or doped with chemical impurities to enhance the semiconducting effects.
- **Integrated Circuit (IC):** fabrication of several transistors and interconnections on a single chip
- **Microprocessor:** microchip that contains all of the circuits and connections that implement a CPU.
- **Moore's Law:** rate of increase in transistor density on microchips doubles every 18 to 24 months.
- **Rock's Law:** cost of fabrication facilities for the latest chip generation doubles every four years
- Increased Chip density allows less voltage, making them more susceptible to damage from surges and static electricity.

Future Trends
- **Optical Processing:** using photons instead of electrons.
- **Electro-Optical Processing:** uses gallium arsenide which has both electrical and optical properties.
- **Quantum Processing:** uses quantum states to encode two values per bit in qubits.

Chapter 5 – Data Storage Technology

Storage Device Characterstics
- **Storage Medium:** device or subtance that actually holds the data
- **Read / Write Mechanism:** device used to read and write data from the storage medium
- **Device Controller:** provides interface between the storage device and system bus
- **Primary Characteristics**
    - **Speed:** most important characteristic differentiating primary and secondary storage. Primary storage, expanding capacity of CPU registers, must be faster.
        - Access Time: time required to perform one read / write operation.
        - Block: generic term for secondary storage transfer units.
        - Sector: data transfer unit for magnetic and optical disk drives.
        - Data Transfer Rate: divide 1 by the access time in seconds
    - **Volatility:** nonvolatile medium stores data for long periods of time without loss. Volatile medium cannot reliable hold data over long periods. Primary storage is volatile, secondary storage is non volatile.
    - **Access Method:** physical structure of a storage device's read /write mechanism and storage medium determines the ways in which data can be accessed.

        - **Serial Access:** stores and retrieves data items in a linear, or sequential order. (ie. Magnetic Tape)
        - **Random / Direct Access:** not restricted to order, any storage location can be accessed.
        - **Parallel Access:** simultaneously access multiple locations (RAM is both parallel and random)
    - **Portability:** the portability of the device storing the data.
    - **Cost and Capacity:** improving any attribute of device increases cost.
    - **Memory-Storage Hierarchy:** range of storage devices in a computer system.

Primary Storage Devices

- **Storing Electrical Signals:** batteries and capacitors can store electric signals. Capacitors are faster and more reusable.
    - **Core Memory:** rings of ferrous materials used for primary storage in early computers
- **Random Access Memory (RAM):** generic term describing primary storage devices that implement microchips with semiconductors, ability to read and write with equal speed, and provide random access to stored bytes, words, or larger data units.
    - **Static RAM (SRAM):** implemented entirely with transistors in flip-flop circuits (electrical switch that remembers its last position).
    - **Dynamic RAM (DRAM):** uses transistors and capacitors. Capacitors are dynamic and require fresh electrical infusions to maintain state.
        - Refresh Cycle: refreshing electrical state
    - SRAM is 10 times more expensive to fabricate than DRAM.
    - RAM cannot match current processor clock rates. Therefore technologies are used to bridge the peformance gap
        - Read-ahead memory access
        - Synchronous read operations
        - On-chip memory caches
    - **Synchronous DRAM (SDRAM):** read-ahead RAM that uses same clock pulse as the system bus.
    - **Enhanced DRAM (EDRAM):** small amount of SRAM placed in each DRAM device. Stores extra data in SRAM for expected future read requests.
- **Nonvolatile Memory (NVM):** semiconductor or other random access memory with long term or permanent data retention.
    - **Read-Only memory (ROM):** earliest type of NVM with data content written permanently during manufacture.
    - **Erasable Programmable ROM (EPROM):** may be erased with exposure to ultraviolet light.
    - **Flash RAM:** slower write performance than DRAM, and mildly destructive with each write operation.
    - **Ferroelectric RAM:** crystal of metallic compound within the bit circuitry, moves an atom to one side or other to represent 0 or 1.
    - **Polymer Memory:** special plastic with electrical resistance increased or decreased with an electrical field.

- **Memory Packaging:** similar to microprocessor packaging, circuits embedded in microchips.
    - **Dual in-line packages (DIPs):** groups of chips packaged on a single circuit. Tedious and precise operation to manufacture.
    - **Single In-Line Memory Module (SIMM):** multiple DIPs on a circuit board, which locks into the motherboard.
    - **Double In-Line Memory Module (DIMM):** SIMM with independent electrical contacts on both sides of the module

CPU Memory Access

- **Physical Memory Organization:** seqence of contiguous memory cells.
    - **Most Significant Byte:** leftmost byte
    - **Least Significant Byte:** rightmost byte
    - **Big Endian:** architectures that store the most significant byte at the lowest memory address.
    - **Little Endian:** architectures that store least significant byte at the lowest memory address
    - **Addressable Memory:** highest numbered storage byte that can be represented.
    - **Physical Memory:** actual number of memory bytes that are physically installed in the machine.
- **Memory Allocation:** assignment of specific memory addresses to a system software, application programs, and data.
- **Absolute Addressing:** memory address operands that refer to actual physical memory locations. Programs that use absolute addressing must be rewritten every time a program offset is changed.
- **Indirect / Relative Addressing:** automatically computing physical memory addresses.
    - **Offset Register:** register that holds the offset value

Magnetic Storage

- **Exploits the duality of magnetism and electricity:** electric currents may generate magnetic fields and magnetic fields can generate electricity.
- **Read / Write head:** applies electrical currents to infuse storage medium with magnetic charge. Positive / Negative charges represent bits.
- Magnetic Storage is subject to deficiencies
    - **Magnetic Decay:** magnetically charged particles lose their charge over time.
    - **Magnetic Leakage:** magnetic charges affecting the charges of neighboring bits
    - **Coercivity:** abililty of a a magnetic storage medium to accept and hold a magnetic charge
    - Areal Density, Recording Density, Bit Density: surface area allocated to each bit
    - Media Integrity: ability of device to withstand humidity and temperature.
- **Magnetic Tape:** ribbon of plastic with coercible surface.
- **Tape Drive:** reads and writes to magnetic tape

- **Linear Recording:** places bits along parallel tracks that run along the entire length of the tape.
- **Helical Scanning:** moves from tape edge to edge to read data.
- **Magnetic Disk:** circular platters with metallic coatings that are rotated beneath read / write heads.
- **Track:** one concentric circle of a platter
- **Cylinder:** set of all tracks at and equivalent distance from the edge or spindle on all platter surfaces
- **Access Arm:** moves read write heads along platters.
- **Hard Disk:** multiple platters with access arms
- **Drive Array:** multiple hard drives in a single storage cabinet
- **Floppy Disk / Diskette:** base of flexible or ridgid plastic material with single platter coated with iron or other metal.
- **Head-to-Head Switching Time:** switching from head to head
- **Track-to-Track Seek Time:** average number due to variations in the time required to start, operate, and stop the positioning servo
- **Sequential Access Time and Sustained Data Transfer Rate:** most important performance numbers
- **Complication:** manufacturers package more sectors on the outside tracks of a platter.

Optical Mass Storage Devices

- Store bit values in variations in light reflection.
- **Compact Disc Digital Audio (CD-DA):** original use for CDs
- **Compact Disc Read-Only Memory (CD-ROM):** includes additional formatting to store directory and file information
- **Compact Disc-Recordable (CD-R):** laser that affects a laser-sensitive dye in the disc to read and write
- **Magneto Optical Drive:** uses lasers and reflected light to sense bit values
- **Phase-Change Optical Discs:** uses non-destructive write method that can be overwritten (CD-RW uses this)
- **Digital Video / Versatile Disc (DVD-ROM):** increased track density that uses smaller wavelength lasers, improved error correction, and multiple recording sides and layers

Chapter 6 – System Integration and Performance

System Bus

- **Bus:** set of parallel communications lies that connect two or more devices
- **System Bus:** connects CPU with main memory and other system components
- **Peripheral Devices:** devices other than CPU and primary storage
- **Address Bus:** carries bits of a memory address
- **Control Bus:** carries commands, command responses, status codes, and similar messages.
- **Bus Clock Pulse:** common timing reference for all attached devices (MHz)
- **Bus Cycle:** time interval from one pulse to the next

- **Data Transfer Rate:** measure of communication capacity
- **Bus Protocol:** governs the format, content, and timing of data, memory addresses, and control messages sent across the bus
- **Bus Master:** CPU
- **Bus Slaves:** all non-CPU devices
- **Direct Memory Access (DMA) and DMA Controller:** transfers between memory and other storage or I/O devices
- **Peer-to-Peer Bus:** and device that can assume control of the bus or act as bus master to any other device.
- **Bus Arbitration Unit:** simple processor attached to peer-to-peer bus that decides which devices must wait when multiple devices want to become bus master.

Logical and Physical Access
- **I/O Port:** communication pathway from the CPU to a peripheral device
- **Logical Access:** CPU and bus interact with peripheral devices as if they were storage devices, LA is a read /write access to this device.
- **Linear Address Space:** set of sequentially numbered storage locations

Device Controllers
- Device Controller performs all the interface functions for its attached peripheral devices.
- Mainframe Channels
    - **I/O Channel / Channel:** device controller is a dedicated special-purpose computer.

Interrupt Processing
- **I/O Wait States:** CPU cycles not devoted to instruction execution.
- **Interrupt:** signal to the CPU that an event has occurred that requires CPU to execute a specific program or process.
- **Interrupt Handler:** processes each possible interrupt
- **Multiple Interrupts:** OS groups interrupts by their priority
- **Stack Processing:** last-in-first-out (LIFO) storage that holds processes or programs interrupted
    - **Push:** moving values in CPU registers to stack
    - **Machine State:** saved values
    - **Pop:** loading stack back into register
    - **Stack Overflow Error:** when stack fills to capacity and cannot accept more values
    - **Stack Pointer:** special purpose register that points to next empty address in the stack
- **Performance Effects:** this is a complex process, consumes CPU cycles.

Buffers and Caches
- **Buffer:** small storage area for data in transit from one device to another for when transfer rates differ

- **Buffer Overflow:** when the buffer is not large enough to hold a full page
- **Diminishing Returns:** there is point when buffer size does not improve interrupt processing and bus transfers
- **Cache:** storage area that improves system performance, stores data for larger transfers
- **Cache Controller:** processor that manages cache content
- **Cache Hit:** read operation accesses data contained in the cache
- **Cache Miss:** when needed data is not in the cache.
- **Cache Swap:** pulling missed data into cache
- **Primary Storage Cache:**
    - **Level One Cache (L1):** within-CPU cache
    - **Level Two Cache (L2):** on-chip cache
    - **Level Three Cache (L3):** off-chip cache
- **Secondary Storage Caches:** disk caching for file and database servers. Gives frequently accessed files higher priority for cache retention, Use read-ahead caching for sequentially-read files, give random access files lower priority.

Processing Parallelism

- **Multicore Processors:** embeds multiple CPUs and cache memory on a single chip.
- **Multi-CPU Architecture:** employs tow or more single core CPUs on a single motherboard
- **Scaling Up:** increasing processing and system power by using larger, more powerful computers.
- **Scaling Out:** partitioning processes and tasks among multiple computer systems

High-Performance Clustering

- Grouping computers so they are able to work best together. For instance, grouping computers by region when computing weather data, with each system forecasting a zone. Computers near one another will be more likely to share data.

Compression

- Compression is a technique that reduces the number of bits used to encode a set of related data items.
- **Compression Algorithm:** specific mathematical compression technique implemented as a program
- **Decompression Algorithm:** restores compressed data to its original state
- **Lossless Compression:** decompressed data is exactly like data before compression
- **Lossy Compression:** decompressed data is similar to, but different from data before compression.
- **Compression Ratio:** ratio of data size in bits before and after compression.

Chapter 7 – Input/Output Technology

Basic Print and Display Concepts

- **Matrix-Oriented Image Composition:** dividing display surface into rows or columns.
    - **Pixel:** a cell in a matrix
    - **Resolution:** number of pixels per measurment unit
    - **Dots Per Inch (DPI):** unit for measuring resolution
    - **Point:** pixel equivalent for printing
- **Fonts:** variations in pixel compositions for representing symbols
- **Color:** frequencies interpretable by the human eye
    - **RGB (Red, Green Blue):** colors used for video display.
        - **Additive Colors:** colors added to produce all colors in visible spectrum (think adding colors to black)
    - **CMYK (cyan, magenta, yellow, black):** colors used for print display
        - **Subtractive colors:** colors added to suppress colors in the visible spectrum (think pulling colors out of white paper)
- **Numeric Pixel Content:** describing pixel content numerically
    - **Bitmap:** stored set of numbers that describe content of all pixels in an image
    - **Monochrome Display:** can display only two colors, requires one bit per pixel
    - **Grayscale:** display black, white, shades of gray. Increases bits per pixel.
    - **Chromatic Depth / Resolution:** number of distinct colors or gray shades that can be displayed.
    - **24-bit Color:** each color represented by and eight-bit number
    - **Palette:** table of colors
    - **Dithering:** placing small dots of different colors in an interlocking pattern to produce other colors.
    - **Half-toning:** grayscale dithering
- **Image Storage Requirements:** depends on number of bits to represent each pixel and the height and width of the image.
- Graphics Interchange Format (GIF), Joint Photographic Experts Group (JPEG), and Moving Picture Experts Group (MPEG) are compression formats.
- **Image Description Languages (IDL):** stores images compactly using embedded fonts, vectors, curves, and shapes, and embedded bitmaps.
    - **Vector:** light segment that has a specific angel and length with respect to a point of origin.
    - **Vector List:** series of concatenanted or linked vectors

Video Display

- **Character-Oriented Video Display Terminals (VDT) or Terminal:** consists of integrated keyboard and telvision screen
- **Network Computer / Thin Client:** hybrid device with mix of VDT and microcomputer characteristics
- **Video Controllers:** connects monitor to system bus
    - **Refresh Cycle:** transfer of full screen of data from display generator to monitor
    - **Refresh Rate:** refresh cycles per second (Hz)
    - **Video RAM (VRAM):** can be written while being read

    - **Dual Porting:** simultaneous read/write capability
    - **Graphics Accelerators:** processors for video controllers
- **Video Monitors:** technologies to generate displays
    - **Cathode Ray Tube (CRT):** enclosed vacuum tube illuminated by an electron gun
    - **Liquid Crystal Display (LCD):** matrix of liquid crystal that twists or untwists under electrical charge to allow light to pass through.
    - **Active Matrix Display:** one or more transistors for every pixel
    - **Passive Matrix Display:** shares transistors among rows and columns of pixels
    - **Thin Film Transistor (TFT):** wiring and transistors are added in thin layers fo glass substrate
    - **Plasma Displays:** combines elements of CRT and LCD. Contains gas that emit ultraviolet light when charged

Printers

- **Inkjet Printer:** liquid ink placed directly on paper using mechanical movement or heat
- **Printer Communications:** uses ASCII or Unicode
- **Laser Printer:** uses electrical charge and attraction of ink to the charge
- **Plotters:** generates line drawings, currently uses laser printer technique
    - Also called: Large Format Printer

Manual Input Devices

- **Keyboards:** use an integrated microprocessor, keyboard controller, to generate bit stream outputs.
    - **Scan Code:** keyboard output when one or more keys are pressed
- **Pointing Devices:** mouse, trackball, joystick, tablet.
    - **Cursor:** controlled by pointing device
    - **Mouse:** moved on flat surface, position corresponds to position on video display
    - **Digitizer:** stylus and tablet, sensitive to position of pointer.
    - **Input Pad:** digitizing tables and tablet PCs. Using Infrared Detector, Photosensor, and Pressure-sensitive pad.

Optical Input Devices

- **Photosensor:** converts light energy into electrical energy
- **Mark Sensor:** scans for light or dark marks at specific locations on a page
- **Bar-Code** Scanner: detects pattern of bars or boxes.
- **Bar Code:** series of vertical bars of equal length, but varying thickness and spacing.
- **Scanning Laser:** sweeps narrow laser beam across bar code
- **Optical Scanner:** generates bitmap representations of printed images
- **Optical Character Recognition (OCR):** processes scanned images to read them into data
- **Digital Cameras:** capture digital images

Audio I/O Devices

- **Sampling:** process of converting analog sound waves to digital representation
- **Analog-to-digital Converter (ADC):** accepts electrical signal and outputs stream of bits representing samples.
- **Digital-to-analog converter (DAC):** accepts streams of bits and outputs electrical signal that can be amplified to a speaker
- **Monophonic Output:** one note can be generated at a time
- **Polyphonic:** multifrequency sound generation
- **Speech Recognition:** process of recognizing and responding to meaning embedded in speech.
- **Phonemes:** sounds in human speech that correspond to letters of the alphabet
- **Speaker Dependent:** speech recognition systems must be trained to individual speakers.
- **Digital Signal Processor (DSP):** microprocessor specialized to processing continuous stream of audio or graphical data.
- **Speech Generation**
    - **Audio Response Unit:** device that generates spoken message based on textual input.
    - **Speech Synthesis:** individual phonemes are stored in the system
- **General-Purpose Audio Hardware**
    - Sound Card / Multimedia Controller
    - **Musical Instrument Digital Interface (MIDI):** standard for storing and transporting control information among computers and electronic musical instruments.