السلام عليكم ورحمة الله وبركاته.. وبعد،

بين يديك ملخص شامل ومنظم لمادة CPCS-214 _ Chapter 1-4، تم إعداده بعناية ليكون عوناً لك في فهم المادة .وقبل البدء، أضع بين يديك ميثاقاً للأمانة العلمية والتعاون:

⚠️ ميثاق الأمانة والمسؤولية:

هذا العمل هو جهد طالب، أضعه بين يديك بنية النفع والفائدة؛ لذا:

- **لا أسامح ولا أحلل استخدامه في الغش أو أي عمل ينافي الأخلاق الإسلامية.**
- **يُمنع منعاً باتاً تداوله كمصدر تجاري للباعة أو استخدامه في أدوات الذكاء الاصطناعي لغرض التحايل او الغش.**
- **الأمانة العلمية تقتضي منك استخدامه كمرجع للفهم والمراجعة، لا كبديل عن الضمير والاجتهاد الشخصي.**

🌐 خدمات إضافية عبر الموقع:

يمكنك تعزيز مذاكرتك من خلال الوصول إلى أسئلة تفاعلية تجريبية للمنهج عبر الرابط: 🔗 kau-one.web.app/quiz

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📣 التواصل معي:

الكمال لله وحده، لذا يسعدني استقبال ملاحظاتكم، تعديلاتكم، أو إضافاتكم عبر:

- **الرقم المباشر: 0530717788**
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توجيه إيماني:

قبل أن تبدأ، استعذ بالله من الشيطان الرجيم، وجدد نيتك بأن يكون هذا الوقت في سبيل طلب العلم النافع الذي يرفع قدرك في الدنيا والآخرة. قال رسول الله ﷺ: "مَنْ سَلَكَ طَرِيقًا يَلْتَمِسُ فِيهِ عِلْمًا سَهَّلَ اللَّهُ لَهُ بِهِ طَرِيقًا إِلَى الْجَنَّةِ" (رواه مسلم).

إعداد الطالب: إلياس حسان بابور الدفعة: 24 — تم اخذ الماده و عمل الملخص على السلايدات او تم اخذ الماده 2026

Introduction

- Computers are products of a vibrant IT industry embracing rapid innovation.
- Over the last 40+ years, numerous new computers appeared to revolutionize the industry, though often surpassed by better computers.
- Current innovation focuses on:
    - Specialized architectures
    - Energy efficiency
    - AI acceleration

The Information Revolution

- Computers have caused a third revolution, joining agricultural and industrial revolutions.
- Profoundly affected daily life and knowledge discovery.
- Now entering the "AI revolution": transforming information processing, decision-making, and human-technology interaction.

اللهم اشفِ مرضانا ومرضى المسلمين، وارحم موتانا وموتى المسلمين.

Revolution in Science

- A new vein of scientific investigation includes computational scientists alongside theoretical and experimental scientists.
- **Fields impacted:**
    - **Astronomy**: Galaxy simulation, exoplanet detection, cosmic microwave background analysis
    - **Biology**: Protein folding (AlphaFold), genomics, drug discovery, personalized medicine
    - **Chemistry**: Molecular dynamics, materials science, catalyst design
    - **Physics**: Particle physics simulations, quantum mechanics, fusion energy research
    - **Climate Science**: Climate modeling, weather prediction, environmental monitoring
    - **Artificial Intelligence**: Large language models, computer vision, neural network research
    - **Medicine**: Medical imaging analysis, treatment planning, epidemic modeling

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Revolution Continues

- Computer revolution accelerates; previously infeasible applications become practical.
- Examples of "science fiction" now realized:
    - **Autonomous vehicles (production testing)**
    - **Real-time language translation (earbuds, phones)**
    - **AI assistants and chatbots (ChatGPT, Claude, Gemini)**
    - **Augmented/Virtual Reality (Apple Vision Pro, Meta Quest 3)**
    - **Cryptocurrency and blockchain**
    - **Quantum computing (emerging)**
    - **Brain-computer interfaces (Neuralink, neural prosthetics)**
    - **Generative AI (images, videos, music, code)**

Impact on Society

- Technology impacts almost every aspect of society.
- Hardware advances enable software creation, explaining computers' omnipresence.
- **Key trends:**
  - Shift from general-purpose to specialized computing (AI accelerators, GPUs, domain-specific architectures)
  - Energy efficiency critical: battery life, data center costs, environmental impact
  - Ubiquitous connectivity: 5G, Wi-Fi 6/7, satellite internet
  - Edge computing: processing at the source instead of cloud

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Tomorrow's Applications

- Emerging technologies suggest future "killer apps":
  - Spatial computing and mixed reality interfaces
  - Generative AI for content creation (text, images, video, 3D models)
  - Autonomous robotics (homes and workplaces)
  - Brain-computer interfaces (accessibility/enhancement)
  - Quantum computing (drug discovery, cryptography)
  - Edge AI processing on IoT devices (smart cities, industrial IoT)
  - Personalized medicine via genomic computing and AI
  - Digital twins of cities, factories, human bodies
  - Ambient intelligence (computers disappearing into environment)

Classes of Computing Applications

- Core hardware technologies are used across smart home devices, phones, and supercomputers.
- Design differs based on performance, power efficiency, cost, size, reliability.
- Computing landscape extends beyond traditional categories.

Modern Computing Classes

- Six major classes:
    1. Personal Mobile Devices (PMDs)
    2. Personal Computers (PCs) / Laptops
    3. Servers and Cloud Infrastructure
    4. Embedded Systems and IoT
    5. Supercomputers and HPC
    6. AI/ML Specialized Systems (emerging, fast-growing)

Personal Mobile Devices (PMDs)

- Dominant computing platform globally.
- Device types: Smartphones, tablets, smartwatches, AR/VR headsets.
- Key characteristics:
  - Battery-powered (energy efficiency critical)
  - Wireless connectivity (5G, Wi-Fi 6/7, Bluetooth 5.x)
  - Touch and voice interfaces replacing keyboard/mouse
  - On-device AI (NPUs) for privacy and responsiveness
  - Rich sensors (cameras, accelerometers, GPS, biometrics)
  - Always connected, always available
- **Examples:** iPhone 16, Samsung Galaxy S24, Google Pixel 9; iPad Pro, Samsung Galaxy Tab; Apple Watch Series 10, Samsung Galaxy Watch; Apple Vision Pro, Meta Quest 3

Personal Computers (PCs) / Laptops

- Designed for individual use with display, keyboard, input devices.
- Mature market, essential for productivity, content creation, gaming.
- Key trends:
  - ARM processors competing with x86 (Apple Silicon M3/M4, Qualcomm Snapdragon X Elite, Better battery life, integrated AI acceleration)
  - AI acceleration standard (NPUs in CPUs),On-device AI for privacy and performance
  - Hybrid work driving demand; focus on power efficiency, battery life
- **Design priorities:** performance per watt, portability vs power balance, display quality, battery life

Servers and Cloud Infrastructure

- Run programs for multiple users, often network-accessed.
- Cost and capability range widely:
    - Entry-level servers: thousands of dollars, small businesses
    - Enterprise servers: hundreds of thousands of dollars, databases, apps
    - Hyperscale data centers: billions, cloud providers(AWS, Azure, Google Cloud) , social media, search engines
- **Applications:** Web services/APIs, databases, cloud infrastructure, AI training/inference, CDNs

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Supercomputers and High-Performance Computing (HPC)

- Highest performance and cost. Used in scientific/engineering applications.
- Modern supercomputers: millions of CPU cores, multiple GPUs, petabytes of memory/storage, high-speed interconnects (InfiniBand, custom networks), 10–40 MW power, cost $100M–$1B+.
- **Applications:** Weather/climate modeling, nuclear simulation and weapons testing, drug discovery, astrophysics (galaxy formation, black holes), AI model training, fusion energy research, earthquake/tsunami prediction.
- **Examples:** Frontier (USA, 1.1 exaflops) First , Fugaku (Japan, 442 petaflops), LUMI (Finland/EU, 379 petaflops)

Embedded Systems and Internet of Things (IoT)

- Computers embedded in devices for specific applications.
- Designed for single or related applications, integrated with hardware.
- Largest class by volume (billions of devices), Span widest range of applications and performance.

- **Applications:**
  - Automotive: ECUs, ADAS, infotainment, EV battery management
  - Smart home: Thermostats (Nest, Ecobee), security cameras, smart appliances(washing machines, refrigerator), voice assistants (Alexa, Google Home)
  - Medical: Pacemakers, insulin pumps, monitoring, diagnostics
  - Industrial IoT: Sensors, predictive maintenance, supply chain tracking
  - Wearables: Fitness trackers, smart glasses

Embedded System Characteristics

- Key constraints: power consumption, cost sensitivity, real-time requirements, reliability/safety, security, size limitations.
- Design priorities: functionality/reliability over performance, power efficiency, long life, minimal maintenance.

AI/ML Specialized Systems (Emerging)

- Fastest-growing computing segment; focused on AI/ML workloads.
- **Specialized hardware accelerators:** TPUs (Google), NPUs (smartphones/PCs), GPU clusters (NVIDIA, AMD), Custom AI chips (Tesla Dojo, AWS Trainium)
- **Capabilities:** Massive parallel processing, high memory bandwidth (HBM), optimized for matrix operations.

AI/ML Specialized Systems – Applications & Examples

- **Applications:**
  - LLM training/inference: GPT, Claude, Gemini, LLaMA
  - Computer vision/image generation: Object detection, face recognition, DALL-E, Midjourney, Stable Diffusion
  - Recommendation systems: Netflix, YouTube, Amazon
  - Autonomous vehicle processing: Real-time sensor fusion, decision-making
  - Scientific AI: Protein folding (AlphaFold), materials discovery
- **Examples:** NVIDIA DGX systems (8x H100 GPUs, $300K+), Google TPU pods (thousands of TPUs), Cerebras wafer-scale systems (2.6 trillion transistors)

The Mobile-First, AI-Everywhere Era

- Generational shift: mobile devices primary platform for billions.
- Key characteristics: PMDs outsell PCs 5:1; 1.4+B smartphones shipped annually vs 260M PCs; always connected; on-device AI standard.
- **Ecosystem-based:** app stores, cloud integration, cross-device sync.
- **Impact:** Changed communication, work, shopping, learning; enabled sharing economy (Uber, Airbnb); mobile payments replacing cash; social media/content creation.

PMD Key Characteristics

- Device types: Smartphones, Tablets, Smartwatches, AR/VR headsets.
- Features: battery-operated (8–24 hours), small, wireless, $100s–$1000+, software via app stores (Apple: 1.8M apps, Google: 3M+), frequent OTA updates.
- **Technologies:** ARM SoCs (Apple A18/A18 Pro, Qualcomm Snapdragon 8 Gen 3, Google Tensor G4, MediaTek Dimensity 9000+), NPUs, 5G, advanced cameras, OLED/AMOLED displays (120Hz), biometric security(fingerprint, face recognition).

PMD vs PC Comparison

- **Similarities:** general-purpose computing, connect to displays/keyboards, apps, web/email/productivity/gaming.

- **Differences:**

  - Input: touch, gestures, voice(Siri, Google Assistant, Alexa),; some stylus support(Apple Pencil, S Pen)

  - Connectivity: always-on (cellular + Wi-Fi), GPS

  - Sensors: cameras, accelerometer, gyroscope, magnetometer, barometer,Environmental awareness.

  - Form factor: pocket-sized, battery-powered

  - Software: curated app stores, frequent automatic updates

Cloud Computing

- Large collections of servers providing services over the Internet.

- Providers rent servers dynamically; scale up/down based on demand; pay only for usage.

- **Key providers:** AWS (~32% market), Microsoft Azure (~23%), Google Cloud (~10%), Alibaba Cloud (Asia), Oracle Cloud, IBM Cloud, Tencent Cloud.

Cloud Computing – Service Models

1. **Infrastructure as a Service (IaaS):** Rent VMs, storage, networking (AWS EC2, Azure VMs, Google Compute Engine)

2. **Platform as a Service (PaaS):** Development/deployment platforms (AWS Elastic Beanstalk, Google App Engine, Heroku)

3. **Software as a Service (SaaS):** Complete applications delivered online (Microsoft 365, Salesforce, Gmail, Dropbox)

Warehouse Scale Computers (WSCs)

- Modern hyperscale datacenter characteristics:
  - 100,000+ servers, forming cloud computing backbone
  - Power: 10–100+ MW (like small city)
  - Operated by Google, Meta, Amazon (dozens of facilities)
  - Storage: Exabytes (millions of terabytes)
  - Networking: Terabits per second internal bandwidth
  - Custom hardware: servers, networking, cooling
- **Cooling:** Liquid, free air, AI-optimized, evaporative water cooling
- **Economics:** Rentable portions, economies of scale, cheaper than on-premises, access for startups
- **Environmental concerns:** Major electricity/water consumers; move toward renewables and carbon neutrality

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Edge Computing

- Processing data closer to generation.
- Complements cloud; distributed continuum: Device → Edge → Cloud.
- **Benefits:**
  - Lower latency (real-time apps: autonomous vehicles, industrial automation, AR),Augmented reality (no perceptible lag)
  - Reduced bandwidth usage (process locally, send only important data)
  - Improved privacy (sensitive data local, compliance)
  - Reliability: works with limited connectivity, critical infrastructure continues

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Edge Computing – Applications & Architecture

- **Applications:** Autonomous vehicles, industrial IoT, smart cities, retail analytics, healthcare, 5G edge computing (MEC) (if need examples check slide 28)
- **Architecture:** Distributed nodes between device and cloud; edge servers at cell towers, factories, retail stores, regional data centers
- **Trend:** Three-tier architecture
    - Device tier: basic processing
    - Edge tier: local aggregation and processing
    - Cloud tier: heavy computation, long-term storage,training

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Software as a Service (SaaS)

- Software delivered over Internet via thin client (browser/mobile app).
- **Advantages:** No installation, automatic updates, access anywhere, collaboration, lower upfront costs (subscription).
- **Examples by category:**
    - Productivity: Microsoft 365, Google Workspace (word,Docs.and ….others)
    - Communication: Slack, Teams, Zoom, Google meet, Gmail, Outlook
    - AI Services: ChatGPT, Claude, Gemini, Midjourney, DALL-E, GitHub Copilot
    - Development: GitHub, GitLab, VS Code Web, cloud IDEs (Replit, CodeSandbox)
    - Business: Salesforce, QuickBooks Online, Shopify
    - Storage: Dropbox, Google Drive, OneDrive

Modern Hybrid Computing Model

- Distributed architecture: computation split across device, edge, cloud; each tier optimized.
- **Device processing:** User interface, immediate responsiveness, smooth gestures, on-device AI for privacy tasks (voice recognition, face unlock, predictive text), offline functionality Maps, documents, music, Works without connectivity, real-time requirements (camera, gaming, AR overlays)
- **Edge processing:** Local aggregation, filtering/preprocessing, low-latency processing, bandwidth optimization(more details slide 31)
- **Cloud processing:** Heavy computation (AI training, big data, simulations), storage/synchronization, multi-user coordination, updates/features
- **Example – Photo App:** Device: capture/basic filters/display; Edge: face detection, initial organization; Cloud: advanced search, sharing, backup, model training

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AI Integration Across All Computing Classes

- AI ubiquitous; no longer limited to specialized systems.
- **AI in PMDs:** On-device NPUs, computational photography, voice assistants, real-time translation, privacy-preserving inference
- **AI in PCs:** NPUs in latest processors(e.g. Windows Copilot, Apple Intelligence), background removal, upscaling, code assistance
- **AI in Cloud/Servers:** Large model training (GPT, Claude, Gemini, Stable Diffusion), Inference at scale: Serving billions of requests
- **AI in Embedded/IoT:** TinyML, predictive maintenance, anomaly detection, voice commands
- **AI in Supercomputers:** Scientific discovery (AlphaFold, climate modeling, drug discovery)
- **Trend:** AI accelerators becoming standard, not optional

Summary – Computer Technology Landscape

- **Six computing classes:** PMDs (dominant), PCs (productivity), Servers/Cloud (Internet backbone), Embedded/IoT (largest volume), Supercomputers (scientific advancement), AI/ML Systems (fastest-growing)

- **Key trends:** Mobile-first/AI-everywhere, energy efficiency critical, specialized architectures replacing general-purpose, edge computing complements cloud, security/privacy by design, sustainability driving design

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Summary – Computing Continuum

- Device → Edge → Cloud working together

- Right computation at right place/time

- **Looking ahead:** AI integration deepening, quantum computing for specific problems, sustainability competitive necessity, new form factors (AR/VR, wearables, ambient computing)

- **Fundamental principle:** Hardware capabilities enable software innovation; understanding hardware helps write better software

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and i skippied the Optional Reading Material as it's optional for viewing it slide 37

لا تتوقف... فالقادم أجمل بإذن الله.

chapter 2

Introduction

- 1960s–1970s: Primary constraint on computer performance was memory size.
- Programmers aimed to minimize memory usage to make programs fast.
- Last decade: Advances in computer design and memory technology reduced importance of small memory size, except in embedded computing systems.

Performance

- Critical for successful software: results must reach the user quickly.
- Programmers must understand new performance issues replacing the simple memory model:
  - Parallel nature of processors
  - Hierarchical nature of memories

Energy Efficiency

- Programmers must consider energy efficiency on PMDs or in the Cloud.
- Understanding computer organization is necessary to build competitive software.

What You Can Learn skipped it as they are questions for more info see slide 6

Program Performance

Depends on combination of:

- Algorithm effectiveness
- Software used to create/translate program into machine instructions
- Hardware effectiveness executing instructions (including I/O)

Hardware and Software Affect Performance

- Both hardware and software determine program execution efficiency

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Great Ideas in Computer Architecture

- Eight fundamental ideas over the last 60 years, still influential today:

1. Design for Moore's Law
2. Use abstraction to simplify design
3. Make the common case fast
4. Performance via parallelism
5. Performance via pipelining
6. Performance via prediction
7. Hierarchy of memories
8. Dependability via redundancy

Moore’s Law

- Integrated circuit resources double every 18–24 months.
- Designs take years; architects must anticipate technology at project completion, not start.

Use Abstraction

- Hide lower-level details to simplify higher-level design
- Improves productivity; prevents design time from growing with Moore’s Law

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Make the Common Case Fast

- Optimizing the common case improves performance more than rare cases
- Requires experimentation to identify common case

Performance via Parallelism

- Achieve higher performance by executing multiple operations simultaneously

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Performance via Pipelining

- A prevalent form of parallelism in computer architecture
- Pattern allows multiple stages of execution concurrently

اللهم اجعل علمنا نافعًا، وعمَلنا صالحًا، ونياتنا خالصة لك.

Performance via Prediction

- Sometimes faster to guess next steps and start processing rather than wait
- Effective if misprediction recovery is inexpensive and prediction is accurate

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Hierarchy of Memories

- Programmers want memory that is fast, large, and cheap (conflicting demands)
- Hierarchical structure:
  - Top: fastest, smallest, most expensive per bit
  - Bottom: slowest, largest, cheapest per bit

Dependability via Redundancy

- Computers must be fast and dependable
- Physical components can fail → system includes redundant components
- Redundancy ensures system continues to operate after a failure
- Redundancy can be restored after failure

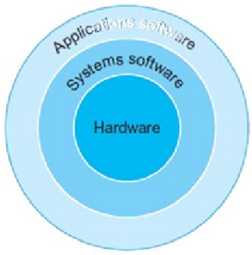
لا تنسونا من خالص دعائكم

اللهم افتح علينا أبواب رحمتك، ويسّر لنا أمورنا، وأصلح حال المسلمين في كل مكان.

شابتر 3

introduction

- Typical applications: millions of lines of code, rely on sophisticated software libraries.
- Hardware executes only simple low-level instructions.
- High-level operations must be interpreted or translated into simple computer instructions.
- Software layers:
  - Application software written in high-level language (HLL)
  - System software
  - Hardware: processor, memory, I/O controllers



Systems Software

- **Operating System**: Interface between user programs and hardware.
  - Handles basic I/O operations
  - Allocates storage and memory
  - Protects shared use among multiple applications
- **Compilers**: Translate HLL programs into instructions that hardware can execute

---

From High-Level Language to Hardware Language

- Computers understand electrical signals: on/off → binary digits (bits) 0 and 1.
- Instructions: collections of bits that computer understands and obeys
- Instructions can be thought of as numbers
- Example: `1000110010100000` instructs computer to add two numbers

Assemblers

- First programmers used binary; tedious → symbolic notations invented
- Initial translation to binary was manual → still tiresome
- Assemblers: programs that translate symbolic notation to binary
- Example: `add A, B` → `1000110010100000`
- Assembly language: symbolic language, contrasted with machine language (binary)
  - Requires programmer to write one line for every instruction that computer will follow
  - Forcing programmer to think like computer

High-Level Programming Languages

- Programs can be written in more natural, powerful languages, then translated into computer instructions by compilers
- Compilers allow programmers to write high-level expressions (e.g., `A + B`) → compiled to assembly instructions (`add A, B`)
- High-level languages improve productivity, reduce programmer burden

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Benefits of High-Level Programming Languages

- Programmers can think using English words and algebraic notation
- Improved productivity
- Programs become independent of the computer they were developed on

اللهم اجعل هذا العمل خالصًا لوجهك الكريم، وانفع به كاتبه وقارئه وسائر المسلمين.

شابتر 4

Basic Functions of Hardware

Hardware in any computer performs the same basic functions:

- Inputting data
- Outputting data
- Processing data
- Storing data

Computer Organization

- Five classic components:
    - Input
    - Output
    - Memory
    - Datapath
    - Control
- Datapath and control are sometimes combined and called the processor.
- This organization is independent of hardware technology.
- Every piece of every computer (past and present) fits into one of these five categories.

Through the Looking Glass

- The most fascinating I/O device is the graphics display.
- Most PMDs use LCDs (Liquid Crystal Displays) for thin, low-power displays.
- Most LCDs use active matrix technology:
    - Each pixel has a tiny transistor switch.
    - This precisely controls current and produces sharper images.

Pixels

- An image is composed of a matrix of picture elements called pixels.
- A pixel is the smallest individual picture element.
- Screens contain hundreds of thousands to millions of pixels.
- Pixels can be represented as a matrix of bits called a bitmap.

Color Display

- Uses 8 bits for each of three colors:
    - Red - Green - Blue (RGB)
- Total = 24 bits per pixel.
- Allows millions of different colors.
- RGB mask determines intensity of the three color components.
- In color LCDs, there are three transistor switches at each pixel.

Frame Buffer

- The image shown on screen is stored in the frame buffer.
- The bit pattern for each pixel is read out at a refresh rate.

Touchscreen

- Tablets and smartphones replaced keyboard and mouse with touch-sensitive displays.
- Advantage:
  - Users directly point to what they are interested in instead of using a mouse.

Opening the Box (Apple iPad 2 Example)

- Contents:
  - Capacitive multitouch LCD screen
  - 3.8 V, 25 Watt-hour battery
  - Computer board
- Of the five components, I/O dominates this device.
- I/O devices include:
  - Multitouch LCD display , Front camera , Rear camera , Microphone , Headphone jack , Speakers , Accelerometer , Gyroscope , Wi-Fi , Bluetooth
- Datapath, control, and memory are a tiny portion of the components.

Chips

- Small rectangles that contain devices driving technology.
- Called integrated circuits (IC) or chips.
- A5 package contains two ARM processors operating at 1 GHz.

Processor (CPU)

- Active part of the computer.
- Follows program instructions exactly.
- Adds numbers, tests numbers, activates I/O devices.
- Also called CPU (Central Processor Unit).

Inside the Processor

- The Apple A5 microprocessor contains two main components:
  - Datapath:
    - Performs arithmetic operations.
  - Control:
    - Directs datapath, memory, and I/O devices according to program instructions.

Memory

- A5 package includes two memory chips.
- Each chip has 2 gibibits capacity → total 512 MiB.
- Stores running programs.
- Stores data needed by running programs.
- Built from DRAM chips.

DRAM (Dynamic Random Access Memory)

- Used together to hold instructions and data.
- Access time is the same regardless of memory location.
  - Different from sequential access memory (e.g., magnetic tapes).

Cache

- Located inside the processor.
- Small, fast memory.
- Acts as a buffer for DRAM.
- (Nontechnical definition of cache is safe place for hiding things)
- Built using SRAM (Static Random Access Memory).
- SRAM:
  - Faster than DRAM
  - Less dense
  - More expensive
- SRAM and DRAM form two layers of the memory hierarchy.

Safe Place for Data

- Memory inside the computer is volatile:
  - Data is lost when power is lost.
- DVD disk is nonvolatile:
  - Data remains without power.
- Volatile memory:
  - Holds data and programs while running.
  - Called main memory or primary memory.
- Nonvolatile memory:
  - Stores data and programs between runs.
  - Called secondary memory.

Secondary Memory

- Next lower layer of memory hierarchy.
- DRAM has dominated main memory since 1975.
- Magnetic disks dominated secondary memory earlier.

Flash Memory

- Nonvolatile semiconductor memory.
- Used in PMDs instead of disks due to size and form factor.
- Slower but cheaper than DRAM.
- Compared to disks:
  - Costs more per bit
  - Smaller
  - Comes in smaller capacities
  - More rugged
  - More power efficient
- Standard secondary memory for PMDs.
- Flash memory wears out after 100,000 to 1,000,000 writes.
- File systems must track writes and avoid wearing out storage by moving popular data.

Communicating with Other Computers

- Networks interconnect computers.
- Extend computing power through communication.
- Backbone of current computer systems.

Network Advantages

- Communication:
    - High-speed information exchange.
- Resource sharing:
    - Share I/O devices across computers.
- Nonlocal access:
    - Users can access distant computers.

Network Performance

- Networks vary in length and performance.
- Communication cost increases with:
    - Speed
    - Distance

Ethernet / LAN

- Most popular network type.
- Up to 1 km long - and transfer up to 40 gigabits per second.
- Example of LAN (Local Area Network).
- Connects computers on the same floor.
- LANs interconnected with switches for routing and security.

WAN (Wide Area Network)

- Cross continents.
- Backbone of the Internet and the Web.
- Based on optical fibers.
- Leased from telecommunication companies.

Network Impact

- Changed computing in the last 30 years.
- More ubiquitous.
- Dramatic performance increases.

Networking Technologies Evolution

- First standardized LAN:
  - 10 million bps maximum
  - Shared by tens or hundreds of computers
- Today’s LAN:
  - 1 to 40 gigabits per second
  - Shared by only a few computers

Optical Communications Technology

- WAN capacity growth:
  - From hundreds of kilobits to gigabits
  - From hundreds of connected computers to millions worldwide

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Wireless Technology

- Innovation reshaped communication.
  - Widespread.
  - Enabled Post-PC Era.
- Standard: 802.11
- Transmission rates: 1 to nearly 100 million bps.
- Different from wired networks:
  - All users share the airwaves in the same area.