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Task#7-8

Embedded Systems Concepts

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1- Computer Systems

A Computer System is a complete setup of hardware and software components, including a CPU, memory, input/output devices, and storage devices, that work together to perform computing tasks. It’s characterized by

its speed, accuracy, diligence, versatility, and storage capacity. The term “system” signifies the interconnectedness of these components.

2- Embedded Systems

These are computer systems that are integrated into a larger system to perform a specific task. They contain both hardware and software components, such as microprocessors, microcontrollers, volatile and non-volatile memory, graphics processing units (GPUs), input/output communication interfaces and ports, power supplies, and system and application code. Embedded systems can range from simple systems like controlling the speed of a DC motor using a microcontroller, to complex systems like creating a smartphone with embedded processors.

- **Microcontrollers :**

  These are integrated circuits that combine a processor core, memory, and input/output peripherals into a single chip. They are commonly used in embedded systems due to their compactness and cost-effectiveness. Microcontrollers are designed for specific tasks with integrated peripherals, while microprocessors are more versatile and handle general-purpose computing.

- **Microprocessors :**

  A microprocessor is a small chip that resides in computers and other electronic devices. Its basic job is to receive input and provide the appropriate output. While this may seem like a simple task, modern processors can handle trillions of calculations per second. The central processor of a computer is also known as the CPU, or “central processing unit.” This processor handles all the basic system instructions, such as processing mouse and keyboard input and running applications.

3- SBC - SOC

- ▢ **System on Chip (SoC) :**
  SoC stands for System on Chip. It is an integrated circuit or silicon chip that

has all the components fabricated on a silicon chip.

- SoC contains memory, oscillator, voltage regulator, ADC, DAC, processor, power management unit, USB, and UART.
- The processor is the heart of SoC, usually, SoC has multiple co-processors. It can be a microcontroller, microprocessor, or DSP.
- SoC is small in size and includes many features and functions. It consumes low power and is cost-effective.
- SoC is less adaptable as compared with SBC and is more expensive compared with SBC.
- SoC is used in smartphones, smartwatches, tablets, computers, and Internet of Things applications such as home automation.

▢ Single Board Computer (SBC) :

SBC stands for Single Board Computer. It is a whole computer constructed on a single printed circuit board that contains memory, processor, I/O devices, and other slots.

- The Blocks of the SBC contain a Power supply, Memory, ethernet port, GPIO pins, processor, SD card slot, HDMI connectors, and USB port.
- Processor is the heart of SBC usually ARM processor is used in SBC.
- SBCs are easy to use, have verified hardware, low power consumption, and good performance at a low price.
- SBC is more adaptable as compared with SoC and is less expensive compared with SoC.
- SBCs are used in flexible IoT gateways, smart assets monitoring, and Artificial Intelligence.

4- Intro to Embedded Systems (IC - MPU - MCU - DSP - ECU)

- **IC (Integrated Circuit) :**
  A small electronic device made up of multiple interconnected electronic components such as transistors, resistors, and capacitors.

- **MPU (Memory Protection Unit) :**
  A computer hardware unit that provides memory protection. It is usually

implemented as part of the central processing unit (CPU).

- **MCU (Microcontroller Unit) :**
  An intelligent semiconductor integrated circuit that consists of a processor unit, memory modules, communication interfaces, and peripherals.

- **DSP (Digital Signal Processing) :**
  The process of analyzing and modifying a signal to optimize or improve its efficiency or performance.

- **ECU (Electronic Control Unit) :**
  A small device in a vehicle's body that is responsible for controlling a specific function.

5- CPU
(Components - Fetch&Execute Cycle - Register Files)

- **CPU (Central Processing Unit) :**
  The CPU is the primary component of a computer that performs most of the processing inside the computer. It's often referred to as the "brain" of the computer.

- **Components of CPU :**

  ### 1- Control Unit (CU) :
  The CU controls the way input and output devices, the ALU, and the computer's memory respond to the instructions sent to the CPU.

  ### 2- Arithmetic Logic Unit (ALU) :
  The ALU is responsible for performing arithmetic and logical calculations.

  ### 3- Registers :
  Registers are part of a computer's memory that is used to store the

instructions temporarily to provide the processor with the instructions at times of need.

- **CPU Fetch and Execute Cycle :**

  - Fetch : Retrieve the next instruction from memory.
  - Decode : The Control Unit decodes the fetched instruction.
  - **Execute**: The decoded instruction is executed, and results are stored. This cycle repeats until the computer is shut down.

- **Register Files :**
  A register file is an array of processor registers in a CPU. The instruction set architecture of a CPU will almost always define a set of registers which are used to stage data between memory and the functional units on the chip. Register files are part of the architecture and visible to the programmer, as opposed to the concept of transparent caches.

6- RISC vs CISC

- **RISC (Reduced Instruction Set Computer) :**
  RISC is a type of CPU architecture that uses a small, optimized set of instructions for high performance and efficiency. The main idea behind RISC is to simplify hardware by using an instruction set composed of a few basic steps for loading, evaluating, and storing operations. This results in simpler instruction decoding, faster execution, and lower power consumption. However, RISC processors require more instructions to perform complex tasks, which can lead to increased memory usage and higher costs.

- **CISC (Complex Instruction Set Computer)** :
  CISC is a computer architecture in which single instructions can execute several low-level operations or are capable of multi-step operations or addressing modes within single instructions. The main idea behind CISC is

that a single instruction will do all loading, evaluating, and storing operations. This leads to reduced code size and more memory-efficient code. However, CISC processors take longer to execute instructions because they have more complex instructions and need more time to decode them. Also, CISC processors have more complex instruction sets, which makes them more difficult to design and manufacture.

7- Types of Memory (Volatile - non Volatile - Hybrid)

- **Volatile Memory :**
  This type of memory requires power to maintain the stored information. When the power is interrupted, the stored data is lost. Types of volatile memory include:

  ### 1- Dynamic RAM (DRAM) :
  Stores each bit of information in a different capacitor within the integrated circuit.

  ### 2- Static RAM (SRAM) :
  Does not need continuous electrical refreshes, but it still requires constant current to sustain the difference in voltage.

- **Non-Volatile Memory :**
  This type of memory can retain stored information even after power is removed. Types of non-volatile memory include:

  ### 1- Mask ROM :
  In this type of ROM, the data is written during the manufacturing process and cannot be electronically modified later.

  ### 2- Read-Only Memory (ROM) :
  Can only read from its memory; it cannot write to and also cannot modify

anything written to it.

3- Programmable ROM (PROM) :

Can be altered once after the memory device is manufactured.

4- Erasable Programmable Read-Only Memory (EPROM) :

This is a type of ROM that can be programmed and then erased by exposing it to UV light. The process of programming and erasing can be repeated several times

5- Electrically Erasable Programmable ROM (EEPROM) :

Can read, modify, and delete information if required.

6- Flash Memory :

A type of EEPROM that is erased and programmed in large blocks.

- **Hybrid Memory :**
  Combines the features of both volatile and non-volatile memory. It can be read and written as desired, like RAM, but maintain their contents without electrical power, just like ROM.

8- Cache Memory (FPU - MPU - MMU)

- **Cache Memory** :
  Cache memory is a type of computer memory that temporarily stores frequently used data for quick access. It's a high-speed memory type that a computer microprocessor can access more quickly than it can access regular RAM. This memory is used to store data that is likely to be used again, allowing future requests for that data to be served faster.

- **FPU (Floating-Point Unit) :**
  An FPU is a part of a computer system specially designed to carry out

operations on floating-point numbers. Typical operations are addition, subtraction, multiplication, division, and square root. Some FPUs can also perform various transcendental functions such as exponential or trigonometric calculations.

- **MPU (Memory Protection Unit) :**
  An MPU is a computer hardware unit that provides memory protection. It is usually implemented as part of the central processing unit (CPU). The MPU is a trimmed down version of the memory management unit (MMU) providing only memory protection support.

- **MMU (Memory Management Unit) :**
  An MMU is a computer hardware component responsible for handling accesses to memory requested by the CPU. It translates virtual addresses into physical addresses, providing memory protection and managing system memory.

9- CPU Architecture (Von Neumann - Harvard)

- **Von Neumann Architecture :**
  Named after mathematician John von Neumann, this is the foundational design principle for modern computers. It separates a computer's memory and processing unit (CPU), allowing program instructions and data to be stored and processed independently. The architecture consists of a Control Unit, Arithmetic and Logic Unit (ALU), Memory Unit, Registers, and Inputs/Outputs. The control and processing units make up the CPU, which contains the ALU, the general-purpose CPU registers, and some special-purpose registers. The Von Neumann architecture is based on the stored-program computer concept, where instruction data and program data are stored in the same memory.

- **Harvard Architecture :**
  This architecture contains separate storage and separate buses (signal path) for instruction and data. It was developed to overcome the bottleneck of Von Neumann Architecture. The main advantage of having separate buses for instruction and data is that the CPU can access instructions and read/write data at the same time. The Harvard architecture is historically, and traditionally, split into two address spaces.

10- Clock Systems (Mechanical - Electrical)

- **Electrical Clock Systems :**
  Electrical clocks convert electrical energy into mechanical motion, allowing the clock hands to rotate and indicate the time. They consist of several key components, including an electrical power source, an oscillator (such as a quartz crystal), and a series of gears and hands.

  ### 1- RC Oscillator :

  An RC (Resistor-Capacitor) Oscillator is a type of feedback oscillator that uses resistors and capacitors for its operation. It provides fast startup and low cost but generally suffers from poor accuracy over temperature and supply voltage, with variations of 5% to 50% of nominal output frequency.

- **Mechanical Clock Systems :**
  Mechanical clocks are complex devices that use various mechanisms to measure and display the passage of time. They consist of several key components: a mainspring, an escapement mechanism, a gear train, and a set of hands that indicate the time. The mechanical clock uses a clockwork as the motive force of the driving system, and drives the escapement governor to work through a transmission system composed of a set of gears.

2- Ceramic Oscillator :

A Ceramic Oscillator uses a ceramic material as the resonant element. It provides a more accurate output than an RC oscillator, but parameters like temperature can affect its accuracy. The accuracy for a ceramic oscillator is typically around 0.1% - 1% .

3- Crystal Oscillator :

A Crystal Oscillator uses a vibrating crystal (usually quartz) to generate an oscillating signal. It provides the most accurate output among the three, with an accuracy typically in the range of 10ppm-1000ppm. However, crystal oscillators are generally more expensive than RC or ceramic oscillators.

11- Mapping (Memory - Port)

- **Memory Mapping :**
  In memory-mapped systems, the I/O device is accessed like it is a part of the memory. Load and Store commands are executed for reading from and writing to I/O devices, just like they are used for the memory. This means I/O devices use the same address bus as memory, meaning that CPU can refer to memory or the I/O device based on the value of the address. This approach requires isolation in the address space: that is, addresses reserved for I/O should not be available to physical memory.

- **Port Mapping :**
  Port-mapped I/O often uses a special class of CPU instructions specifically for performing I/O. These instructions can read and write one to four bytes to an I/O device. I/O devices have a separate address space from general memory, either accomplished by an extra “I/O” pin on the CPU’s physical interface, or an entire bus dedicated to I/O. Because the address space for I/O is isolated from that for main memory, this is sometimes referred to as isolated I/O.

12- Bus Bridge

A Bus Bridge is a computer communication pathway used to connect two buses (groups of wires) that operate at different speeds. The bus bridge allows data to be transferred from one bus to another, usually at a higher speed. Computers have evolved different standards for interfacing with peripherals, etc. Common Bus Bridges you see are PCI to PCMCIA adapters that are actually bus bridges, or PCI-E to ExpressCard bus bridges . In a computer system, the role of a bus bridge is to communicate between the processor (or memory) and the input/output devices .

13- Hardware Ports (Master - Slave)

- **Master Ports :**
  In the context of hardware ports, a master port is typically associated with a device or process that controls one or more other devices or processes, known as slaves. The master initiates and controls the communication or data transfer process. It requests data from or sends data to the slaves. In a bus with many slaves, the master can communicate with all of them, but the slaves cannot communicate between them .

- **Slave Ports :**
  A slave port is associated with a device or process that is controlled by another device or process, known as the master. The slave cannot initiate a bus transaction. It must wait until the master communicates to it. The slave responds to the requests made by the master .

14- Transactions (Write - Read)

- **Read Transaction :**
  A read transaction is a process that involves obtaining data from a designated location, which could be memory, a register, or an input/output device. The sequence usually initiates with the entity requesting the data,

commonly a Central Processing Unit (CPU) or another device, dispatching a read request to the desired location. Subsequently, the specified location reacts to the read request by delivering the solicited data back to the entity that made the request.

- **Write Transaction :**
  A write transaction is a process that entails depositing or refreshing data at a designated location, which could be memory, a register, or an input/output device. Analogous to a read transaction, the sequence initiates with the entity, often a Central Processing Unit (CPU) or another device, dispatching a write request to the desired location, accompanied by the data to be stored. The specified location acknowledges the write request and modifies its contents with the supplied data.

15- AMBA
(Advanced Microcontroller Bus Architecture)

AMBA (Advanced Microcontroller Bus Architecture) is an open standard developed by ARM for the connection and management of functional blocks in a system-on-chip (SoC). It aids in the development of multiprocessor designs with numerous controllers and peripherals. Key AMBA specifications include AMBA CHI, AMBA AXI, AMBA AHB, and AMBA APB, each serving different purposes and applications. AMBA 5, the latest generation, introduces the Coherent Hub Interface (CHI) architecture for connecting fully coherent processors and high-performance interconnects.
