Kuwait University
College of Engineering and Petroleum

جامعة الكويت
KUWAIT UNIVERSITY

ME319 MECHATRONICS

Part I: The Brains - – Microcontrollers, Software and Digital Logic

Lecture 1: Microcontroller Architecture

Spring 2021

Ali AlSaibie

Lecture Plan

- Objectives:
  - Review the fundamentals of a microcontroller architecture

Anatomy of a Typical Mechatronic System

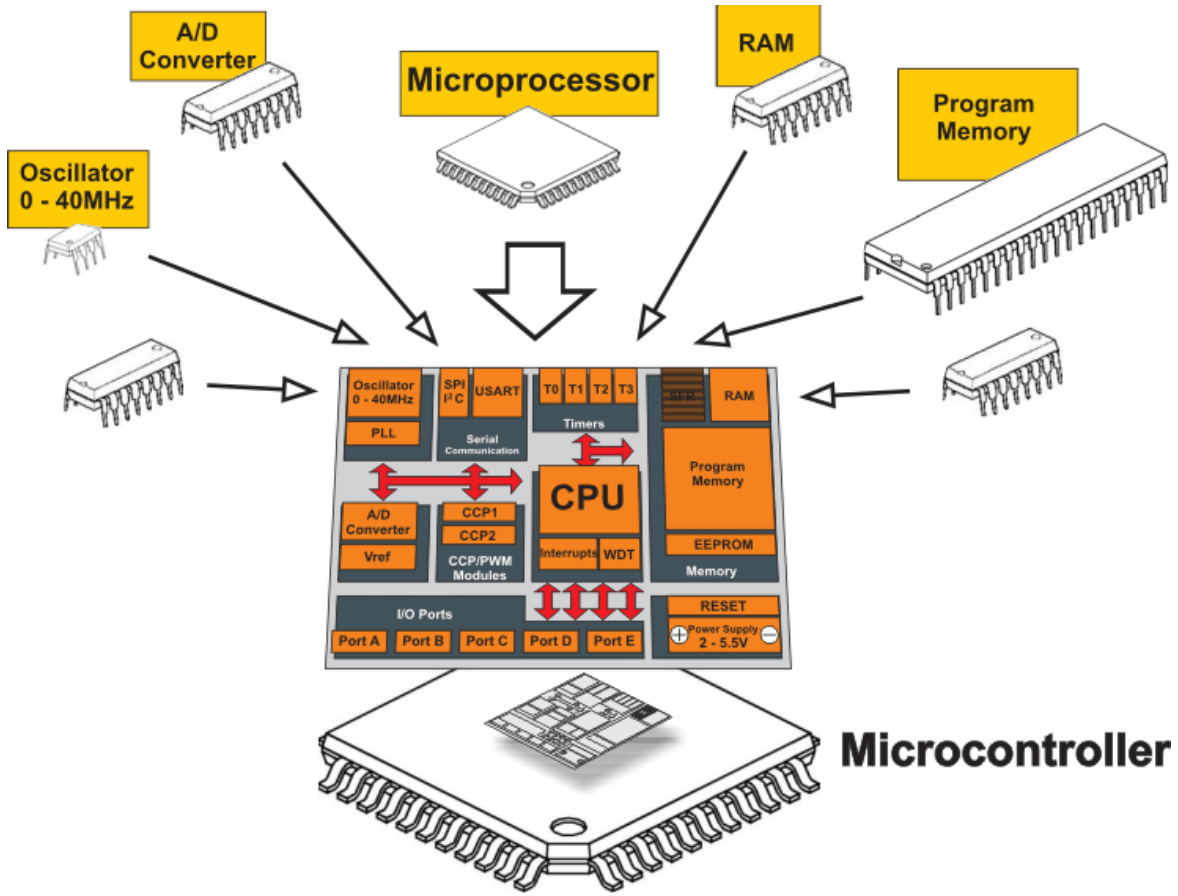
What is a microcontroller

- A microcontroller (abbreviated µC, uC or MCU), is a small computer on a single integrated circuit:
  - Contains at least a processor, memory, and general purpose input/output.
- Microcontrollers are the brains in modern systems:
  - Automotive, Robotics, Households, Manufacturing, Aerospace, Astrospace, Military, and much more
- Depending on their design they may include:
  - Analog/Digital converter, Clock generator, Memories (RAM, ROM, EEPROM, EPROM), serial input/output.
- Different companies make different types of microcontrollers, and they:
  - Differ in size, price, capabilities and applications.
  - Must be programmed to implement specific task.

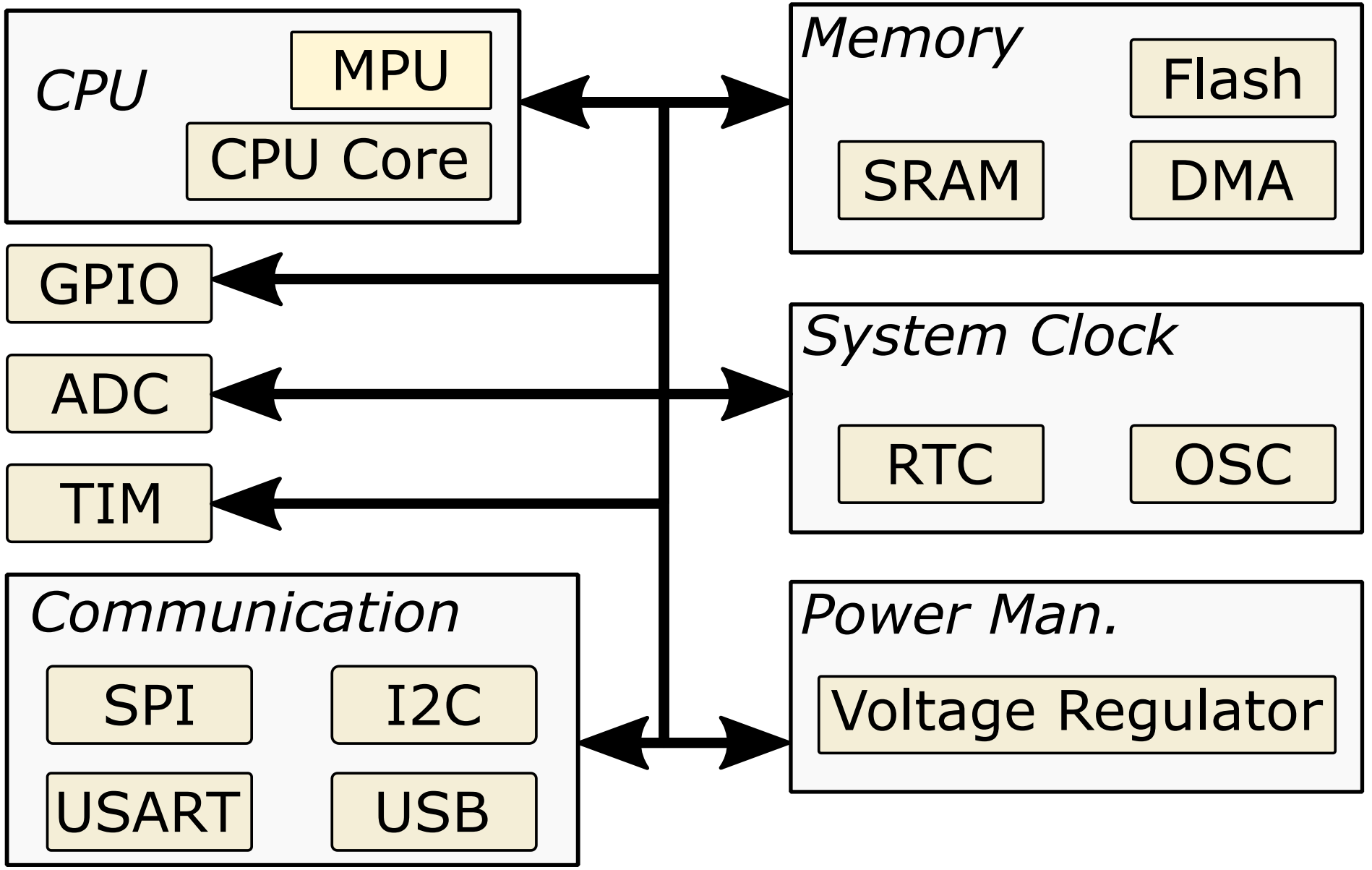
جامعة الكويت
KUWAIT UNIVERSITY

What is a microcontroller

- Microcontrollers include many sub-systems/components in small package.
- Connecting external components to Microcontrollers increase their functionality.



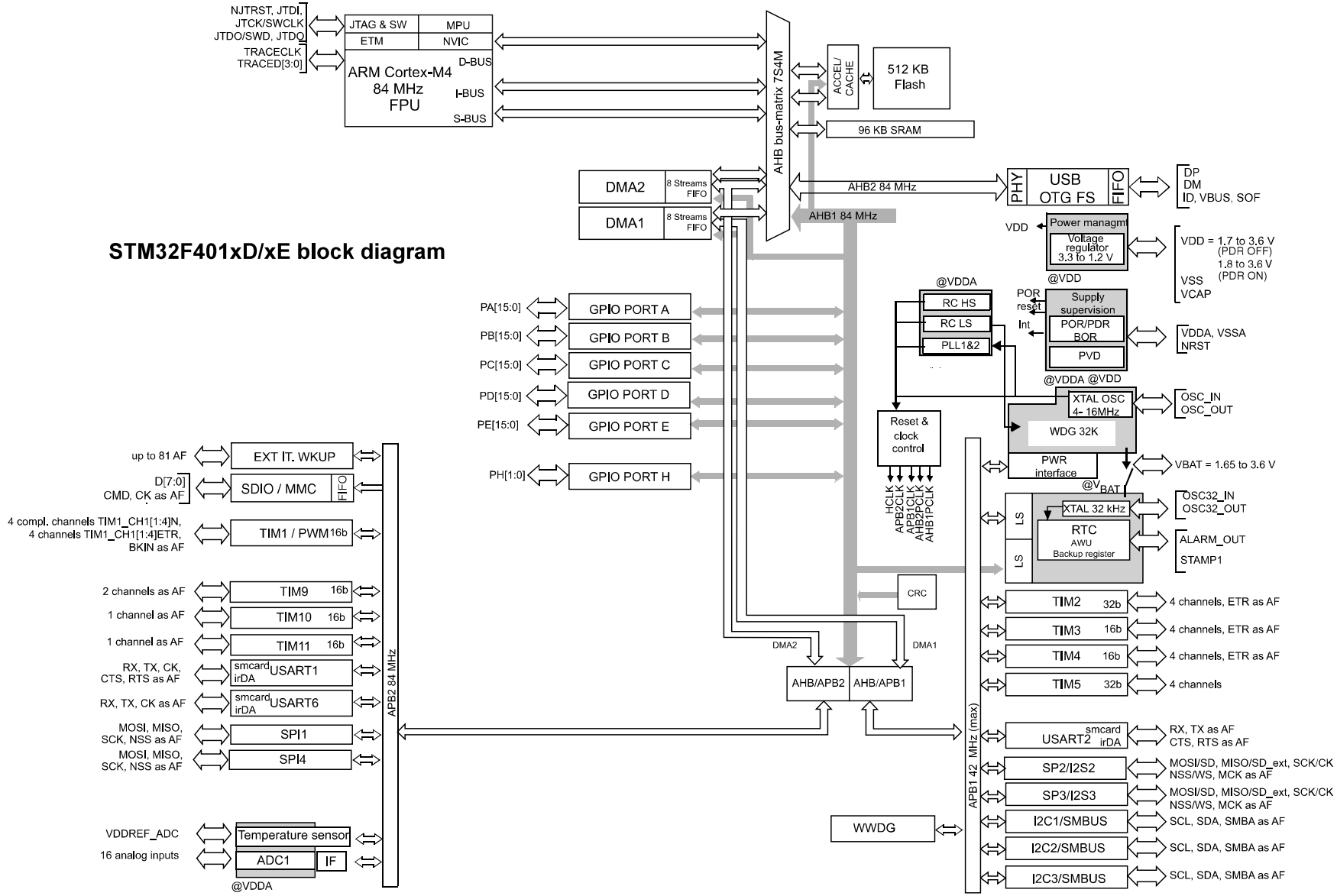
Microcontroller Architecture



- **CPU**: Central Processing Unit. **MPU**: Memory Protection Unit
- **GPIO**: General Purpose Input/Output
- **ADC**: Analog-to-Digital Conversion
- **RTC**: Real-Time Clock
- **OSC**: Oscillator
- **SRAM**: Static Random-Access-Memory. Flash: A Type of **EEPROM**
- **DMA**: Direct Memory Access
- **I2C**: Inter squared C, synchronous communication
- **SPI**: Serial Peripheral Interface, synchronous communication
- **USART**: Universal Synchronous/Asynchronous Receiver/Transmitter
- **USB**: Universal Serial Bus
- **TIM**: Timer

جامعة الكويت
KUWAIT UNIVERSITY

STM32F401xD/xE Block Diagram



Microprocessor vs. Microcontroller vs. DSP vs. FPGA

- Microprocessor
  - Only a Central Processing Unit (CPU): Intel CPU, AMD etc.
- Microcontroller
  - Encompasses CPU + Memory (RAM, ROM) + Peripherals (A/D, UART, etc.)
- DSP
  - Digital Signal Processor (Very similar to MCUs nowadays, but focused on fast math)
- FPGAs
  - Field Programmable Gate Arrays

جامعة الكويت
KUWAIT UNIVERSITY

CPU

- The functional heart of the microcontroller
- Its job is to retrieve data from memory or peripheral and manipulate the data
- Manipulate: Perform Logical/Math/Reorganize Operations
- A CPU does not store data within it, it only processes the data
- Data is represented as numbers, a combination of **1's** and **0's**

جامعة الكويت
KUWAIT UNIVERSITY

CPU Instruction

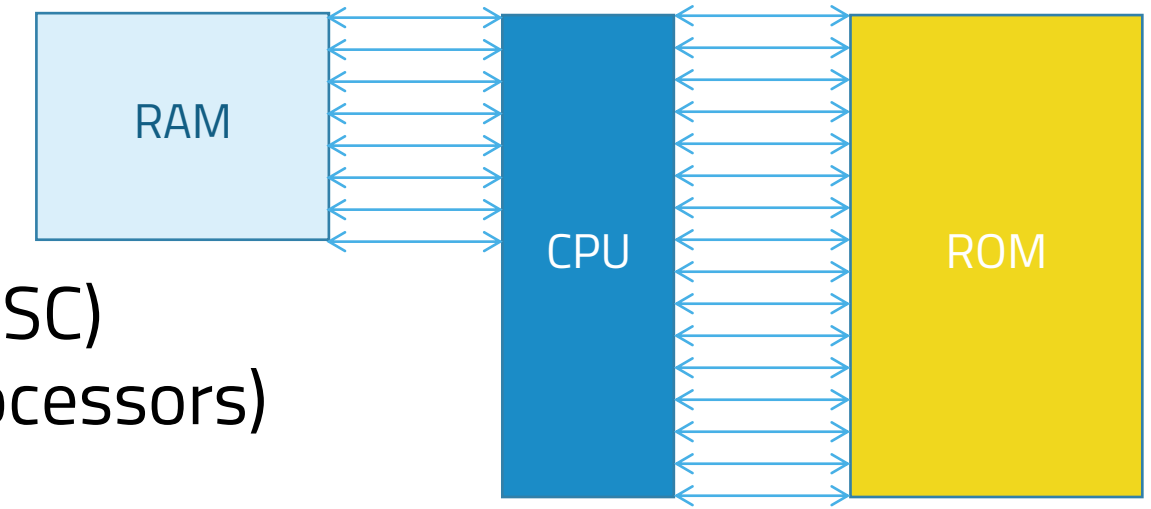
- Every CPU manufactured has a set of defined instructions, examples:
  - Retrieve data in address bank 2
  - Add data in address bank 1 to data in address bank 2
  - Move data from address bank 2 to address bank 3
  - Go to address bank 4, then execute the instruction saved there
- Some operational instructions are built into the CPU
- Other instructions are available to be used by the programmer
- Millions of simple instructions build up complicated programs
- The concept is true in 8-bit microcontrollers or 64-bit 16-core processors

جامعة الكويت
KUWAIT UNIVERSITY

CPU Architecture

- Von-Neumann Architecture
  - Complex Instruction Set Computer (CISC)
    - Still used by Intel and AMD (primarily)
  - Instructions Take >1 Cycle
  - Efficient RAM use

- Harvard Architecture
  - Reduced Instruction Set Computer (RISC)
    - Used by ARM, AVR (Embedded Processors)
  - Single-Cycle Instructions
  - Simple and standardized instructions
  - Emerged in 1980s



- Unless otherwise mentioned, we will be dealing with RISC

جامعة الكويت
KUWAIT UNIVERSITY

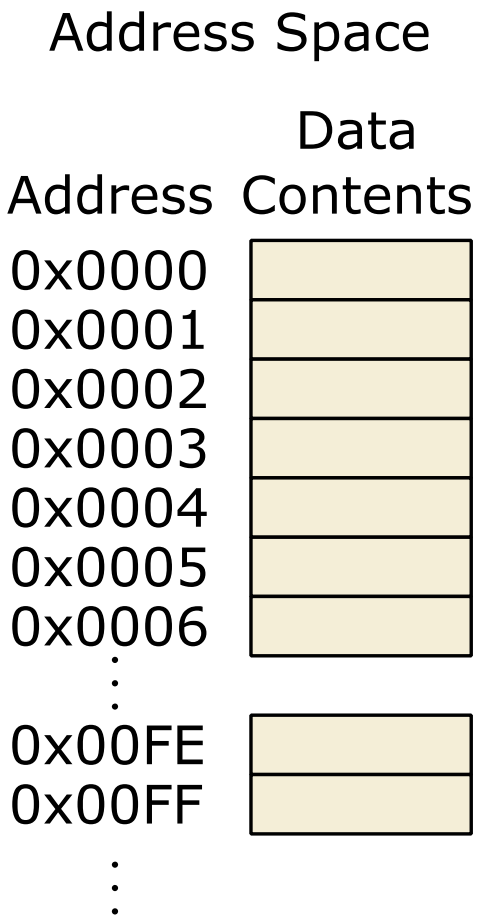
CPU Clock

- Processors loops through given instructions at a determined frequency
- Clock speed determines the frequency
- For MCUs the clock speed is normally fixed
  - Setup by the programmer
  - Can be reduced in a more complex program (hibernation, sleep)
- A CPU uses a type of oscillator to synchronized the clock
  - MCUs typically use a crystal oscillator (quartz, think of your wristwatch)
- Clock speed is related to energy use
  - Faster Clock setting -> More energy used
  - Faster not always better

جامعة الكويت
KUWAIT UNIVERSITY

Memory

- The same types of memory available in computers, can be used in MCUs
- MCUs generally come with Memory, and external memory can be connected
- Memory Map:
  - Memory content is reached via addresses
  - Each memory space has a distinct address
  - Memory space can be:
    - Data Memory
    - Program Memory
    - Control Registers
    - Interrupt Vectors



Memory Types

- Volatile vs. Non-Volatile
  - Volatile: Content will be erased if power is removed

Volatile Memory:

- RAM: Random Access Memory
  - SRAM: Static RAM – Typically Used for CPU Cache <- **MCU's Data Memory**
  - DRAM: Dynamic RAM – Typically used for Computer Memory

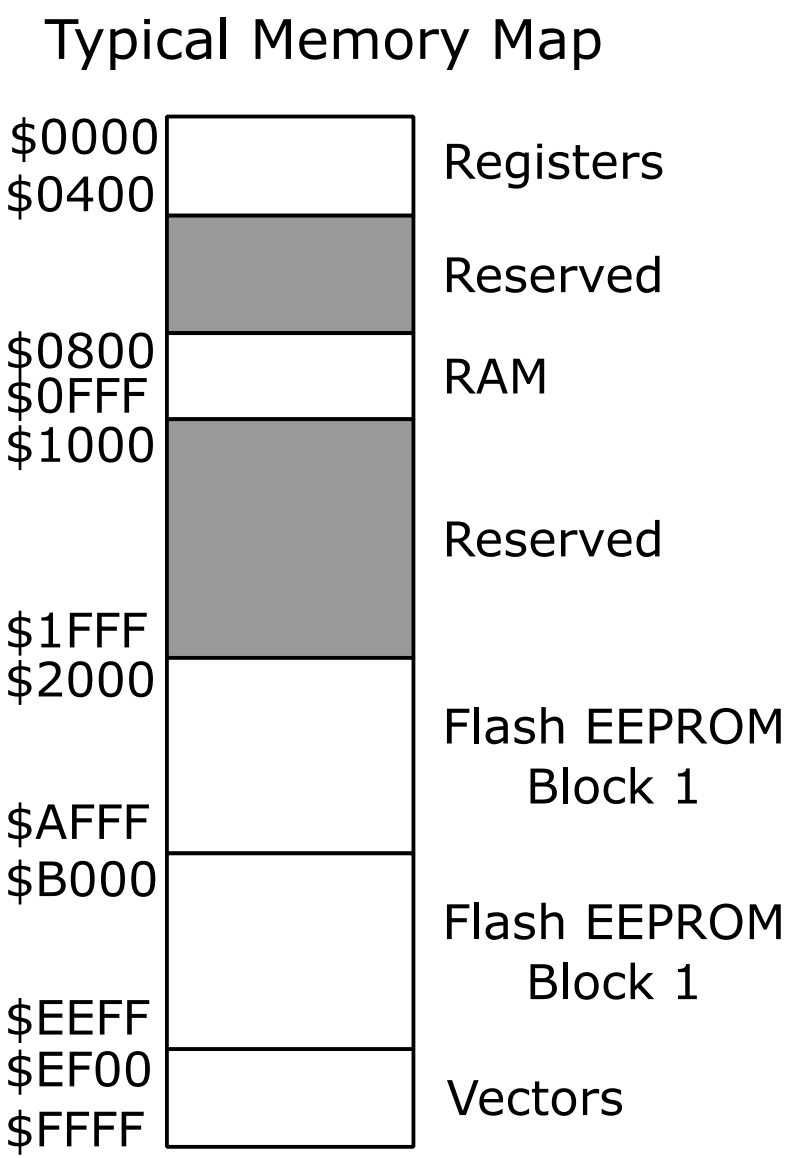
Non-Volatile Memory:

- EEPROM: Electronically Erasable Programmable Read Only Memory
- Flash Memory: A type of EEPROM **<- MCU's Program Memory**
- ROM: Read Only Memory <- **Small but available in MCU**

جامعة الكويت
KUWAIT UNIVERSITY

Memory Map

- The different types of memories inside a microcontroller are mapped in an organized fashion.
- The address range for each block is typically expressed using hexadecimal representation.
- The dollar sign indicates hex
- Hex can also be expressed by 0x prefix
- An 8-bit MCU means each memory address holds 8 bits of data
- A 16-bit MCU means each memory address holds 16-bits of data



Subsystems and Peripherals

- Most microcontrollers include additional subsystems + CPU + Memory
- Control Registers
  - Special memory locations where MCU is configured and controlled
- Input/Output Ports
  - Provide simple interaction with outside world
- Timers and Counters
  - Keep track of time, register time when events occured
- Serial Communication
  - Many different types: communicate with other sensors, other MCUs, other PCs
- Analog-to-Digital Convertors
  - Many sensors are analog, a special subsystem to convert readings to digital
- Digital-to-Analog Convertors
  - Emulate an analog signal
- And the list keeps growing every year