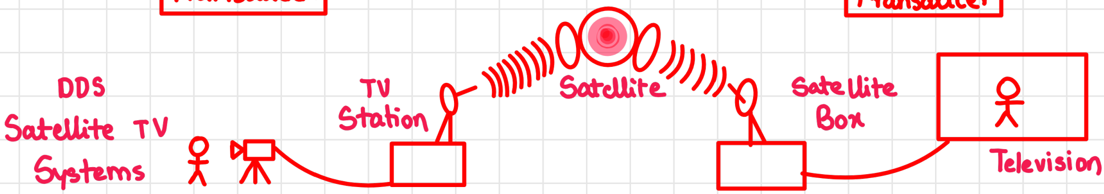
Communication Systems and Core of embedded Systems

COMMUNICATION SYSTEMS

- Communication
  - The process of transmission of an idea or feeling so that sender & reciever share same level of understanding

- Input → Input Transducer → Transmitter → Channel → Reciever → Output Transducer → Output



- Input Transducer
  - Converts message produced by a source to a form suitable for the communication system
  - Source :
    Analog / Digital

  ex: Speech waves, Microphone voltage

- Transmitter
  - Converts electrical signal into transmission suitable signal over a given medium
  - Transmission channel is the physical medium on which signal is carried
  - Every channel has some amount of distortion, noise and interference.

  ex: Air, wires, Coaxial cable, radio wave, laser beam, fiber optic cable

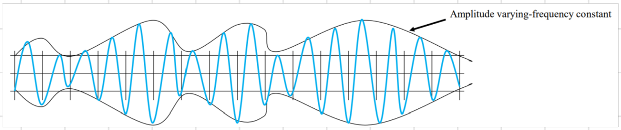
- Reciever
  - Device which recovers signal that is transmitted from the channel
  - Ideally, receiver output is scaled & delayed version of message signal
  - Practically, reciever signal will have signal component disturbed by noise

  ex: TV, Radio, Web Client

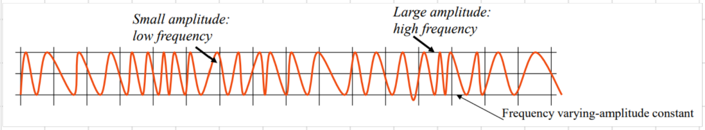
- Output Transducer
  - Converts electrical signal to desired form by system
  - Can be active or passive transducer based on whether power source is required or not
    - Active transducers don't need as they work on energy conversio
    - Passive transducers require external power source for operation

- MODULATION
  - The process of changing carrier signal characteristics according to the message signal
  - Types of Modulation
    - Continuous Modulation :
      - AM - Amplitude Modulation
      - FM - Frequency Modulation
    - Digital Modulation :
      - ASK - Amplitude Shift Keying
      - PSK - Phase Shift Keying
      - FSK - Frequency Shift Keying

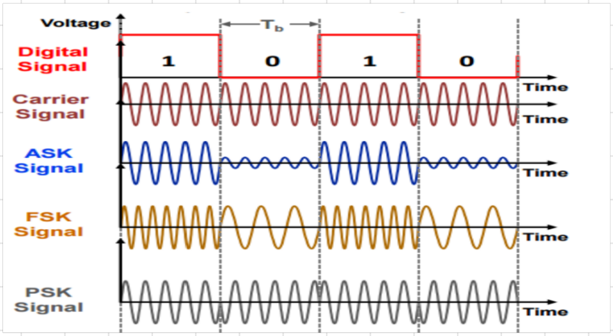
- Types of Analog Modulation :
  - Amplitude Modulation
    - Amplitude of carrier is varied according to message



  - Frequency Modulation :
    - Frequency of carrier is varied according to message



- Types of digital modulation :
  - Info is in 1's & 0's but carrier is continuous



Amplitude / Phase of carrier varies according to binary data

NEED FOR MODULATION

- Increases distance over which signal can be transmitted
- Reduces Antenna height
- Avoid Mixing of Signals
- Reduces Noise & Interference
- Multiplexing
- Helps adjust bandwidth

DEMODULATING

- Process of Recovering message from modulated signal
- 2 Types of Demodulation
  - Coherent → Local Oscillator is tuned to a frequency of carrier
  - Non- Coherent → No Local Oscillator

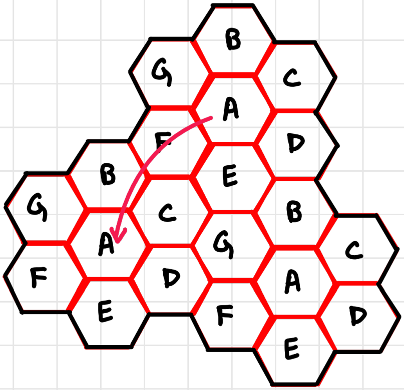
- Applications :
  - AM Radio → 0.54-1.6 MHz
  - TV → 54-88 (or) 174-216 MHz
  - FM Radio → 88-108 MHz
  - Cellular Mobile Radio → 806-901 MHz

CELLULAR CONCEPT SYSTEM DESIGN FUNDAMENTALS

- Goal of Cellular system :
  - High Capacity
  - Large Coverage Area
  - Efficient use of limited spectrum
- A single transmission :
  - Requires tall tower & high power
  - Provides only to small no. of users & has poor spectrum utilization
    - Inefficient

Only same frequency antennas communicate with each other

• Frequency Reuse Pattern



- **Cell** is a base station which is allocated a group of radio channels within a small geographic area.
- Neighbouring cells assigned different channel groups
- Channel groups maybe reused by limiting coverage area
- Keeps interface levels within tolerable limits
- Frequency reuse which includes 7 groups from A to G footprint of each cell in radio coverage
- Each cell uses omni-directional antenna

• Cellular Concept

- Solves problem of spectral congestion & user capacity
- Offers high capacity in limited spectrum w/o major technical change
- Helps in reuse of radio channel in different cells
- Enable fin no. of channels to serve an arbitrarily large no. of users by reusing channel throughout coverage region

• Cells

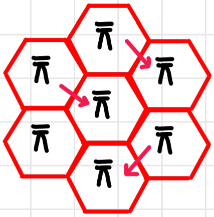
- Base station antennas designed to cover specific cell area
- Footprint ⟶ Hexagonal Shape
  Circle leaves gap (simple model for analysis)
  Actual footprint ⟶ Amorphous / No Shape
  - Tx successfully serves mobile unit ↗ 360° coverage
- Base Station location ⇒ Call center ⟶ Omni-directional antenna
(Not necessary to be in exact center, can be upto R/4 from ideal location
- Cell Corners → Sectored (or) directional antennas on 3 corners with 120° coverage

Antennas
Base Station

So, Cell has 3 antennas in center (or) antennas at 3 corners

HANDS-OFF STRATEGIES

- When mobile unit moves from one cell to another while call is in progress, MSC (Mobile Switching Centre) must transfer call to a new channel belonging to a new base station
  - New Voice & control channel frequencies
  - Often this is given higher priority than new call Because its better to deny new call than the one in progress



When person moves from one call center to another, MSC helps change frequency of that center instead of cutting the call

- There is some handoff threshold before which signal becomes too low, at which the channels switch to another Base Station

ROAMING

- A mobile moves into a different system controlled by a different MSC, called Intersystem handsoff

- Issues in Roaming:

GoS - Grade of Service

PRIORITIZING HANDSOFF

- Percieved GoS - service quality as viewed by users
- Service Quality ✓
  Voice Quality ✗
- Assign higher priority to handoff than new call as its more aggravating

QUEING HANDOFF REQUESTS

- Use time delay b/w handoff threshold & min. useable signal level to place the blocked handoff request in ueue
- So, requests & handoff can be prioritized as needed
- Calls are dropped if time period expires

GUARD CHANNELS

- % of total available cell channels exclusive for handoff makes less channels for new calls.
- No. of guard channels can be adjusted as per demand & no wastage of cells with low traffic

- Practical Hand off Considerations:
  - Mobile velocities are in a large range which is a problem
  - Small cell size leads to large number of handoffs.
  - MSC load is heavy when high speed users pass by b/w small cells

- UMBRELLA CELLS
  - Use different heights & Tx power levels to provide both large & small cell coverage
    Transmitter
  - Multiple antennas & Tx can be located at single location if necessary (saves on obtaining new tower licenses)
  - Large Cell → High Speed Traffic → Less Handoffs
    Small Cell → Low Speed Traffic → More Handoffs

ex: Shopping Malls, Office Park, Highway passing through an urban center.

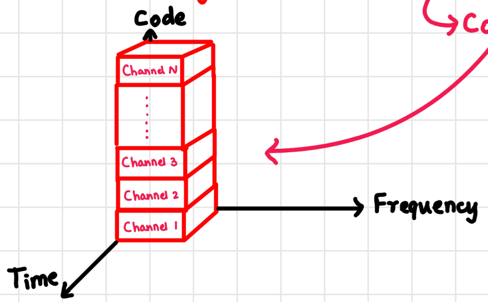
- Typical handoff Parameters

  - 1st generation – Analog Cellular
    - Threshold margin $\Delta \simeq 6-12$ Db
    - Total time to complete handoff $\simeq 8-10$ sec

  - 2nd generation – Digital Cellular
    - Threshold margin $\Delta \simeq 0-6$ Db
    - Total time to complete handoff $\simeq 1-2$ sec

- Benefits of Small handoff time
  - Greater flexibility in handling high/low speed users
  - Queing & Prioritizing handoffs
  - More time for rescuing calls in need of handoff
  - Fewer dropped calls
  - Can make desicions over wide range of metrics (other than signal str.)
  - Multidimensional algorithm for decision making
  - MSC also decides which signal is best and listens to that
  - Mobile user does nothing but transmit.
    MSC does all the work
  - Advantage unique to CDMA Systems (If enough codes are available)

    CDMA → Code Division Multiple Access



- **CO-CHANNEL INTERFERENCE**

  - During frequency reuse, many cells using same frequency lead to co-channel interference.
  - To reduce CCI, Co-channel cell must be seperated by min. distance

  - When size of cell is approximately same :
    - Co-channel interference is independant of transmitted power
    - Co-channel interference is a function of:

      R & D

      R → Radius of cell

      D → Distance to centre of nearest co-channel cell

      $Q = D/R$

      Q → Co-channel reuse ratio

- Embedded Systems
  - Embedding means attaching something over another thing
  - System is an arrangement in which all units assemble and work together according to some rules

- Embedded System is a special-purpose system in which computer is completely encapsulated by the device it controls

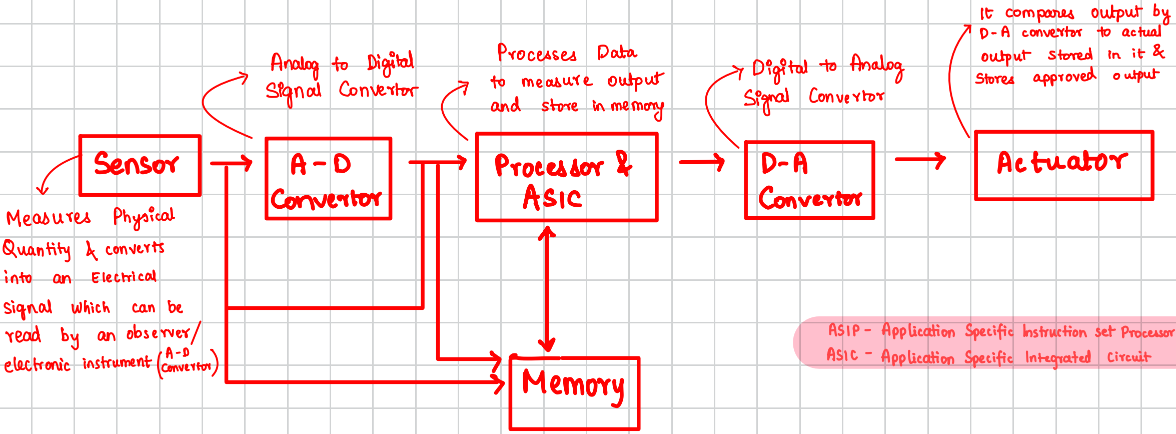
  It is a microcontroller/microprocessor based system designed to perform a specific task

- So, An Embedded System is a dedicated computer system, designed to work for one or many functions within a larger system

- They have 3 components :
  - Has hardware
  - Has application software
  - Has Real time operating system

Hardware ⇔ RTOS ⇔ Application Software

- RTOS supervises software & provides mechanism to let processor run a process as per schedule

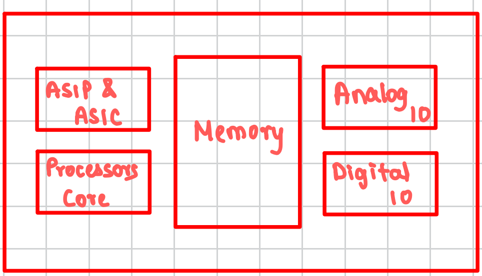


ASIP - Application Specific Instruction set Processor
ASIC - Application Specific Integrated Circuit

FEATURES OF EMBEDDED SYSTEM

- Single Functioned
  - Does a specialized operation & does it repeatedly
- Tightly Contained
  - Embedded Systems have 4 design metrics
    - power
    - performance
    - cost
    - size
  - It must be the size of a chip & must process fast enough data to process data in real time & consume min. power
- Reactive & Real Time
  - Embedded Systems must continuously be reacting to changes in system's environment & compute results in real time w/o delay
- Microprocessor Based
  - Must be based on microprocessors / microcontrollers
- Memory
  - Must have memory as software usually embeds in ROM
  - No secondary memories are required
- Connected
  - Must have connected peripherals to connect input & output device
- HW-SW Systems
  - Hard Ware - Performance & Security
  - Soft Ware - More features & flexibility

Q. What are the design metrics of Embedded System?
Q. Wdym by single functioned system?
Q. Explain features of Embedded System
Q. Wdym by tightly contained embedded system?



- APPLICATIONS OF EMBEDDED SYSTEMS
  - Consumer Electronics
    - TVs, Cameras, Printers, Computer, Video Game Consoles
  - Household Appliances
    - Fridge, Microwave, ACs, Washing Machine
  - Medical Equipment
    - MRI, CT, ECG Machines, BP Monitor, Glucometer
  - Automobiles
    - Fuel injection systems, anti-lock braking system, infotainment system, AC controls, ADAS
  - Industrial
    - Assembly lines, Feedback systems, Data collection Systems
  - Aerospace
    - Navigation & Guidance Systems, GPS
  - Communication
    - Routers, Satellite Phones

Q. Give some real life applications of E.S

Q. What are some advantages of E.S

- ADVANTAGES
  - Easy mass production
    Low price per piece
  - Highly Stable & Reliable
  - Very small. (Can be loaded & carried anywhere)
  - Fast & use less power
  - Optimize power usage
  - Improve product quality

CHARACTERISTICS OF EMBEDDED SYSTEMS

- All Systems are task specific
- Perform tasks within certain time frame
- Minimal or NO UI
- Designed to react to external stimulii & react accordingly
- Built to achieve certain efficiency levels
- Can't be changed (or) upgraded by users
- Microcontroller/Microprocessors are used to design Embedded Systems
- Hardware is used for security & performance
  Software is used for features

CLASSIFICATION OF EMBEDDED SYSTEM BASED ON DIFFERENT CRITERIA

- **Based on Generation**
  - 1st Generation → 8 bit microprocessor & 8 bit microcontroller. Simple Hardware circuit & firmware developed (ex: Digital Telephone & Keypads)
  - 2nd Generation → 16 bit microprocessor & 8 bit microcontroller. More Complex & Powerful than 1G (ex: SCADA Systems) — Supervisory Control And Data Acquisition
  - 3rd Generation → 32 bit microprocessor & 16 bit microcontroller. Concepts like DSPs, ASICs evolved (ex: Robotics, Media etc.,)
  - 4th Generation → 64 bit microprocessor & 32 bit microcontroller. Concepts of SoC, Multicore Processor evolved. Highly complex & powerful (ex: Smart Phones)

    SoC - System on Chips
- **Based on complexity & performance**
  - Small scale Embedded Systems → Simple application, Built around 8 or 16 bit μP / μC. Performance isn't time critical. ex: electronic toy
  - Medium scale Embedded Systems → Slightly complex, Built around 16 or 32 bit μP/μC. Usually contains O.S. ex: Industrial Machines
  - Large scale Embedded Systems → Highly complex, Built around 32 or 64 bit μP/μC or PLDs or Multicore Processors. Response time must be fast. ex: Mission Critical applications
- **Based on Deterministic Behaviour**
  - Applicable for 'Real time' systems
  - Task behaviour for embedded system can be:
    - Deterministic
    - Non-Deterministic
  - Based on Execution behaviour, Real time Embedded Systems can be:
    - Soft
    - Hard

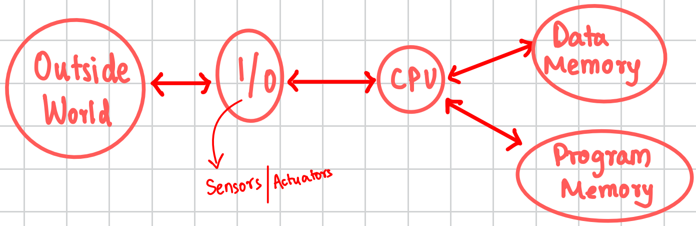
    ex: Digital Camera
  - Embedded systems which are 'Reactive' in nature can be based on triggering:
    - Reactive Systems can be:
      - Event triggered ex: Thumb impression reader & ATM
      - Time triggered ex: Alarms, Time bombs

> **SCADA Systems**
> - Category of Software applications for controlling industrial processes, which is gathering of data in real time from remote locations to control equipment & conditions

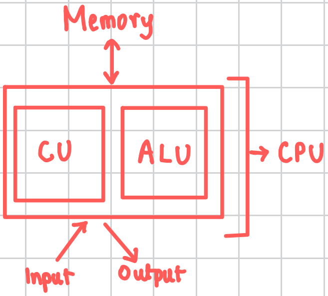
- CORE OF THE EMBEDDED SYSTEM

- Embedded Systems are domain & application specific & built around a central core
- They can be any among the following categories :
  - General Purpose & Domain Specific Processors
    - Microprocessors (MP)
    - Microcontrollers (MC)
    - Digital Signal Processors (DSP)
  - ASIC - Application Specific Integrated Circuits
  - PLDs - Programmable Logic Devices
  - COTs - Commercial Off-the-shelf Components

- 80% of the embedded system are processor/controller based
- Processor maybe MP/MC/DSP, depending on domain & application



- ## MICROPROCESSORS
  - It is a silicon chip, which represents only CPU
  - It doesn't consist of any other hardware component, other than CPU. Thus, it is a dependant unit & requires :
    - I/O Ports
    - ROM / Flash Memory
    - RAM, Counters, Timers etc.,



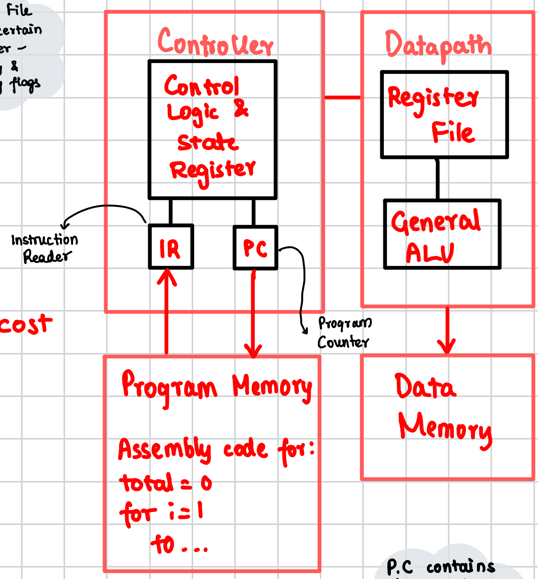
- Microprocessors & their developers :
  - Intel 4004 - Intel - Nov 1971
  - Intel 4040 - Intel
  - Intel 8008 - Intel - April 1972
  - Intel 8080 - Intel - April 1974
  - Motorola 6800 - Motorola
  - Intel 8085 - Intel - 1976
  - Z80 - Zilog - July 1976

ALU - Arithmetic & Logical Unit

- Processor's essential units :
  - CU - Program Flow Control Unit
    - Includes a fetch unit for fetching instructions from memory
    - Includes ALU & also circuits that execute instructions for program control task like interrupt (or) jump to another set of instructions
  - EU - Execution Unit
    - Has circuits that implement instructions pertaining to data transfer operation & data conversion from one form to another.
  - Processor fetches & executes instructions in same sequence as they were fetched from memory.

- **GENERAL PURPOSE PROCESSORS**
  - Also called microprocessor
  - Features :
    - Program memory
    - General Data path with larger register file & general ALU
  - Benefits
    - Low 'time-to-market' & NRE (Non-Returning Expenses) cost
    - High Flexibility
  - Pentium is a well known GPP

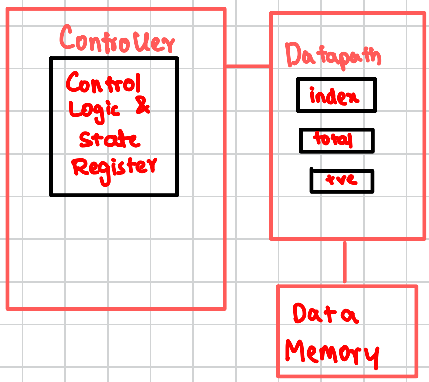
Register File contains certain flag register - zero, carry & auxillary flags



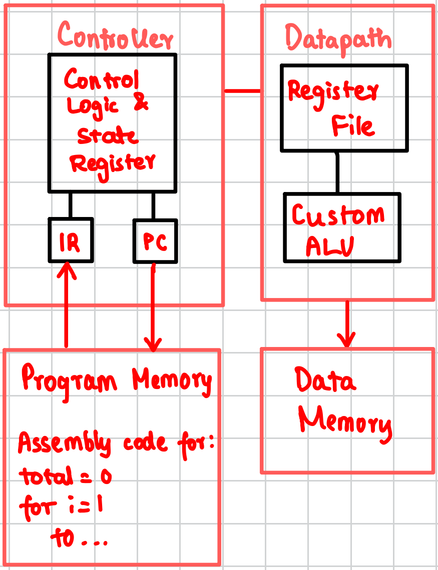
P.C contains address of the next instruction to be executed

IR stores the instructions temporarily

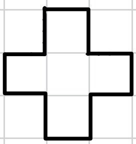
- **SINGLE PURPOSE PROCESSOR**
  - Digital Circuit executes only 1 program (coprocessor, accelerator, peripheral)
  - FEATURES :
    - Contains only required components to execute single problem
    - No program memory
  - BENEFITS :
    - Fast
    - Low power
    - Small size



- **APPLICATION - SPECIFIC PROCESSORS**
  - Programmable processor that is used for a specific class of application having common characteristics
  - Features :
    - Program Memory
    - Optimized Data Path
    - Special Functional units
  - Benefits :
    - Flexibility
    - Good Performance
    - Good Size
    - Good Power

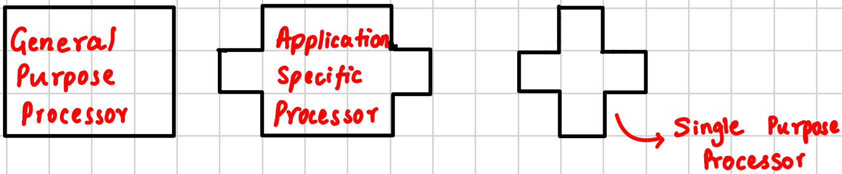


- Processors vary in their customization for the problem at hand



If this is the desired functionality

```
total = 0
for i = (1 to N) loop
total += M[i]
end loop
```

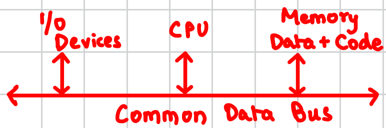
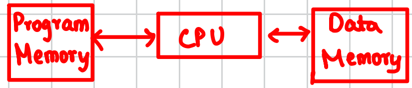


- MICROCONTROLLER
  - A single VLSI unit, although having limited computational compabilities, has enhanced I/O capability & a lot of on-chip functional units.
  - Usually used in real-time control applications with the following hardware components:
    - CPU
    - RAM & ROM
    - I/O Port
    - Timer
    - Serial COM Port

MICROPROCESSOR	MICROCONTROLLER
Consists of CPU, ALU & Registers	Consists CPU, I/O Ports, Counters, Timers, ROM, RAM etc.,
Mainly used in Personal Computers	Mainly used in Embedded System
Complex & Expensive, with lot of instructions to process	Simple & inexpensive with less no. of instructions to process
Dependant unit	Independant Unit
Consumes lot of power	Consumes less power
Limited Power Saving Options	Lot of Power Saving Options
Von Neumann Model based Architecture	Harvard Based Architecture
Uses external bus to interface RAM, ROM etc.,	Uses internal controlling bus

Build Smaller Chips (<3nm) in iphone 15

• Classification Based on Architecture

VON-NEUMANN ARCHITECTURE	HARVARD ARCHITECTURE
• Ancient Computer Architecture	Modern Architecture Technique
	
• CPU can't acess instructions & data at same time	CPU can access instructions & data at same time
• Same physical address is used for instructions & data	Seperate physical address is used for instructions & data
• Common bus is used for data & instruction transfer	Seperate bus is used for data & instruction transfer
• Slower speed of execution	Faster speed of execution
• Cheaper	Expensive
• More hardware required	Less hardware required
• Low performance	High performance
• Used in µCs & DSPs	Used in PC & small computer

- Classification Based on Instruction set

	RISC	CISC
•	Reduced Instruction Set Computer	Complex Instruction Set Computer
•	Software centric design	Hardware centric design
•	Low Power consumption	High Power consumption
•	Needs more RAM	Needs less RAM
•	Simple decoding of instruction	Complex decoding of instruction
•	Highly pipelined Processors	No or Less pipelined Processors
•	Less execution time	More Execution Time
•	Uses single register	Uses multiple registers
•	External memory required for calculations	No external memory required for calculations
•	Compound Addressing Mode	Limited Addressing mode
•	Used in high-end applications like telecommunication, image processing, video processing etc.,	Used in low-end applications like home automation, security system, consumer goods etc.,
•	Small code size	Large code size
•	Fixed Instruction Format (32 bit)	Varying Formats (16-64 bits)
ex	ARM, PIC, Power Architecture, Alpha, AVR, ARC & Spark	VAX, Motorola 6800 Family, System/360, AMD, Intel x86 CPU etc.,

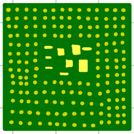
- DIGITAL SIGNAL PROCESSORS
  - DSPs are powerful 8/16/32 bit microprocessor which fulfills the demand & power constraints of embedded systems.
  - They are 2-3 times faster than general purpose microprocessors in signal processing applications.
  - DSPs implement algorithm in hardware → Faster Speed of Execution
    GPPs implement algorithm in software → Speed of Execution depends on Clock for processors

- Key units of DSPs :
  - Program Memory : Memory for storing program to work on data
  - Data Memory : Memory for storing temporary variable & data to be processed
  - Computational Engine : Performs signal processing in accordance with stored program memory.
    Many specialized ALUs & hardware shifters operate simultaneously to increase execution speed
  - I/O Unit : Interface b/w outside world & DSPs.
    They capture & deliver signals

- Operations performed by DSPs :
  - SOP (Sum of Products)
  - convulation
  - FFT (Fast Fourier Transform)
  - DFT (Discrete Fourier Transform)

- **Application Specific Integrated Circuit (ASIC)**
  - It is a microchip design to perform specific & unique applications
  - Only 1 chip is used in which several functions are integrated thereby, reducing system development cost.
  - Most ASICs are proprietary products, referred as ASSP
    Have some trade name
    Application Specific Standard Products
  - It consumes very small area with high capabilities (or) functionalities
  - Developers of such chips may prefer not to reveal much about internal detail.

ASIC



- **Programmable Logic Device's (PLD's)**
  - It is an electrical component used to build reconfigurable digital circuits
  - Logic gate → Fixed Function
    PLD → No fixed Function & can be reconfigured
  - Offers wide range of logic capacity, features, speed & voltage characteristics

  - PLD's are of 2 types:
    - CPLD – They offer much smaller amount of logic upto 1000 gates.
      Complex Programmable Logic Device
    - FGPA – They offers highest amount of performance, logic density, and features
      Field Programmable Gate Arrays

- **Commercial off-the-shelf components (COTs)**
  - It is a product that is developed around general purpouse (or) domain specific processor (or) ASIC (or) PDIs and is used 'as is'
  - They are readily available in market, so developer can cut down on the development time to a great extent
  - Advantages:
    - Ready to use
    - Easy to integrate
    - Reduces development time
  - Disadvantages:
    - The manufacturer may withdraw or discontinue the COT at any time when there is rapid change in technology

ex: POS (or) Card Machine,

Sensors & Actuators

- Sensor :
  - Used for taking input
  - It is a transducer which converts energy from one form to another for any measurement (or) control purpouse

  ex: Temperature Sensor

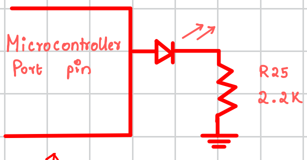
- Actuator
  - Used for giving output
  - It is a transducer which maybe mechanical or electrical which converts signal to corresponding physical actions.

  ex: LEDs

- LEDs :
  - It is a p-n junction diode & contains cathode & anode

    Anode ⇒ +ve end of power supply

    Cathode ⇒ −ve end of power supply

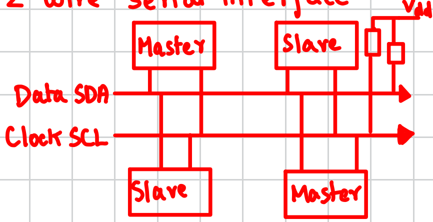


  - Max current flowing through LED is limited by connecting resistor is series b/w power supply & LED

  - There are 2 ways to interface an LED to $\mu p / \mu c$:
    - Anode of LED is connected to port pin & cathode to Ground
      - Port pin sources the current to LED when logic is high (ie. 1)
    - Cathode of LED is connected to port pin & cathode to V_{cc}
      - Port pin sinks currents & LED is turned on when logic is low (ie. 0)

V_{cc} : Power supply

- Communication interfaces are 2 types:
  - **Onboard Communication Interfaces**
    - Used for <u>internal communication</u> of embedded system
    - Synchronous, Bi-directional, half duplex, 2 wire serial interface
    - Developed for Philips Semiconductors



ex: I2C - Inter Integrated Circuit
- It comprises of 2 buses:
  - Serial Clock (SCL)
  - Serial Data (SDA)
    - SCL generates synchronized clock pulses
    - SDA transmits data serially across devices
    - I2C is a shared bus system to which many devices are connected
    - Devices connected by I2C can act as master (or) slave
    - Master device controls communication by initiating/terminating data
    - Devices acting as slave waits for master's commands & responds to them

SPI - Serial Peripheral Interface
UART - Universal Asynchronous Reciever Transmitter
1 Wire Interface
Parallel Interface

- **External / Peripheral Communication Interfaces**
  - Used for <u>external communication</u> of embedded system

ex: • RS-232C & RS-485
- It is wired, asynchronous, serial, full duplex communication
- RS-232 is the extension to UART
- It uses +3 to +25 V to signify '0' ⇒ Space
  and -3 to -25 V to signify '1' ⇒ Mark
- It is used only for point to point connections
- Susceptible to noise, thus limited to short distance
- RS485 supports 32 transmitters & receivers

- USB (Universal Serial Bus)
- IEEE 1394 (Fire Wire)
- Infrared (IrDA)
- Bluetooth
- Wi-Fi
- Zigbee
- General Packet Radio Service (GPRS)

Half Duplex
→ Can transmit & recieve data but 1 at a time

Full Duplex
→ Can transmit & recieve data at same time

Simplex
→ Can only recieve data

PURPOUSE OF EMBEDDED SYSTEMS

- Data Collection / Storage / Representation
  - Embedded System acquires data from external world
  - Usually done for storage, analysis, manipulation & transmission
  - Can be analog / digital

  ex: Digital Camera

TCP - Transmission Control Protocol
IP - Internet Protocol

- Data Communication
  - Embedded Systems used in complex satellite communication to simple home networking
  - Data transmission either by wire-line (or) wire-less medium
    - wire-line → USB, TCP-IP
    - wire-less → Bluetooth, Wi-Fi
  - Can be transmitted by analog / digital means

- Data Signal Processing
  - Embedded Systems used in speech coding, audio-video codec, transmission application etc.,

  ex: Digital hearing aid

- Monitoring
  - Embedded Systems used in medical field are usually have monitor functions

  ex: Electro-Cardiogram monitors heartbeat
  Digital CRO, Multi-meters, Logic Analyzers

- Control
  - Embedded Systems that have both sensors & actuators
  - Sensors connected to input port
    Actuators connected to output port

  ex: Air-Conditioner

- Application Specific User Interface
  - Designed to perform specific task within a broader domain

  ex: Buttons, Switches, Keypad, Lights, Bells, Display units, Mobile phones etc.,

- **MEMORY**
  - It is required for holding data temporarily during certain operations
  - On chip : built-in memory
    Off chip : external memory connected with controller / processor for storing
  - Program Storage Memory
  - Also called cold storage of ES.
    ↳ Stores program instructions even when device is turned off.

Floating Gate
→ It is a kind of a transistor commonly used for non-volatile storage like FLASH, EPROM, EEPROM.
→ They are called cuz of ability to store an electrical charge for extended periods of time w/o power supply

MEMORY

RAM

Working memory of Controller/processor where it can read & write from
It is volatile

RAM → SRAM, DRAM, NVRAM, Memory according to interface

STATIC RAM
- Fastest form of RAM
- Made of flip flops & stores data in form of voltage
- Has 6 MOSFETs/CMOS → 4 for Latch, 2 for controlling access
- Limitation is Low Capacity & high cost

CMOS - Complementary Metal Oxide Semiconductor

DYNAMIC RAM
- Stores data in form of charge
- High Density & Low Cost
- Since data is stored as charge, it gets leaked & refreshing required
- Special circuits like DRAM controller are used for refreshing
- Writes faster than read

used in smartphones

NON VOLATILE RAM
- RAM with battery backup
- Contains static RAM based memory
- Lifespan around 10 years

ex: DS1744 from Maxim/Dallas

MEMORY ACC. TO INTERFACE
Classification. Not a memory lol

- ‖el Interface : ‖el data lines for 8 bit processor/controller connected to memory (in Kilobytes)
- Serial Interface : 2 line Serial interface (used in EEPROM, in Kilobits)
  ex: AT24C512 (512 K bits)
- Semi Peripheral Interface : 2+n line interface
  SPI n = total no. of SPI bus devices in system
- Single Wire Connection

ROM

ROM → MROM, PROM, EPROM, EEPROM, FLASH

MASKED ROM
- One Time Programmable Device
- Use hardwared technology to store data
- Low cost for high production
- Good candidate for storing embedded for low cost embedded device
- Limitation is inability to modify device firmware against upgrades
- Programmed by manufacturer

PROGRAMMABLE ROM
- End user can program memory
- Consists of polysilicon or nichrome wires functionally viewed as fuses
- Fuses which aren't burned → logic '1'
  Fuses which are burned → logic '0'
- OTP/PROM used in commercial production of ES
- Programmed by End User

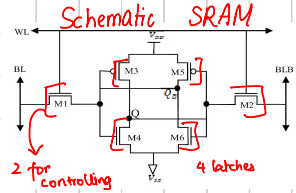
ERASABLE PROGRAMMABLE ROM
- EPROM gives flexibility to re-program same chip
- Stores bit information by charging the floating gate of FET to high voltage
- Contains quartz crystal window, which absorb UV rays & erases memory
- Limitation is erasing memory is a tedious & time-taking process

ELECTRICALLY ERASABLE PROGRAMMABLE ROM
- Info contained can be reprogrammed in-circuit using electrical signals at Byte level
- Provides more flexibility for system design
- Limitation is capacity (Only Kb)

FLASH
- Latest ROM tech which combines reprogrammibility of EEPROM & high capacity standards of ROM
- Organized as sectors / pages
- Stores info in array of floating gate of MOSFET
- Each sector is erased before reprogramming & done at sector/page level w/o affecting sector / page
- Typical erasable capacity is 1000 cycles

ex: W27C512 from WINDBOND

Schematic SRAM



2 for controlling
4 latches

- **ARM PROCESSOR**
  - Short for Advance RISC Machines
    ↳ Reduced Instruction Set Computing
  - Founded in 1990
    Owned by Acorn, Apple & VLSI
  - It is one of the most licensed & widespread processor cores in the world
  - Used in portable devices because of low power consumption & reasonable performance
  - It also has high code density especially in devices like mobile phone & mass storage devices which have limited on-board memory
  - Applications:
    PDA, cell phones, multimedia players, handheld consoles, TVs & Cameras

- ARM has several processors that are grouped into many no. of families based on processor core that they are implemented with
  ex: ARM7, ARM9, ARM10, ARM11

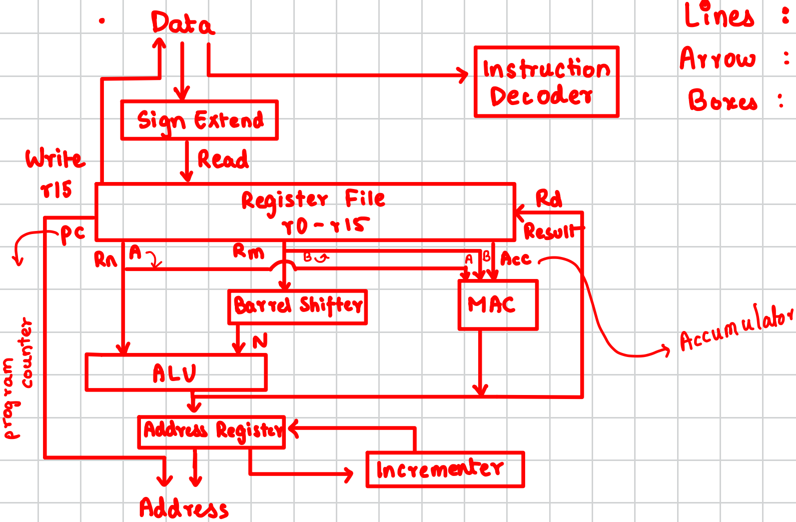
- RISC Characteristics
  - <u>Instructions</u>: Each instruction has a fixed length (So, pipeline can fetch future instructions before decoding current one) & because of this, it can execute in only 1 cycle.
    CISC has variable size & takes many cycles to execute
  - <u>Pipeline</u>: Instructions can be decodes in 1 pipeline stage where they they are broken into smaller units & executed in $||^{el}$ by pipelines
    This is to get maximum throughput
    CISC uses a seperate device, microcode to execute instructions
  - <u>Registers</u>: RISC has large register which contains data or address
    It acts as fast local memory store (all data)
  - <u>Load-store architecture</u>: RISC operates on data in registers so that memory access isn't used, because its costly.
    CISC operates directly on memory

- Features of ARM7
  - 32 bit Processor
  - 32 bit ALU
  - 32 bit Data bus
  - 32 bit Instructions
  - 32 Address bus
  - Von Nevmann Architecture
  - 3 Stage Pipelining

PADI AB VN 3P

- Fundamentals of ARM Processor
  - Data

Lines : Data buses
Arrow : Flow of Data
Boxes : Operation unit/storage area



- <u>Instruction Decoder</u> : Translates instructions into the address in micro memory where decoding begins
- <u>Sign Extend</u> : Data passes in register file through this block. It has 32 bit registers. It converts 8 & 16 bit numbers to 32 bit.
- <u>Register File</u> : ARM has Load - Structure architecture
  Load - Copy data from memory to registers (Read)
  Structure - Copy data from registers to memory (write)
- Rn-A, Rm-b, Rd-Result : Rn & Rm are source registers & carry value of variables
  A & B are internal buses which read source operands
  Rd is destination register which carries final output from ALU

- **ALU & MAC** :
  - ARM has 2 processing units
    ALU : Arithmetic Logic Unit
    MAC : Multiply & Accumulate Unit
  - Both take Rn & Rm register values from Buses A & B
    They perform operations & compute result
  - Stores result directly to Rd register
    Result bus carries final output

Matrix Multiplication

$$\begin{bmatrix} 1 & 4 & 6 \end{bmatrix}\begin{bmatrix} 2 & 3 \\ 5 & 8 \\ 7 & 9 \end{bmatrix} = \begin{bmatrix} 64 & 89 \end{bmatrix}$$

$= (1 \cdot 2)+(4 \cdot 5)+(6 \cdot 7) = 64$

$= (1 \cdot 3)+(4 \cdot 8)+(6 \cdot 9) = 89$

- **Address Register** :
  - Load Store instructions use ALU to generate address
  - Address is held in Address register
  - Address is broadcasted through address bus
- **Barrel Shifter** :
  - Registers Rm can be alternatively preprocessed in barrel shifters before it enters ALU
  - Barrel Shifter shift bits by bits data for processing
  - They check wide range of expressions & addresses
- **Incrementer** :
  - For load & Store instructions having incrementer for updating the next sequential address in Address Register or Memory location
  - After incrementing, next read/write is performed
  - It keeps executing instructions until an exception is generated else normal execution flow is there

Left Shift

0010 = 2 ⟹ 0100 = 4

Right Shift

1000 = 8 ⟹ 0100 = 4

- ARM has 37 Registers :
  All are 32bit
  - 1 dedicated program counter
  - 1 dedicated current program status register
  - 5 dedicated saved program status register
  - 30 General purpouse registers
    ↳ 20 of them are hidden, shown only when processor is in particular mode
    ↳ Called banked Registers

- Stack point - Stores head of stack in current processor mode
- Link register - Core puts return address when it calls a subroutine
- Program counter - Contains address of next instruction to be fetched by processor
- In ARM state, R0 - R15 registers are orthogonal
- Instructions applied to R0 equally apply to all other registers as well

- Current Program Status Register
  - 32 bit register
  - Contains the present status of internal operation
  - ARM uses CPSR to monitor & control internal operations

Flags				Status / Extensions	Control			
31	30	29	28		7	6	5	4 0
N	Z	C	V		I	F	T	Mode
Condition flags					Interrupt Masks			Processor mode

- PROCESSOR MODES
  - User - Unpriviliged mode under which most tasks run
  - FIQ - Entered when high priority is raised
  - IRQ - Entered when low priority is raised
  - Supervisor - Entered on reset & when software interrupt instruction is raised
  - Abort - Used to handle memory access violation
  - Undefined - Used to handle undefined instructions
  - System - Privileged mode using same registers as user mode

- Processor mode
  - It determines which registers are active the access rights to the CPSR register itself

  - Non-Privilegaded Mode
    - Read access to control field to CRSP
    - Read write access to conditional flags
    - User

  - State & Instruction sets
    - State of core determines which instruction set is being executed
    - 3 Instruction sets are :
      ARM-ARM State, Thumb-Thumb State, Jazelle-Jazelle State