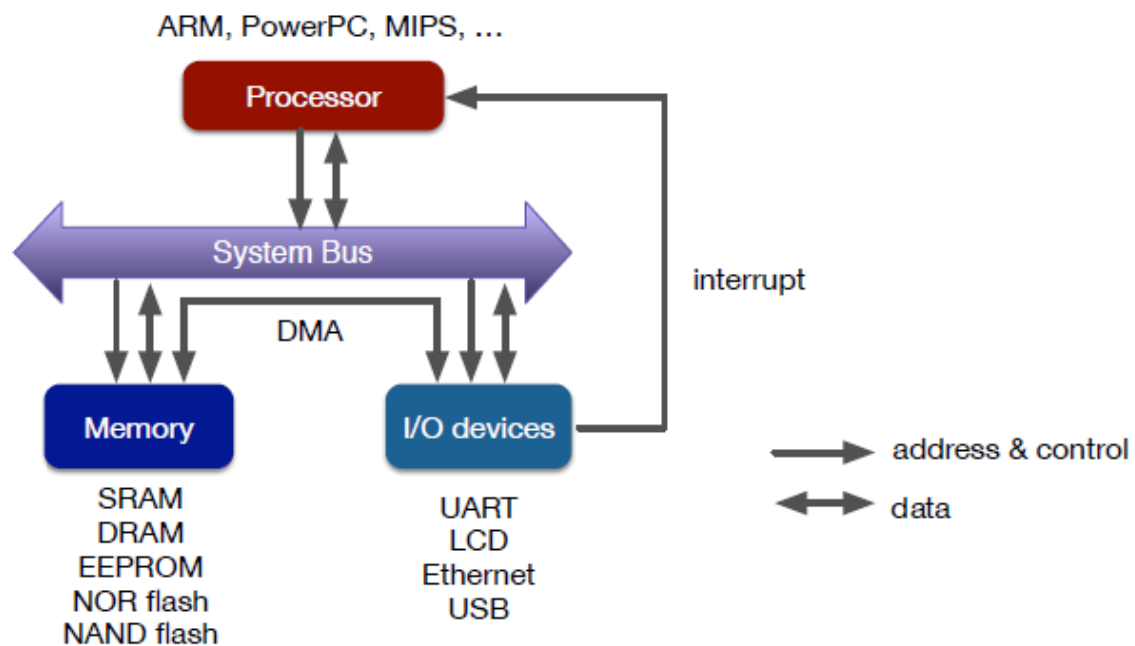


Memory Systems

Embedded HW Structure



Role

- Workspace for computer programs
- Permanent storage for programs and data

Abstraction of memory

- Virtually **flat** memory space
 - A single **logical address space** from an application perspective
 - **Assume** an ideal memory : read/write any location in 1 CPU clock

Implementation

- **Impossible** to implement using a single type of memory device
- A well-implemented "**Memory Hierarchy**"
- Composed of a set of memory **subsystems**
 - Caches, DRAMs, disks, tapes, distributed file systems, etc.

Goal

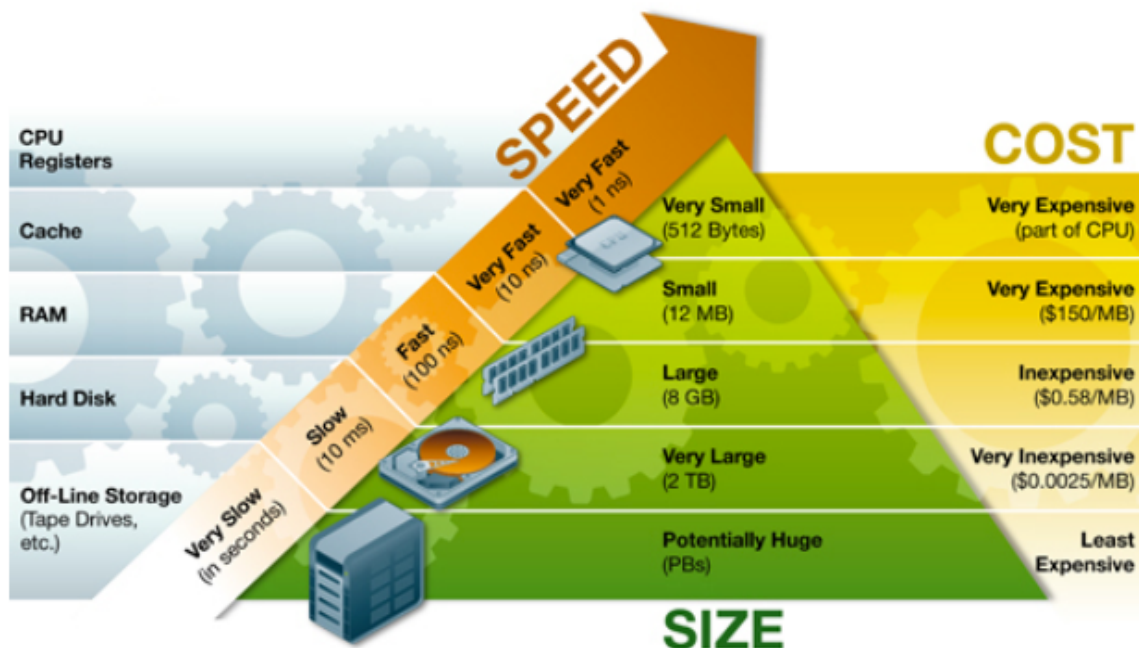
- Simultaneously achieve **speed & capacity**
 - Speed : to provide the performance of the fastest component
 - Capacity : At a cost of the cheapest component

Locality of reference

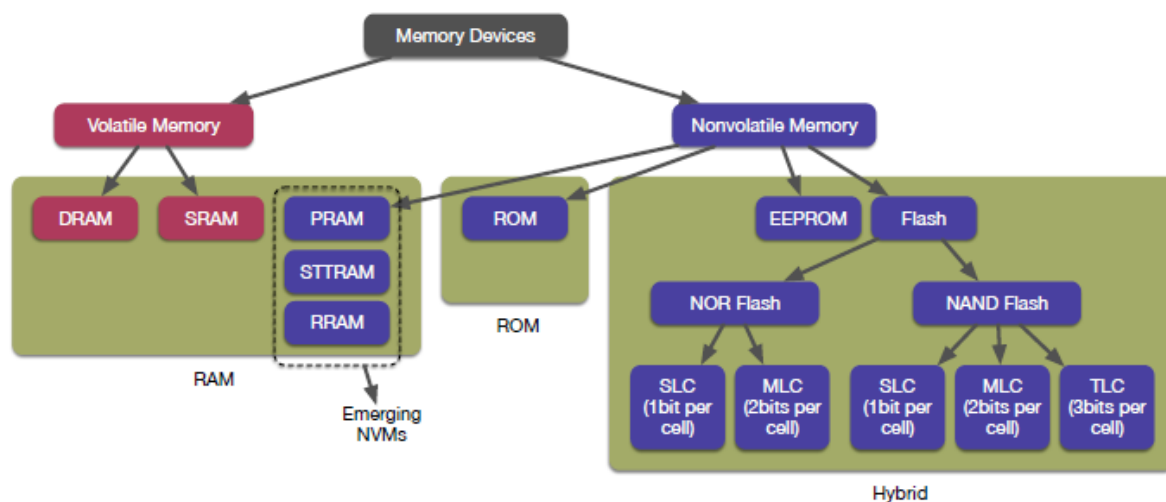
- The key to memory hierarchy design

| Temporal Locality | Spatial Locality |
|---|---|
| If one memory location is referenced, it will be highly likely to be referenced again in the near future. | If one memory location is referenced, its neighbor will be highly likely to be referenced in the near future. |

Memory Hierarchy



Memory Taxonomy



SRAM(Static RAM)

- 4T or 6T Structure (T = Transistor)
- **Volatile** : Data is lost when not powered
- **Stable** : Holds value as long as power applied
- Very **fast** (~tens of ns) : Suitable for L1 and L2 caches
- Very **expensive** : Typical size range : tens of Kbits ~ several Mbits

DRAM(Dynamic RAM)

- 1T1C Structure (C = Capacitor) : The charge gradually leaks off
- **Volatile** : Data is lost when not powered
- **Unstable** : Data is lost without a periodic refresh
- **Destructive read** (charge consumed by read) : Must rewrite after read
- **Fast** (~hundreds of ns) : Suitable for main memory
- Very **Expensive** : Typical size range : several **Gbits**

Flash Memory

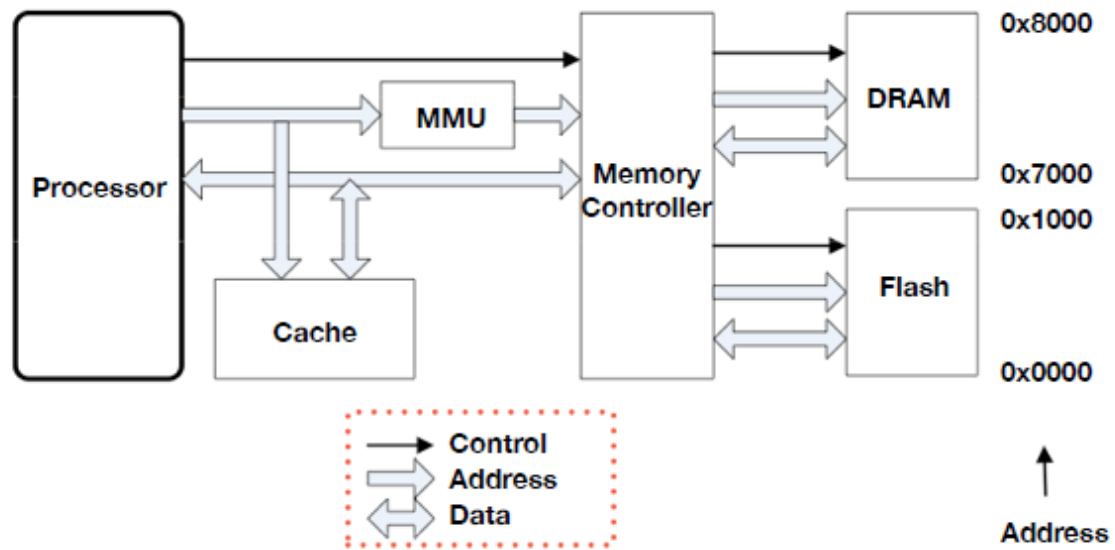
- **Operation principle**
 - Electrons trapped in the floating gate
- **Nonvolatile**
 - Electrons remain without power supply
 - Can be removed when high voltage supplied (erase operation)
- **Read/Write(Program) Unit**
 - Page (1KB ~ 4KB)
- **Erase Unit** : Block tens of pages
- **Out-place update**
 - Erase-before write constraint
 - Requires garbage collection

Multi-Level Cell Flash

- Store **two or more bits per cell**
 - Fine-grained control of the amount of charge to be stored
- Features
 - Lower **cost-per-bit**
 - Slower **program speed**
 - Slower **read speed**
 - Decreased **write endurance**
 - Decreased **data retention time**



Memory System Structure



I/O Systems
