

# Module 2

## Embedded Processors and Memory

Lesson

6

Memory-II

## Instructional Objectives

After going through this lesson the student would

- Memory Hierarchy
- Cache Memory
  - Different types of Cache Mappings
  - Cache Impact on System Performance
- Dynamic Memory
  - Different types of Dynamic RAMs
- Memory Management Unit

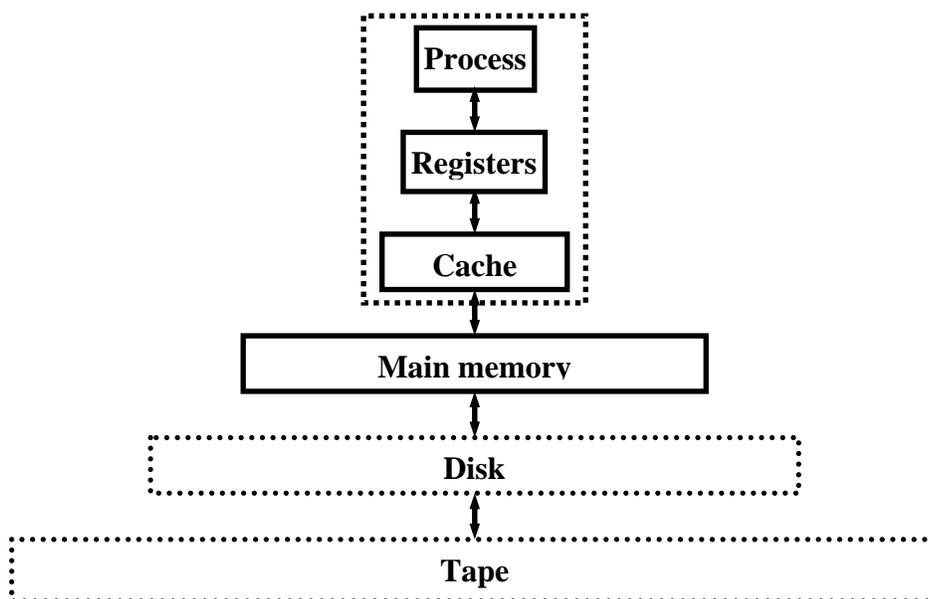
## Pre-Requisite

Digital Electronics, Microprocessors

### 6.1 Memory Hierarchy

Objective is to use inexpensive, fast memory

- Main memory
  - Large, inexpensive, slow memory stores entire program and data
- Cache
  - Small, expensive, fast memory stores copy of likely accessed parts of larger memory
  - Can be multiple levels of cache



**Fig. 6.1 The memory Hierarchy**

## 6.2 Cache

- Usually designed with SRAM
  - faster but more expensive than DRAM
- Usually on same chip as processor
  - space limited, so much smaller than off-chip main memory
  - faster access (1 cycle vs. several cycles for main memory)
- Cache operation
  - Request for main memory access (read or write)
  - First, check cache for copy
  - cache hit
    - copy is in cache, quick access
  - cache miss
    - copy not in cache, read address and possibly its neighbors into cache
- Several cache design choices
  - cache mapping, replacement policies, and write techniques

## 6.3 Cache Mapping

- is necessary as there are far fewer number of available cache addresses than the memory
- Are address' contents in cache?
- Cache mapping used to assign main memory address to cache address and determine hit or miss
- Three basic techniques:
  - Direct mapping
  - Fully associative mapping
  - Set-associative mapping
- Caches partitioned into indivisible blocks or lines of adjacent memory addresses
  - usually 4 or 8 addresses per line

## Direct Mapping

- Main memory address divided into 2 fields
  - Index which contains
    - cache address
    - number of bits determined by cache size
  - Tag
    - compared with tag stored in cache at address indicated by index
    - if tags match, check valid bit
- Valid bit
  - indicates whether data in slot has been loaded from memory
- Offset
  - used to find particular word in cache line

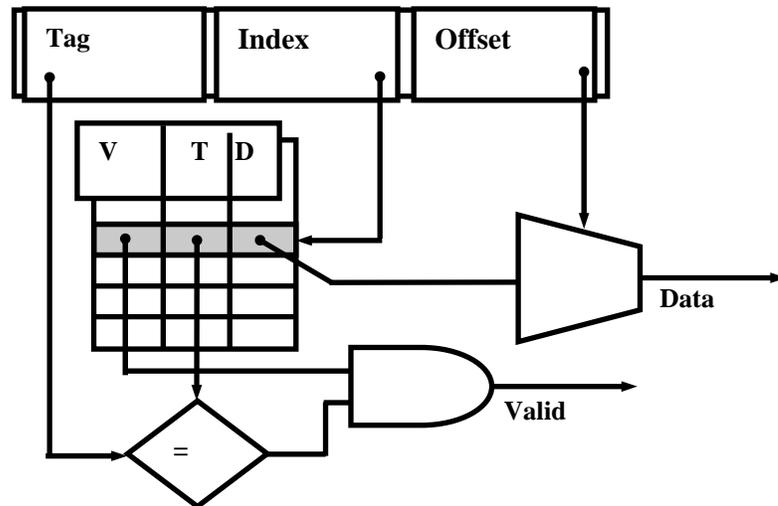


Fig. 6.2 Direct Mapping

## Fully Associative Mapping

- Complete main memory address stored in each cache address
- All addresses stored in cache simultaneously compared with desired address
- Valid bit and offset same as direct mapping

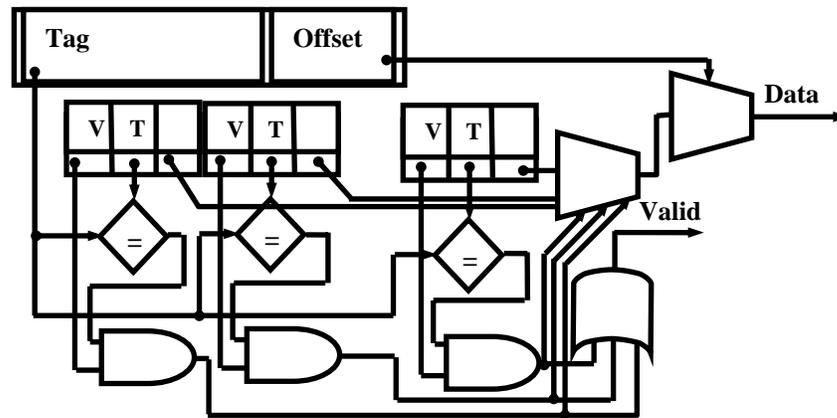


Fig. 6.3 Fully Associative Mapping

## Set-Associative Mapping

- Compromise between direct mapping and fully associative mapping
- Index same as in direct mapping
- But, each cache address contains content and tags of 2 or more memory address locations
- Tags of that set simultaneously compared as in fully associative mapping
- Cache with set size N called N-way set-associative
  - 2-way, 4-way, 8-way are common

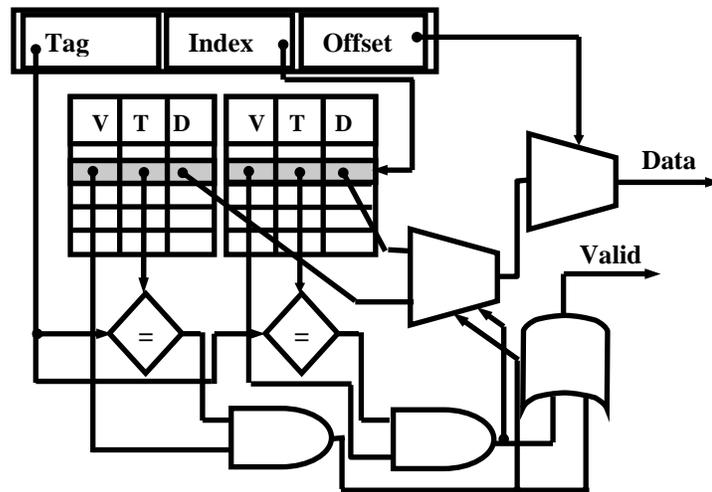


Fig. 6.4 Set Associative Mapping

## 6.4 Cache-Replacement Policy

- Technique for choosing which block to replace
  - when fully associative cache is full
  - when set-associative cache's line is full
- Direct mapped cache has no choice
- Random
  - replace block chosen at random
- LRU: least-recently used
  - replace block not accessed for longest time
- FIFO: first-in-first-out
  - push block onto queue when accessed
  - choose block to replace by popping queue

## 6.5 Cache Write Techniques

- When written, data cache must update main memory
- Write-through
  - write to main memory whenever cache is written to
  - easiest to implement
  - processor must wait for slower main memory write
  - potential for unnecessary writes
- Write-back
  - main memory only written when "dirty" block replaced
  - extra dirty bit for each block set when cache block written to
  - reduces number of slow main memory writes

## 6.6 Cache Impact on System Performance

- Most important parameters in terms of performance:

- Total size of cache
  - total number of data bytes cache can hold
  - tag, valid and other house keeping bits not included in total
- Degree of associativity
- Data block size
- Larger caches achieve lower miss rates but higher access cost
  - e.g.,
    - 2 Kbyte cache: miss rate = 15%, hit cost = 2 cycles, miss cost = 20 cycles
      - avg. cost of memory access  
 $= (0.85 * 2) + (0.15 * 20) = 4.7$  cycles
    - 4 Kbyte cache: miss rate = 6.5%, hit cost = 3 cycles, miss cost will not change
      - avg. cost of memory access =  $(0.935 * 3) + (0.065 * 20) = 4.105$  cycles **(improvement)**
    - 8 Kbyte cache: miss rate = 5.565%, hit cost = 4 cycles, miss cost will not change
      - avg. cost of memory access =  $(0.94435 * 4) + (0.05565 * 20) = 4.8904$  cycles

## 6.7 Cache Performance Trade-Offs

- Improving cache hit rate without increasing size
  - Increase line size
  - Change set-associativity

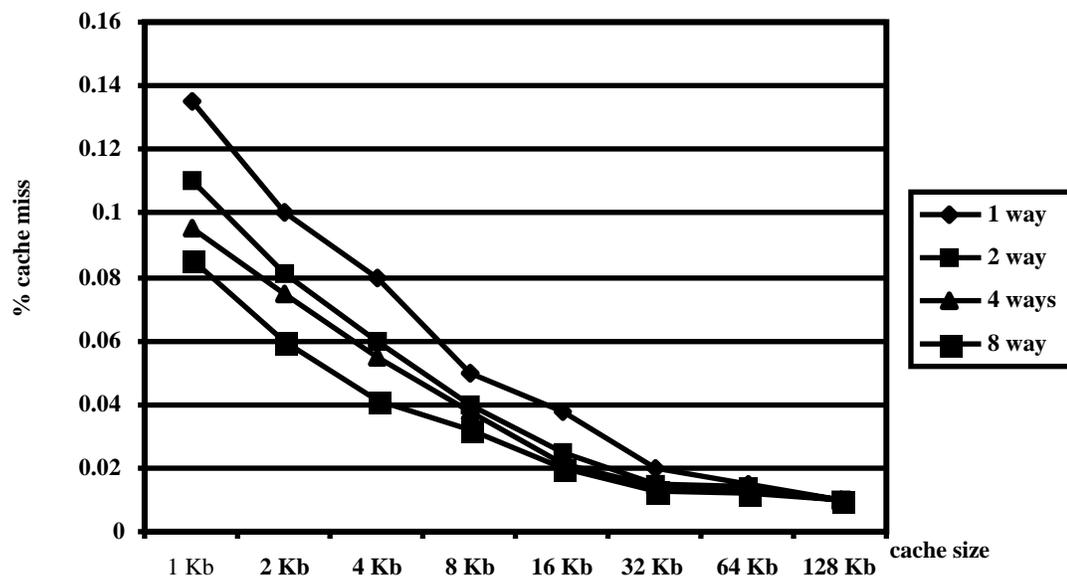


Fig. 6.5 Cache Performance

## 6.8 Advanced RAM

- DRAMs commonly used as main memory in processor based embedded systems
  - high capacity, low cost
- Many variations of DRAMs proposed
  - need to keep pace with processor speeds
  - FPM DRAM: fast page mode DRAM
  - EDO DRAM: extended data out DRAM
  - SDRAM/ESDRAM: synchronous and enhanced synchronous DRAM
  - RDRAM: rambus DRAM

## 6.9 Basic DRAM

- Address bus multiplexed between row and column components
- Row and column addresses are latched in, sequentially, by strobing *ras* (row address strobe) and *cas* (column address strobe) signals, respectively
- Refresh circuitry can be external or internal to DRAM device
  - strobes consecutive memory address periodically causing memory content to be refreshed
  - Refresh circuitry disabled during read or write operation

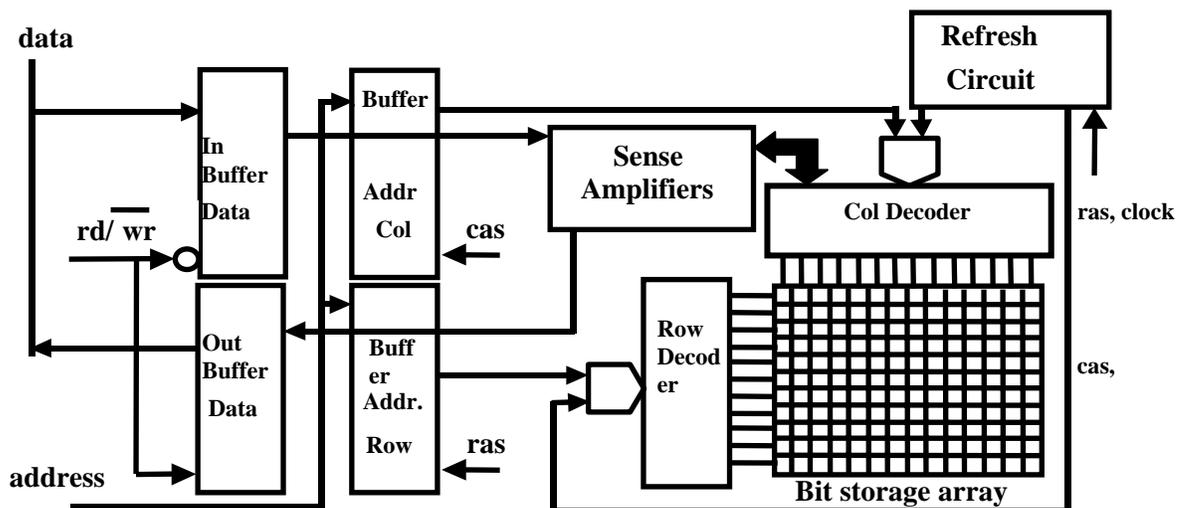


Fig. 6.6 The Basic Dynamic RAM Structure

## Fast Page Mode DRAM (FPM DRAM)

- Each row of memory bit array is viewed as a page
- Page contains multiple words
- Individual words addressed by column address
- Timing diagram:
  - row (page) address sent
  - 3 words read consecutively by sending column address for each

Extra cycle eliminated on each read/write of words from same

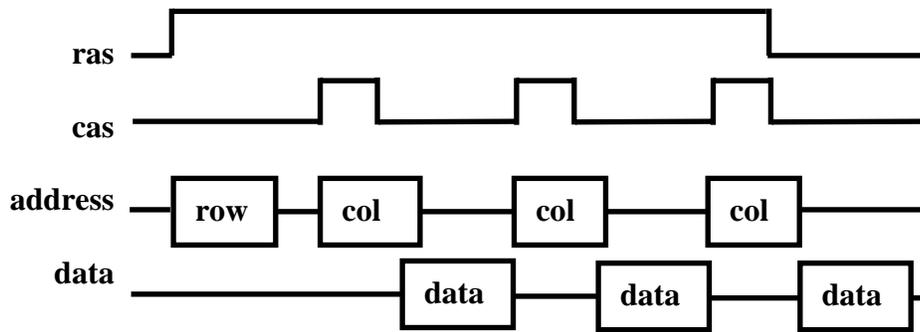


Fig. 6.7 The timing diagram in FPM DRAM

## Extended data out DRAM (EDO DRAM)

- Improvement of FPM DRAM
- Extra latch before output buffer
  - allows strobing of *cas* before data read operation completed
- Reduces read/write latency by additional cycle

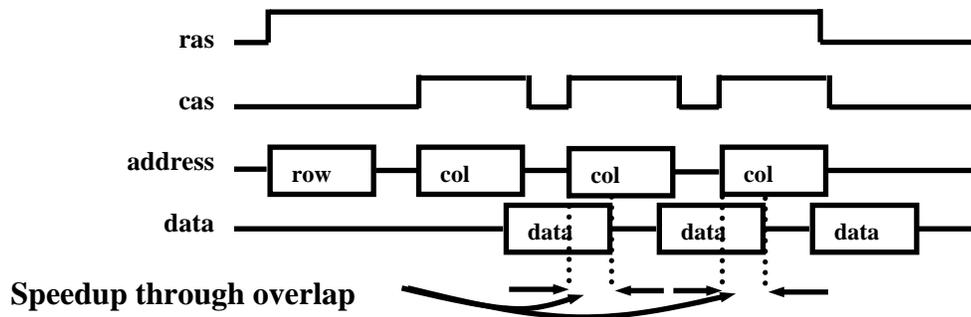
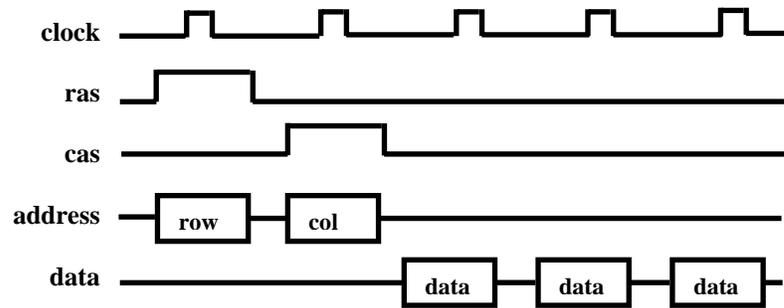


Fig. 6.8 The timing diagram in EDORAM

## (S)ynchronous and Enhanced Synchronous (ES) DRAM

- SDRAM latches data on active edge of clock
- Eliminates time to detect *ras/cas* and *rd/wr* signals
- A counter is initialized to column address then incremented on active edge of clock to access consecutive memory locations
- ESDRAM improves SDRAM
  - added buffers enable overlapping of column addressing
  - faster clocking and lower read/write latency possible



**Fig. 6.9** The timing diagram in SDRAM

## Rambus DRAM (RDRAM)

- More of a bus interface architecture than DRAM architecture
- Data is latched on both rising and falling edge of clock
- Broken into 4 banks each with own row decoder
  - can have 4 pages open at a time
- Capable of very high throughput

## 6.10 DRAM Integration Problem

- SRAM easily integrated on same chip as processor
- DRAM more difficult
  - Different chip making process between DRAM and conventional logic
  - Goal of conventional logic (IC) designers:
    - minimize parasitic capacitance to reduce signal propagation delays and power consumption
  - Goal of DRAM designers:
    - create capacitor cells to retain stored information
  - Integration processes beginning to appear

## 6.11 Memory Management Unit (MMU)

- Duties of MMU
  - Handles DRAM refresh, bus interface and arbitration
  - Takes care of memory sharing among multiple processors
  - Translates logic memory addresses from processor to physical memory addresses of DRAM
- Modern CPUs often come with MMU built-in
- Single-purpose processors can be used

## 6.12 Question

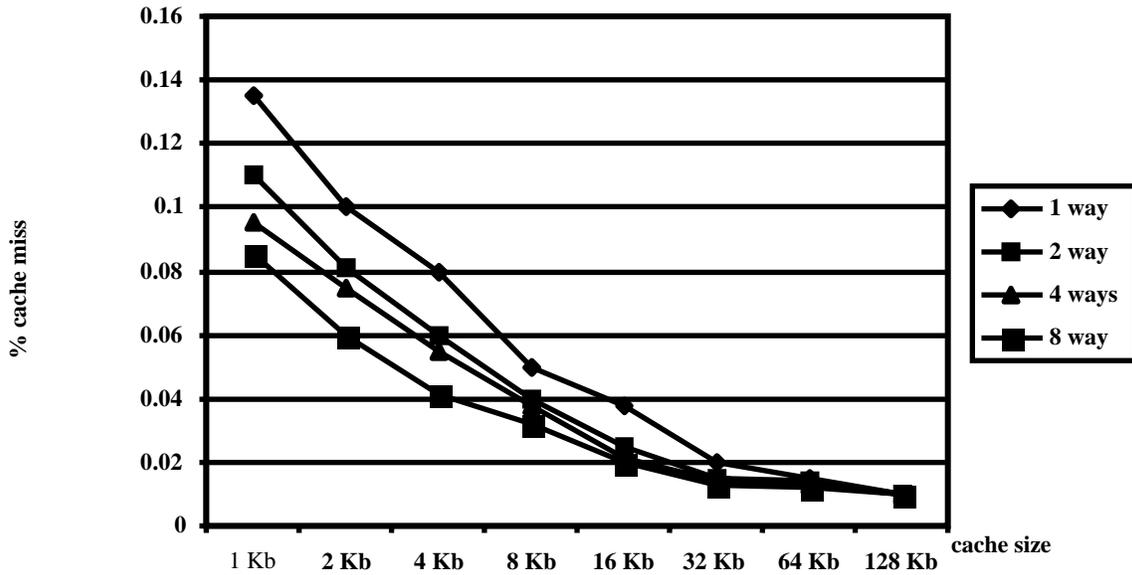
Q1. Discuss different types of cache mappings.

Ans:

Direct, Fully Associative, Set Associative

Q2 Discuss the size of the cache memory on the system performance.

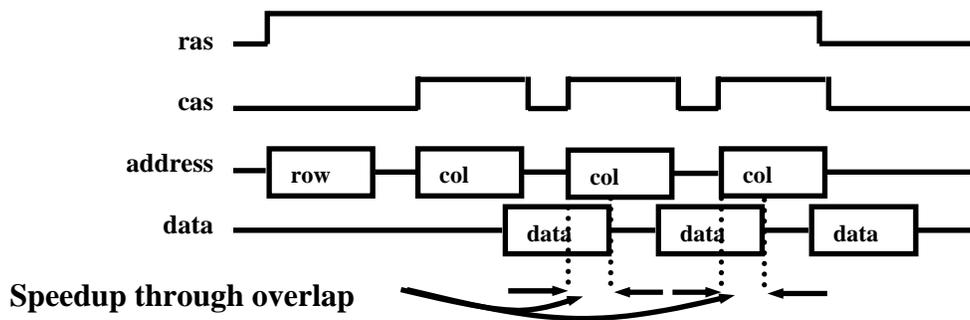
Ans:



Q3. Discuss the differences between EDORAM and SDRAM

Ans:

## EDO RAM



# SDRAM

