

# Embedded Systems Design: A Unified Hardware/Software Introduction

## Chapter 5 Memory

### Introduction

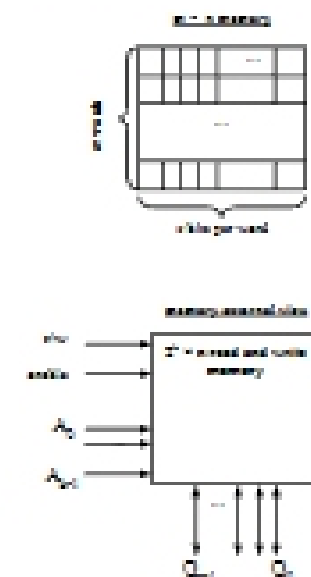
- Embedded system's functionality aspects
  - Processing
    - processors
    - transformation of data
  - Storage
    - memory
    - retention of data
  - Communication
    - buses
    - transfer of data

## Outline

- Memory Write Ability and Storage Permanence
- Common Memory Types
- Composing Memory
- Memory Hierarchy and Cache
- Advanced RAM

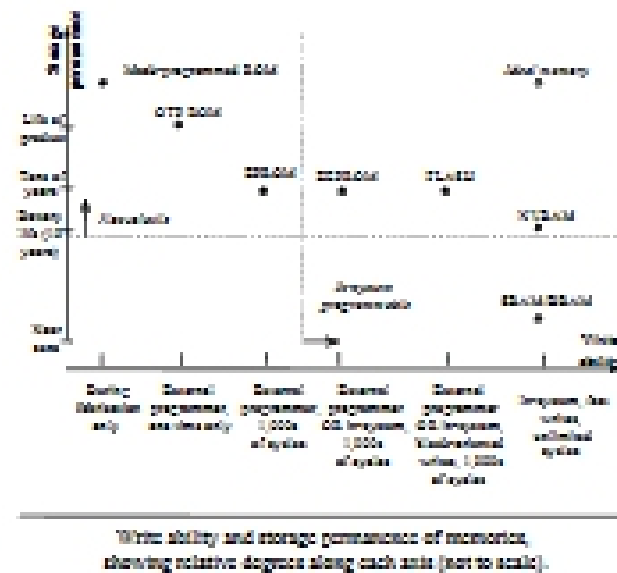
### Memory: basic concepts

- Stores large number of bits
  - $m \times n$ :  $m$  words of  $n$  bits each
  - $k = \log_2(m)$  address input signals
  - or  $m = 2^k$  words
  - e.g., 4,096 x 8 memory:
    - 32,768 bits
    - 12 address input signals
    - 8 input/output data signals
- Memory access
  - $r/w$ : selects read or write
  - enable: read or write only when asserted
  - multiport: multiple accesses to different locations simultaneously



## Write ability/ storage permanence

- Traditional ROM/RAM distinctions
  - ROM
    - read only, bits stored without power
  - RAM
    - read and write, lose stored bits without power
- Traditional distinctions blurred
  - Advanced ROMs can be written to
    - e.g., EEPROM
  - Advanced RAMs can hold bits without power
    - e.g., NVRAM
- Write ability
  - Manner and speed a memory can be written
- Storage permanence
  - ability of memory to hold stored bits after they are written



## Write ability

- Ranges of write ability
  - High end
    - processor writes to memory simply and quickly
    - e.g., RAM
  - Middle range
    - processor writes to memory, but slower
    - e.g., FLASH, EEPROM
  - Lower range
    - special equipment, "programmer", must be used to write to memory
    - e.g., EPROM, OTP ROM
  - Low end
    - bits stored only during fabrication
    - e.g., Mask-programmed ROM
- In-system programmable memory
  - Can be written to by a processor in the embedded system using the memory
  - Memories in high end and middle range of write ability

## Storage permanence

- Range of storage permanence
  - High end
    - essentially never loses bits
    - e.g., mask-programmed ROM
  - Middle range
    - holds bits days, months, or years after memory's power source turned off
    - e.g., NVRAM
  - Lower range
    - holds bits as long as power supplied to memory
    - e.g., SRAM
  - Low end
    - begins to lose bits almost immediately after written
    - e.g., DRAM
- Nonvolatile memory
  - Holds bits after power is no longer supplied
  - High end and middle range of storage permanence

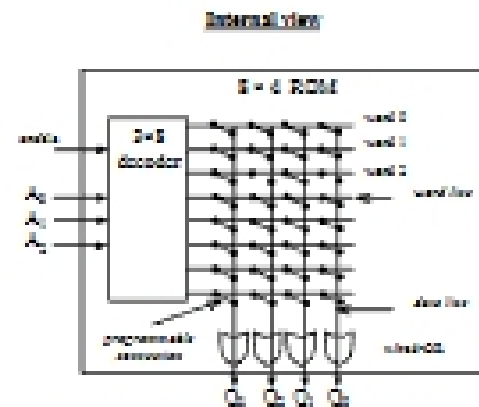
## ROM: "Read-Only" Memory

- Nonvolatile memory
- Can be read from but not written to, by a processor in an embedded system
- Traditionally written to, "programmed", before inserting to embedded system
- Uses
  - Store software program for general-purpose processor
    - program instructions can be one or more ROM words
  - Store constant data needed by system
  - Implement combinational circuit



## Example: 8 x 4 ROM

- Horizontal lines = words
- Vertical lines = data
- Lines connected only at circles
- Decoder sets word 2's line to 1 if address input is 010
- Data lines Q3 and Q1 are set to 1 because there is a "programmed" connection with word 2's line
- Word 2 is not connected with data lines Q2 and Q0
- Output is 1010



## Implementing combinational function

- Any combinational circuit of  $n$  functions of same  $k$  variables can be done with  $2^k \times n$  ROM



## Mask-programmed ROM

- Connections "programmed" at fabrication
  - set of masks
- Lowest write ability
  - only once
- Highest storage permanence
  - bits never change unless damaged
- Typically used for final design of high-volume systems
  - spread out NRE cost for a low unit cost

## OTP ROM: One-time programmable ROM

- Connections "programmed" after manufacture by user
  - user provides file of desired contents of ROM
  - file input to machine called ROM programmer
  - each programmable connection is a fuse
  - ROM programmer blows fuses where connections should not exist
- Very low write ability
  - typically written only once and requires ROM programmer device
- Very high storage permanence
  - bits don't change unless reconnected to programmer and more fuses blown
- Commonly used in final products
  - cheaper, harder to inadvertently modify