Chapter 5

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Part-1

Internal Memory

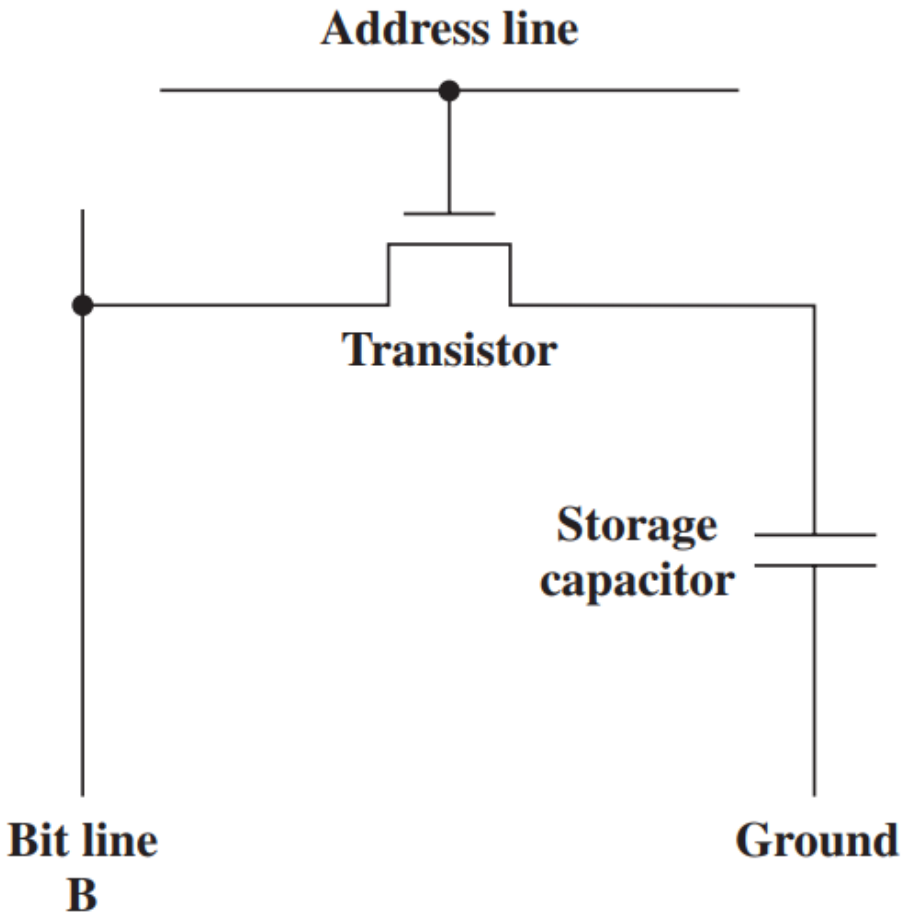
Semiconductor Memory

- RAM (Random Access Memory)
  - Misnamed as all semiconductor mem. are random access
  - Read/Write
  - Volatile
  - Temporary storage
  - Static or dynamic
- ROM (Read only memory)
  - Permanent storage
  - Read only

Dynamic RAM

- Bits stored as charge in capacitors
- Charges leak
- Need refreshing even when powered
- Simpler construction
- Smaller per bit
- Less expensive
- Need refresh circuits
- Slower
- Main memory (static RAM would be too expensive)

Dynamic RAM


Address line
Transistor
Storage
capacitor
Bit line
B
Ground

Static RAM

- Bits stored as on/off switches
- No charges to leak
- No refreshing needed when powered
- More complex construction
- Larger per bit
- More expensive
- Does not need refresh circuits
- Faster
- Cache (here the faster the better)

Read Only Memory (ROM)

- Permanent storage
- Microprogramming (see later)
- Library subroutines
- Systems programs (BIOS)
- Function tables

Types of ROM

- Written during manufacture
  - Very expensive for small runs
- Programmable (once)
  - PROM
  - Needs special equipment to program
- Read "mostly"
  - Erasable Programmable (EPROM)
    - Erased by UV (it can take up to 20 minuts)
  - Electrically Erasable (EEPROM)
    - Takes much longer to write than read
    - a single byte can be erased
  - Flash memory
    - Erase memory electrically "block-at-a-time"

Physical Characteristics

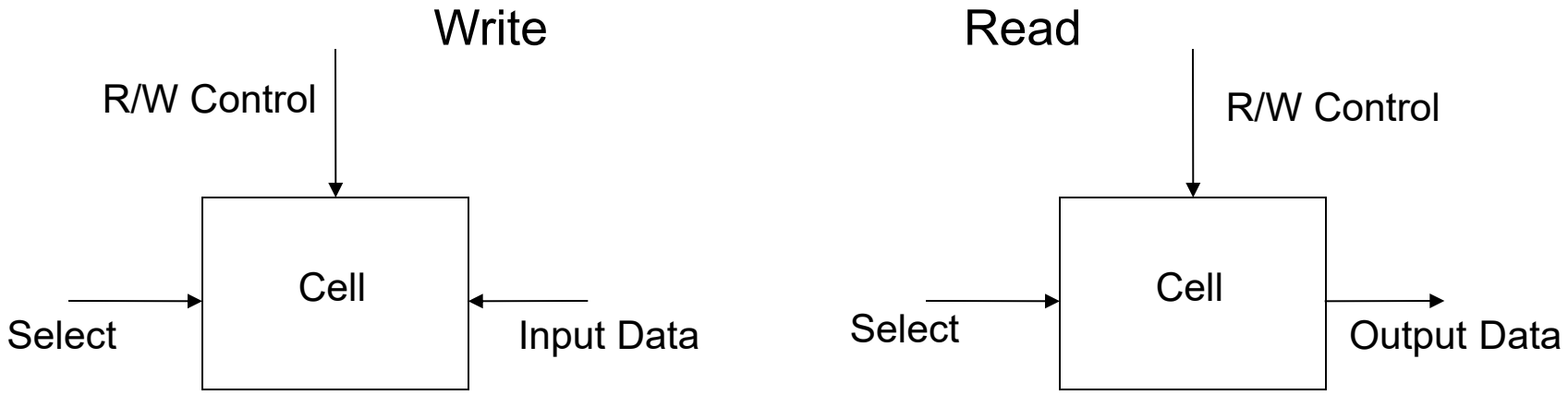
- Decay (refresh time)
- Volatility (needs power source)
- Erasable
- Power consumption

Organisation

- Physical arrangement of bits into words
- Not always obvious
  - e.g. interleaved

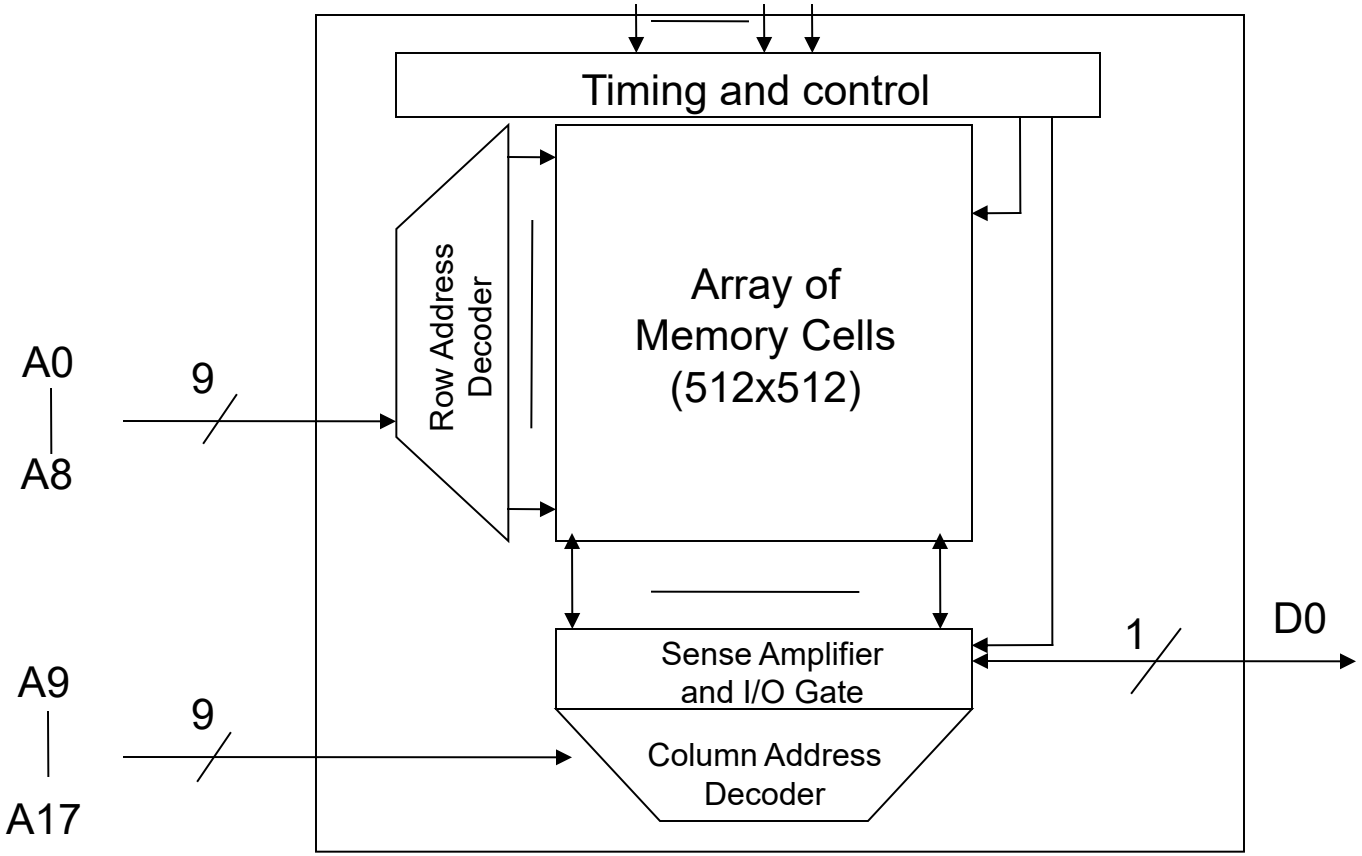
Basic Organization (1)

- Basic element: memory cell
  - has 2 stable states: one represent 0, the other 1
  - can be written at least once
  - can be read



Basic Organization (2)

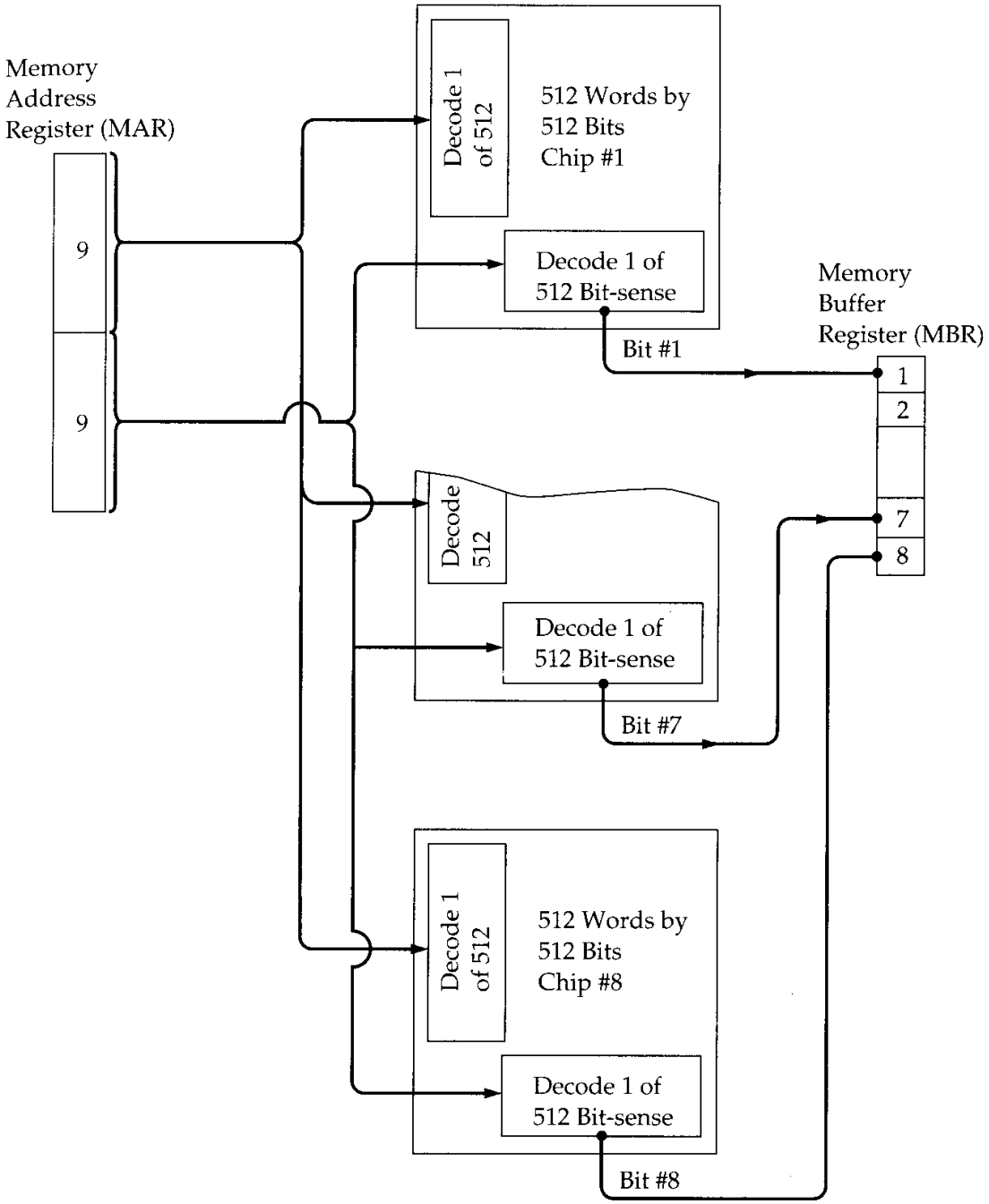
- Basic organization of a 512x512 bits chip



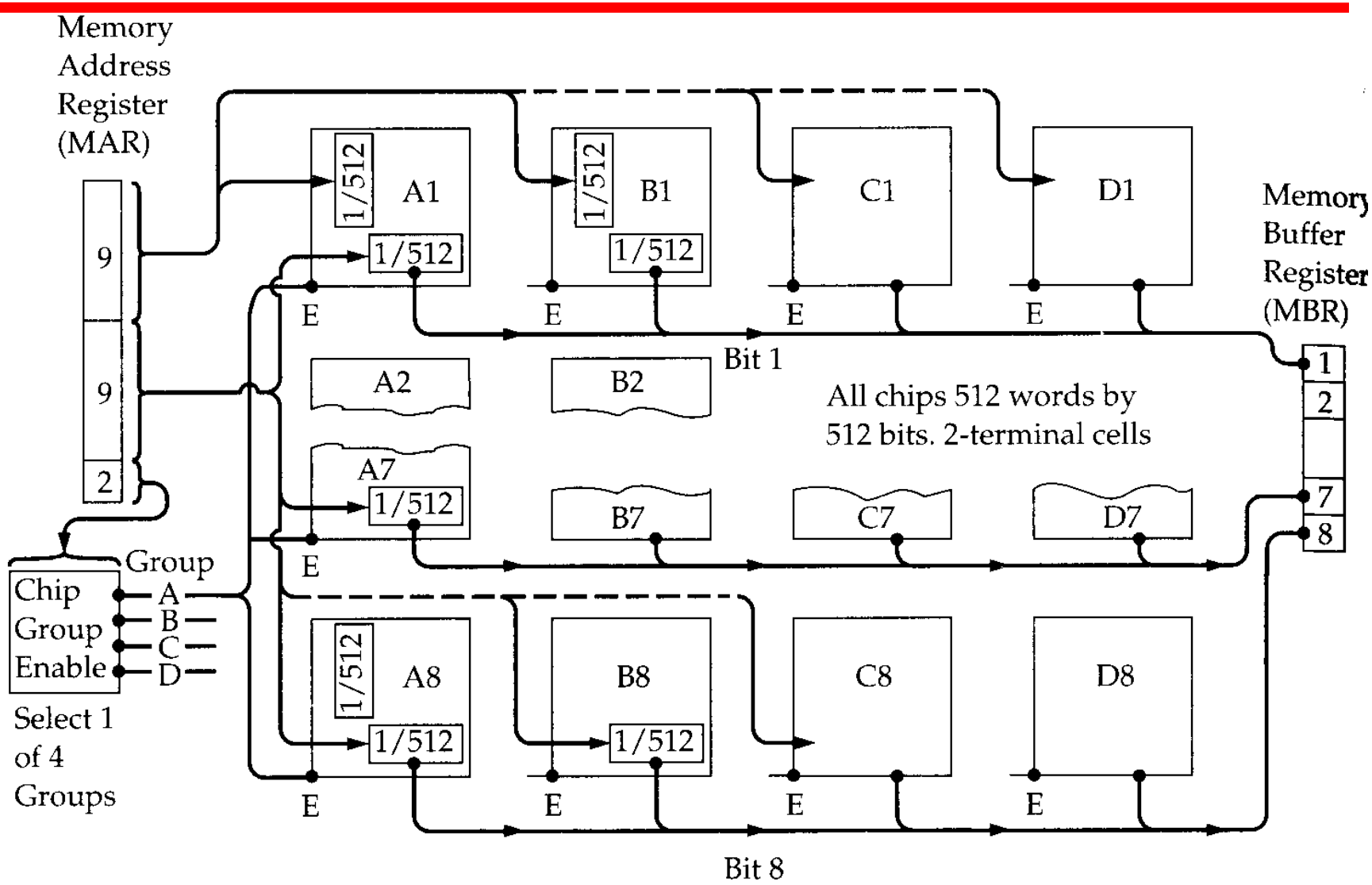
Module Organisation

- Basic organization of a 256KB chip
- 8 times a 512x512 bits chip

- ...For a 1 MB chip replicate 4 times this organization...

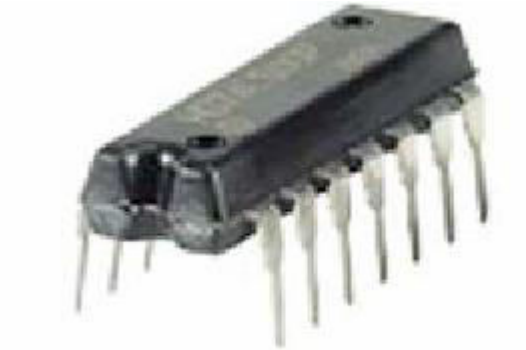


Module Organisation (1 MByte)

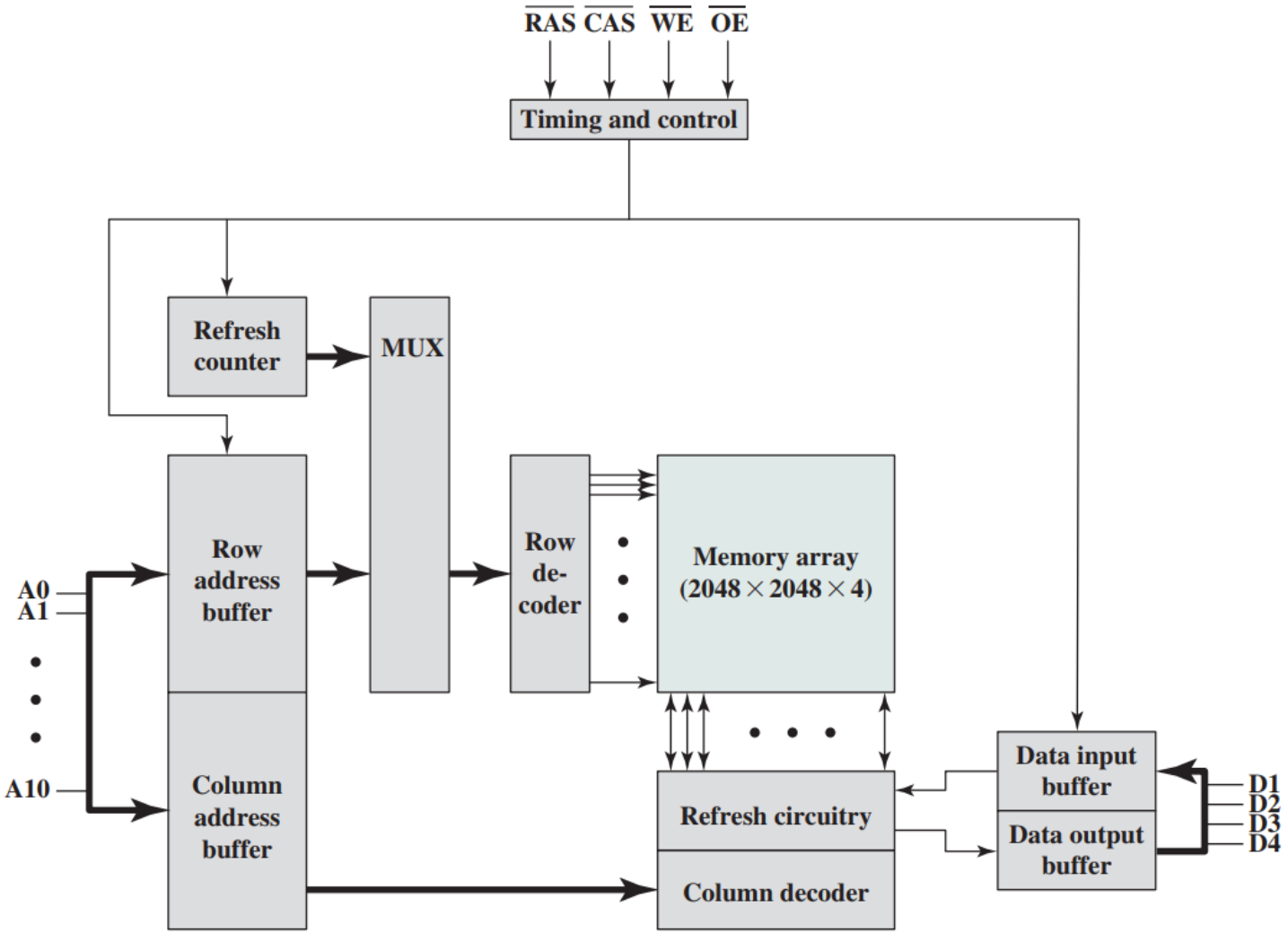


Organisation for larger sizes

- The larger the size the higher the number of address pins
- For 2^k words, k pins are needed
- A solution to reduce the number of address pins
  - Multiplex row address and column address
  - $k/2$ pins to address 2^k Bytes
  - Adding one more pin doubles range of values so x4 capacity



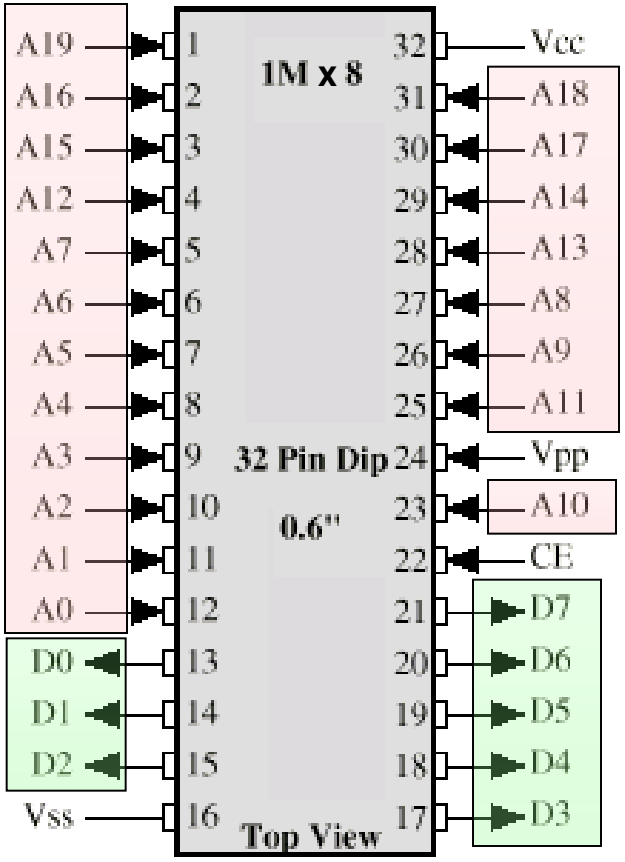
Typical 16 Mb DRAM (4M x 4)



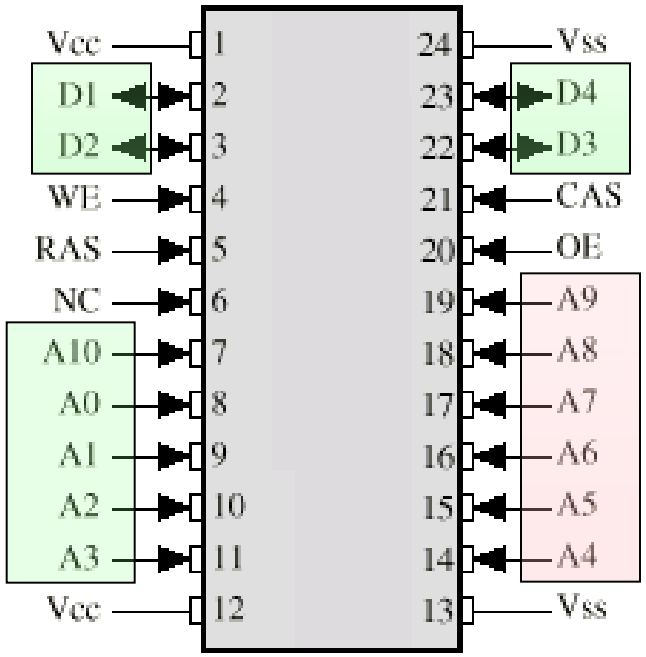
Refreshing (Dynamic RAM)

- Refresh circuit included on chip
- Disable chip
- Count through rows
- Read & Write back
- Takes time
- Slows down apparent performance

Packaging



(a) 8 Mbit EPROM

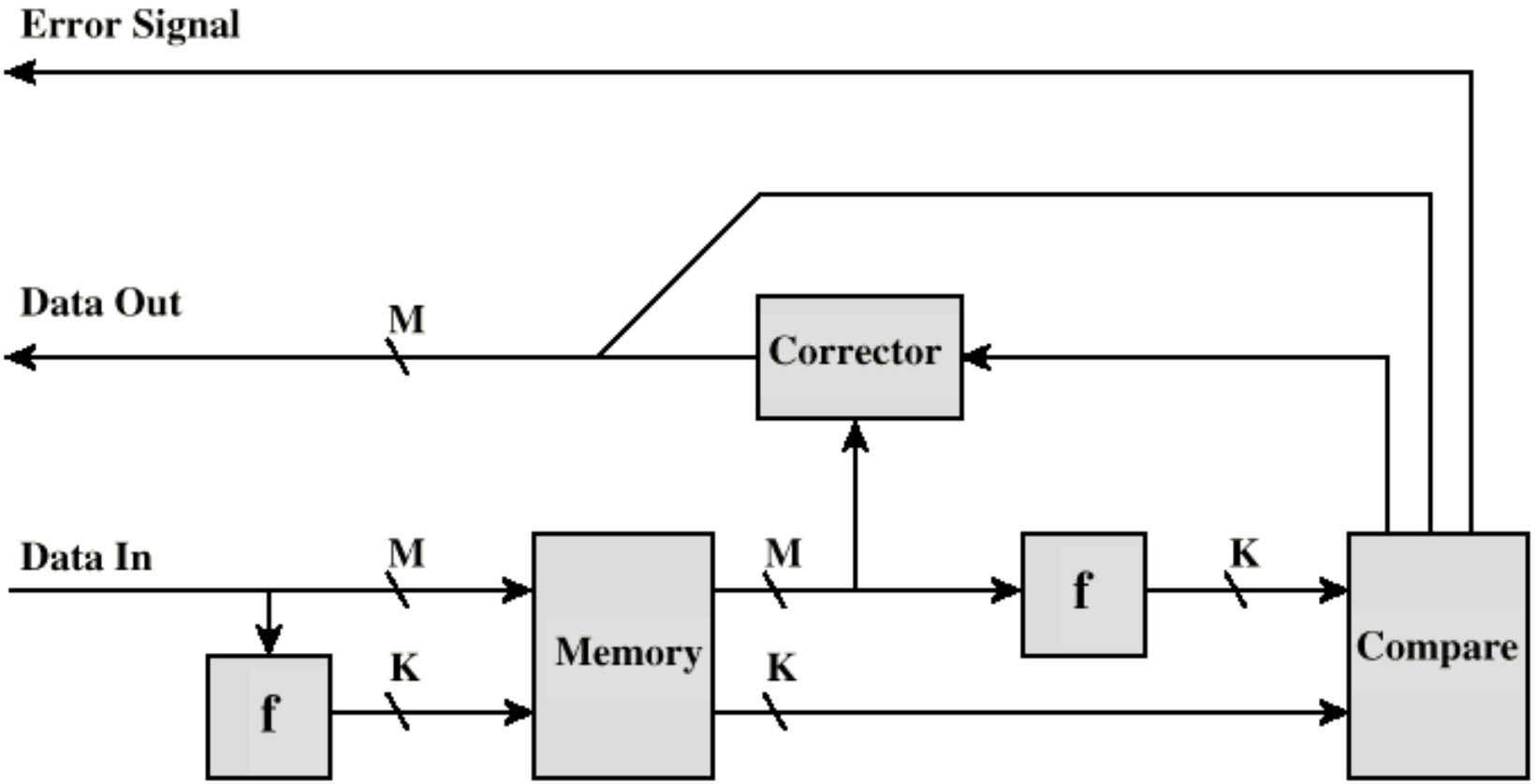


(b) 16 Mbit DRAM

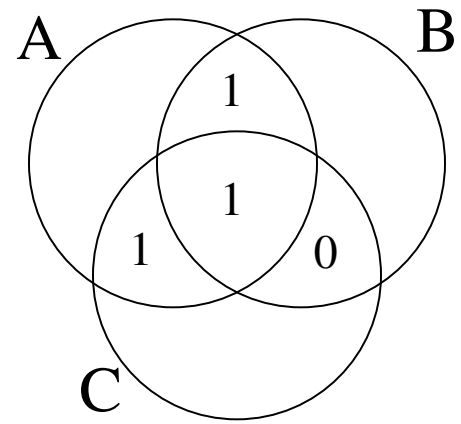
Error Correction

- Hard Failure
  - Permanent defect
- Soft Error
  - Random, non-destructive
  - No permanent damage to memory
- Detected using Hamming error correcting code
  - it is able to detect and correct 1-bit errors

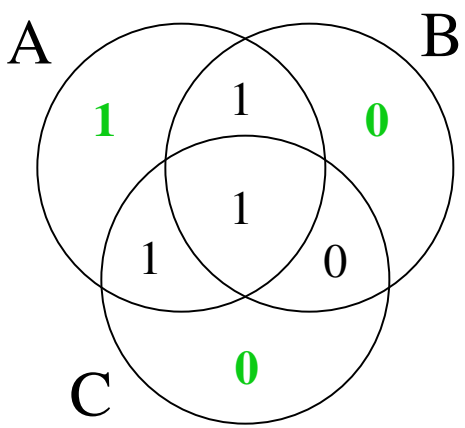
Error Correcting Code Function



A simple example of correction (1)

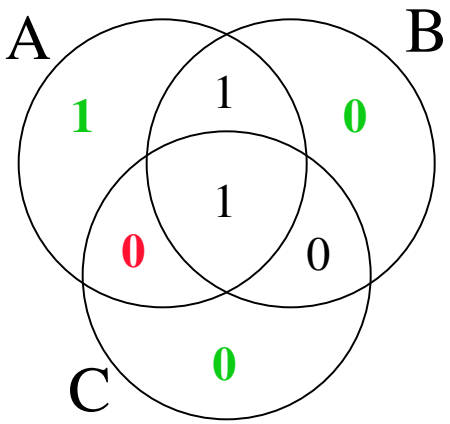


- Correcting errors in 4 bits words
- 3 control groups

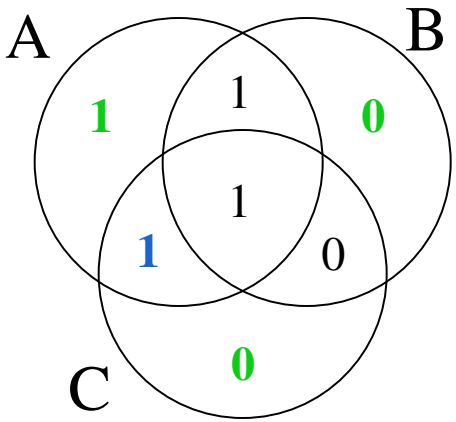


- In each control group add 1 parity bit

A simple example of correction (2)



- One of the bits change value



- Using control bit the right value is restored

Compare Circuit

- it takes two K-length binary strings X, Y as input
  - $X=X_K \ldots X_1$
  - $Y=Y_K \ldots Y_1$
- it returns a K-length binary string Z (syndrome)
  - $Z=Z_K \ldots Z_1$
  - $Z_i=X_i \oplus Y_i$ for each i=1,…,K
- Z=0…0 means no error

Relation between M and K

- Z may assume 2^K values
- the value Z=0…0 means no error
- the error may be in any bit among the M+K bits
- it must be

$$2^K - 1 \geq M+K$$

Data bits (M)	Control Bits (K)	Additional Memory (%)
4	3	75
8	4	50
16	5	31,25
32	6	18,75
64	7	10,94
128	8	6,25
256	9	3,52

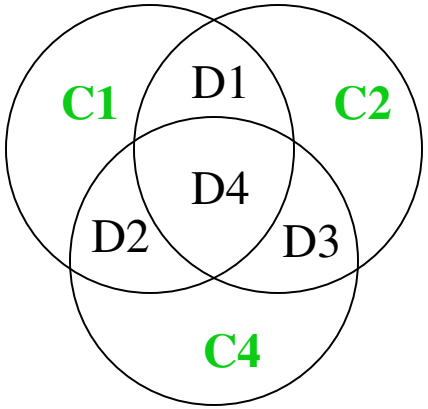
How to arrange the M+K bits

- the M+K bits are arranged so that
  - if Z contains a single bit equal to 1
    - error occured in the corresponding control bit
  - if Z contains more than one bit equal to 1
    - error occured in the *i*-th bit where *i* is the value (in binary) of Z

The case M=4

bit position	7	6	5	4	3	2	1
position number	111	110	101	100	011	010	001
data bits	D4	D3	D2		D1		
control bits				C4		C2	C1

$$C1 = D1 \oplus D2 \oplus D4$$
$$C2 = D1 \oplus D3 \oplus D4$$
$$C4 = D2 \oplus D3 \oplus D4$$



Exercise

- Design a Hamming error correcting code for 8-bit words
- See the textbook for the solution

Chapter 5
Part 2

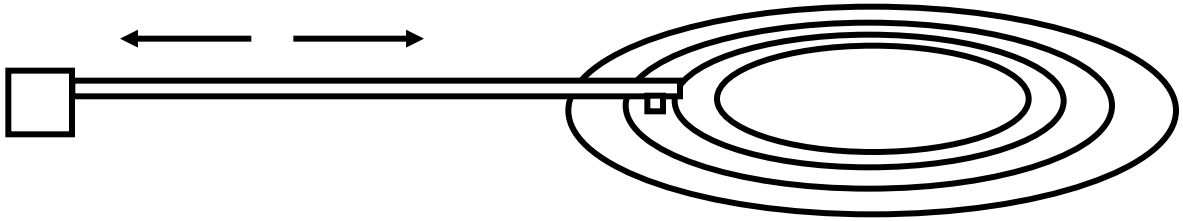
External Memory

Types of External Memory

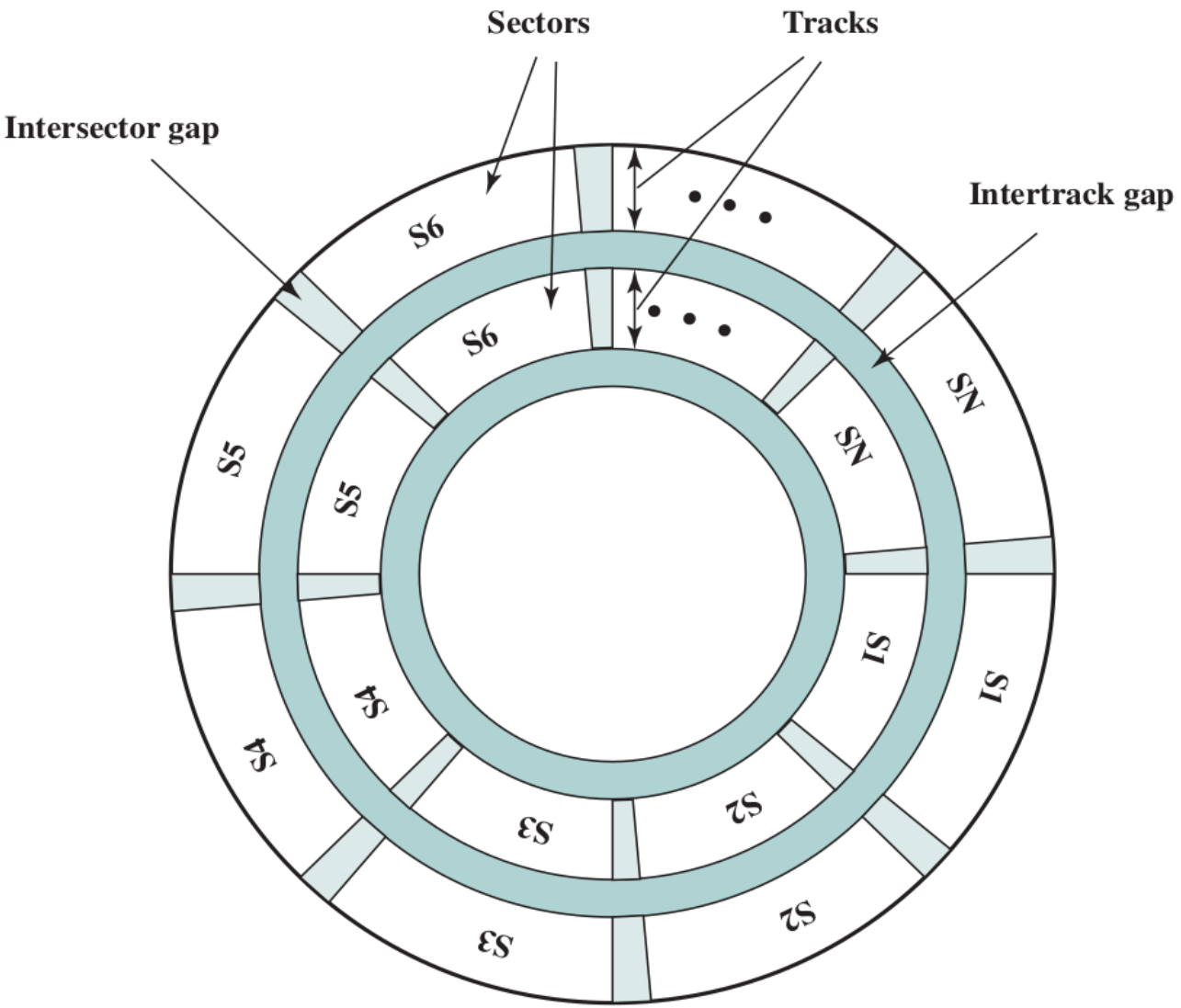
- Magnetic Disk
  - RAID
- Magnetic Tape
- Optical
  - CD-ROM
  - CD-R
  - CD-RW
  - DVD

Magnetic Disk

- Metal or plastic disk coated, on one or both sides, with ***magnetizable material***
- Data read and written through a magnetic head (coil) by means of induction



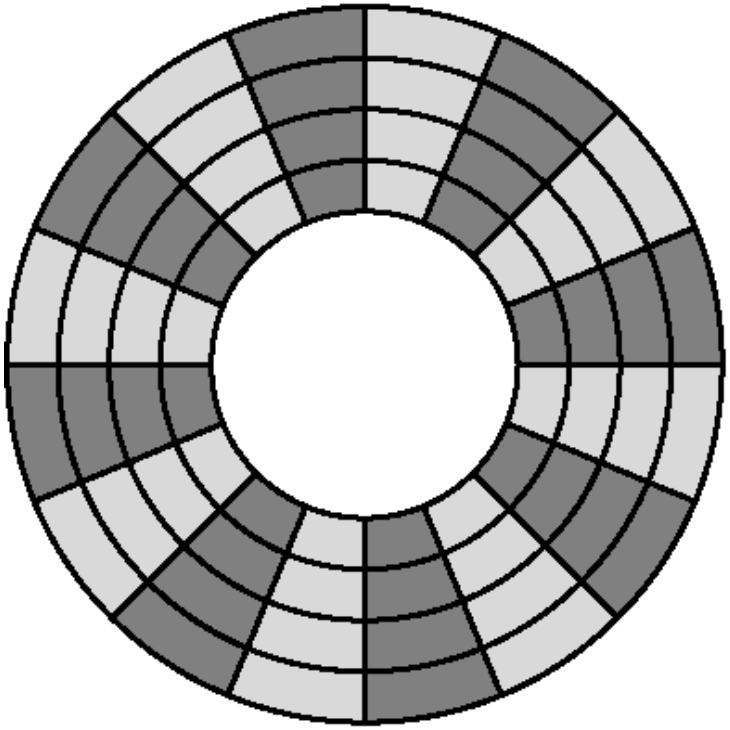
Disk Data Layout



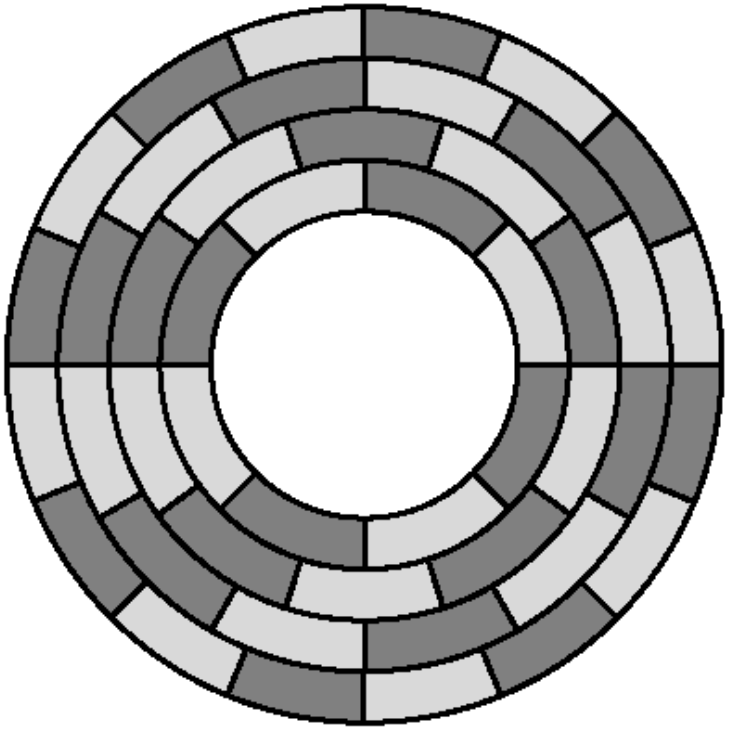
Data Organization and Formatting

- Concentric rings or tracks
  - Gaps between tracks
  - Reduce gap to increase capacity
  - Same number of bits per track
  - Constant angular velocity
- Tracks divided into sectors
- Data read/written in blocks
  - Minimum block size is one sector
  - May have more than one sector per block

Comparison of variable/fixed density



(a) Constant angular velocity

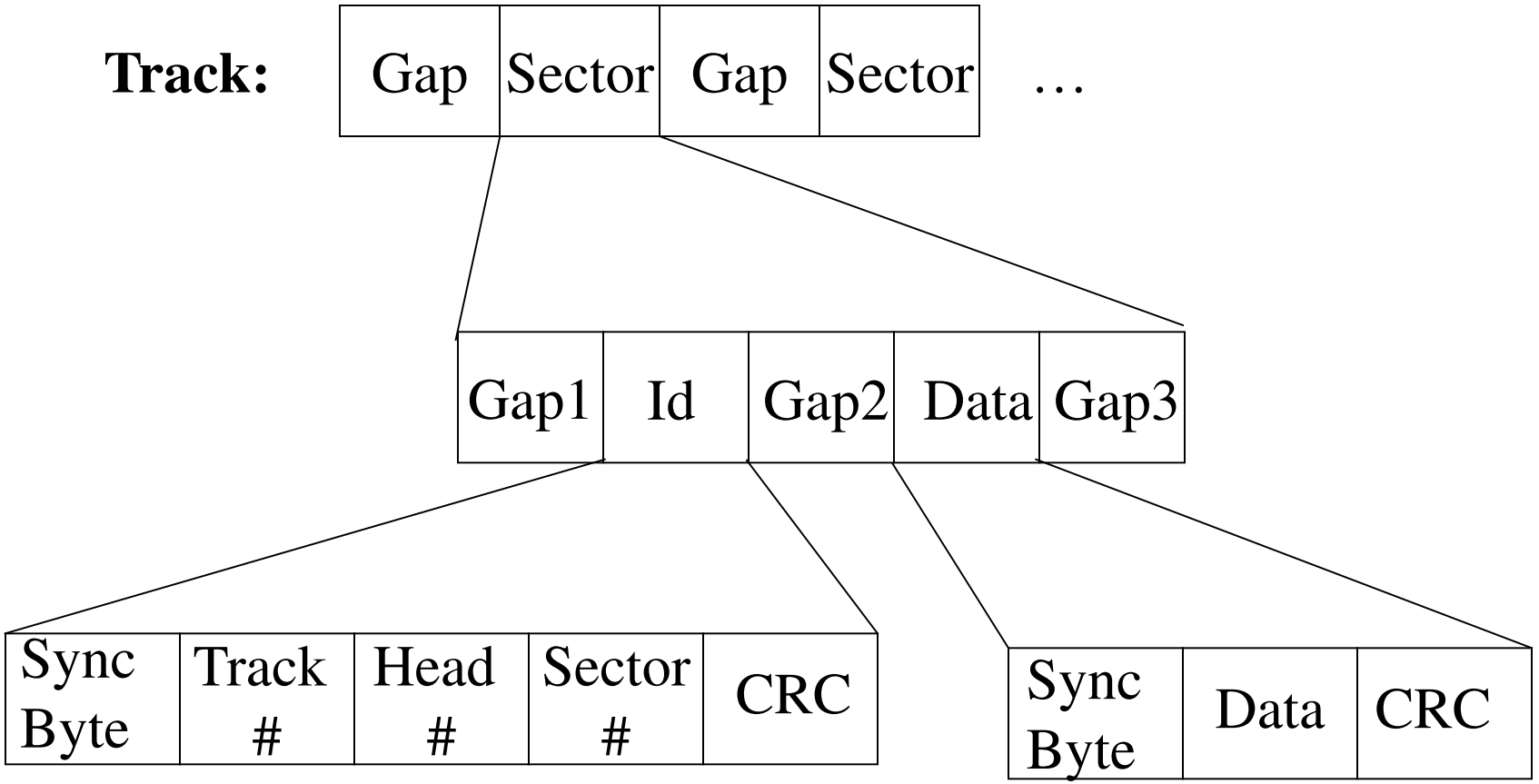


(b) Constant linear velocity

Finding Sectors

- Must be able to identify start of track and sector
- Format disk
  - Additional information not available to user
  - Marks tracks and sectors

An example format



Characteristics of magnetic disks

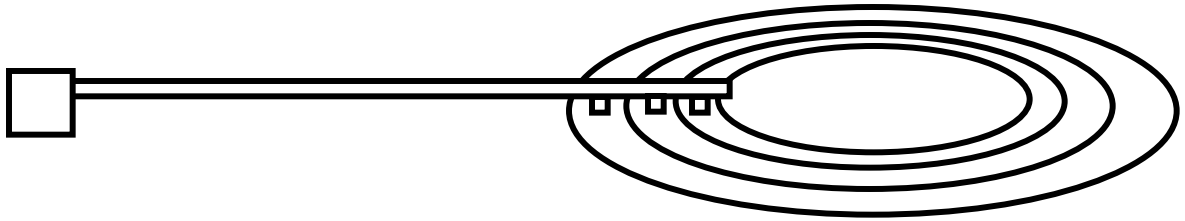
- Single or double (usually) sided
- Removable or fixed
- Fixed or movable head
- Single or multiple platter
- Head mechanism
- Speed

Removable or Not

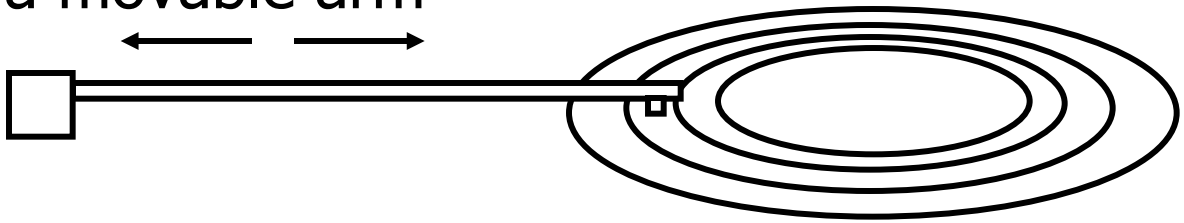
- Removable disk
  - Can be removed from drive and replaced with another disk
  - Provides unlimited storage capacity (by changing disk)
  - Easy data transfer between systems
- Nonremovable disk
  - Permanently mounted in the drive

Fixed/Movable Head Disk

- Fixed head
  - One read/write head per track
  - Heads mounted on a fixed arm

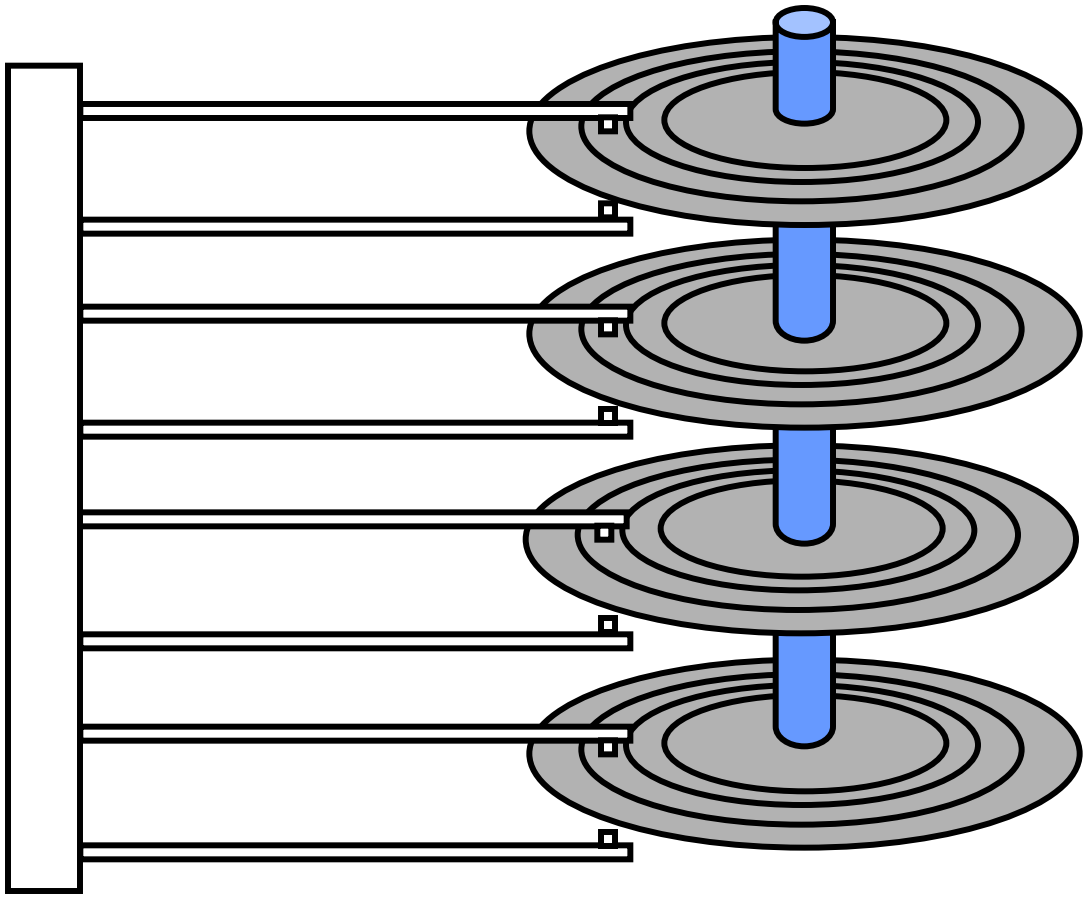


- Movable head
  - One read/write head per side
  - Mounted on a movable arm



Multiple Platters

- One head per side
- Heads are joined and aligned
- Aligned tracks on each platter form cylinders
- Data is striped by cylinder
  - reduces head movement
  - increases speed (transfer rate)



Head mechanism

- Contact
  - Floppy
- Fixed gap
- Aerodynamic gap or flying head
  - Winchester

Winchester Hard Disk (1)

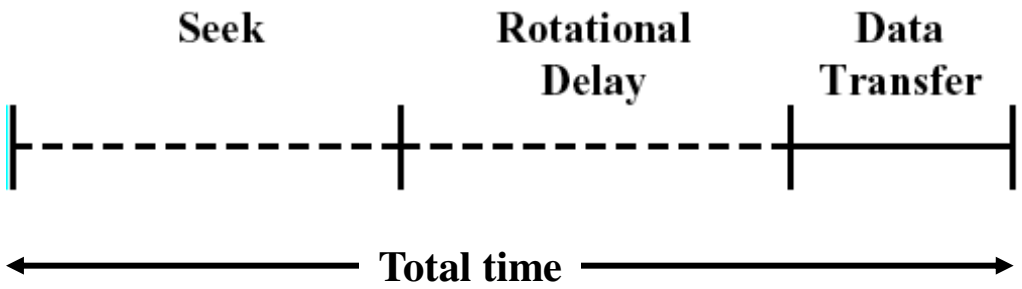
- Developed by IBM in Winchester (USA)
- Sealed unit
- One or more platters (disks)
- Heads fly on boundary layer of air as disk spins
- Very small head-to-disk gap
- Getting more robust

Winchester Hard Disk (2)

- Universal
- Cheap
- Fastest external storage
- Getting larger all the time
  - Multiple Gigabyte now usual

Speed

- Seek time
  - Moving head to the right track
- (Rotational) latency
  - Waiting for data to rotate under head
- Access time = Seek + Latency
- Transfer rate: speed of copying bytes from disk



Cont'd

TRANSFER TIME The transfer time to or from the disk depends on the rotation speed of the disk in the following fashion:

$$T = \frac{b}{rN}$$

where

T = transfer time
b = number of bytes to be transferred
N = number of bytes on a track
r = rotation speed, in revolutions per second

Thus the total average access time can be expressed as

$$T_a = T_s + \frac{1}{2r} + \frac{b}{rN}$$

RAID

- Redundant Array of **Independent** Disks
- At least 7 different versions in common use (Not a hierarchy)
- Set of physical disks viewed as single logical drive by the operating system
- Data distributed (**striped**) across physical drives
- Can use redundant capacity to store parity information and provide fault tolerance

Magnetic Tape

- Only sequential access
- Slower than magnetic and optical disks
- Very very cheap
- Backup and archive

Optical Storage: CD-ROM

- Originally for audio
- 650 Mbytes giving over 70 minutes audio
- Polycarbonate coated with highly reflective coat, usually aluminum
- Data stored as pits
- Read by reflecting laser
- Audio is single speed
  - Constant linear velocity
  - 1.2 m/s
  - Track (spiral) is 5.27km long
  - Gives 4391 seconds = 73.2 minutes

Random Access on CD-ROM

- Difficult, due to constant density and single track
- Move head to rough position
- Set correct speed
- Read address
- Adjust to required location

CD-ROM Pros and Cons

- Large capacity
- Easy to mass produce
- Removable
- Robust

- Expensive for small runs
- Slower than magnetic disk
- Read only

Other Optical Storage

- CD-R (for Recordable)
  - Writable, but ... Write Once Read Many (WORM)
  - Now affordable
  - Compatible with CD-ROM drives
- CD-RW (for ReWritable)
  - Erasable, hence writable many times (~1000)
  - Different technology (phase change vs pit)
  - Getting cheaper
  - Mostly, but not always, CD-ROM drive compatible

DVD - Digital Video/Versatile Disk

- Optical (CD-sized) disk with a very high capacity:
  - 4.7 GB per layer (smaller pits and closer tracks)
  - Up to 2 layers on each of the 2 sides (total 17 GB)
- Drives are CD-ROM compatible
- Also writable (DVD-R, DVD-RW), but not yet fully standardized