

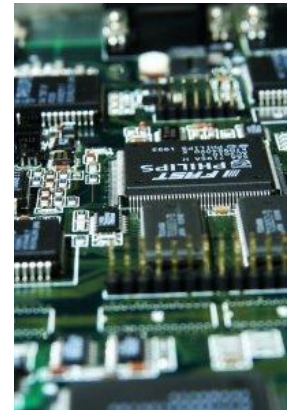
CSE 321b

Computer Organization (2)

تنظيم الحاسب (2)



3rd year, Computer Engineering
Winter 2016
Lecture #2



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Credits to Dr. Ahmed Abdul-Monem Ahmed for the slides

Adminstrivia

- Schedule:
 - Lectures: Monday 9:00am – 11:30am
 - Tutorials: Sunday 10:00am – 11:30am
 - Office hour: TBA
- Assignment #1:
 - To be released next week

Website: <http://www.bit.do/hshehata-courses-zu-cse321b>

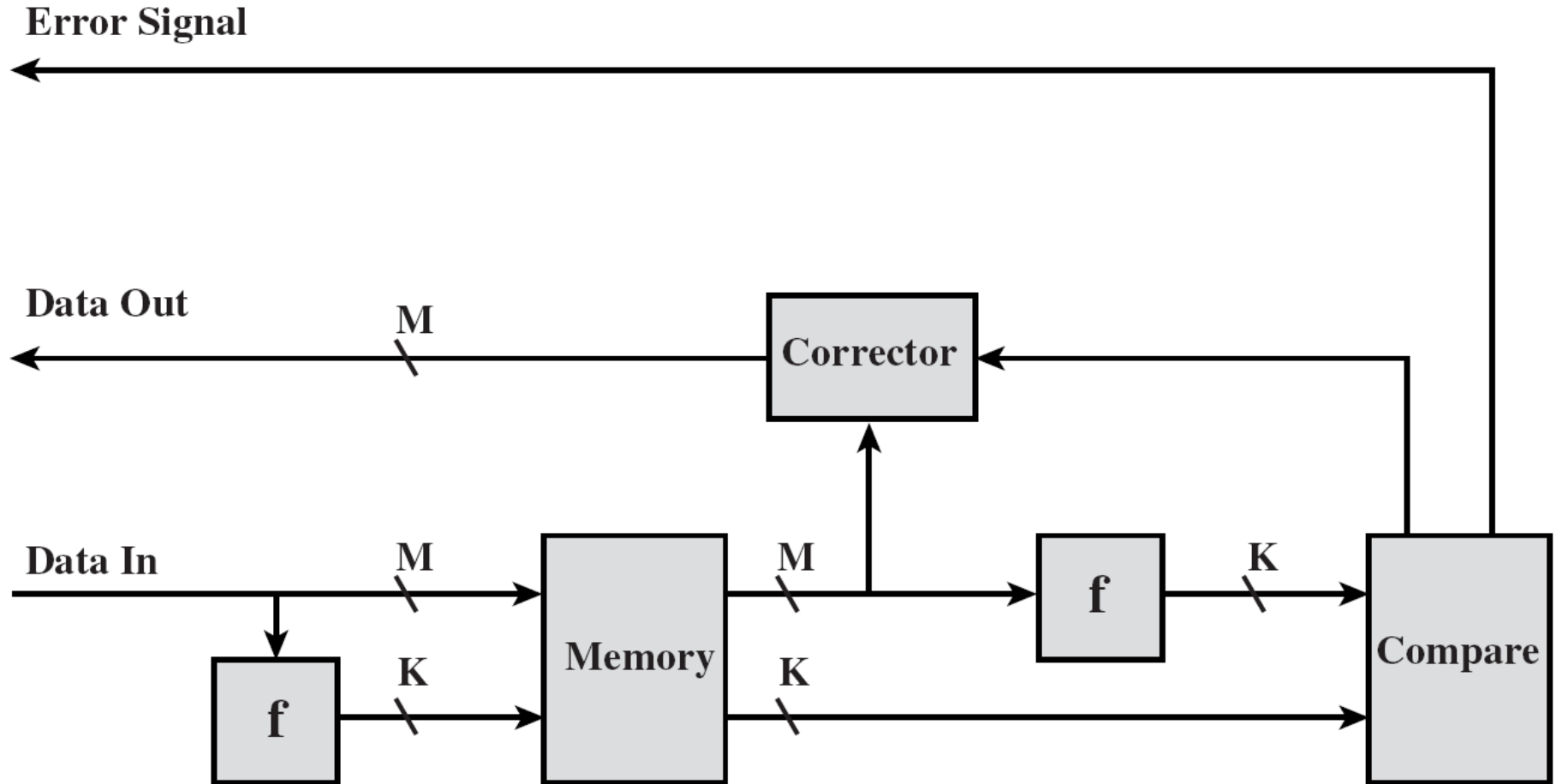
Office hours: TBA

Ch 5: Internal Memory (*Cont.*)

Error Correction

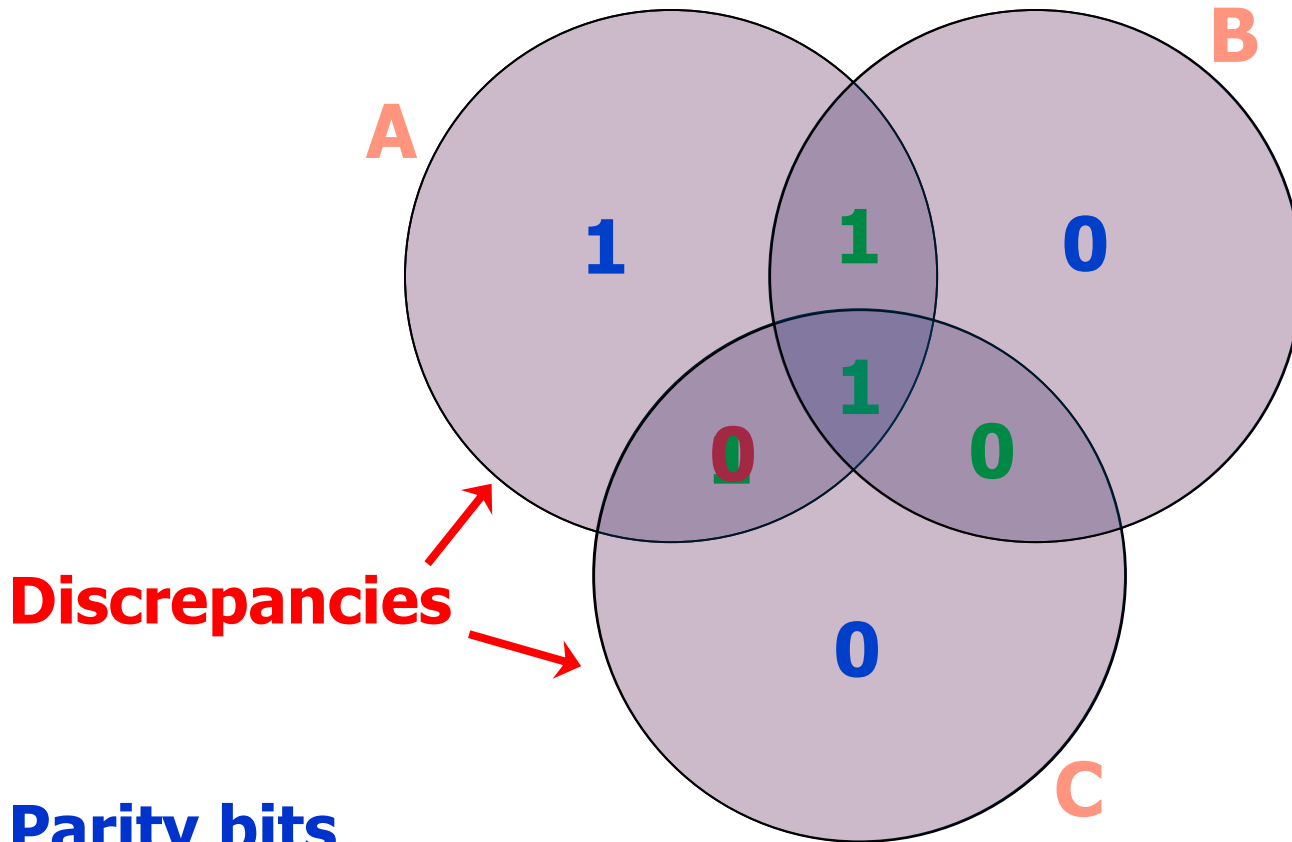
- Semiconductor memory is subject to errors
 - Rate: 1 error/hour to 1 error/century in a 1GB memory!
 - Types: hard and soft.
- Hard Failure
 - Permanent physical defect.
 - Mem. cells can't store data: stuck at 0 or 1, or switching.
 - Caused by harsh environments, manufacturing defects, or wear.
- Soft Error
 - Random, non-destructive event that alters contents of one or more memory cells.
 - No permanent damage to memory.
 - Caused by power supply problems or alpha particles.
- Detected/corrected using Hamming error correcting code.

Error-Correcting Code Function



Hamming Error-Correcting Code

Data bits: 1110



Parity bits

Chosen so that total number of 1s in each circle is even.

By checking the parity bits, discrepancies are found → error can be easily found and corrected.

Error-Correcting Codes

- A **codeword** consists of N bits split into M data bits and K check (redundant) bits
 - $N = M + K$.
- **Hamming distance**: Number of bit-positions in which two codewords differ.
 - Ex.: 1**1001**001, 1**0100**001 \rightarrow Hamming distance = 3 \rightarrow 3 bit errors are needed to convert one into the other.
- Note: in a code, not all 2^N codewords are legal.
- **Hamming distance of the whole code**: minimum Hamming distance between 2 legal codewords.
- A distance d code can:
 - **Detect**: $d - 1$ errors.
 - **Correct**: $(d - 1)/2$ errors if d is odd, or $(d/2) - 1$ errors if d is even.

Error Detection/Correction

- **Detection:** parity bit.
 - Distance = 2 \rightarrow can detect up to 1 bit error.
 - Ex.: data=1011010 \rightarrow codeword=10110100 \rightarrow any codeword with a distance = 1 (such as: 10100100) is considered illegal \rightarrow single-bit errors are detectable.
- **Correction:** Consider a code with 4 valid codewords:
0000000000, 0000011111, 1111100000, 1111111111
 - Distance = 5 \rightarrow can correct up to 2 bit errors.
 - If 0000000111 arrives, \rightarrow 0000011111
 - If 0000000000 becomes 0000000111 due to 3 errors \rightarrow cannot be corrected properly.

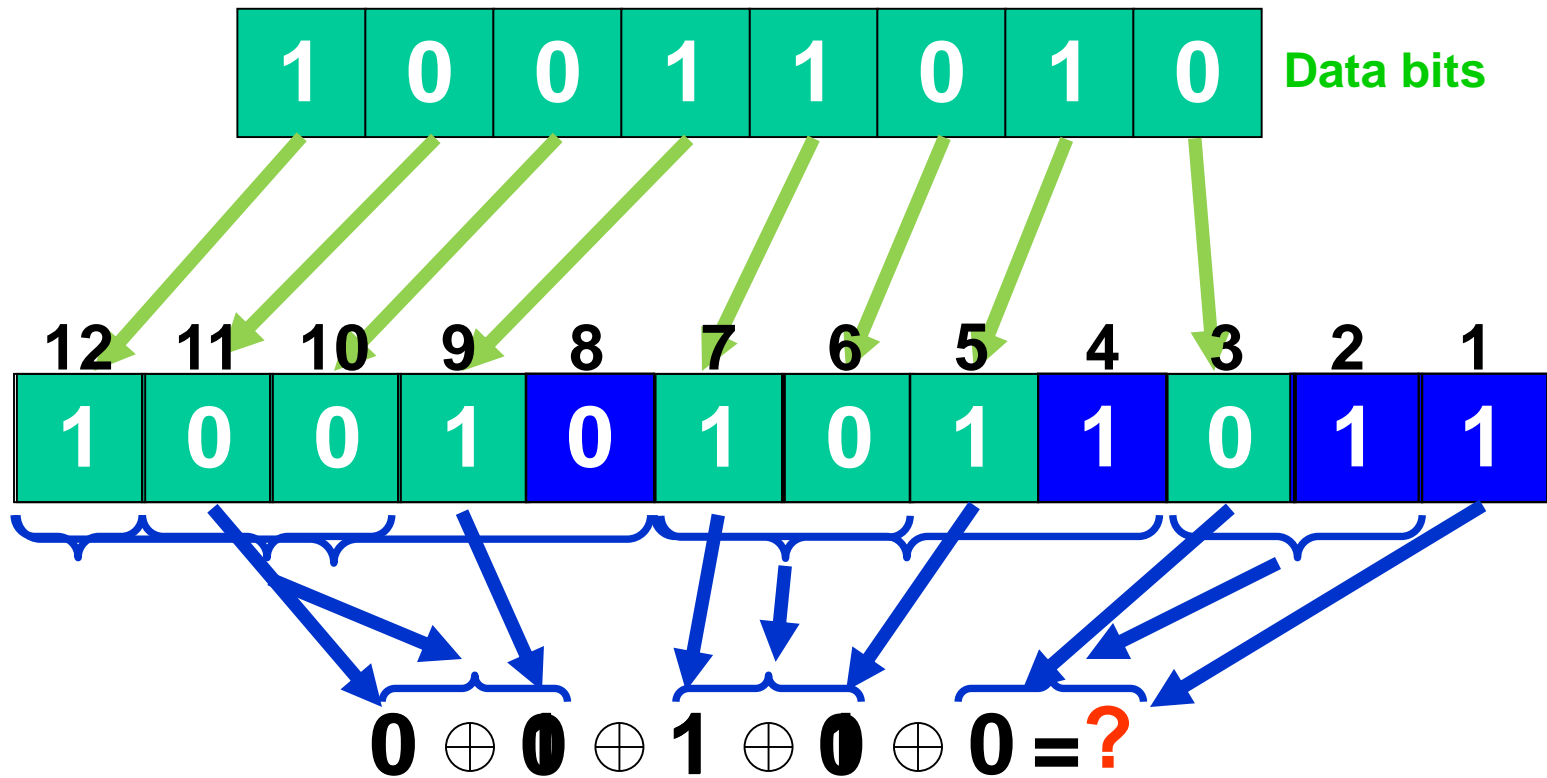
Single Bit Error Correction

Design a code to correct all single bit errors.

- M = data bits, K = check bits
- $N = M + K$
- **Rule:** Choose K s.t. $M + K + 1 \leq 2^K$
- **Justification:**
 - Each of the 2^M legal words has N illegal codewords at distance 1.
 - Thus, each of the 2^M legal words requires $(N + 1)$ bit patterns dedicated to it.
 - $(N + 1) 2^M \leq 2^N \rightarrow M + K + 1 \leq 2^K$

Hamming Code

$$2^K - 1 \geq M + K \rightarrow 2^K \geq 9 + K \rightarrow K = 4$$



Bit position 8

Bit position 8: 0

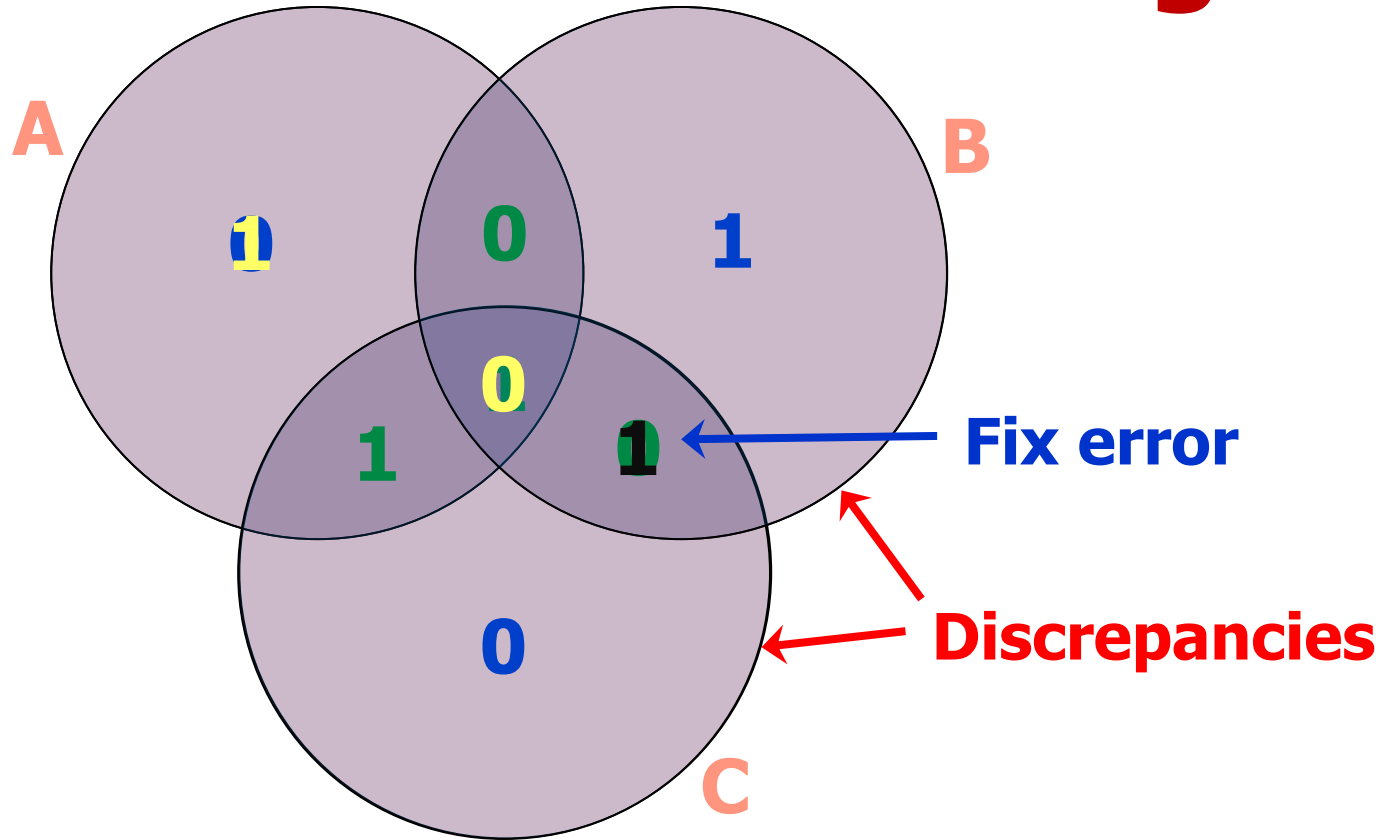
Hamming Code (2)

| 12 | 11 | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 |
|----|----|----|---|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 |

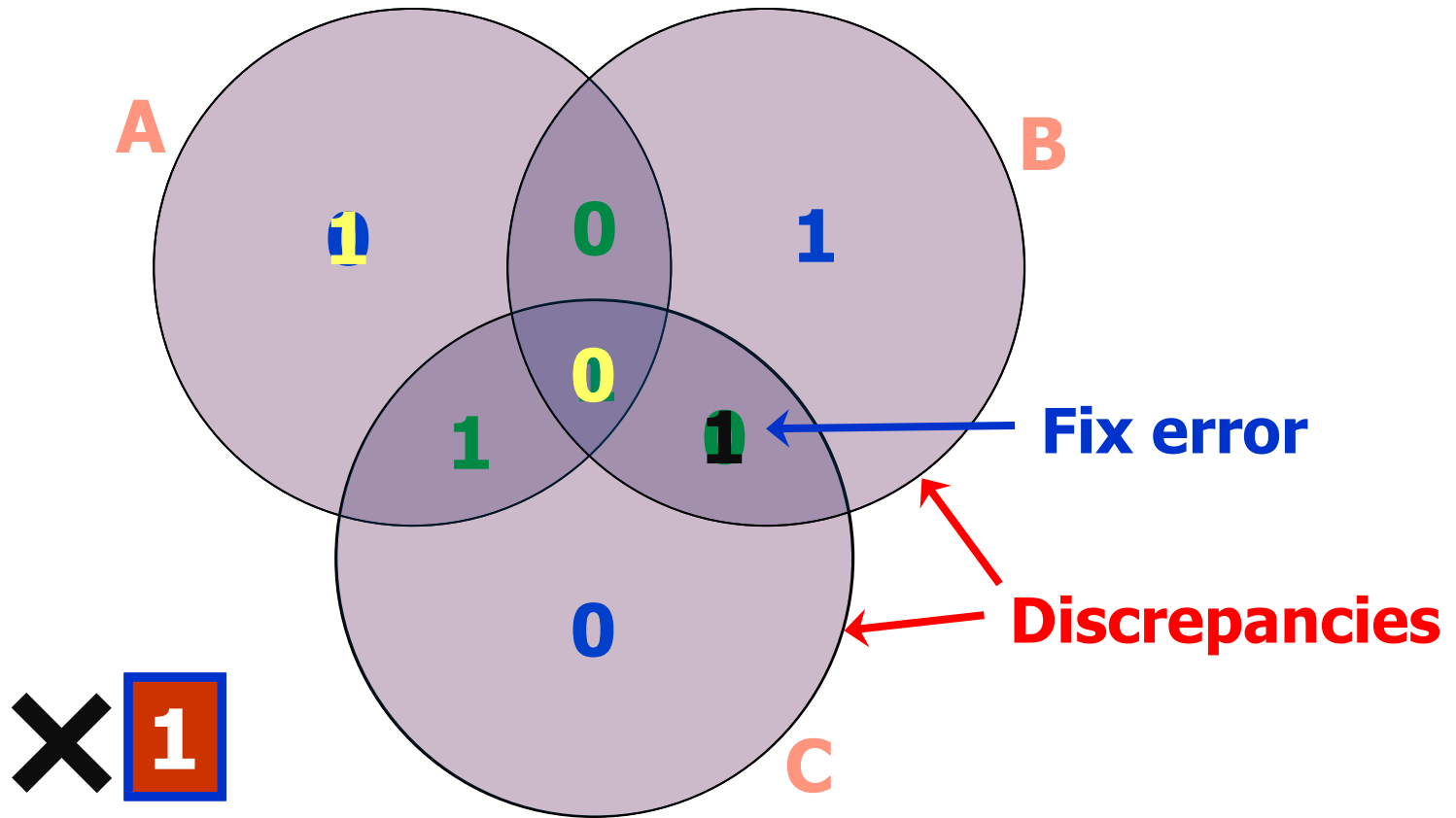
- Assume error in bit 9.
- Recompute the check bits.
- Bit 1 = 0 (**error**).
- Bit 2 = 1.
- Bit 4 = 1.
- Bit 8 = 1 (**error**).
- Error is in bit position = 1 + 8 = 9 → flip it (correction).

Hamming SEC-DED Code

Wrong!!!



Hamming SEC-DED Code (2)



Increase in Word Length with Error Correction

| | Single-Error Correction | | Single-Error Correction/ Double-Error Detection | |
|-----------|-------------------------|------------|--|------------|
| Data Bits | Check Bits | % Increase | Check Bits | % Increase |
| 8 | 4 | 50 | 5 | 62.5 |
| 16 | 5 | 31.25 | 6 | 37.5 |
| 32 | 6 | 18.75 | 7 | 21.875 |
| 64 | 7 | 10.94 | 8 | 12.5 |
| 128 | 8 | 6.25 | 9 | 7.03 |
| 256 | 9 | 3.52 | 10 | 3.91 |

Advanced DRAM Organization

- Interface to MM is a system bottleneck.
- DRAM chip is the main building block of MM.
- Basic DRAM architecture same since 1970s!
- Enhancements to basic DRAM architecture
 - Synchronous DRAM (SDRAM)
 - DDR-SDRAM, DDR2-SDRAM, DDR3-SDRAM
 - Rambus DRAM (RDRAM)
 - Cache DRAM (CDRAM)

Synchronous DRAM (SDRAM)

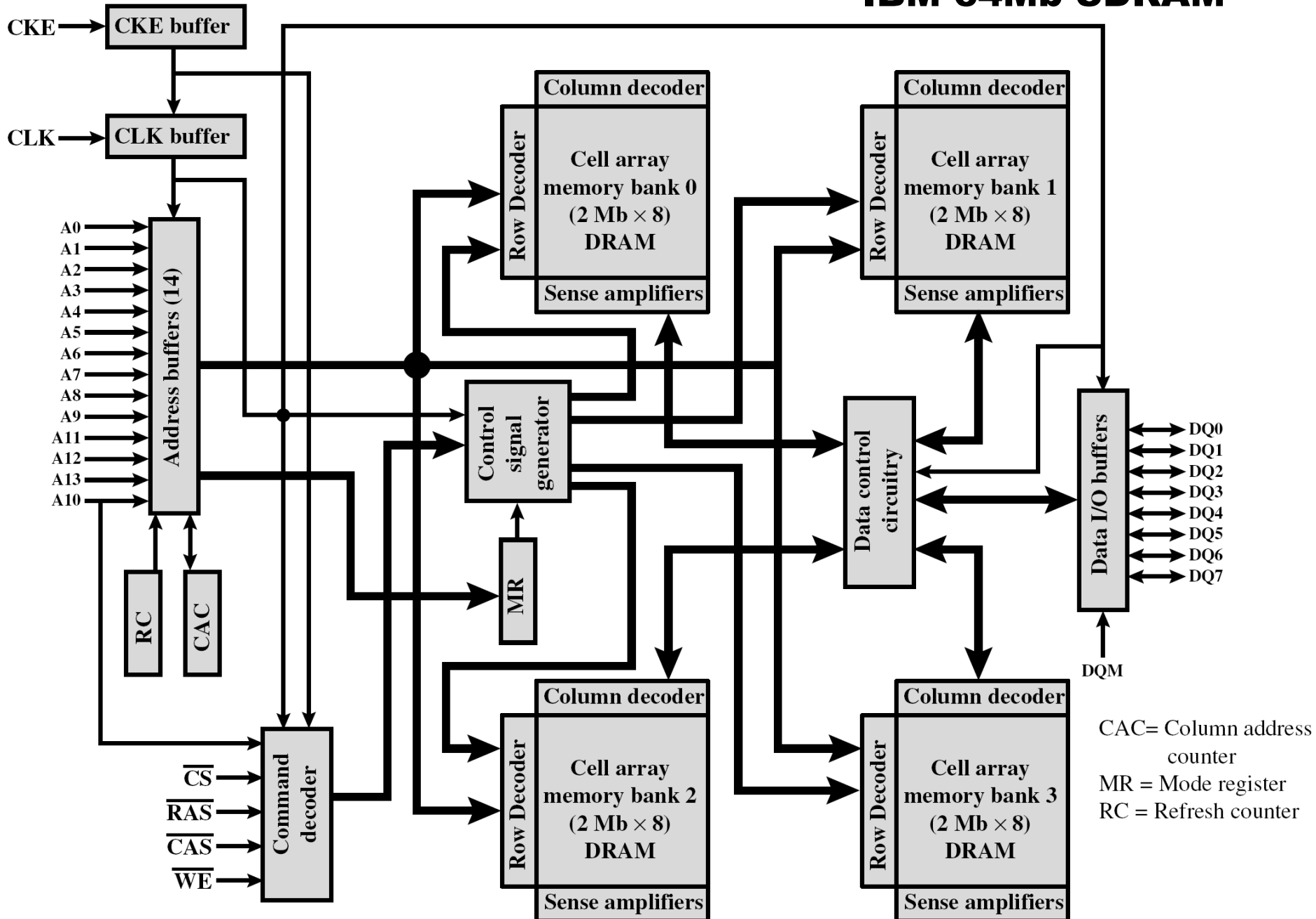


- Unlike traditional DRAM (which is asynchronous), SDRAM exchanges data with CPU synchronized to an external clock (system bus).
- No wait states!
 - SDRAM moves data in/out under control of system clock.
 - CPU issues command and address.
 - Latched by the SDRAM.
 - SDRAM responds after a number of clock cycles.
 - Meanwhile, CPU can do other tasks → no waits.

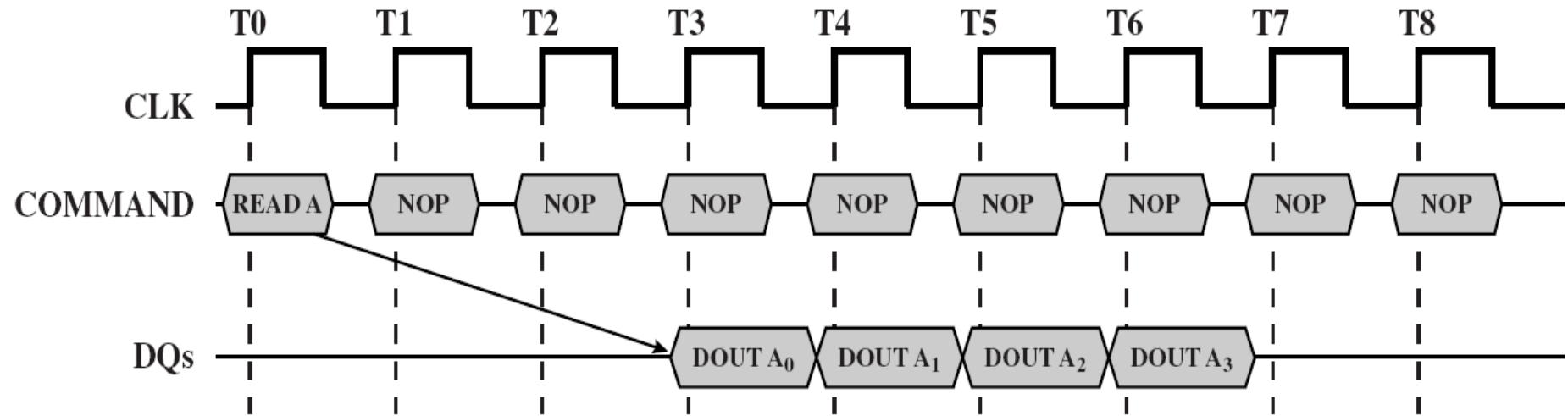
Synchronous DRAM (SDRAM) (2)

- **Burst mode**: a series of data bits can be clocked out rapidly after the first bit has been accessed.
- Eliminates row and column address setup time.
- Useful when the required bits are in sequence and in the same row of the array as the initial access.
- Multiple-bank internal architecture improves opportunities for parallelism.
- Mode Register (MR)
 - Specifies burst length.
 - Allows programmer to adjust latency between read request and data transfer.

IBM 64Mb SDRAM



SDRAM Operation



- Burst type, length and latency are set in mode reg.
 - Type: interleaved or sequential
 - In the example: length=4 and latency=3
- Burst read command is initiated.
 - At the rising edge of the clock: CS & CAS → low, and RAS & WE → high.
- Address inputs determine starting column for burst.

Enhanced versions of SDRAM

- Double Data Rate (DDR-SDRAM)
 - produces two words of data every memory cycle
 - sends data to CPU twice per clock cycle (at leading & trailing edges of the clock)
 - 2x data rate of SDRAM (with same cell speed)
- DDR2-SDRAM
 - produces four words of data every memory cycle
 - 2x bus speed & data rate of DDR (with same cell speed)
- DDR3-SDRAM
 - produces eight words of data every memory cycle
 - 2x bus speed & data rate of DDR2 (with same cell speed)

Rambus DRAM (RDRAM) (1)

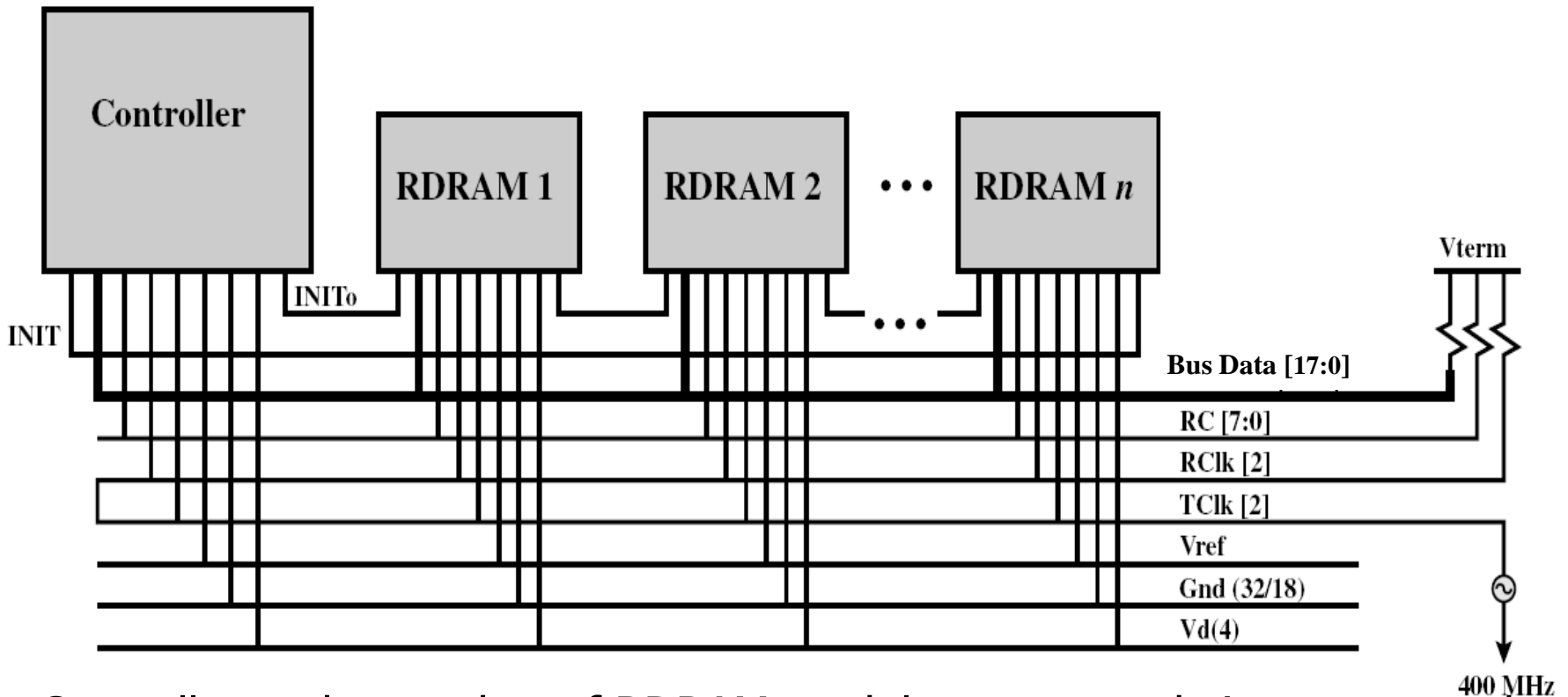


- Adopted by Intel for Pentium & Itanium in late 90s.
- Was main competitor to SDRAM.
- Chips are vertical packages – all pins on one side.
- Data exchange over 28 wires < 12 cm long.
- Bus can address up to 32 RDRAM chips and is rated at 1.6 GBps.

Rambus DRAM (RDRAM) (2)

- Asynchronous block-oriented protocol
 - Initial 480 ns access time.
 - Then 1.6 GB/s.
- What makes this speed possible is the bus itself, which defines impedances, clocking, and signals very precisely.
- RDRAM gets a memory request over the high-speed bus (unlike conventional DRAMs controlled by RAS, CAS, R/W, and CE).
- This request contains address, operation, number of bytes.

RDRAM Diagram



- Controller and a number of RDRAM modules connected via a common bus.
- Bus: 18 data lines, cycling at twice the clock rate → 800 Mbps per line.
- Address and control signals: 8 lines (RC)
- Clock starts at the far end from the controller, propagates to the controller end, then loops back.
- Module sends data to the controller synchronously to the clock to master.
- Controller sends data to a module synchronously with the clock in the opposite direction.

Cache DRAM (CDRAM)

- CDRAM integrates a small SRAM cache (16 kb) onto a generic DRAM chip.
- CDRAM can be used in two ways:
 1. As a **true cache** with 64-bit lines.
 2. As a **buffer** to support serial access of a data block.
 - e. g., to refresh a bit-mapped screen, the CDRAM can **prefetch** the data from the DRAM into the SRAM buffer. Subsequent accesses to the chip results in accesses to the SRAM only.

Reading Material

- Stallings, Chapter 5:
 - Pages 170 – 180