# IE1204 Digital Design

# L14: Semiconductor memory, microcomputer


KTH Informations- och kommunikationsteknik

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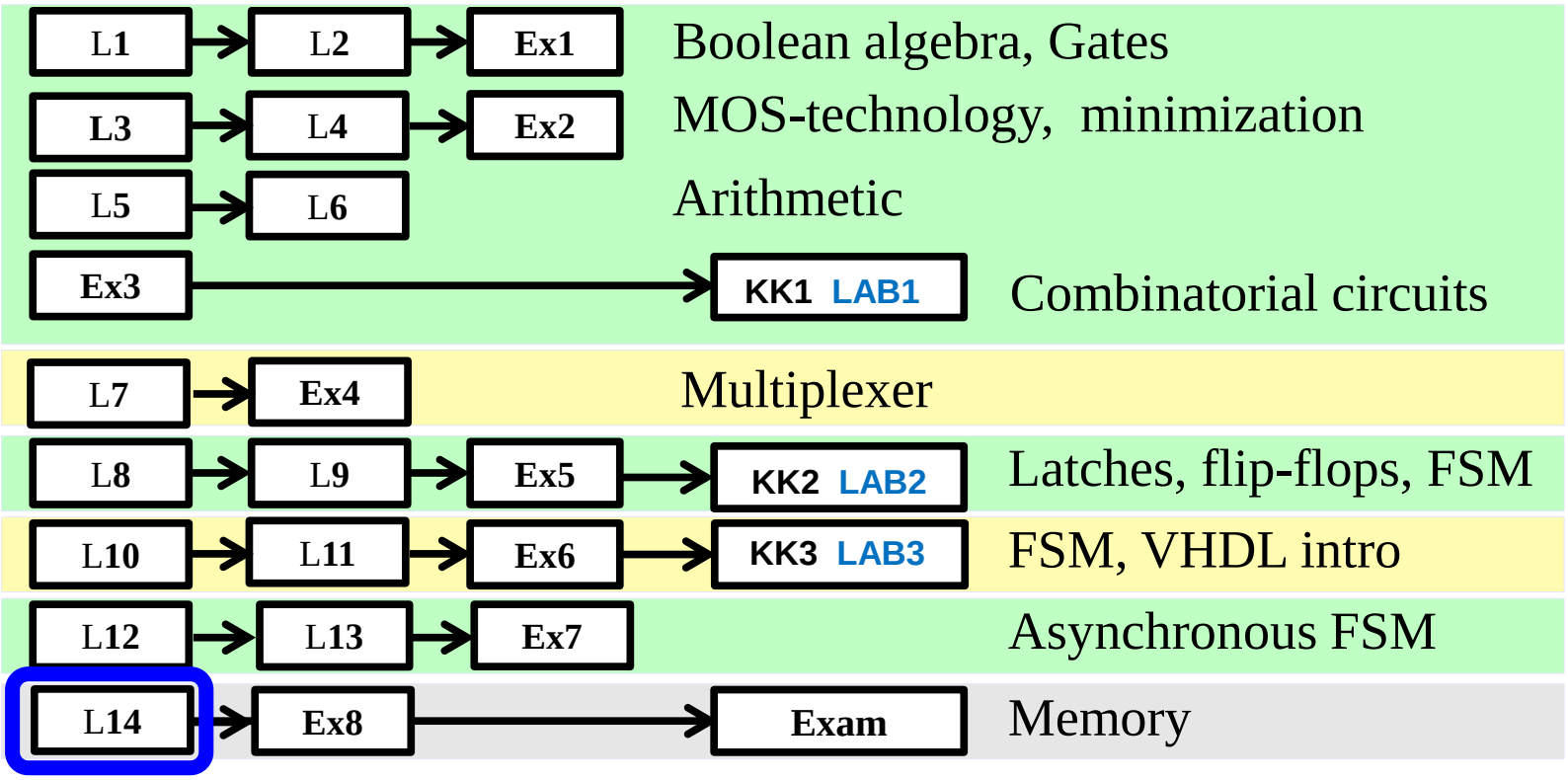
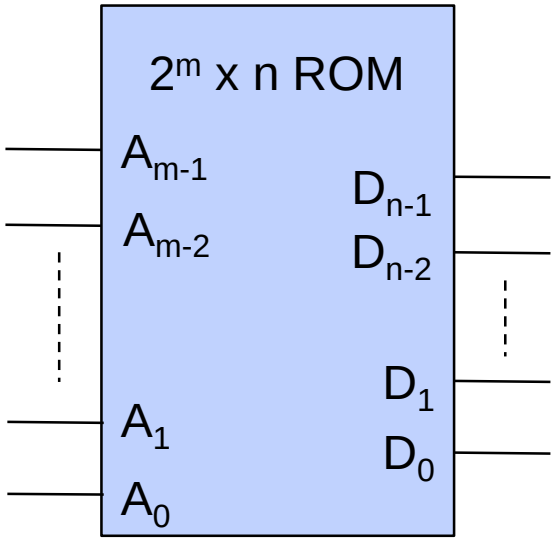
# IE1204 Digital Design

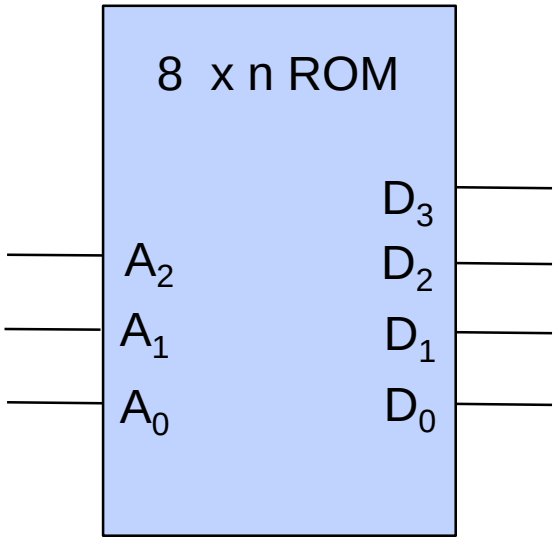


# Read Only Memory (ROM)

- A read only memory has the address inputs and data outputs
- With m address lines, $2^m$ different memory addresses can be accessed
- At each address, there is one data word of n bits
- Usually, the ROM also has an Output Enable (OE) input



# 8x4 ROM

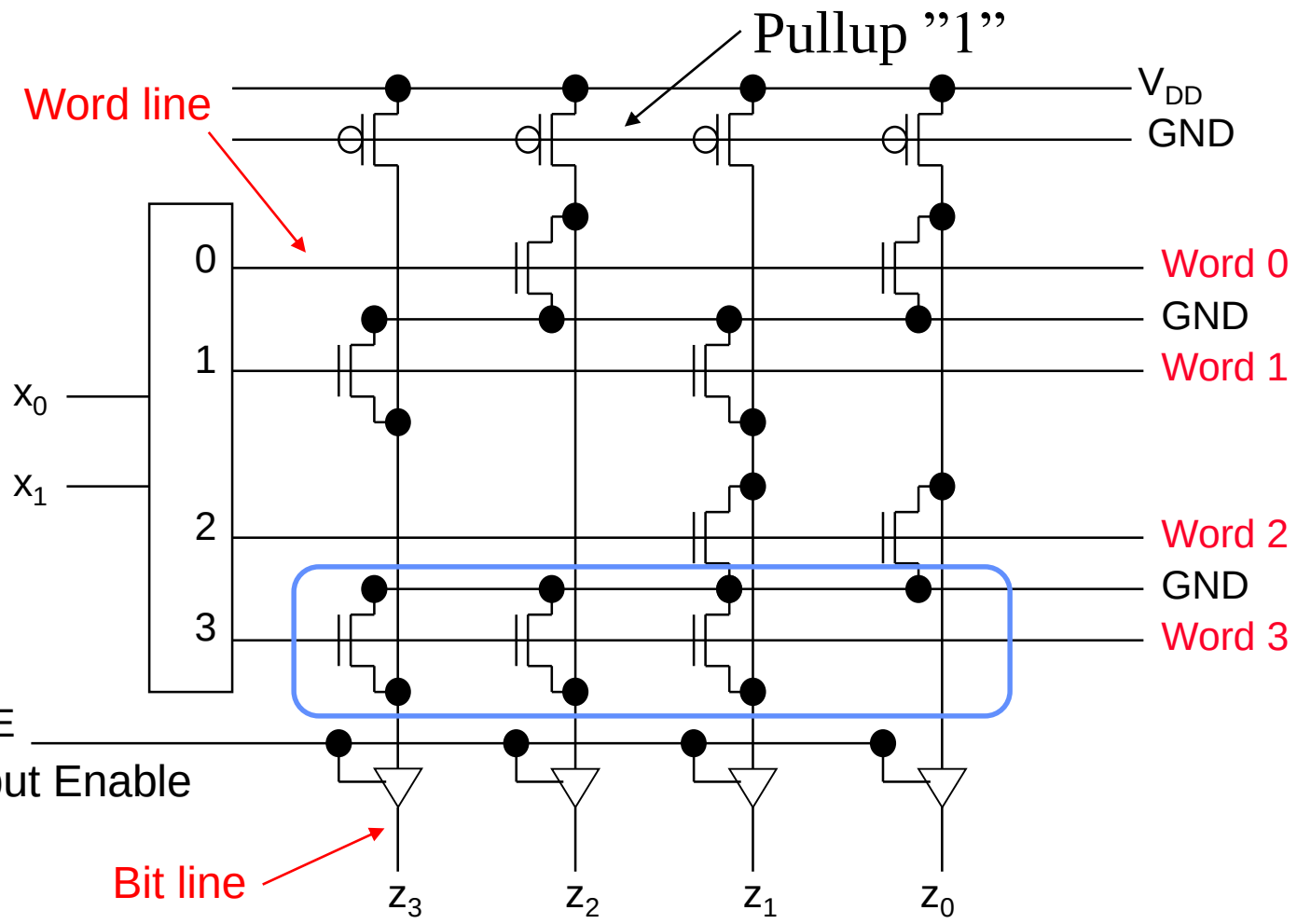



Possible memory content

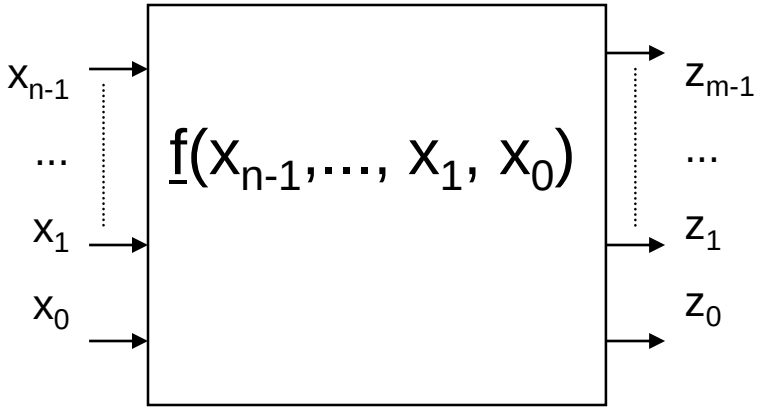
| $A_2$ | $A_1$ | $A_0$ | $D_3$ | $D_2$ | $D_1$ | $D_0$ |
|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 1 | 0 |
| 0 | 0 | 1 | 0 | 1 | 1 | 0 |
| 0 | 1 | 0 | 1 | 1 | 1 | 1 |
| 0 | 1 | 1 | 1 | 1 | 0 | 1 |
| 1 | 0 | 0 | 0 | 0 | 1 | 1 |
| 1 | 0 | 1 | 0 | 0 | 0 | 0 |
| 1 | 1 | 0 | 1 | 0 | 0 | 1 |
| 1 | 1 | 1 | 0 | 0 | 1 | 1 |

# Read-Only Memory (ROM)

| Adress | Content |
|---|---|
| $x_1x_0$ | $z_3z_2z_1z_0$ |
| 00 | 1010 |
| 01 | 0101 |
| 10 | 1100 |
| 11 | 0001 |



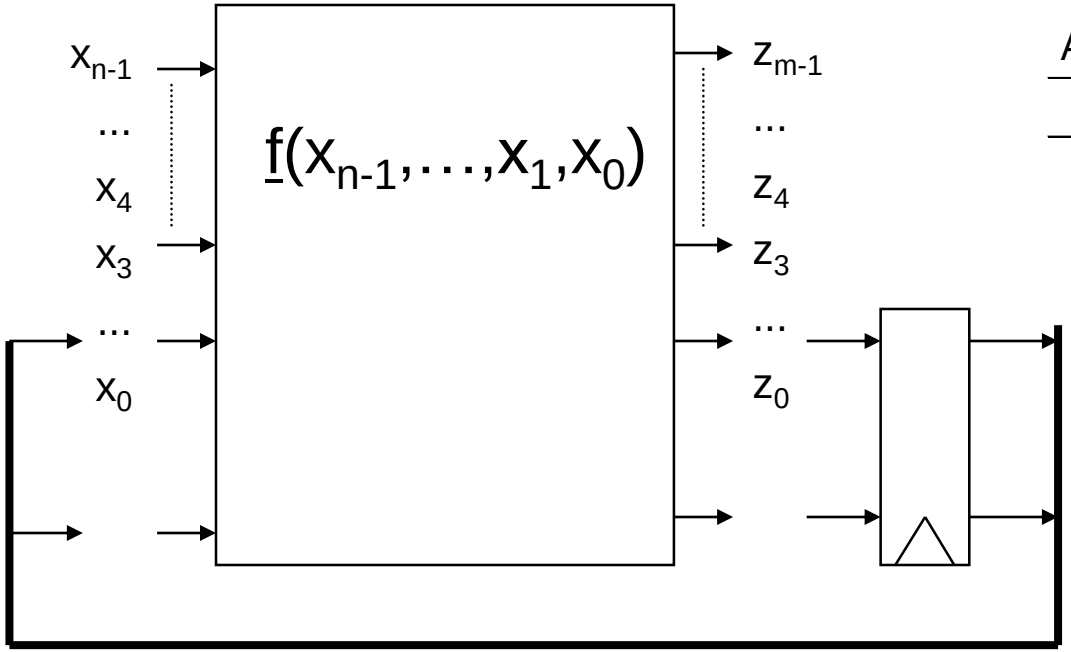
# Use of ROM for implementing logic functions




| Address | Content |
|---|---|
| $x_{n-1}\ldots x_1x_0$ | $z_{m-1}\ldots z_1z_0$ |
| 0…00 | 1…10 |
| 0…01 | 0…01 |
| … | … |
| 1…11 | 0…01 |

A ROM having n inputs and m outputs can be used to implement a combinatorial function with m outputs and $2^n$ minterms

# Use of ROM for implementing sequential circuits

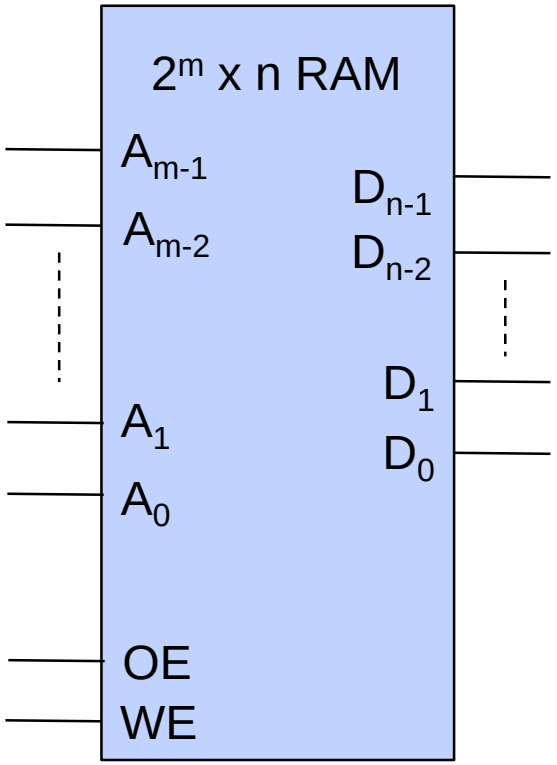



| Adress | Content |
|---|---|
| $x_{n-1}\ldots x_3x_2x_1x_0$ | $z_{m-1}\ldots z_3z_2z_1z_0$ |
| 0…0000 | 1…0001 |
| 0…0001 | 0…0010 |
| … | … |
| 1…1111 | 0…0000 |

By using feedback, ROM can be adopted to implement sequential circuits and state machines

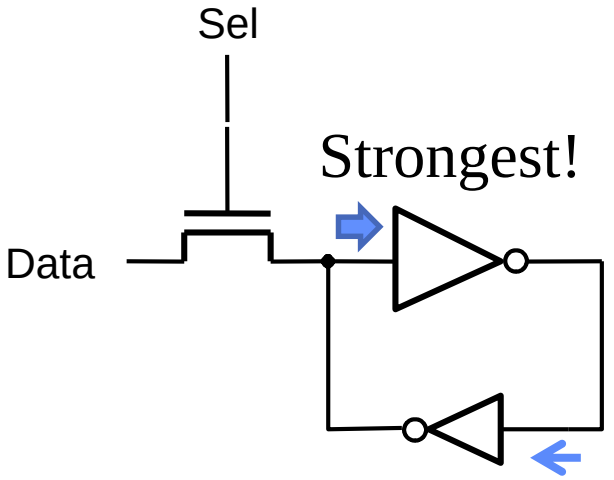
# Random-Access Memory (RAM)

- RAM also has a **Write Enable (WE)** input that allows to write a data word at a given address
- $D_{n-1}$ ... $D_0$ serve as both, inputs and outputs



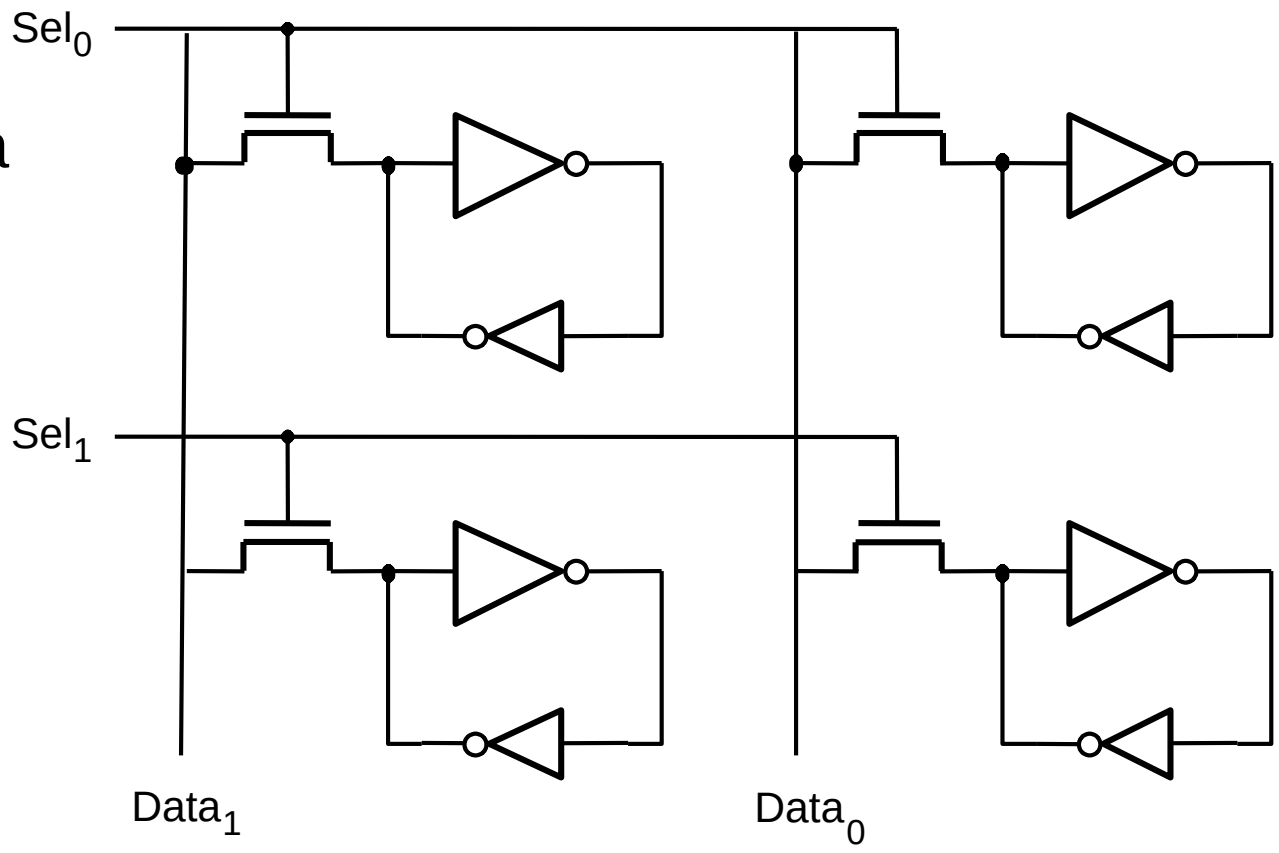
# SRAM
# Static Random Access Memory

- An SRAM memory contains a matrix of SRAM cells
- **To write**, 'data' is used as input
  - 'Sel' is set to 1 and the value at 'data' is written into the cell
- **To read**, 'data' is used as output
  - "Sel" is set to 1 and the value from the cell is transferred to the output



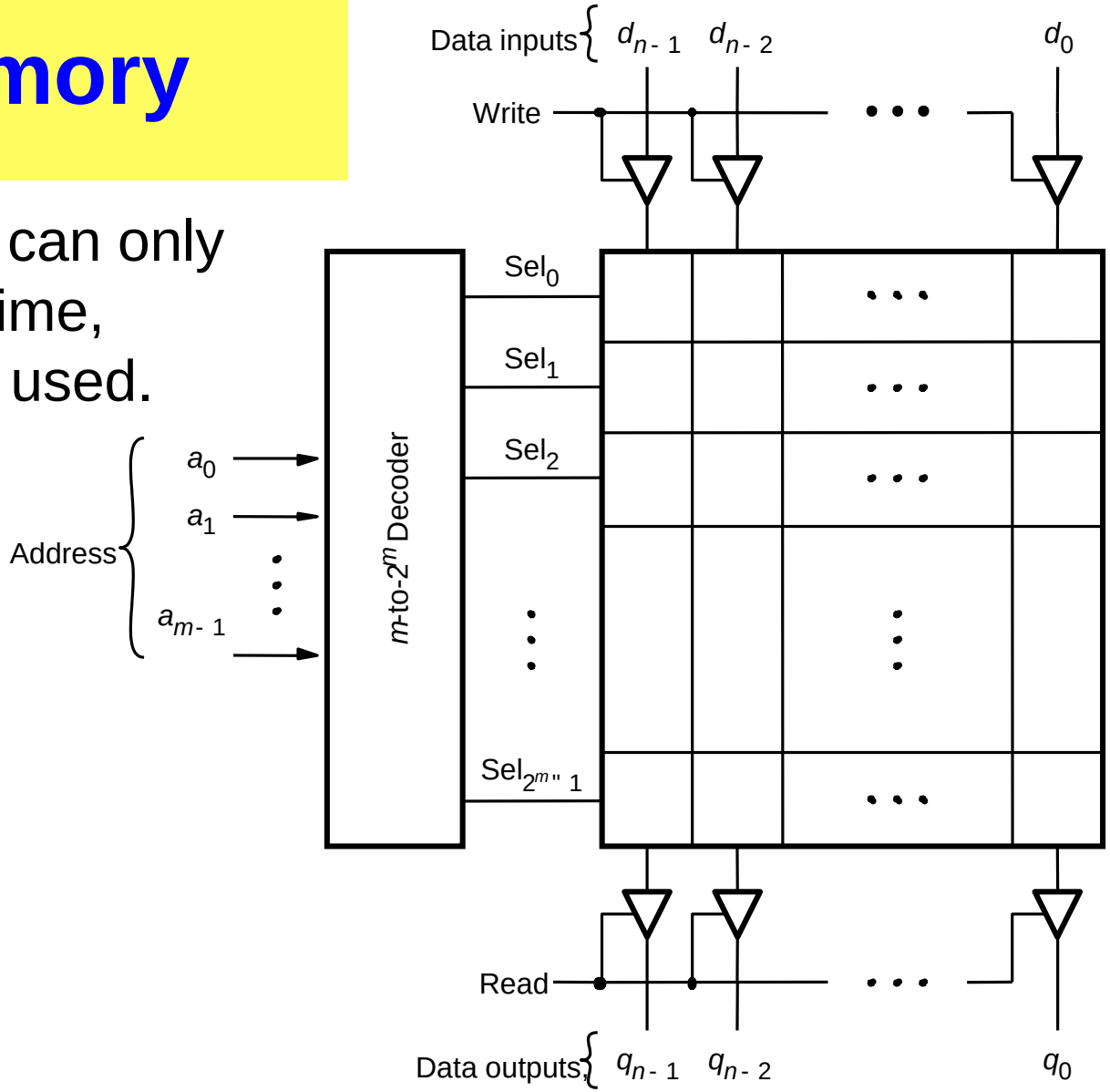
# SRAM

Here we have a matrix of $2^m$ x n SRAM cells



# SRAM memory

- To ensure that we can only read or write at a time, tristate buffers are used.

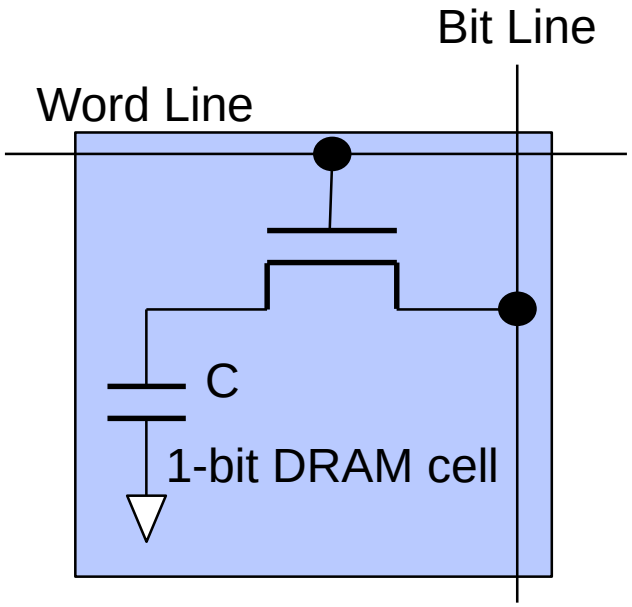


# Dynamic RAM

- SRAM memory cell requires four transistors, so large memories are too costly to implement in this way
- DRAM memory cells use only one transistor and a capacitor
  - capacitor stores a quantity of charge that corresponds to the logical value of the signal

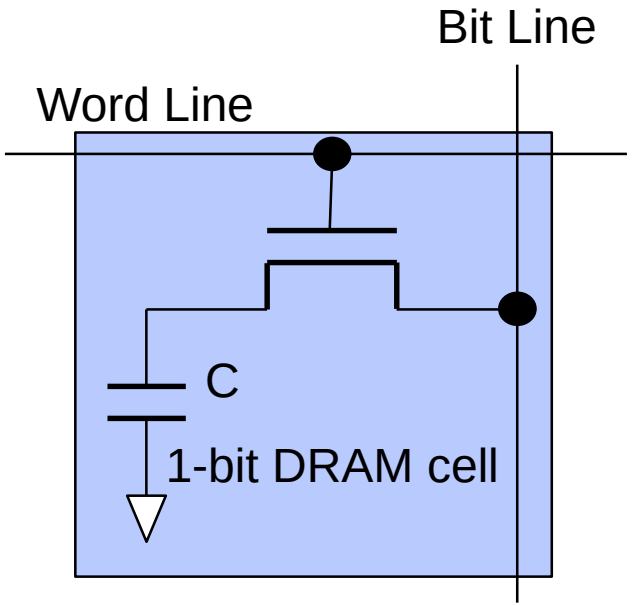
# DRAM Memory Cell

- DRAM cell consists of only one transistor and one capacitor
- **Writing**
  - To load the cell, word line should be set to "1"
    - The cell now gets the value on the bit line



# DRAM Memory Cell

- **Reading** is more complex
  - We don't want to lose data when reading!
  - The bit line is set at a voltage between the High and Low
  - To read from the cell, the word line is set to "1"
    - Bit line adjusts its voltage either up or down
    - An additional circuit (sense amplifier) detects the change direction and creates a real 0 or 1
    - The charge in the capacitor C must be restored!



# SRAM vs DRAM

- SRAM takes more space than DRAM, but it has a simpler access logic and is therefore faster (but also more expensive)
- When power is shut down, the content of SRAM or DRAM memory disappears

# Memory Types

- Volatile memories
  - Memories lose their information if power supply is shut down
    - Static RAM (SRAM)
    - Dynamic RAM (DRAM)
- Non-volatile memories
  - Memories keep their information if power supply is shut down
    - Flash
    - EPROMs, EEPROMs

A combination of different memories is required in an electronic design!

# Flash Memory

- Non-volatile memory
  - Found in over 90% PCs, over 90% cellular phones and over 50% modems
  - Key component of the digital imaging and audio markets where it serves as the digital "film" or digital "tape"
- Low cost and low power consumption
- Can be erased and updated, but it takes much more time than in a RAM

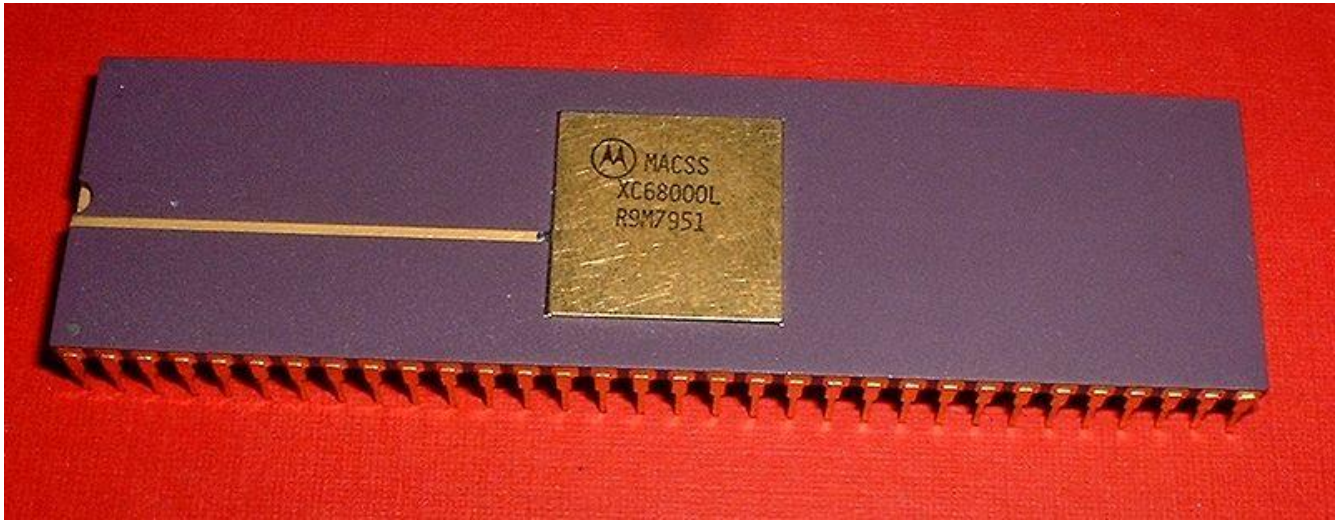
# Memory Access Times and Costs

| Memory Technology | Typical Access Time | $ Per GB in 2004 |
|---|---|---|
| SRAM | 0.5 ns -5 ns | $ 4,000 - $ 10,000 |
| DRAM | 50 ns - 70 ns | $ 100 - $ 200 |
| Magnetic disk | 5,000,000 ns - 20,000,000 ns | $ 0.5 - $ 2 |

Source: Patterson and Hennessy, 2004

# Microcomputer

- A microcomputer consists of both combinational and sequential digital logic




Motorola 68000 (1979-prerelease)

# Motorola 68000

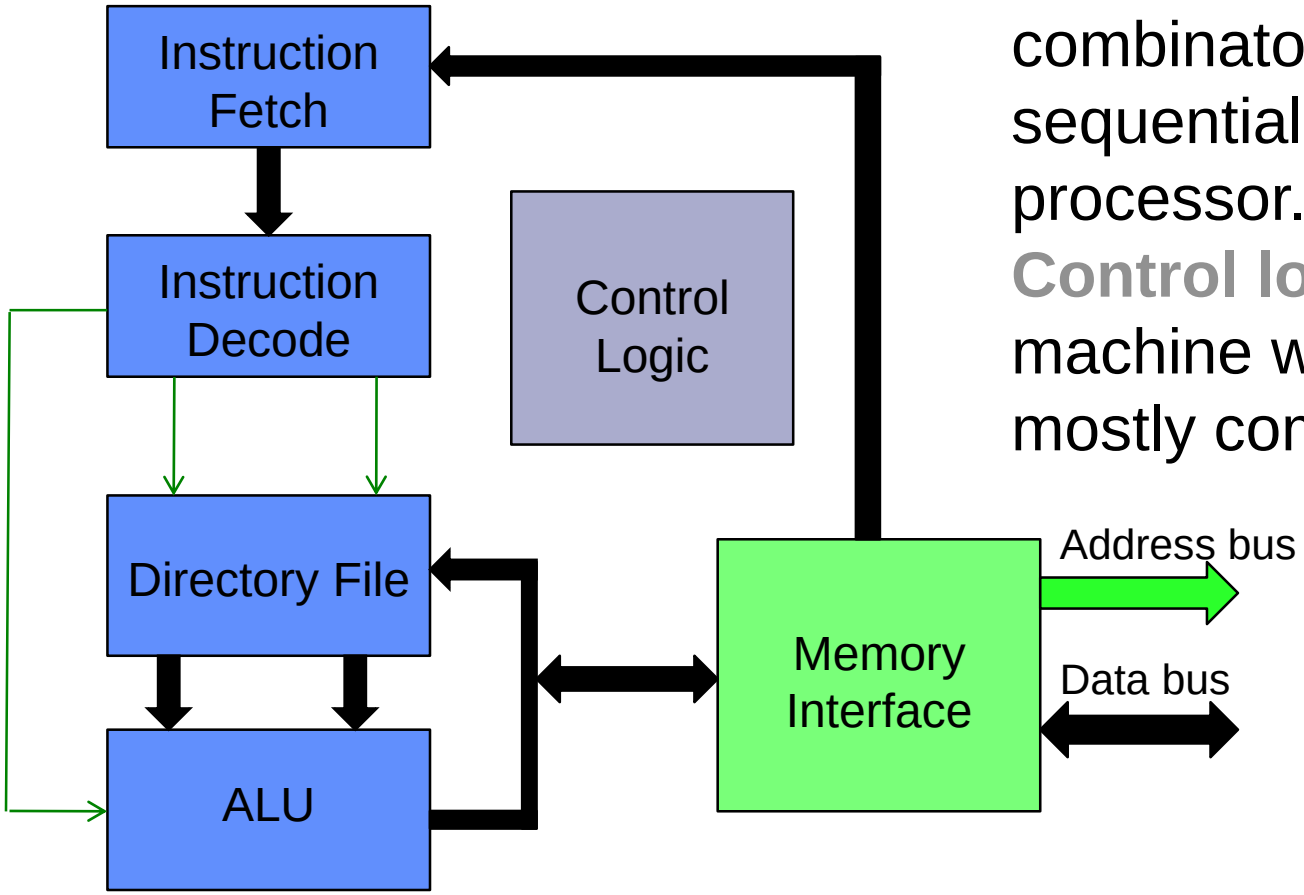
- Motorola 68000 was a highly successful processor that formed the brain in several desktop computers (not in the IBM PC) in the 1980s

Commodore Amiga

Atari ST

Apple Macintosh

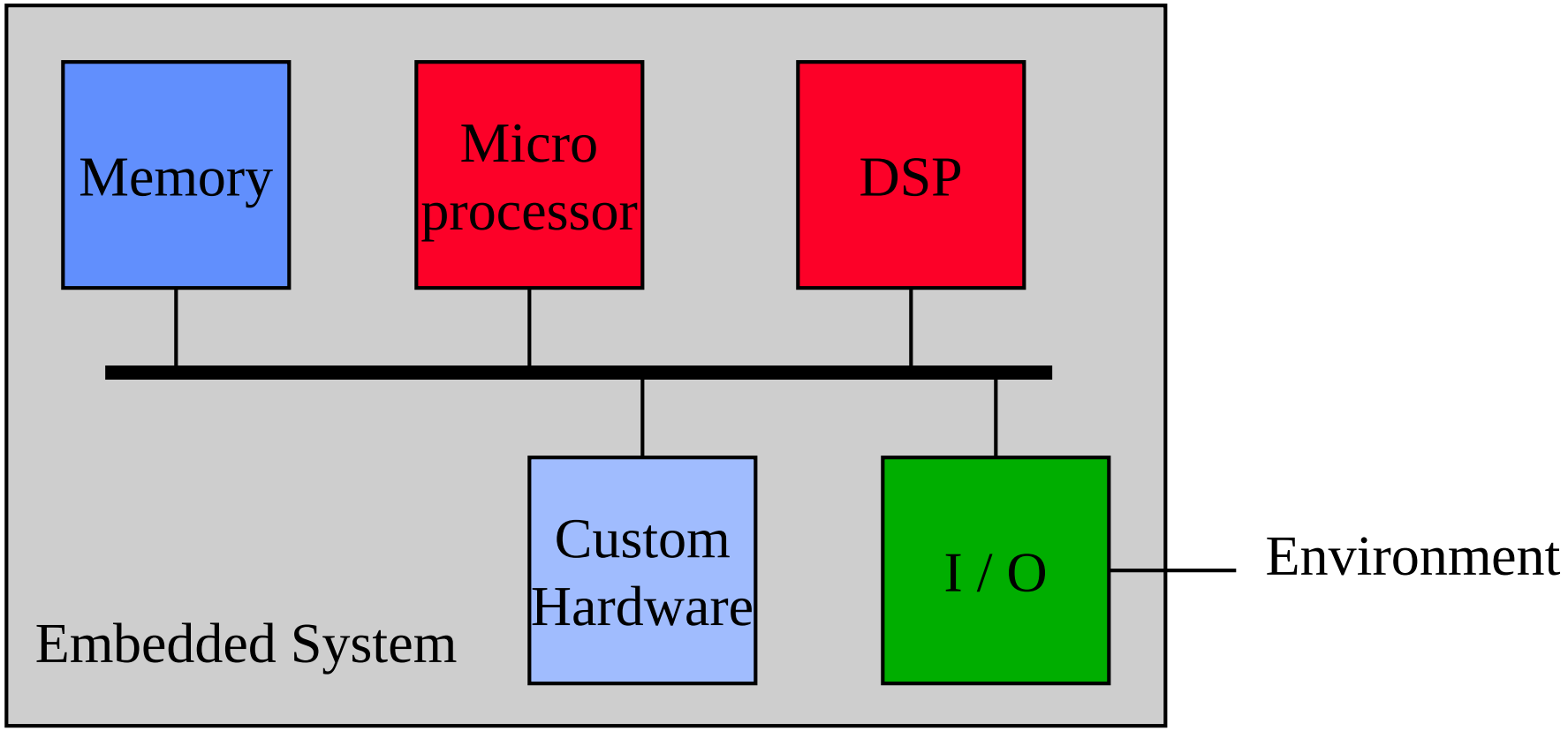
# Principles of Microcomputer Architecture



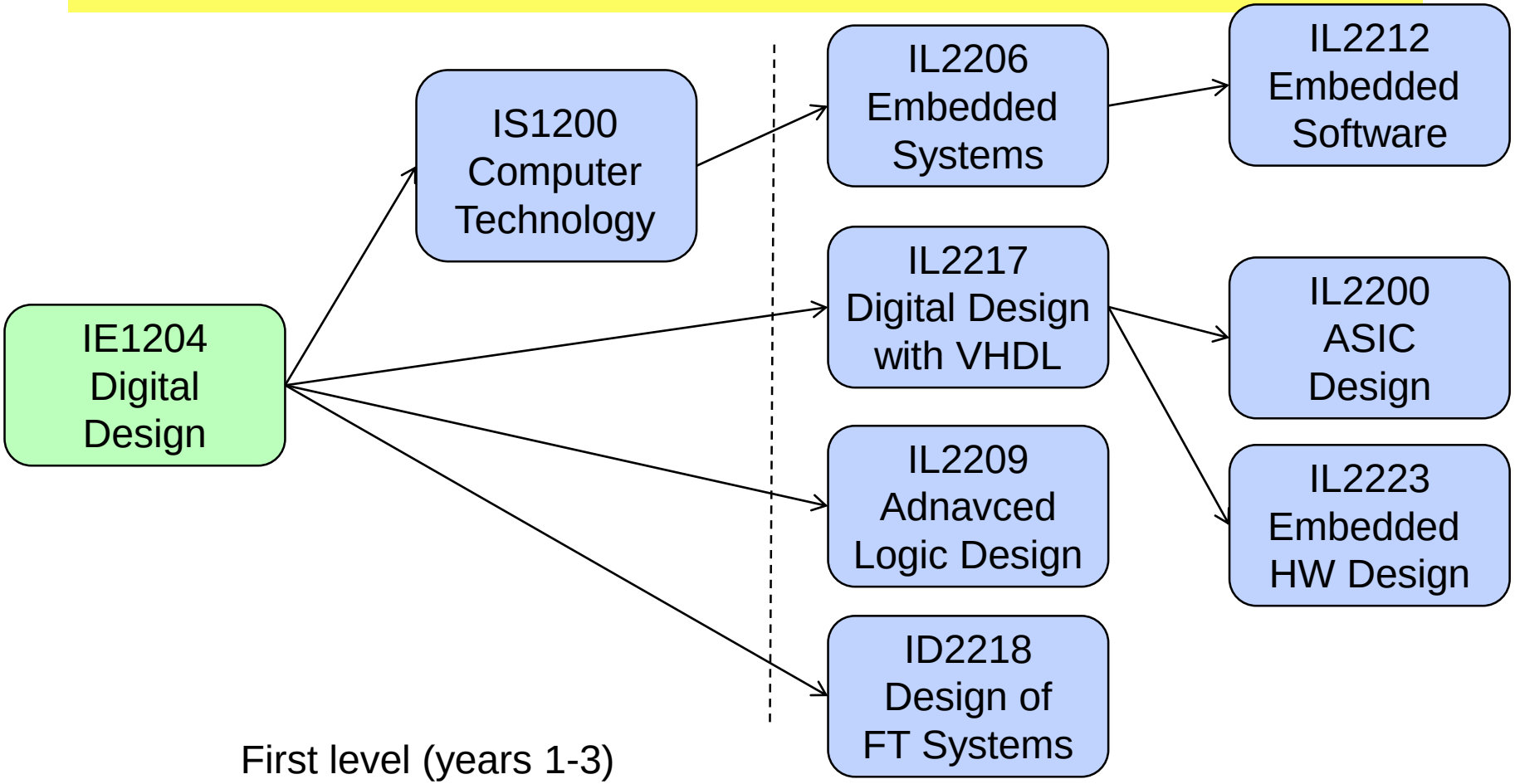

There are both combinatorial and sequential logic in a processor.

**Control logic** is a state machine while the **ALU** is mostly combinatorial.

# Hardware architecture of a small embedded system



# Supplementary courses



# Course evaluation

- It is important that we get your feedback!
- You will soon receive an e-mail with instructions for course evaluation
- Help us to improve the course with your feedbacks (Please comment)