Let’s us Design a Logic Circuit…

REVIEW

Design a logic circuit

1. Implement with basic logic gates
2. Implement with Decoder + Gates (**ROM**)

Example; Design a Logic Circuit

- Design a binary logic circuit, having two inputs. The binary output **f(X),** follows the rule: If the input **f(A),** is less or equal to 1. Then: **f(X)= f(A)+2_{10}**. Otherwise: **f(X)= f(A)-1.**

Set Up the truth table

Example

- Design a binary logic circuit, having two inputs. The binary output **f(X),** follows the rule: If the input **f(A),** is less or equal to 1. Then: **f(X)= f(A)+2_{10}**. Otherwise: **f(X)= f(A)-1.**

	f(A)		f(X)	
	A_1	A_0	X_1	X_0
0	0	0		
1	0	1		
2	1	0		
3	1	1		

Truth table

- Design a binary logic circuit, having two inputs. The binary output **f(X),** follows the rule: If the input **f(A),** is less or equal to 1. Then: **f(X)= f(A)+2_{10}**. Otherwise: **f(X)= f(A)-1.**

	f(A)		f(X)	
	A_1	A_0	X_1	X_0
0	0	0	1	0
1	0	1	1	1
2	1	0	0	1
3	1	1	1	0

n=2: Inputs
m=2: Outputs

Logic equations?

Logic equations

$X_1 =$

$X_0 =$

A_1	A_0	X_1	X_0
0	0	1	0
0	1	1	1
1	0	0	1
1	1	1	0

Logic equations

$$X_1 = \overline{A_1}\,\overline{A_0} + \overline{A_1}A_0 + A_1A_0$$

$$X_0 = \overline{A_1}A_0 + A_1\overline{A_0}$$

A_1	A_0	X_1	X_0
0	0	1	0
0	1	1	1
1	0	0	1
1	1	1	0

Implement X_0 and X_1 using:

1. Basic logic gates
2. Decoder + OR gates

Next Implement with basic logic gates

Using basic gates (**Must USE K-Maps**)

X_1

	$\bar{A}_0$	A_0
$\bar{A}_1$	1	1
A_1	0	1

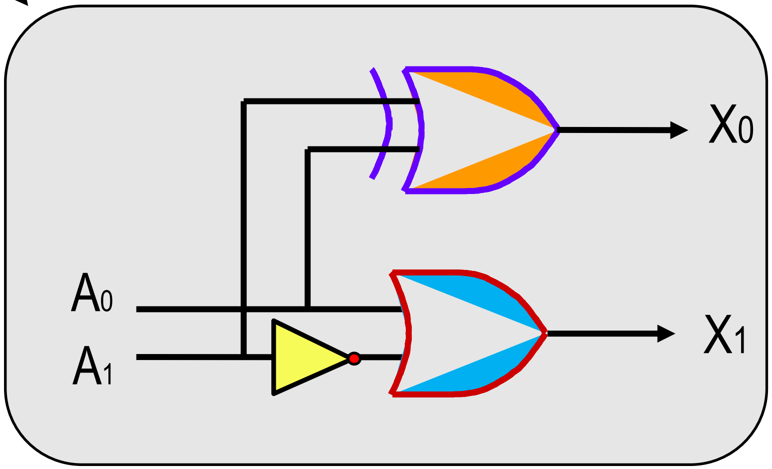
$X_1 = \bar{A}_1 + A_0$

$X_0 = A_1$ **XOR** A_0

$$X_1 = \bar{A}_1\bar{A}_0 + \bar{A}_1A_0 + A_1A_0$$

$$X_0 = \bar{A}_1A_0 + A_1\bar{A}_0$$

A_1	A_0	X_1	X_0
0	0	1	0
0	1	1	1
1	0	0	1
1	1	1	0



$$X_1 = \overline{A_1}\,\overline{A_0}+\overline{A_1}A_0+A_1A_0$$

$$X_0 = \overline{A_1}A_0+A_1\overline{A_0}$$

Next Implement with Decoder + Gates

OR gates and Decoder

$$X_1 = \overline{A_1}\,\overline{A_0} + \overline{A_1} A_0 + A_1 A_0$$

$$X_0 = \overline{A_1} A_0 + A_1 \overline{A_0}$$

- Size of the Decoder: ?
- Number of OR gates: ?

Decoder 2-4 and 2 OR gates

- Since we have (n) 2 inputs …
- … the size of the Decoder is (n-2^n): 2-4
- Since we have (m) 2 outputs …
- … the number of the OR gates is (m): 2

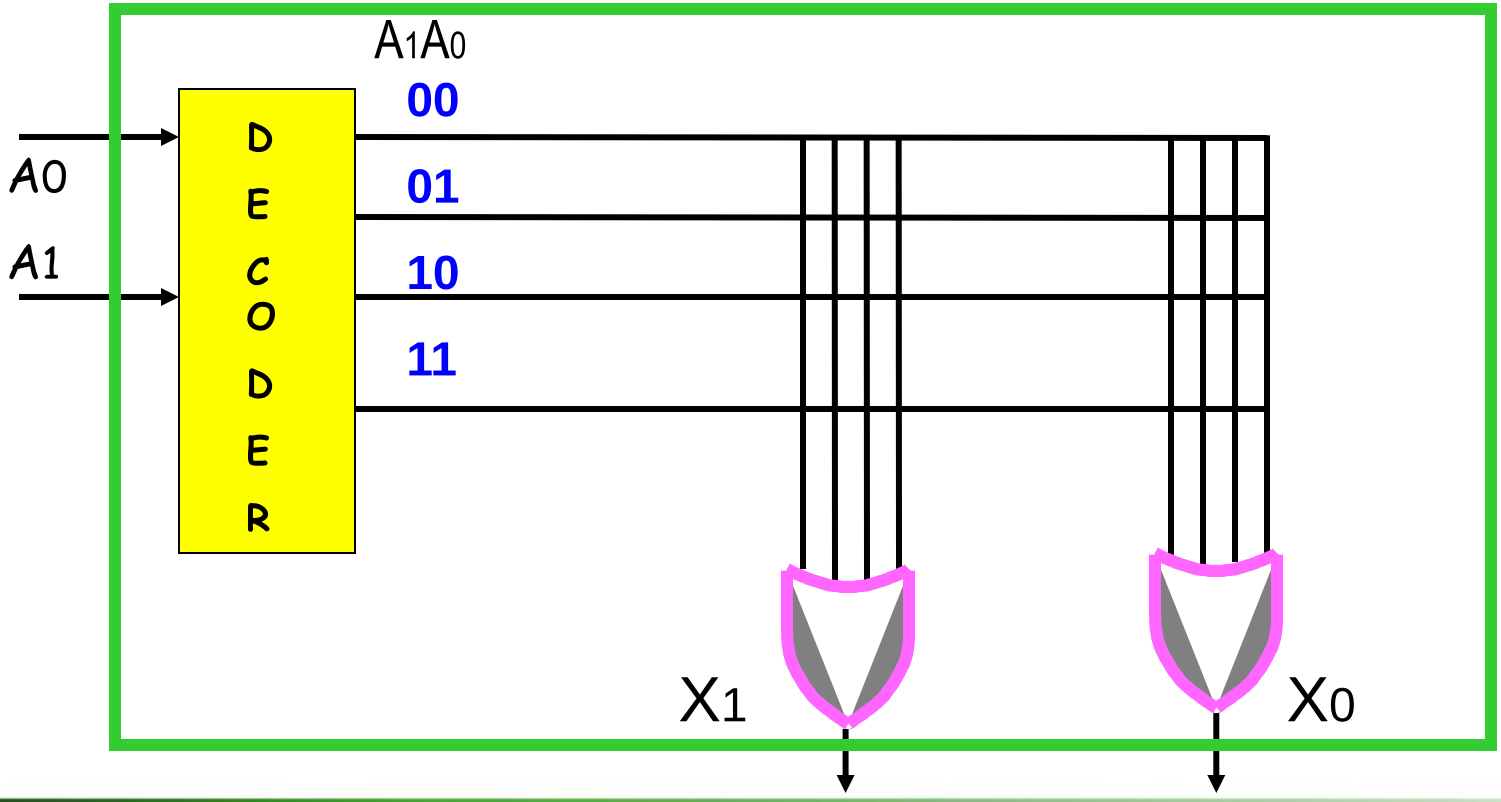
Implement with a Decoder + Gates

$$X_1 = \overline{A_1}\,\overline{A_0} + \overline{A_1}A_0 + A_1A_0$$

$$X_0 = \overline{A_1}A_0 + A_1\overline{A_0}$$

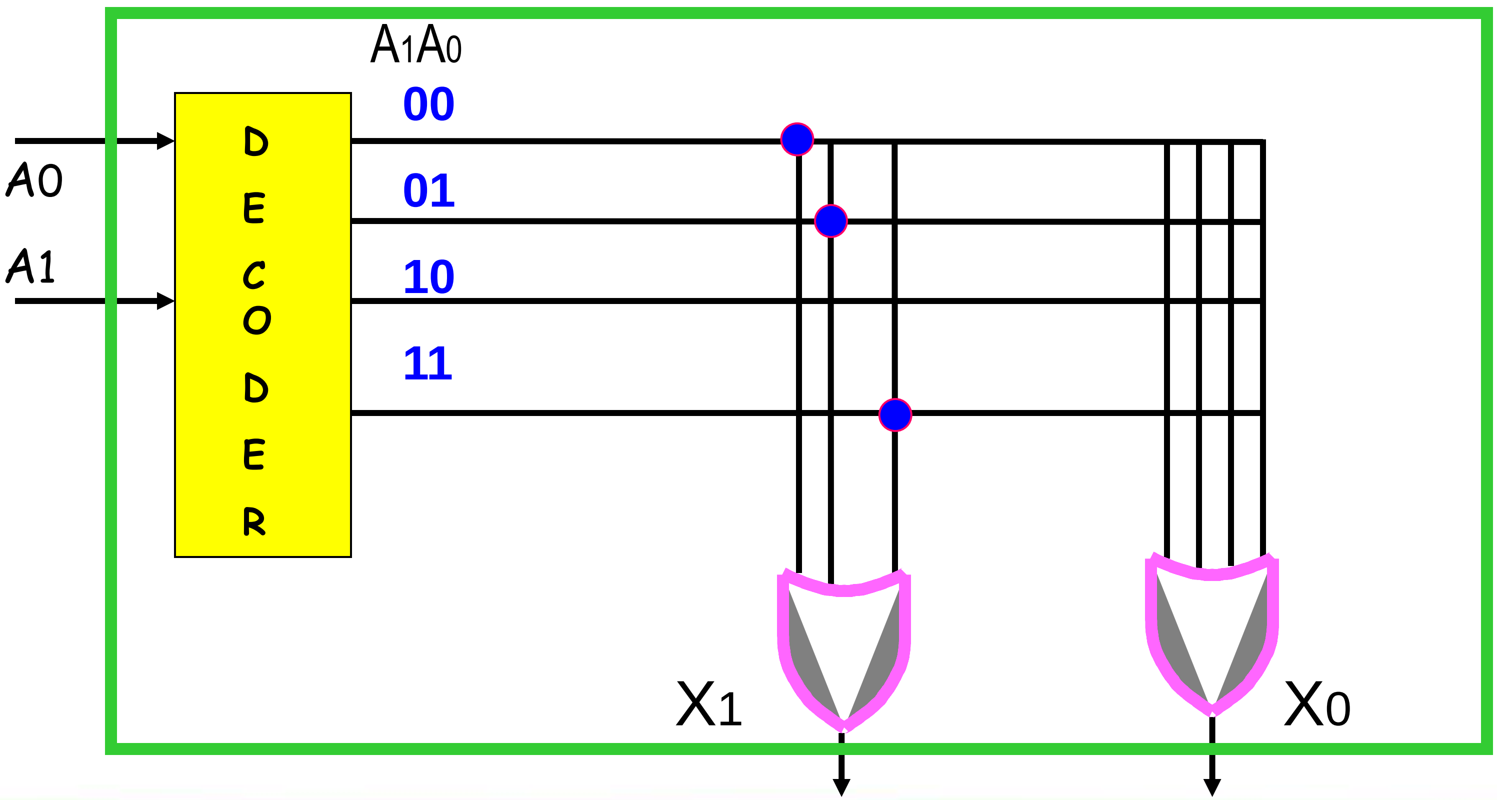
- Size of the Decoder: 2-4
- Number of OR gates: 2

Decoder + Gates (unprogrammed circuit)



X_1

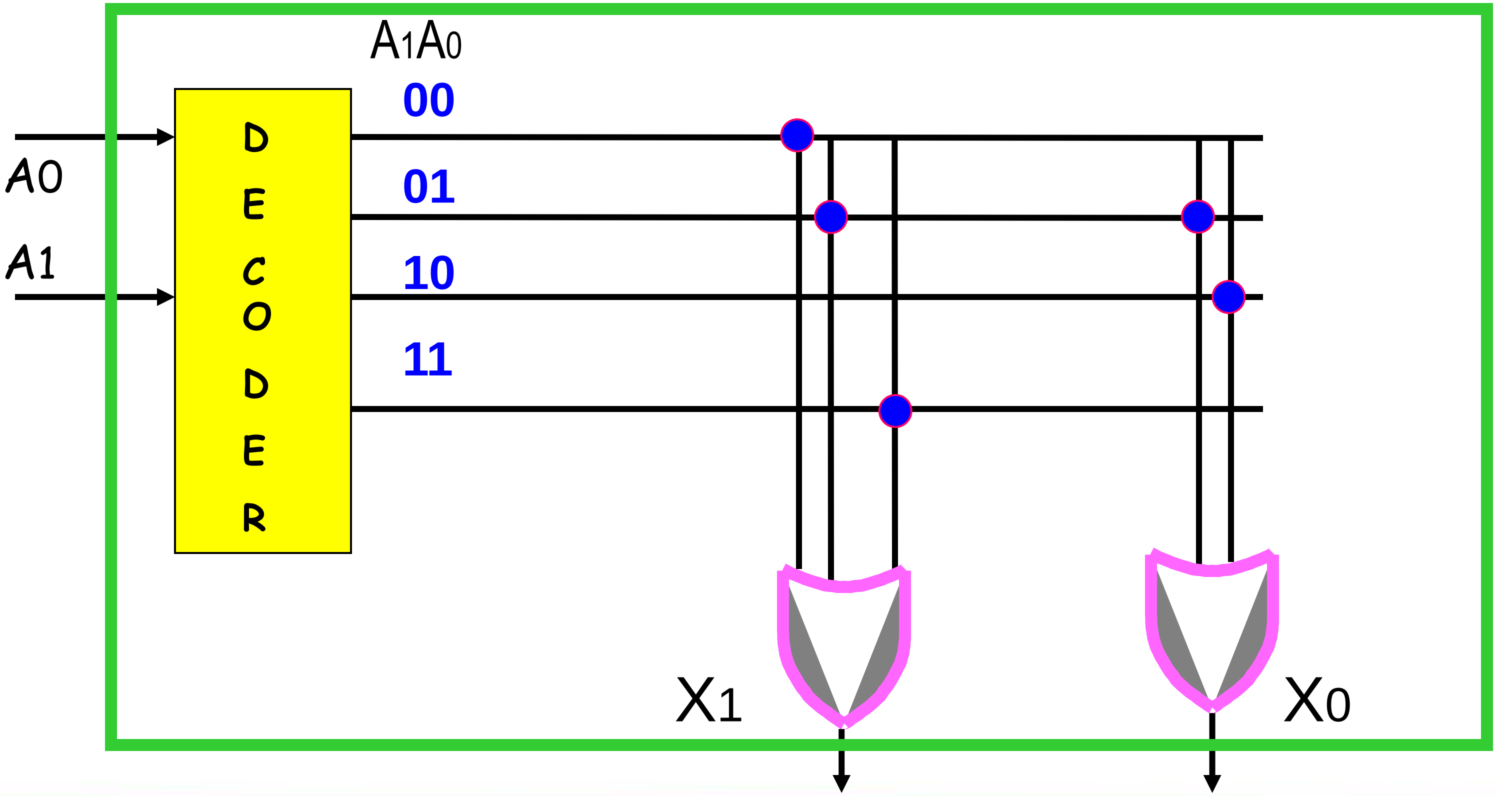
$$X_1 = \bar{A}_1\bar{A}_0 + \bar{A}_1A_0 + A_1A_0$$



X_0

.

$X_0 = \overline{A}_1 A_0 + A_1 \overline{A}_0$

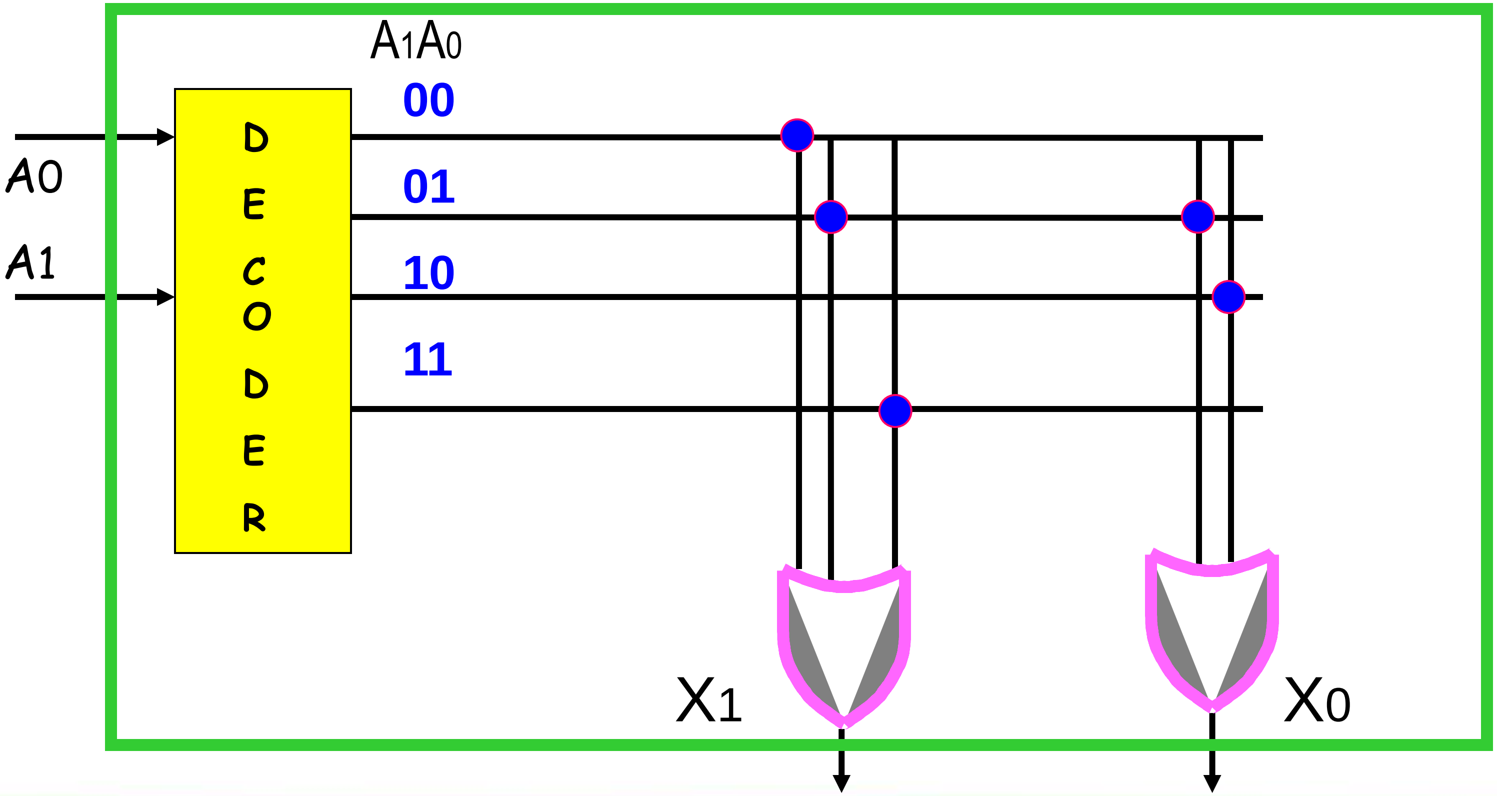


X_0 and X_1 (Programmed circuit)

$$X_1 = \bar{A}_1\bar{A}_0 + \bar{A}_1 A_0 + A_1 A_0$$

$$X_0 = \bar{A}_1 A_0 + A_1 \bar{A}_0$$

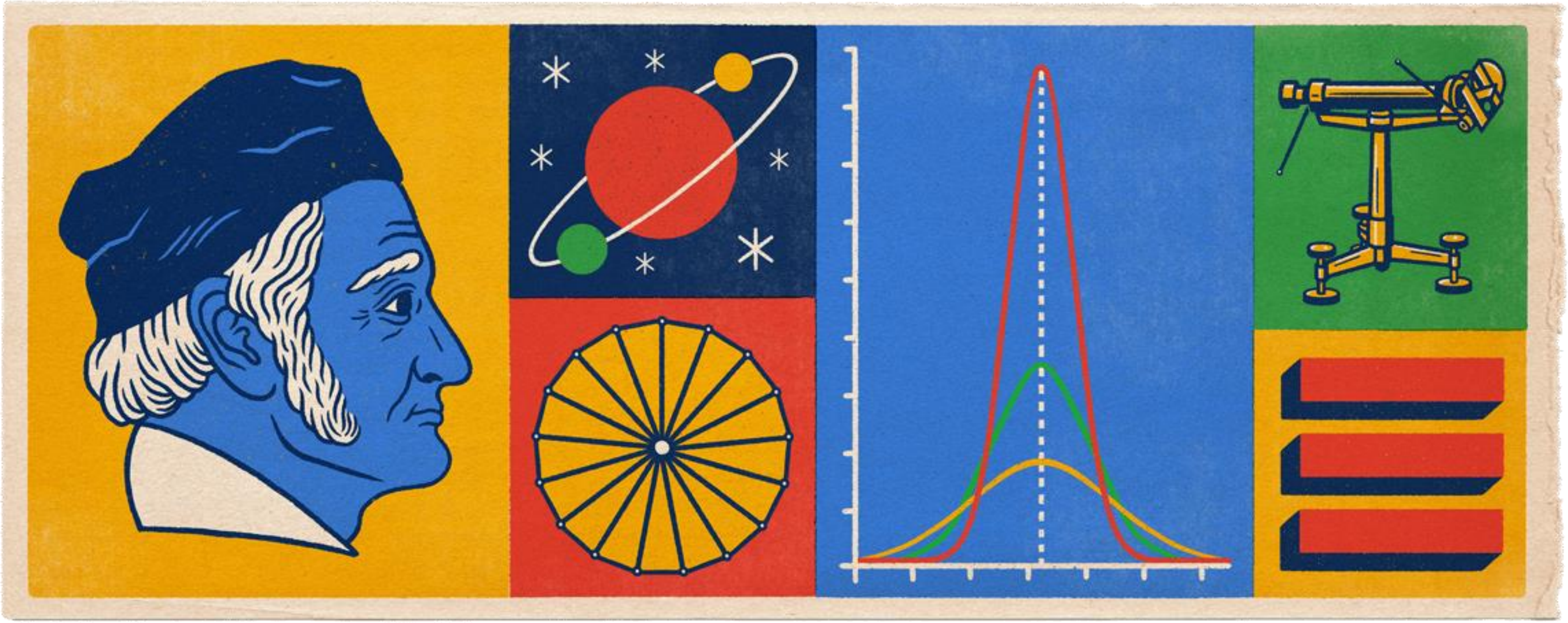
Burning



The design of a logic circuit using a Decoder + OR gates is the main idea for the design of **R**ead **O**nly **M**emories (**ROM**).

ROM

Read Only Memory



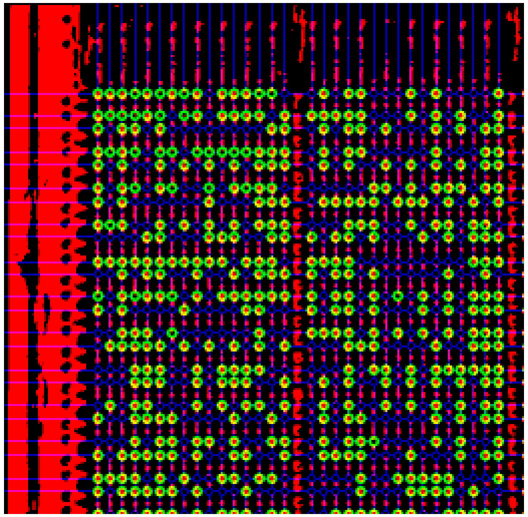
Read Only Memory (ROM)

- **ROM =** Electronic component

  = I.C (Integrated Circuit) package

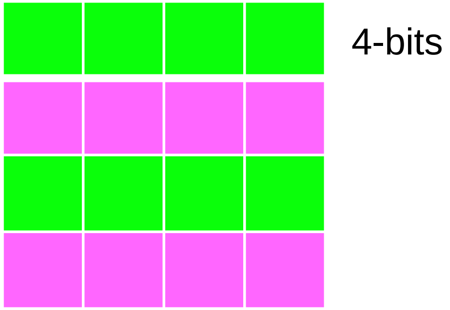
- Permanent binary information is stored

- “ROM chips contain a software that is burned onto the chip during the design phase of the semiconductor manufacturing process”

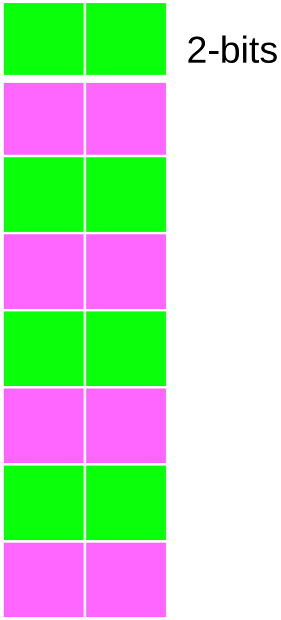


http://www.globalspec.com

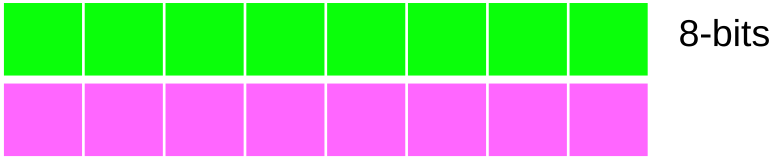
A ROM can be organized in different ways



4 x 4 memory array



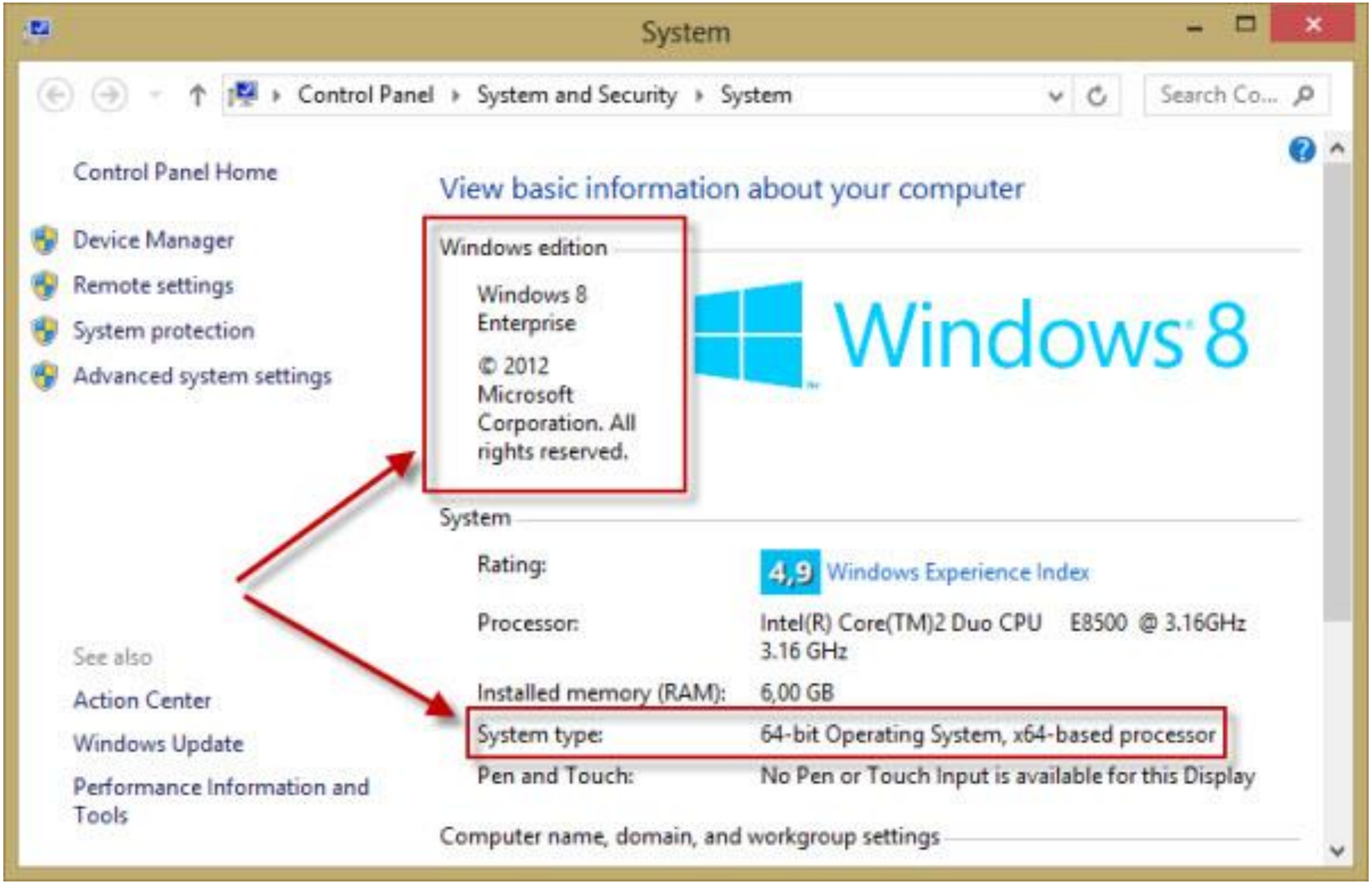
8 x 2 memory array



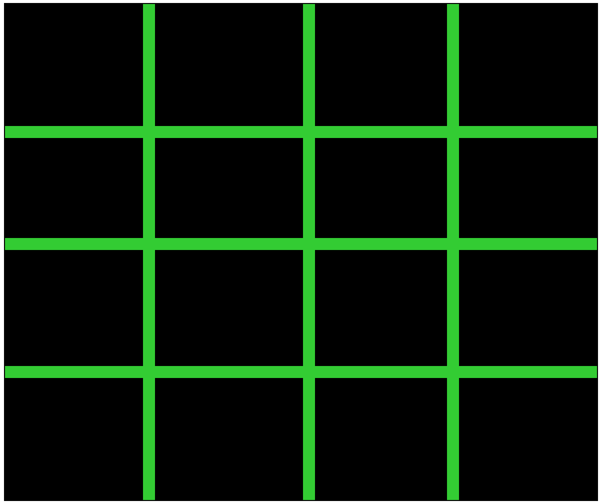
2 x 8 memory array

16-bit memories

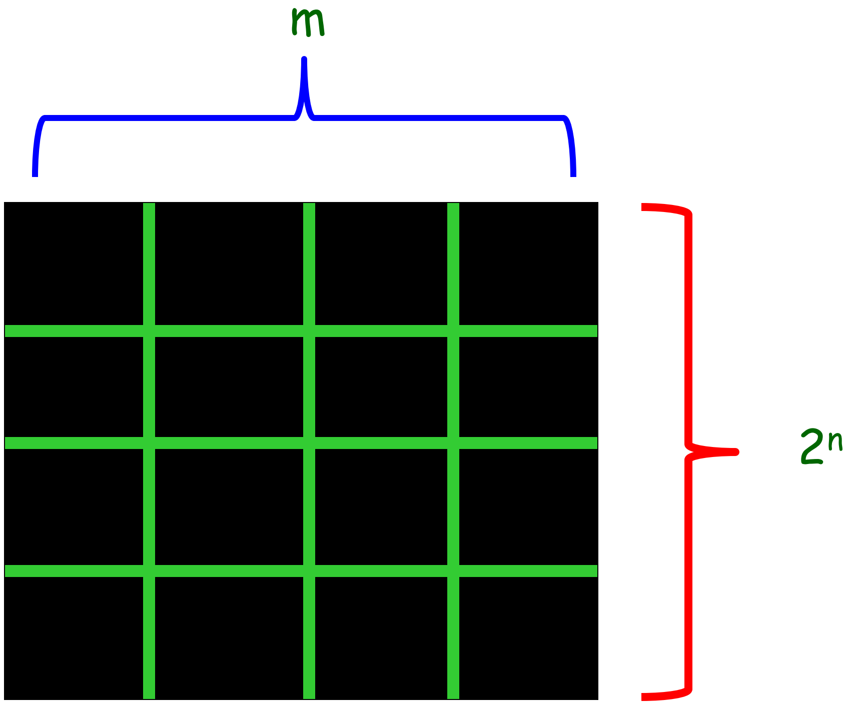
Today … 64-bit systems and memories



ROM

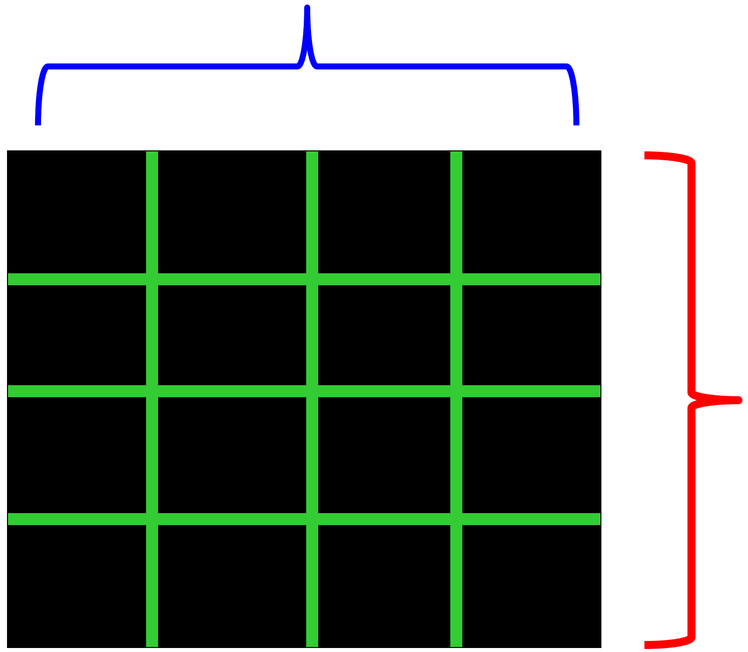


ROM capacity



ROM capacity: $2^n * m$

m = 4



4 – Words = 2^n

Total ROM capacity → 16 Bits x 4 memory

$2^n * m = 4 * 4 =$ 16 Bits x 4 memory

Capacity (size) of a ROM

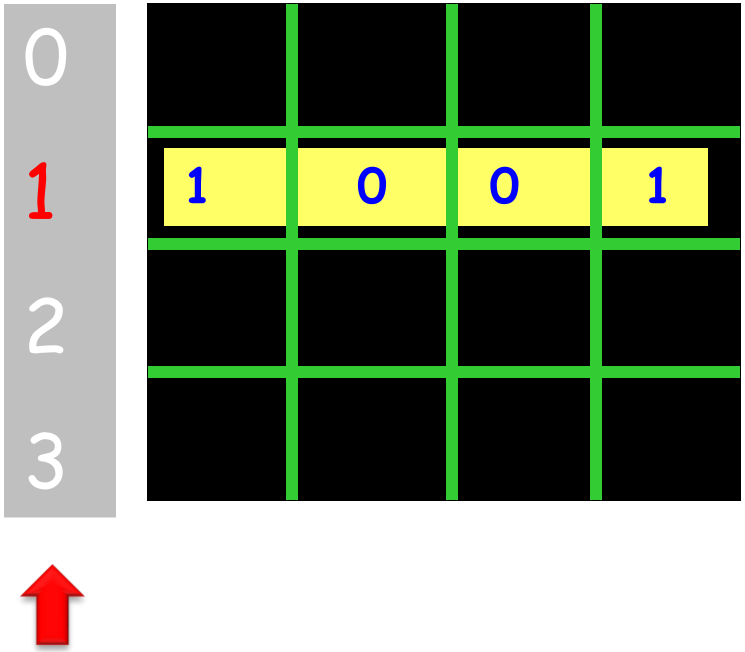
- A ROM is characterized by the number of the bits

$$\boxed{2^n * m}$$

2^n = number of words stored in the ROM

m = number of bits per word

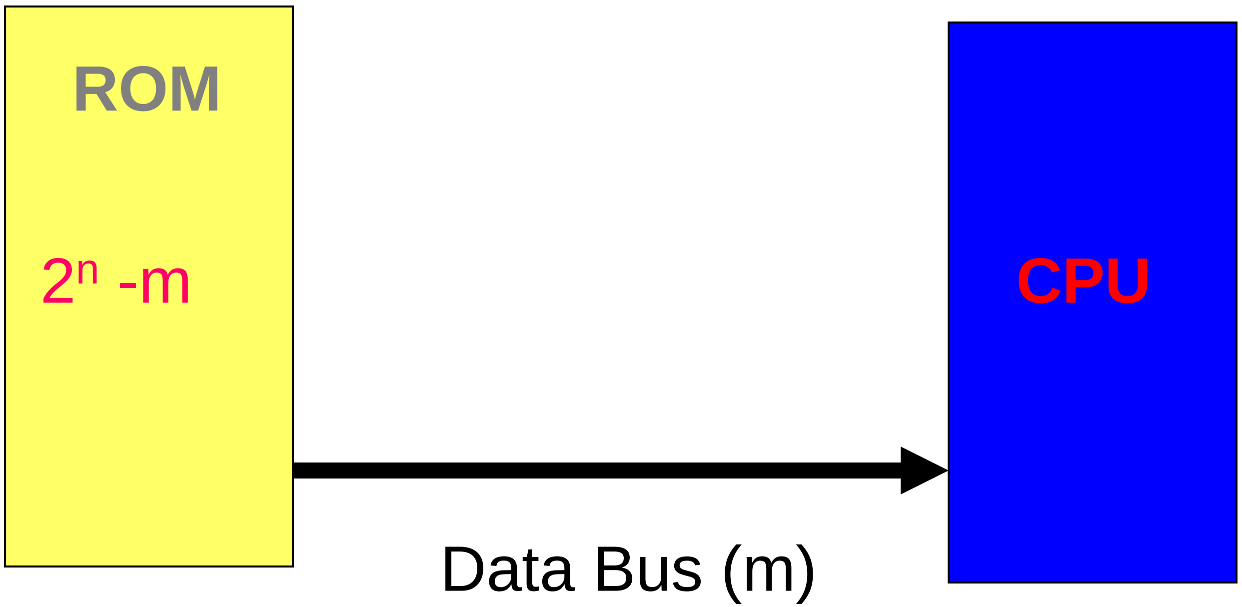
ROM: Data & Address



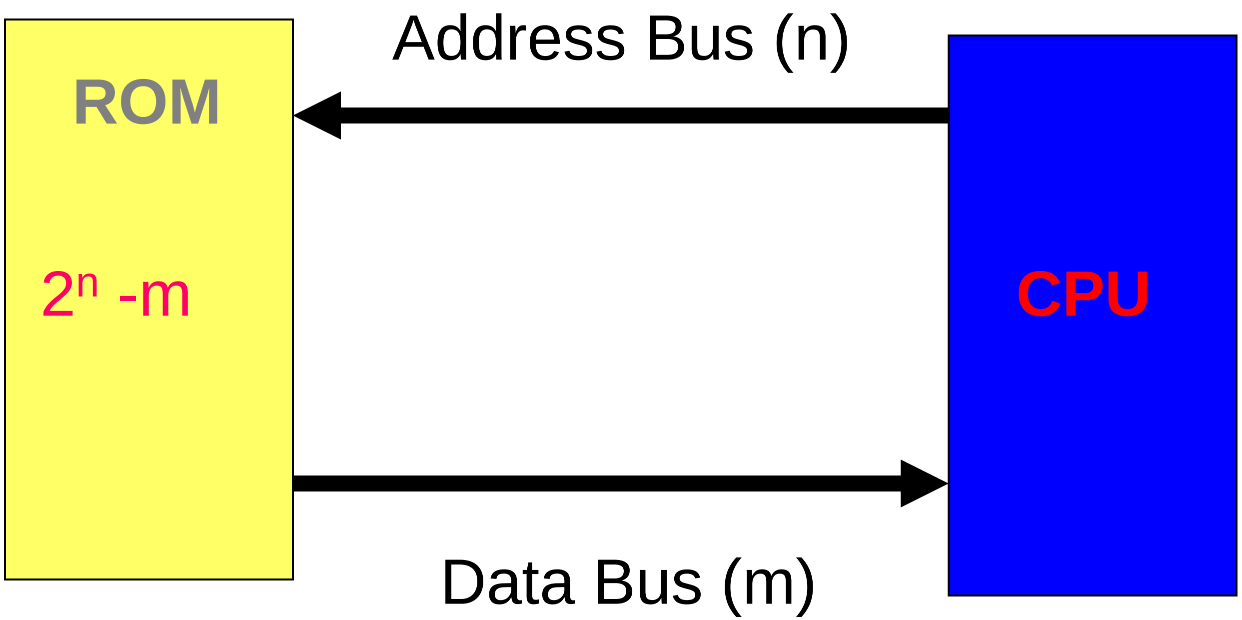
The address of the selected word in yellow, with data: 1001 is 1

ROM and CPU

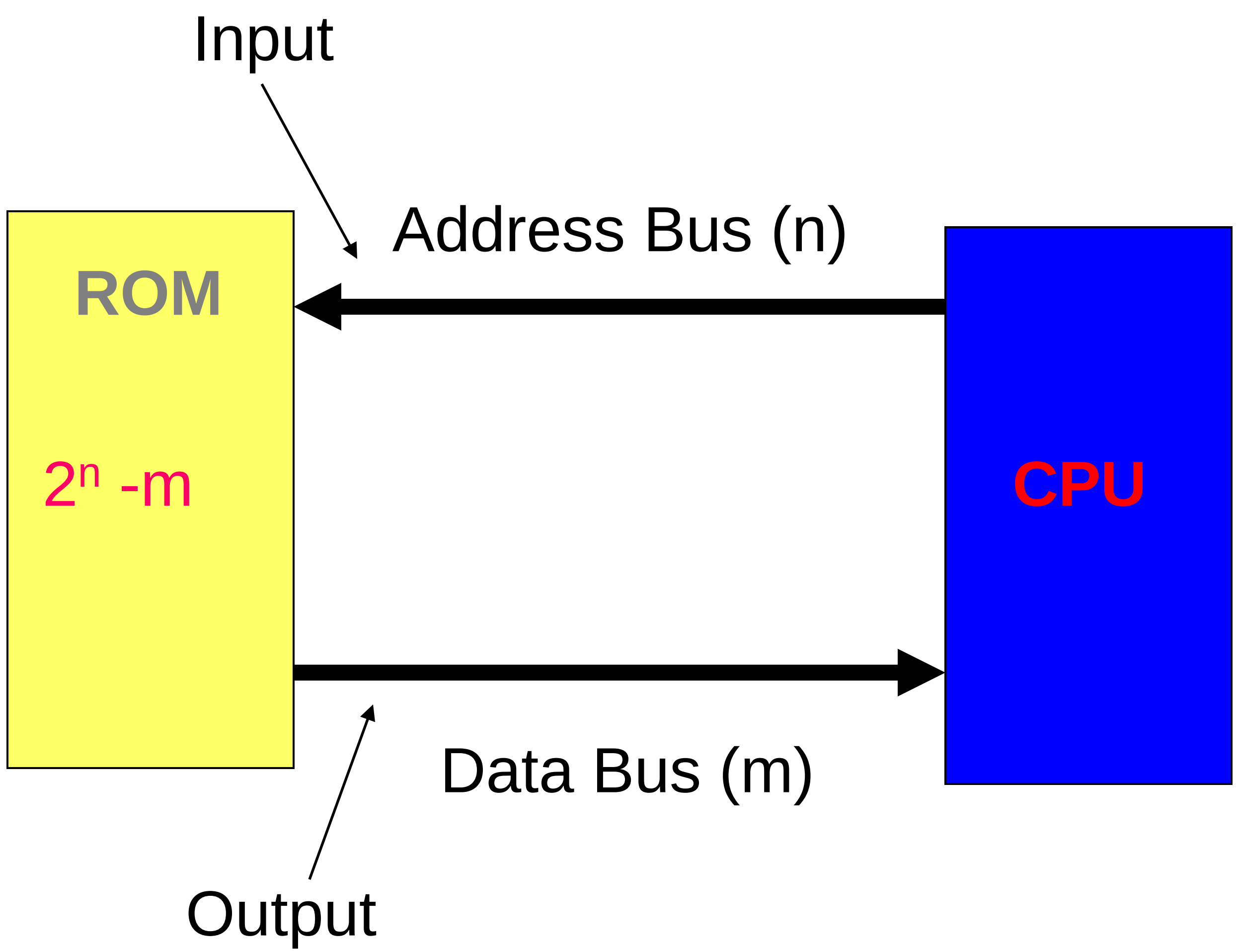
Data Bus



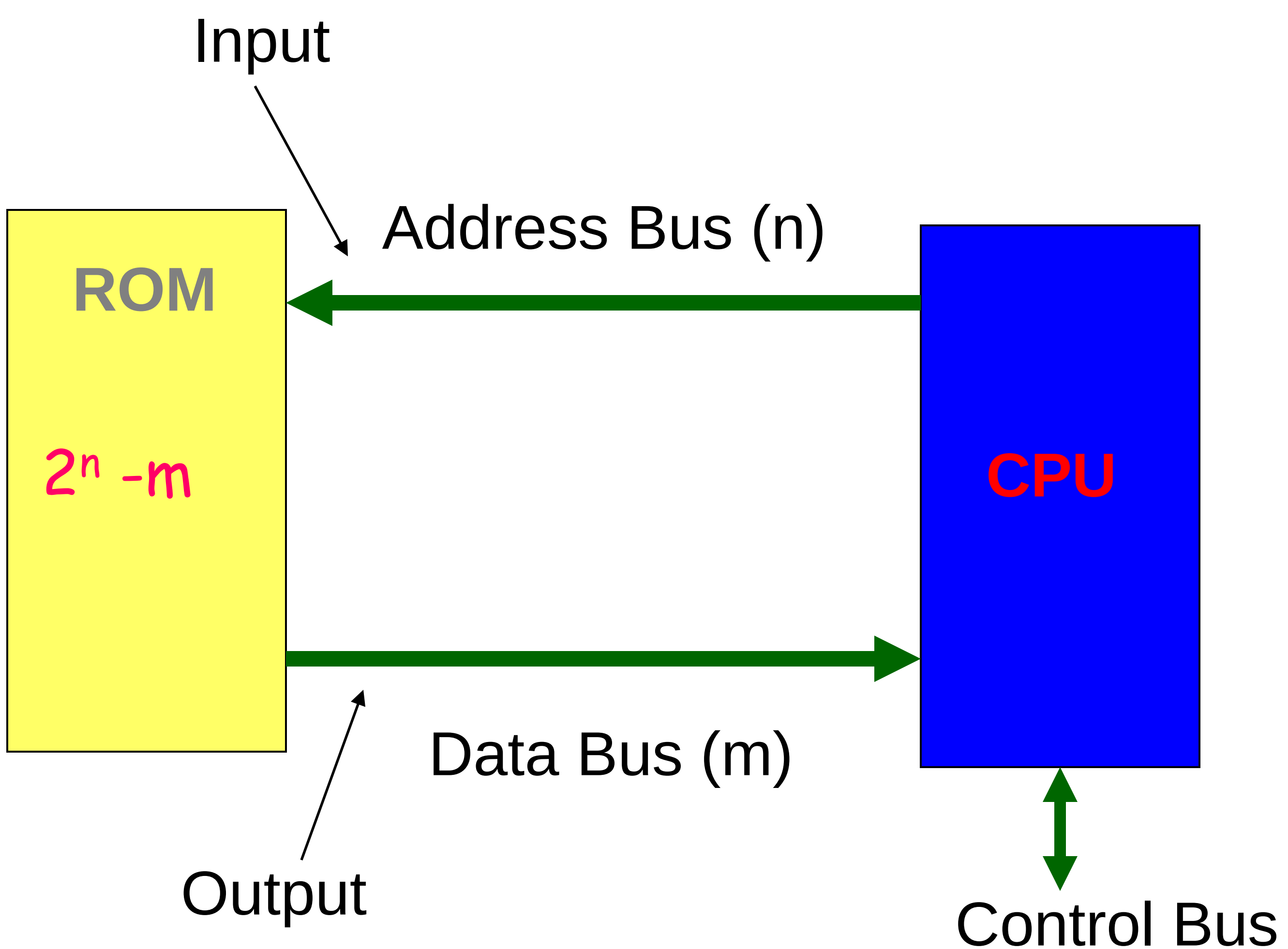
Address bus



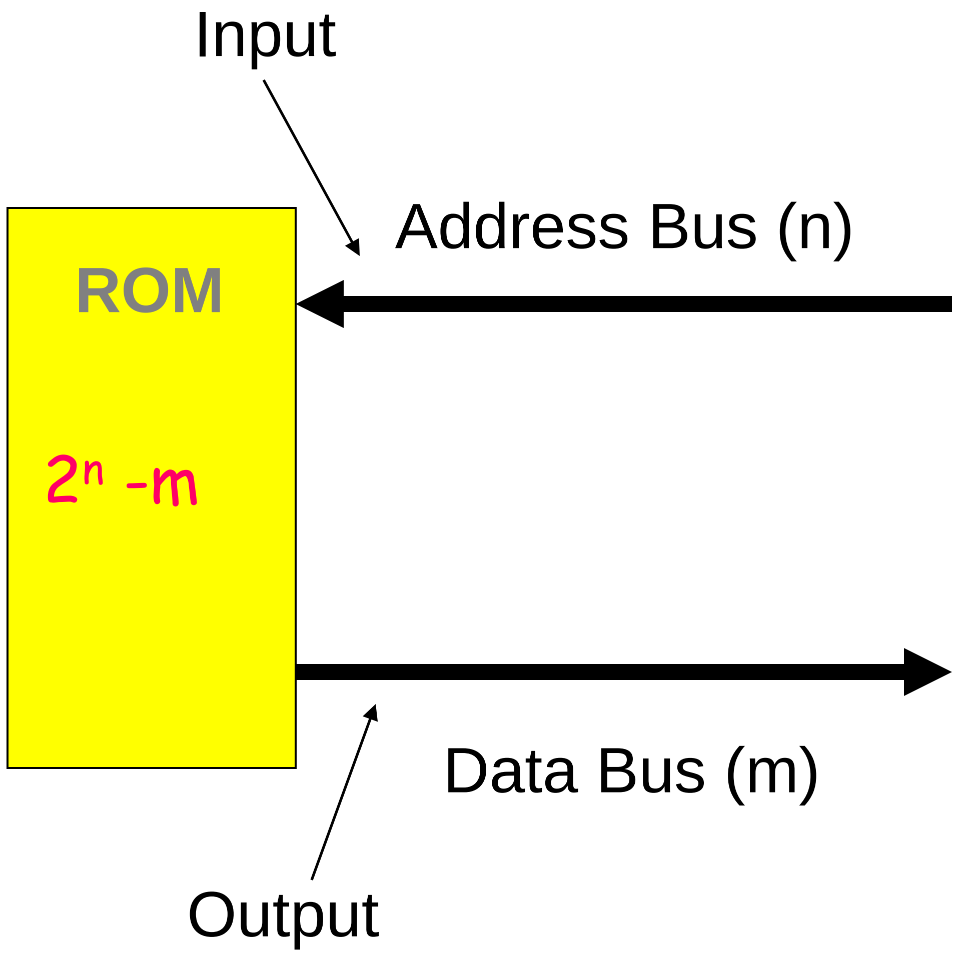
Input/Output



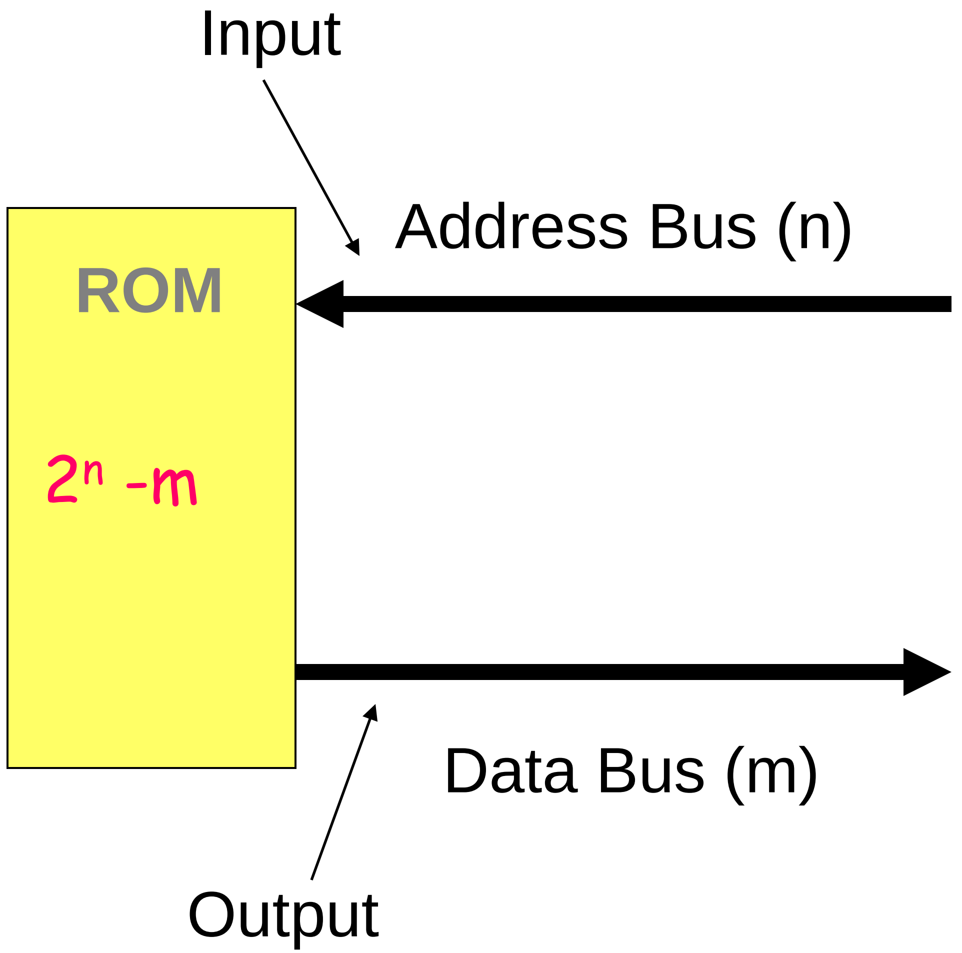
The 3 buses



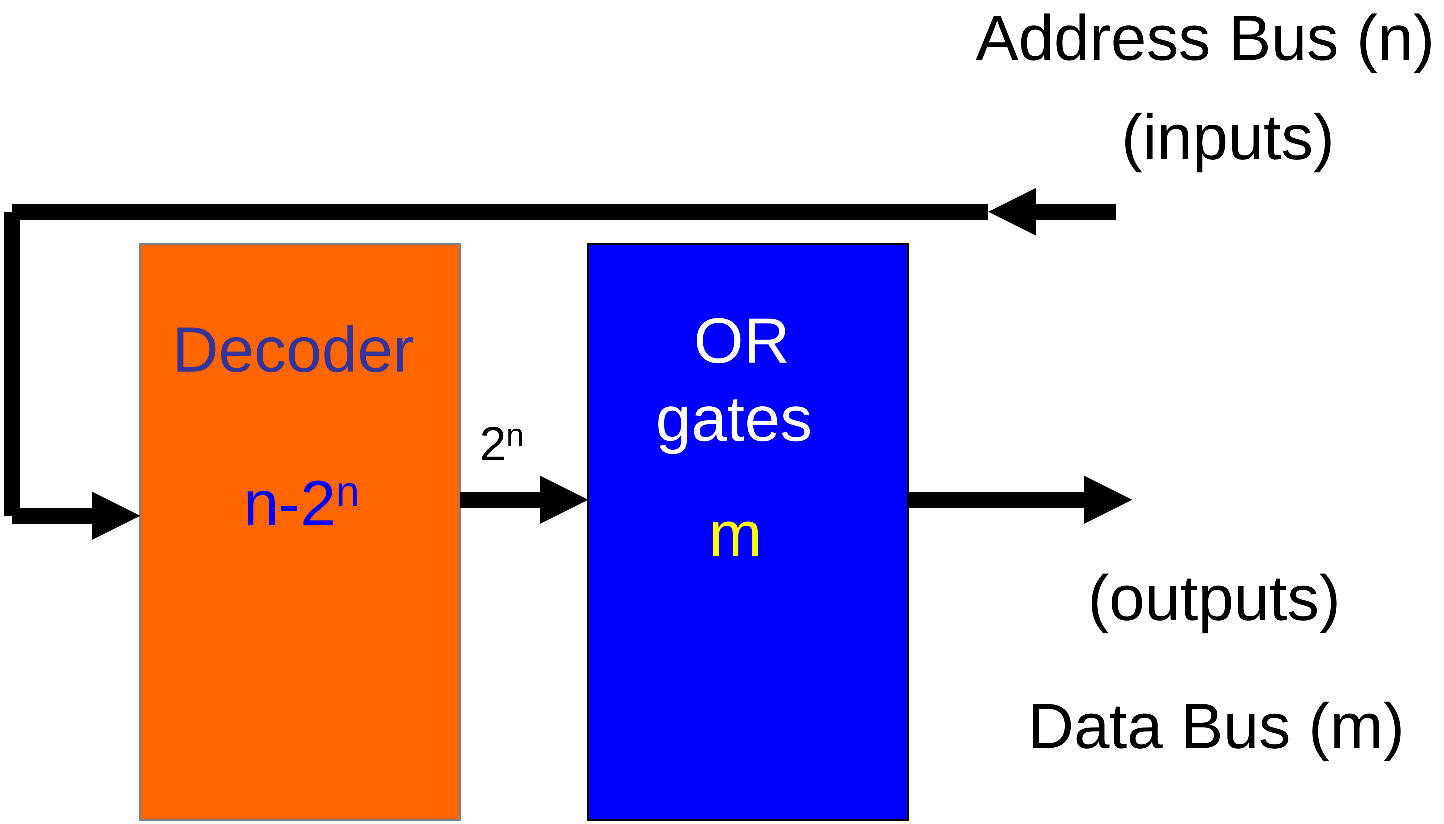
ROM (with n-inputs and m-outputs)



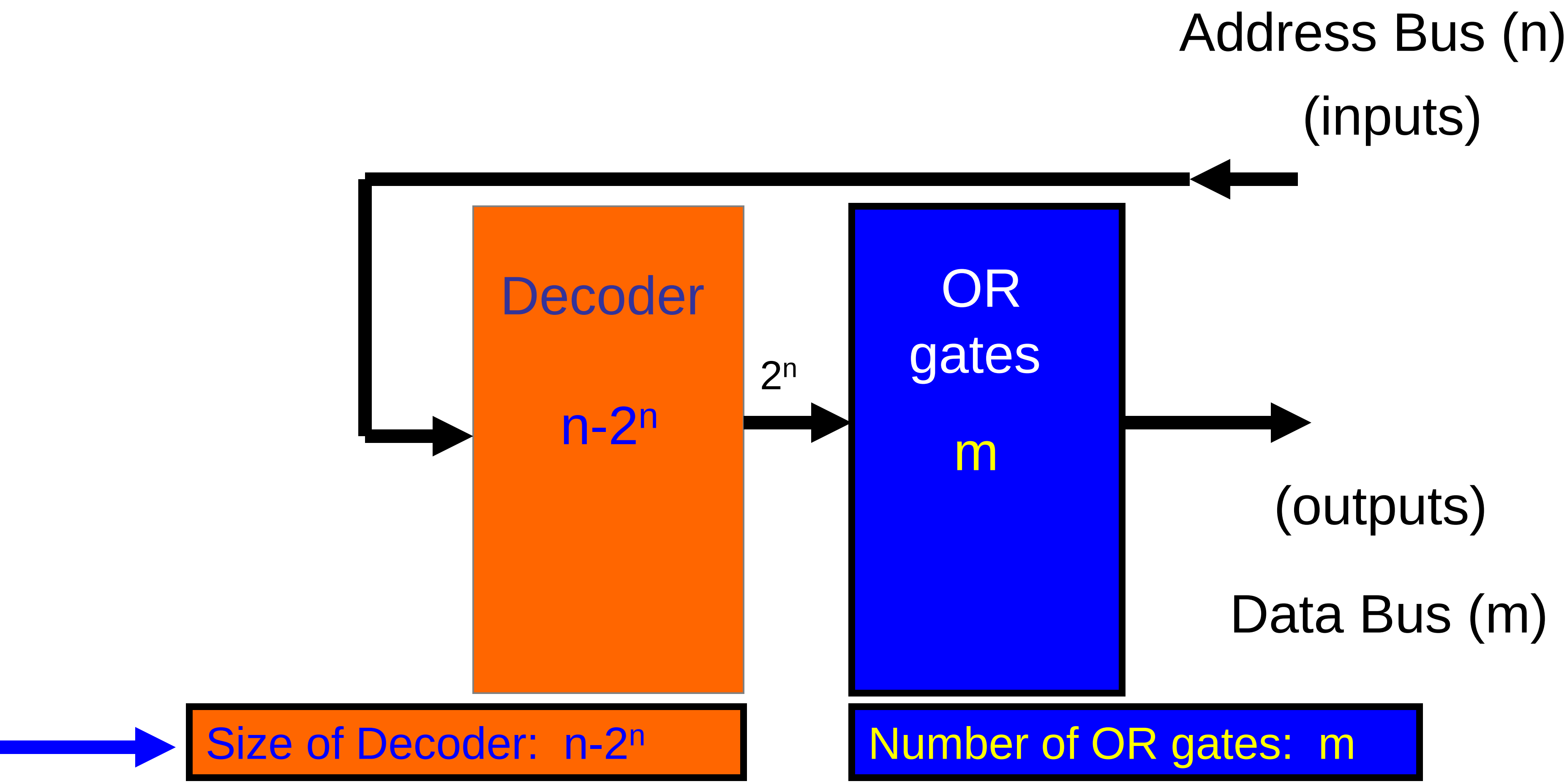
What is inside the ROM



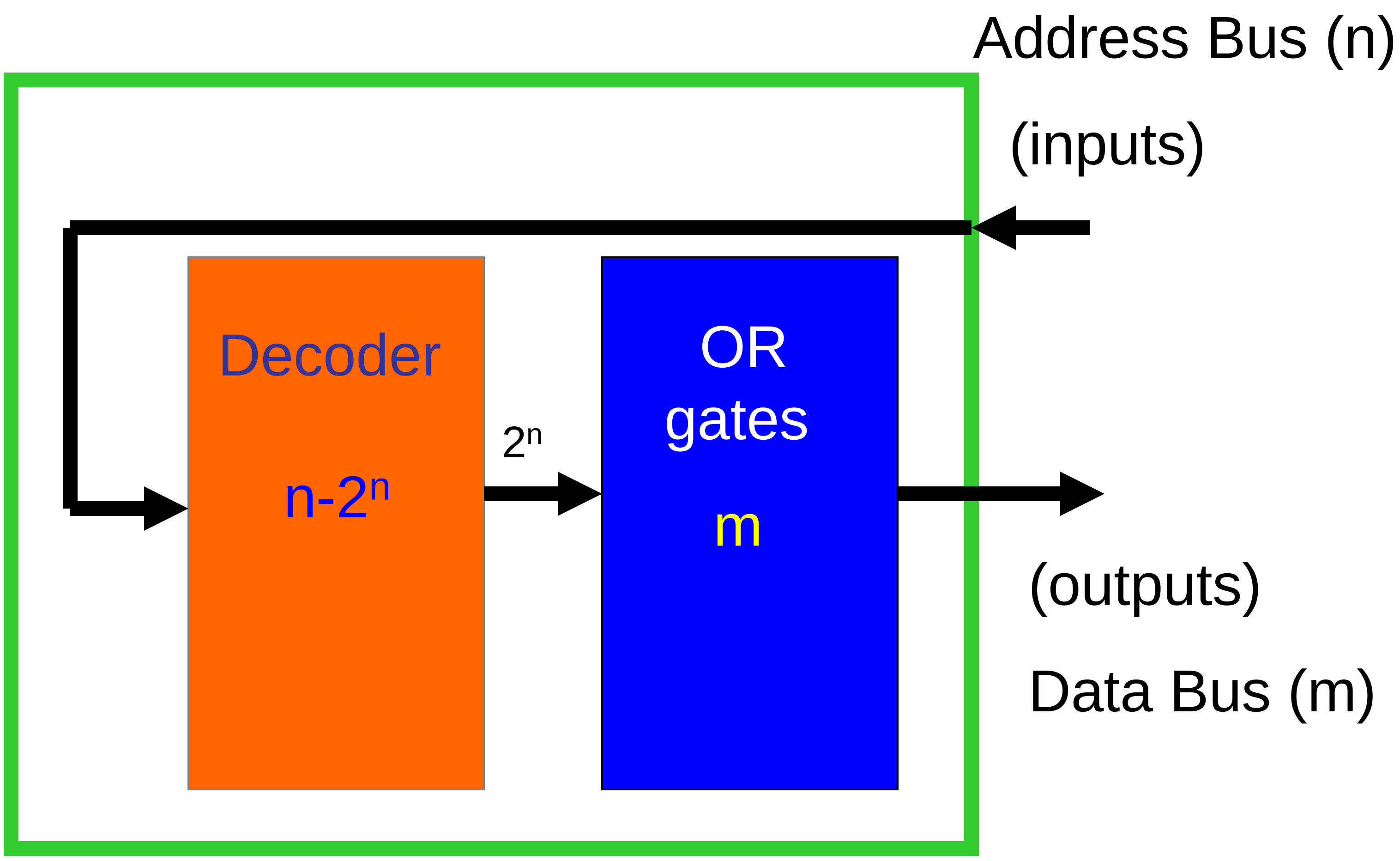
ROM = Decoder + OR gates



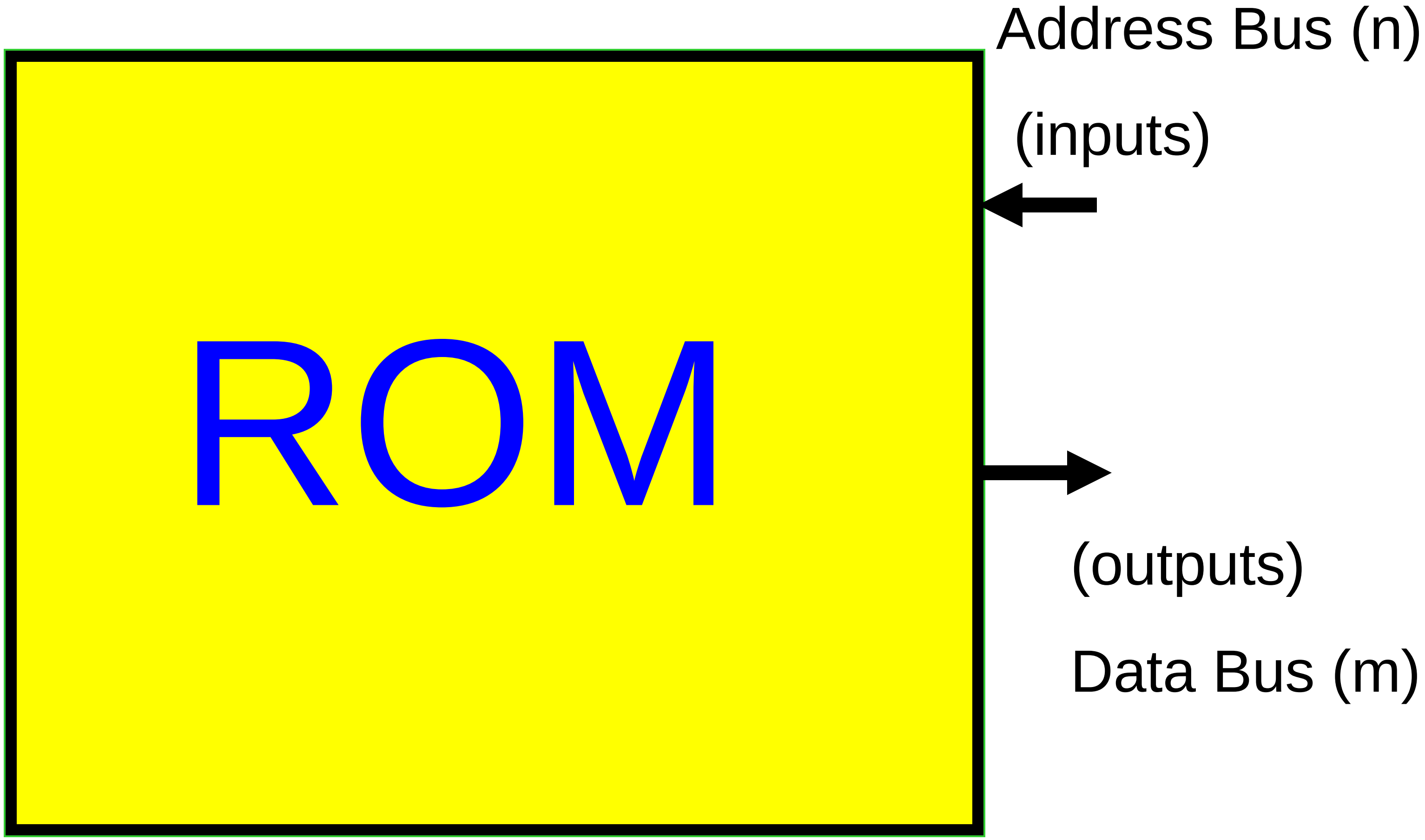
Size of ROM/Number of OR gates



ROM architecture



ROM: (2^n)*m



ROM Characteristic

- ROM = Realizes a truth table

… Note that a truth table can represent mathematical and logic functions.

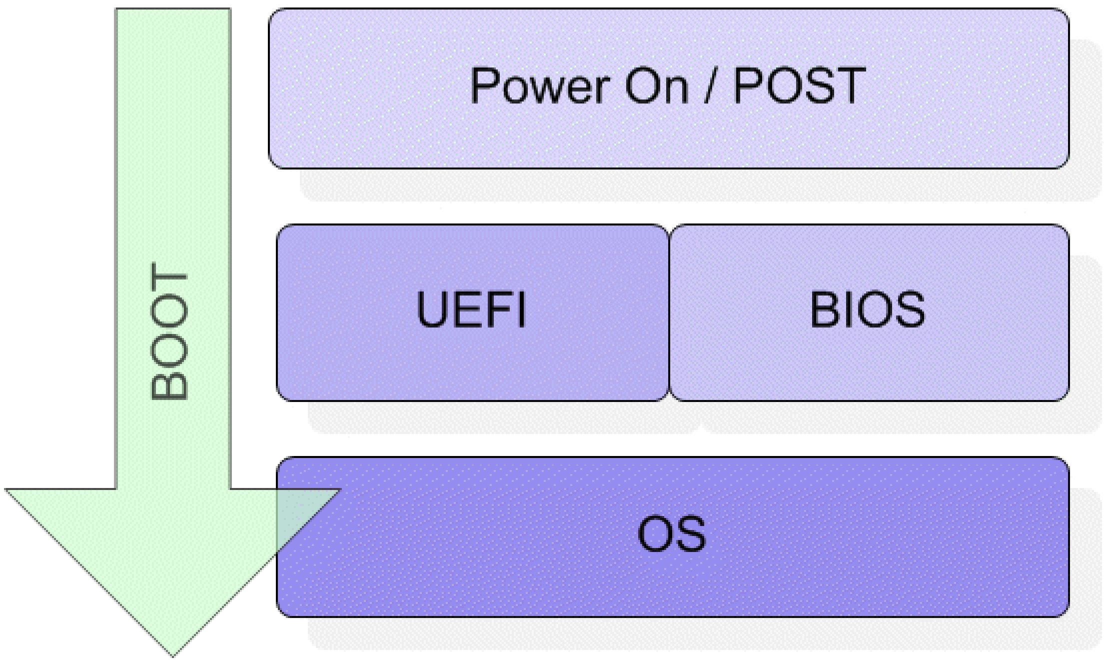
ROM applications

- Dynamic
- Static.

ROM (Dynamic application)

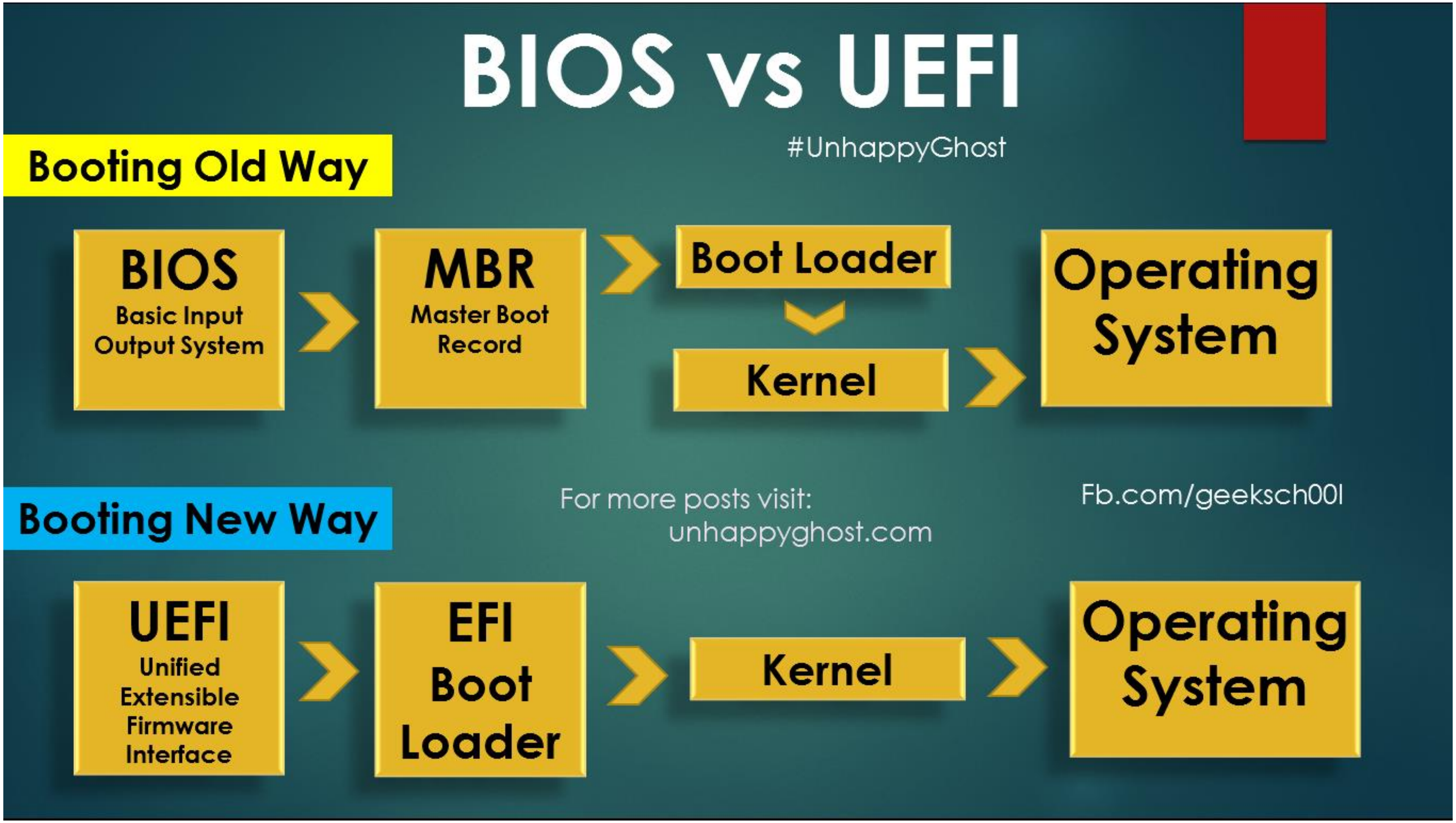
- BIOS (Basic Input Output System)
- All PC's had a BIOS [microcode (Intel Assembly) -hardwire] chip built in …
- «BIOS gets the computer started before the operating system is loaded from the hard drive».

Unified Extensible Firmware Interface (UEFI)



Today … all Intel based CPU Computer Systems use UEFI (not BIOS)

BIOS vs UEFI

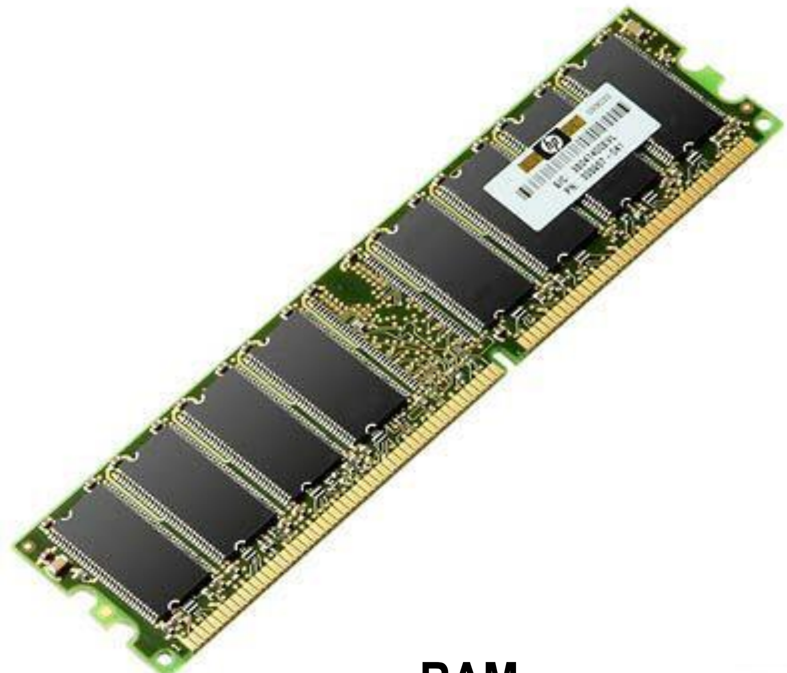


Kernel is a computer program that manages I/O (input/output) requests from software, and translates them into data processing instructions for the central processing unit and other electronic components of a computer. The kernel is a fundamental part of a modern computer's operating system. (Wikipedia.com)

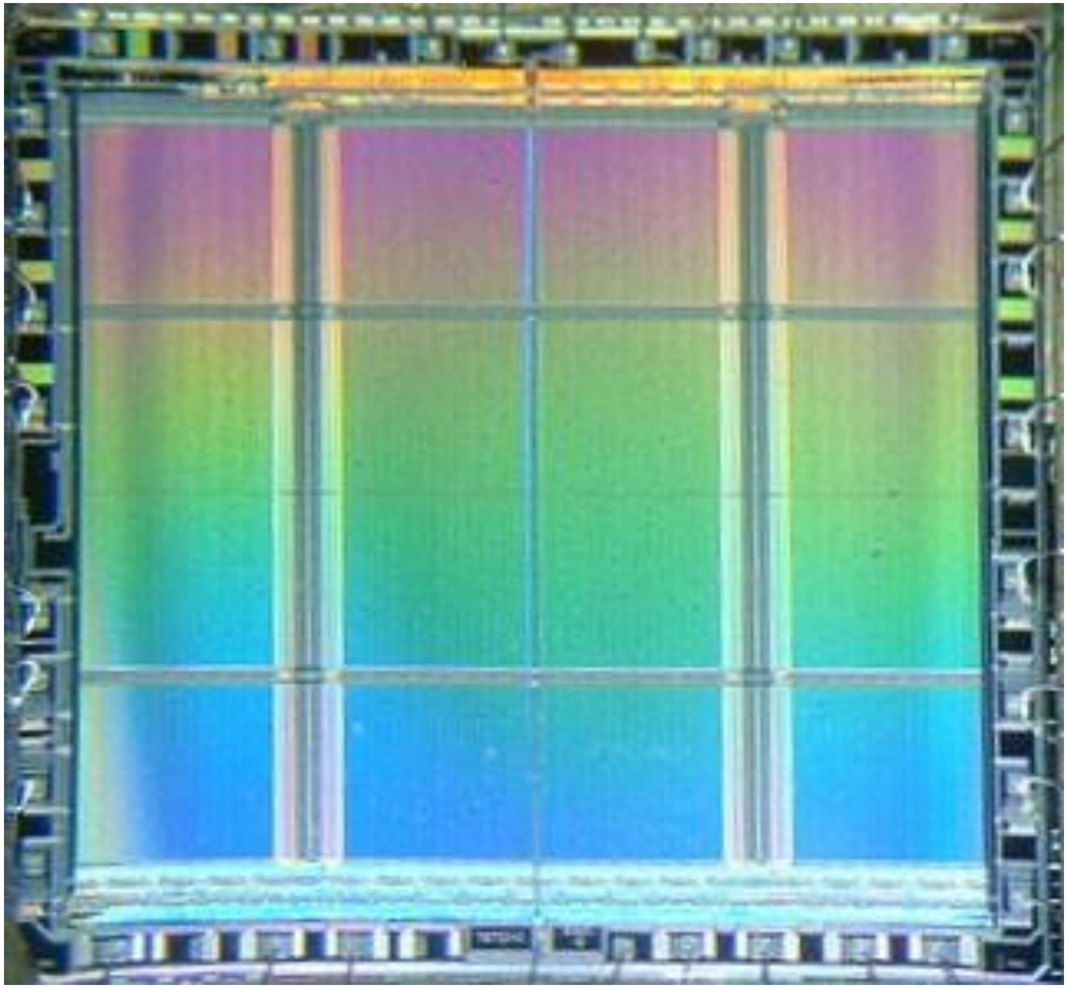
ROM (Static application)

- A ROM can be used to control fonts in printers
- As table-Look-Up (data storage)
- Code converters
- Video games
- Terminals in stores
- Security systems.

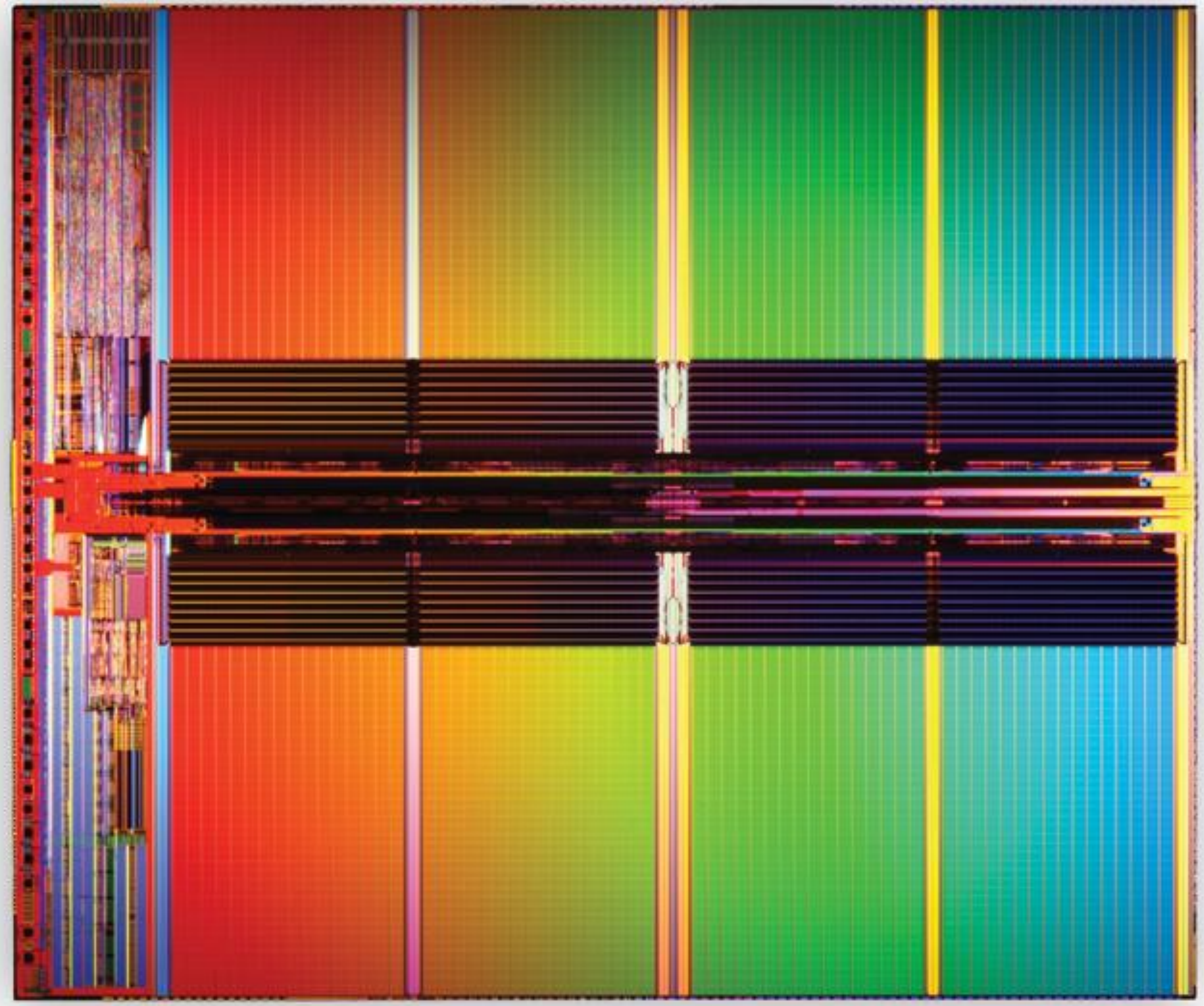
ROM



RAM



4Mbit EPROM Texas Instruments TMS27C040 (Wikipedia)



2. Micron's triple-level cell (TLC) flash memory stores 3 bits of data in each transistor.

ROM design problem

ROM design problem

Design a ROM (static) that will accept a 3-bit (binary) number and generate a binary number equal to the square of the input.

Lets create the required truth table…

How many inputs … outputs do we need?

Truth Table

Design a ROM (static) that will accept a 3-bit (binary) number and generate a binary number equal to the square of the input.

	Inputs A_2 A_1 A_0	Outputs
0	0 0 0	?
1	0 0 1	
2	0 1 0	
3	0 1 1	
4	1 0 0	
5	1 0 1	
6	1 1 0	
7	1 1 1	

Truth Table

Design a ROM (static) that will accept a 3-bit (binary) number and generate a binary number equal to the square of the input.

	Inputs			Outputs			
	A_2	A_1	A_0	B_2	B_1	B_0	
0	0	0	0			0	0
1	0	0	1			1	1
2	0	1	0	1	0	0	4
3	0	1	1				
4	1	0	0				
5	1	0	1				
6	1	1	0				
7	1	1	1				

Truth Table

	Inputs			Outputs						
	A_2	A_1	A_0	B_5	B_4	B_3	B_2	B_1	B_0	
0	0	0	0	0	0	0	0	0	0	0
1	0	0	1	0	0	0	0	0	1	1
2	0	1	0	0	0	0	1	0	0	4
3	0	1	1	0	0	1	0	0	1	9
4	1	0	0	0	1	0	0	0	0	16
5	1	0	1	0	1	1	0	0	1	25
6	1	1	0	1	0	0	1	0	0	36
7	1	1	1	1	1	0	0	0	1	49

Inputs … Outputs

- Inputs = n = 3
- Outputs = m = 6

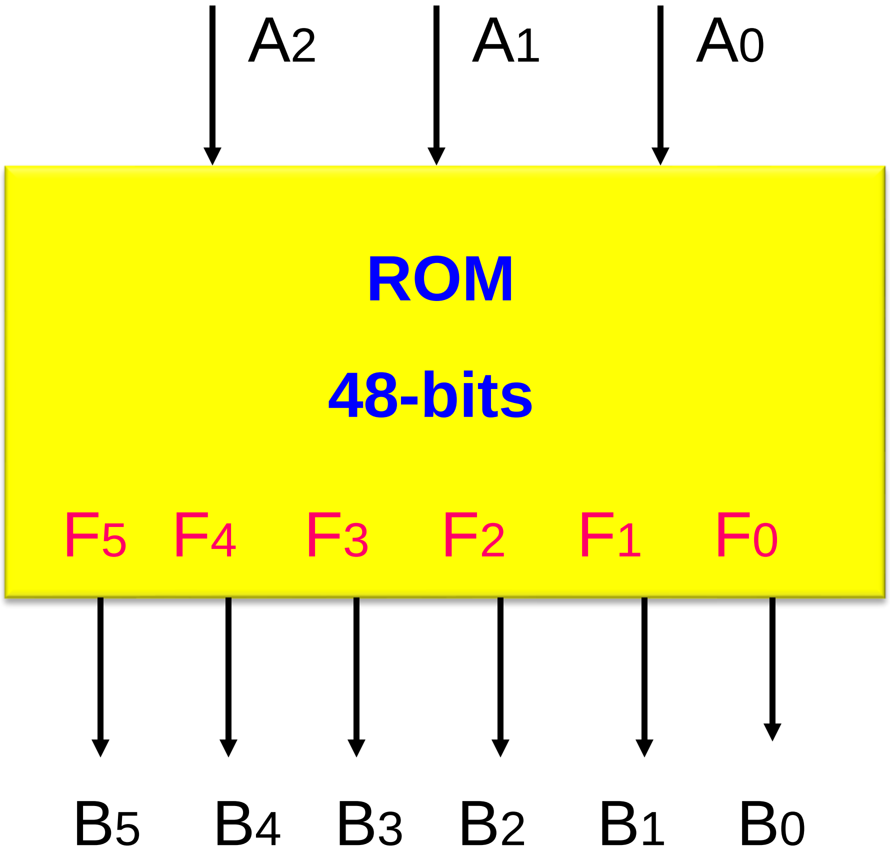
Size of ROM

- Inputs = n = 3
- Outputs = m = 6

$\mathbf{2^n * m}$

$\mathbf{2^n * m = 2^3 * 6 = 48}$**-bits**

The ROM has 48-bits



Can we simplify?

The ROM simplification, ONLY involves columns (truth table)

K-Maps or Boolean Theorems can NOT be used in ROM simplification

Eliminate Outputs [**ONLY Columns**]

	Inputs			Outputs						
	A_2	A_1	A_0	B_5	B_4	B_3	B_2	B_1	B_0	
0	0	0	0	0	0	0	0	0	0	0
1	0	0	1	0	0	0	0	0	1	1
2	0	1	0	0	0	0	1	0	0	4
3	0	1	1	0	0	1	0	0	1	9
4	1	0	0	0	1	0	0	0	0	16
5	1	0	1	0	1	1	0	0	1	25
6	1	1	0	1	0	0	1	0	0	36
7	1	1	1	1	1	0	0	0	1	49

Eliminate Outputs [**ONLY Columns**]

	Inputs			Outputs						
	A_2	A_1	A_0	B_5	B_4	B_3	B_2	B_1	B_0	
0	0	0	0	0	0	0	0	0	0	0
1	0	0	1	0	0	0	0	0	1	1
2	0	1	0	0	0	0	1	0	0	4
3	0	1	1	0	0	1	0	0	1	9
4	1	0	0	0	1	0	0	0	0	16
5	1	0	1	0	1	1	0	0	1	25
6	1	1	0	1	0	0	1	0	0	36
7	1	1	1	1	1	0	0	0	1	49

Simplification equations

$B_0 = A_0$ and $B_1 = 0$

Our new simplified ROM: Truth Table

	Inputs			Outputs			
	A_2	A_1	A_0	F_3	F_2	F_1	F_0
0	0	0	0	0	0	0	0
1	0	0	1	0	0	0	0
2	0	1	0	0	0	0	1
3	0	1	1	0	0	1	0
4	1	0	0	0	1	0	0
5	1	0	1	0	1	1	0
6	1	1	0	1	0	0	1
7	1	1	1	1	1	0	0

Inputs … Outputs

- Inputs = n = 3
- Outputs = m = 4

Size of simplified ROM?

- Inputs = $n = 3$
- Outputs = $m = 4$

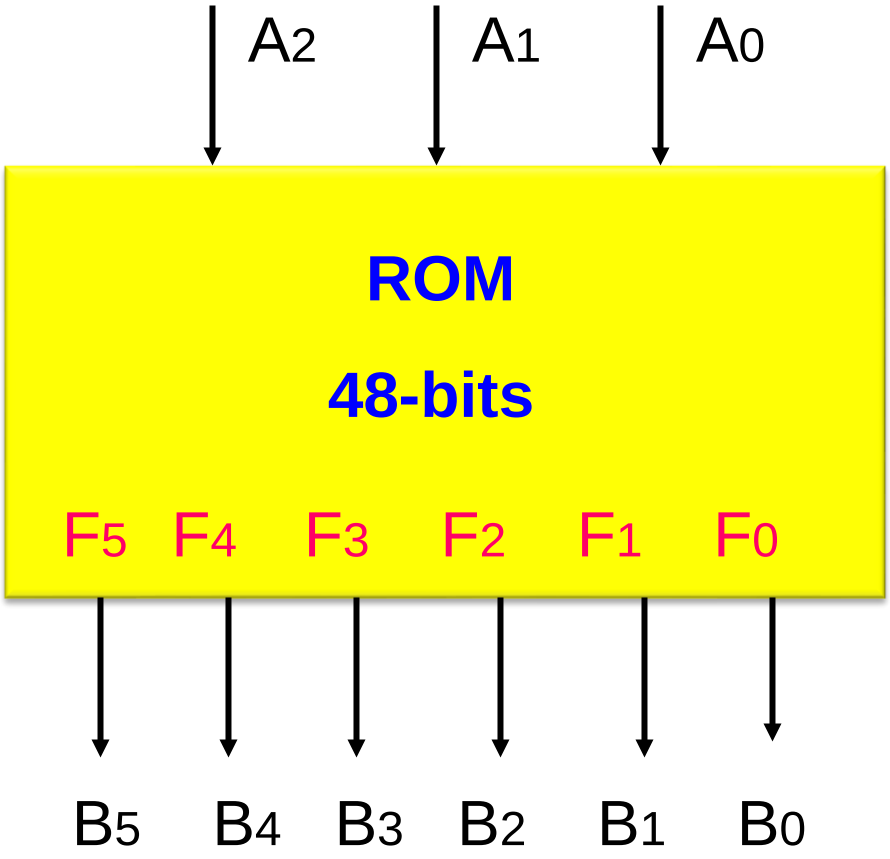
Size of simplified ROM?

- Inputs = n = 3
- Outputs = m = 4

Size = $2^n * m = 2^3 * 4 = 32$ bits

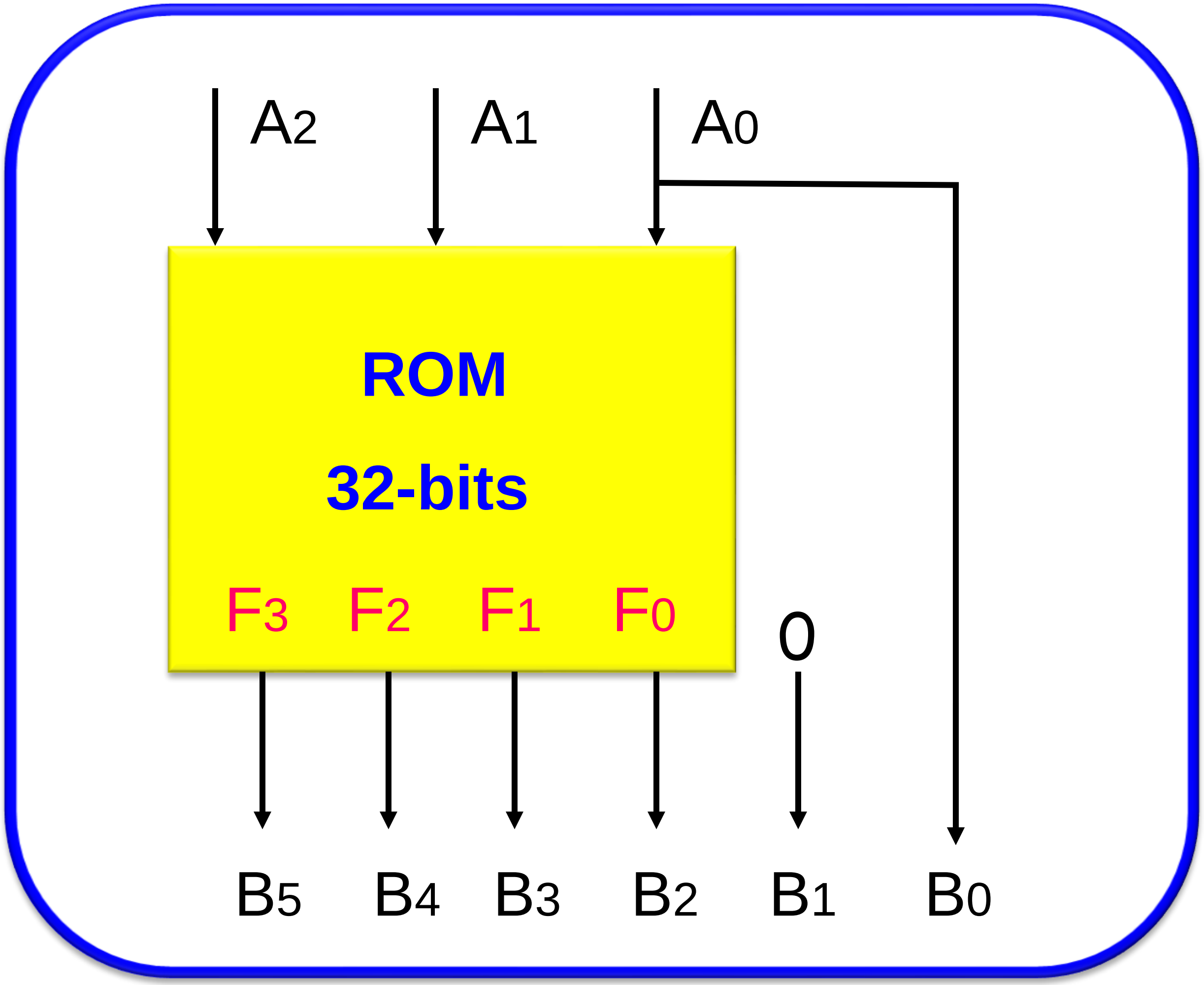
- Initially 48 bits
- Therefore we saved: 33.3%

Initial 48-bit ROM

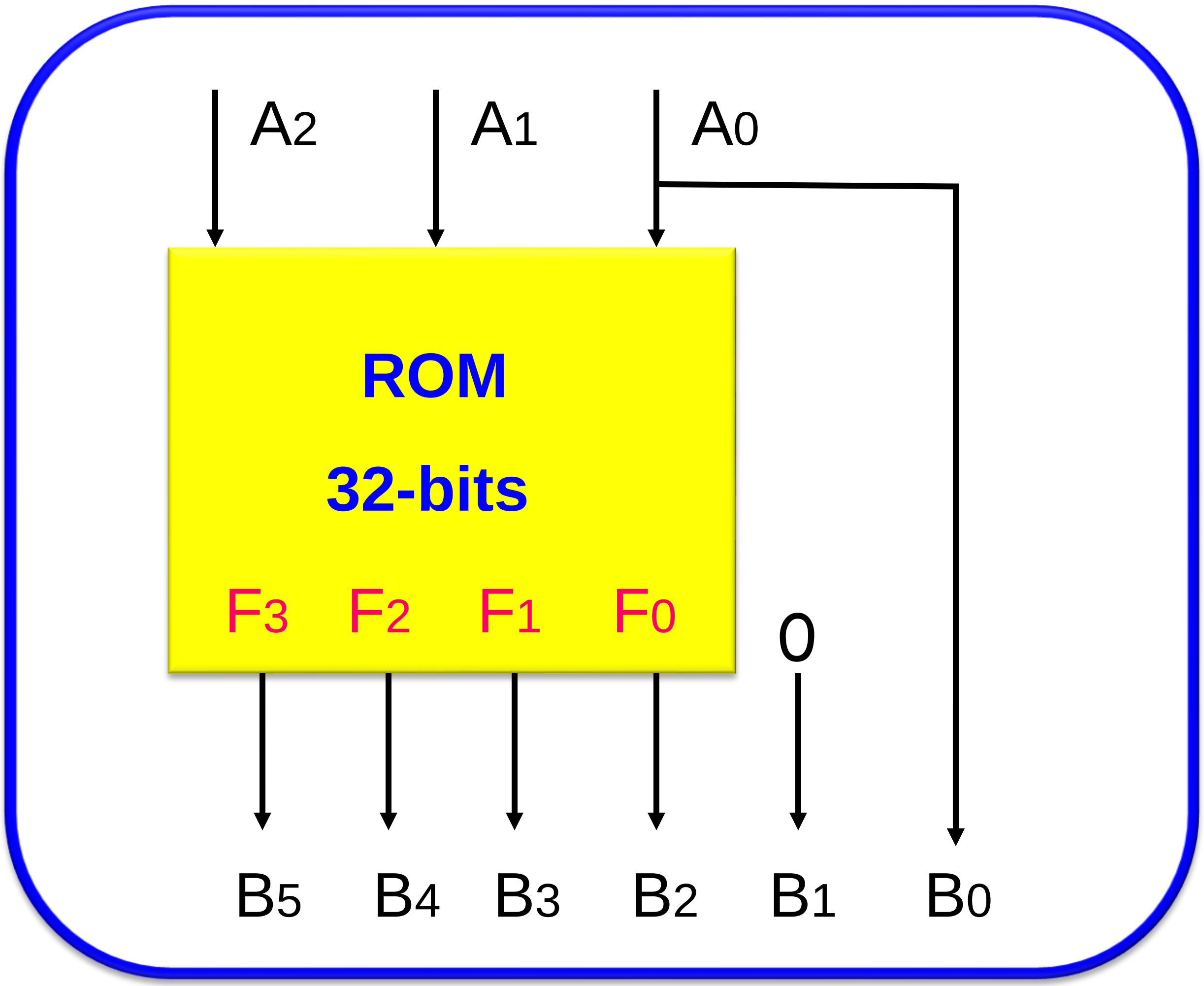


Simplified 32-bit ROM

$B_0 = A_0$ and $B_1 = 0$



Inside the yellow box …



Go to the simplified truth table and derive the logic equations

Our new simplified ROM: Truth Table

	Inputs			Outputs			
	A_2	A_1	A_0	F_3	F_2	F_1	F_0
0	0	0	0	0	0	0	0
1	0	0	1	0	0	0	0
2	0	1	0	0	0	0	1
3	0	1	1	0	0	1	0
4	1	0	0	0	1	0	0
5	1	0	1	0	1	1	0
6	1	1	0	1	0	0	1
7	1	1	1	1	1	0	0

Our new output logic equations

.$F_3 = \overline{A_0} A_1 A_2 + A_0 A_1 A_2$

$F_2 = \overline{A_0}\,\overline{A_1} A_2 + A_0 \overline{A_1} A_2 + A_0 A_1 A_2$

$F_1 = A_0 A_1 \overline{A_2} + A_0 \overline{A_1} A_2$

$F_0 = \overline{A_0} A_1 \overline{A_2} + \overline{A_0} A_1 A_2$

- **When we design ROM's, DO NOT use K-Maps or logic theorems to simplify the above equations**
- **The above equations are not further simplified.**

Use a Decoder and Gates to implement

- Size of the Decoder: ?
- How many OR gates: ?

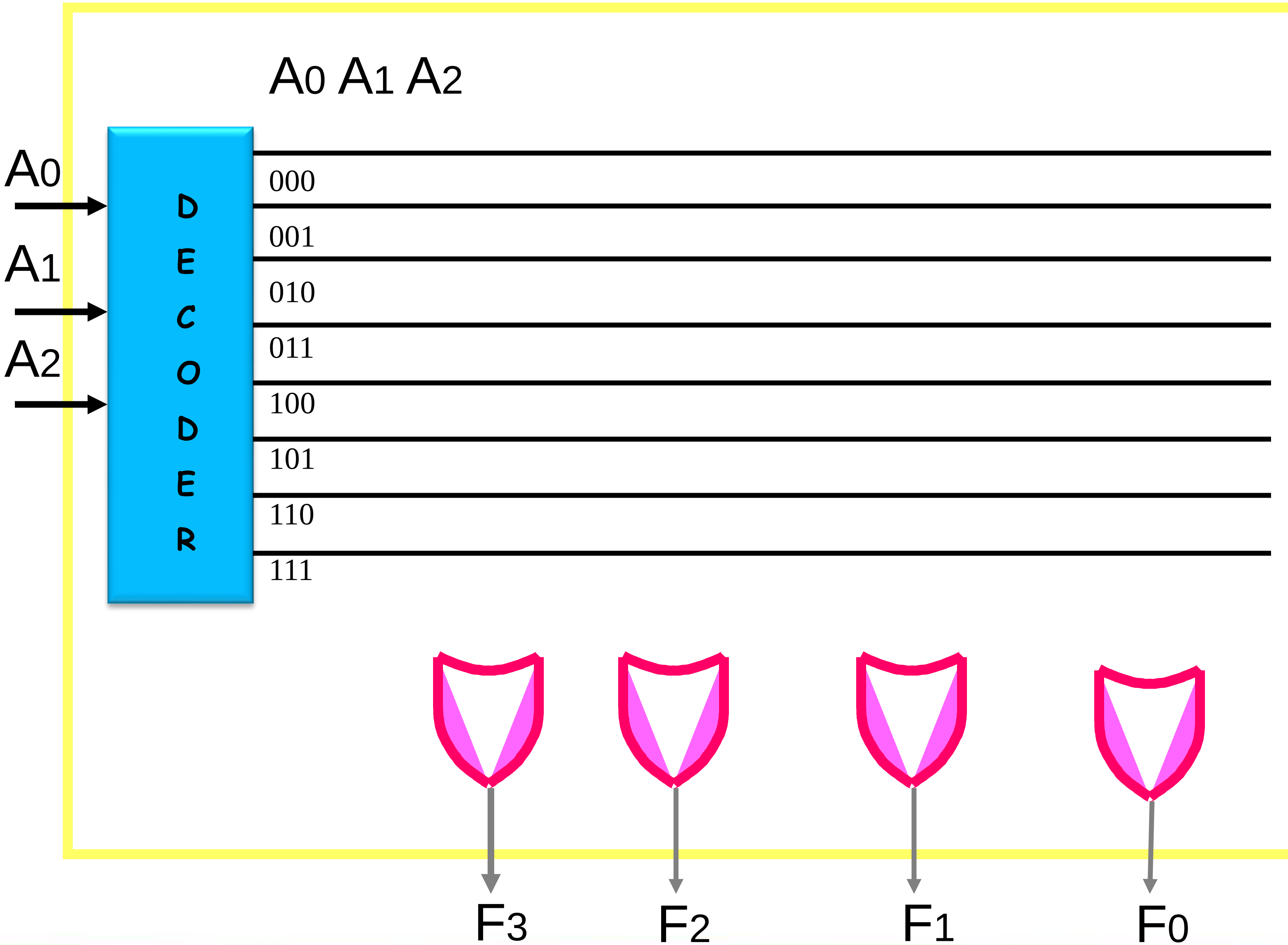
3-8 Decoder and 4 OR gates

- Since we have (n) 3 inputs…
- … the size of the Decoder (n–2^n) is: 3-8
- Since we have 4 outputs …
- … the number of OR gates is: 4

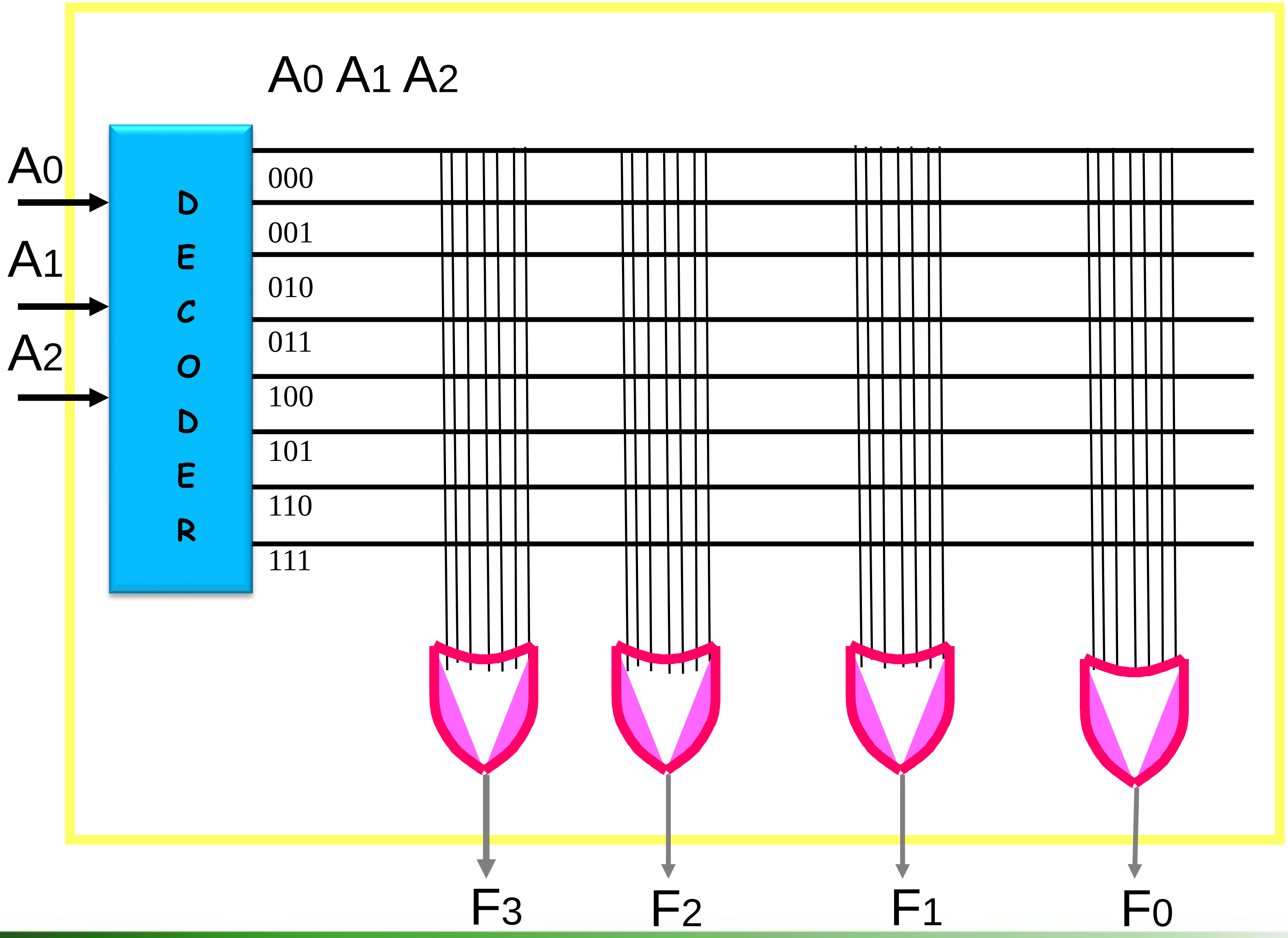
Implement using Decoder and OR-gates

- Size of the Decoder: 3-8
- How many OR gates: 4

3-8 Decoder and 4 OR gates



Un-programmed ROM



To program use our logic equations

$.F_3 = \overline{A_0} A_1 A_2 + A_0 A_1 A_2$

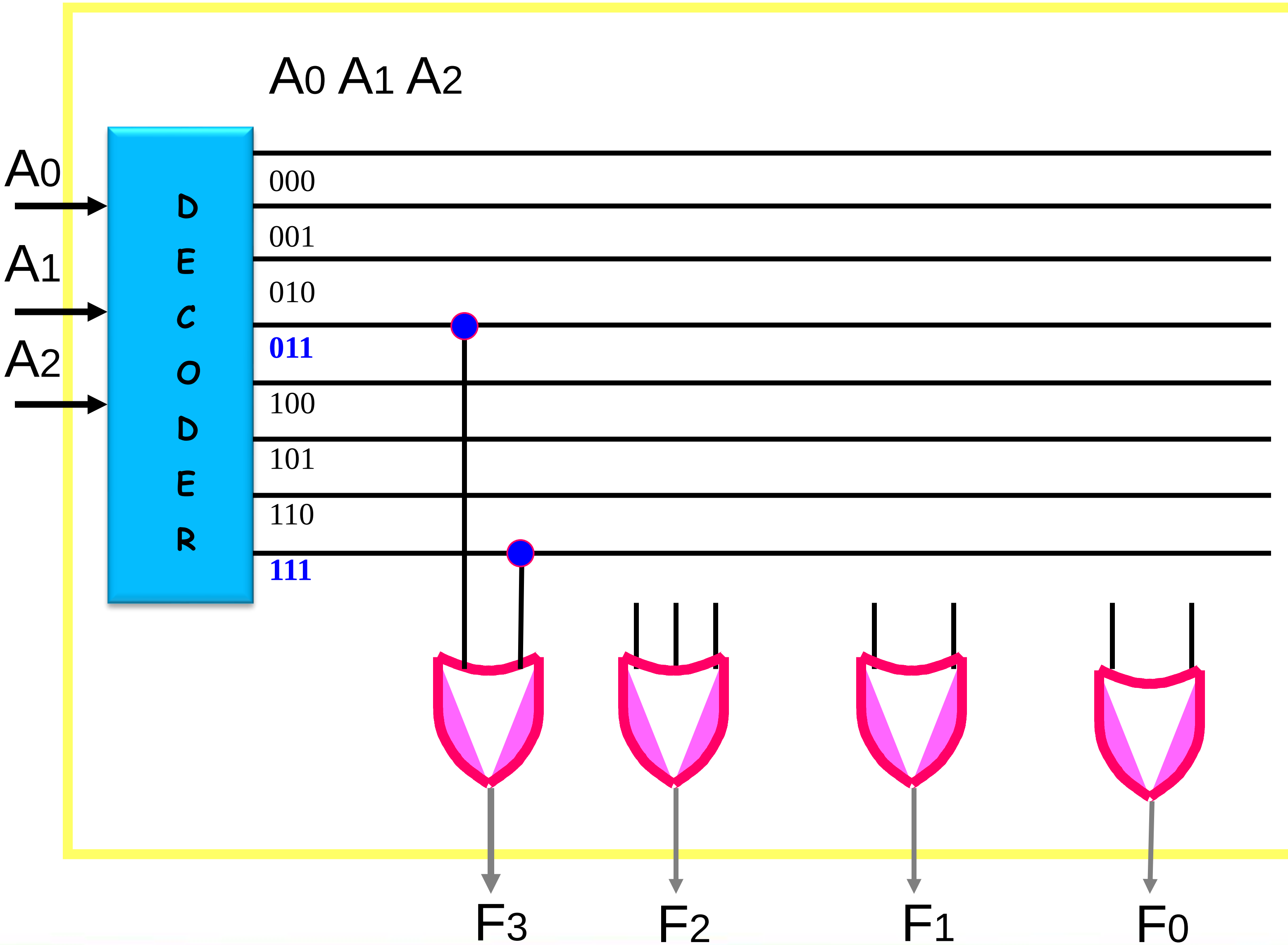
$F_2 = \overline{A_0}\, \overline{A_1} A_2 + A_0 \overline{A_1} A_2 + A_0 A_1 A_2$

$F_1 = A_0 A_1 \overline{A_2} + A_0 \overline{A_1} A_2$

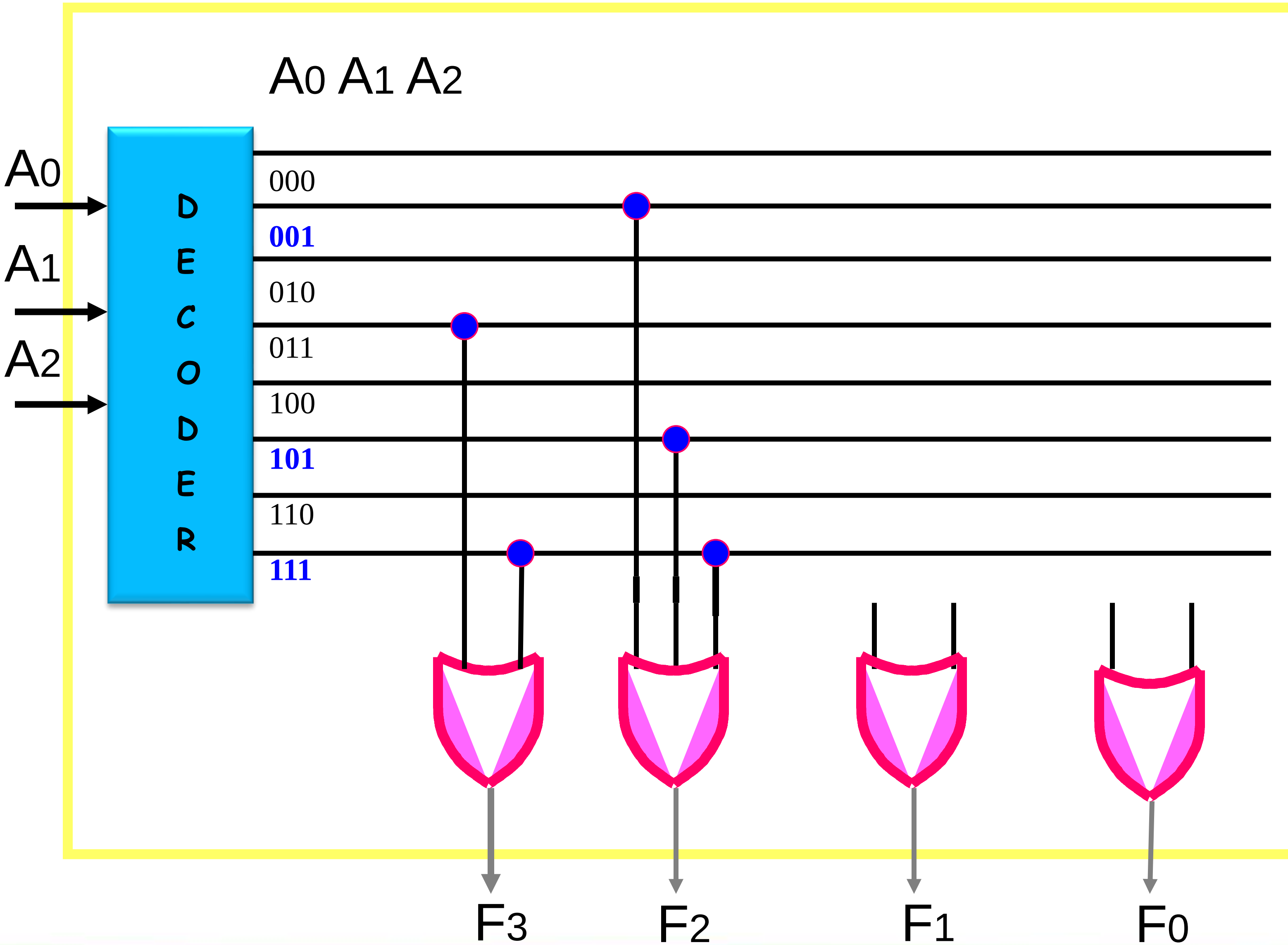
$F_0 = \overline{A_0} A_1 \overline{A_2} + \overline{A_0} A_1 A_2$

- **When we design ROM's, DO NOT use K-Maps or logic theorems to simplify the above equations**
- **The above equations are not further simplified.**

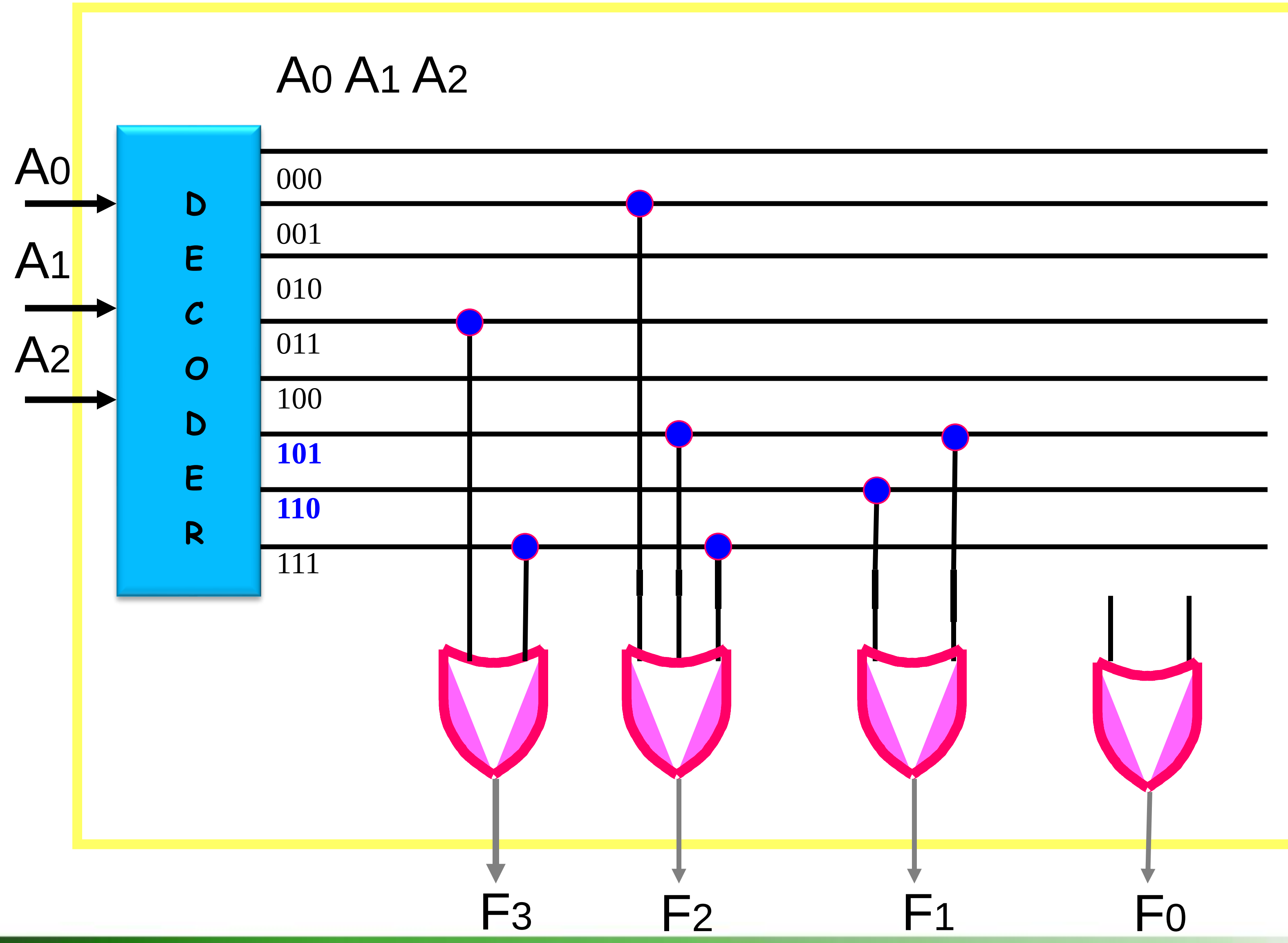
$$F_3 = \overline{A_0}\,A_1\,A_2 + A_0\,A_1\,A_2$$



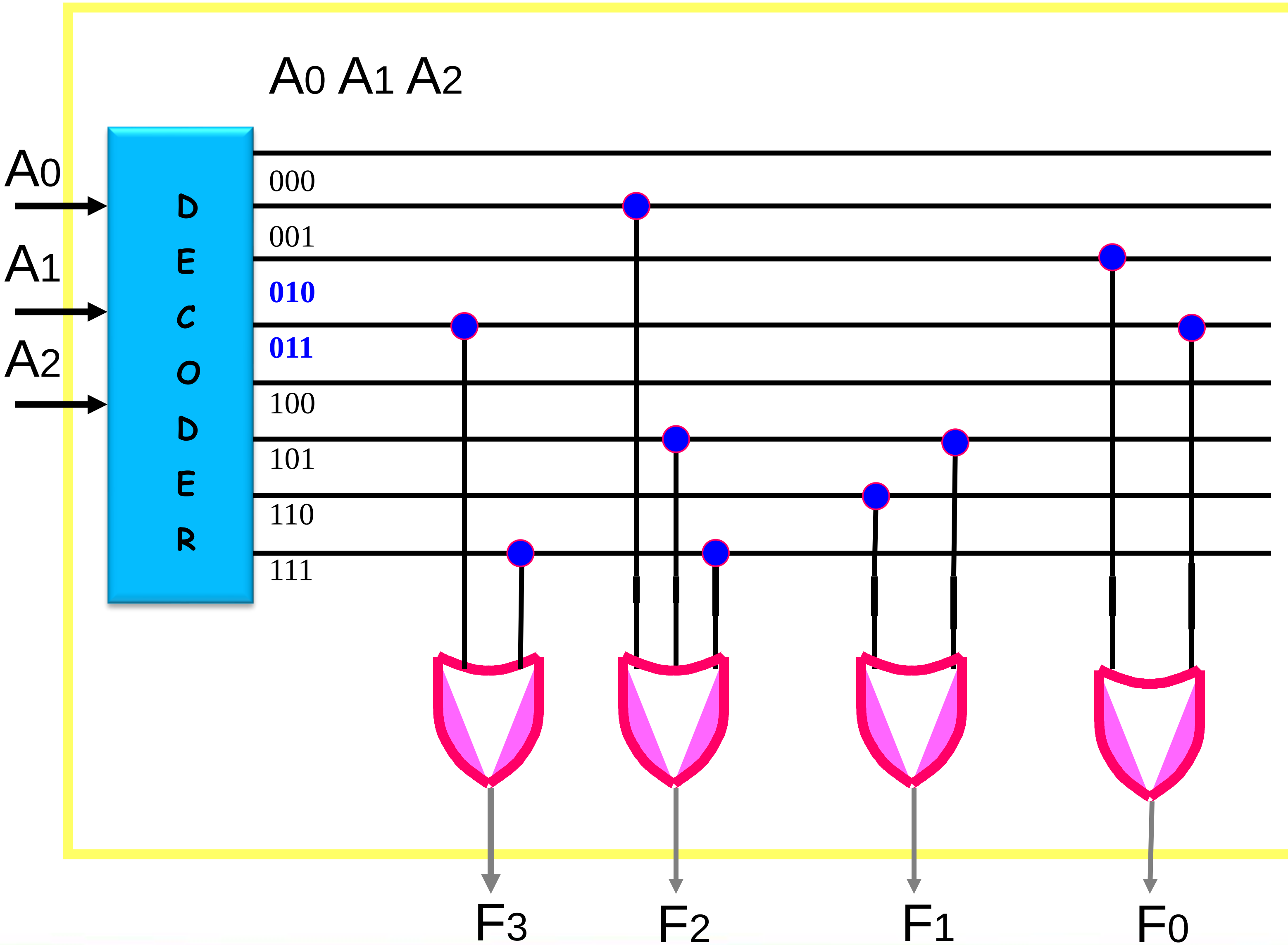
$$F_2 = \overline{A_0}\,\overline{A_1}\,A_2 + A_0\,\overline{A_1}\,A_2 + A_0\,A_1\,A_2$$



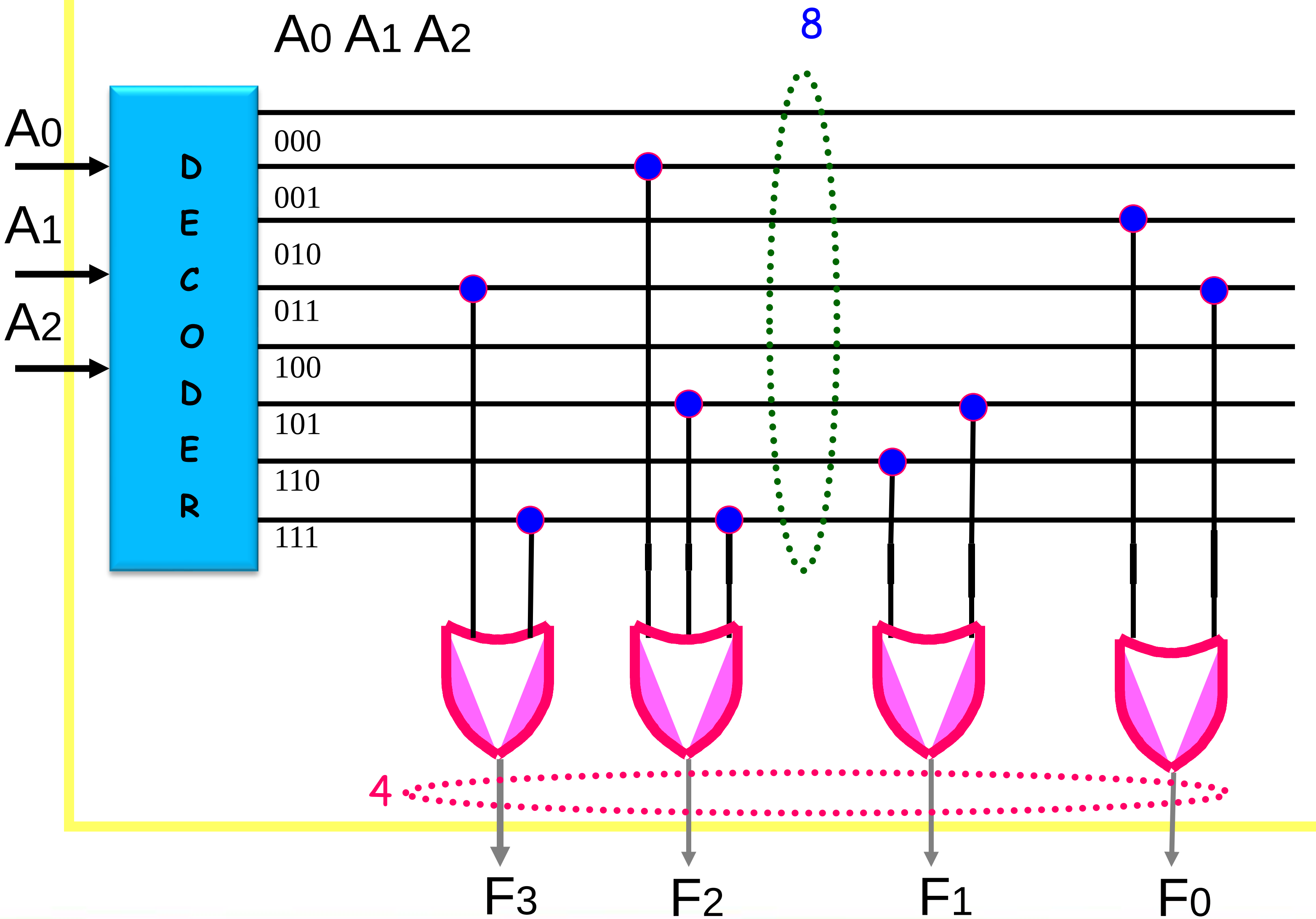
$$F_1 = A_0 A_1 \overline{A_2} + A_0 \overline{A_1} A_2$$



$$F_0 = \overline{A_0}\, A_1\, \overline{A_2} + \overline{A_0}\, A_1\, A_2$$

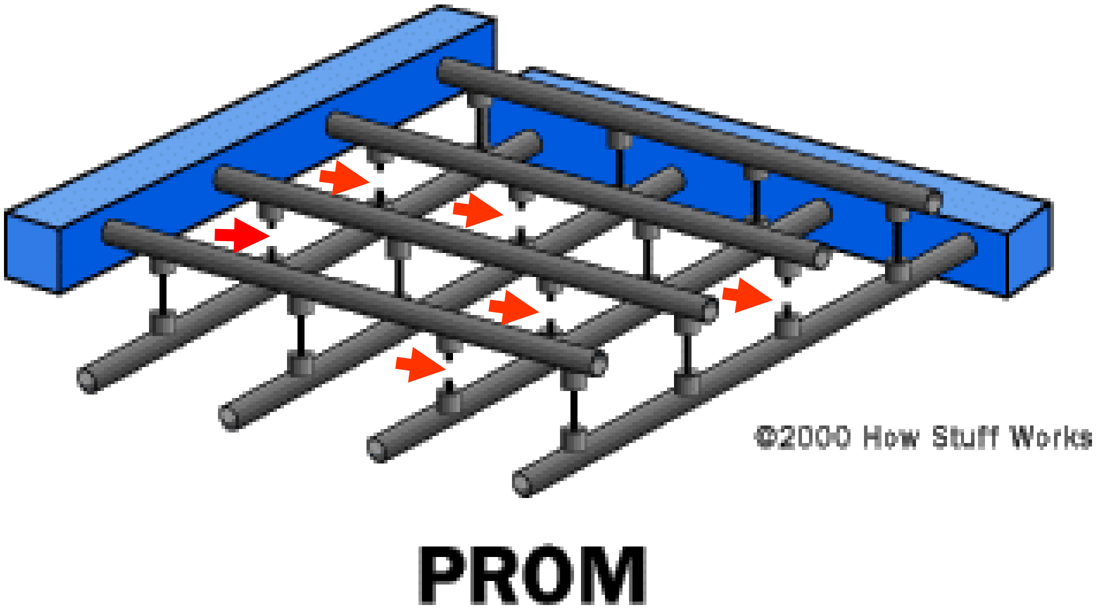


Programmed ROM … (32 bits)

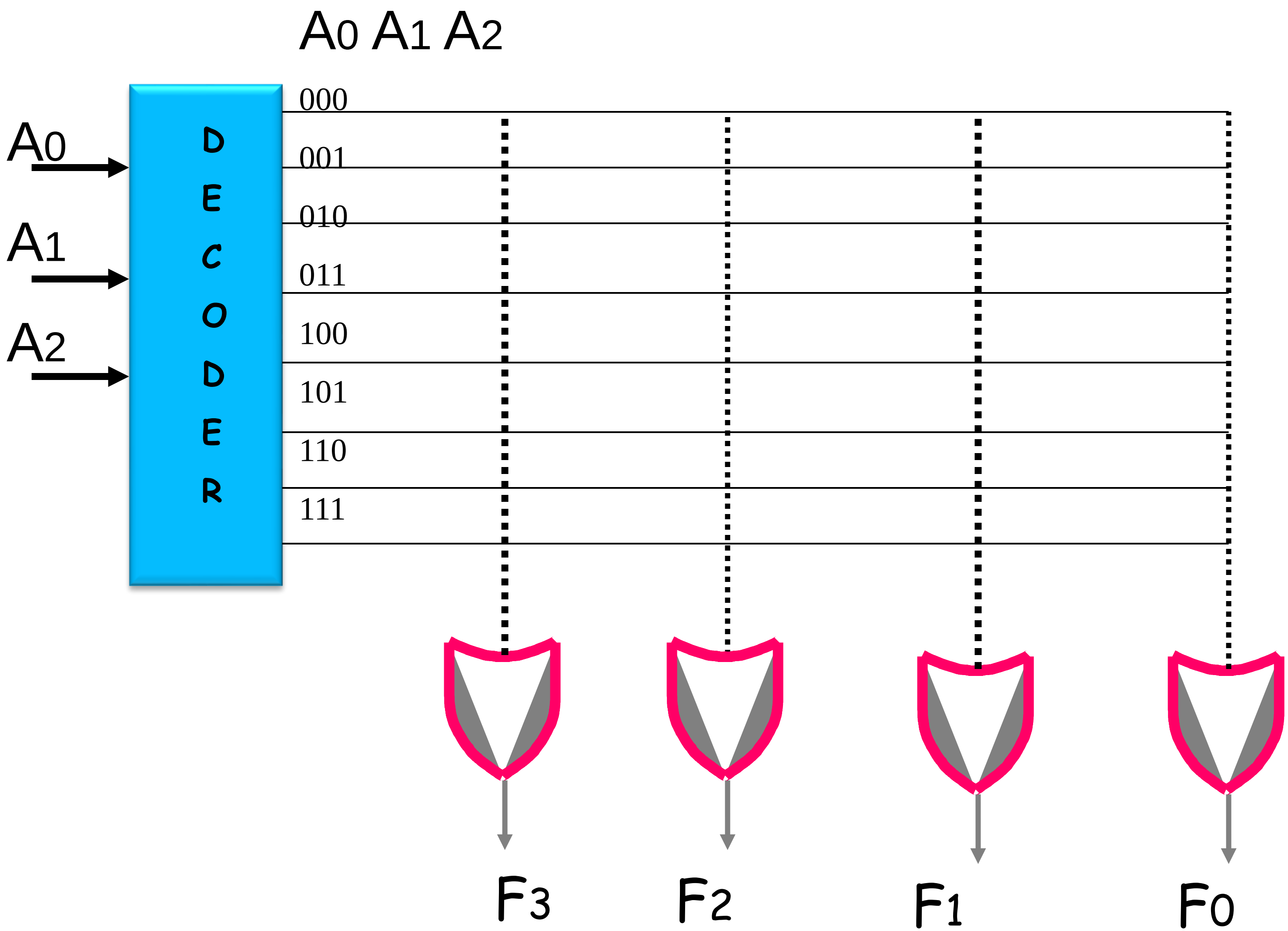


4 x 8 = 32

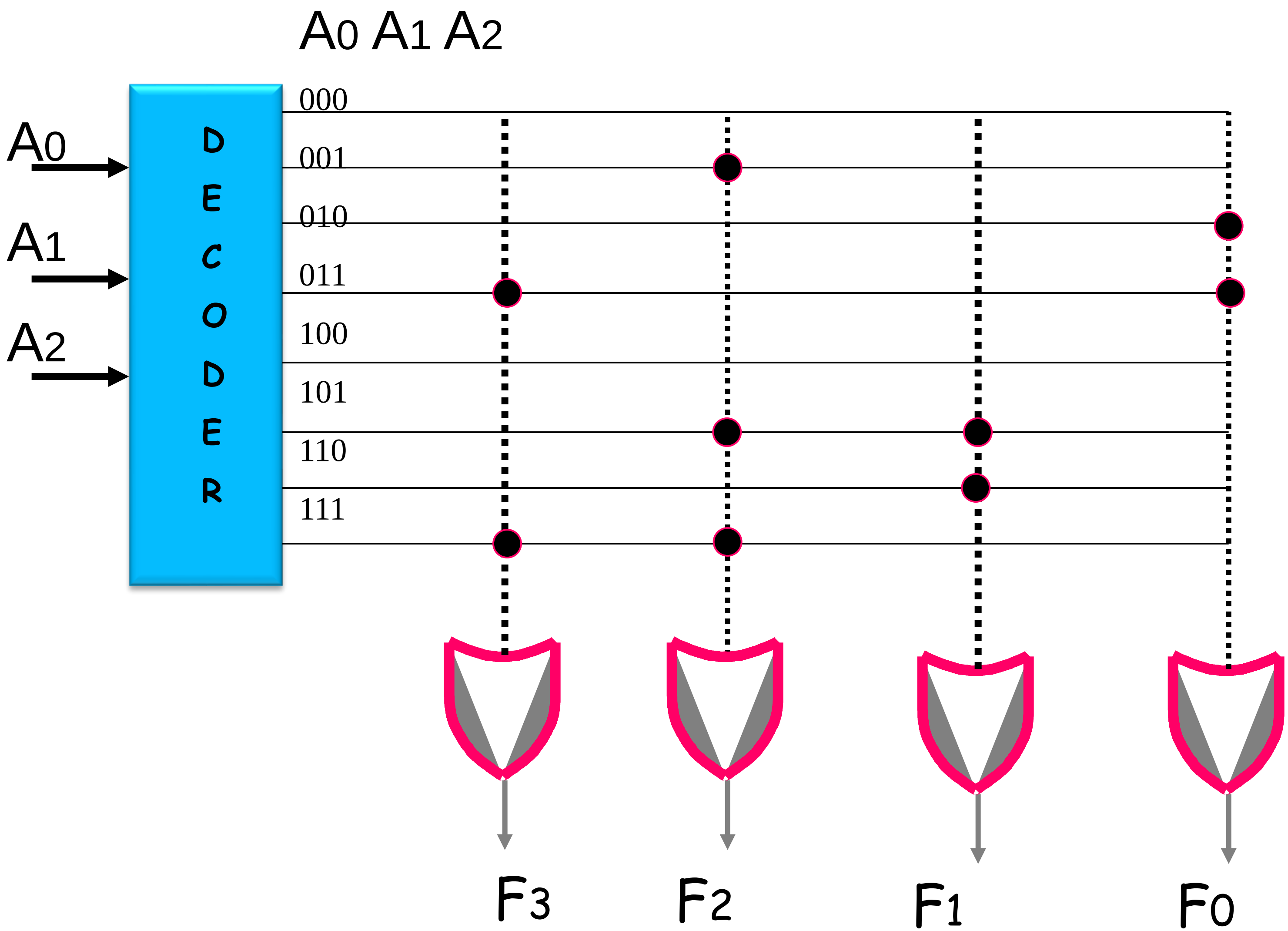
Programmable Read Only Memory (PROM)… Burning



A simplified way

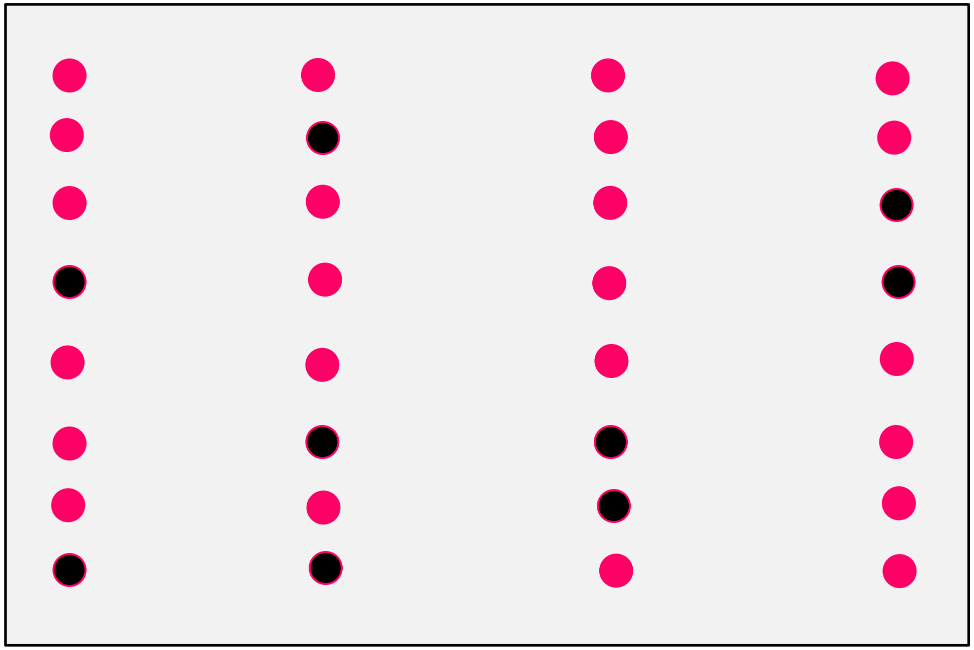


A simplified way



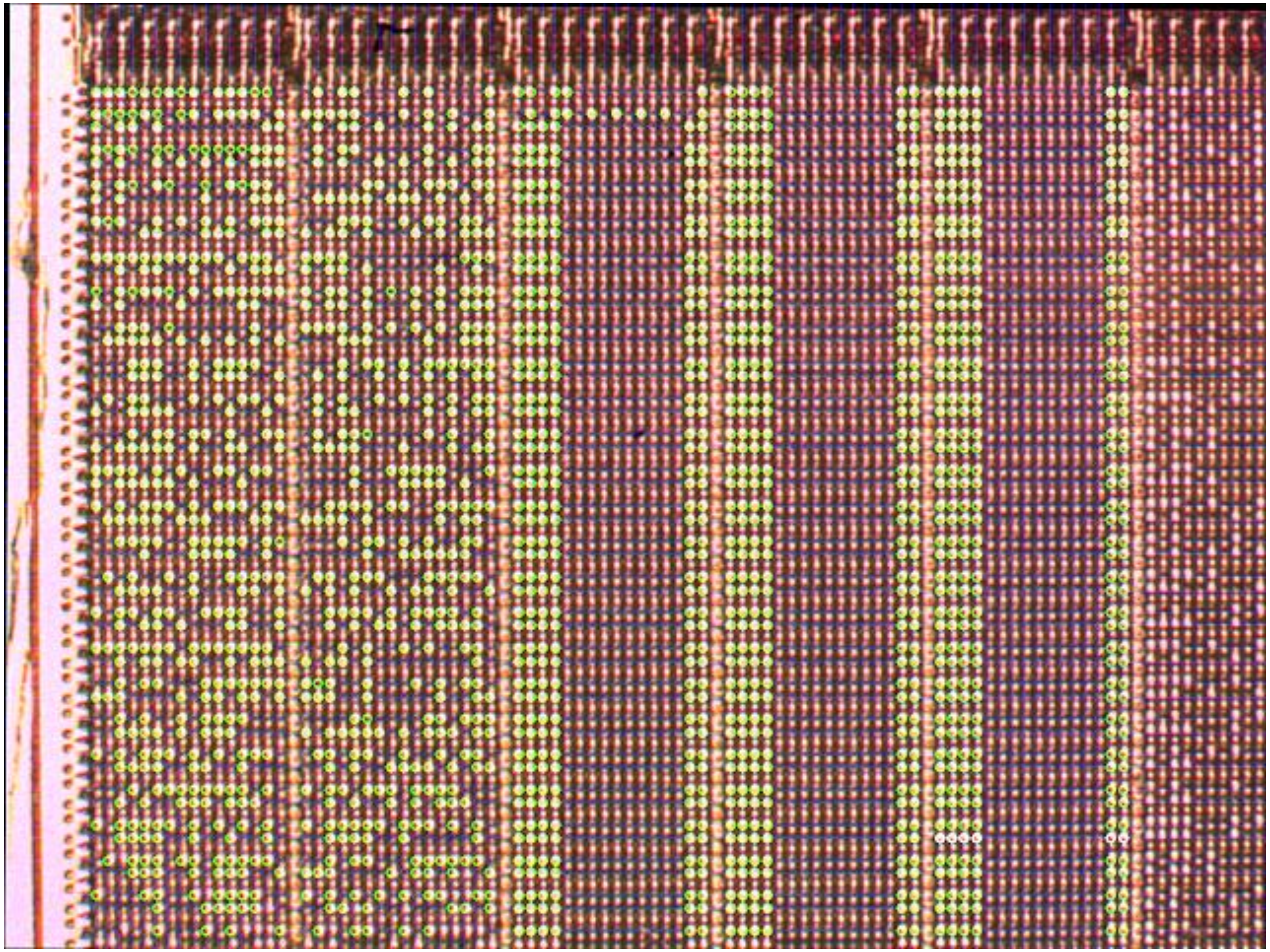
8*4 = 32-bits (32-dots total)

8

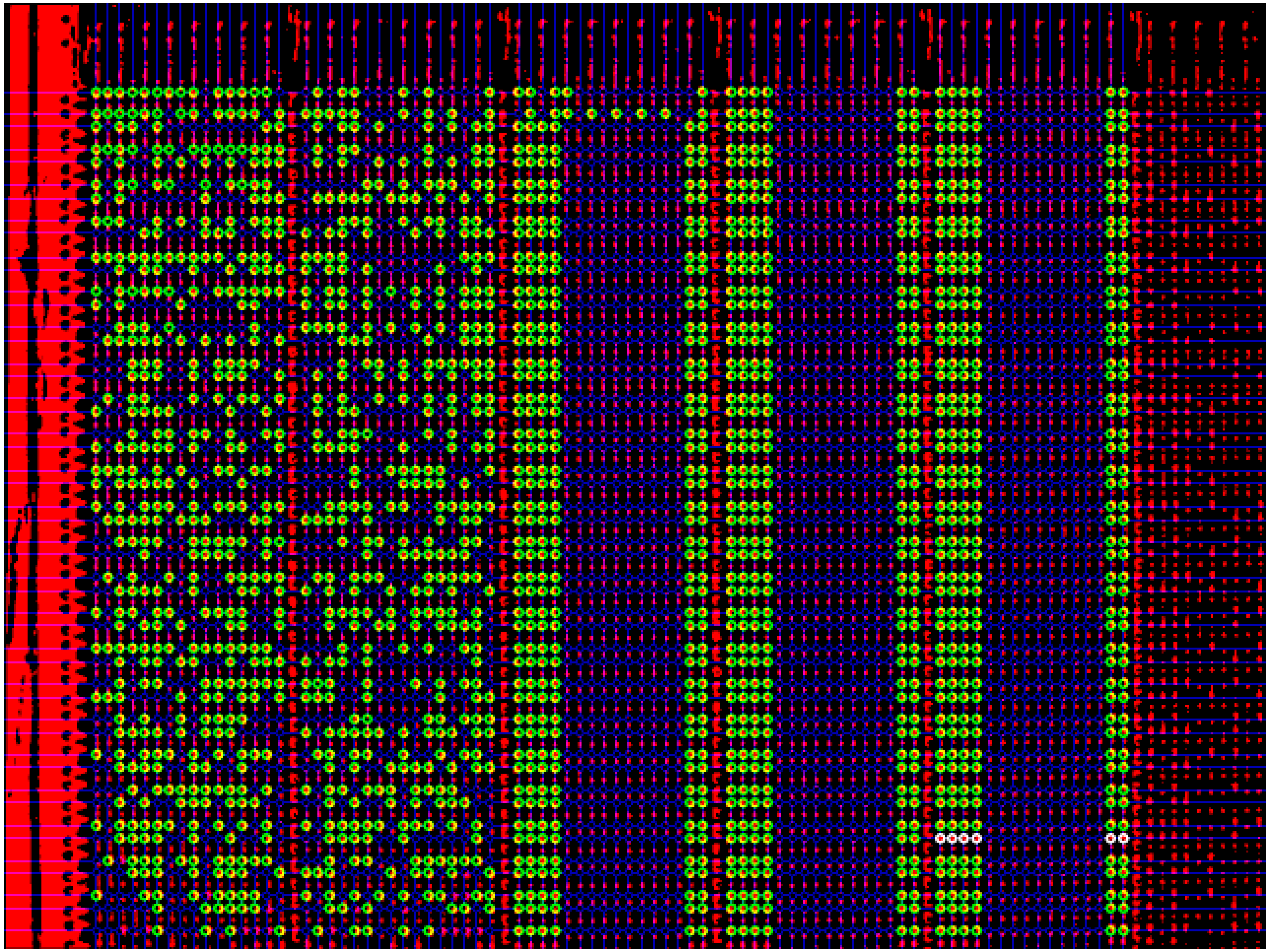


4

Masked ROMs - Atmel MARC4

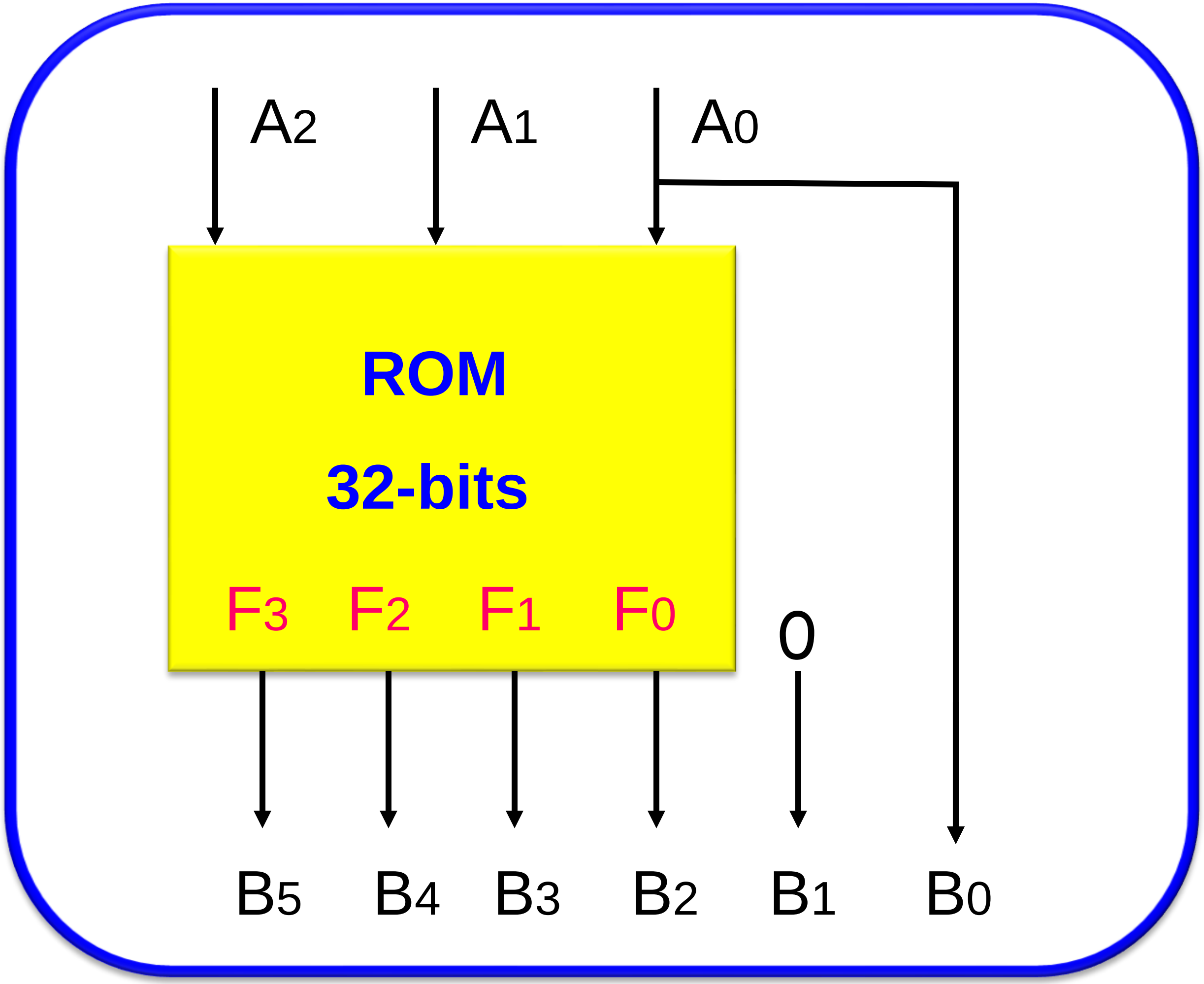


Masked ROMs - Atmel MARC4

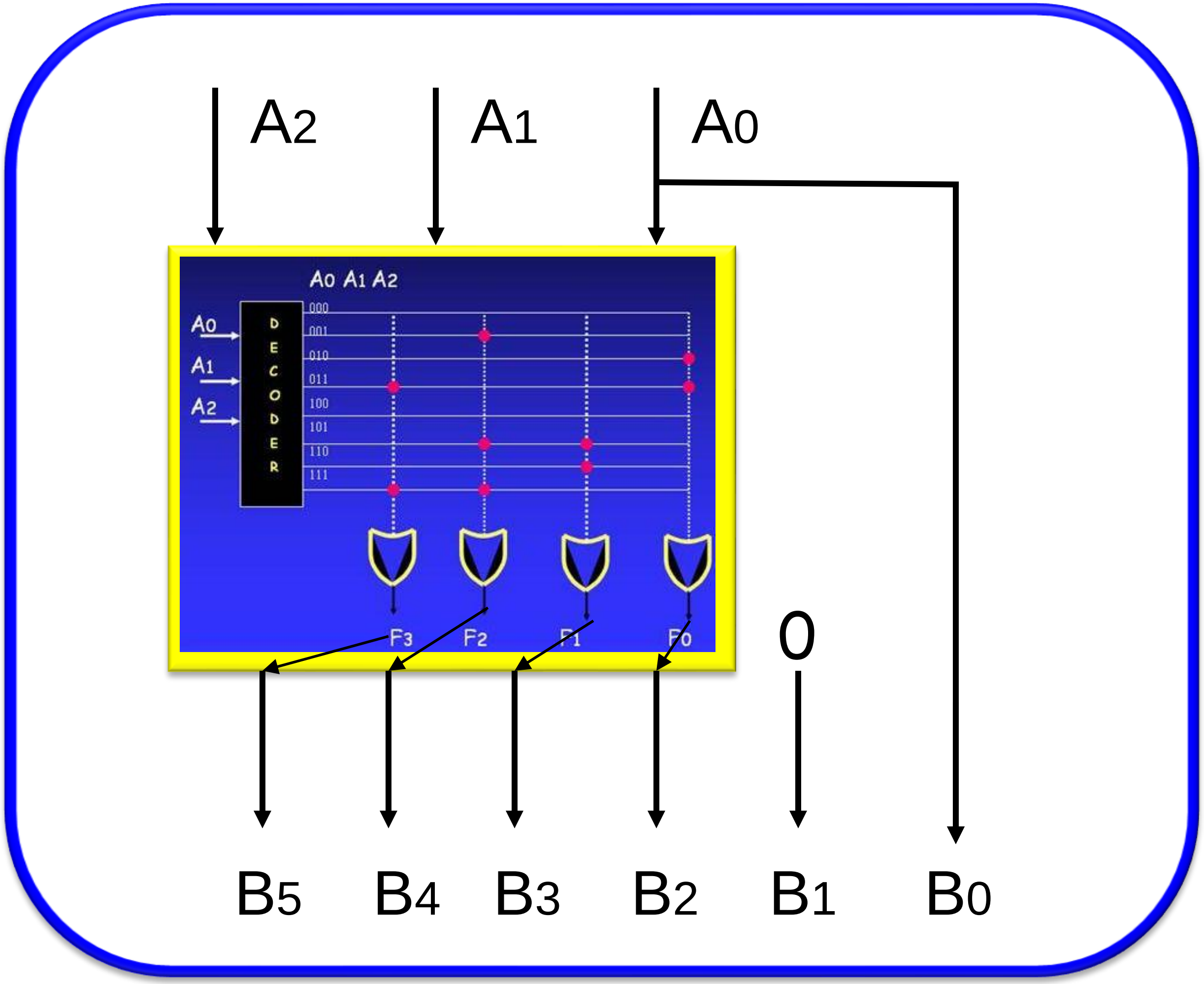


Final ROM

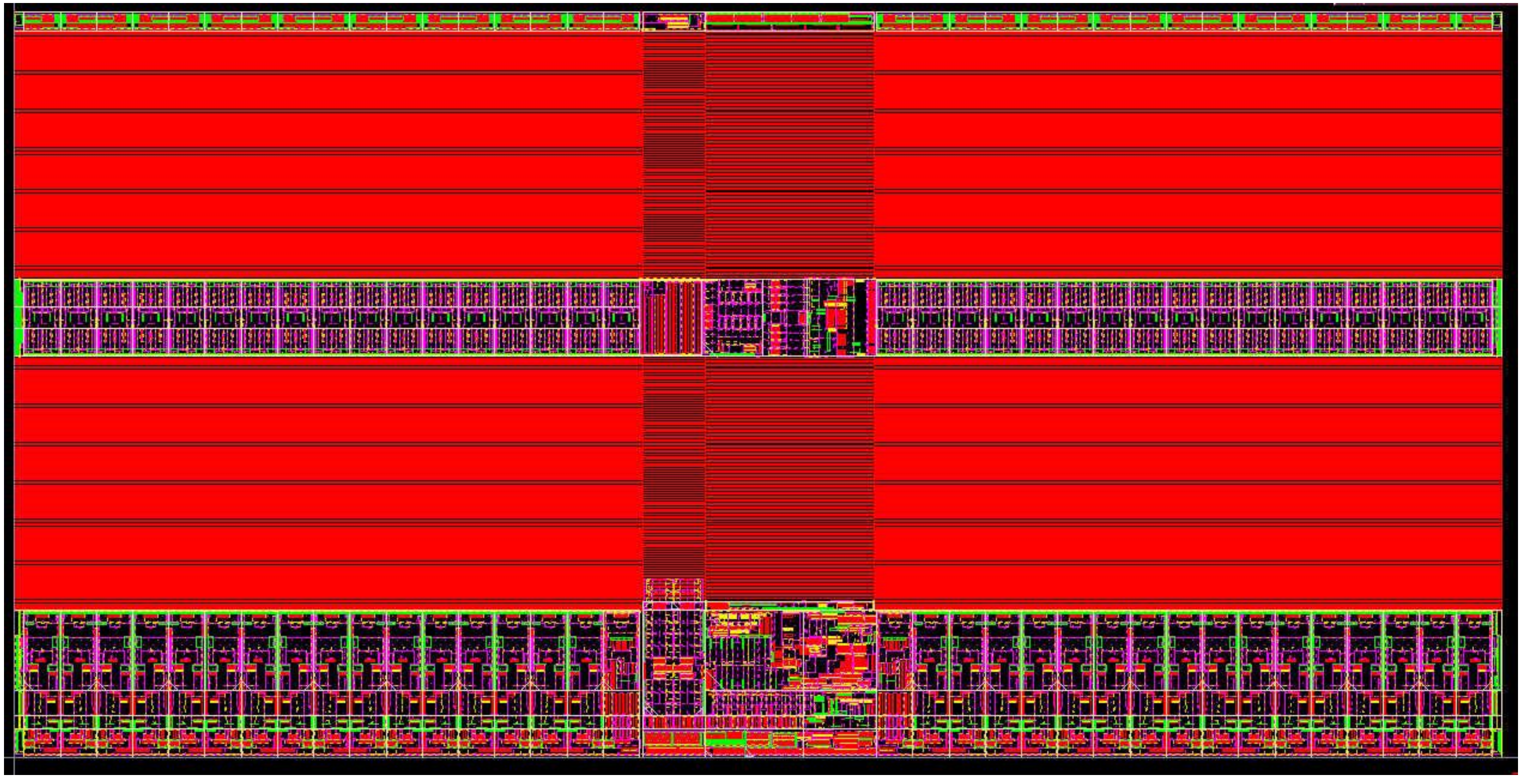
$B_0 = A_0$ and $B_1 = 0$



Final ROM with Decoder and Gates



ARM (ROM)



ROM (Read Only Memory) is also used in permanent storage of data within an SoC (System on Chip) or other integrated circuit applications.