Fundamentals of Computer Systems

Memory

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Memory Architecture

Memory Cell Technologies

Programmable Logic Devices

Memory Architecture

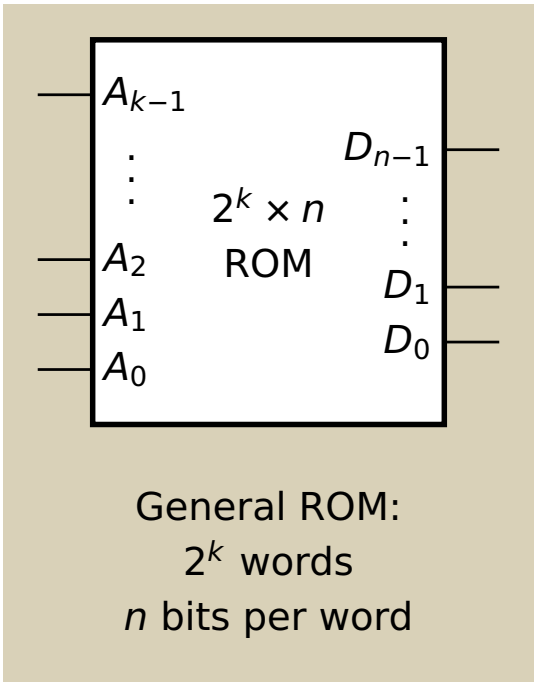
Memory Interface

Data stored in *word* units

A word is several bytes (powers of two are typical)

write operations store data to memory

read operations retrieve data from memory

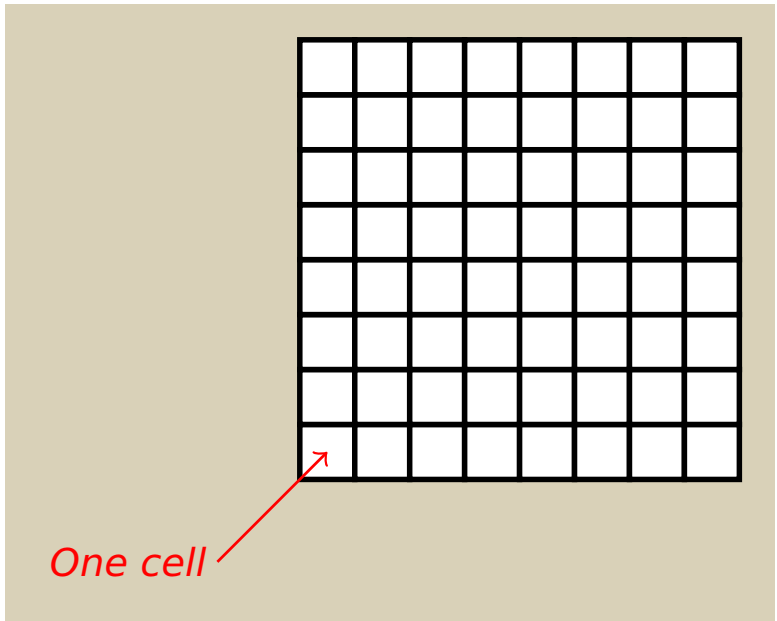


General ROM:
2^k words
n bits per word

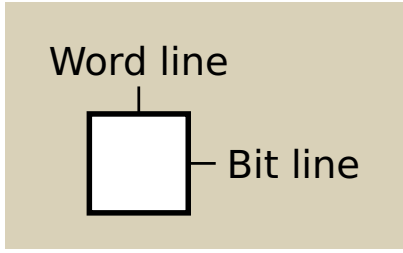
Conceptual View of Memory

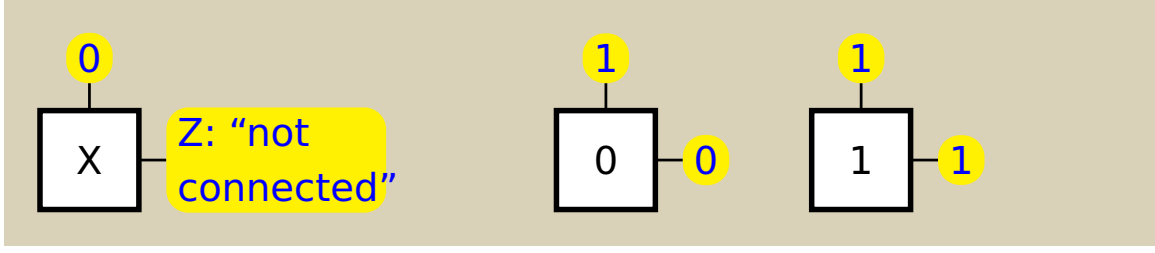
Memory is an array of *cells*.

Each cell stores a single bit.



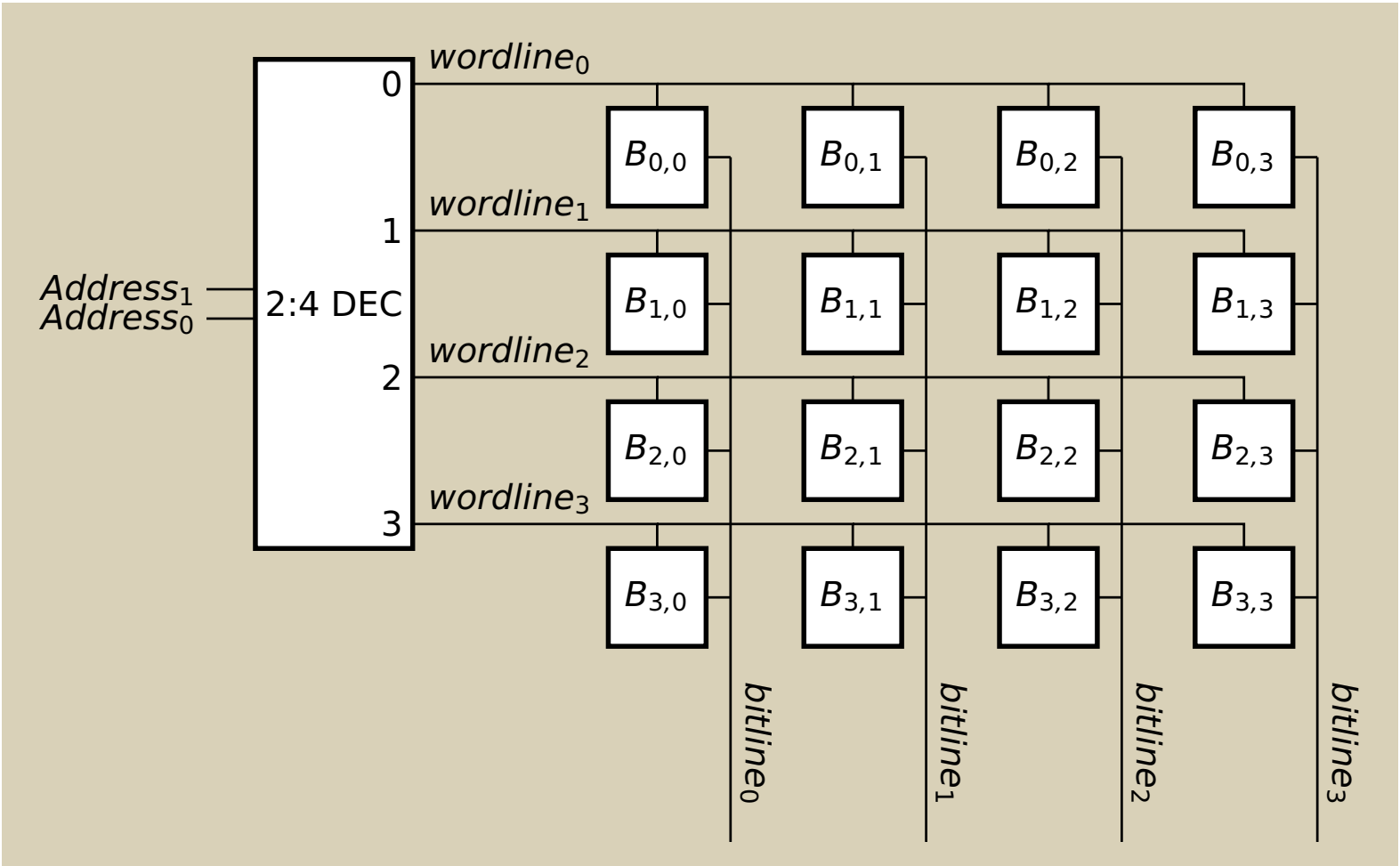
Cell Behavior



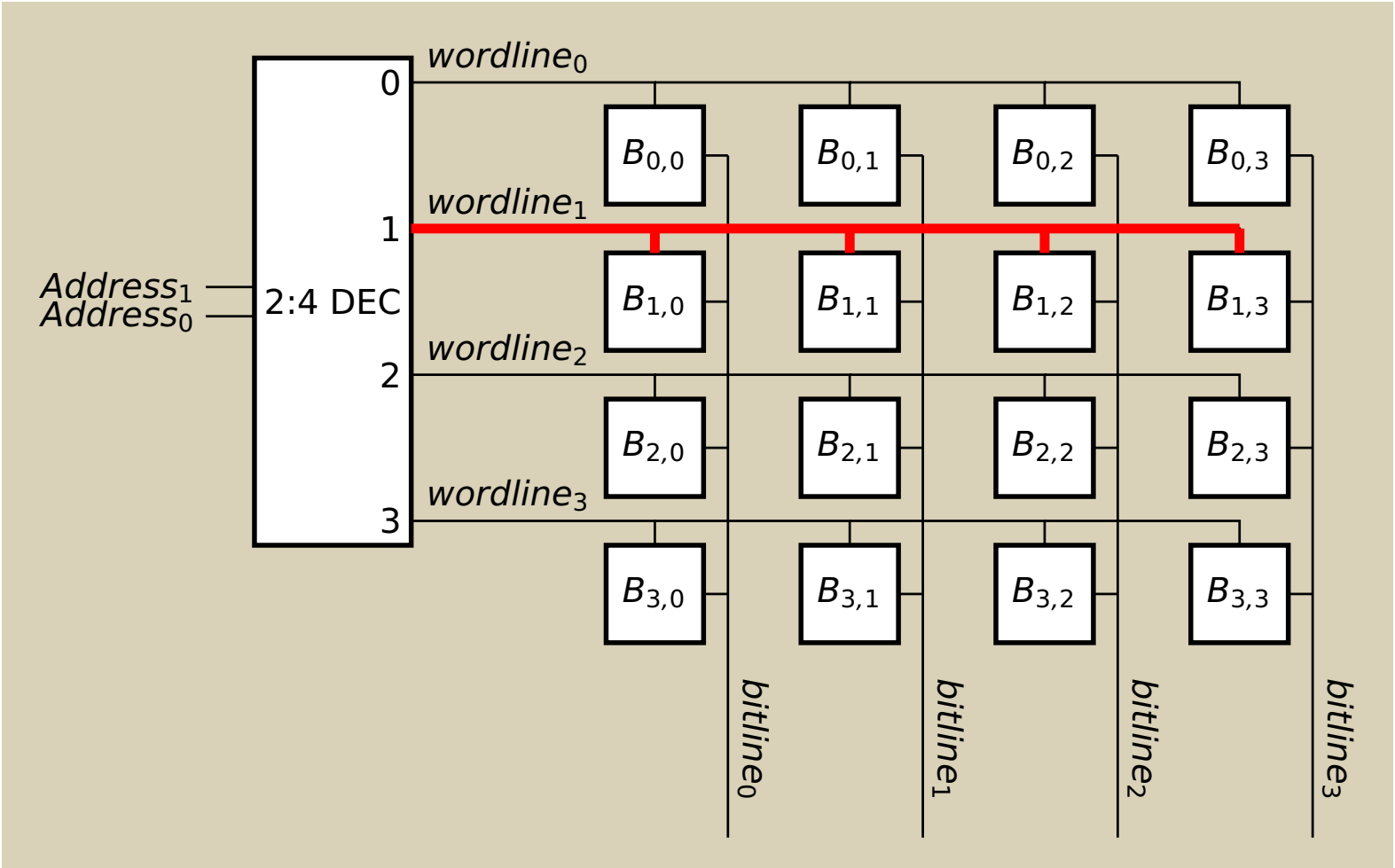


Implementation of cell depends on type of memory.

Generic Memory Array Architecture



Generic Memory Array Architecture

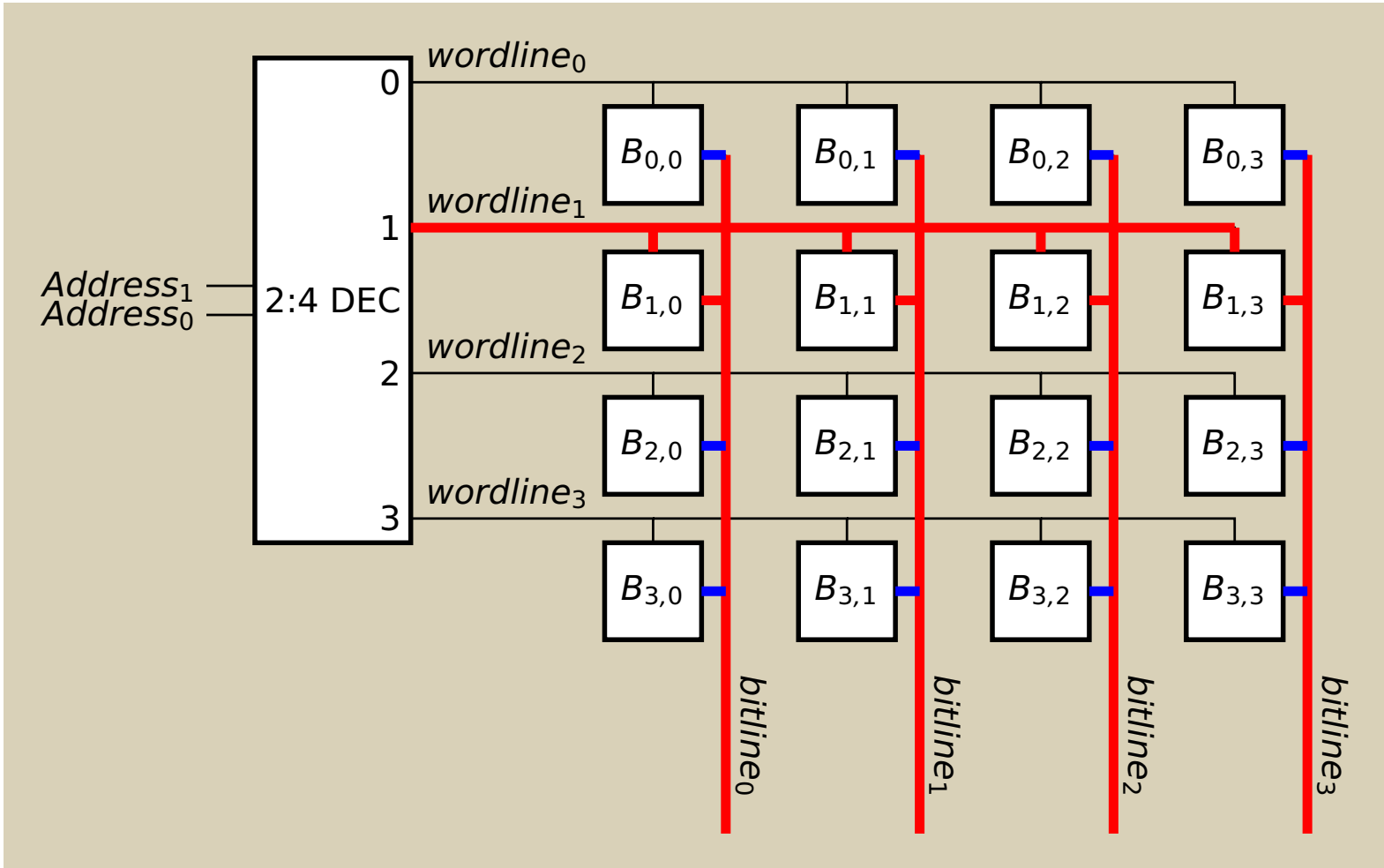


Address is decoded into set of wordlines.

Wordlines select row to be read/written.

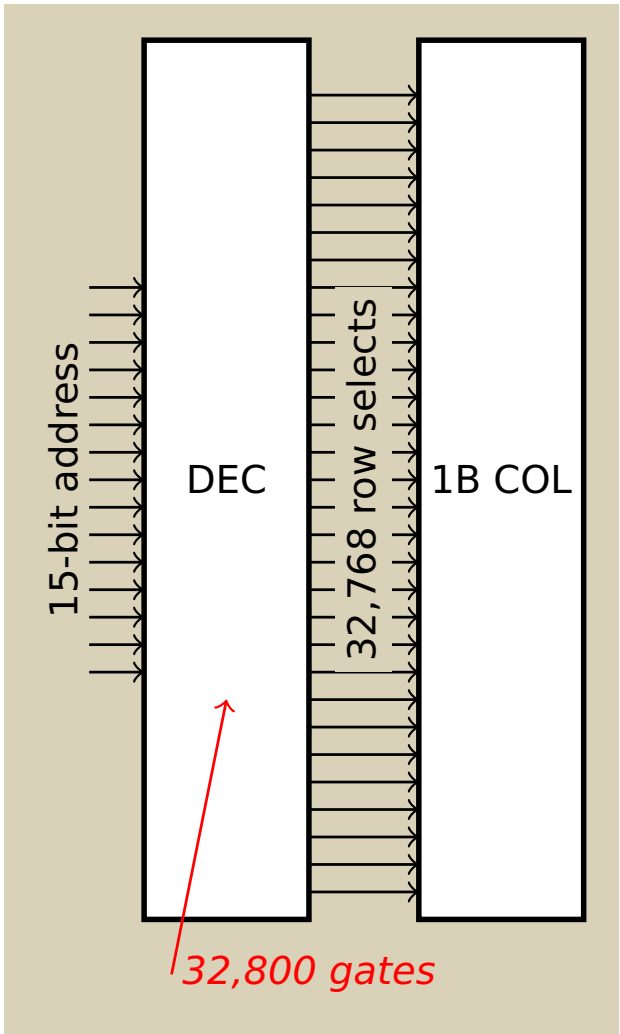
Only one wordline=1 at a time.

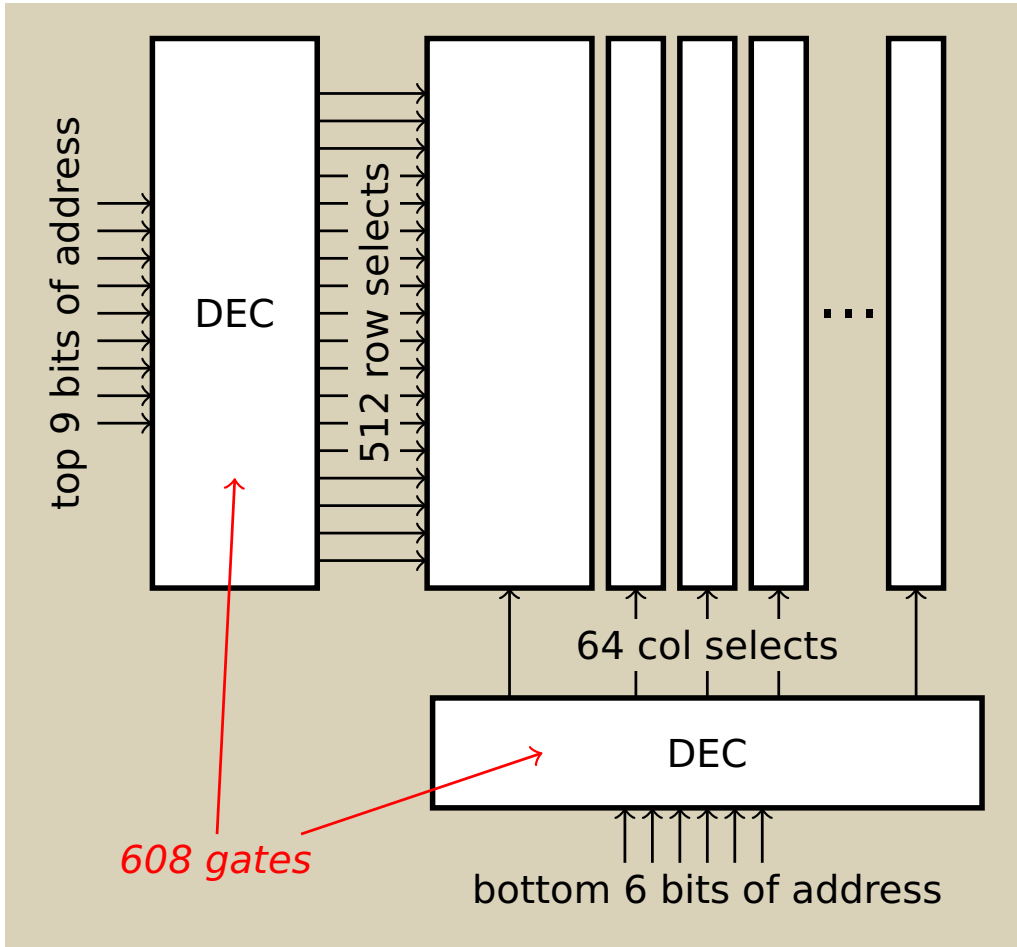
Generic Memory Array Architecture



Multiple cells read in parallel, setting values of multiple bitlines.

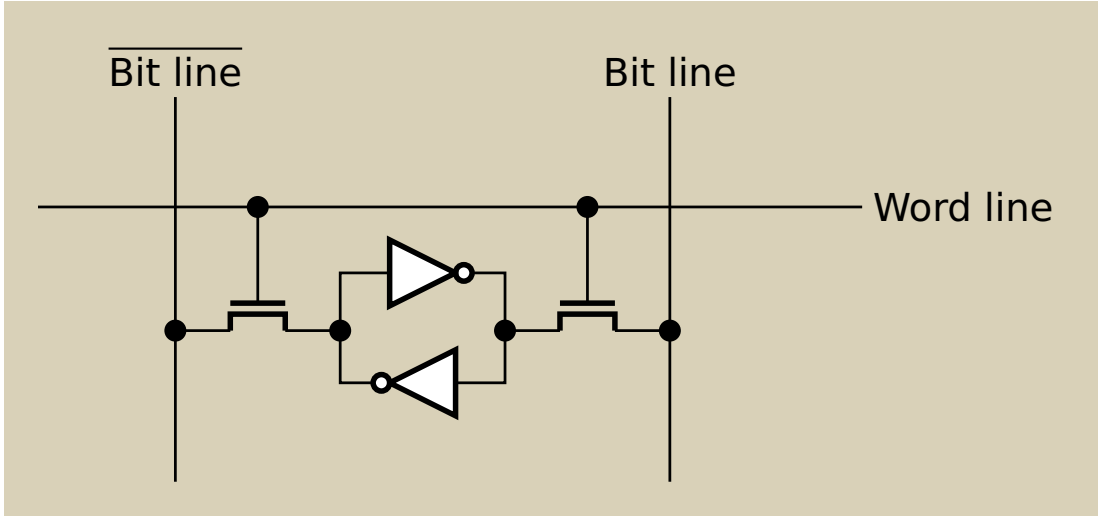
Coincident Selection Saves Decode Logic



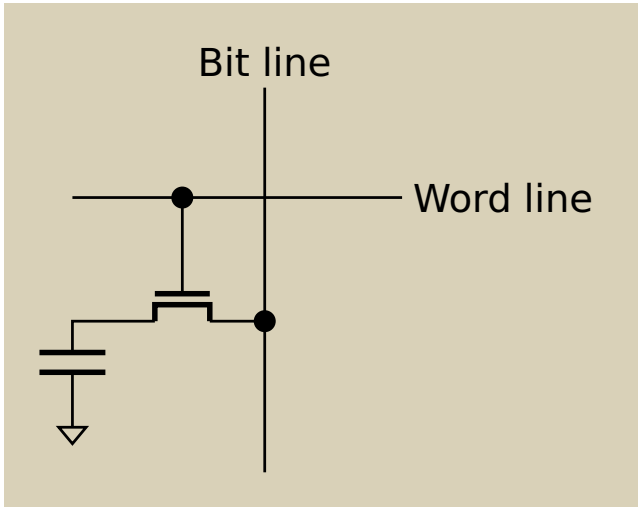


Memory Cell Technologies

Static Random-Access Memory Cell (SRAM)

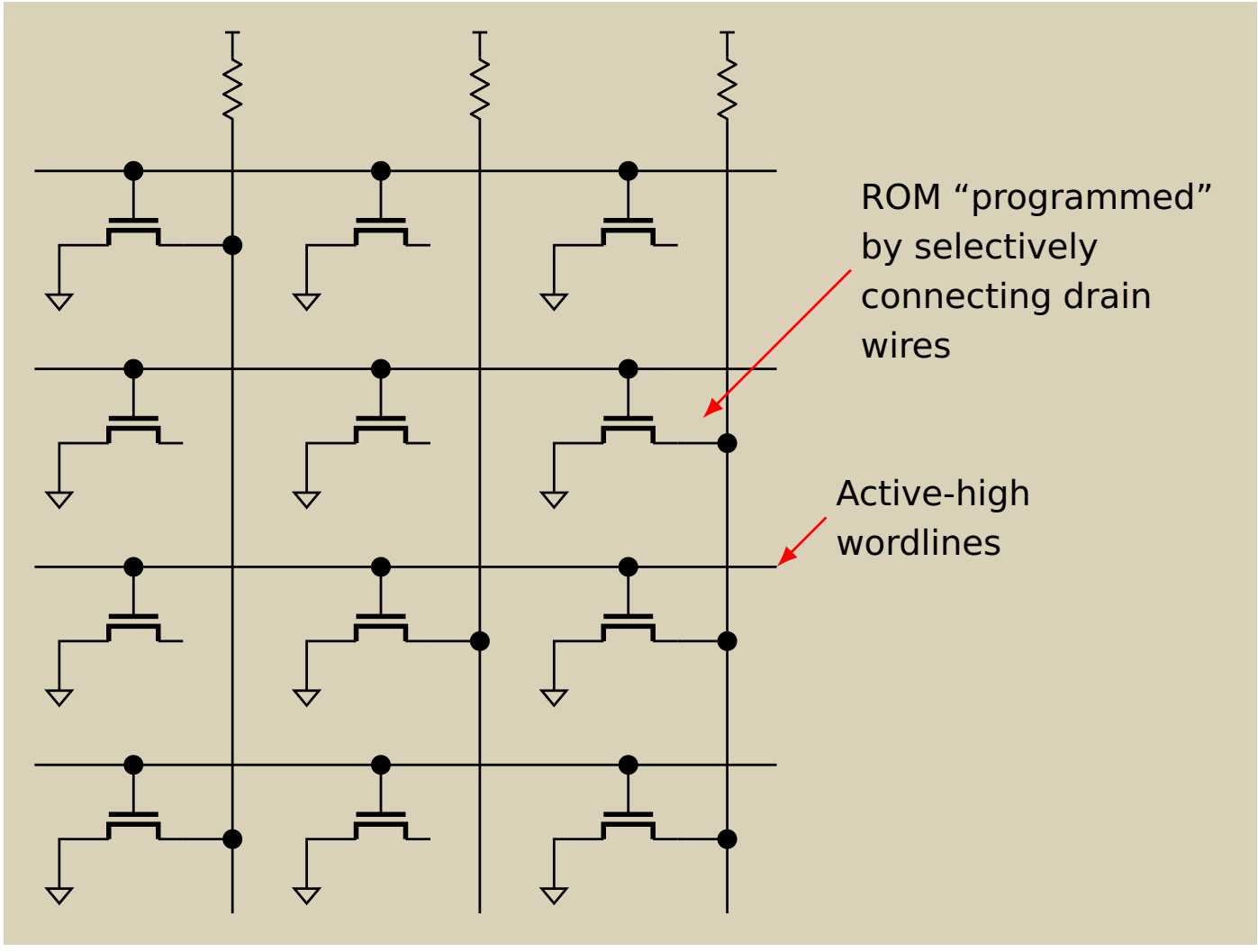


Dynamic RAM Cell

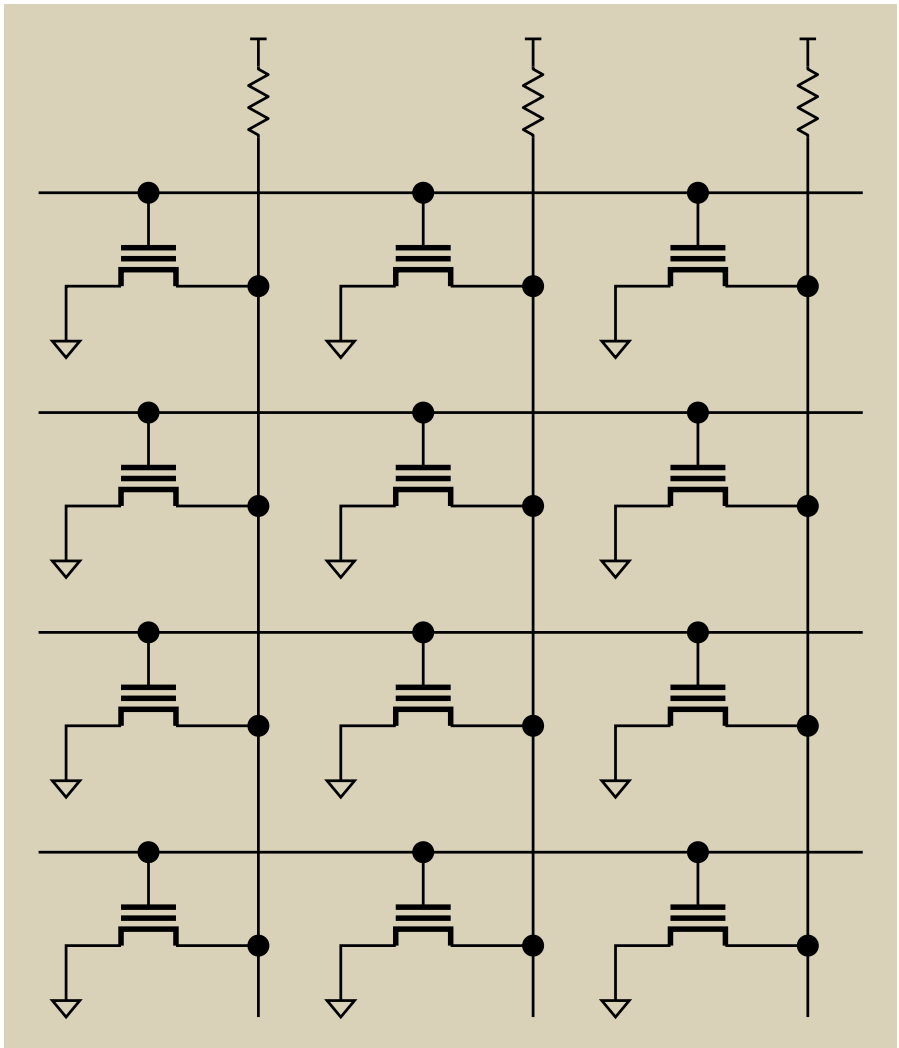


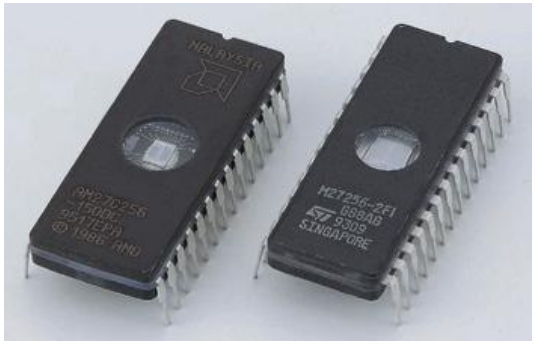
CMOS Mask-Programmed ROMs

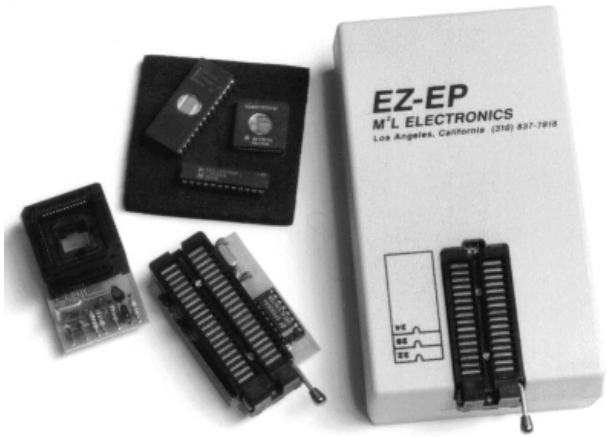
Add.	Data
00	011
01	110
10	100
11	010



EPROMs and FLASH use Floating-Gate MOSFETs







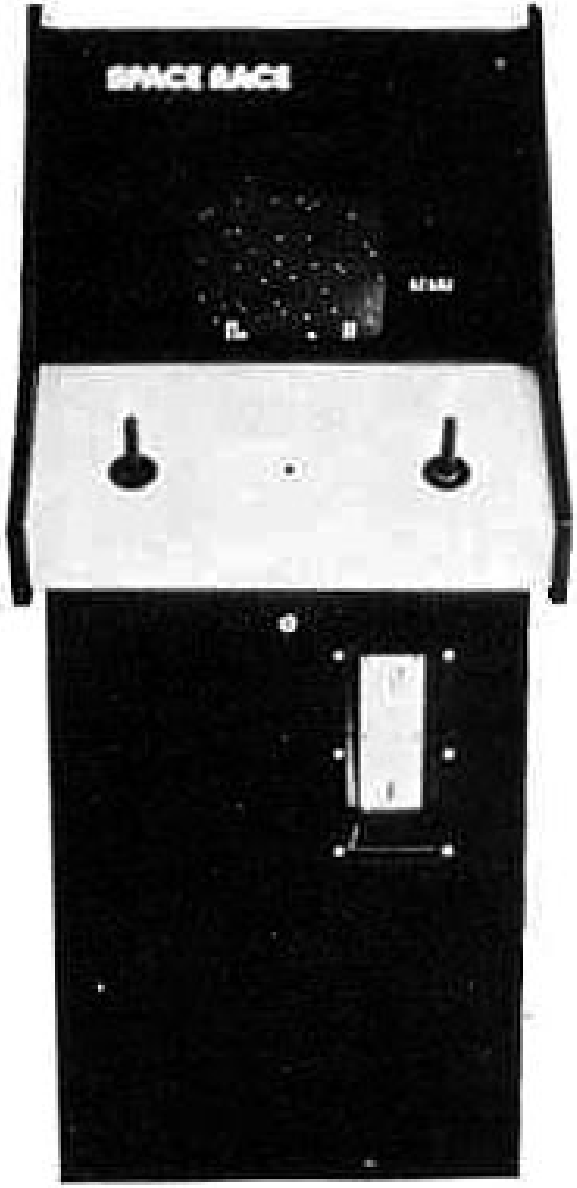
Volatile Storage Comparisons

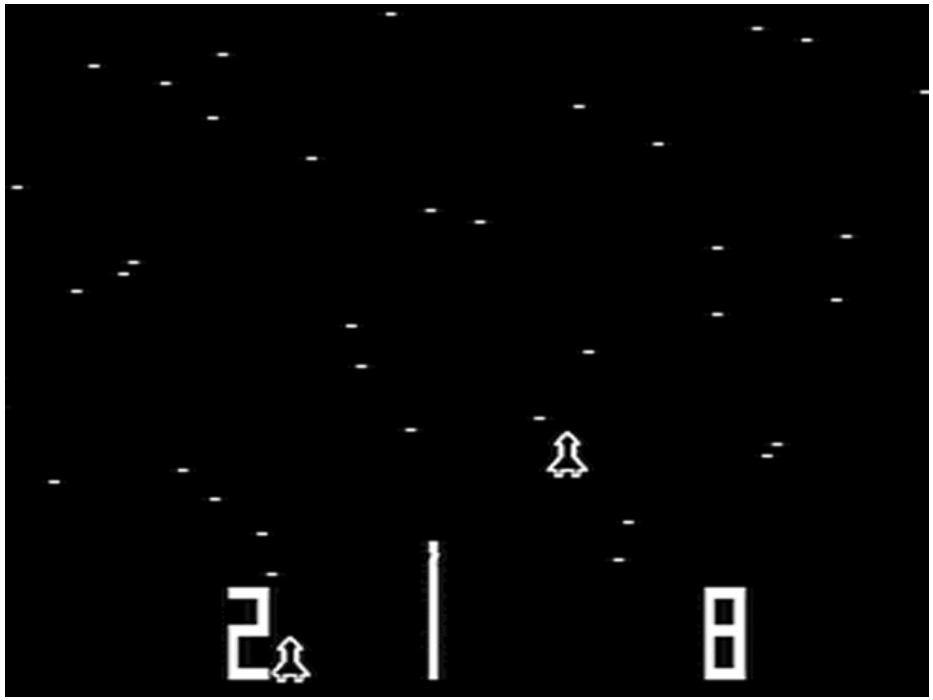
	Flip-Flop	SRAM	DRAM
Transistors/Bit	Approx. 20	6	1
Density	Low	Medium	High
Access Time	Fast	Medium	Slow
Destructive Read?	No	No	Yes[1]
Power	High	Medium	Low

[1] Therefore refresh required

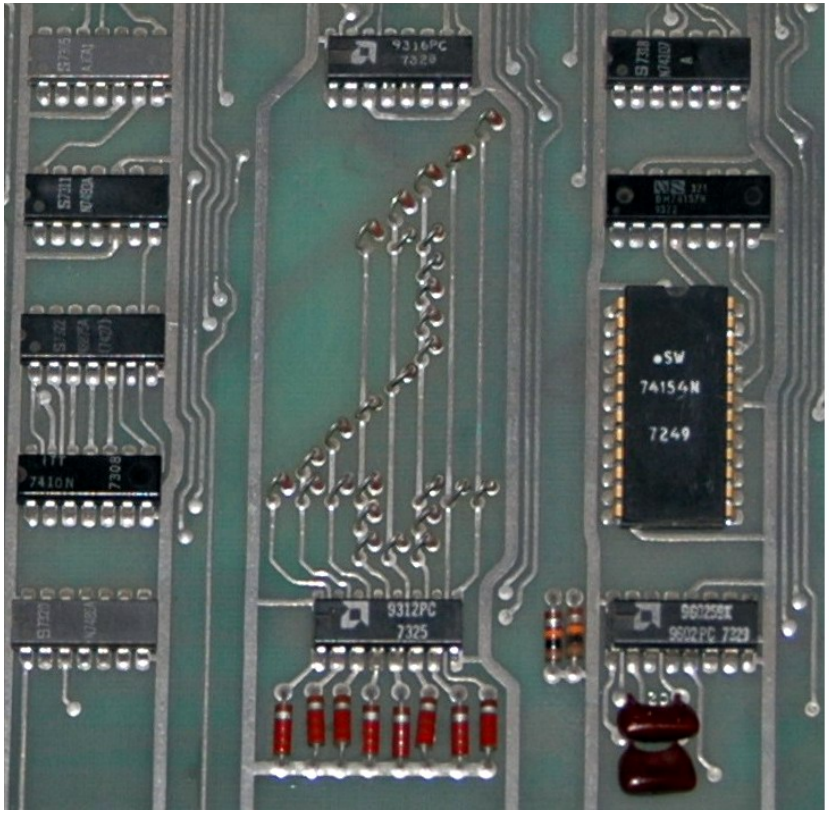
Programmable Logic Devices

Atari Space Race, 1973

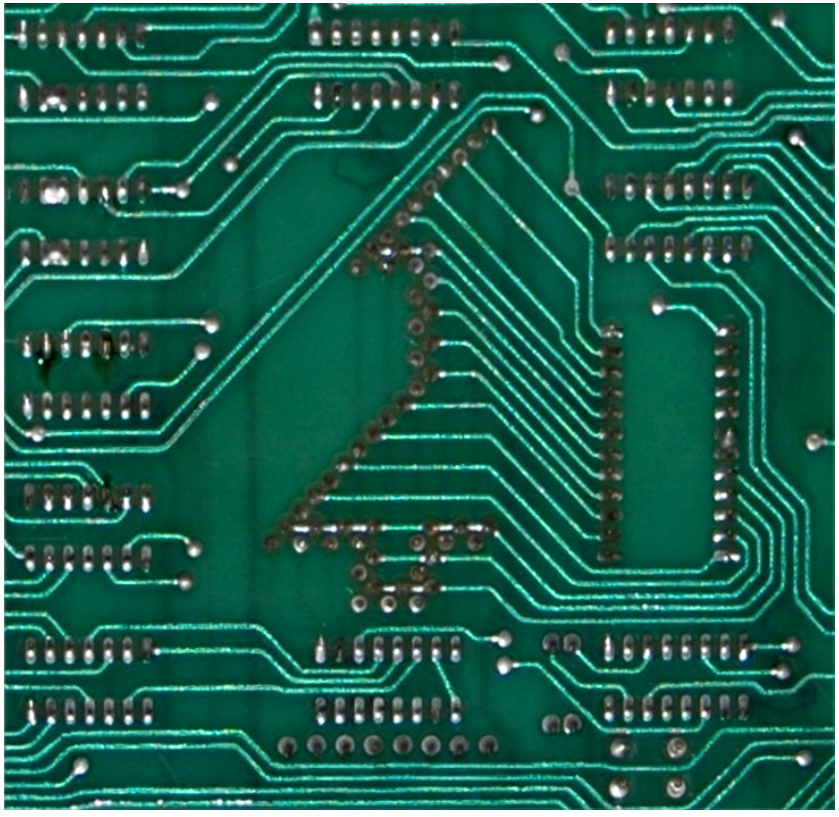




Atari Space Race PCB

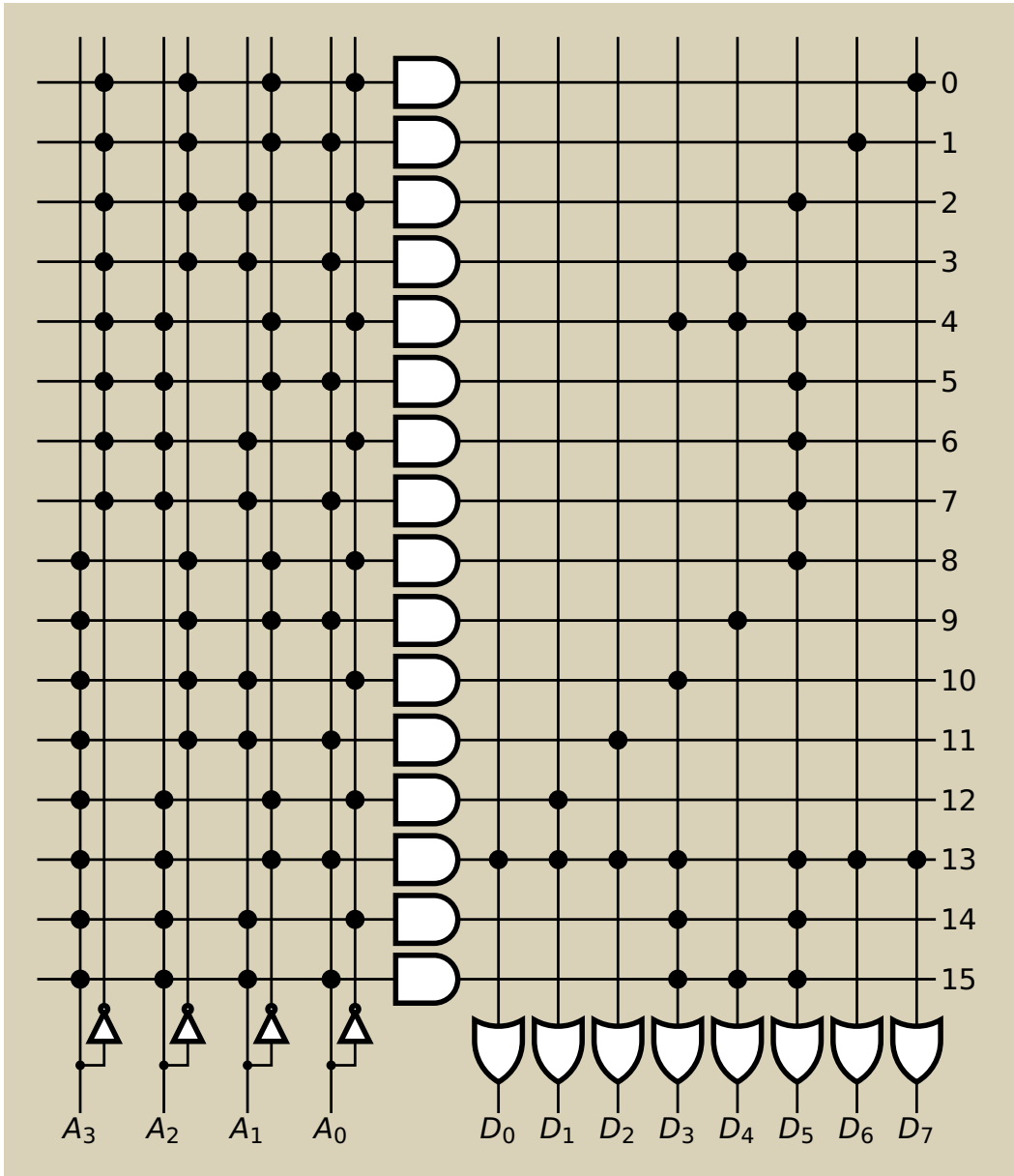


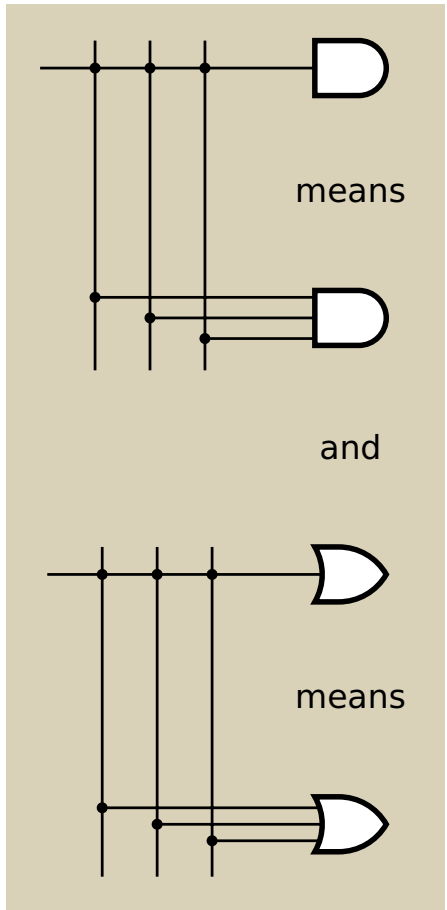
Front



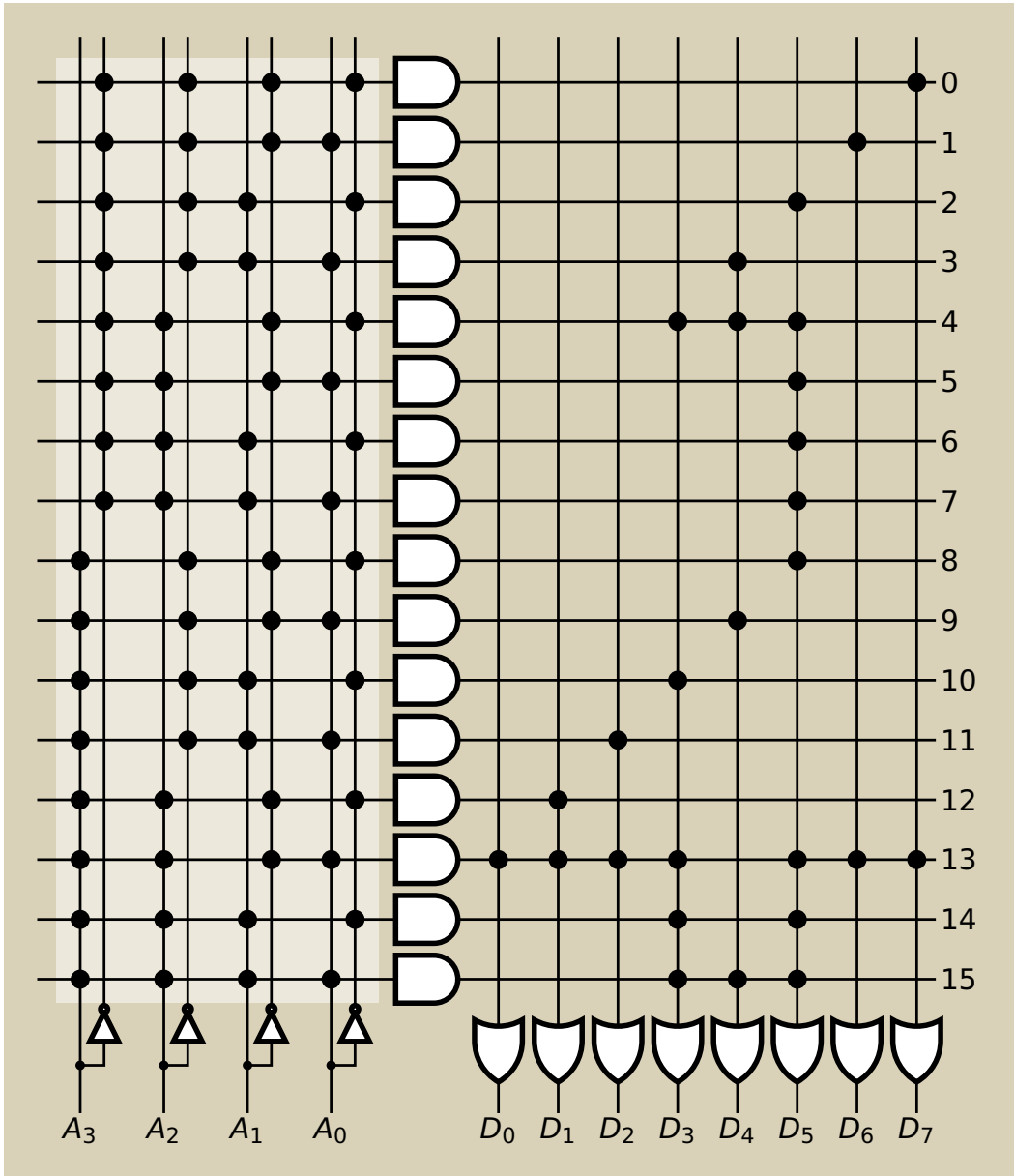
Back (mirrored)

The Space Race ROM





The Space Race ROM

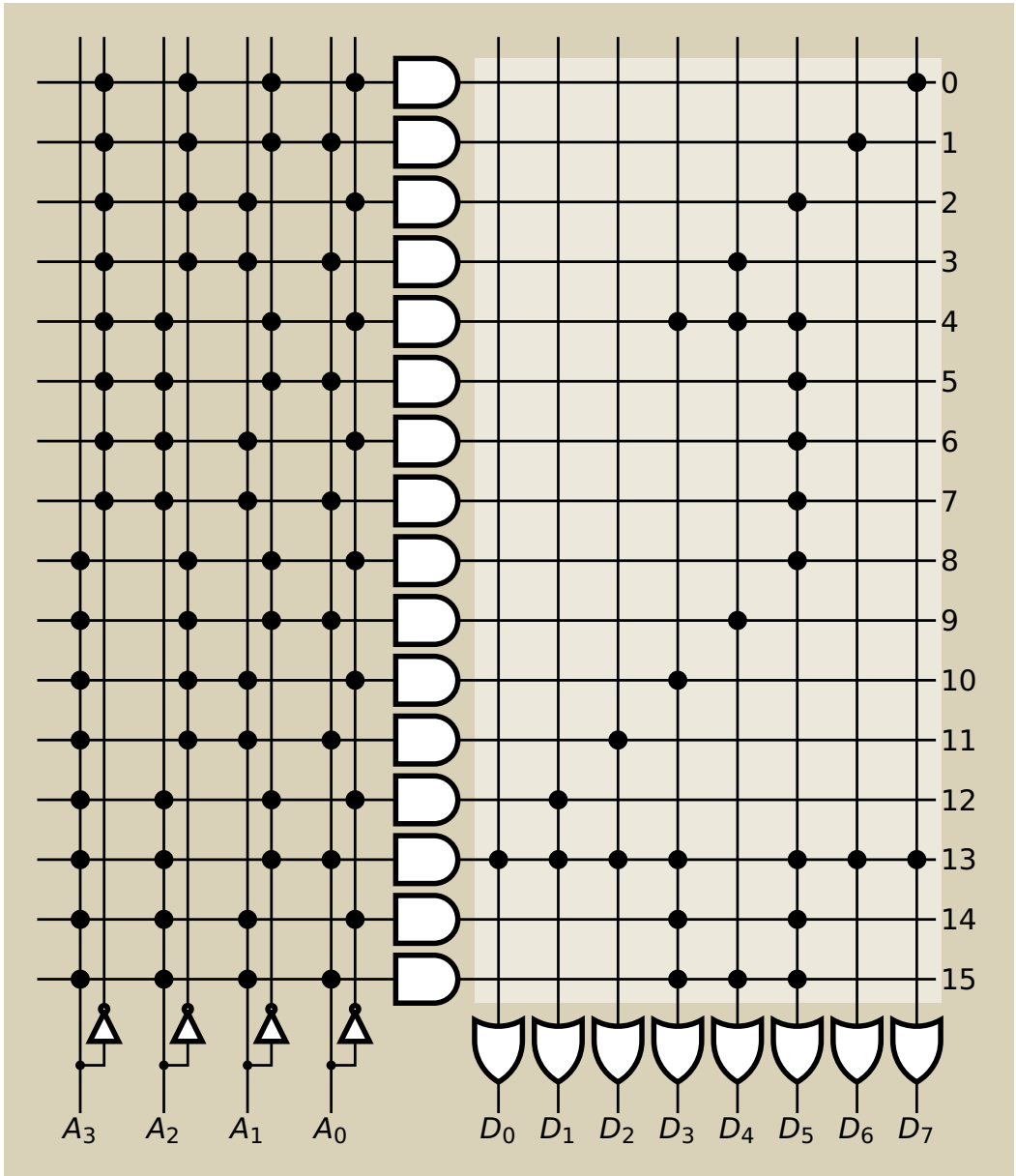


The decoder or "AND plane"

In a RAM or ROM, computes every minterm

Pattern is not programmable

The Space Race ROM

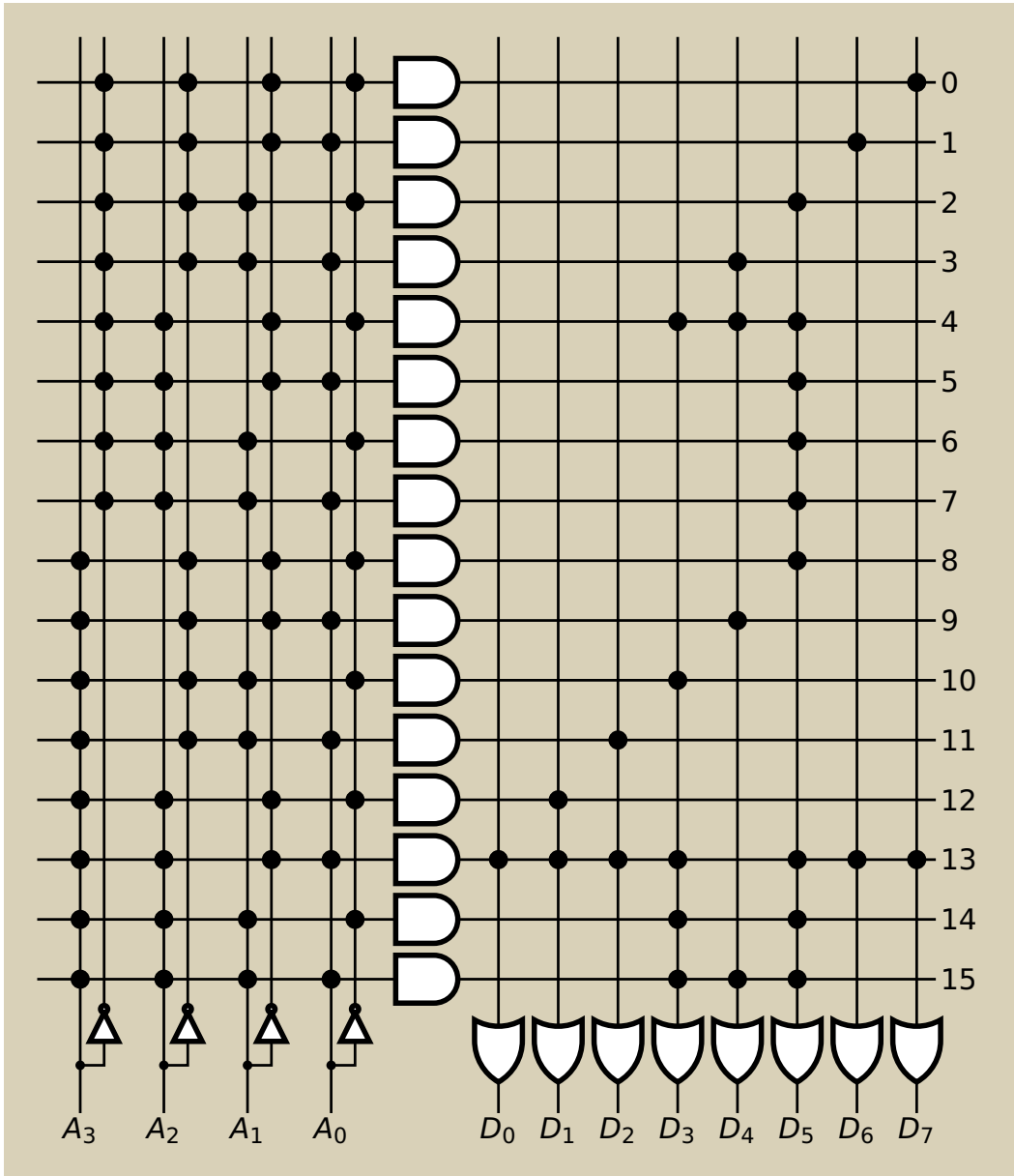


The contents or “OR plane”

One term for every output

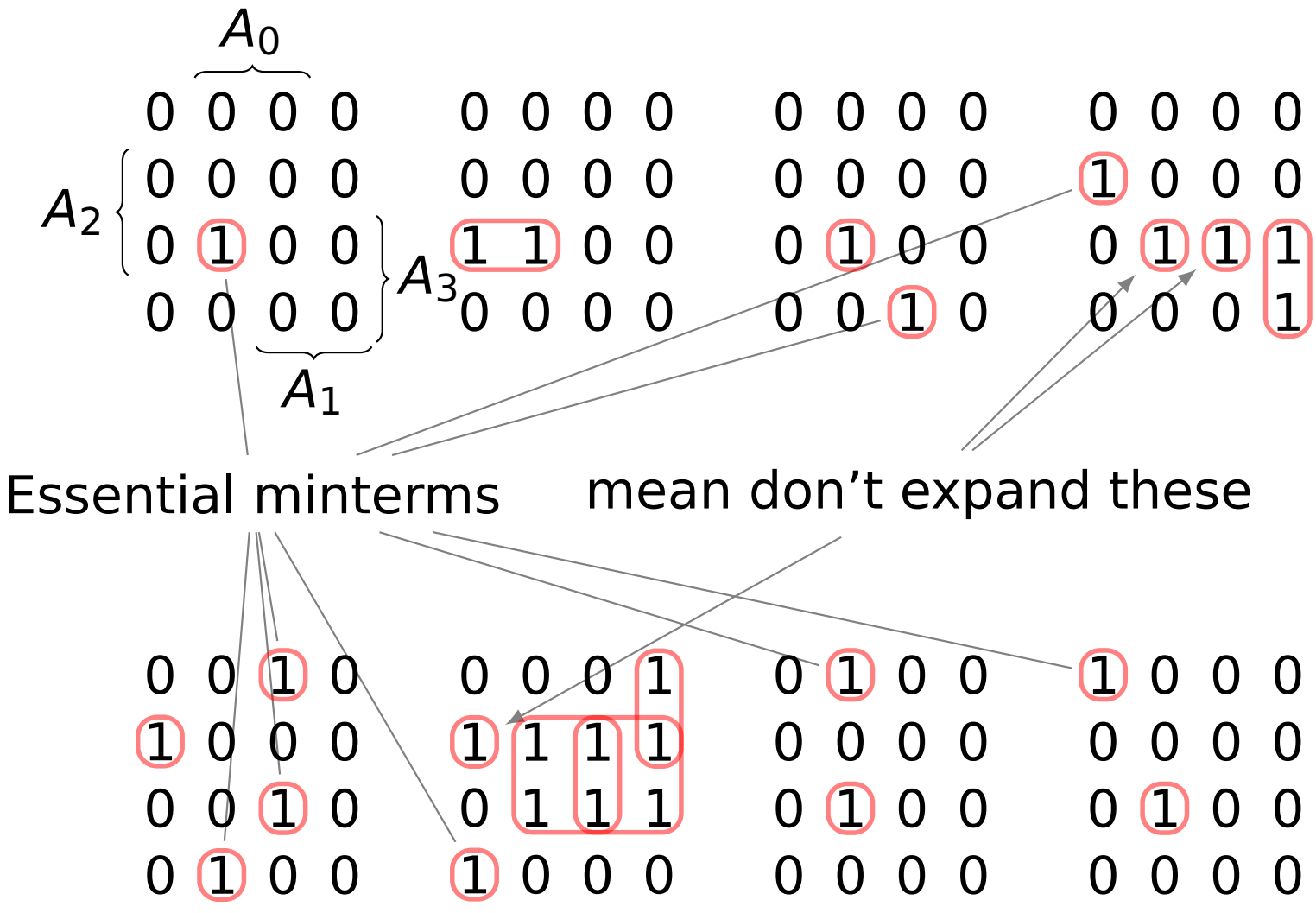
Pattern is programmable = the contents of the ROM

The Space Race ROM

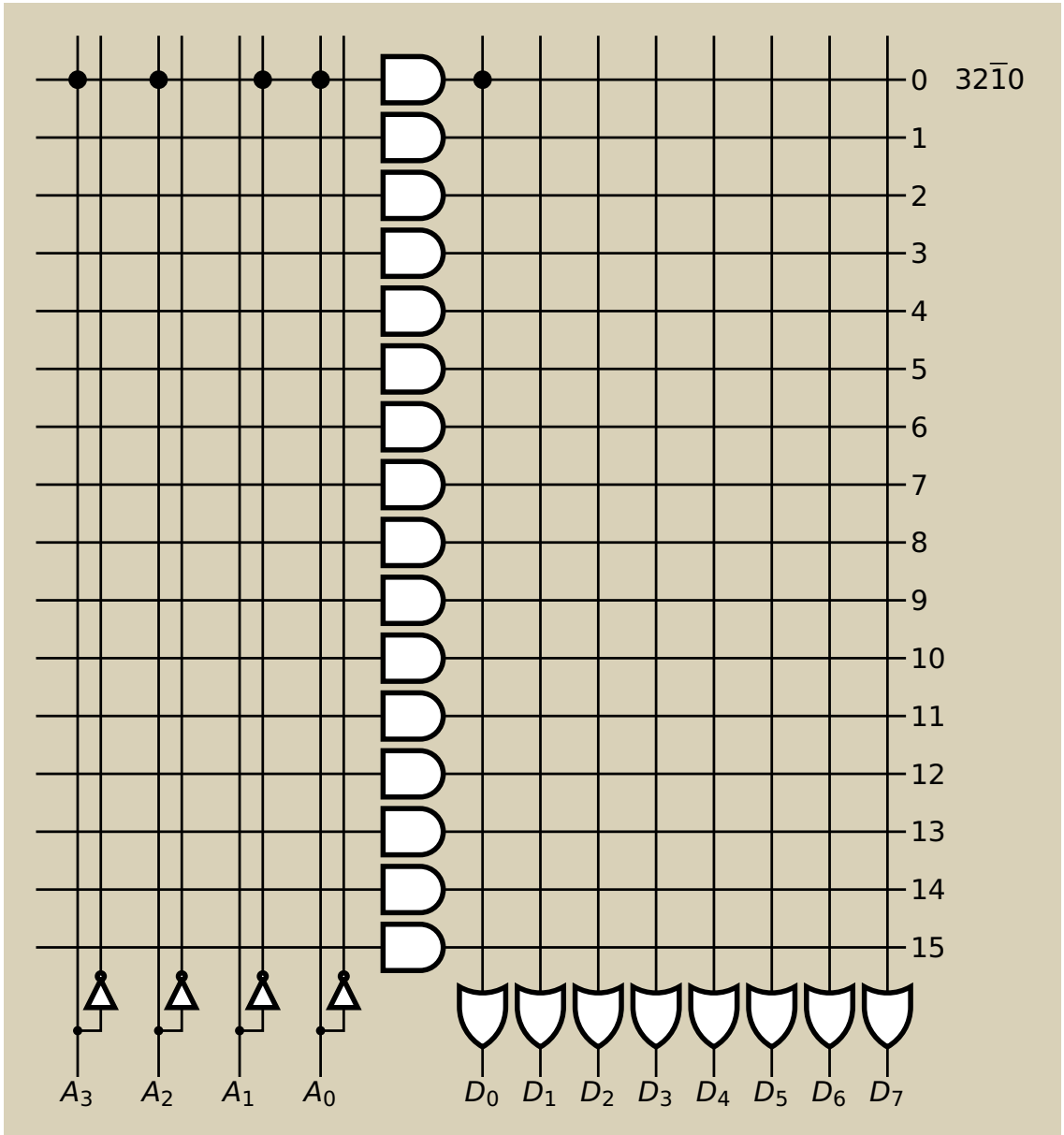


Can we do better?

Simplifying the Space Race ROM (D_0-D_7)

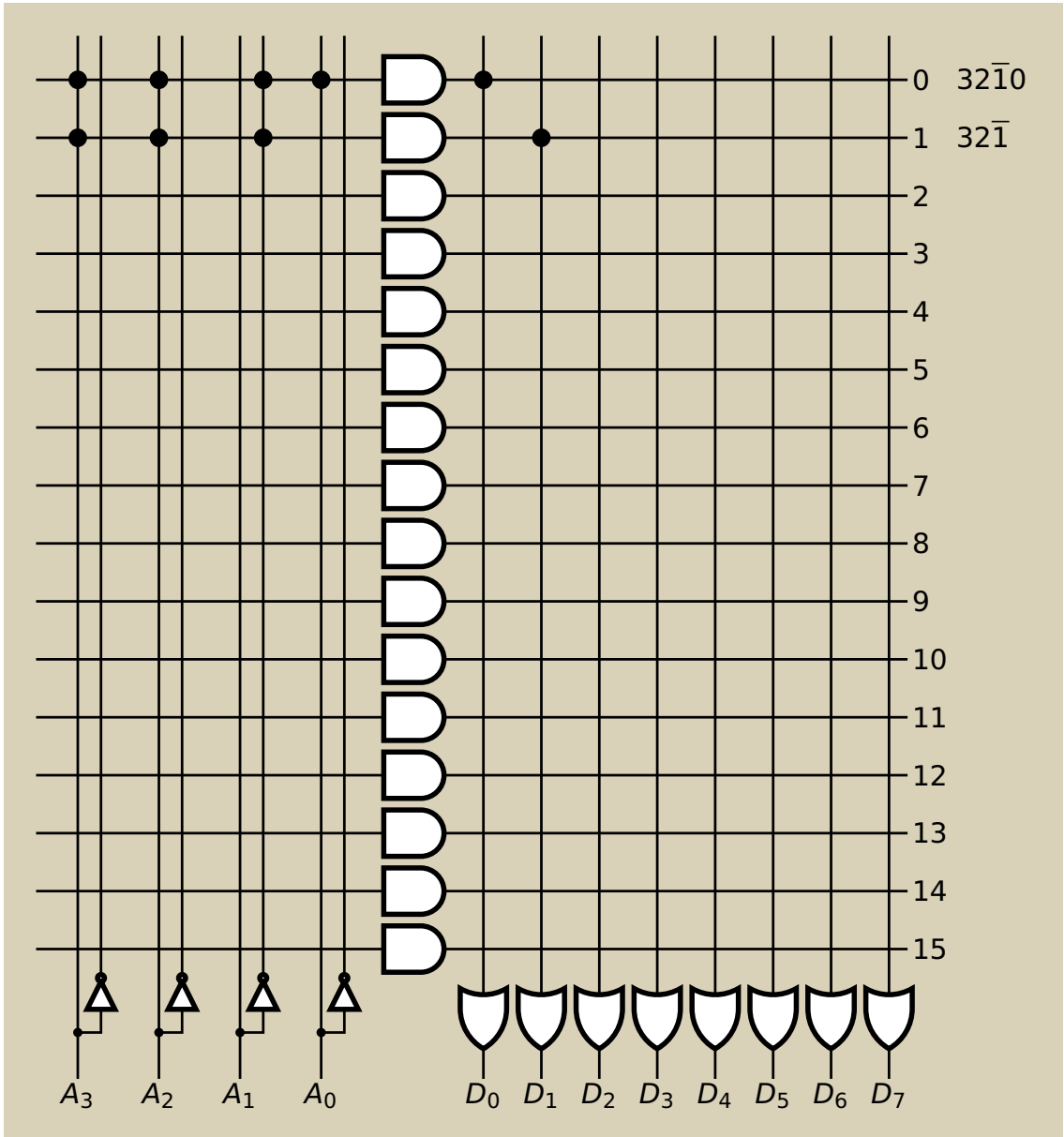


The Space Race ROM – using PAL



$$D_0 = 32\bar{1}0$$

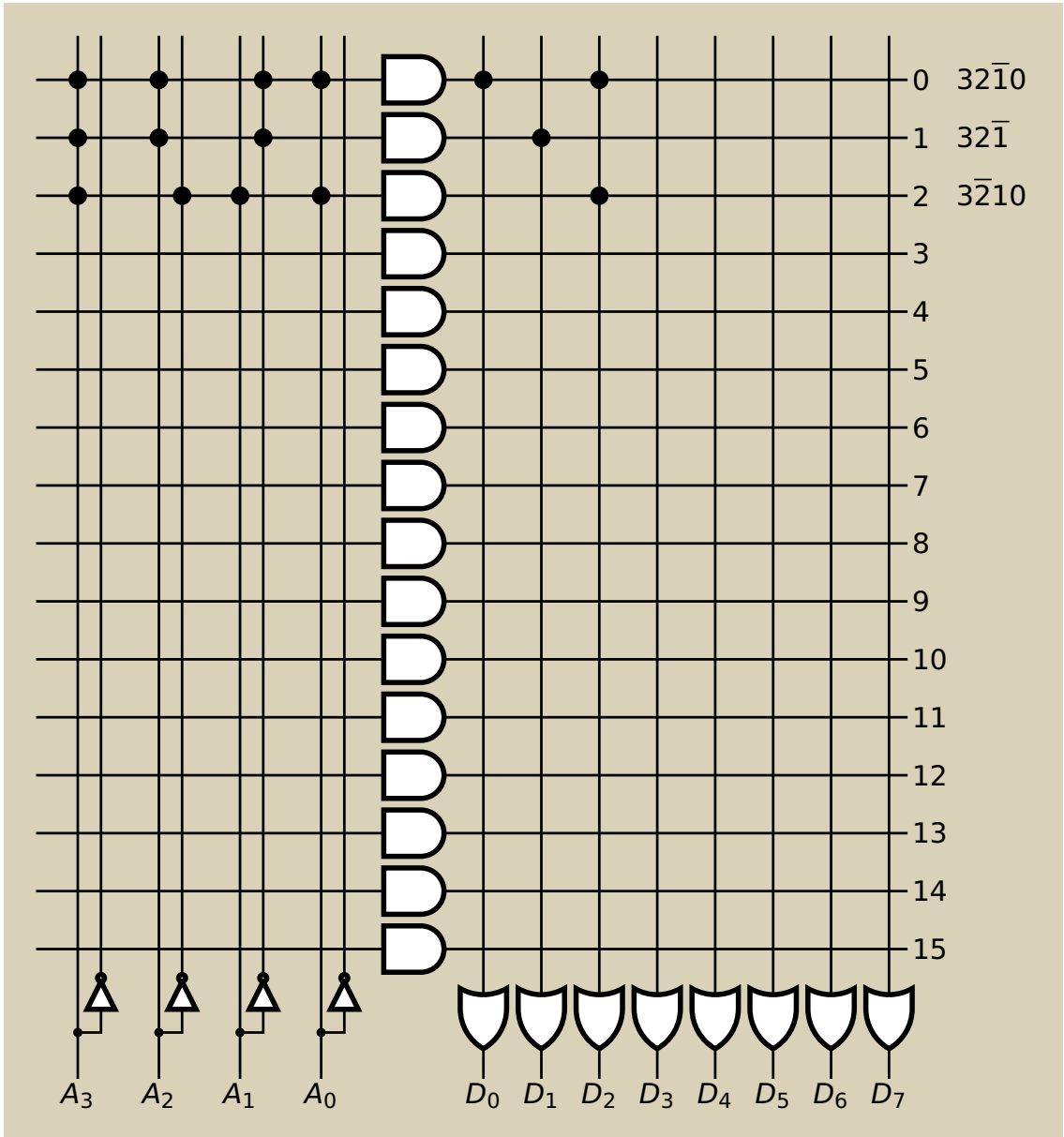
The Space Race ROM – using PAL



$$D_0 = 32\bar{1}0$$

$$D_1 = 32\bar{1}$$

The Space Race ROM – using PAL

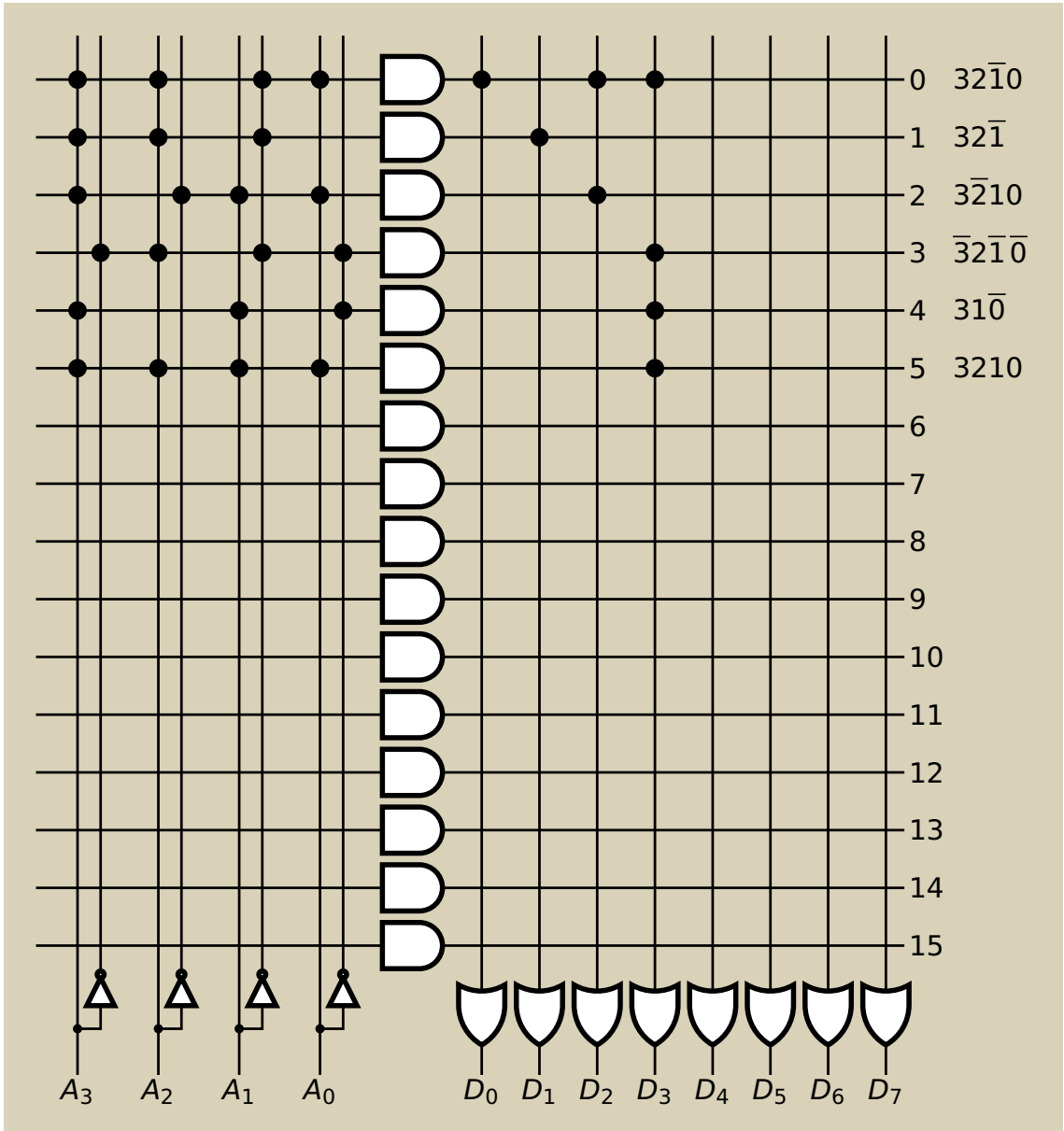


$$D_0 = 32\bar{1}0$$

$$D_1 = 32\bar{1}$$

$$D_2 = 3\bar{2}10 + 32\bar{1}0$$

The Space Race ROM – using PAL



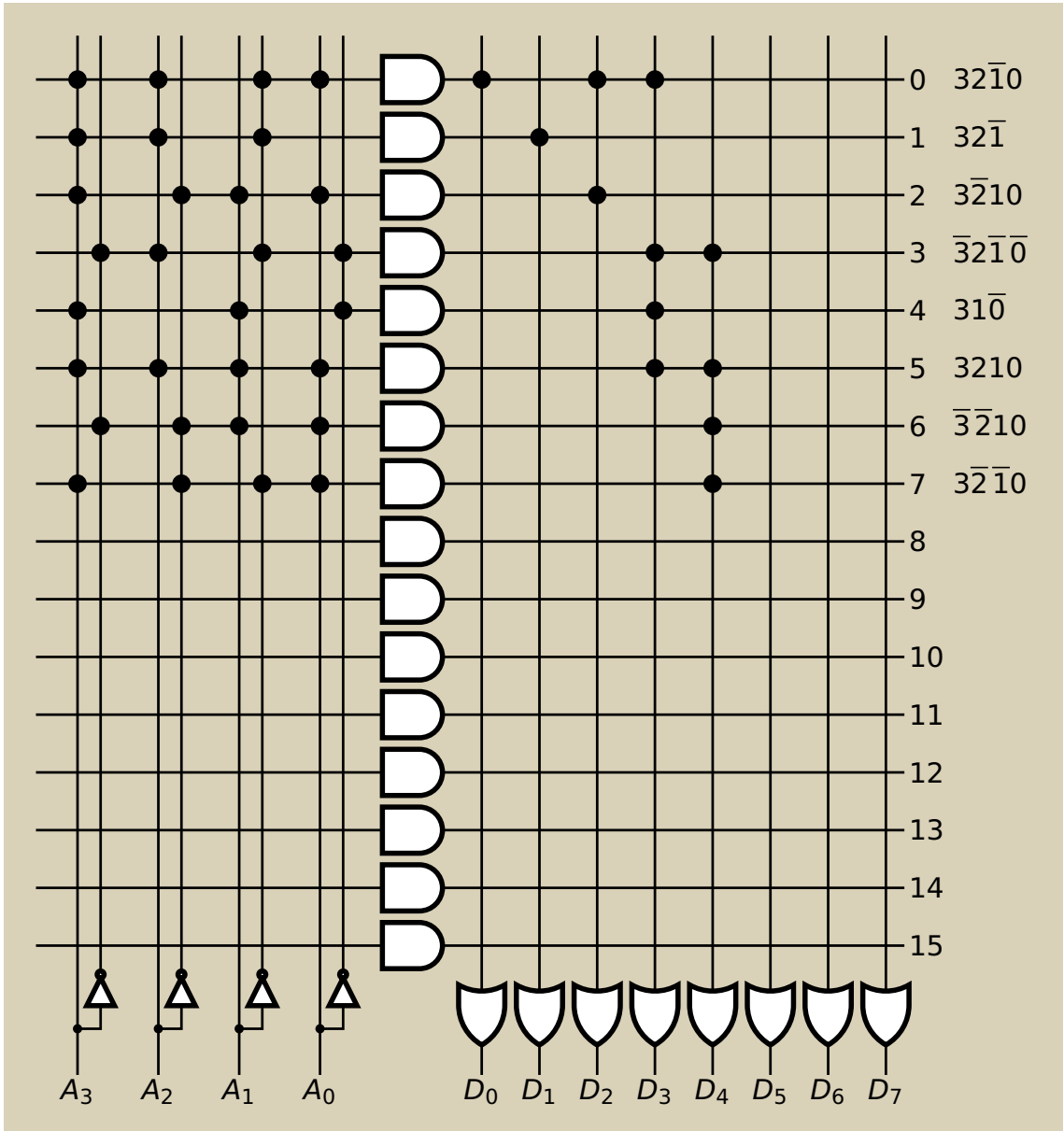
$$D_0 = 32\bar{1}0$$

$$D_1 = 32\bar{1}$$

$$D_2 = 3\bar{2}10 + 32\bar{1}0$$

$$D_3 = \bar{3}2\bar{1}\bar{0} + 31\bar{0} + 32\bar{1}0 + 3210$$

The Space Race ROM – using PAL



$$D_0 = 32\overline{1}0$$

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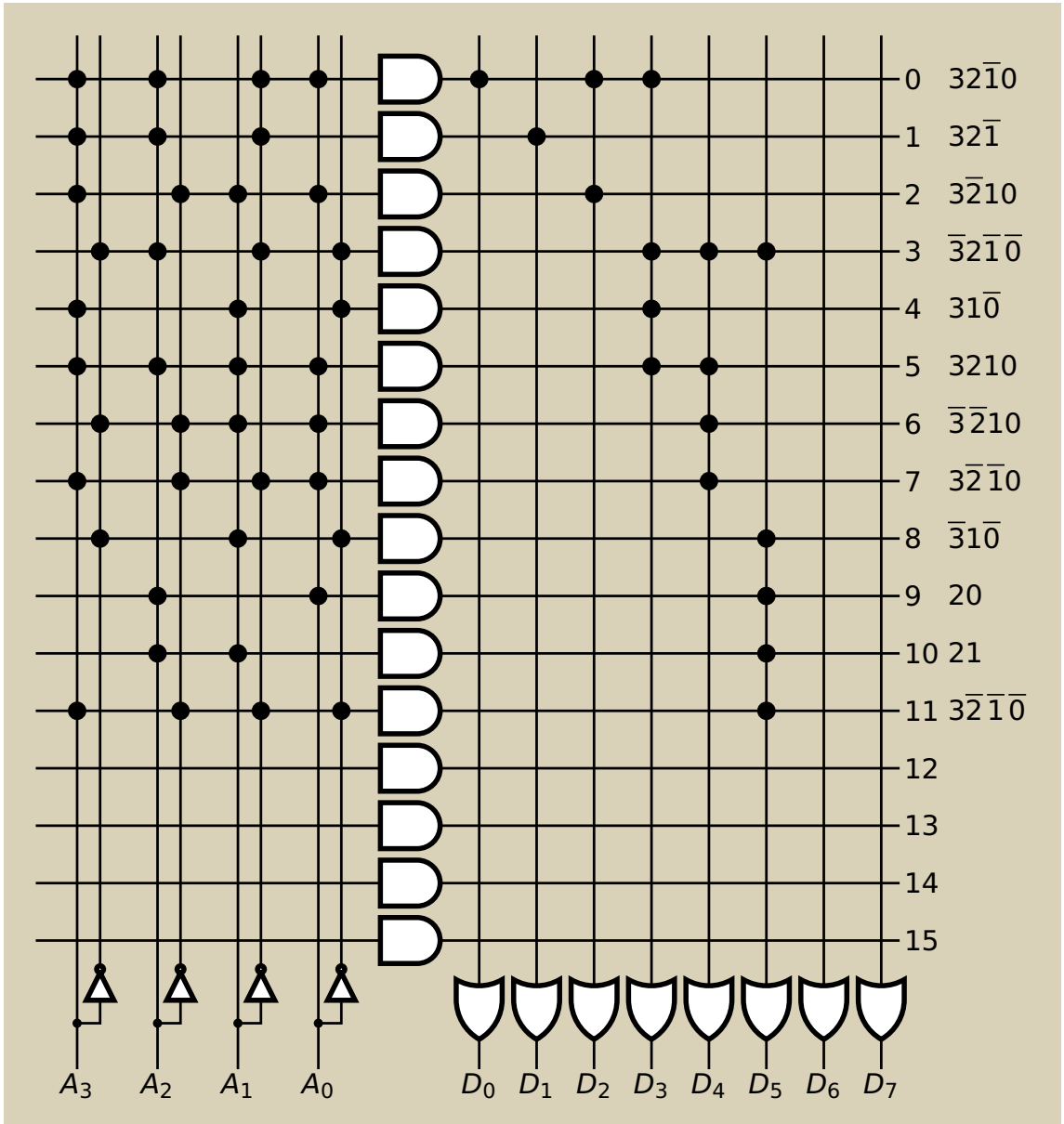
$$D_2 = 3\overline{2}10 + 32\overline{1}0$$

$$D_3 = \overline{3}2\overline{1}\,\overline{0} + 31\overline{0} + 32\overline{1}0 + 3210$$

$$D_4 = \overline{3}\,\overline{2}10 + \overline{3}2\overline{1}\,\overline{0} + 3\overline{2}\,\overline{1}0 + 3210$$

The Space Race ROM – using PAL



$$D_0 = 32\bar{1}0$$

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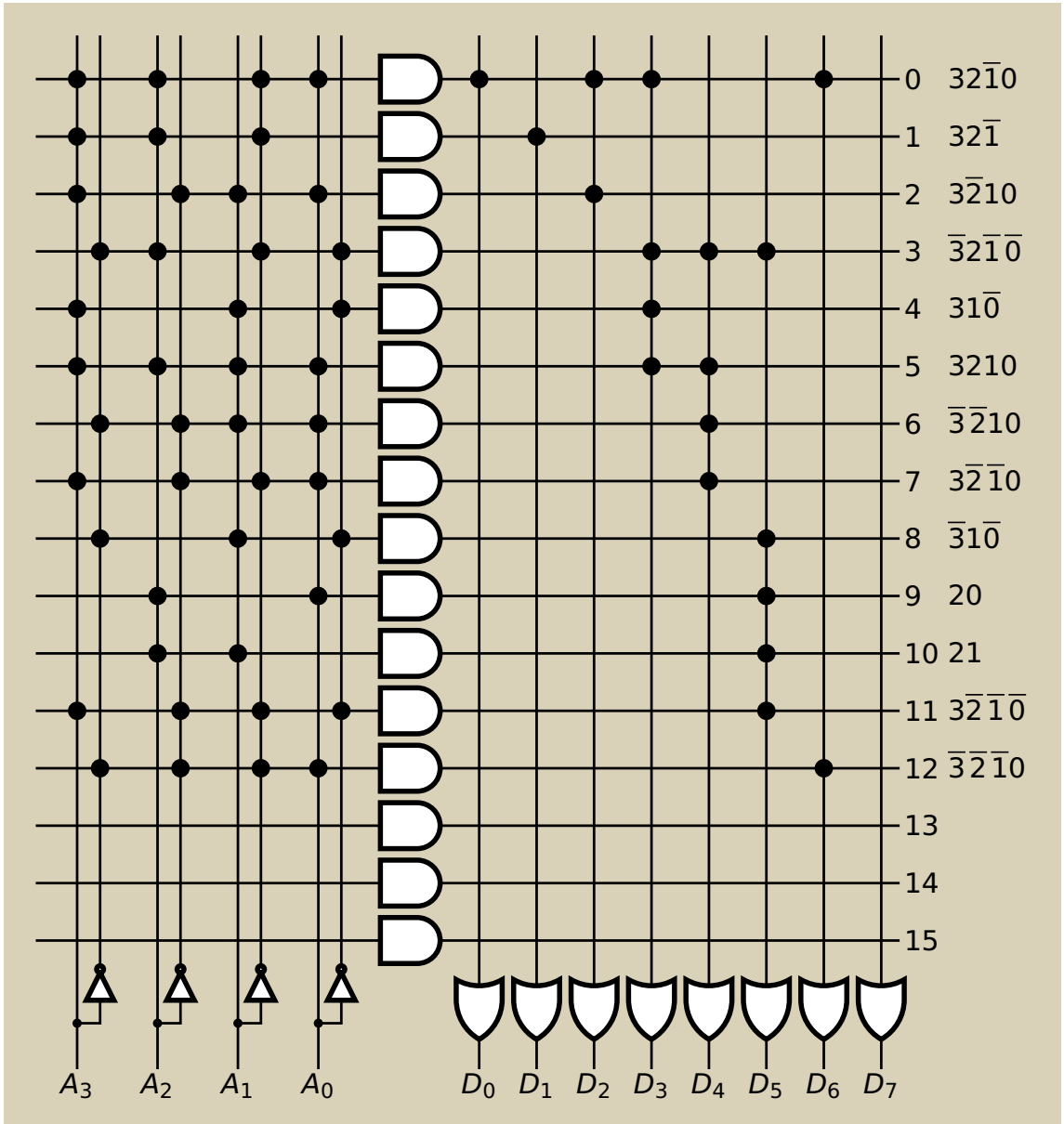
$$D_3 = \bar{3}2\bar{1}\bar{0} + 31\bar{0} + 32\bar{1}0 + 3210$$

$$D_4 = \bar{3}\bar{2}10 + \bar{3}2\bar{1}\bar{0} + 3\bar{2}\bar{1}0 + 3210$$

$$D_5 = \bar{3}1\bar{0} + 20 + 21 + \bar{3}2\bar{1}\bar{0} + 3\bar{2}\bar{1}\bar{0}$$

The Space Race ROM – using PAL



$$D_0 = 32\overline{1}0$$

$$D_1 = 32\overline{1}$$

$$D_2 = 3\overline{2}10 + 32\overline{1}0$$

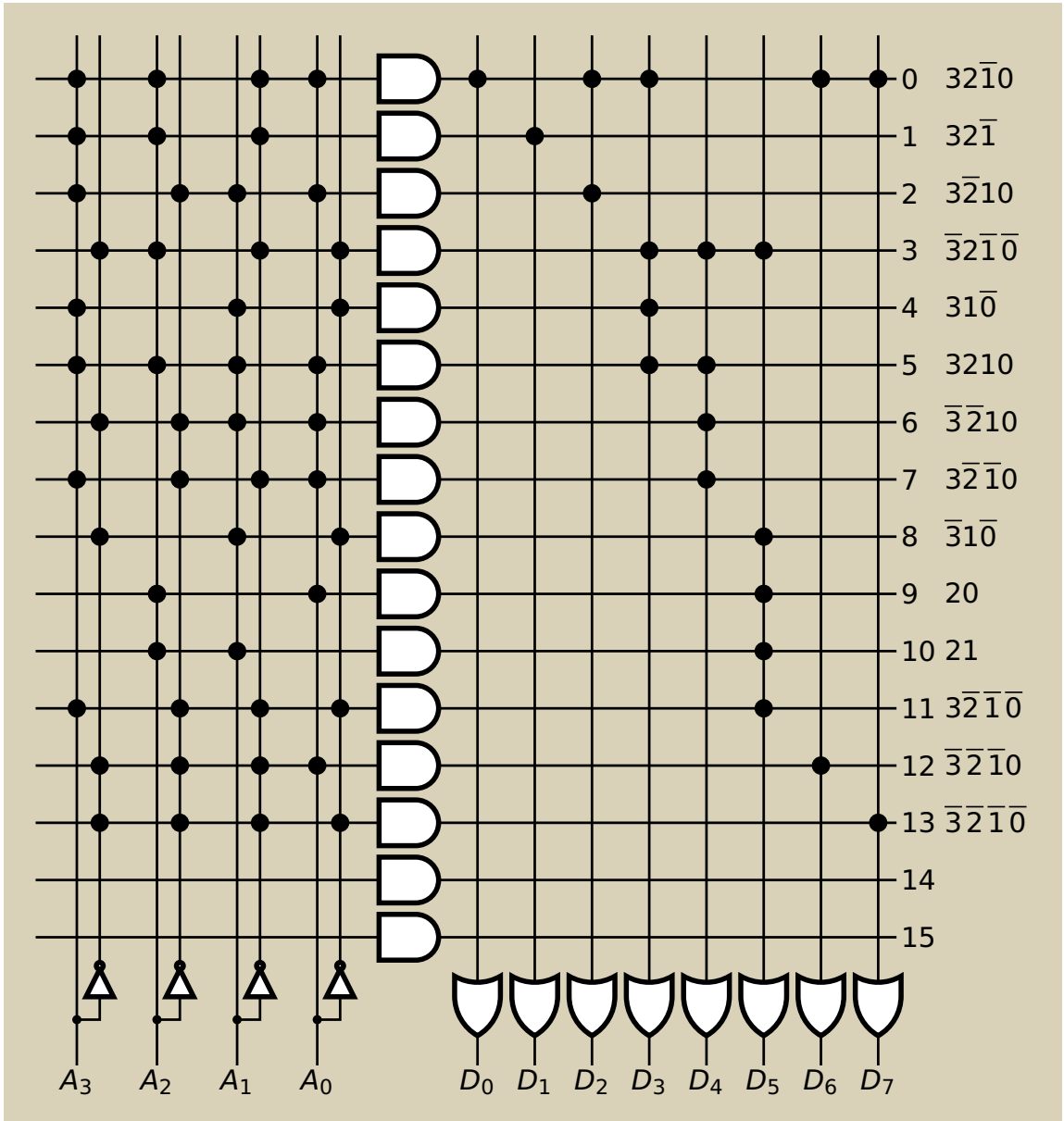
$$D_3 = \overline{3}2\overline{1}\,\overline{0} + 31\overline{0} + 32\overline{1}0 + 3210$$

$$D_4 = \overline{3}\,\overline{2}10 + \overline{3}2\overline{1}\,\overline{0} + 3\overline{2}\,\overline{1}0 + 3210$$

$$D_5 = \overline{3}1\overline{0} + 20 + 21 + \overline{3}2\overline{1}\,\overline{0} + 3\overline{2}\,\overline{1}\,\overline{0}$$

$$D_6 = \overline{3}\,\overline{2}\,\overline{1}0 + 32\overline{1}0$$

The Space Race ROM – using PAL



$$D_0 = 32\overline{1}0$$

$$D_1 = 32\overline{1}$$

$$D_2 = 3\overline{2}10 + 32\overline{1}0$$

$$D_3 = \overline{3}2\overline{1}\,\overline{0} + 31\overline{0} + 32\overline{1}0 + 3210$$

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$$D_6 = \overline{3}\,\overline{2}\,\overline{1}0 + 32\overline{1}0$$

$$D_7 = \overline{3}\,\overline{2}\,\overline{1}\,\overline{0} + 32\overline{1}0$$

Saved two ANDs

Field-Programmable Gate Arrays (FPGAs)