Warmup

Use a k-map to find a minimal implementation of this truth table:

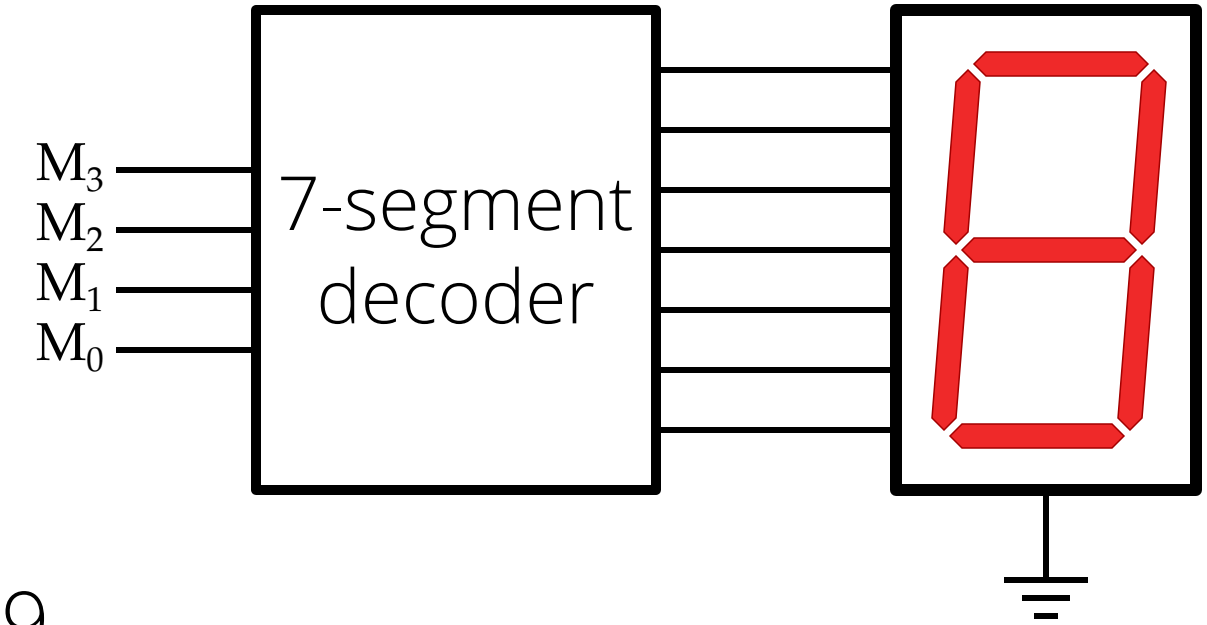
A	B	C	D	Y
0	0	0	0	0
0	0	0	1	0
0	0	1	0	1
0	0	1	1	1
0	1	0	0	0
0	1	0	1	0
0	1	1	0	1
0	1	1	1	1

A	B	C	D	Y
1	0	0	0	0
1	0	0	1	1
1	0	1	0	0
1	0	1	1	1
1	1	0	0	0
1	1	0	1	1
1	1	1	0	0
1	1	1	1	1

Respond at **pollev.com/stevenbell**

Preview of lab 4

4-bit binary number

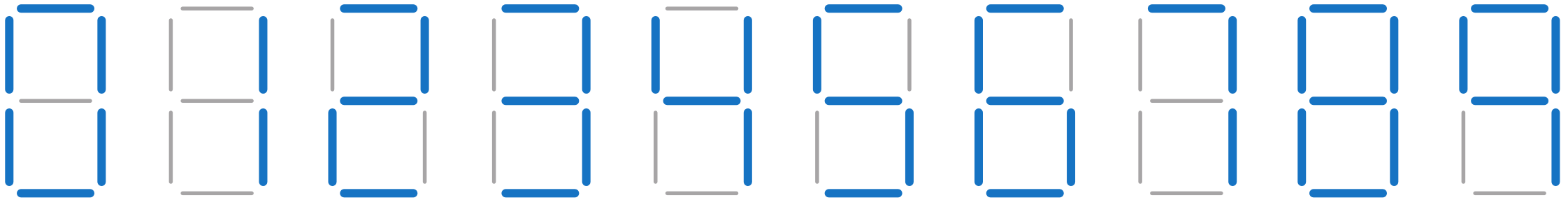


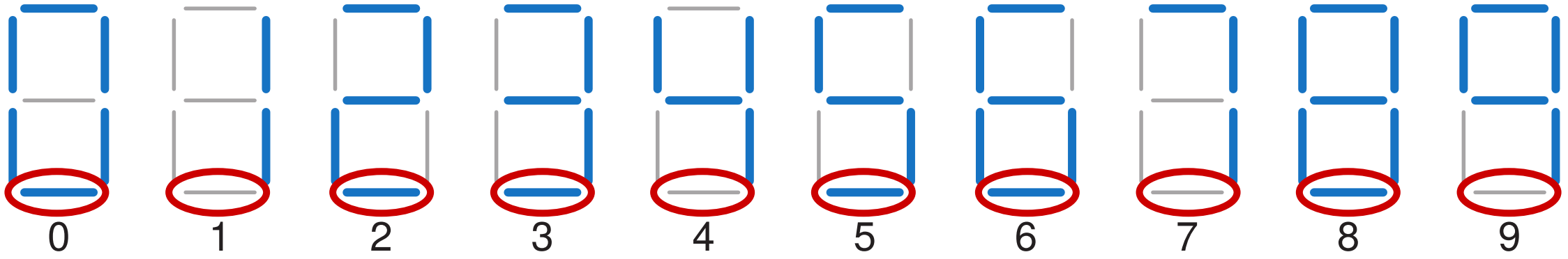
1 0 0 1 = 9

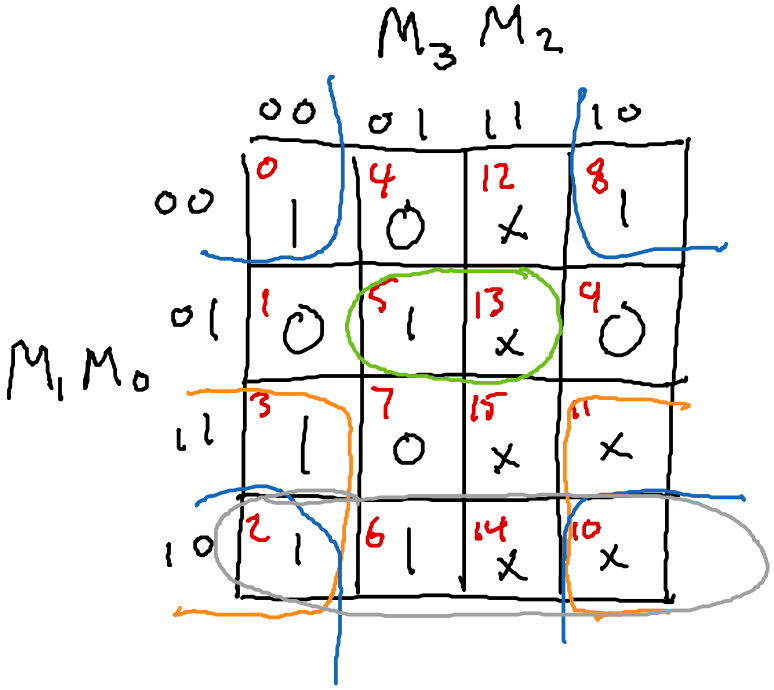
M_3 M_2 M_1 M_0 $8M_3+4M_2+2M_1+M_0$

Most siginficant bit (MSB)

Least siginficant bit (LSB)


0
1
2
3
4
5
6
7
8
9





$M_2 \overline{M_1} M_0$

$\overline{M_2}\ \overline{M_0}$

ES 4: Multiplexers and FPGAs

Steven Bell

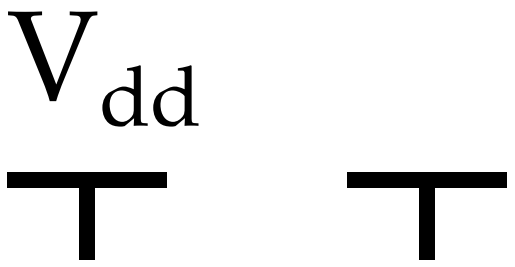
22 September 2021

Tufts UNIVERSITY

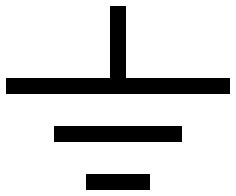
By the end of class today, you should be able to:

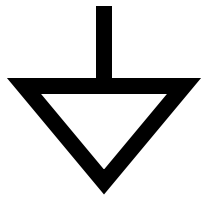
- Explain what a multiplexer is
- Draw a logic diagram using a 2^N-input multiplexer to implement an N-variable or (N+1)-variable boolean equation
- Describe the basic structure of an FPGA

Some schematic terminology



VDD 5V HIGH **1**

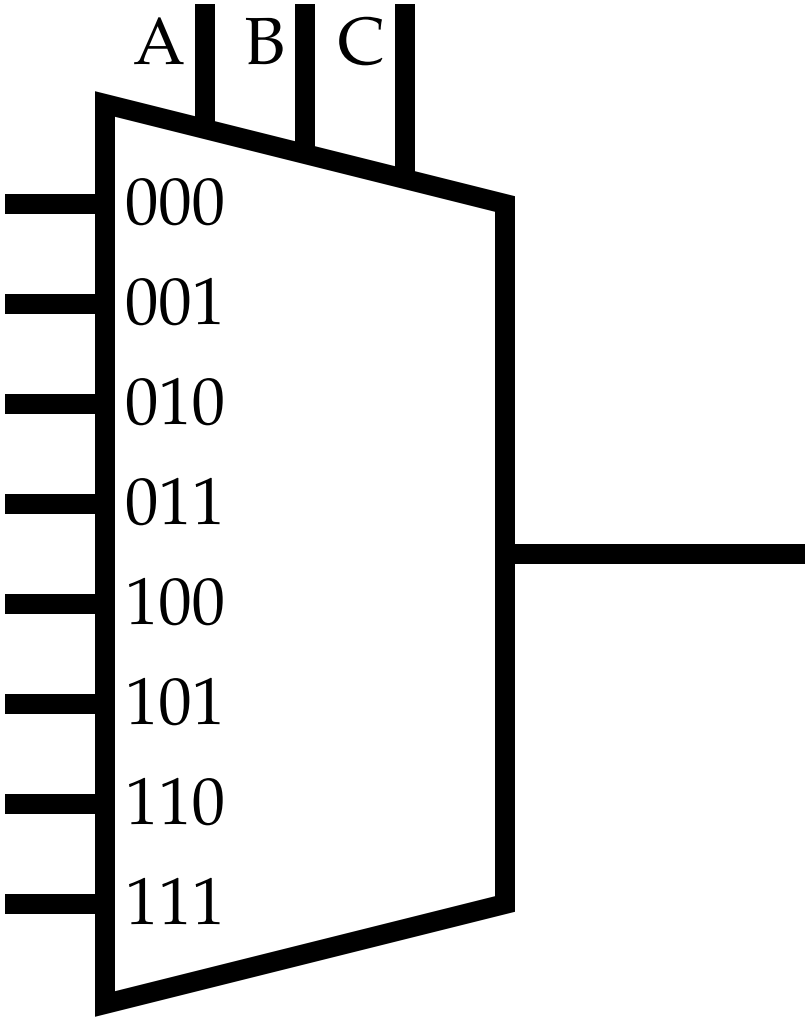




Ground 0V LOW **0**

Multiplexers

Select one of 2^N inputs based on the binary value of N control wires

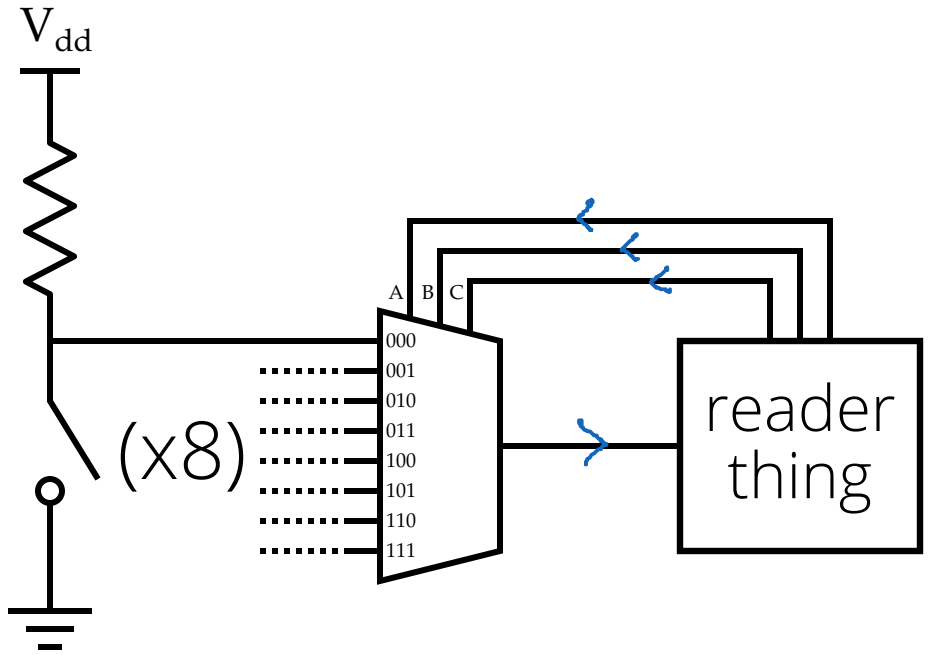


What good are multiplexers?

1) Allow you to select (or control) one signal out of many

A practical example

Suppose you want to read 8 switches
but you only have 4 inputs/outputs.



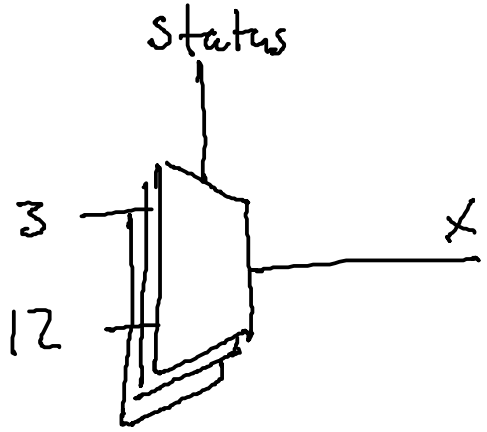
What good are multiplexers?

1) Allow you to select (or control) one signal out of many

1B) Allow you to make a choice based on a control value

It's like an **`if`** or **`case`** statement in software

```
if (status == 1){
   x = 12;
} else {
   x = 3;
}
```



What good are multiplexers?

1) Allow you to select (or control) one signal out of many

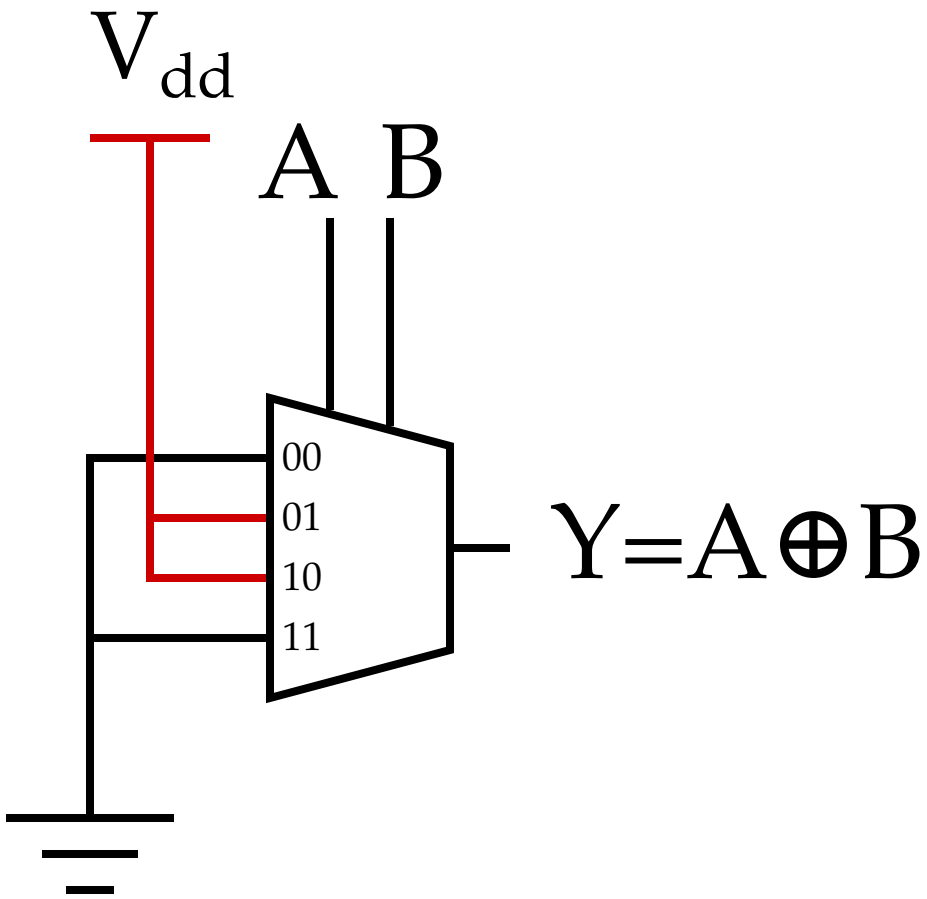
1B) Allow you to make a choice based on a control value

It's like an `if` or `case` statement in software

2) Make it easy to implement arbitrary logic functions

Implementing XOR

Using a mux as a look-up table (LUT)



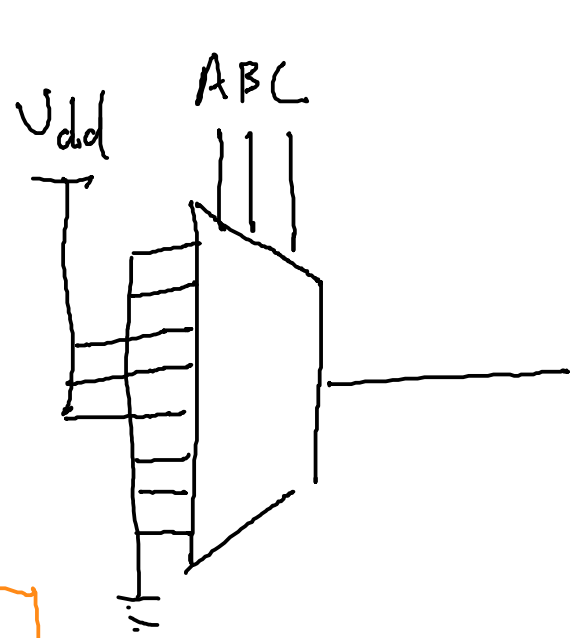
Multiplexer practice 1

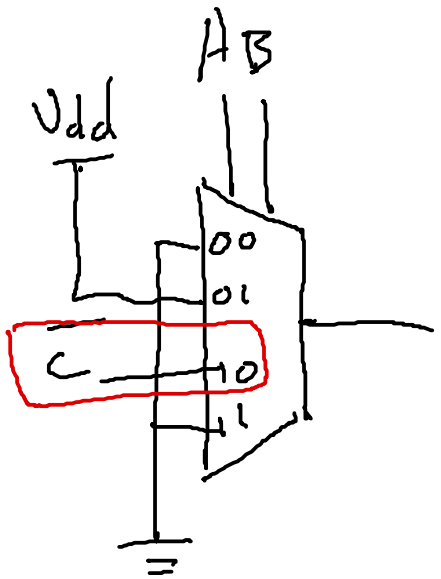
Implement this logic equation using

1) 8:1 multiplexer
2) 4:1 multiplexer

$$Y=\overline{A}B+A\overline{B}\overline{C}$$

A	B	C	$\overline{A}B$	$A\overline{B}\overline{C}$	
0	0	0	0	0	
0	0	1	0	0	
0	1	0	1	0	
0	1	1	1	0	
1	0	0	0	1	1
1	0	1	0	0	0
1	1	0	0	0	
1	1	1	0	0	





Implement a 2-bit adder with multiplexers (Prelab 3)

How are you feeling about multiplexers?

Respond at **pollev.com/stevenbell**

Will a time come when it's cheaper to use a microprocessor than to implement something with discrete logic gates?

iCE40UP block diagram

Clock stuff

Fixed-function multipliers

Memory

Logic "fabric"

Fixed-function I/O modules

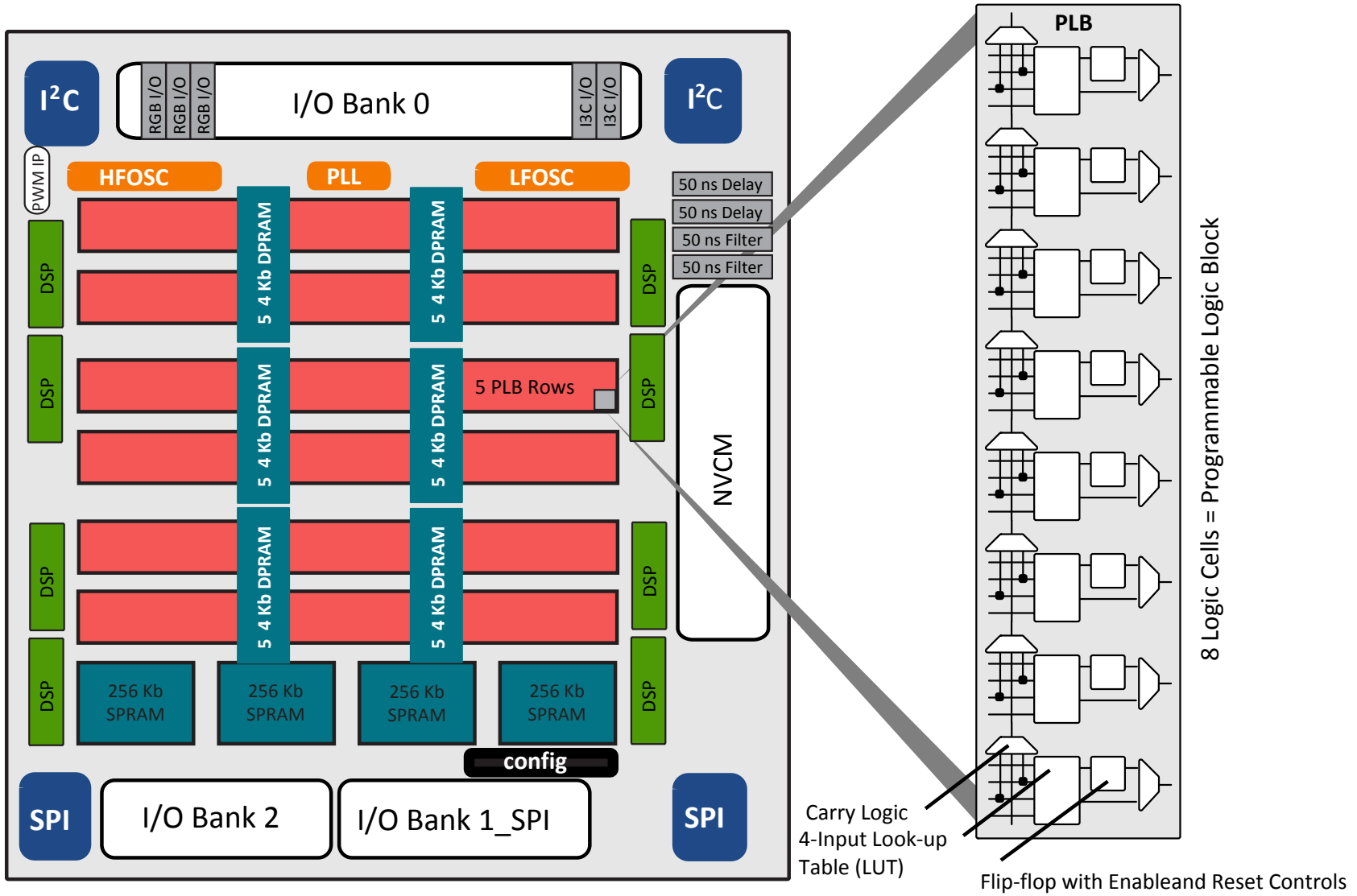


Figure 3.1. iCE40UP5K Device, Top View

iCE40UP logic element

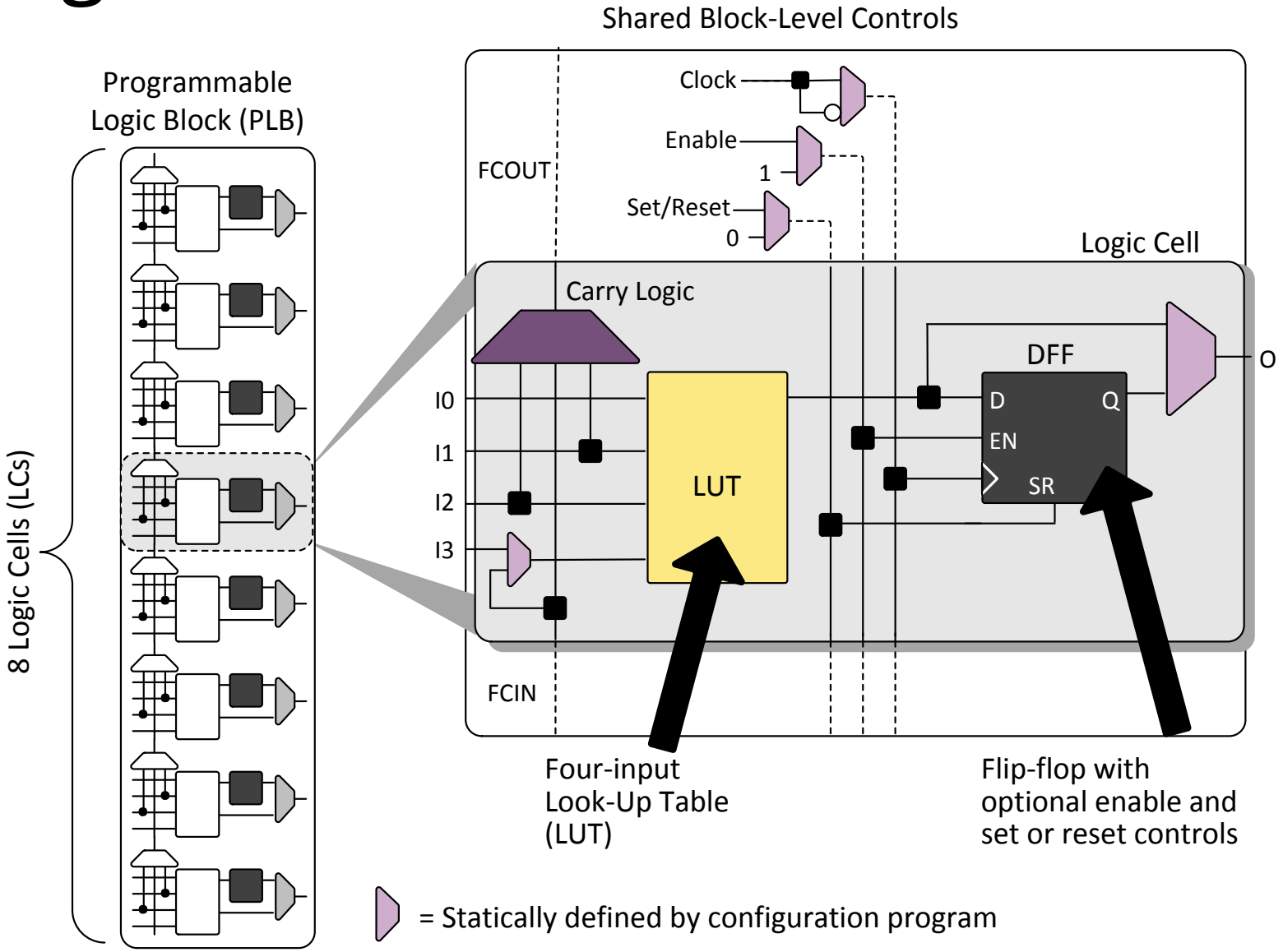


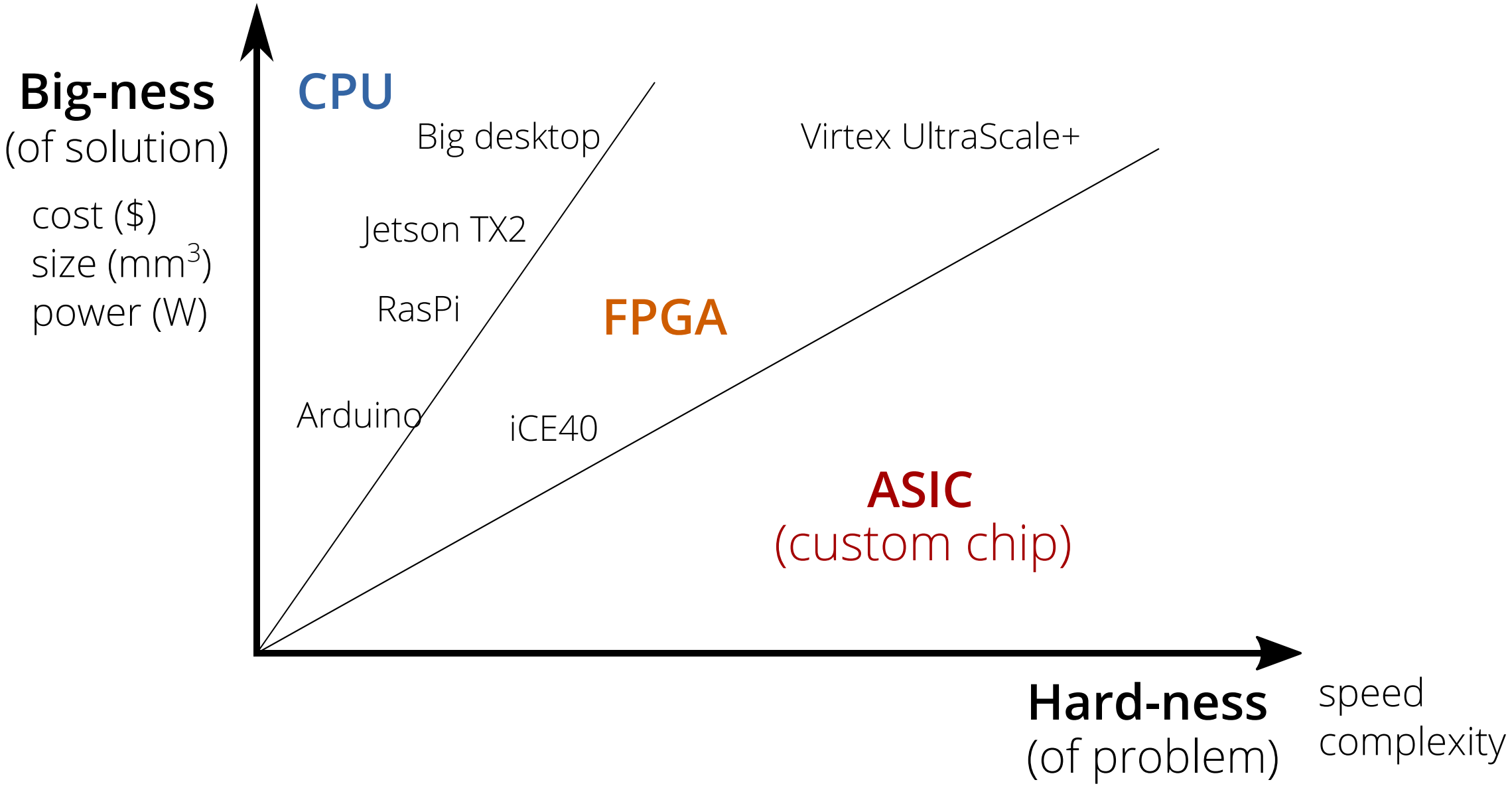
Figure 3.2. PLB Block Diagram

What is one question you have after today's class?

Respond at **pollev.com/stevenbell**

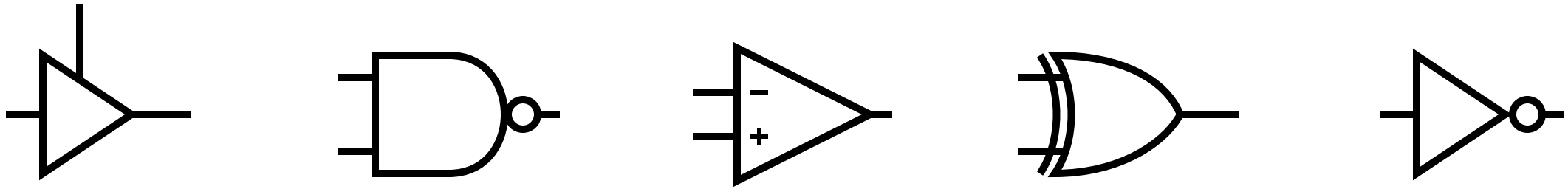
For Wednesday

1. Read the book (2.9) and complete the reading check
2. Lab 2 report is due next week at your lab time
   See the video and handout (posted tonight) on the course website
3. Prelab 3 is due next week 24 hours before your lab time
4. Homework 2 (posted today) will be due next Wednesday (9/29)


Big-ness
(of solution)
cost ($)
size (mm3)
power (W)
CPU
Big desktop
Jetson TX2
RasPi
Arduino
FPGA
iCE40
Virtex UltraScale+
ASIC
(custom chip)
Hard-ness
(of problem)
speed
complexity

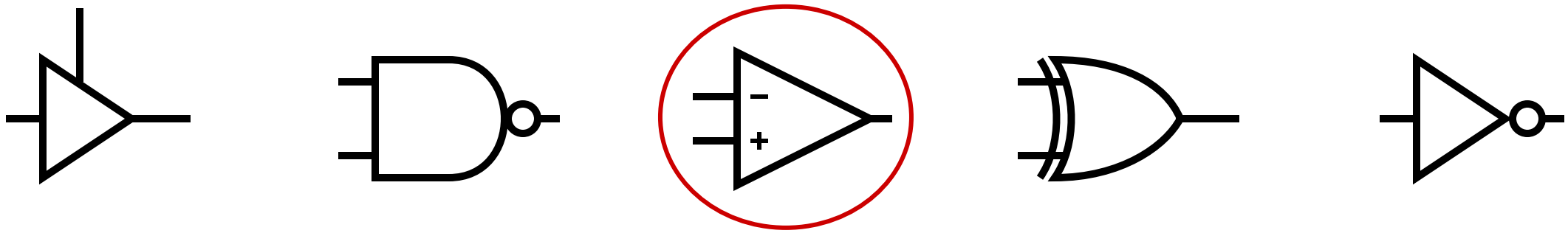
Terminology

Which of these is not a digital circuit element?



Terminology

Which of these is not a digital circuit element?



This is an op-amp!