

# **CSE 2600**

# **Intro. To Digital Logic & Computer Design**

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# Announcements

- Homework 1: Returned in a few days
  - Can request “regrade” of problems for ~1 week on assignments  
Not accepted after that.
- Homework 3A Posted / Due Sunday at 11:59pm

# Chapters 1-2: Combinational Logic

- (Purely) combines current inputs to produce output
  - Doesn't depend on past inputs
  - Can be represented with a simple table
  - One-way: Doesn't have any feedback paths from output back to inputs

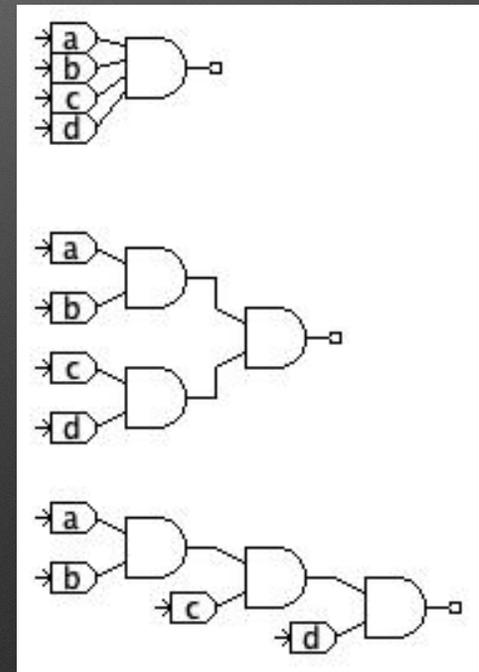


# Big-Picture So Far...

- We can build reliable, complex machines that work in binary
  - Yay Transistors!
- We can represent almost any information via binary encodings
  - Integers: We can even easily do arithmetic operations (+, -, etc.)
  - Letters/characters, “real” numbers, etc.

# Big-Picture So Far...

- Gates: We can represent some primitive binary “machines” via a symbolic notation. Structure shows the flow of information.



# Big-Picture So Far...

- Almost any simple mapping (function) can be represented via a table
- Show the “output” for all possible combinations of inputs

INPUTS (IN BINARY)	OUTPUTS (IN BINARY)
...	...

# Big-Picture So Far...

- Any full table can be converted to a boolean logic equation

Inputs		Output
S	I	O
0	0	
0	1	
0	2	
0	3	
1	0	
1	1	
1	2	
1	3	

# Big-Picture So Far...

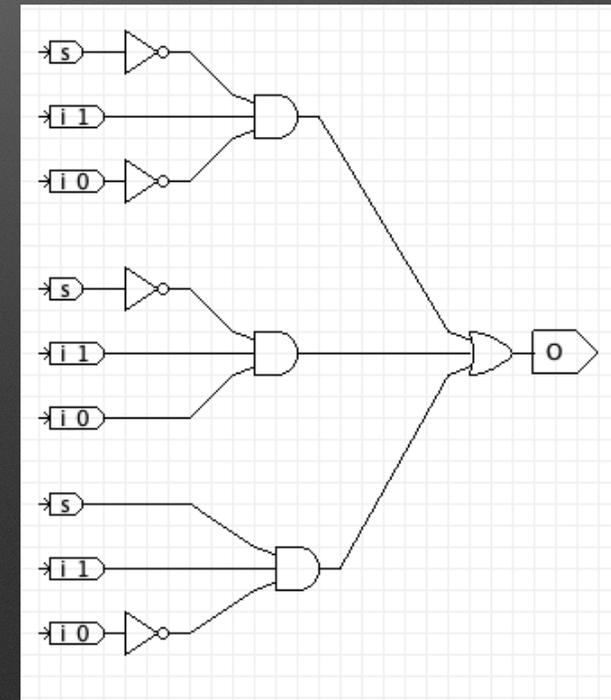
- Any full table can be converted to a sum-of-products (SOP) boolean equation

Inputs			Output
S	I <sub>1</sub>	I <sub>0</sub>	O
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	0
1	0	1	0
1	1	0	1
1	1	1	0

$$\bar{S} \cdot I_1 \cdot \bar{I}_0$$

$$\bar{S} \cdot I_1 \cdot I_0$$

$$S \cdot I_1 \cdot \bar{I}_0$$



# Big-Picture So Far...

- Any mapping/function that combines current inputs to produce the output could be described as a table
  - The table could be turned into equations
  - The equations could be made into machines
- Works on small problems, but table is too large for many problems
  - Ex: Add 2, 32-bit numbers:
    - Table with 64 columns of input
    - 18446744073709551616 rows in that table...

# Studio 2B Recap

- Karnaugh Maps
  - Cells represent minterms
  - Combining cells is application of Theorem 10:  $(B \cdot C) + (B \cdot \bar{C}) = B$
  - Only works if rows and columns are in Gray code order

# Studio 2A: Example

- Small tables can be represented via K-Maps

Inputs			Output
S	I <sub>1</sub>	I <sub>0</sub>	O
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	0
1	0	1	0
1	1	0	1
1	1	1	0

	I			
S	00	01	11	10
0				
1				

# Studio 2A: Example

- K-Maps represent SOP equations

	I			
S	00	01	11	10
0	0	0	1	1
1	0	0	0	1

# Studio 2B Misc.

- Negation Notation
  - $\overline{AB}$  vs.  $\overline{A} \cdot \overline{B}$ 
    - $\overline{A} \cdot \overline{B} = \overline{AB}$
- Glitches: ... a single input transition can cause multiple output transitions.
  - Often a result of different delays in a path
  - Example
- Packages & Packages

# Getting Loopy

- “Iterative” computations are common
  - Accumulation pattern (as pseudo-code):

```
sum = 0
for i=0..length(A)
    sum = sum + A[i]
```
  - Signal processing / filters
  - “Location” (state) tracking:  
where I am now = f(where I was in past, decisions)

**Goal: Stable (Synchronized) Behavior**

**Another Goal: Store Data**

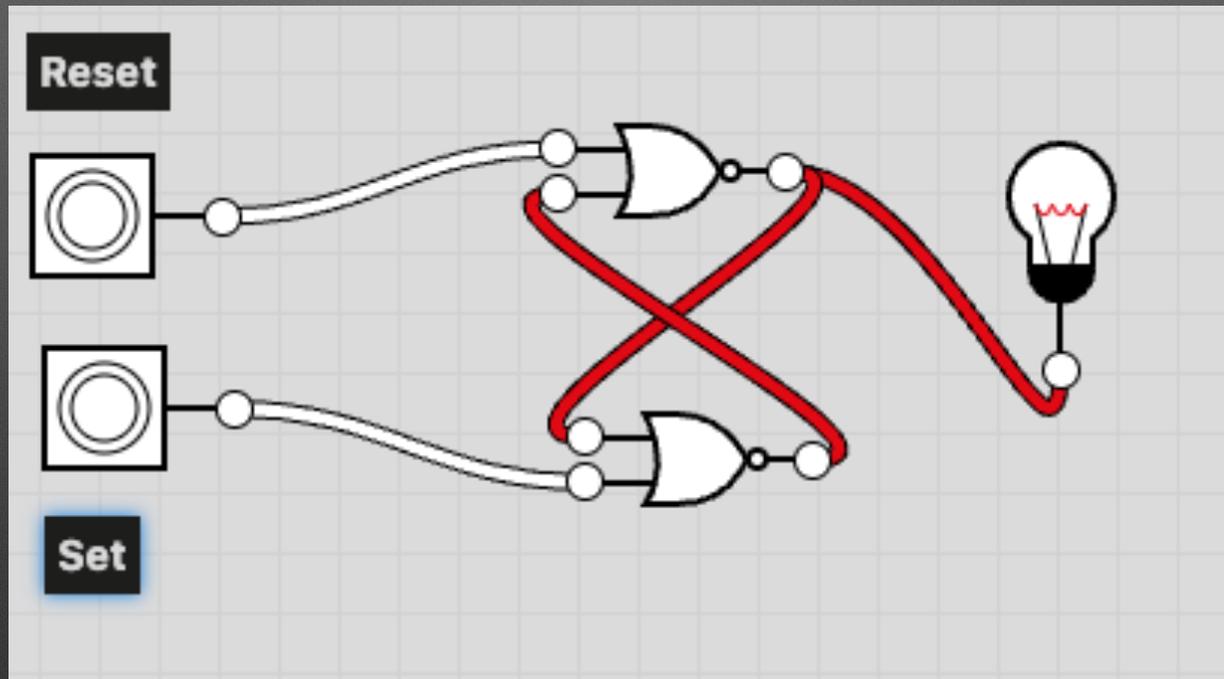
# Examples

- Bistable Example 1: Inverters
- Bistable Example 2A: Inverters & some control
- Bistable Example 2B: Inverters, control, and ...

# Stable, Reinforcing Setup: SR Latch

- On-line Demo: <https://logic.ly/>
  - Bistable: Two stable configurations
- Goal: Met!
  - S=Set, R=Reset

# SR Latch



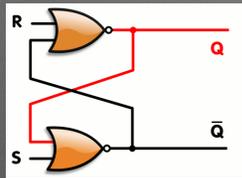
# Story Time: Latches+

# Goal: Store Data

- Set/Reset is *inconvenient*
  - We want something like,  $\text{data} = X$ , where  $x$  is 0 or 1 (store  $X$ , not “set or reset data based on  $X$ ”)
  - We want to store  $X$  in data *when we're ready to!*
- *Clock (Clk)*: Indicates *when* we want to change the data

# D-Latch

- Start with SR Latch

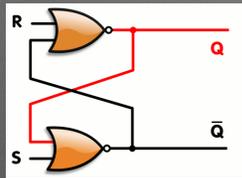


- Describe Desired Behavior (of output, Q)

CLOCK	DATA	Q
0	0	(Unchanged)
0	1	(Unchanged)
1	0	0
1	1	1

# D-Latch

- Start with SR Latch

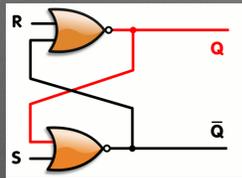


- Describe Desired Behavior (of output, Q)

CLOCK	DATA	Q
0	0	$Q_{prev}$
0	1	$Q_{prev}$
1	0	0
1	1	1

# D-Latch

- Start with SR Latch

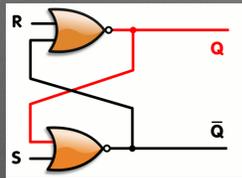


- Describe Desired Behavior (of output, Q)

CLOCK	DATA	Q
0	0	$Q_{prev}$
0	1	$Q_{prev}$
1	0	RESET
1	1	SET

# D-Latch

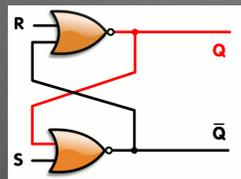
- Start with SR Latch



- Describe Desired Behavior (of output, Q)
- Just combinational logic

CLOCK	DATA	Q
0	0	$Q_{prev}$
0	1	$Q_{prev}$
1	0	RESET
1	1	SET

# D-Latch



- Start with SR Latch
- Describe Desired Behavior (of output, Q)
- Just combinational logic
- Reset = Clock \* /Data  
Set = Clock \* Data

CLOCK	DATA	Q
0	0	$Q_{prev}$
0	1	$Q_{prev}$
1	0	RESET
1	1	SET

# Updates: D-Latch



# D-Latch

- “Latches on” to last data value when clock goes low
  - Is sensitive to the level of the clock
  - Is “transparent” when the clock is high

# Goal: Store Data

- D-Latch is *still* a bit *inconvenient*
  - We'd like something like a (simple) camera
  - The instant shutter is “pressed” we capture data *at that exact instant* (no transparent phase)

# Flip-Flop

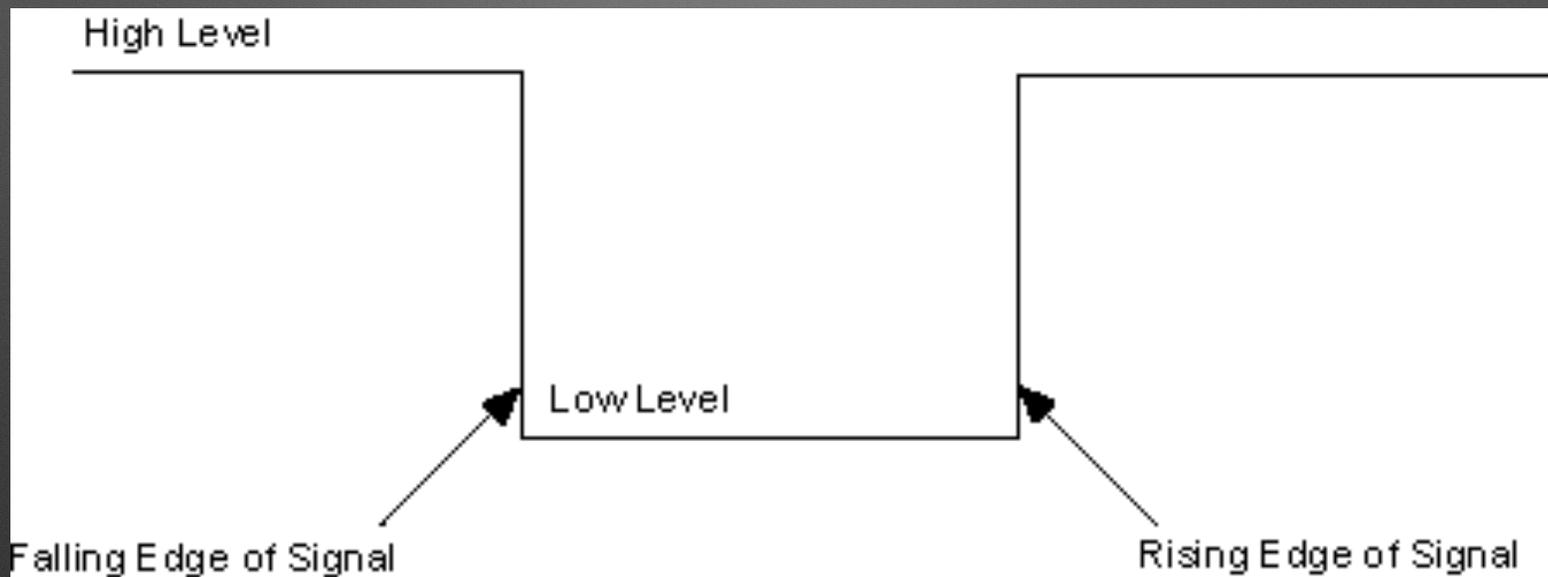


<https://openclipart.org/detail/288726/flip-flops-4>

# D Flip-Flop

- Two D-Latches with clocks in opposite states (via an inverter)
  - First stage: Transparent when clock is Low
  - Second stage: Transparent when clock is High
  - Effect: Capture D at precise instant clock goes from low to high
    - I.e. the clock EDGE
    - Edge triggered. Specifically, Rising Edge Triggered

# Signal Edges

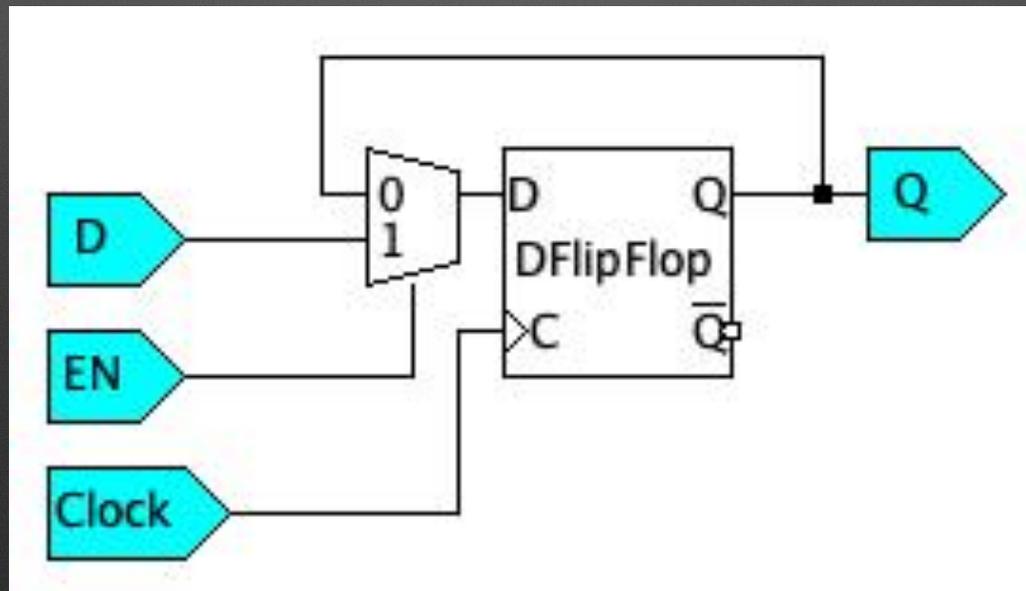


[https://www.ni.com/docs/en-US/bundle/ni-hsdio/page/hsdio/fedge\\_trigger.html](https://www.ni.com/docs/en-US/bundle/ni-hsdio/page/hsdio/fedge_trigger.html)

# Updates: D-Flip-Flop

# “Enable”

- We may want to have two things control timing: the clock and an enable
- Ex:  $X[0] = 1$  (in a program) . We only want to modify  $X$  *when that line runs*.



# Chapter 3: Sequential & Synchronous Logic

- Need to know sequence of inputs
  - Can't be represented with a *simple* table of just inputs and outputs (Possibly a complex table that includes some representation of history of inputs and outputs)
- Text: "Some sequential circuits are just plain kooky"

# Synchronous\* Sequential Circuits

- Are synchronized by a common clock
- Uses registers (D Flip Flops)
- Mix of registers and combinational logic
- Cycles in circuit include at least one register
- Goal: Impose predictable behavior!

\* eliminates the “kooky”

# Synchronous\* Sequential Circuits

- The Adder loop – revisited

\* eliminates the “kooky”

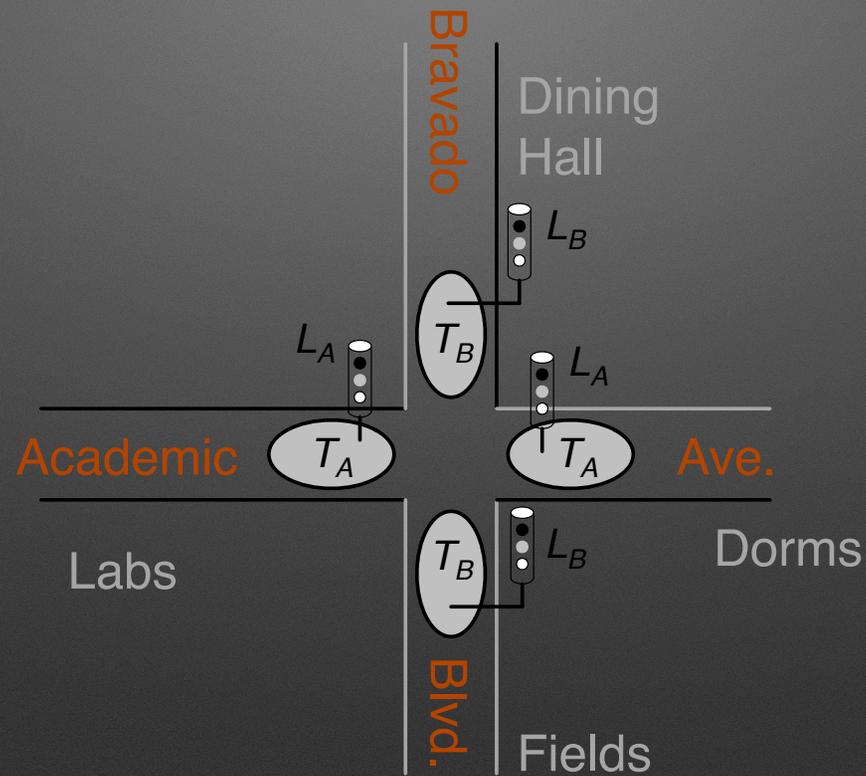
# Finite State Machines

- State: A condition of being
- Finite: Er. Finite
  - Real machine has real-world limitations:  $k \times$  D-latches
  - $k$  D-Latches means  $\leq 2^k$  states (finite)

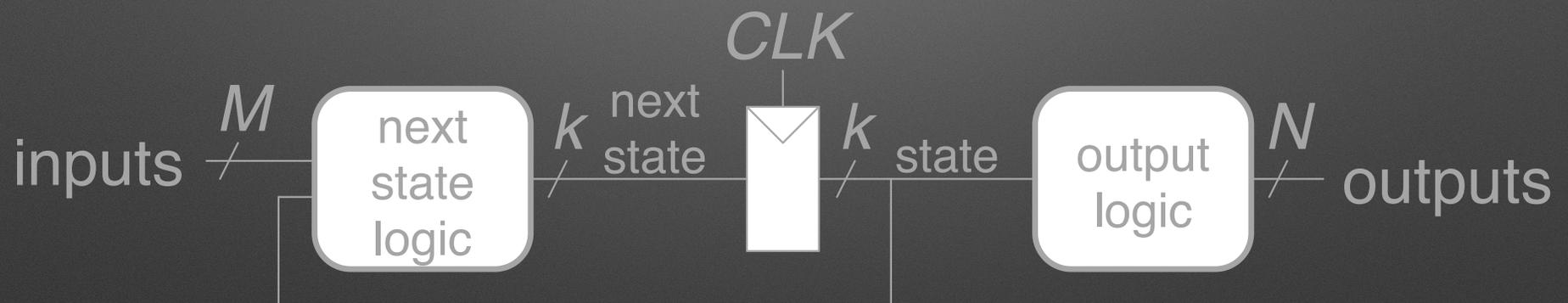
# FSM Applications

- Things with modes or sequences of steps. Examples:
  - Washing Machine (fill, agitate, rinse, spin)
  - Stop lights & Traffic control: Green, Yellow, Red
  - Locks: Locked & unlocked
  - Computer programs: Playing game vs. on menu
  - Elevator controls (state = floor)
  - ...

# Book Example Variation: Stop Light

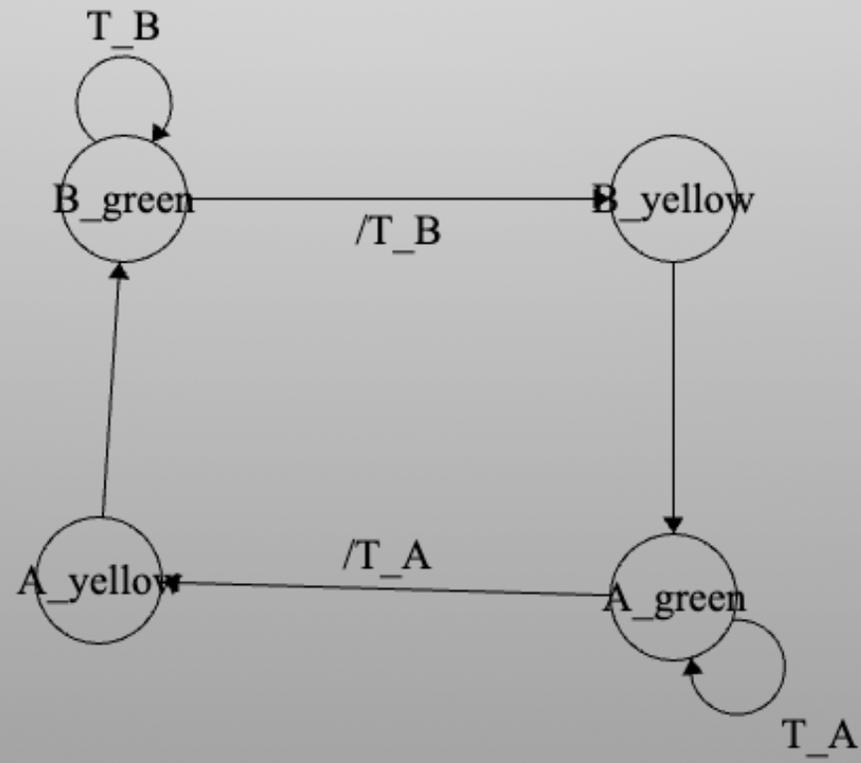


# FSM: Moore Machine Structure

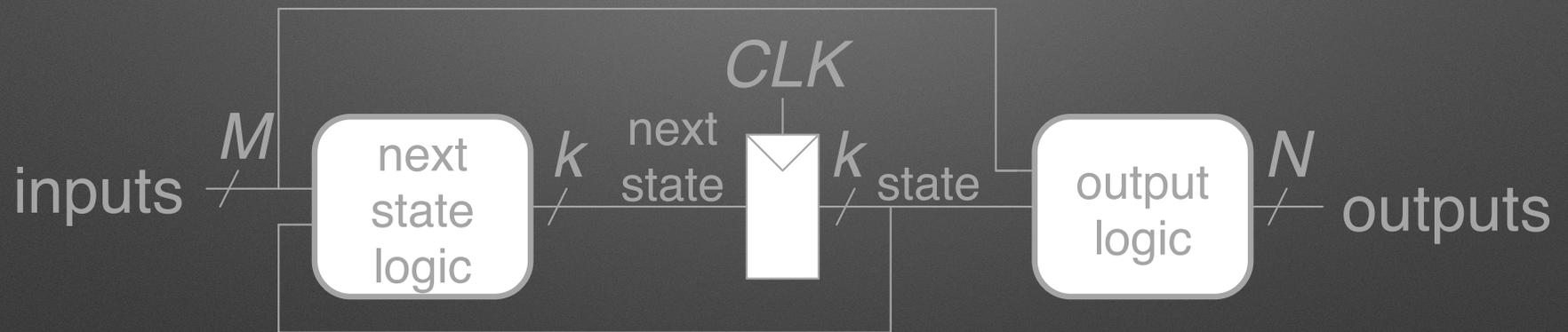


# Background

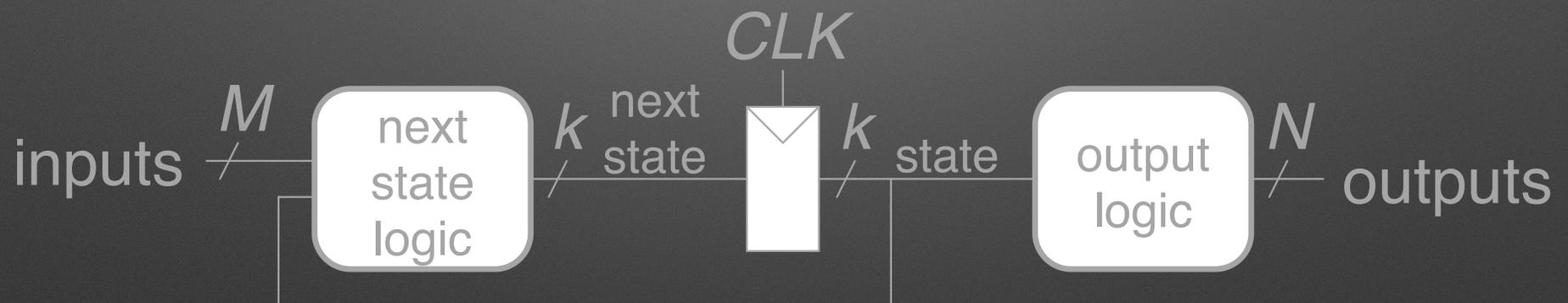
- Clock is 5s: minimum time in a state
- Need to describe behavior over time
- State diagram forms
  - FSM Designer: <https://wilsonem.github.io/fsm/>
- Example: Variation on textbook;  
Different output signals and “one hot” encoding (Completed)



# FSM: Mealy Machine



# FSM: Moore Machine Structure



# Partial JLS Implementation

# Questions

- [State Machine Encoding Choices?]  
Memory vs. Logic: They can impact complexity of combinational logic.  
(Typically One-hot: more memory, but simpler logic))
- [FSMs? Mealy? Moore?]: More (Moore?) next time
- [I don't get/understand Latches/Edges/Levels/Flip-Flops/etc.]
- [Which memory things are important]: (Rising) Edge Triggered D-latch.  
(Most others were just part of the journey to it)

# Questions

- [What about async stuff / parallel? Does it matter? Where is it used?]
  - Yes, matters. Is often critical in high performance systems (real time computations, handling volumes of streaming data, etc.)
- Will we make FSMs? Yep.
- Are FSMs part of modern computers? Yes —they often handle the control of CPU operations. We'll see this later.
- Is this “clock” related to the computer clock? How does it relate to computer performance? It's the same basic idea. Much of a computer is controlled by a synchronous machine. The clock speed is based on propagation delay and dictates the speed of computations.

# Next Time

- Studio