Welcome to The Logic Design Lab!

Fall 2022

Lab 4: Finite State Machines

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Agenda

- Lab 4 Outline
- Lab 4 Basic Questions
- Lab 4 Advanced Questions

Lab 4 Outline

- Basic questions (1.5%)
  - Individual assignment
  - Due on 11/10/2022 (Thu). In class.
- Advanced questions (5%)
  - Group assignment
  - Demonstration on your FPGA board on 11/10/2022 (Thu), in class
  - Lab report should be submitted using PDF format
  - Assignment submission (Submit to EEClass)
    - EEClass submission due on 11/10/2022 (Thu) 23:59:59 for all Advanced Questions.

Lab 4 Rules

- Please note that grading will be based on **NCVerilog**
- You can use **ANY** modeling techniques

- If not specifically mentioned, we assume the following SPEC
  - **clk** is **positive edge triggered**
  - Synchronously reset the Flip-Flops when **rst_n == 1'b0, if there exists one rst_n signal in the specification**

Lab 4 Submission Requirements

- Source codes and testbenches
  - Please follow the templates EXACTLY
  - We will test your codes by TAs' testbenches
- Lab 4 report
  - Please submit your report in a single PDF file
  - Please draw the **block diagrams** and **state transition diagrams** of your designs
  - Please explain your designs in detail
  - Please list the contributions of each team member clearly
  - Please explain how you test your design
  - What you have learned from Lab 4

Agenda

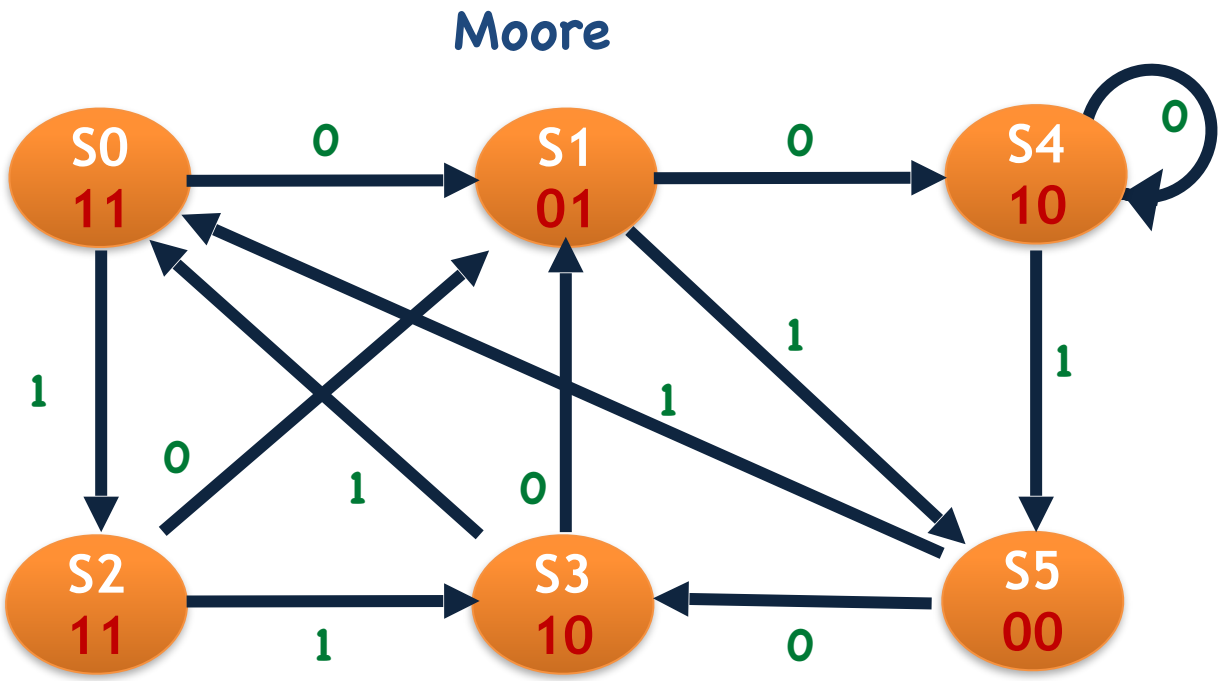
- Lab 4 Outline
- Lab 4 Basic Questions
- Lab 4 Advanced Questions

Basic Questions

- Individual assignment
- Verilog questions (due on 11/10/2022. In class.)
  - Moore machine
  - Mealy machine
  - Many-to-one linear-feedback shift register
  - One-to-many linear-feedback shift register
- Demonstrate your work by waveforms

Verilog Basic Question 1

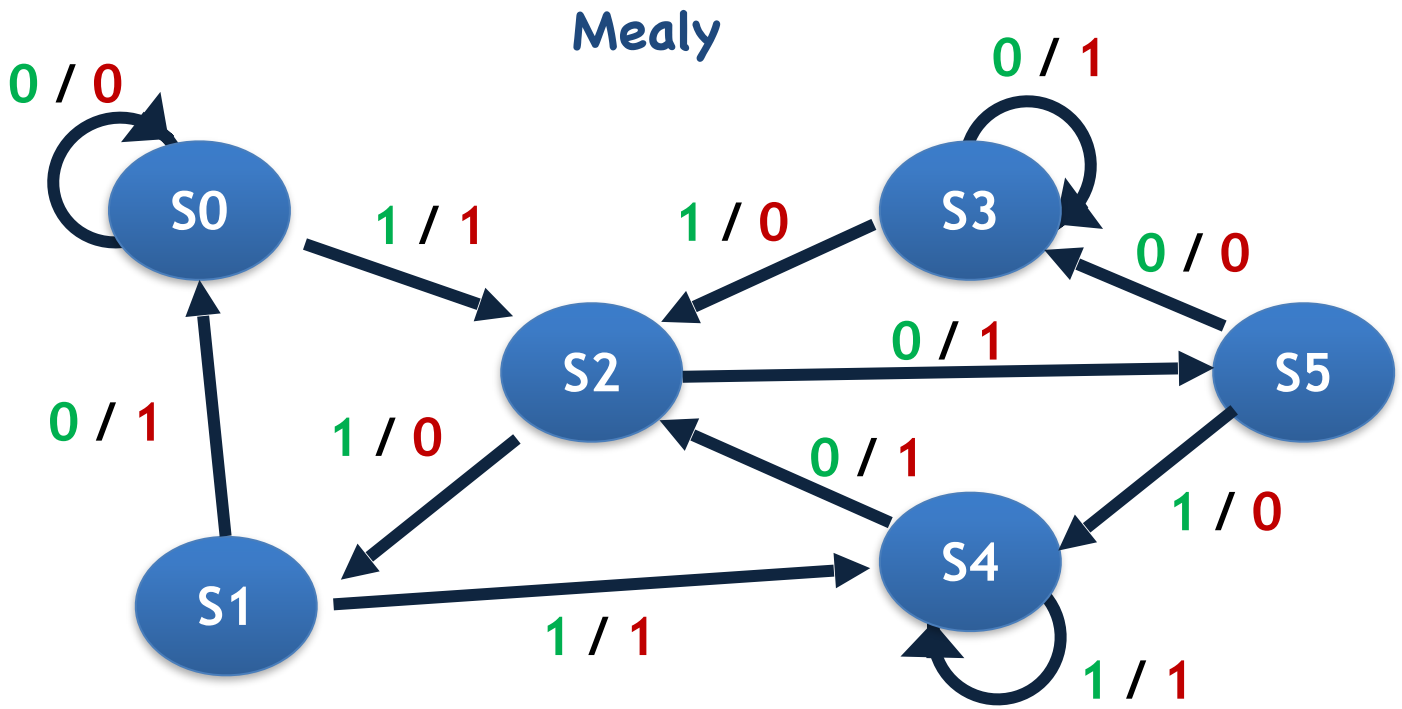
- Moore machine
  - **Green** represents input, while **red** represents output
  - Output your **current state** as well
  - When **rst_n** == 1'b0, **state** = S0



S0: 3'b000 S1: 3'b001 S2: 3'b010 S3: 3'b011 S4: 3'b100 S5: 3'b101

Verilog Basic Question 2

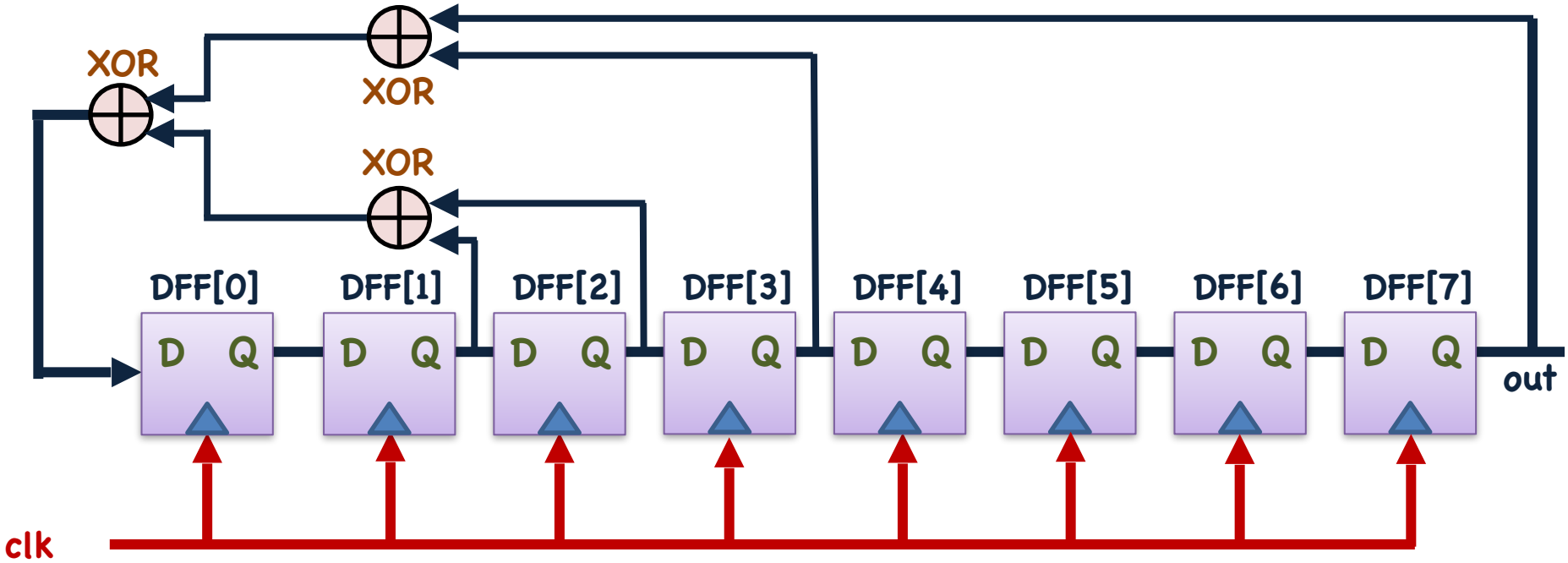
- Mealy machine
  - **Green** represents input, while **red** represents output
  - Output your **current state** as well
  - When **rst_n** == 1'b0, **state** = S0



S0: 3'b000 S1: 3'b001 S2: 3'b010 S3: 3'b011 S4: 3'b100 S5: 3'b101

Verilog Basic Question 3

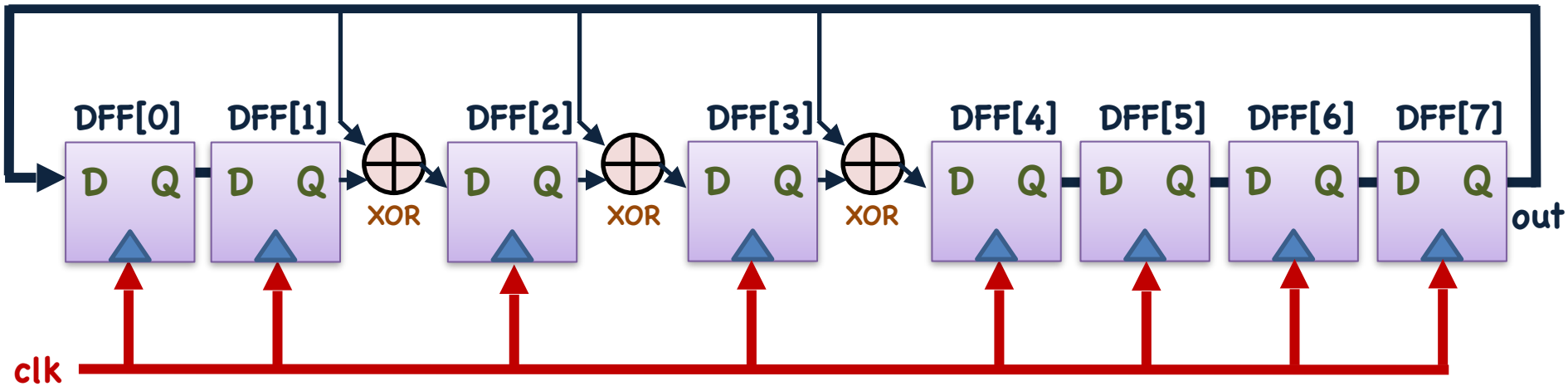
- Many-to-one linear-feedback shift register (LFSR)



- When **rst_n == 1'b0**, reset DFF[7:0] to **8'b10111101**
- Please draw the **state transition diagram** of the DFFs in LFSR for the first ten states after **rst_n** is raised to **1'b1** in your report
- Please describe what happens if we reset the DFFs to **8'd0** in your report

Verilog Basic Question 4

- One-to-many linear-feedback shift register (LFSR)



- When **RESET == 1'b0**, reset DFF[7:0] to **8'b10111101**
- Please draw the **state transition diagram** of the DFFs in LFSR for the first ten states after **rst_n** is raised to **1'b1** in your report
- Please describe what happens if we reset the DFFs to **8'd0** in your report

Agenda

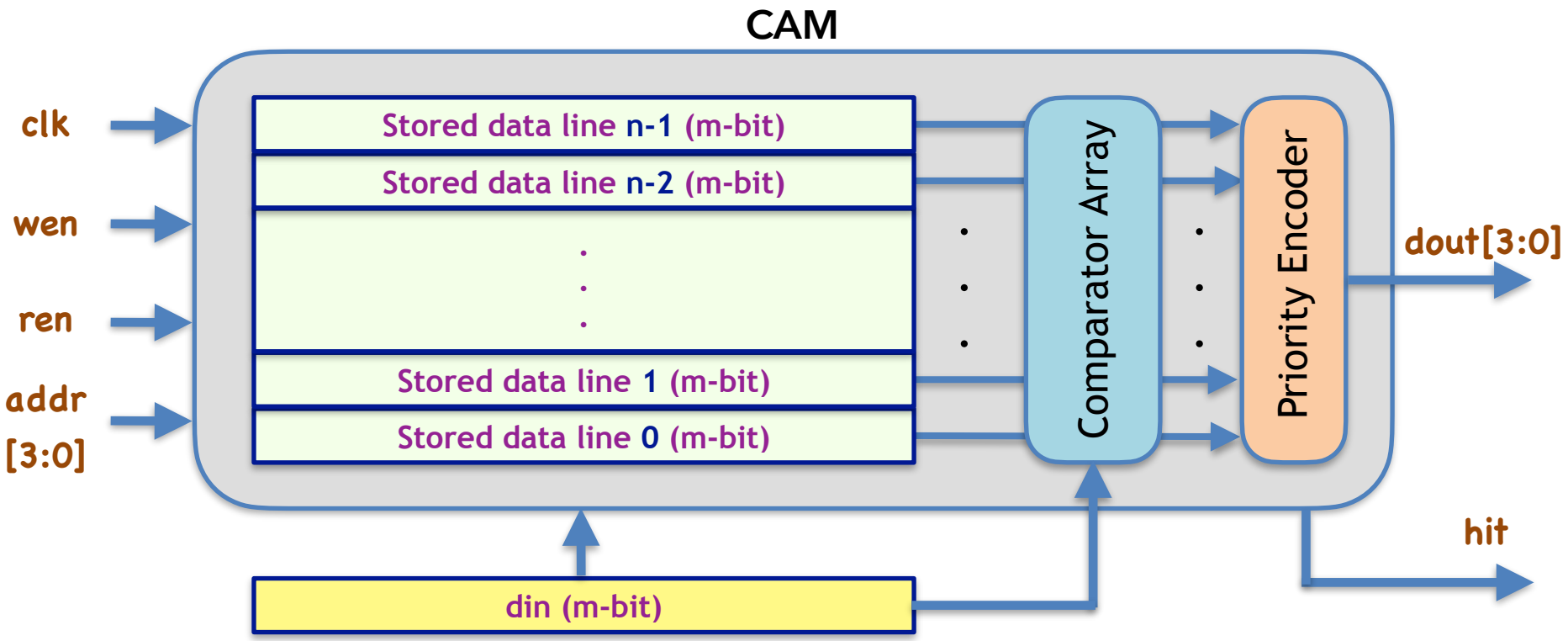
- Lab 4 Outline
- Lab 4 Basic Questions
- Lab 4 Advanced Questions

Advanced Questions

- Group assignment
- Verilog questions
  - Source codes and the report due on 11/10/2022. 23:59:59.
    - Content-addressable memory (CAM) design
    - Scan chain design
    - Built-in self test
    - Mealy machine sequence detector
- FPGA demonstration (due on 11/10/2022. In class.)
  - 1A2B game

Verilog Advanced Question 1

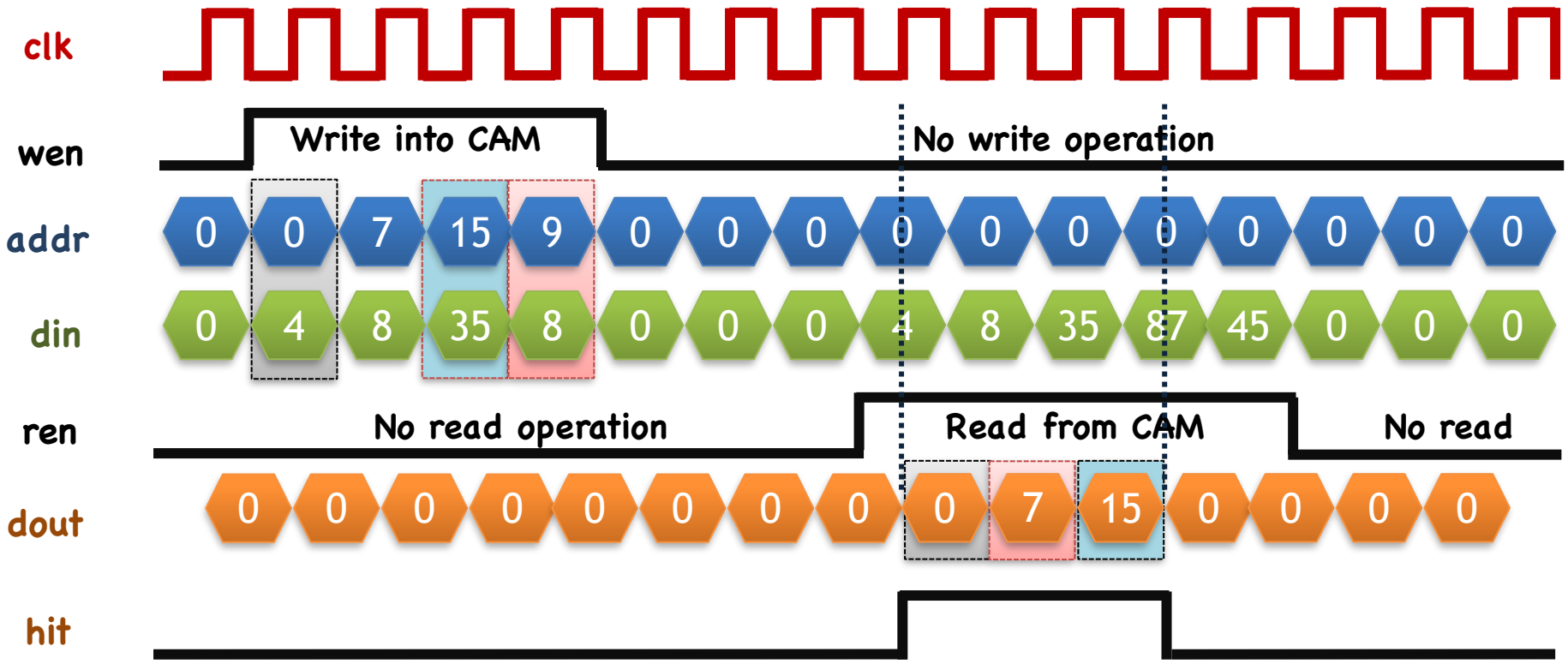
- **Content-addressable memory (CAM) design**
  - Design a CAM that stores **n** sets of **m**-bit data lines **(n = 16, m = 8)**
  - Input: **clk, wen, ren, addr[3:0], din[m-1:0]**
  - Output: **dout[3:0], hit**



Verilog Advanced Question 1 (Con't)

- When **wen == 1'b1**, write **din** to CAM[**addr**] and set **dout** to **4'b0** and **hit** to **1'b0**
- When **ren == 1'b1**:
  - If there is only one matching data in the CAM, set **dout** to the matching data's address and set **hit** to **1'b1**
  - If there are multiple matches in the CAM, set **dout** to the **smallest address among them** and set **hit** to **1'b1**.
  - If there is no match in the CAM, set **dout** to **4'b0** and set **hit** to **1'b0**
- When both **wen** and **ren** are **1'b1**, **perform read operation only and ignore the write request**
- When both ren and wen are 1b'0, set **dout** to 4'b0 and set **hit** to 1'b0
- Please refer to the next page for example waveform

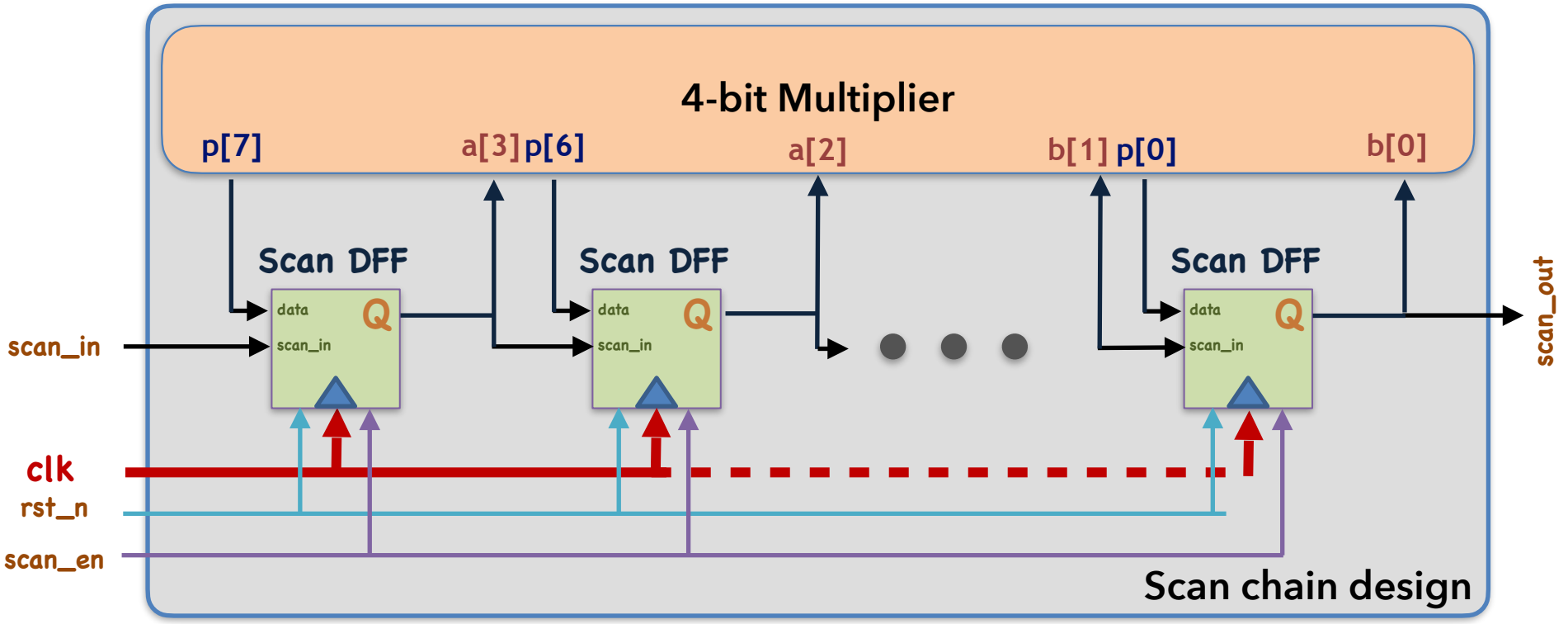
Verilog Advanced Question 1 (Con't)

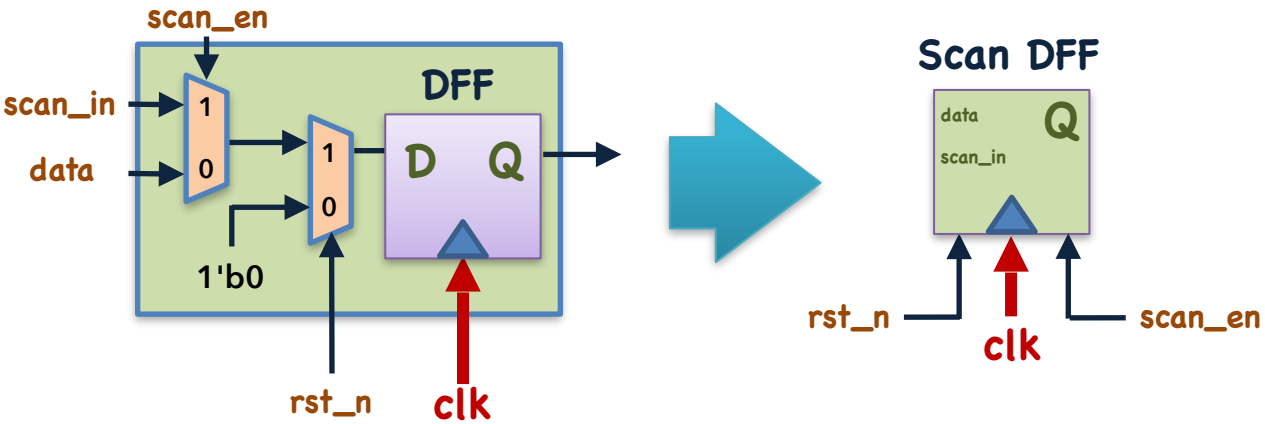


Verilog Advanced Question 2

- **Scan chain design**
- Scan chain is a technique used in design for testing. The objective is to make testing easier by providing a simple way to set and observe every flip-flop in a circuit. The structure of a scan chain is illustrated in the next page.
  - In order to achieve the above objective, the DFFs in a circuits are all replaced by a special type of DFF, called scan DFF (SDFF), which is also shown in the next page. An SDFF contains several extra ports: **scan_in** and **scan_en**, and is larger than the original DFF.
  - All the SDFFs are connected in a chain, which is called a scan chain.
- In this question, you are required to design a scan chain for a 4-bit multiplier, which is a combinational circuit and can be designed by any modeling technique.
  - Input: **clk**, **rst_n**, **scan_in**, **scan_en**
  - Output: **scan_out**
- Reset all SDFFs to **1'b0** when **rst_n** == 1'b0

Verilog Advanced Question 2 (Con't)

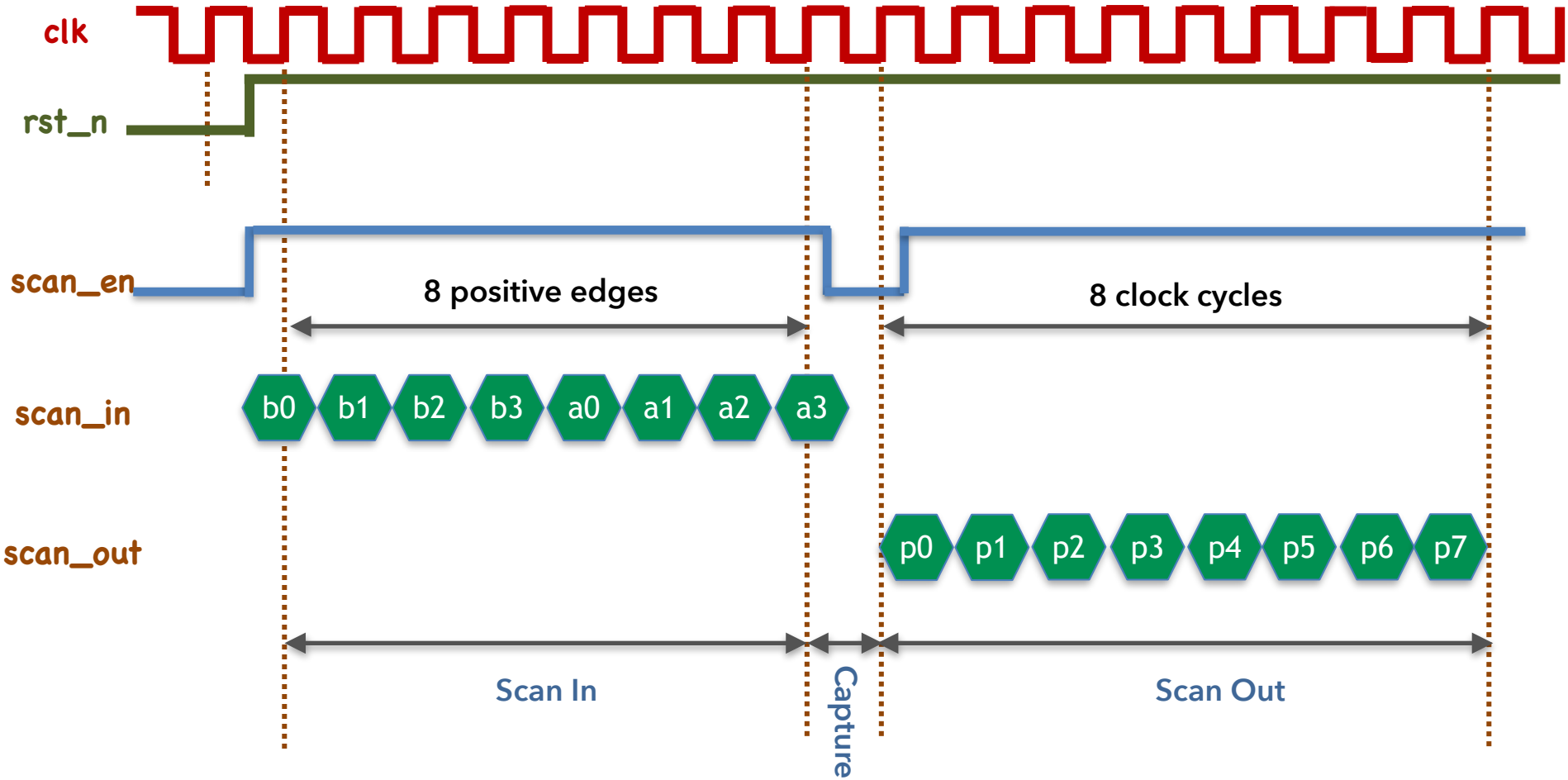




Verilog Advanced Question 2 (Con't)

- **The behavior of a scan chain**
- The behavior of a scan chain contains three phases: **scan in**, **capture**, and **scan out**.
  - **Scan in**
    - In this phase, **scan_en** is set to **1'b1**, and a test pattern is scanned (shifted) from the **scan_in** port into the scan chain bit-by-bit.
  - **Capture**
    - In this phase, **scan_en** is set to **1'b0**, and the circuit performs its original functionality.
    - The inputs of the multiplier is provided by the values stored in SDFF. The output of the multiplier is stored back to the SDFFs at the positive clock edge.
  - **Scan out**
    - In this phase, **scan_en** is set to **1'b1** again, and the values stored in the SDFFs are shifted to the **scan_out** port of the scan chain bit-by-bit.
- In TA's test bench, the **scan_en** signal is controlled **according to this three-phase behavior pattern** to test your scan chain design.
- Please refer to the next page for the example behavior waveform.

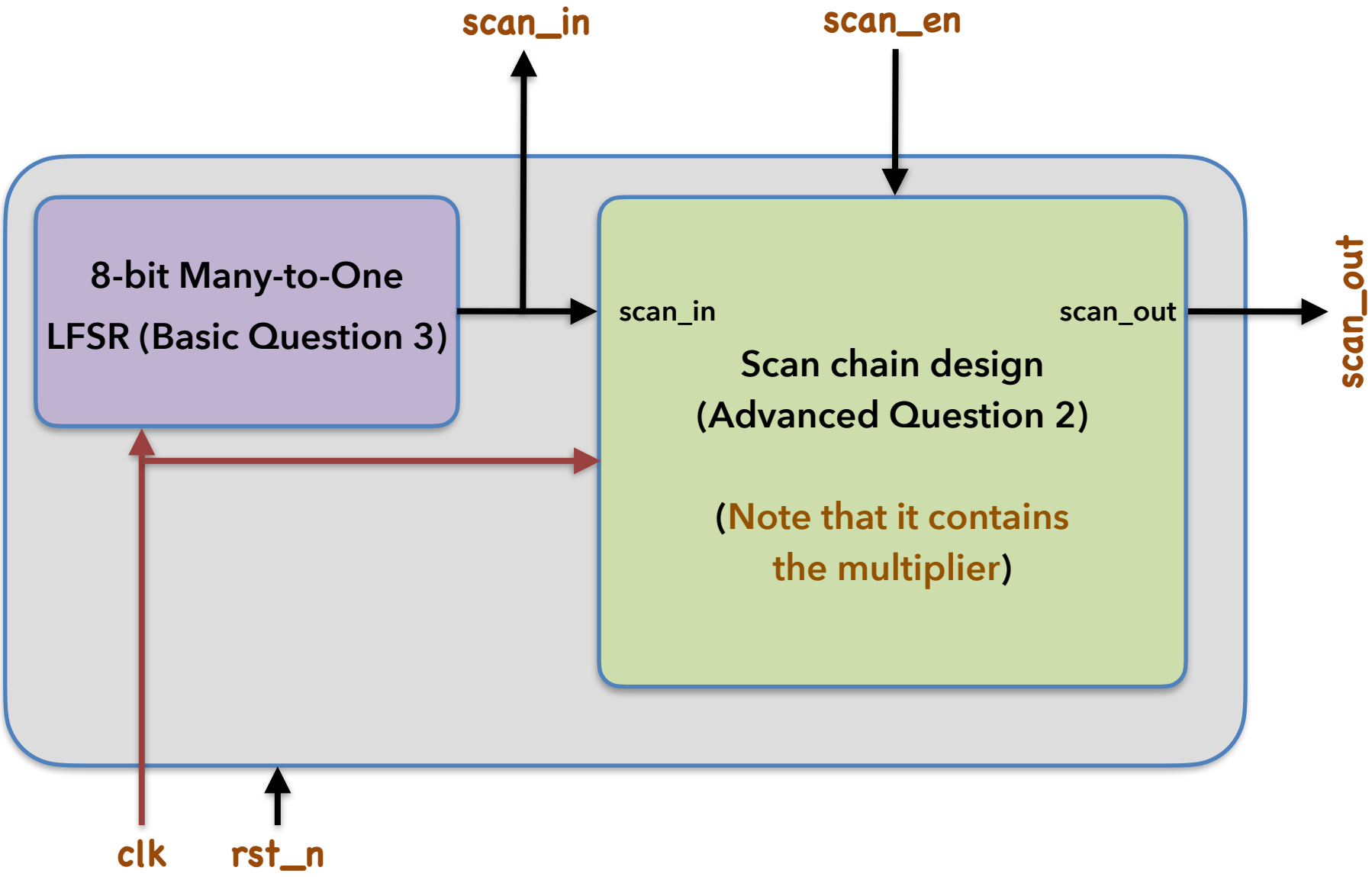
Verilog Advanced Question 2 (Con't)



Verilog Advanced Question 3

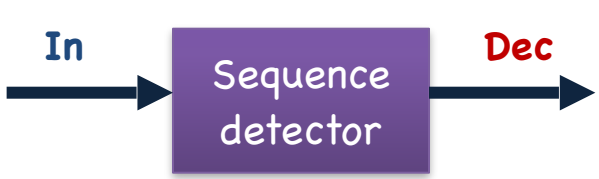
- **Built-in self test (BIST)**
- In the previous question, we designed a scan chain. Now we add a test pattern generator in front of it. The test pattern generator is implemented by a 8-bit many-to-one LFSR, which is the same as the design in the basic question 3. Since the test pattern generator is inside a chip, this architecture is called "built-in self test (BIST)".
- Please reuse the scan chain from the advanced question 2
- **Please modify your LFSR from the basic question 3 so that only the MSB of the LFSR is shifted into the scan chain.**
- Typically, a circuit with BIST does not have **scan_in** and **scan_out** ports. However, for the grading purposes, the two ports are set as output ports, so as to allow them to be observable.
- Input: **clk**, **rst_n**, **scan_en**
- Output: **scan_in**, **scan_out**

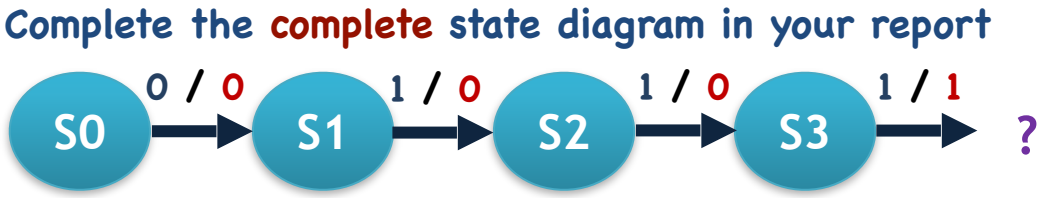
Verilog Advanced Question 3 (Con't)

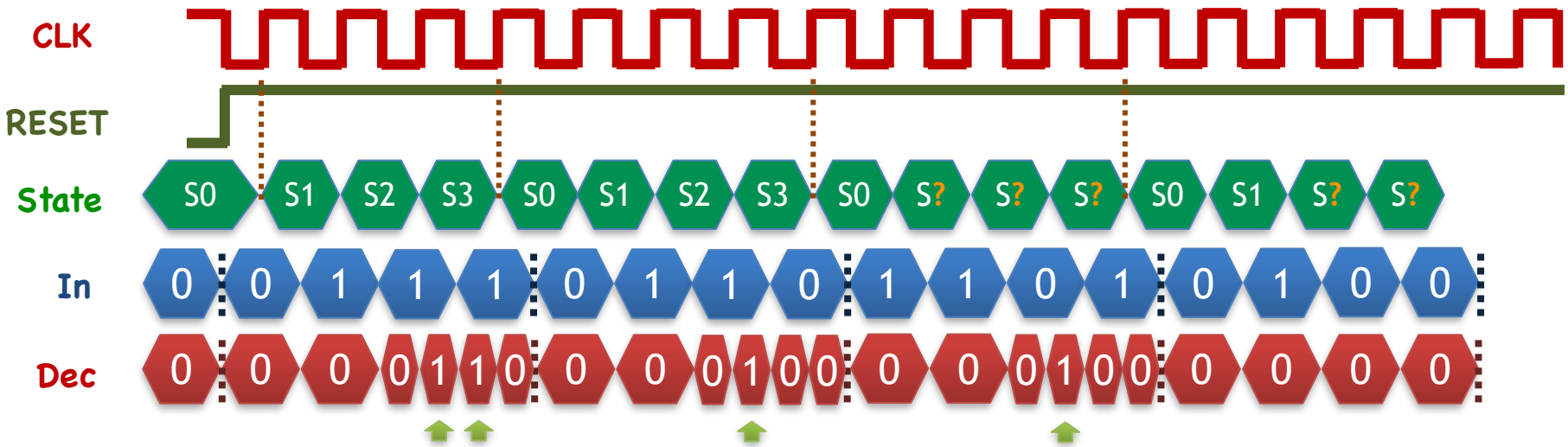


Verilog Advanced Question 4

- **Mealy machine sequence detector**
  - 1-bit input **In** and 1-bit output **Dec**
  - When the four bit sequence is **0111**, **1011**, or **1100**, **Dec** is set to **1**
  - Re-detect the sequence **every four bits**
  - Please draw your state diagram in your report







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  - 1A2B game

FPGA Demonstration

- **The 1A2B game**
  - Traditionally, this is a two-player code-breaking game. However, in this lab, we modify it to a single-player game

- **The rule**
  - In the beginning of each game, the FPGA generates a random number consisting of **four non-repeating digits**, where **each digit ranges from 0 to 9**
  - The player's task is to guess this number using the hints given by the FPGA
  - The behavior of this game contains two phases: **the initial phase** and **the guessing phase**

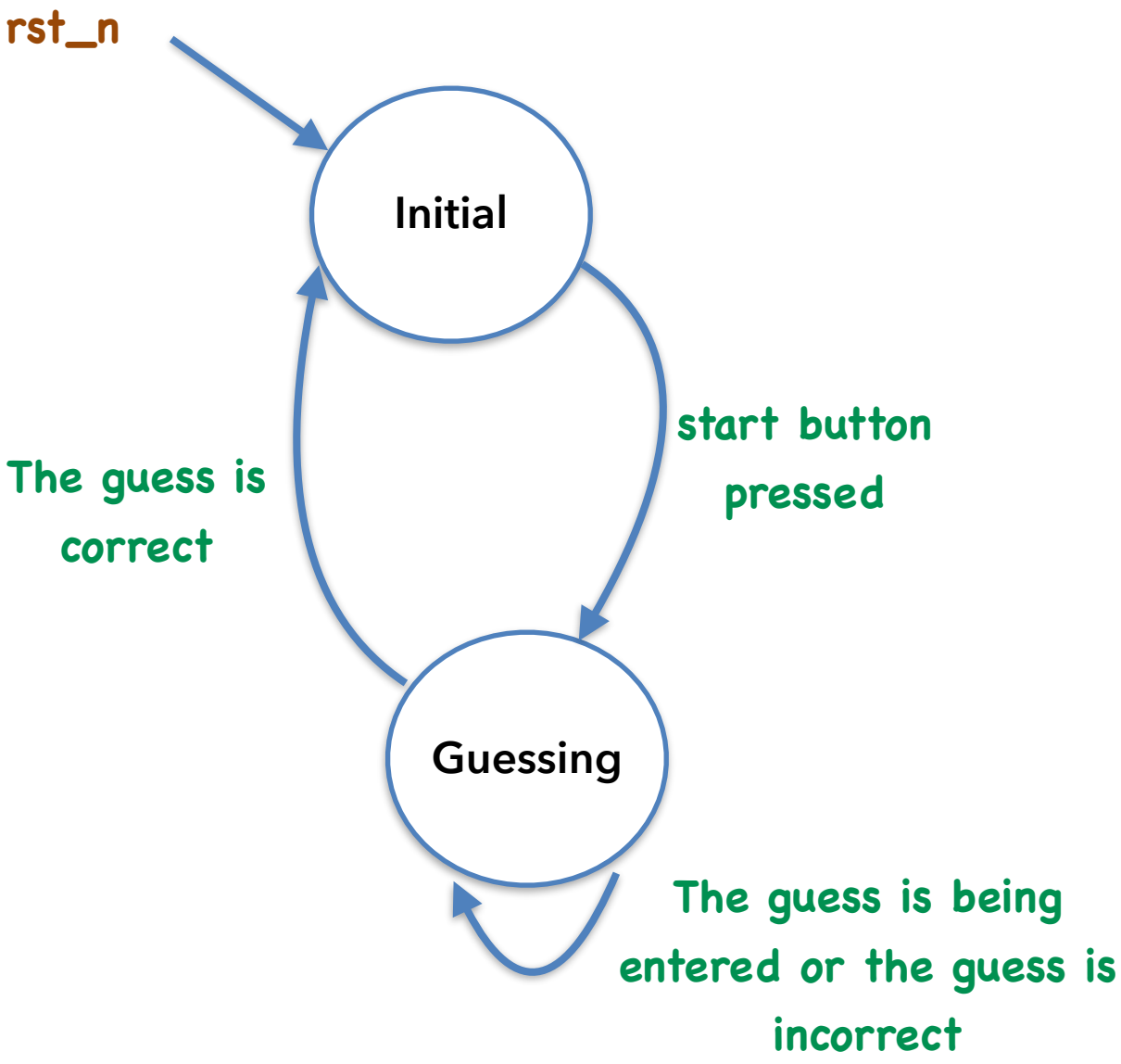
- **The initial phase**
  - When the **reset button** is pressed, reset the game to this phase
  - In this phase, the seven-segment display shows **"1A2b"**, and wait for the player to push the **start button**
  - After pressing **the start button**, a random non-repeating 4 digit answer is generated and displayed using the LEDs, where LED[15:12] represents the first digit, LED[11:8] represent the second digit, and so on

FPGA Demonstration (con't)

- **The guessing phase**
  - The LEDs should continue displaying the generated answer
  - The player is required to guess this number one by one, from the MSB to the LSB using the leftmost 4 switches (i.e., SW[15:12]). The digit that is being guessed will flicker until the player enters his/her guess using the **enter button**
  - After all the 4 digits have been entered, the seven segment display should show **XAYb** according the correctness of the player's guess, where **X** is the number of the digits with correct digit positions, and **Y** is number of the correct digits that are out of place.
  - If the player's guess matches the answer, return the game to **the initial phase** after the **enter button** is pressed (remember to clear all the LEDs!)
  - If the player's guess does not match the answer, return to this guessing phase and guess again after the **enter button** is pressed
- Please note that the answer of each game should be random and generated using the LFSR, which should keep operating and is only sampled when the **start button** is pressed
- Please refer to the demonstration video from the TAs
- Please refer to the next page for the state transition diagram

FPGA Demonstration (con't)

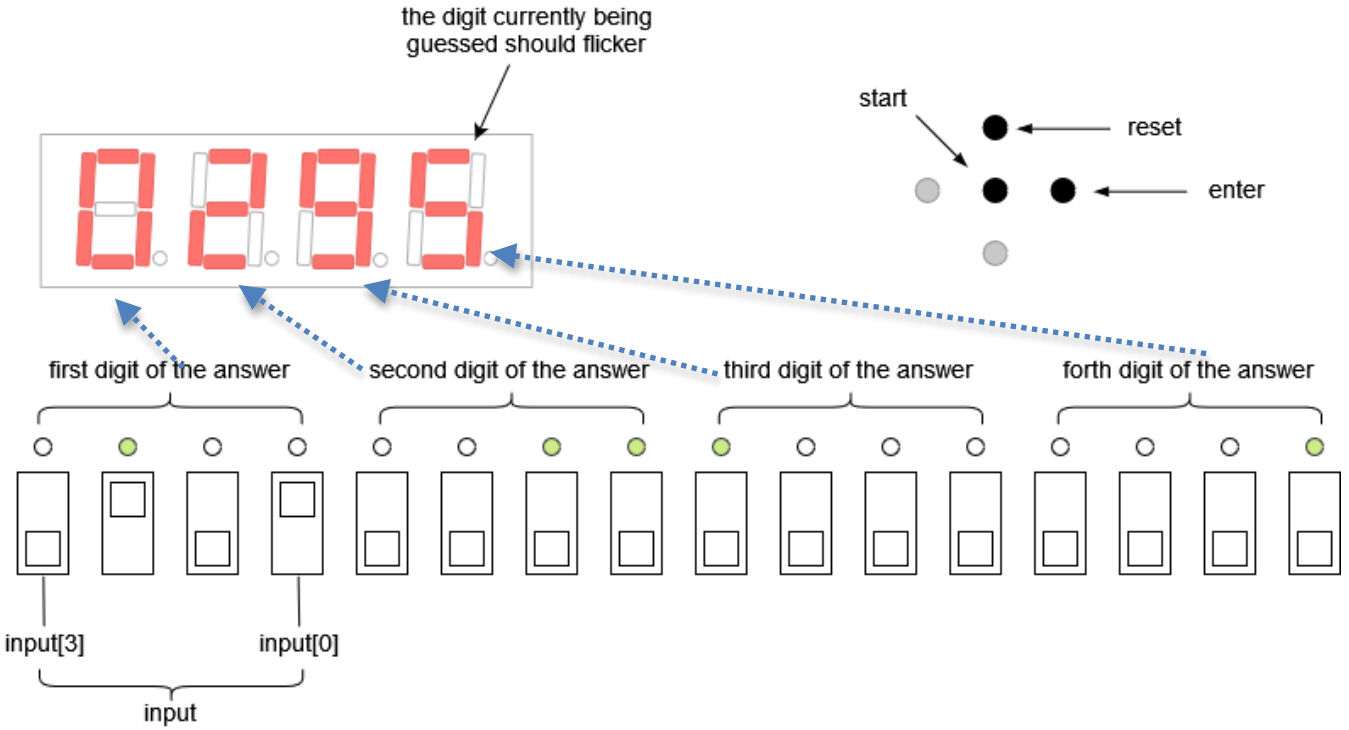
- An example of the state transition diagram



FPGA Demonstration (con't)

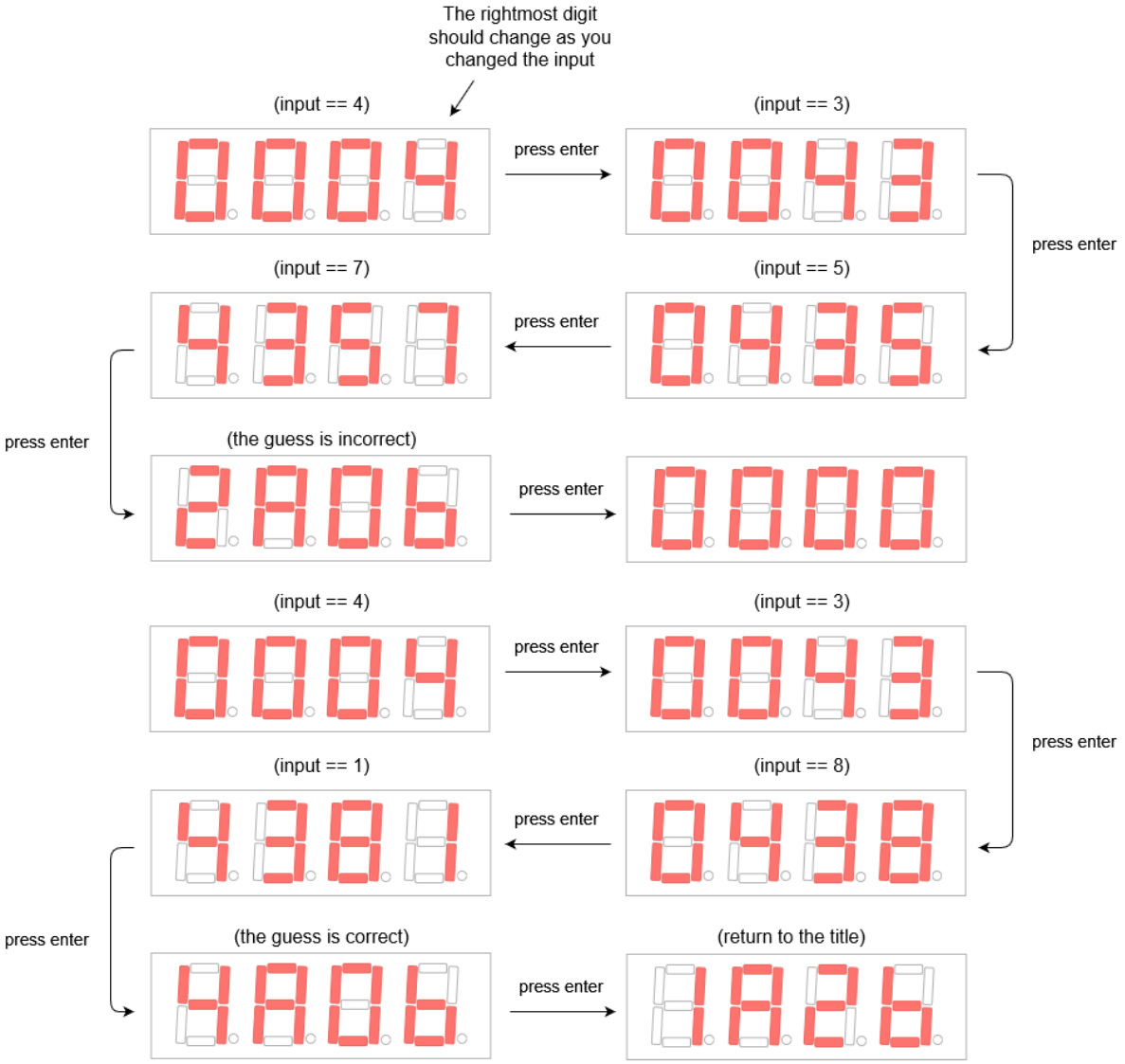
- The layout of the switches, the buttons, and the seven segment display

- The real answer in the following example is 4381, as indicated by the LED pattern



FPGA Demonstration (con't)

- An example of the behavior of the 1A2B game (the answer in this example 4381)
- Video demonstration link: shorturl.at/iuvJ3
- Please note that we will not intentionally input patterns with:
  - Repeating digits
  - Digits with values larger than 9



*The first Starbucks at Seattle, Washington, USA
This picture is taken by Chun-Yi Lee himself, who is also a fan of photography