



Welcome to The Logic Design Lab!

Fall 2021

Lab 4: Finite State Machines

Prof. Chun-Yi Lee

Department of Computer Science
National Tsing Hua University

Agenda

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



Lab 4 Outline

- Basic questions (1.5%)
 - Individual assignment
 - Due on **11/2/2021 (Thu). In class.**
- Advanced questions (5%)
 - Group assignment
 - Demonstration on your FPGA board (**In class**)
 - Assignment submission (**Submit to eeclass**)
 - EEClass submission due on **11/11/2021 (Thu). 23:59:59.**
 - Source codes and testbenches
 - Lab report in PDF

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



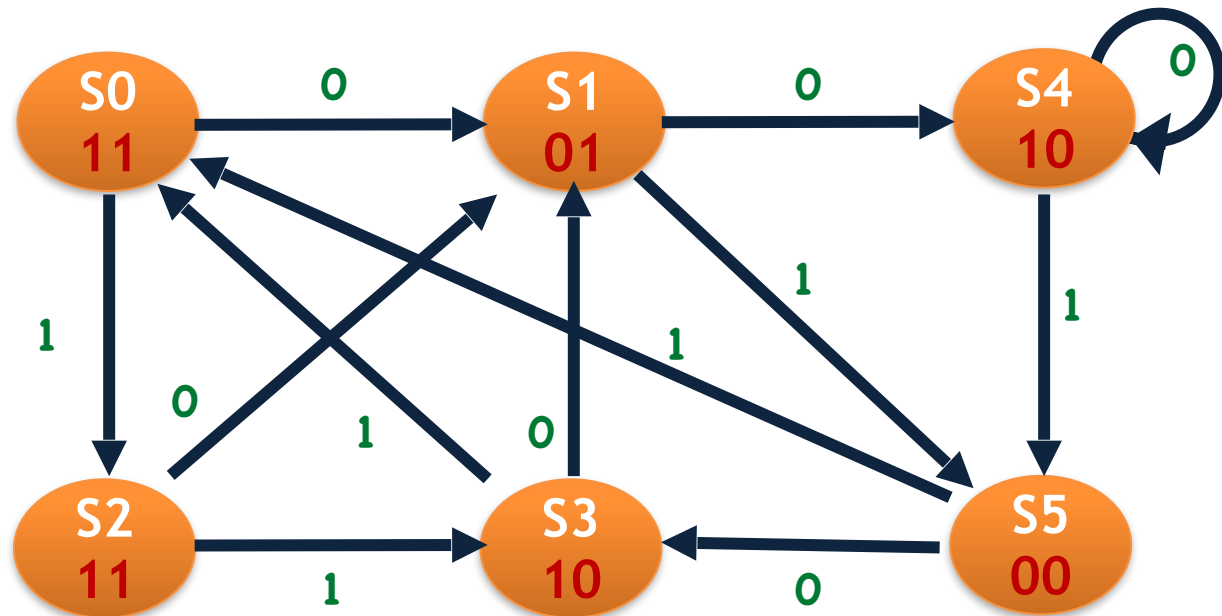
Basic Questions

- Individual assignment
- Verilog questions (due on 11/2/2021. 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

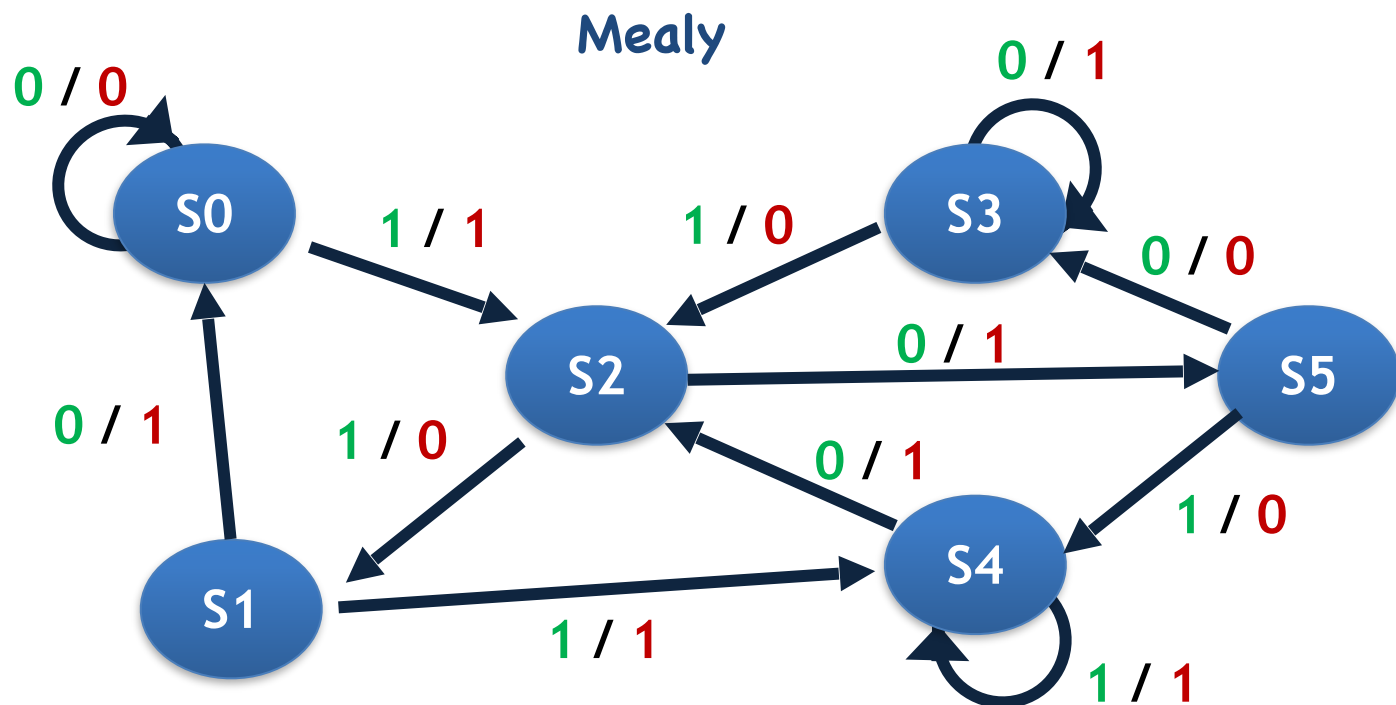
Moore



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

Verilog Basic Question 2

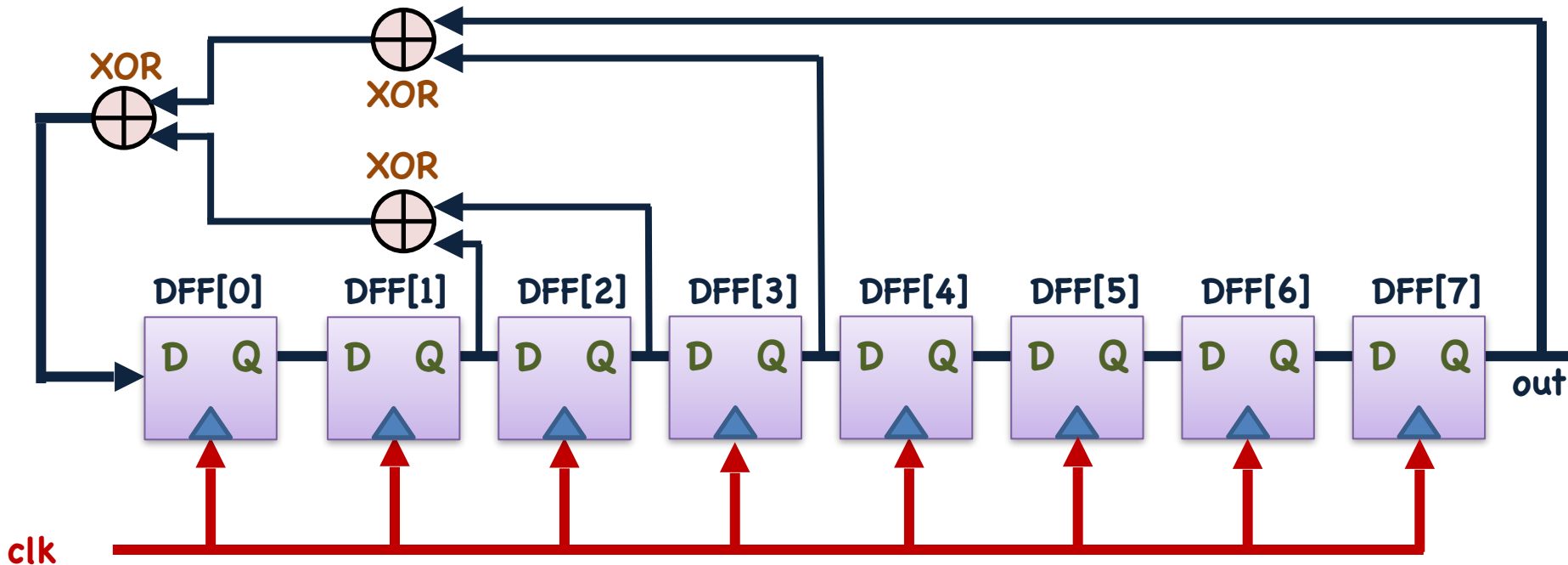
- Mealy machine
 - **Green** represents input, while **red** represents output
 - Output your **current state** as well
 - When `rst_n == 1'b0`, `state = S0`



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

Verilog Basic Question 3

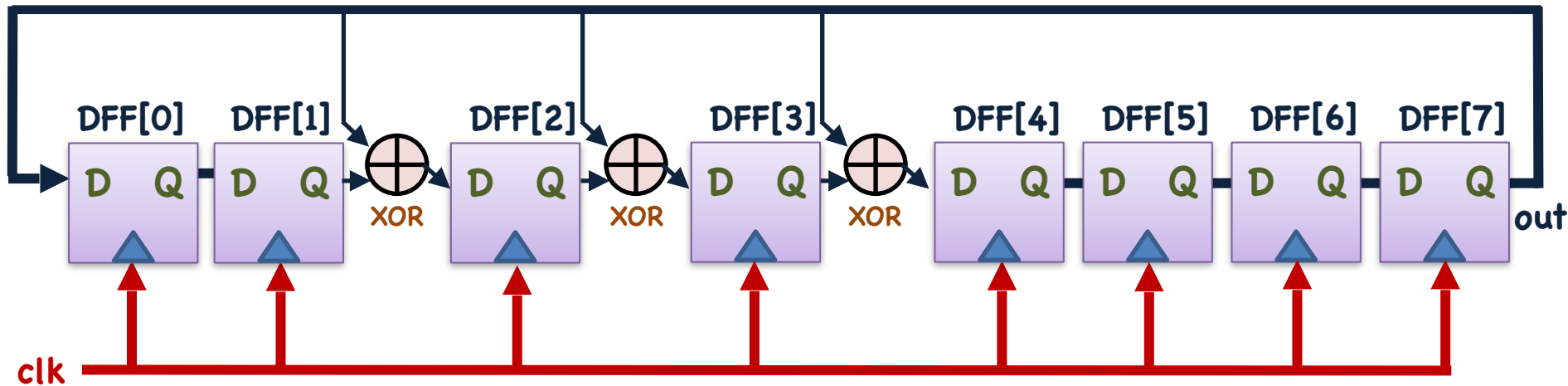
- Many-to-one linear-feedback shift register (LFSR)



- 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

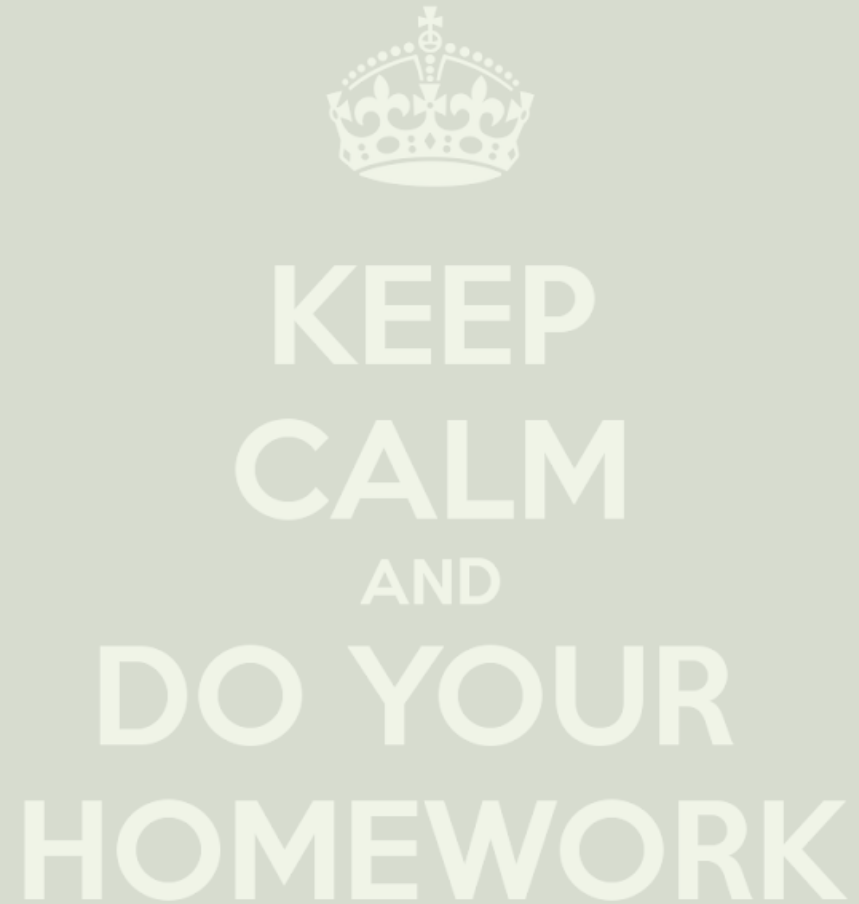
- One-to-many linear-feedback shift register (LFSR)



- 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**

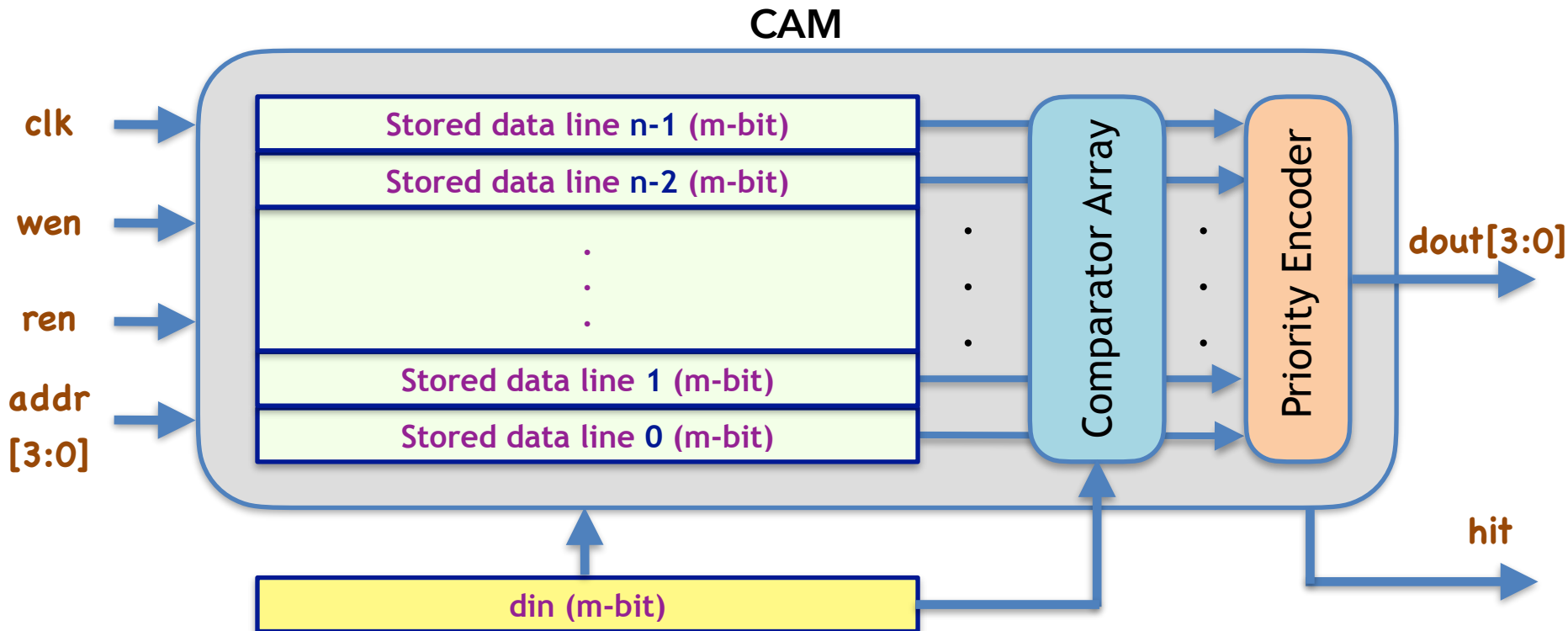


Advanced Questions

- Group assignment
- Verilog questions
 - Source codes and the report due on 11/11/2021. 23:59:59.
 - Content-addressable memory (CAM) design
 - Scan chain design
 - Built-in self test
 - Mealy machine sequence detector
- FPGA demonstration (due on 11/18/2021. In class.)
 - 1A2B game

Verilog Advanced Question 1

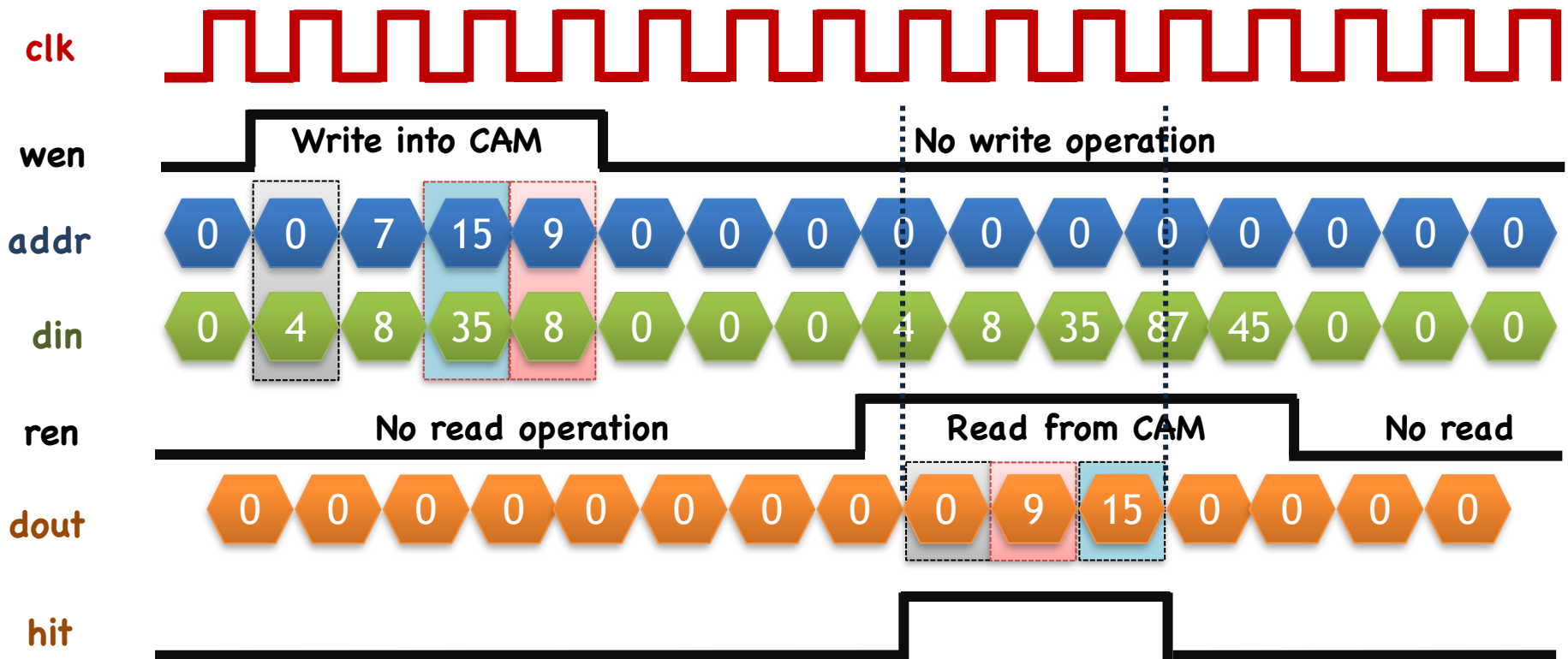
- Content-addressable memory (CAM) design
 - Design a CAM that stores **n** sets of **m**-bit data lines (**n** = 16, **m** = 8)
 - Input: **clk**, **wen**, **ren**, **addr[3:0]**, **din[m-1:0]**
 - Output: **dout[3:0]**, **hit**



Verilog Advanced Question 1 (Con't)

- When **wen** == 1'b1, write **din** to CAM[**addr**]
- 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 **largest address among them** and set **hit** to 1'b1.
 - If there is no match in the CAM, set **dout** to 1'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 1'b0, set **dout** to 1'b0 and set **hit** to 1'b0
- Please refer to the next page for example waveform

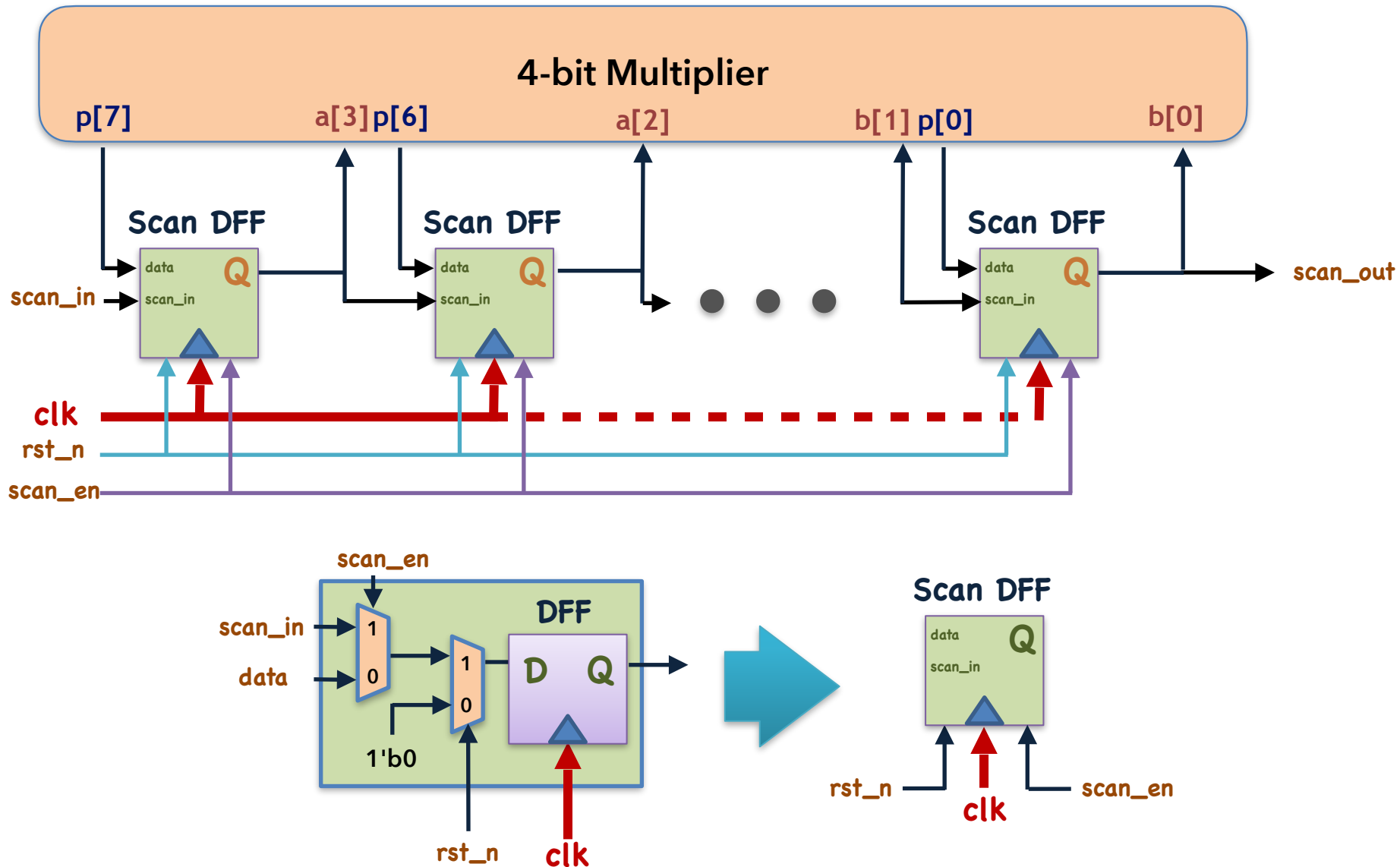
Verilog Advanced Question 1 (Con't)



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**

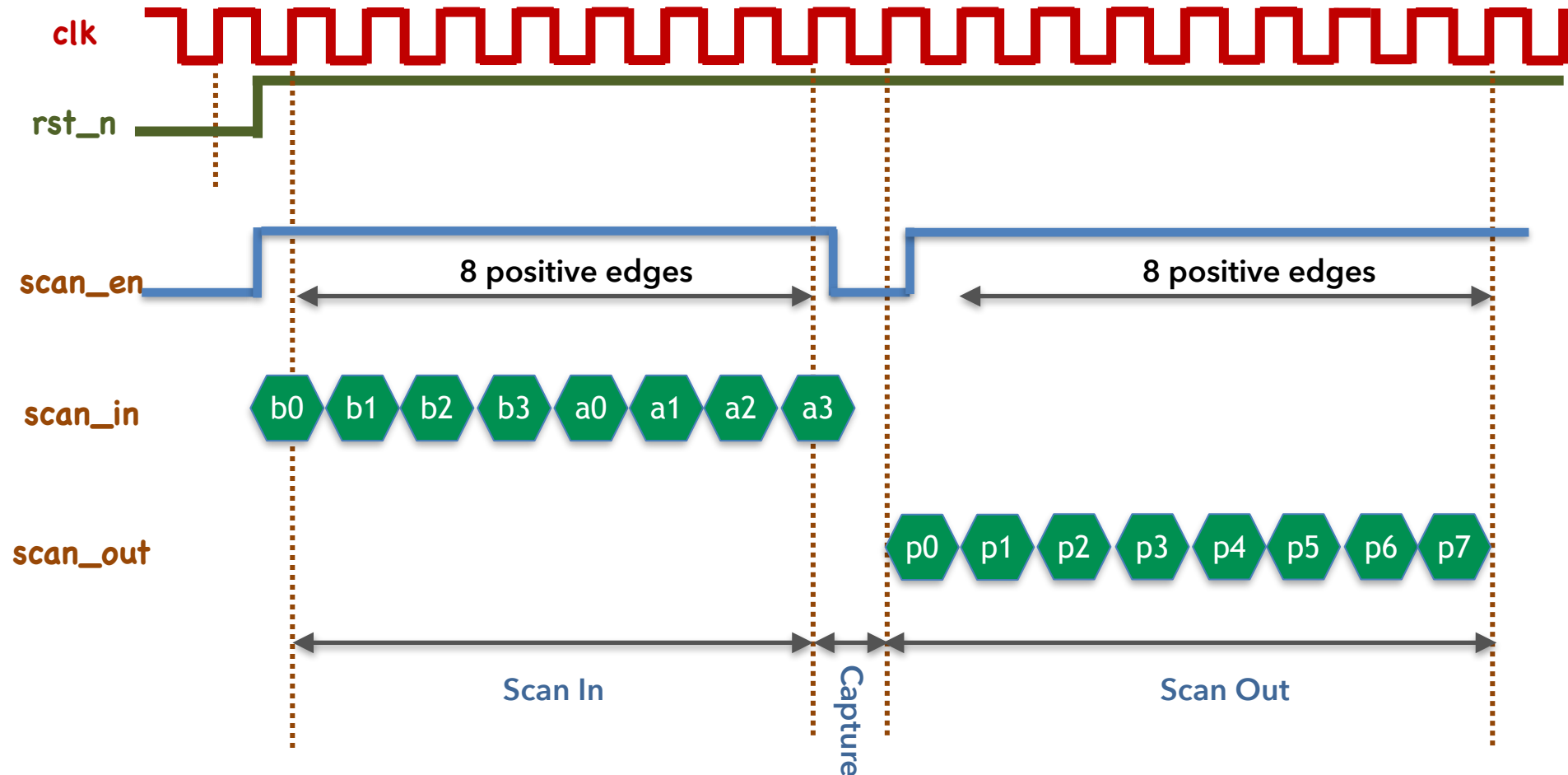
Verilog Advanced Question 2 (Con't)



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.

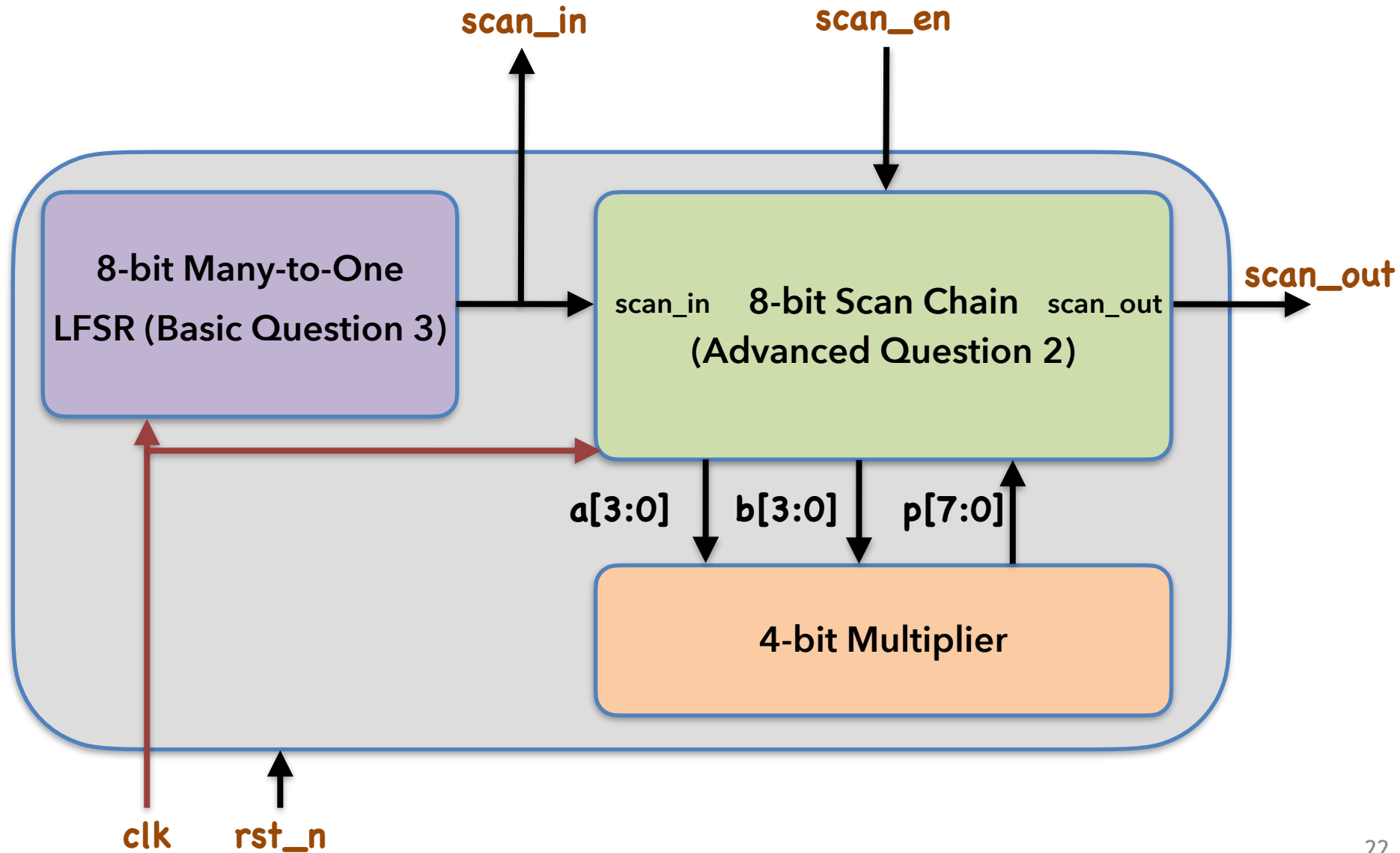
Verilog Advanced Question 2 (Con't)



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**

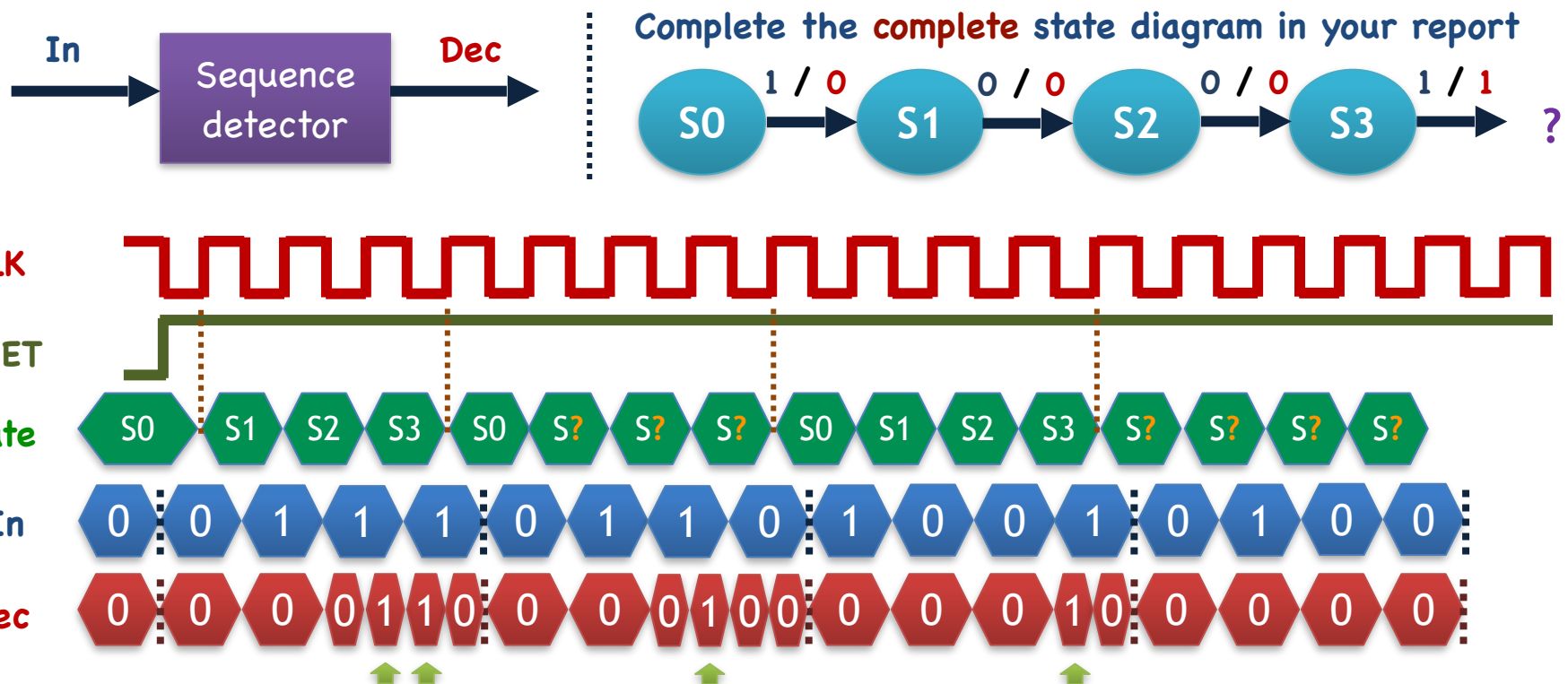
Verilog Advanced Question 3 (Con't)



Verilog Advanced Question 4

■ Mealy machine sequence detector

- 1-bit input **In** and 1-bit output **Dec**
- When the four bit sequence is **0111**, **1001**, or **1110**, **Dec** is set to 1
- Re-detect the sequence **every four bits**
- Please draw your state diagram in your report



Advanced Questions

- Group assignment
- Verilog questions
 - Source codes and the report due on **11/11/2021. 23:59:59.**
 - Content-addressable memory (CAM) design
 - Scan chain design
 - Built-in self test
 - Mealy machine sequence detector
- **FPGA demonstration** (due on **11/18/2021. In class.**)
 - 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

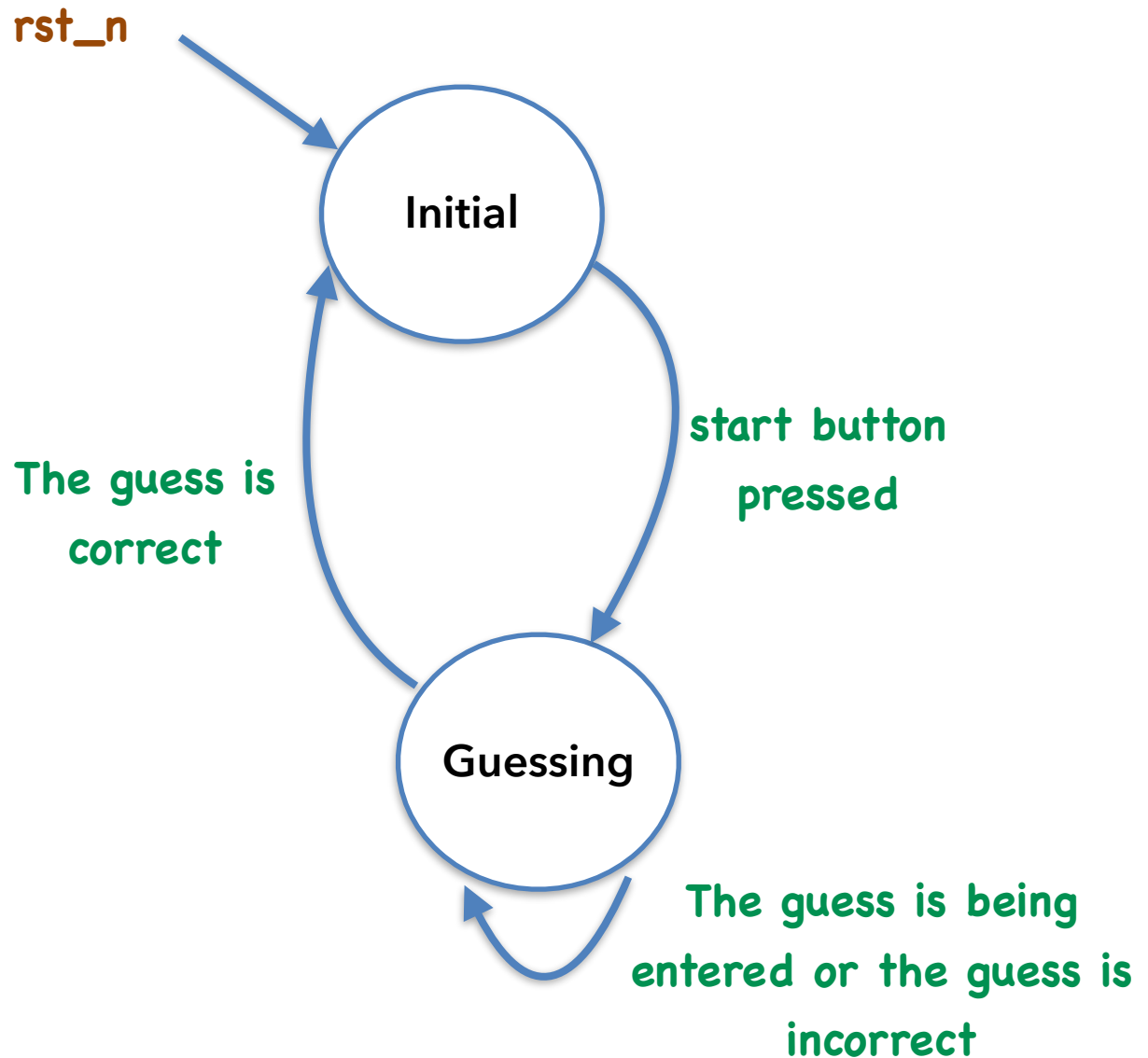
- When the **reset button** is pressed, reset the game to this phase.
- In this phase, the seven-segment display shows "**1A2b**", and wait for the player to push the **start button**
- After pressing **the start button**, a random non-repeating 4 digit answer is generated and displayed using the LEDs, 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 LFRS, 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

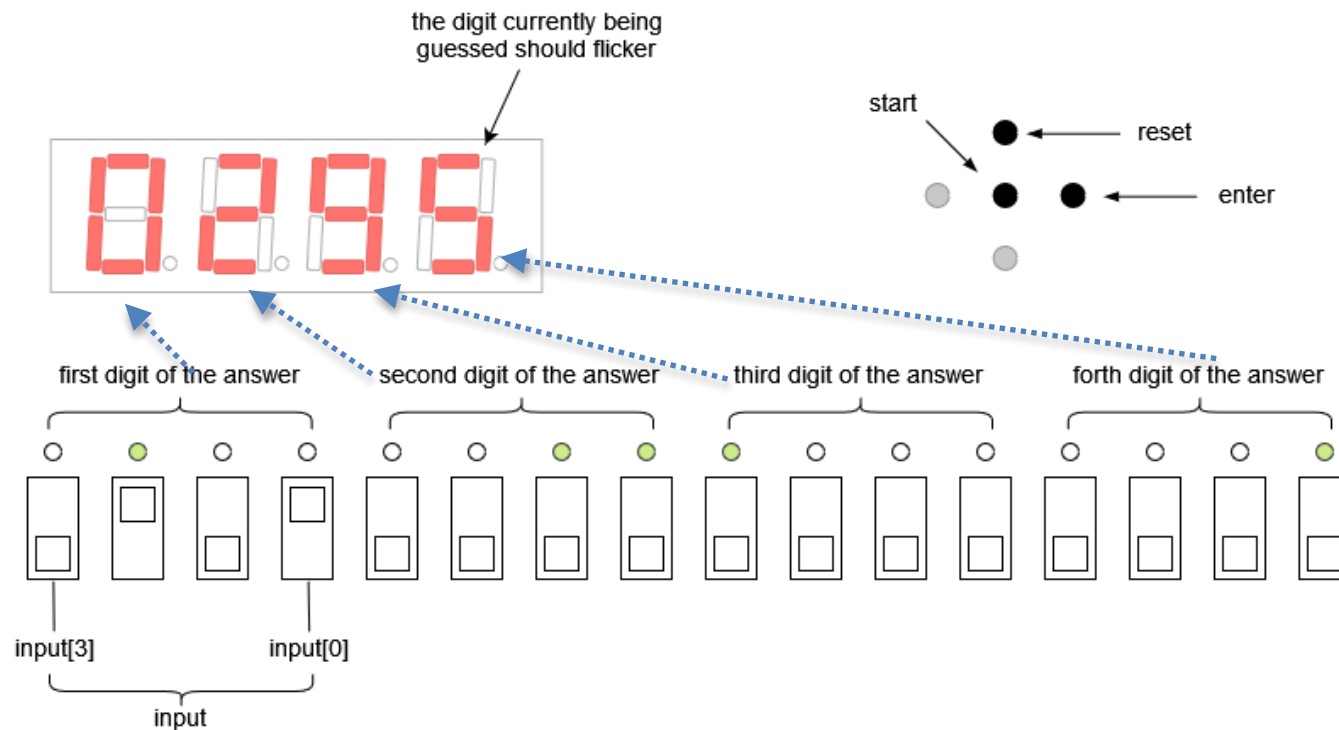
FPGA Demonstration (con't)

- An example of the state transition diagram

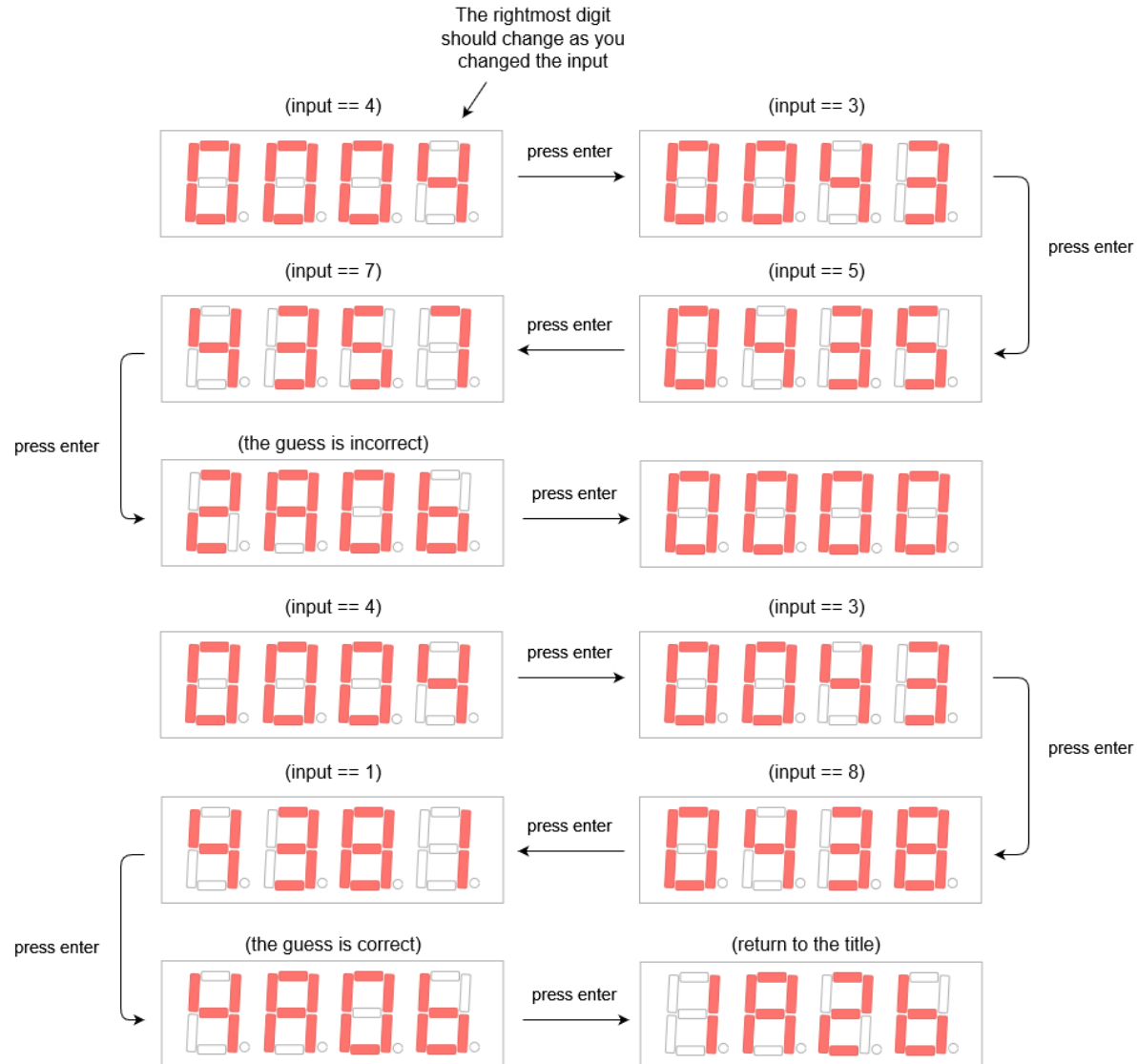



FPGA Demonstration (con't)

- 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



- An example of the behavior of the 1A2B game (the answer in this example 4381)





Thank you for your attention!

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