2.03.20 12:00 PM

CSCI 150
Introduction to Digital and Computer System Design
Lecture 4: Sequential Circuit III

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2020 Winter Semester (S1)

Overview

- Focus: Basic Information Retaining Blocks
- Architecture: Sequential Circuit
- Textbook v4: Ch5 5.3, 5.4; v5: Ch4 4.2 4.3
- Core Ideas:
    1. Sequential Circuit Analysis: State Diagram
    2. Sequential Circuit Design Procedures

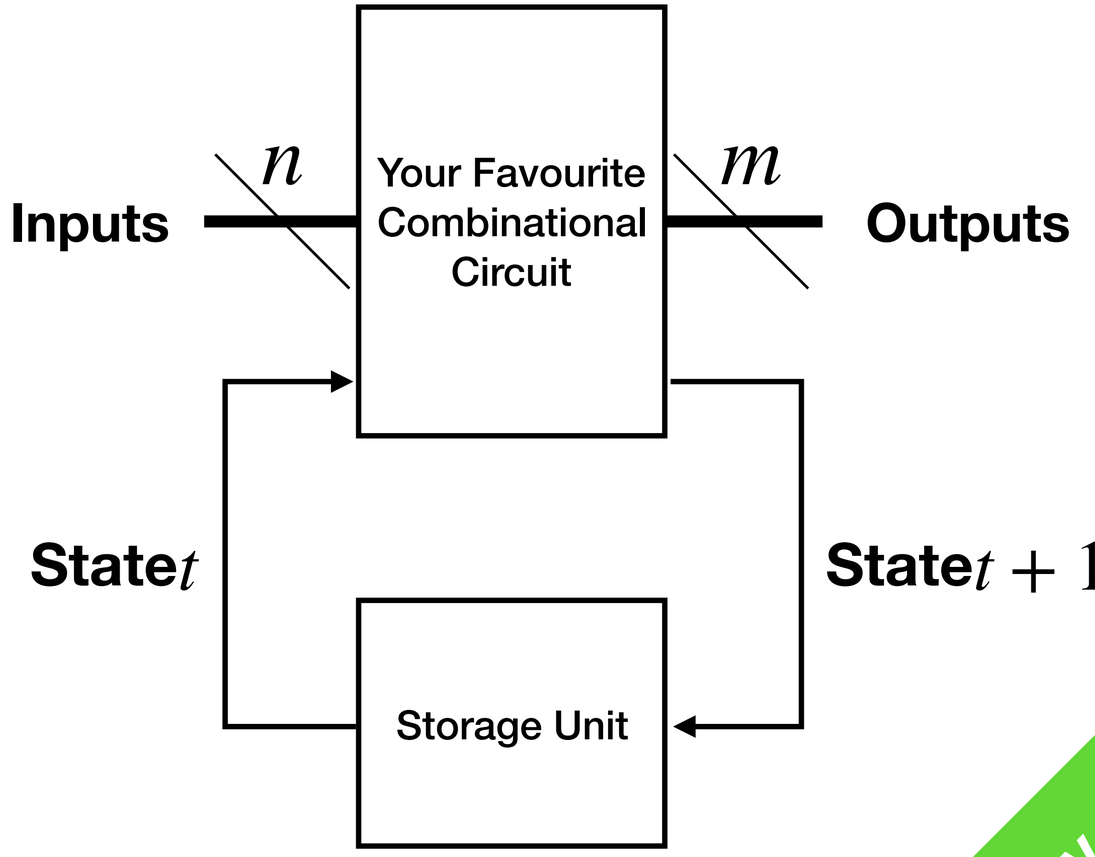
Definitions

1. **Storage Elements**
   circuits that can store binary information

2. **State**
   partial results, instructions, etc.

3. **Synchronous Sequential Circuit**
   Signals arrive at discrete instants of time, outputs at next time step

4. **Asynchronous Sequential Circuit**
   Signals arrive at any instant of time, outputs when ready



Review

P0
Review

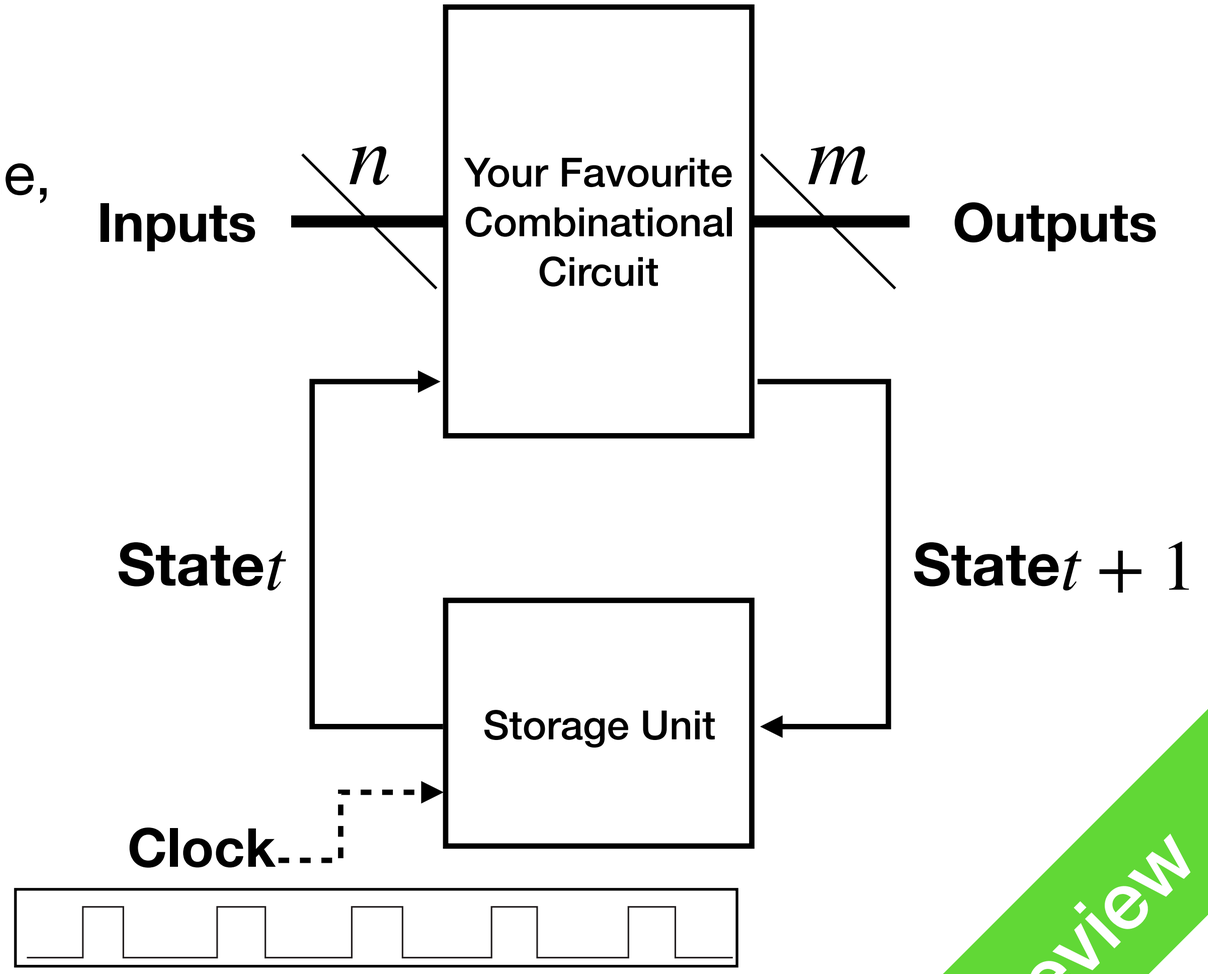
Definitions

3. **Synchronous Sequential Circuit**
   Signals arrive at discrete instants of time, outputs at next time step

   - Has Clock

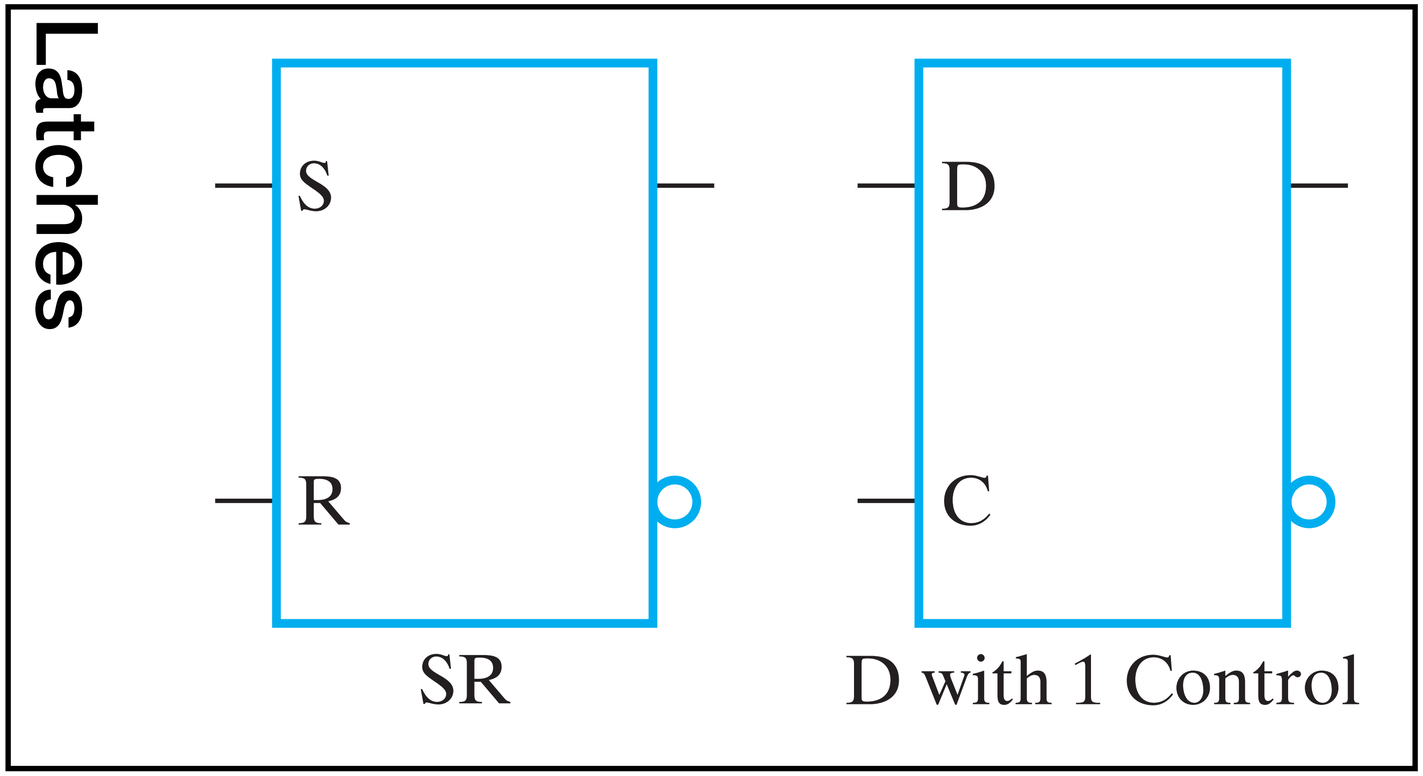
4. **Asynchronous Sequential Circuit**
   Signals arrive at any instant of time, outputs when ready

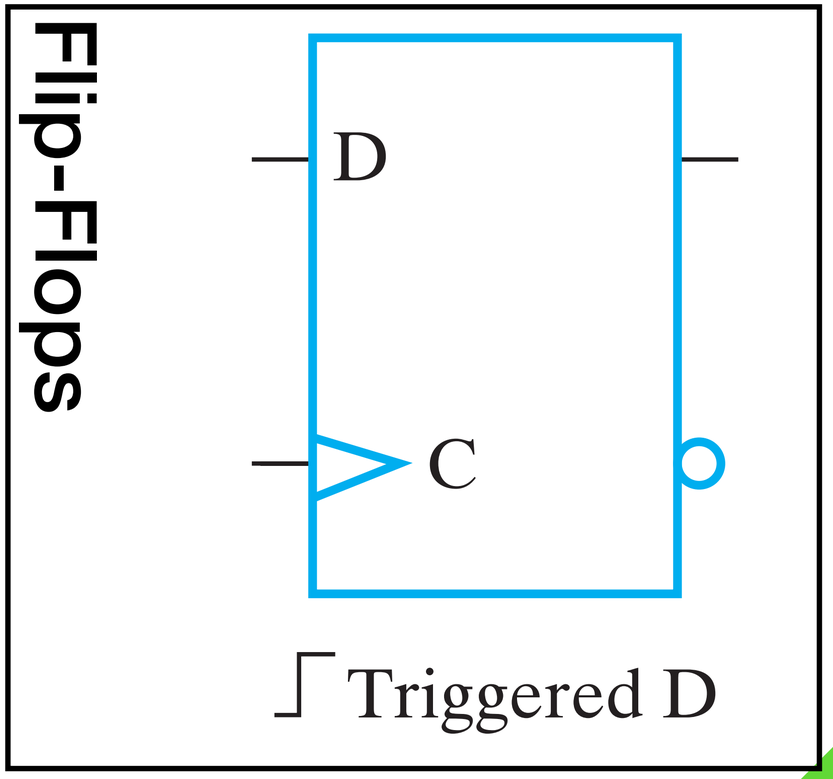
   - May not have Clock



Review

Summary





Demo

P1
Analysis

Sequential Circuit Analysis II

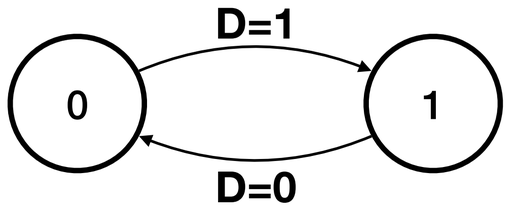
State Diagram

Summary

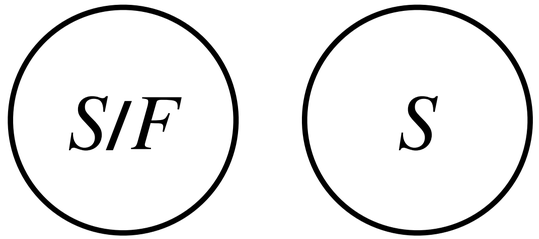
P1
Analysis

State Diagram

- Similar to state table
  - Models state transitions
  - A state is represented in a bubble



  - Directed links between bubbles: the input used to perform transition
    Source: **present** state, Target: **next** state (next **CLK**)
  - State bubble with state as S (optional output F)



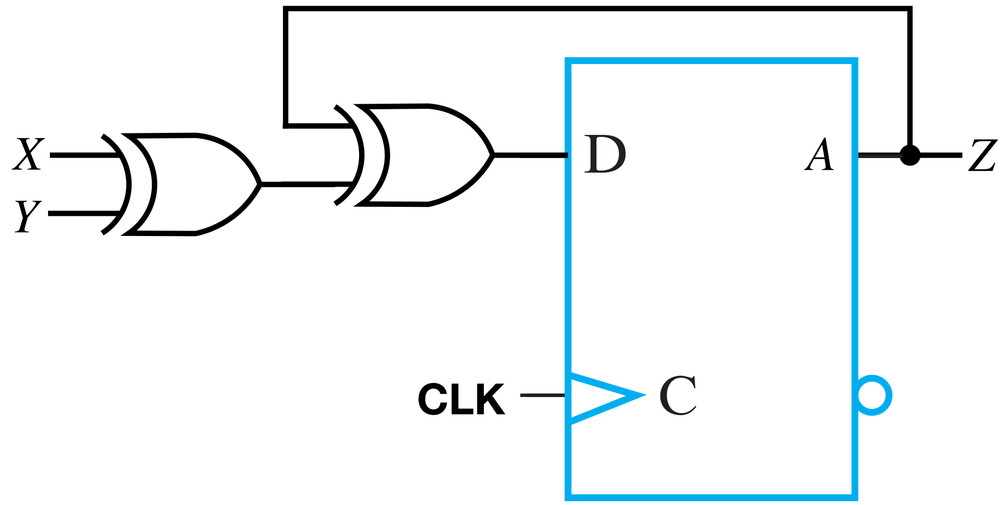
Concept

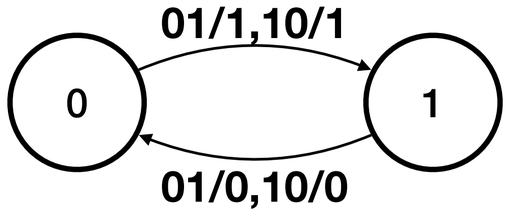
P1
Analysis

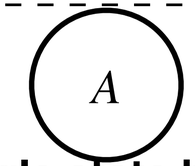
State Diagram

State Table

Present State	X	Y	Next State	F
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	0
1	0	0	1	1
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1







A single state bubble

A single link

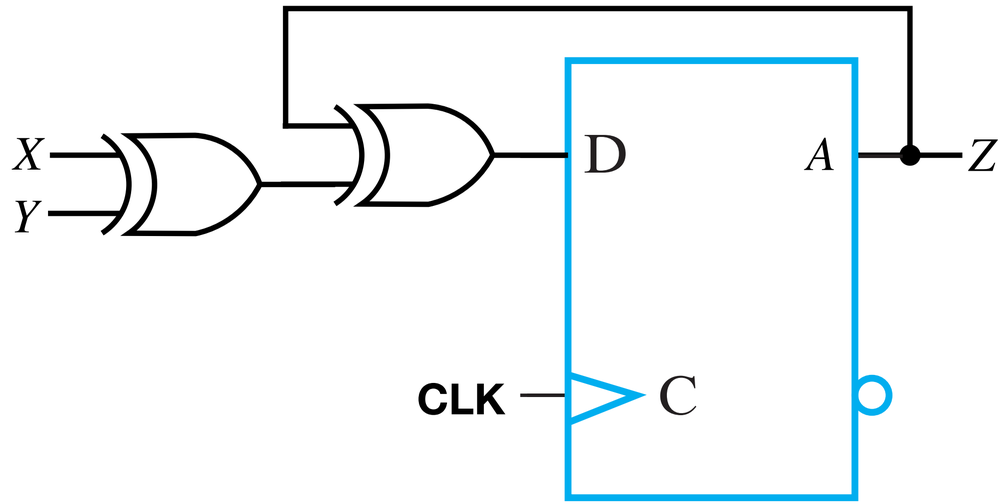
Concept

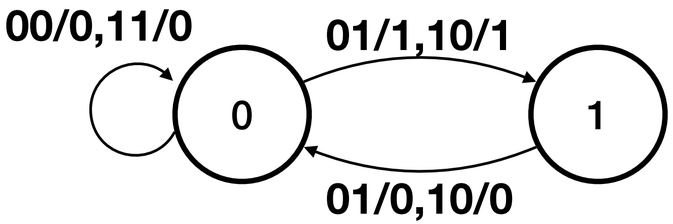
P1
Analysis

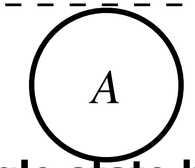
State Diagram

State Table

Present State	X	Y	Next State	F
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	0
1	0	0	1	1
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1







A single state bubble

A single link

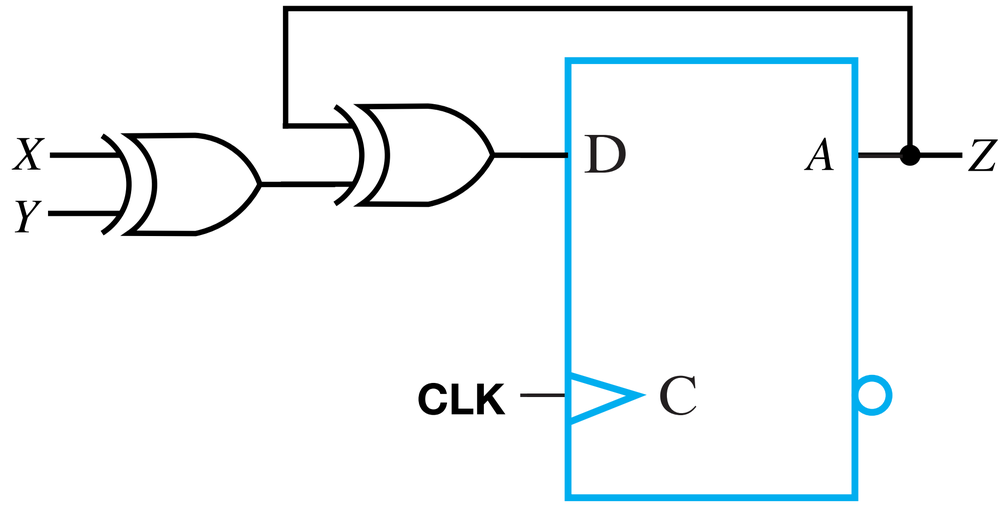
Concept

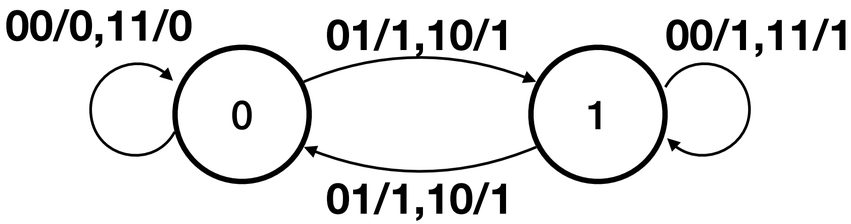
P1
Analysis

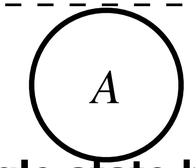
State Diagram

State Table

Present State	X	Y	Next State	F
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	0
1	0	0	1	1
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1







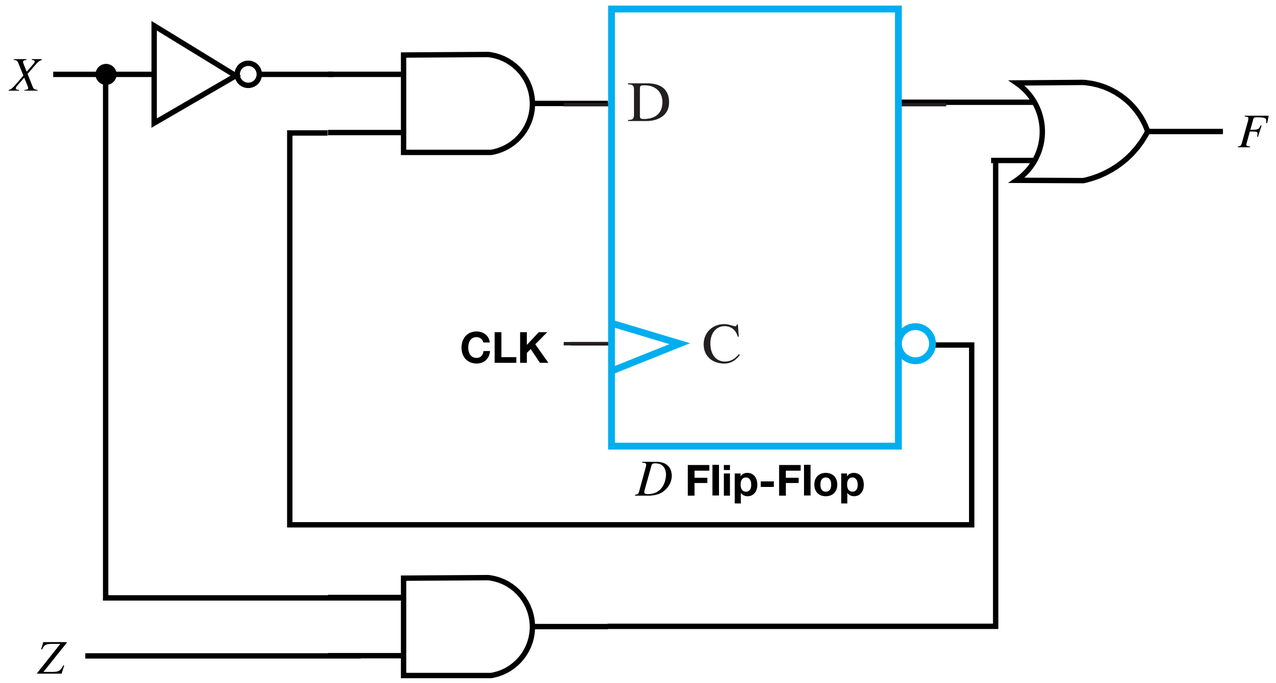
A single state bubble

A single link

Concept

P1
Analysis

State Diagram



Example

P1
Analysis

State Diagram

- Draw the state diagram for: $D_A = \overline{X}A + XY$, $D_B = \overline{X}B + XA$, $Z = XB$

Exercise

P1
Analysis

In Class Exercise 1

- A circuit with one D flip-flop: $D_A = A \oplus X$
- Draw the state diagram

State Table

Present State	X	Next State
0	0	0
0	1	1
1	0	1
1	1	0

Exercise

P1
Analysis

In Class Exercise 2

- A circuit with 2 D flip-flops: $D_A = A \oplus B$, $D_B = \overline{B} \cdot X$, $F = \overline{A}B$
- Do the state diagram

State Table

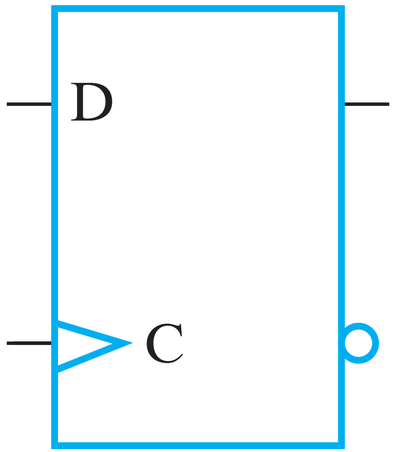
Present State		X	Next State		F
A	B		A	B	
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	1	0	1
0	1	1	1	0	1
1	0	0	1	0	0
1	0	1	1	1	0
1	1	0	0	0	0
1	1	1	0	0	0

Exercise

P1
Analysis

LogicWorks Exercise

- Implement D flip flop using D latch and SR latch
  Save it as a component in your library
- Implement circuit $D_S = X \oplus Y \oplus S$, where D_S is a D flip flop
- Implement $D_A = \overline{X}A + XY$, $D_B = \overline{X}B + XA$, $Z = XB$
- Draw the state table and diagram, and verify your table with LogicWorks



Exercise

P2
Design

Sequential Circuit Design I

8 Step Design Procedures; Formulation

Summary

P2
Design

Systematic Design Procedures Combinational Circuits

1. **Specification**
2. **Formulation**
3. **Optimisation**
4. **Technology Mapping**
5. **Verification**

Review

P2
Design

Systematic Design Procedures
Sequential Circuits

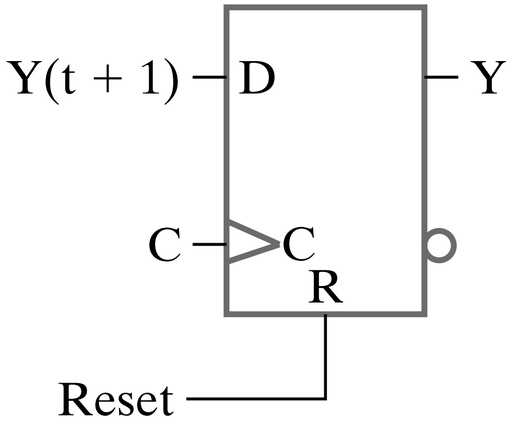
1. **Specification**
2. **Formulation**
   e.g. using state table or state diagram
   TODAY'S FOCUS
3. **State Assignment**: assign binary codes to states
4. **Flip-Flop Input Equation Determination**: Select flip-flop types, derive input equations from next-state entries
5. **Output Equation Determination**: Derive output equations from the output entries
6. **Optimisation**
7. **Technology Mapping**
8. **Verification**

Concept

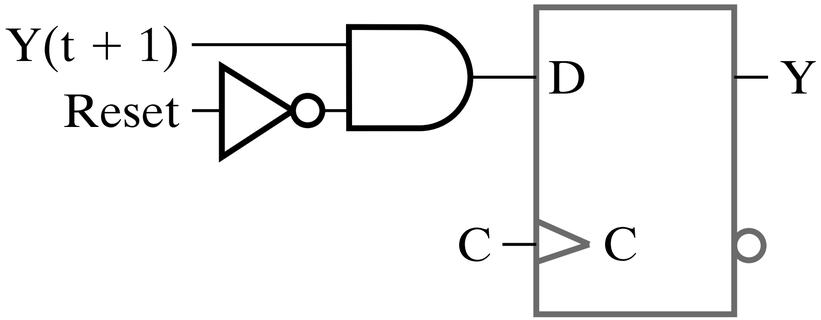
0. Reset

- When the power was first turned on, the states in flip-flops are all unknown
  This requires resetting!

- Flip-Flops with Reset



(a) Asynchronous Reset



(b) Synchronous Reset

-

Concept

P2
Design

0. Reset

- In reality, all storage devices in a computer has a Reset mode for easy reseting to all 1s or all 0s
- e.g. C: `memset( void* ptr, int value, size_t num);`
  Fill blocks of memory

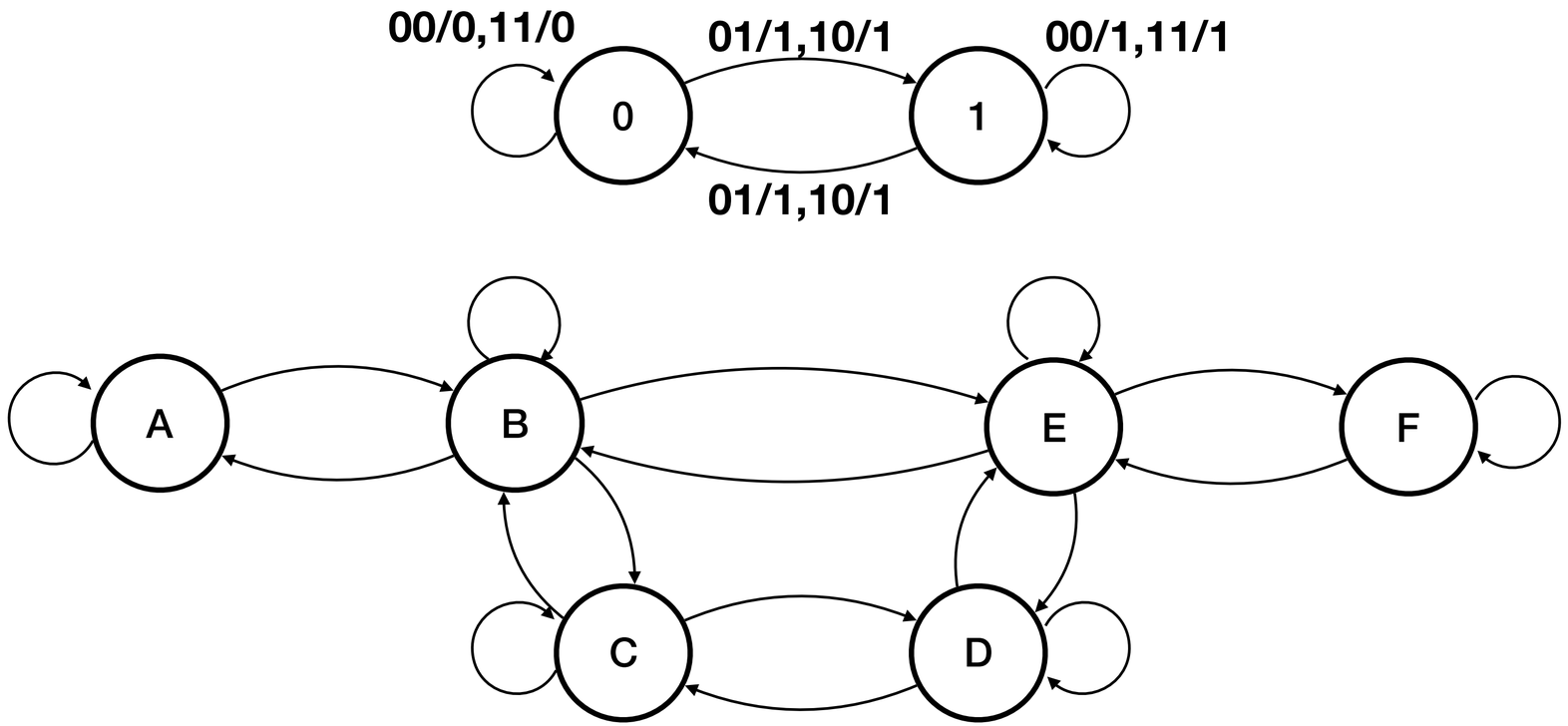
Concept

1. Specification

- Same as combinational

2. Formulation

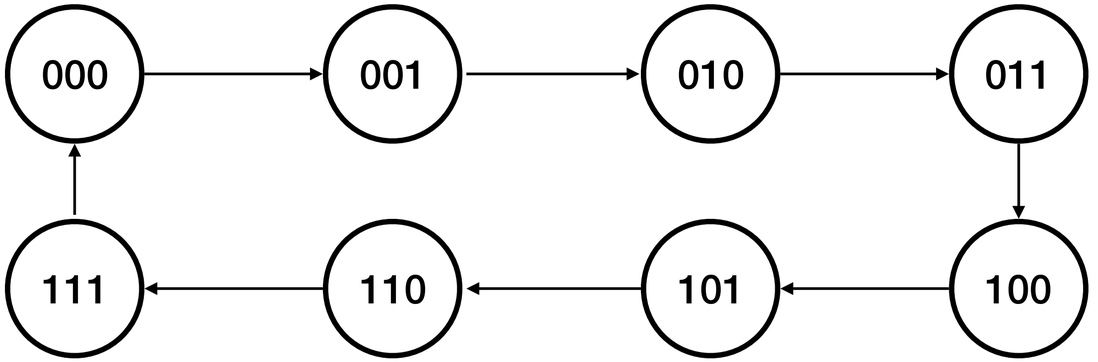
- Sometimes it is more intuitive to describe state transitions then defining the states



P2
Design

2. Formulation

- Incrementer: perform +1 operation every `CLK` on 3-bit

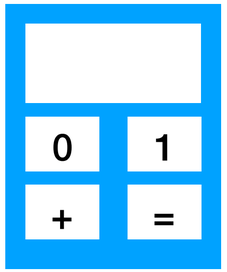


Example

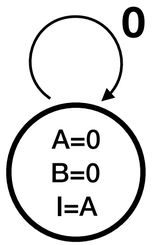
P2
Design

2. Formulation

- Simple 1-bit binary calculator
- Input: 0 button, 1 button, Add button, Equ button
- Storage: A, B: variables; I: operator



First Input



Example

P2
Design

2. Formulation

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- Input: 0 button, 1 button, Add button, Equ button
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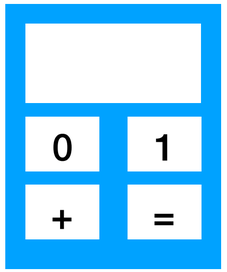
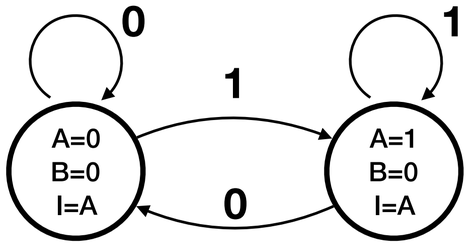


First Input

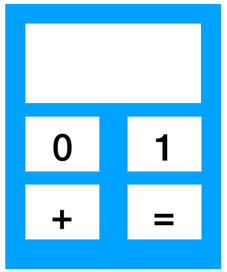


Example

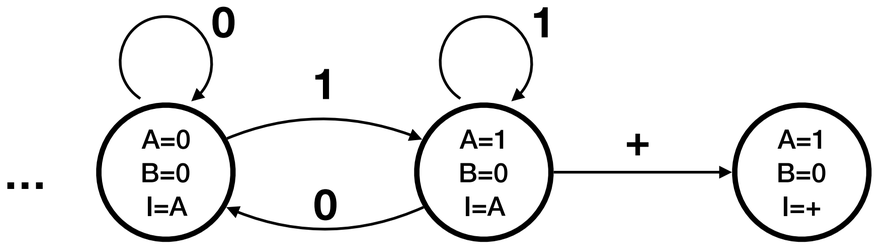
P2
Design

2. Formulation

- Simple 1-bit binary calculator
- Input: 0 button, 1 button, Add button, Equ button
- Storage: A, B: variables; I: operator



After first input, press add

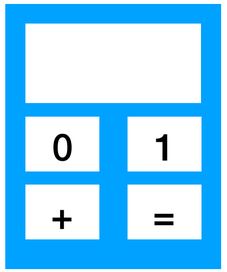


Example

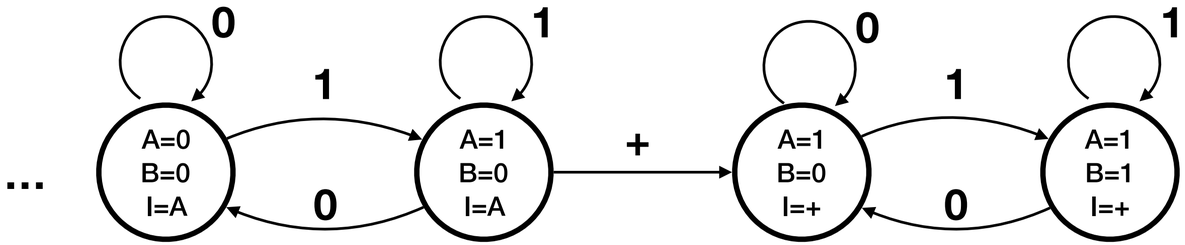
P2
Design

2. Formulation

- Simple 1-bit binary calculator
- Input: 0 button, 1 button, Add button, Equ button
- Storage: A, B: variables; I: operator



Second input

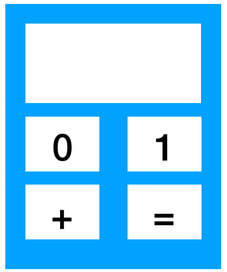


Example

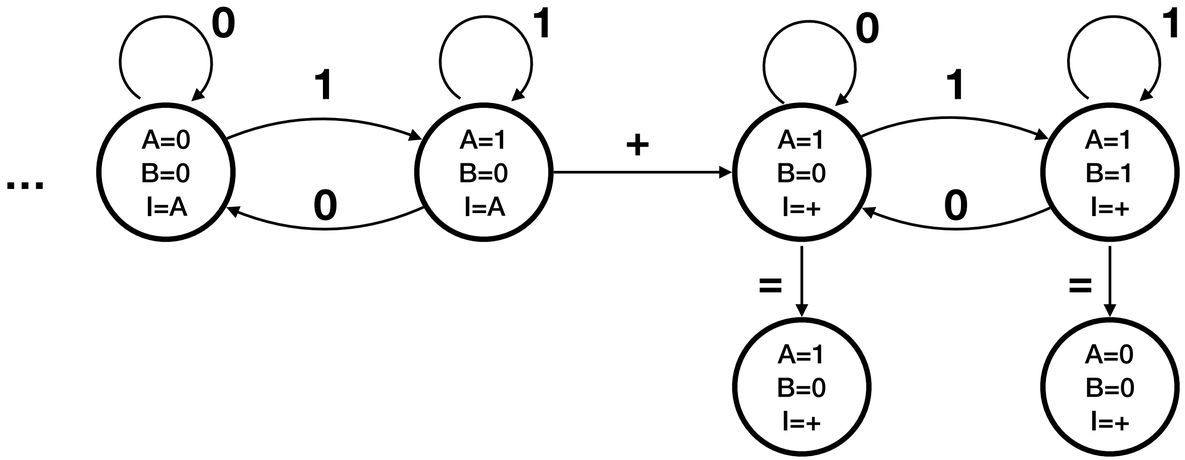
P2
Design

2. Formulation

- Simple 1-bit binary calculator
- Input: 0 button, 1 button, Add button, Equ button
- Storage: A, B: variables; I: operator



Get result



Example

P2
Design

2. Formulation

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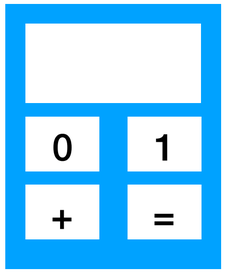
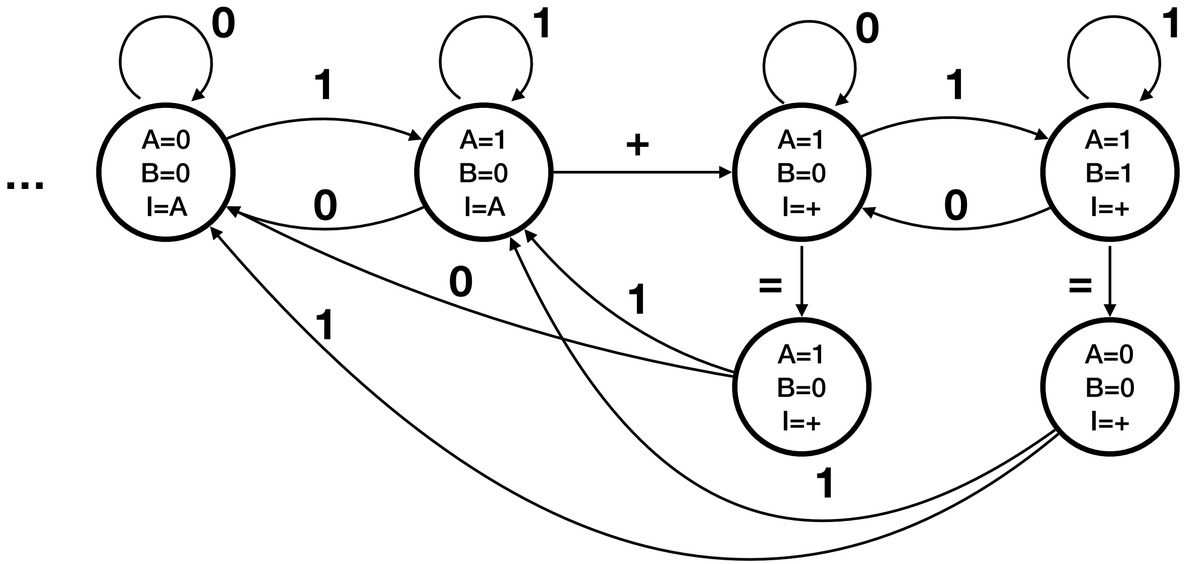


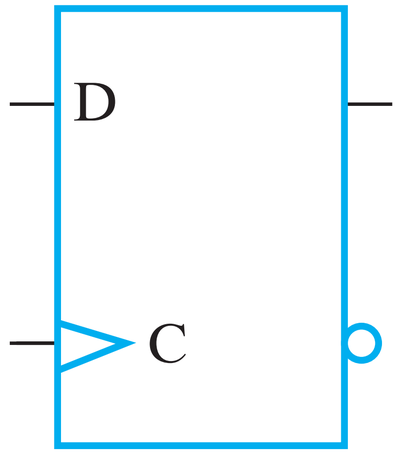
Next calculation



Example

Exercise

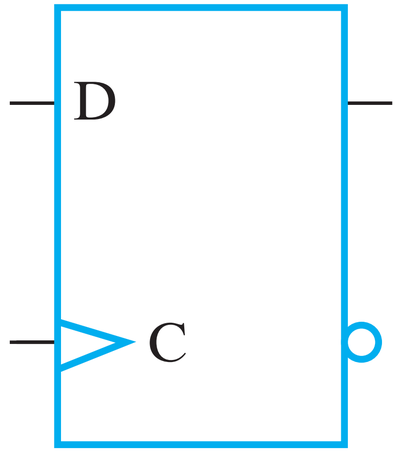
- Draw the state diagram of 3-bit incrementer/decrementer
  - Input X: 0 for increment, 1 for decrement
- Do the state table



Exercise

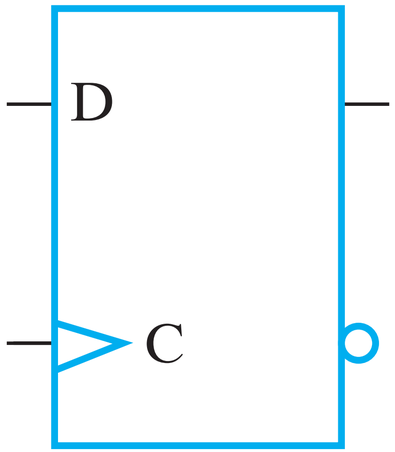
Exercise

- Draw the state diagram of rotator
  - Start state $X_3X_2X_1X_0$: original 4-bit
  - Input Y:
    0 for left rotation (output $X_2X_1X_0X_3$);
    1 for right rotation (output $X_0X_3X_2X_1$);
  - Every CLK triggers a shift



Exercise

- Draw the state diagram of rotator
  - Start state $X_3X_2X_1X_0$: original 4-bit
  - Input Y:
    0 for left rotation (output $X_2X_1X_0X_3$);
    1 for right rotation (output $X_0X_3X_2X_1$);
  - Every CLK triggers a shift
- Try to write down the equations for each flip-flop, treat X_i as constants. Implement in LogicWorks



Exercise