# ECED2200 – Digital Circuits

Sequential Logic

# General Notes

- See updates to these slides: www.newae.com/teaching
- These slides licensed under 'Creative Commons Attribution-ShareAlike 3.0 Unported License'
- These slides are not the complete course – they are extended in-class
- You will find the following references useful, see www.newae.com/teaching for more information/links:
  - The book "Bebop to the Boolean Boogie" which is available to Dalhousie Students
  - Course notes (covers almost everything we will discuss in class)
  - Various websites such as e.g.: www.play-hookey.com
  - The book "Contemporary Logic Design", which was used in previous iterations of the class and you may have already

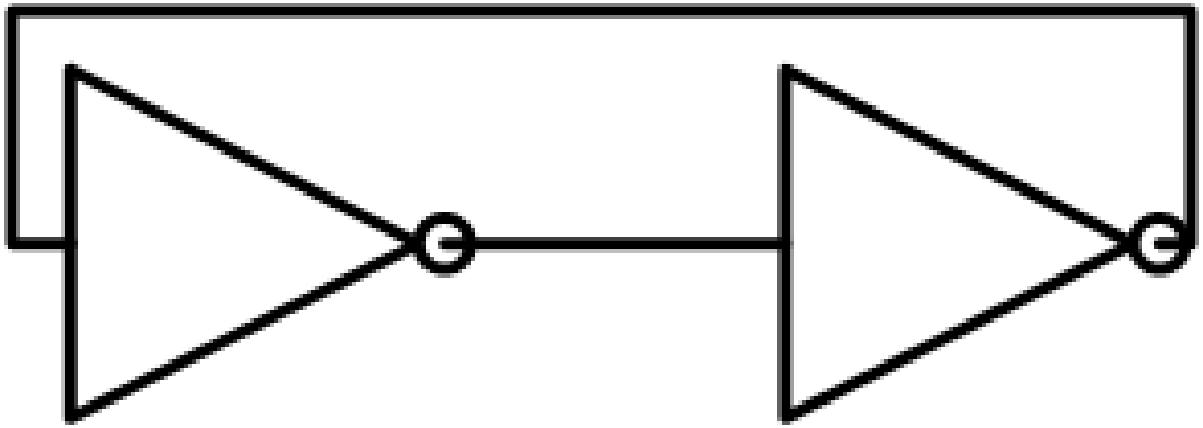
# Combinational Logic

# Sequential Logic

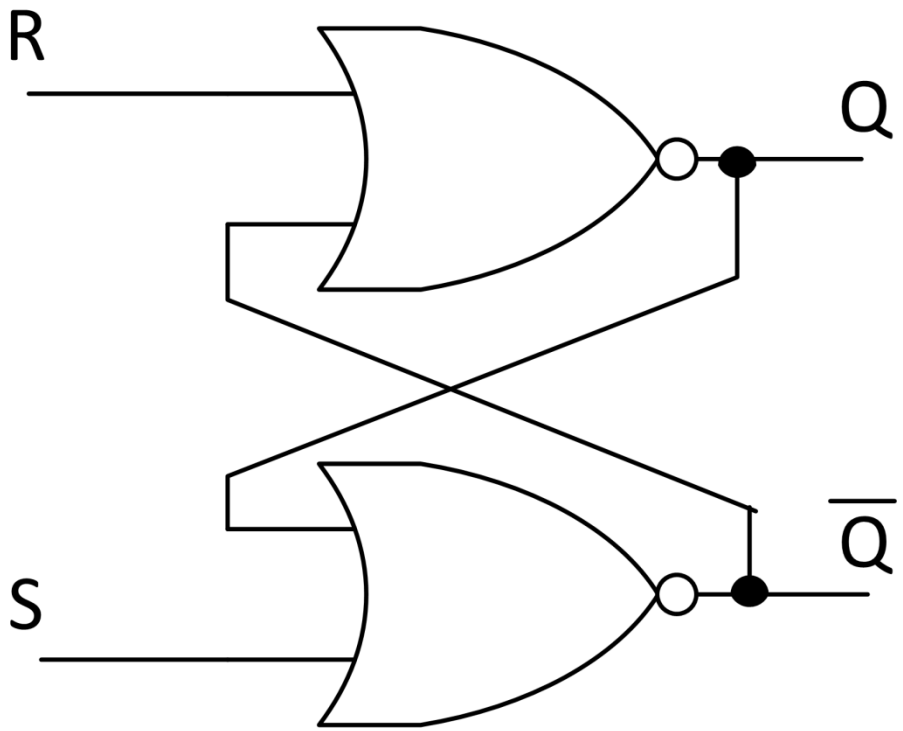
# Combinational vs Sequential

- Output of combinational logic depends ONLY on current inputs
- Output of sequential logic depends on internal state

# Basic State Storage Element

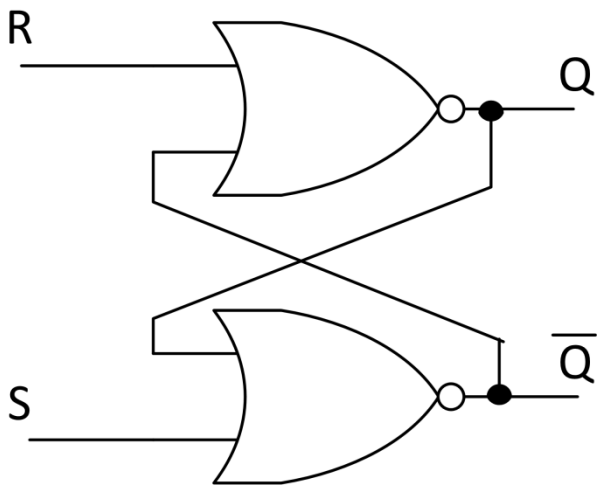


# Reset / Set (RS) Latch



# RS Latch Experiments

| $Q_-$ | S | R | $\overline{Q}^+$ | $Q^+$ |
|---|---|---|---|---|
| 0 | 0 | 0 | 1 | 0 |
| 0 | 1 | 0 | | |
| | 1 | 0 | | |
| | 0 | 0 | | |
| | 1 | 0 | | |
| | 0 | 0 | | |
| | 0 | 1 | | |
| | 0 | 1 | | |
| | 0 | 0 | | |
| | 1 | 1 | | |

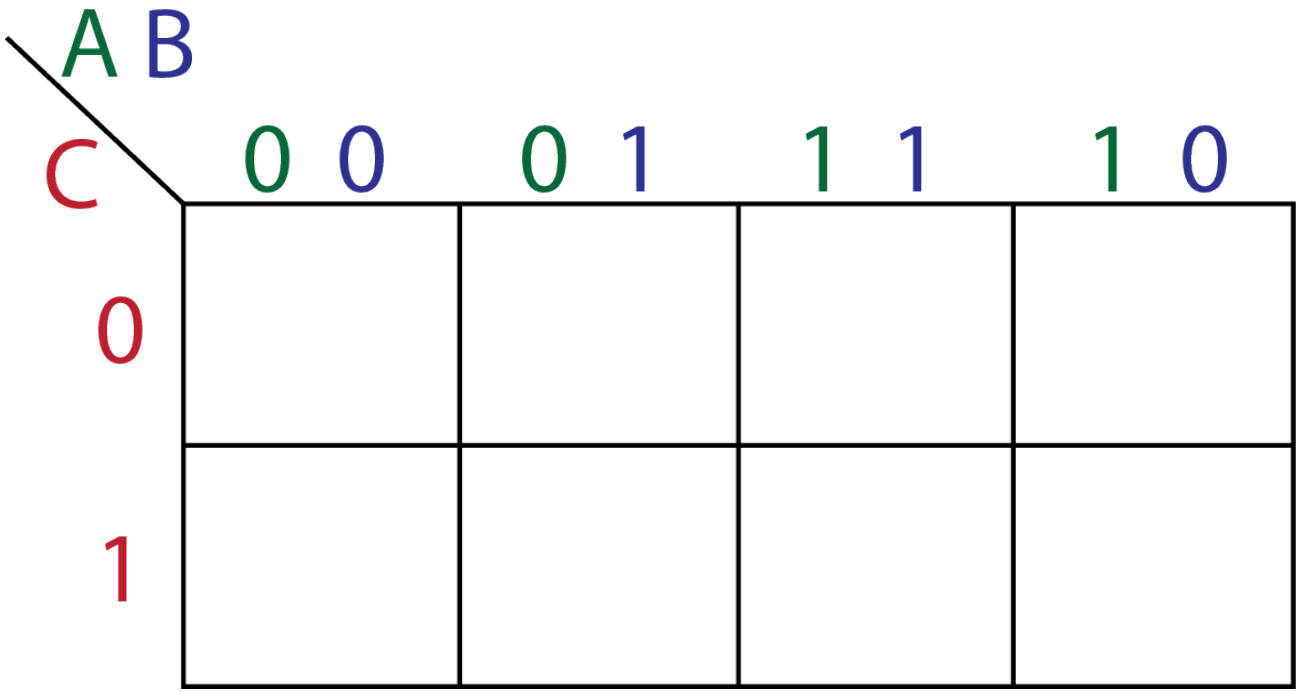


# RS Latch Truth Table

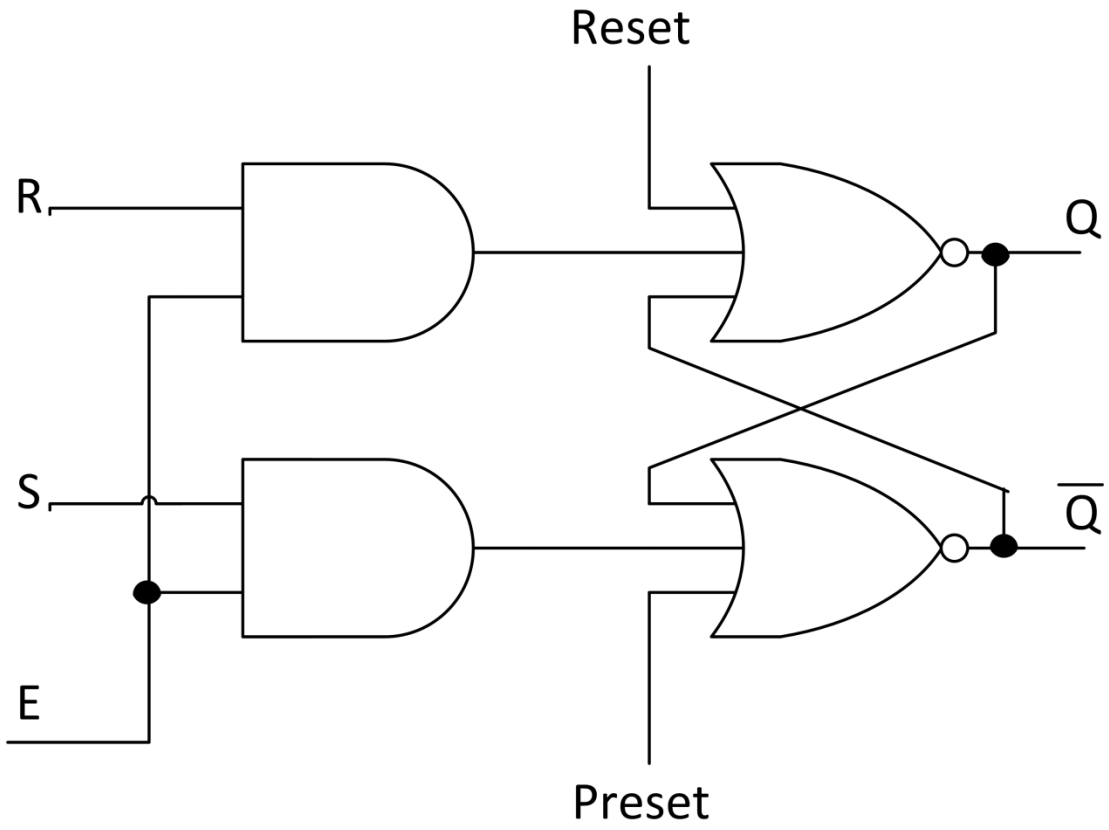
| S | R | Q | $Q^+$ | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | Hold |
| 0 | 0 | 1 | 1 | |
| 0 | 1 | 0 | 0 | Reset |
| 0 | 1 | 1 | 0 | |
| 1 | 0 | 0 | 1 | Set |
| 1 | 0 | 1 | 1 | |
| 1 | 1 | 0 | X | ??? |
| 1 | 1 | 1 | X | |

# Equation of RS Latch

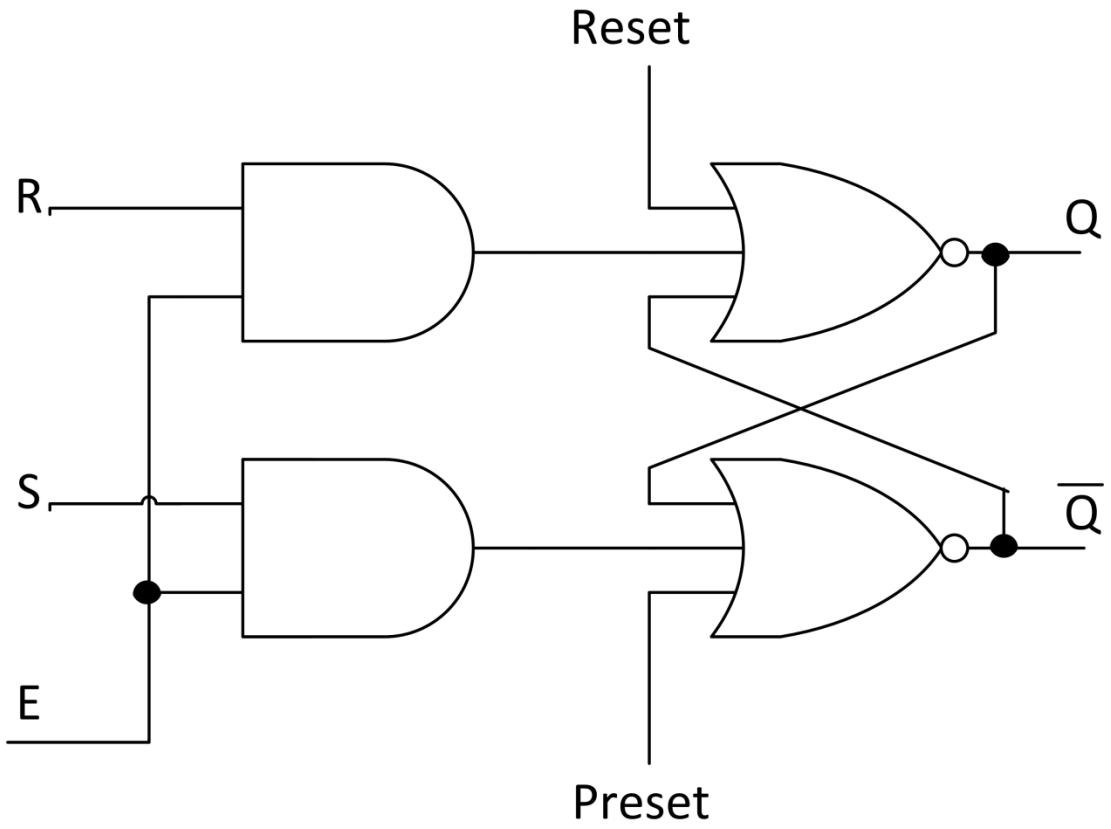
| R | S | Q | $Q^+$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 |
| 1 | 0 | 0 | 1 |
| 1 | 0 | 1 | 1 |
| 1 | 1 | 0 | X |
| 1 | 1 | 1 | X |



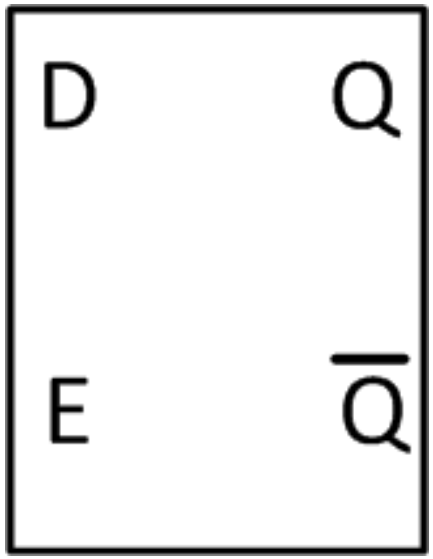
# Additional Inputs



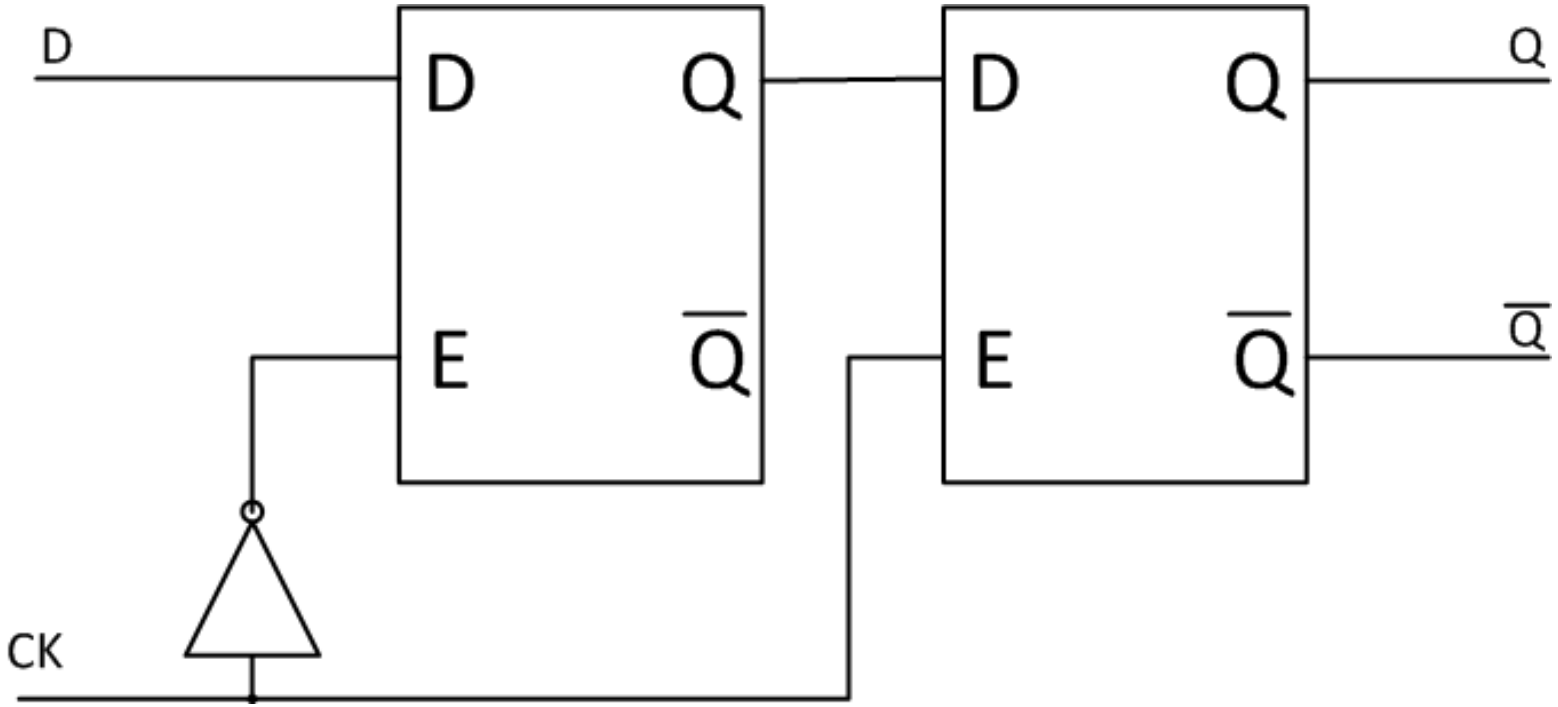
# Data Latch



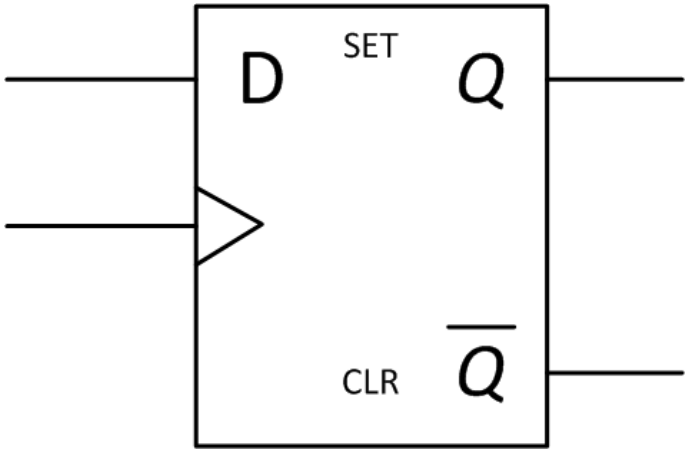
# Data Latch Symbol

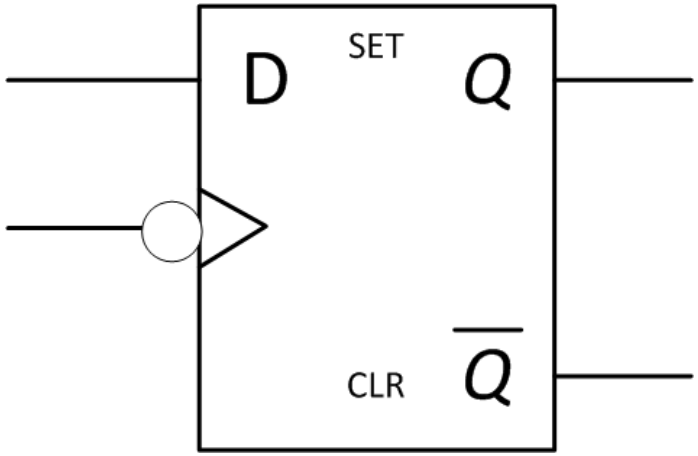


# D Flip-Flop

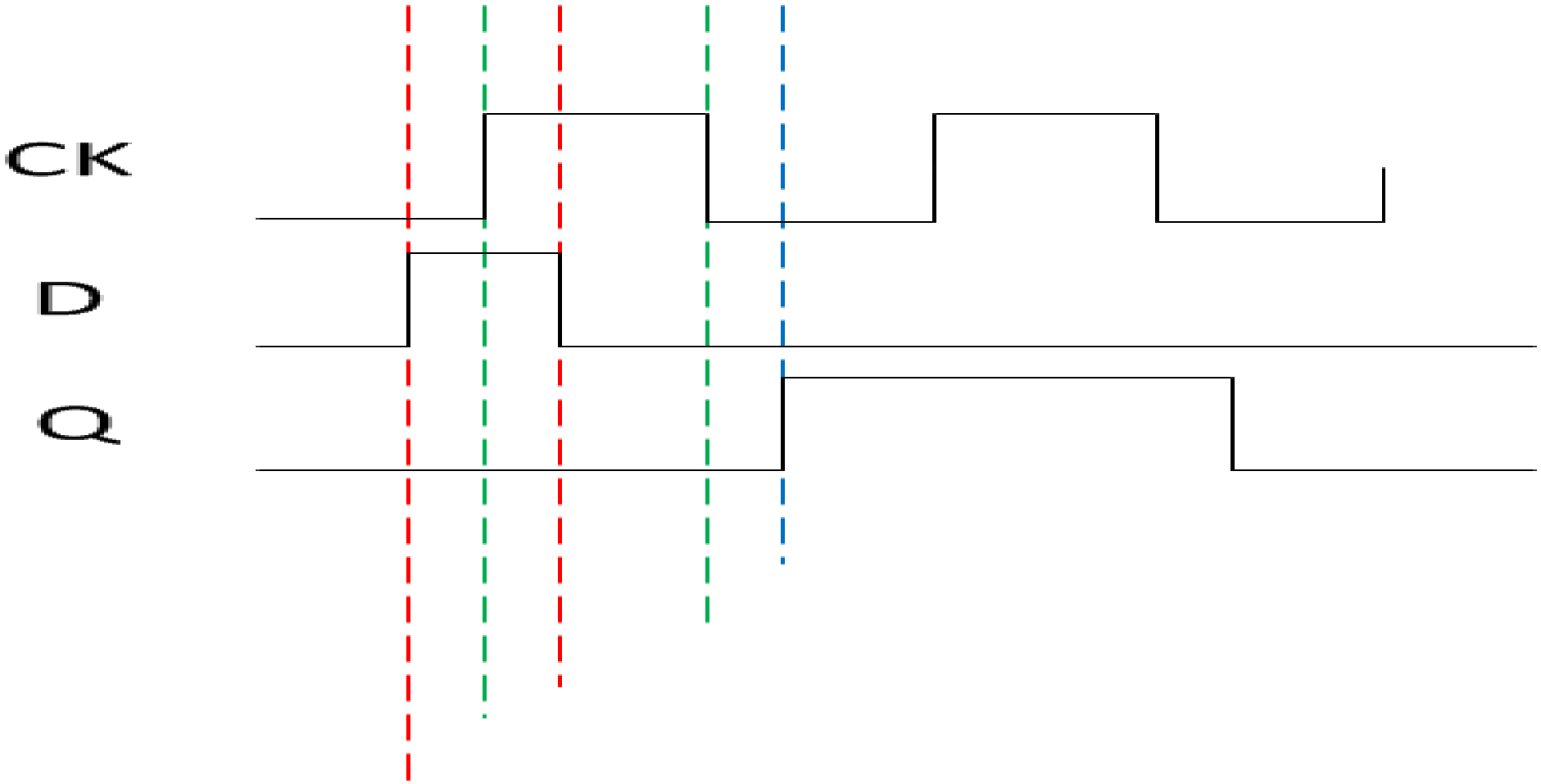


# Flip-Flops

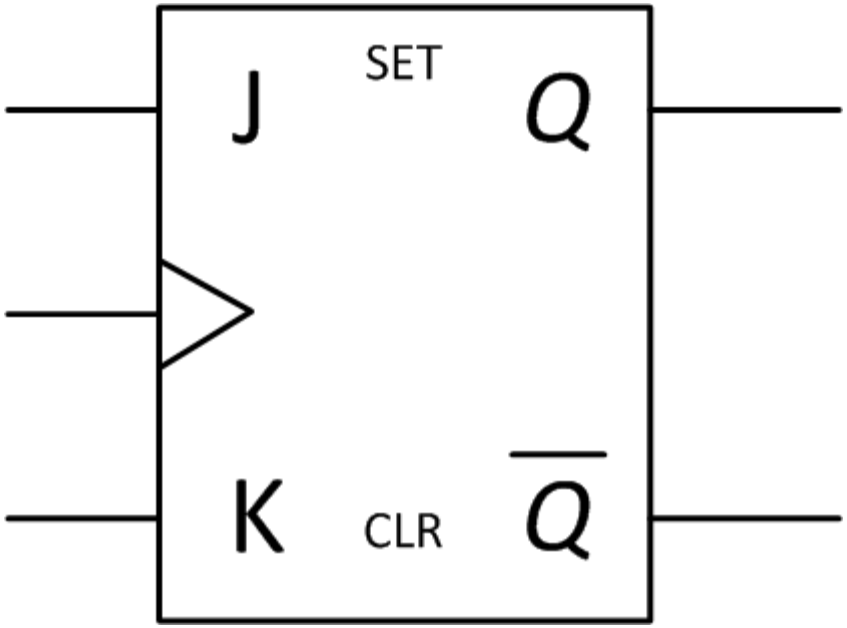


# Timing in Flip-Flops



# The JK Flip Flop

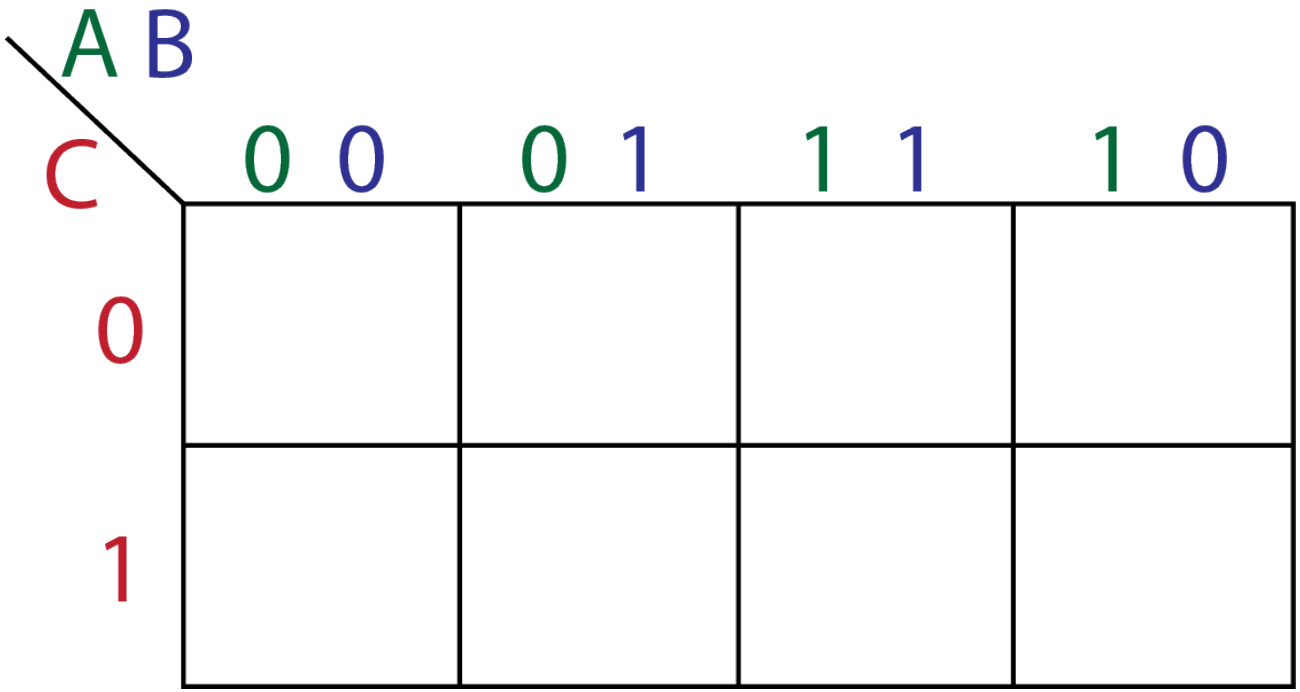


# JK Flip Flop Truth Table

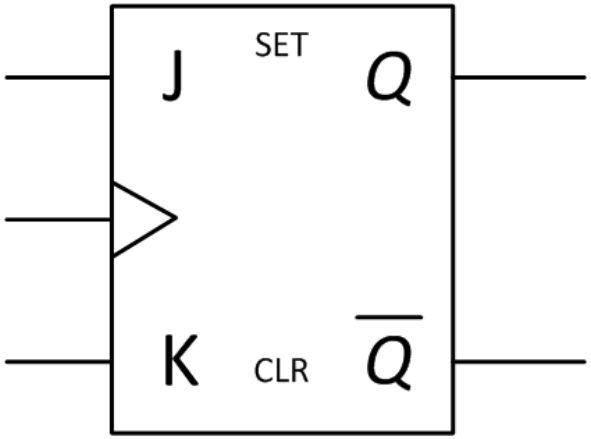
| J | K | Q | $Q^+$ | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | Hold |
| 0 | 0 | 1 | 1 | |
| 0 | 1 | 0 | 0 | Reset |
| 0 | 1 | 1 | 0 | |
| 1 | 0 | 0 | 1 | Set |
| 1 | 0 | 1 | 1 | |
| 1 | 1 | 0 | 1 | Toggle |
| 1 | 1 | 1 | 0 | |

# Equation of JK Flip-Flop

| J | K | Q | $Q^+$ |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 0 | 1 | 1 |
| 0 | 1 | 0 | 0 |
| 0 | 1 | 1 | 0 |
| 1 | 0 | 0 | 1 |
| 1 | 0 | 1 | 1 |
| 1 | 1 | 0 | 1 |
| 1 | 1 | 1 | 0 |

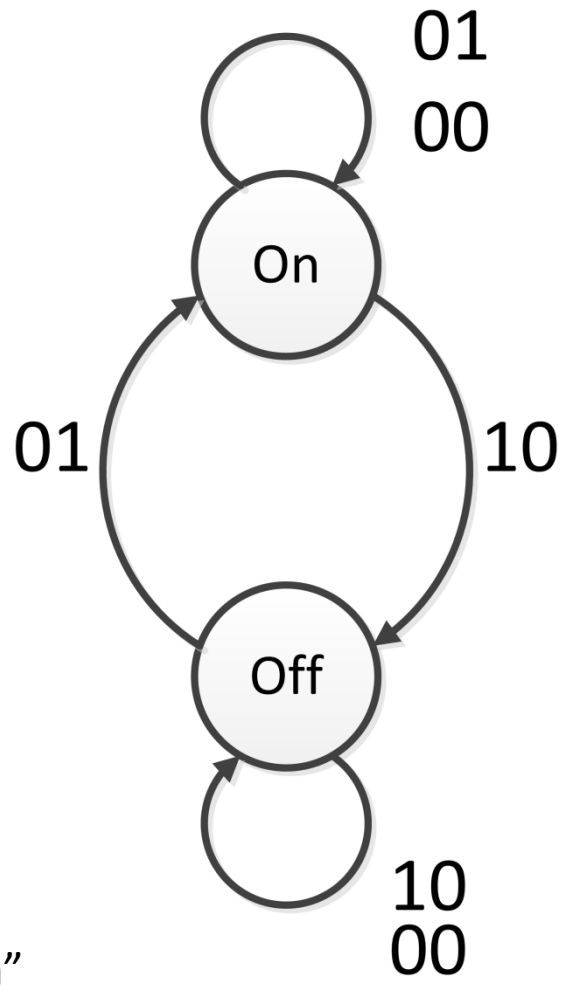


# Toggle (T) Flip Flop



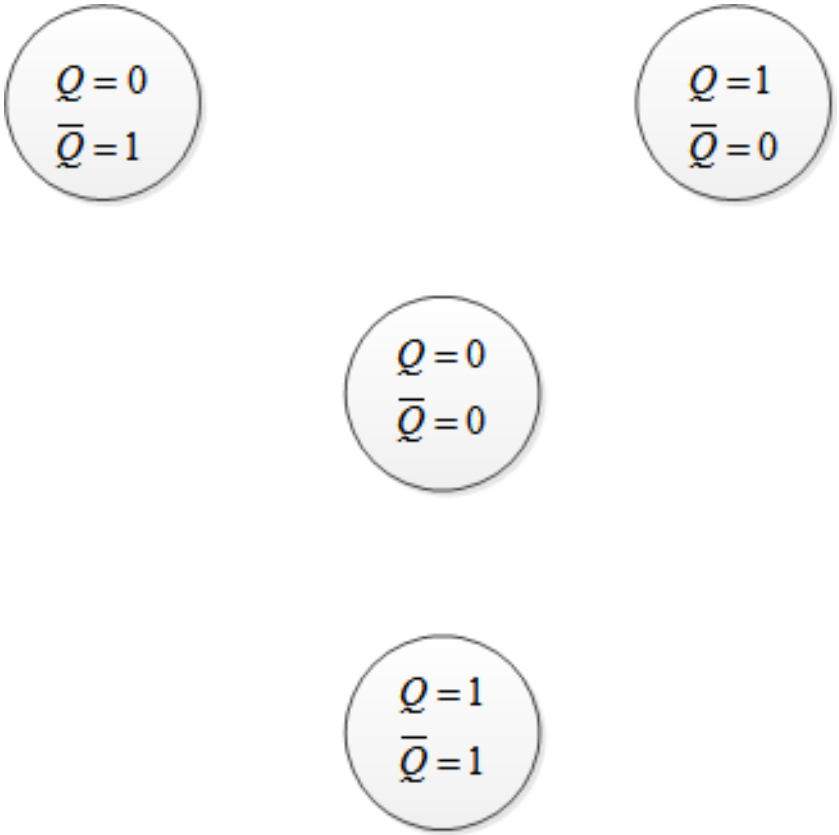
# DESCRIBING FF STATE TRANSITIONS

# State Diagram




State = “Off Button” “On Button”
e.g.: 01 = on button pressed

# RS State Diagram



# State Transition Table - RS

| Q | $Q^+$ | | |
|---|---|---|---|
| 0 | 0 | | |
| 0 | 1 | | |
| 1 | 0 | | |
| 1 | 1 | | |

# State Transition Table - RS

| Q | $Q^+$ | R | S |
|---|---|---|---|
| 0 | 0 | ? | 0 |
| 0 | 1 | 0 | 1 |
| 1 | 0 | 1 | 0 |
| 1 | 1 | 0 | ? |

# State Transition Table - D

| Q | $Q^+$ | | |
|---|---|---|---|
| 0 | 0 | | |
| 0 | 1 | | |
| 1 | 0 | | |
| 1 | 1 | | |

# State Transition Table - D

| Q | $Q^+$ | D | |
|---|---|---|---|
| 0 | 0 | 0 | |
| 0 | 1 | 1 | |
| 1 | 0 | 0 | |
| 1 | 1 | 1 | |

# State Transition Table - JK

| Q | $Q^+$ | | |
|---|---|---|---|
| 0 | 0 | | |
| 0 | 1 | | |
| 1 | 0 | | |
| 1 | 1 | | |

# State Transition Table - JK

| Q | $Q^+$ | J | K |
|---|---|---|---|
| 0 | 0 | 0 | ? |
| 0 | 1 | 1 | ? |
| 1 | 0 | ? | 1 |
| 1 | 1 | ? | 0 |

# State Transition Table - T

| Q | $Q^+$ | | |
|---|---|---|---|
| 0 | 0 | | |
| 0 | 1 | | |
| 1 | 0 | | |
| 1 | 1 | | |

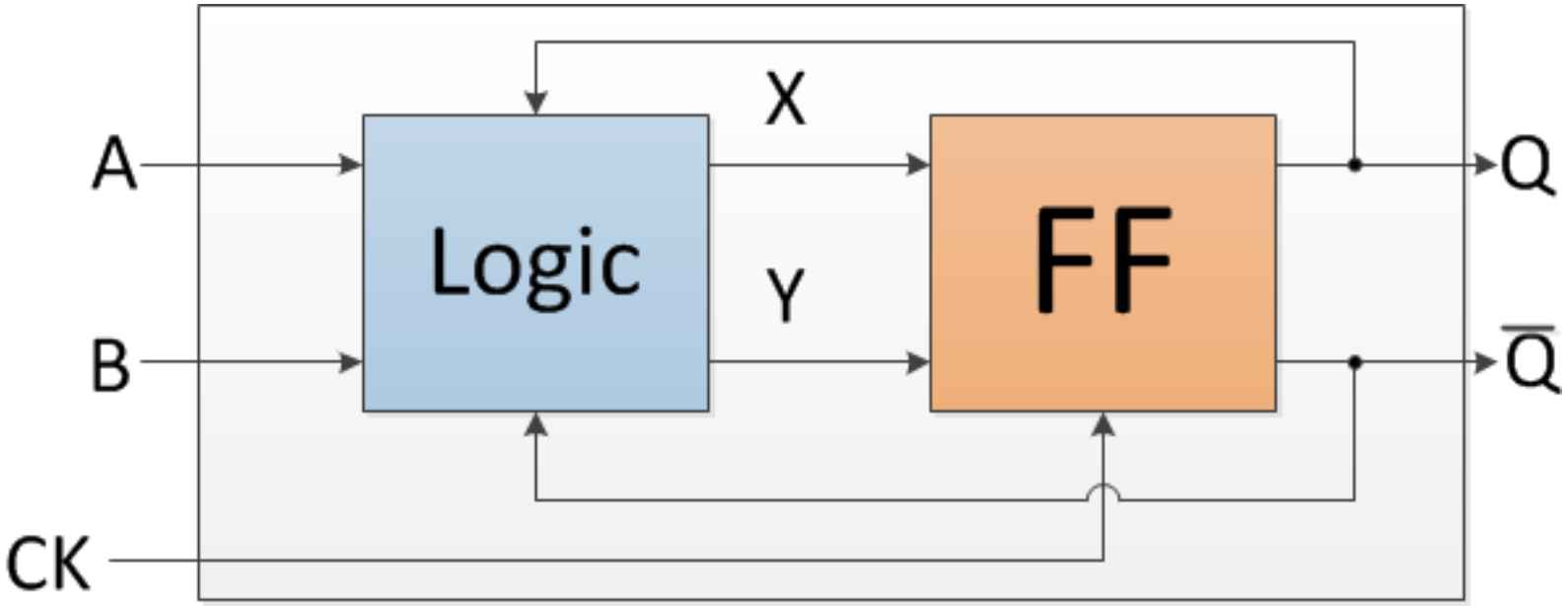
# State Transition Table - T

| Q | $Q^+$ | T | |
|---|---|---|---|
| 0 | 0 | 0 | |
| 0 | 1 | 1 | |
| 1 | 0 | 1 | |
| 1 | 1 | 0 | |

# State Transition Table - Master

| Q | $Q^+$ | R | S | D | J | K | T |
|---|---|---|---|---|---|---|---|
| 0 | 0 | ? | 0 | 0 | 0 | ? | 0 |
| 0 | 1 | 0 | 1 | 1 | 1 | ? | 1 |
| 1 | 0 | 1 | 0 | 0 | ? | 1 | 1 |
| 1 | 1 | 0 | ? | 1 | ? | 0 | 0 |

# Conversion of FF Types



# Example: JK with D

| Q | $Q^+$ | D | J | K |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | ? |
| 0 | 1 | 1 | 1 | ? |
| 1 | 0 | 0 | ? | 1 |
| 1 | 1 | 1 | ? | 0 |

# Example: JK with D

| Q | $Q^+$ | D | J | K |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | ? |
| 0 | 1 | 1 | 1 | ? |
| 1 | 0 | 0 | ? | 1 |
| 1 | 1 | 1 | ? | 0 |

| Q | D | J | K |
|---|---|---|---|
| 0 | 0 | 0 | ? |
| 0 | 1 | 1 | ? |
| 1 | 0 | ? | 1 |
| 1 | 1 | ? | 0 |

| Q | J | K | D |
|---|---|---|---|
| 0 | 0 | ? | 0 |
| 0 | 1 | ? | 1 |
| 1 | ? | 1 | 0 |
| 1 | ? | 0 | 1 |

# Example: JK with D

| Q | J | K | D |
|---|---|---|---|
| 0 | 0 | ? | 0 |
| 0 | 1 | ? | 1 |
| 1 | ? | 1 | 0 |
| 1 | ? | 0 | 1 |

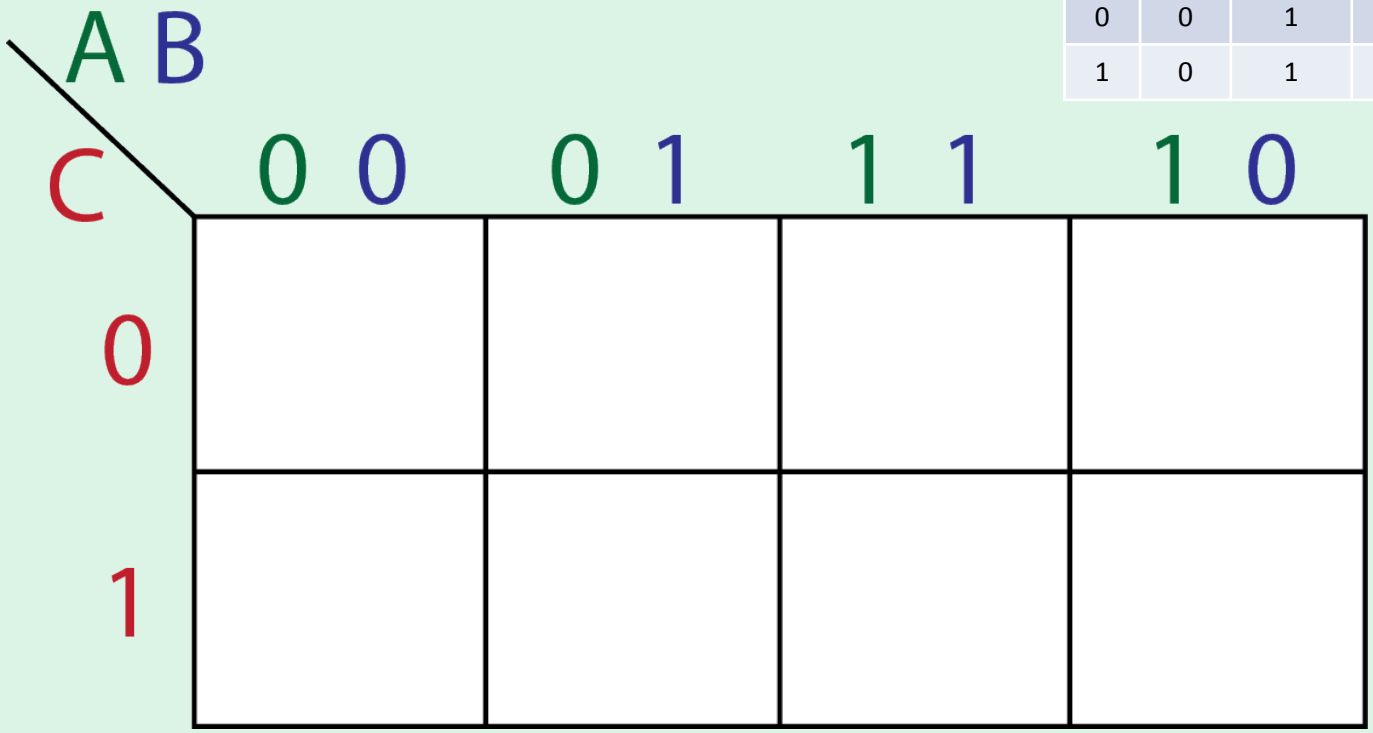
| J | K | Q | D (out) |
|---|---|---|---|
| 0 | ? | 0 | 0 |
| | | | |
| 1 | ? | 0 | 1 |
| | | | |
| ? | 1 | 1 | 0 |
| | | | |
| ? | 0 | 1 | 1 |

# Example: JK with D

| J | K | Q | D (out) |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 0 | 1 |
| 0 | 1 | 1 | 0 |
| 1 | 1 | 1 | 0 |
| 0 | 0 | 1 | 1 |
| 1 | 0 | 1 | 1 |

# Example: JK with D

| J | K | Q | D (out) |
|---|---|---|---|
| 0 | 0 | 0 | 0 |
| 0 | 1 | 0 | 0 |
| 1 | 0 | 0 | 1 |
| 1 | 1 | 0 | 1 |
| 0 | 1 | 1 | 0 |
| 1 | 1 | 1 | 0 |
| 0 | 0 | 1 | 1 |
| 1 | 0 | 1 | 1 |




$$D = J \bullet \overline{Q} + \overline{K} \bullet Q$$

# Example: JK with D

# Example: D with JK

| Q | $Q^+$ | D | J | K |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | ? |
| 0 | 1 | 1 | 1 | ? |
| 1 | 0 | 0 | ? | 1 |
| 1 | 1 | 1 | ? | 0 |

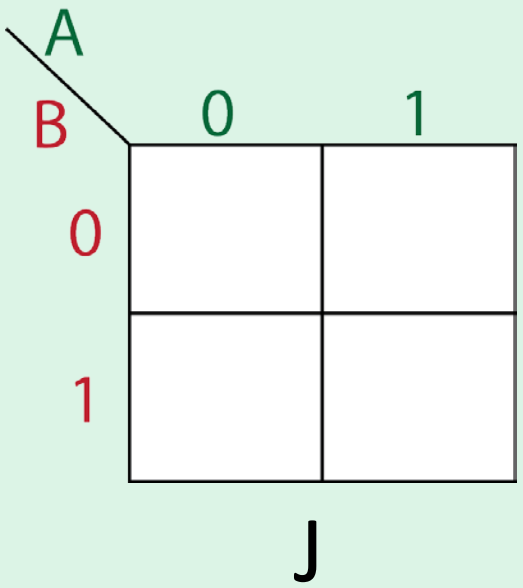
# Example: D with JK

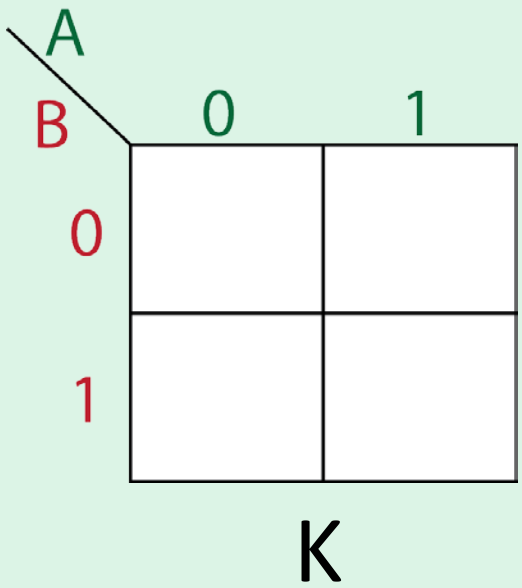
| Q | $Q^+$ | D | J | K |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | ? |
| 0 | 1 | 1 | 1 | ? |
| 1 | 0 | 0 | ? | 1 |
| 1 | 1 | 1 | ? | 0 |

| Q | D | J | K |
|---|---|---|---|
| 0 | 0 | 0 | ? |
| 0 | 1 | 1 | ? |
| 1 | 0 | ? | 1 |
| 1 | 1 | ? | 0 |

# Example: D with JK

| D | Q | J (out) | K (out) |
|---|---|---|---|
| 0 | 0 | 0 | ? |
| 1 | 0 | 1 | ? |
| 0 | 1 | ? | 1 |
| 1 | 1 | ? | 0 |



# Example: D with JK

# FF Conversion Process

1. Draw out a truth table where the input(s) are your input(s) for the FF you are creating + current state Q, and the output(s) are the required inputs to the FF you have
2. Fill out the outputs based on the state transition table
3. Move to a K-Map
4. Create logic expressions

# Summary

ECED Notes “Sequential Logic Design”

Bebop to the Boolean Boogie Chapter 11