



Sequential Circuits

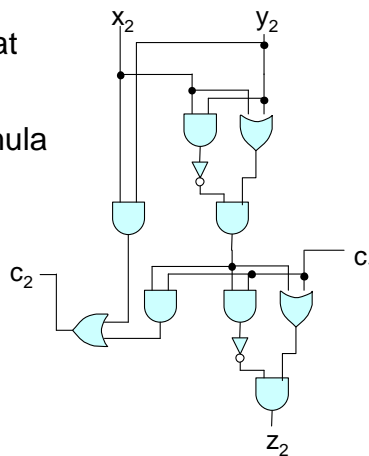
CS 217

1



Combinational circuit

- Directed *acyclic* graph (no loops)
- Outputs, at any given time, dependent only on inputs at that time (after *signal propagation*)
- Equivalent to one boolean formula per output

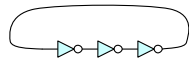


2

Cycles in the circuit



- What happens if there are cycles?

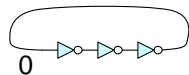


3

Cycles in the circuit



- Simulate . . .

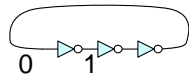


4

Cycles in the circuit



- Simulate . . .

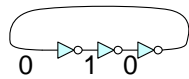


5

Cycles in the circuit



- Simulate . . .

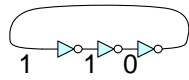


6

Cycles in the circuit



- Simulate . . .

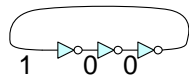


7

Cycles in the circuit



- Simulate . . .

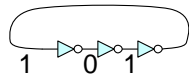


8

Cycles in the circuit



- Simulate . . .

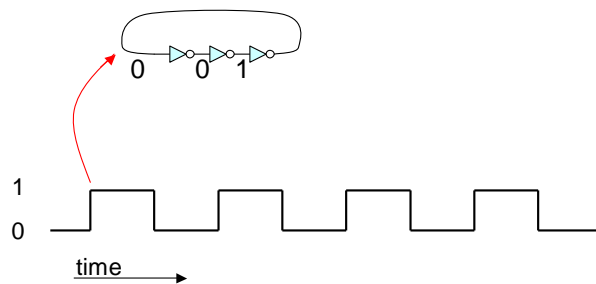


9

Cycles in the circuit



- Simulate . . .



Outputs, at any given time, dependent ***not*** only on inputs at that time; also dependent on history. A “sequential” circuit.

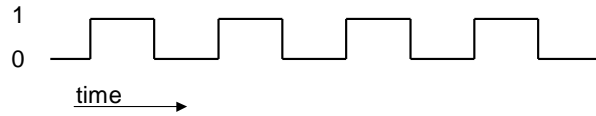
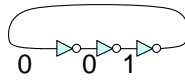
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Another circuit with cycles



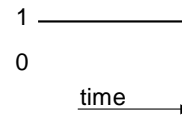
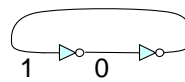
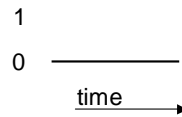
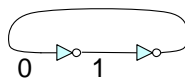
Three inverters:

astable



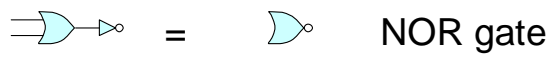
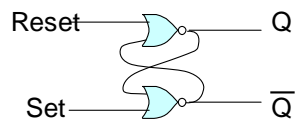
Two inverters:

bistable



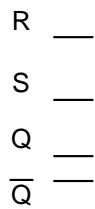
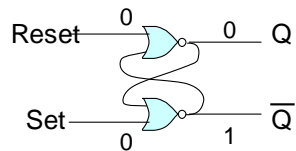
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R-S Latch



12

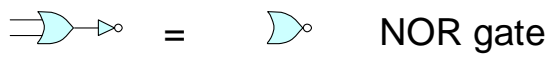
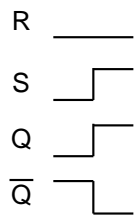
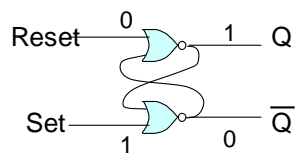
R-S Latch



NOR gate

13

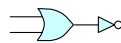
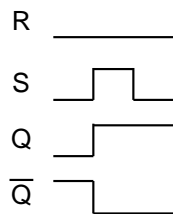
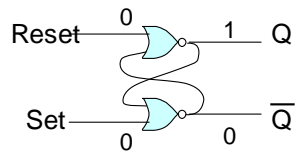
R-S Latch



NOR gate

14

R-S Latch



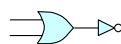
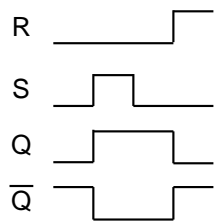
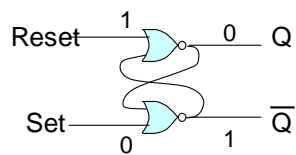
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NOR gate

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R-S Latch



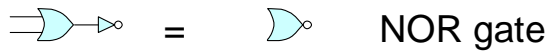
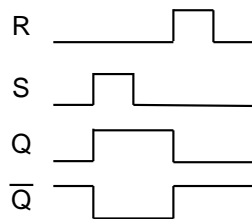
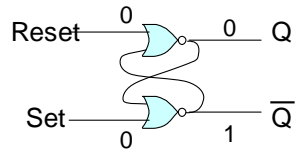
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NOR gate

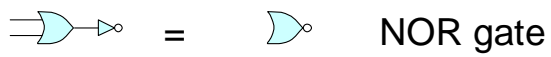
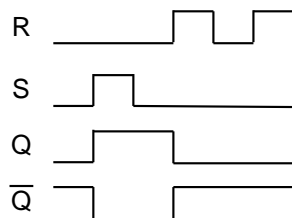
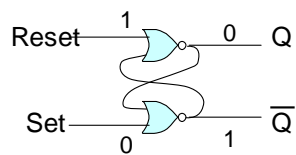
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R-S Latch



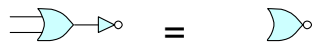
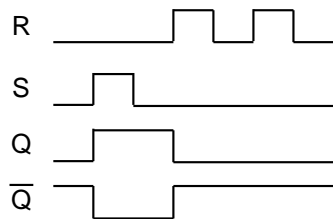
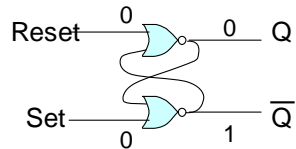
17

R-S Latch



18

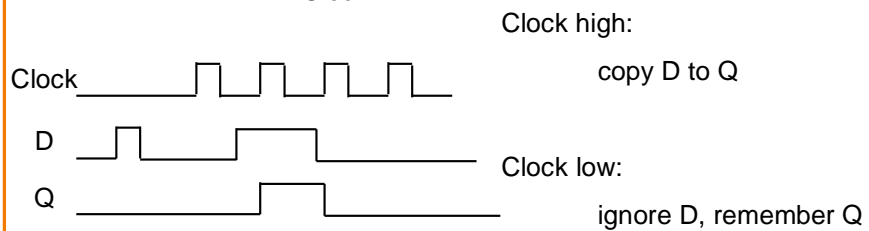
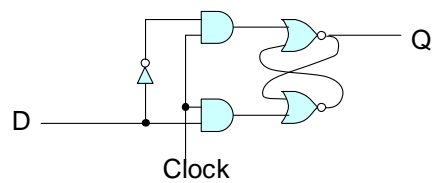
R-S Latch



NOR gate

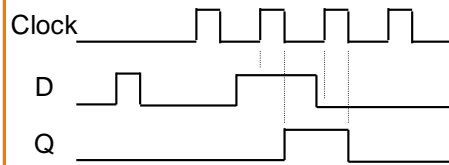
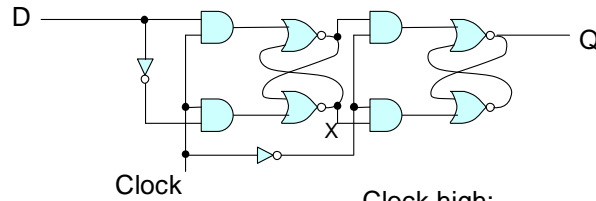
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Clocked flipflop



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Master/Slave flipflop



Clock high:

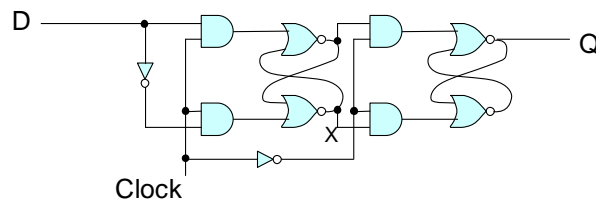
copy D to X; keep Q

Clock low:

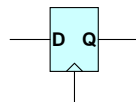
copy X to Q; keep X

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Master/Slave flipflop

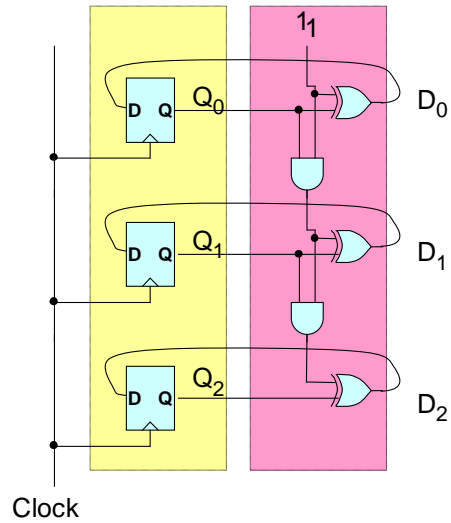


Circuit symbol:



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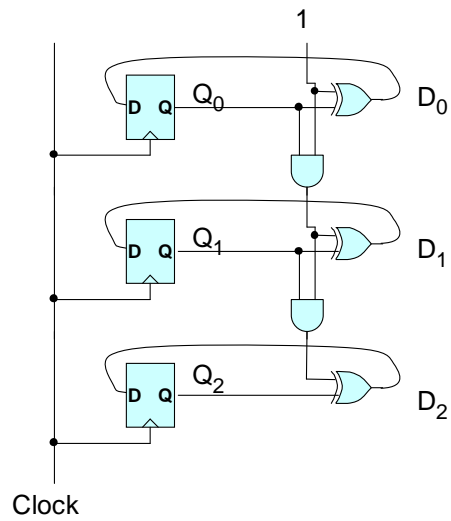
Synchronous sequential circuits



- Flipflops all clocked simultaneously
- Combinational circuit determines next flipflop values (calculates D's from Q's).

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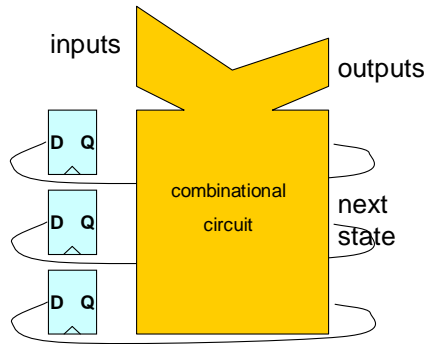
Analysis of sequential circuits



Q_2	Q_1	Q_0	D_2	D_1	D_0
0	0	0	0	0	1
0	0	1	0	1	0
0	1	0	0	1	1
0	1	1	1	0	0
1	0	0	1	0	1
1	0	1	1	1	0
1	1	0	1	1	1
1	1	1	0	0	0

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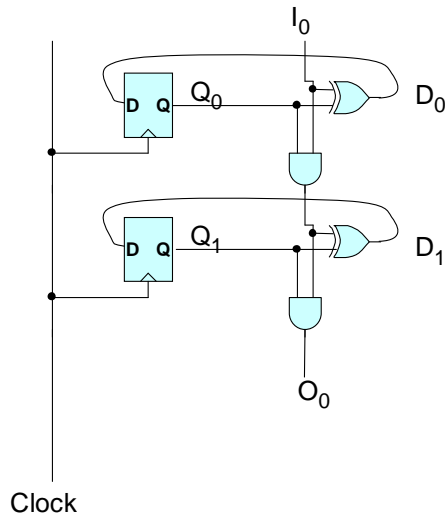
Input / Output



State			Inputs		NextS			Outputs
Q_2	Q_1	Q_0	I_2	I_1	D_2	D_1	D_0	O_0
0	0	0	0	0	0	1	0	1
0	0	0	0	1	0	0	0	0
0	0	0	1	0	0	0	0	0
1	1	1	1	0	1	0	1	0
1	1	1	1	1	1	0	1	0

25

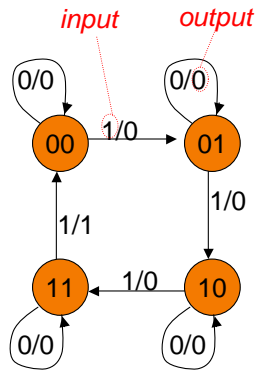
Circuit with I/O



Q_1	Q_0	I_0	D_1	D_0	O_0
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	0	1	0
0	1	1	1	0	0
1	0	0	1	0	0
1	0	1	1	1	0
1	1	0	1	1	0
1	1	1	0	0	1

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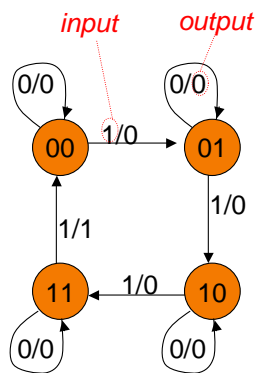
State Machine



Q_1	Q_0	I_0	D_1	D_0	O_0
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	0	1	0
0	1	1	1	0	0
1	0	0	1	0	0
1	0	1	1	1	0
1	1	0	1	1	0
1	1	1	0	0	1

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What does it do?



Counts up if input=1;
 stays stationary if input=0.
 Output is "carry" when counter
 wraps around.

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Synthesis procedure



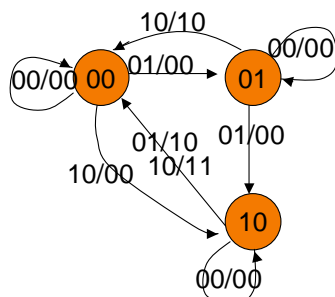
1. State purpose of circuit in words
2. Make state machine
3. Make truth tables
4. Apply combinational-circuit synthesis procedure:
 - Identify “true” rows
 - Construct sum-of-products expression
 - Construct circuit

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Vending machine



1. State purpose of circuit in words
 - Accept nickels and dimes
 - Candy costs 15¢
 - Dispense candy bar and appropriate change
 - Inputs: D (dime), N (nickel) Outputs: C (candy), O (nickel change)
2. Make state machine



States:

00: 0¢ credit

01: 5¢ credit

10: 10¢ credit

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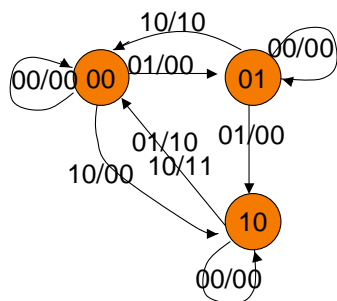
Vending machine



3. Make truth table

Assume: D&N impossible

"x" means don't-care



$Q_1 Q_0 D N$	$D_1 D_0 C O$
0 0 0 0	0 0 0 0
0 0 0 1	0 1 0 0
0 0 1 0	1 0 0 0
0 0 1 1	x x x x
0 1 0 0	0 1 0 0
0 1 0 1	1 0 0 0
0 1 1 0	0 0 1 0
0 1 1 1	x x x x
1 0 0 0	1 0 0 0
1 0 0 1	0 0 1 0
1 0 1 0	0 0 1 1
1 0 1 1	x x x x
1 1 0 0	x x x x
1 1 0 1	x x x x
1 1 1 0	x x x x
1 1 1 1	x x x x

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Vending machine



4. Make sum-of-products expressions

$$D_1 = \overline{Q_1} \overline{Q_0} D \overline{N} + \overline{Q_1} Q_0 \overline{D} N + Q_1 \overline{Q_0} \overline{D} \overline{N}$$

$Q_1 Q_0 D N$	$D_1 D_0 C O$
0 0 0 0	0 0 0 0
0 0 0 1	0 1 0 0
0 0 1 0	1 0 0 0
0 0 1 1	x x x x
0 1 0 0	0 1 0 0
0 1 0 1	1 0 0 0
0 1 1 0	0 0 1 0
0 1 1 1	x x x x
1 0 0 0	1 0 0 0
1 0 0 1	0 0 1 0
1 0 1 0	0 0 1 1
1 0 1 1	x x x x
1 1 0 0	x x x x
1 1 0 1	x x x x
1 1 1 0	x x x x
1 1 1 1	x x x x

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Vending machine



4. Make sum-of-products expressions

$$D_1 = \overline{Q_1} \overline{Q_0} \overline{D} \overline{N} + \overline{Q_1} Q_0 \overline{D} N + Q_1 \overline{Q_0} \overline{D} \overline{N}$$

$$D_0 = \overline{Q_1} \overline{Q_0} \overline{D} N + \overline{Q_1} Q_0 \overline{D} \overline{N}$$

$$C = \overline{Q_1} Q_0 \overline{D} \overline{N} + Q_1 \overline{Q_0} \overline{D} N + Q_1 \overline{Q_0} \overline{D} \overline{N}$$

$$O = Q_1 \overline{Q_0} \overline{D} \overline{N}$$

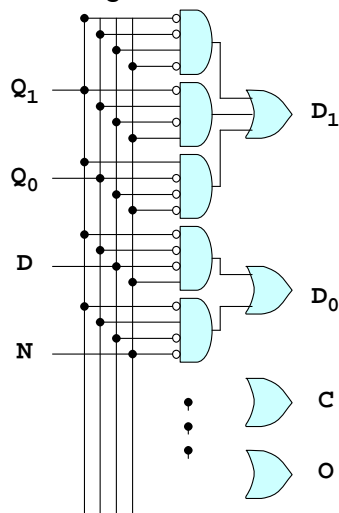
$Q_1 Q_0 D N$	$D_1 D_0 C O$
0 0 0 0	0 0 0 0
0 0 0 1	0 1 0 0
0 0 1 0	1 0 0 0
0 0 1 1	x x x x
0 1 0 0	0 1 0 0
0 1 0 1	1 0 0 0
0 1 1 0	0 0 1 0
0 1 1 1	x x x x
1 0 0 0	1 0 0 0
1 0 0 1	0 0 1 0
1 0 1 0	0 0 1 1
1 0 1 1	x x x x
1 1 0 0	x x x x
1 1 0 1	x x x x
1 1 1 0	x x x x
1 1 1 1	x x x x

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Vending machine



4. Make gates



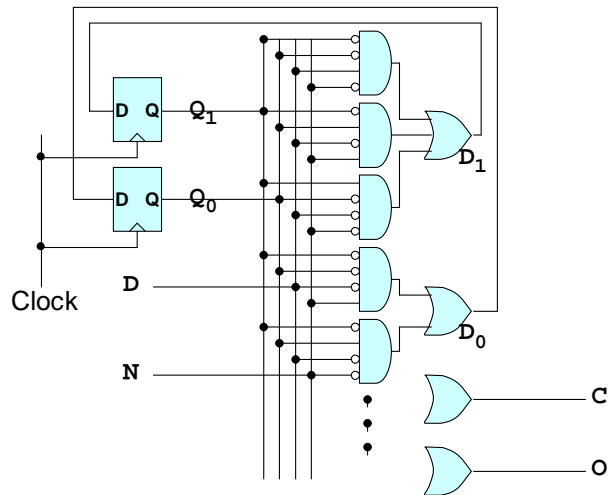
$Q_1 Q_0 D N$	$D_1 D_0 C O$
0 0 0 0	0 0 0 0
0 0 0 1	0 1 0 0
0 0 1 0	1 0 0 0
0 0 1 1	x x x x
0 1 0 0	0 1 0 0
0 1 0 1	1 0 0 0
0 1 1 0	0 0 1 0
0 1 1 1	x x x x
1 0 0 0	1 0 0 0
1 0 0 1	0 0 1 0
1 0 1 0	0 0 1 1
1 0 1 1	x x x x
1 1 0 0	x x x x
1 1 0 1	x x x x
1 1 1 0	x x x x
1 1 1 1	x x x x

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Vending machine



5. Hook up flipflops, clocks, inputs, outputs



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Summary



- Sequential circuits
 - Store state in latches
 - Connect latches with combinational circuits
- Next time
 - Building a computer out of sequential circuits

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