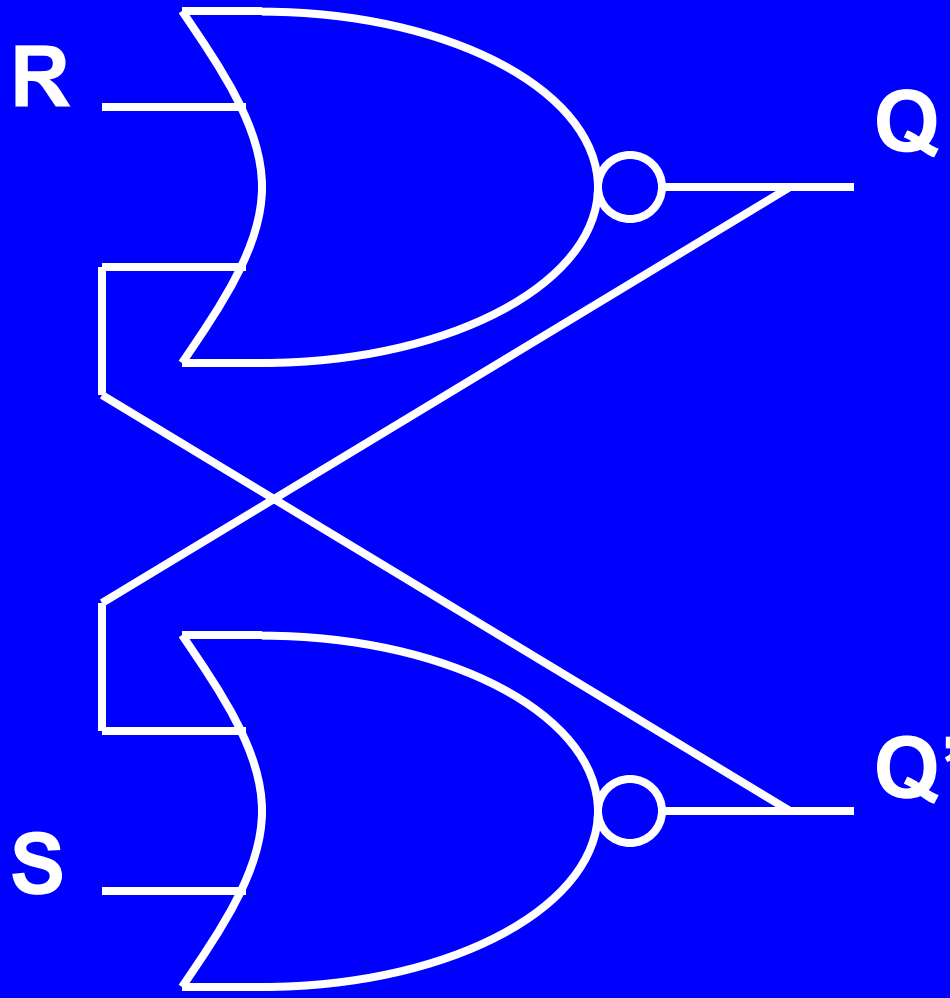
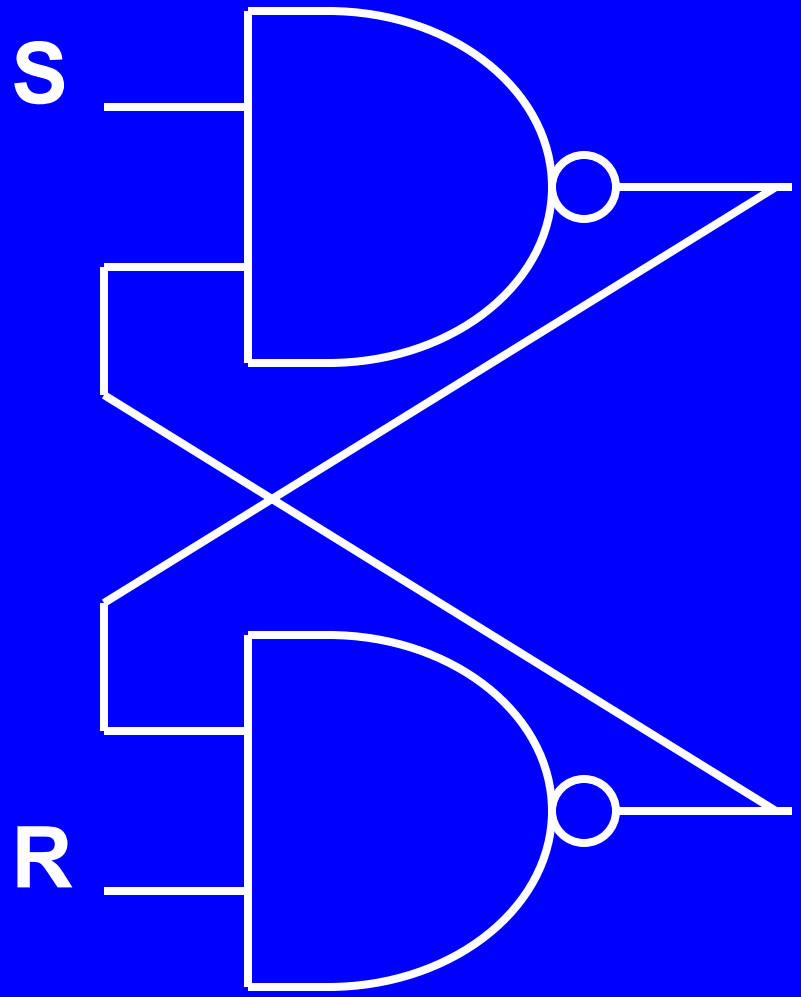
SR latch



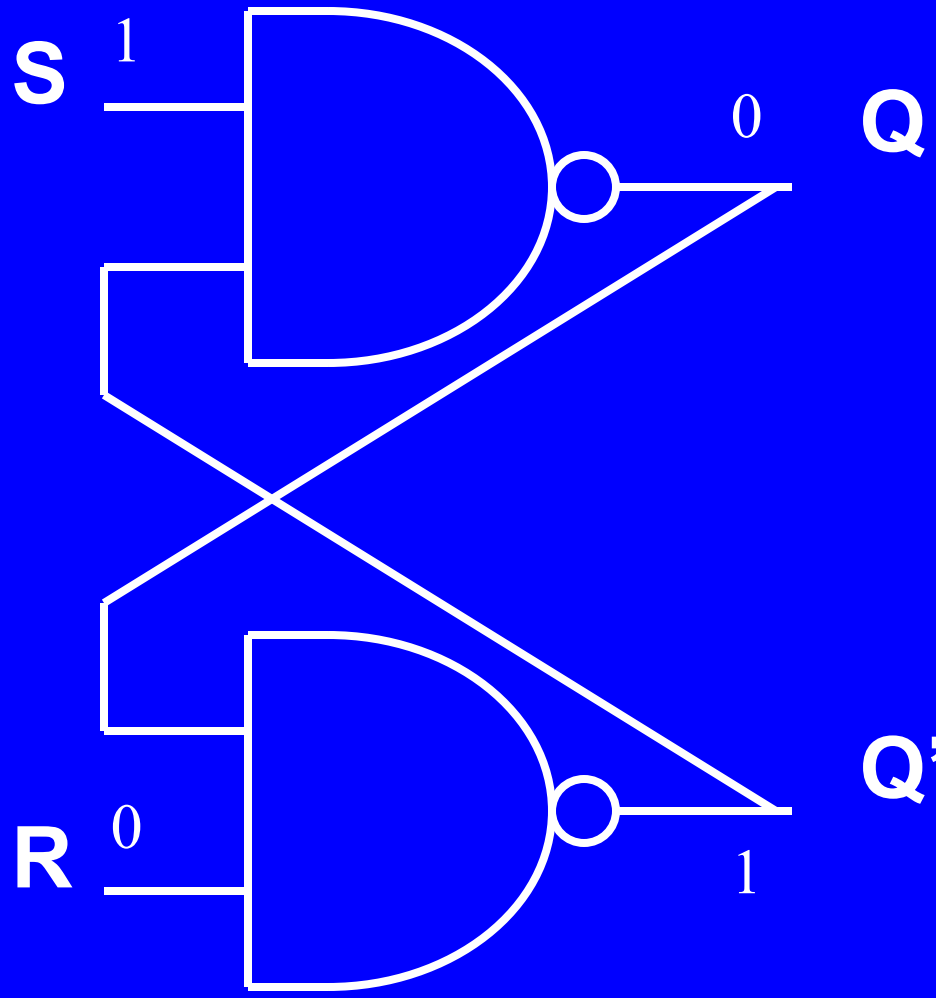
S	R	Q	Q'
1	0	1	0
0	0	1	0
0	1	0	1
0	0	0	1
1	1	0	0

SR latch



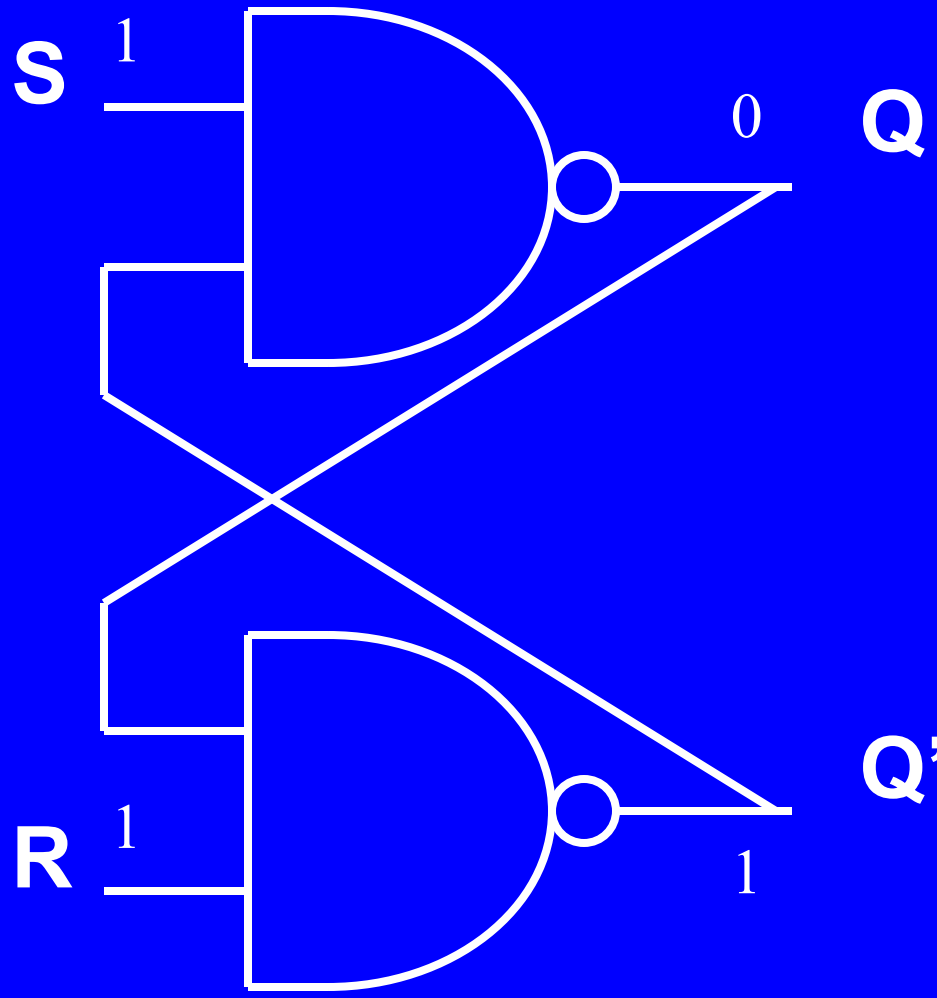
S	R	Q	Q'
1	0	0	1
1	1	0	1
0	1	1	0
1	1	1	0
0	0	1	1

SR latch



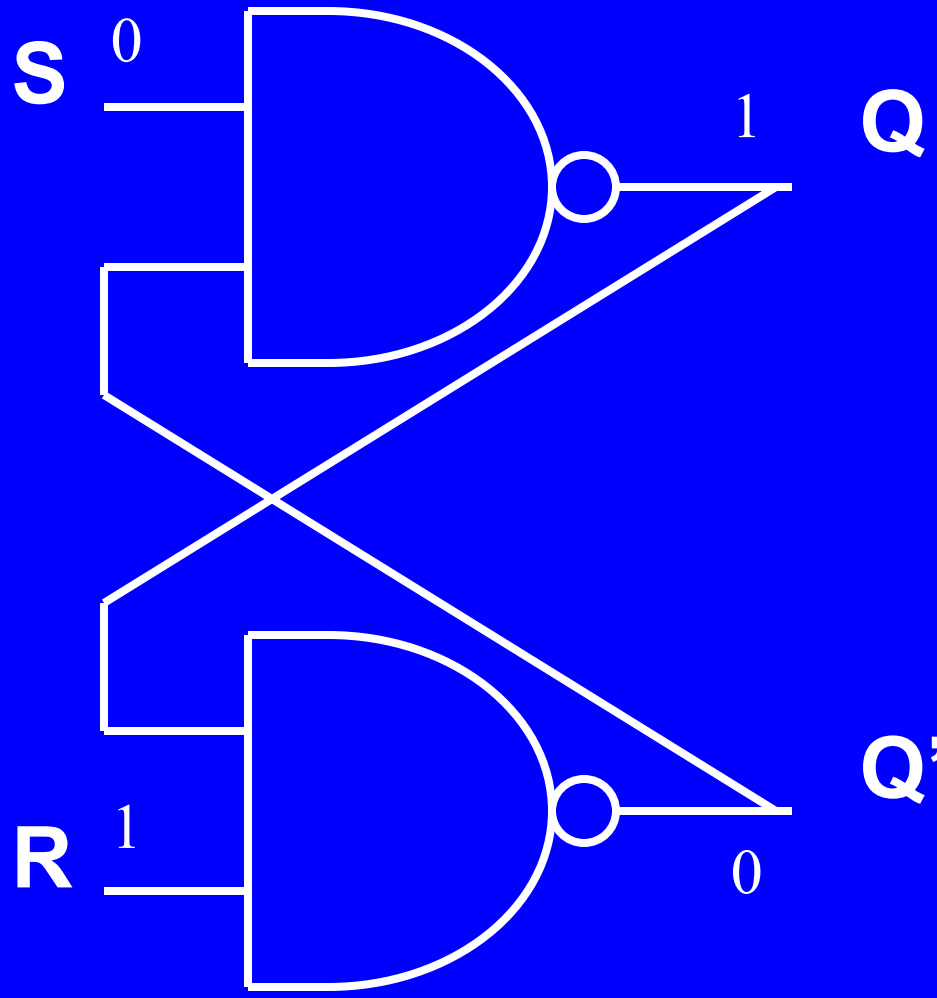
S	R	Q	Q'
1	0	0	1
1	1	0	1
0	1	1	0
1	1	1	0
0	0	1	1

SR latch



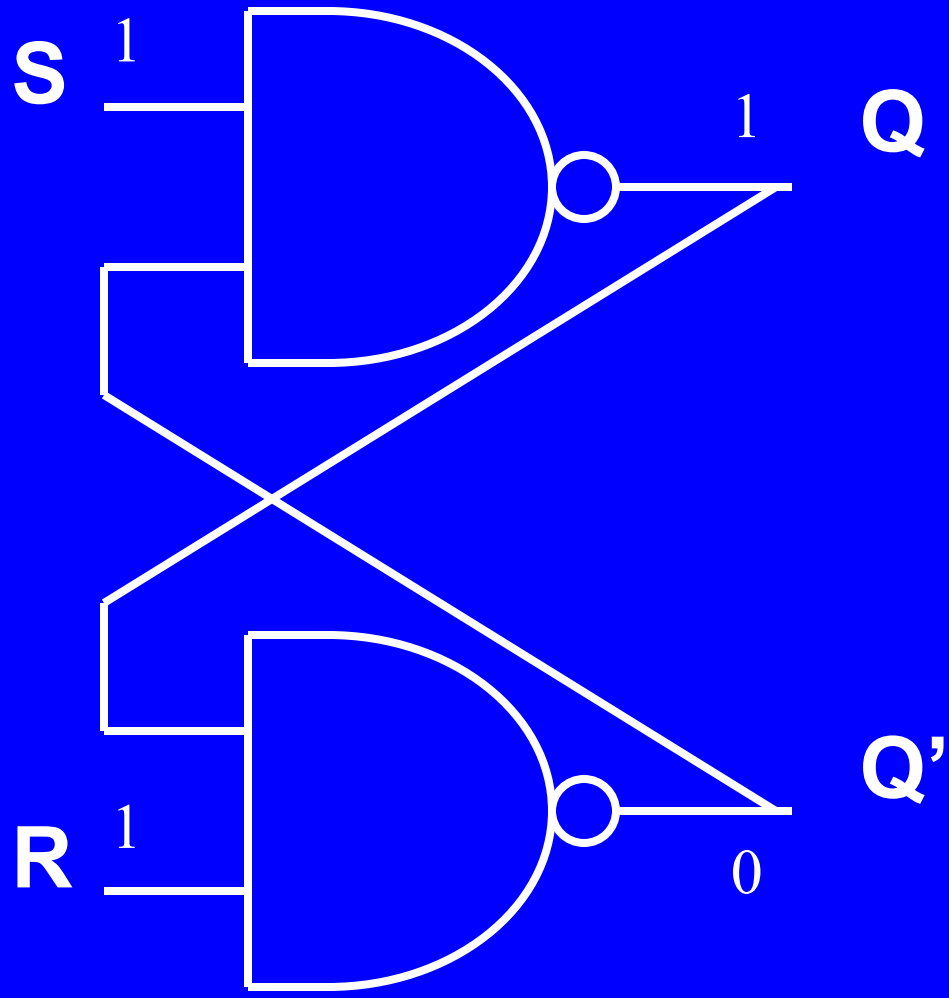
S	R	Q	Q'
1	0	0	1
1	1	0	1
0	1	1	0
1	1	1	0
0	0	1	1

SR latch



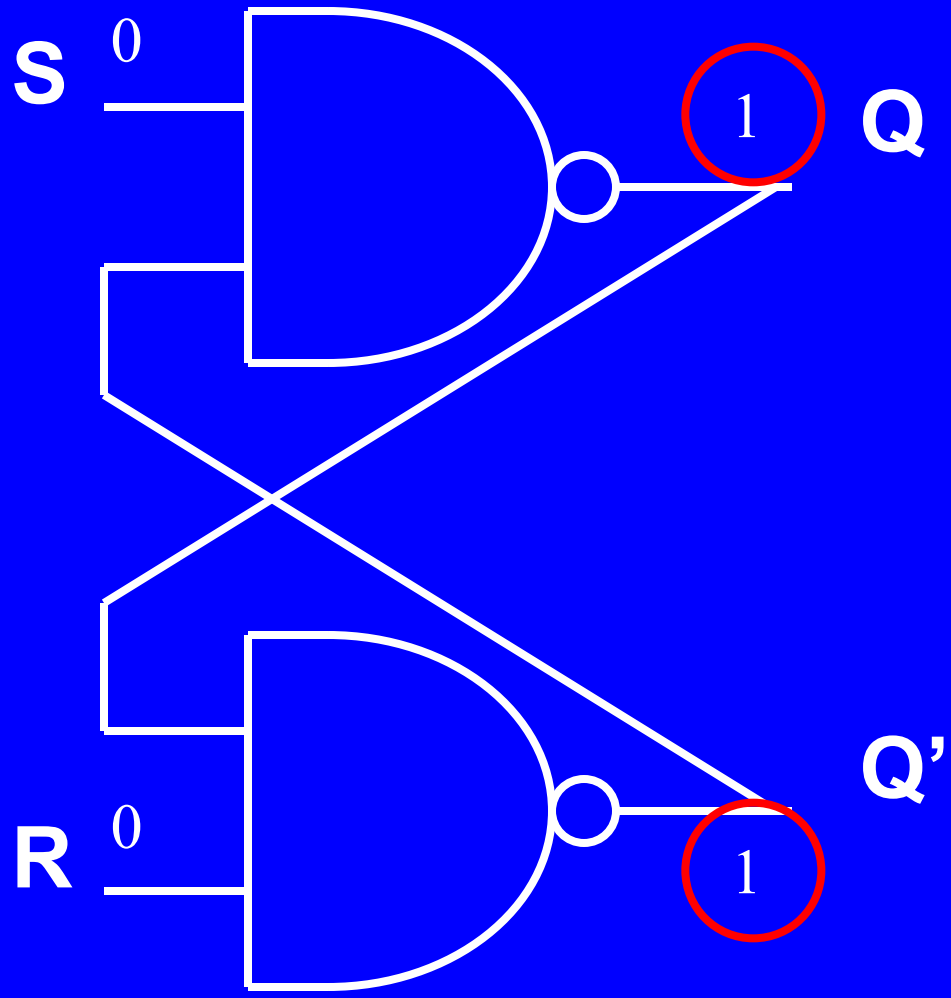
S	R	Q	Q'
1	0	0	1
1	1	0	1
0	1	1	0
1	1	1	0
0	0	1	1

SR latch



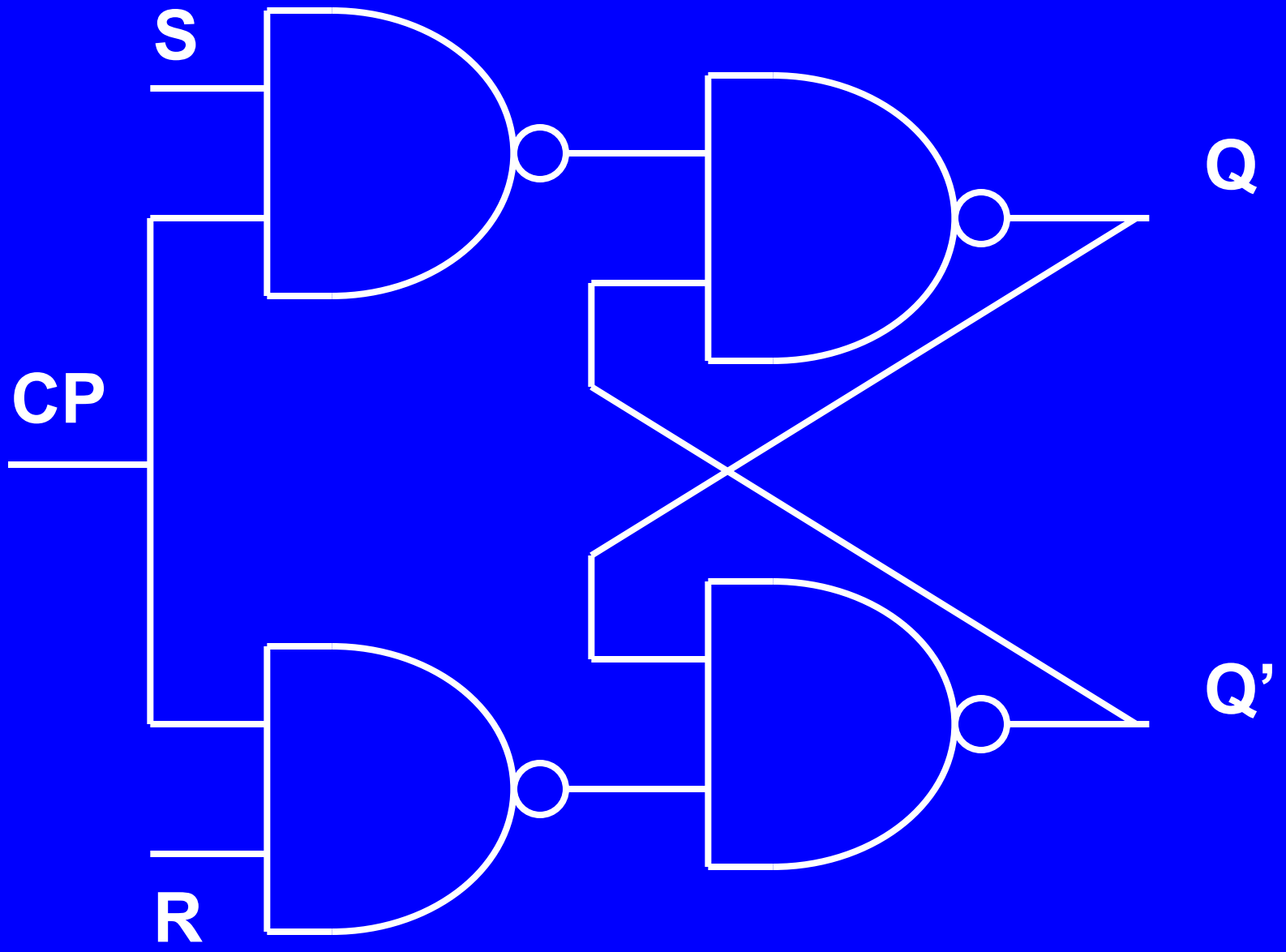
S	R	Q	Q'
1	0	0	1
1	1	0	1
0	1	1	0
1	1	1	0
0	0	1	1

SR latch

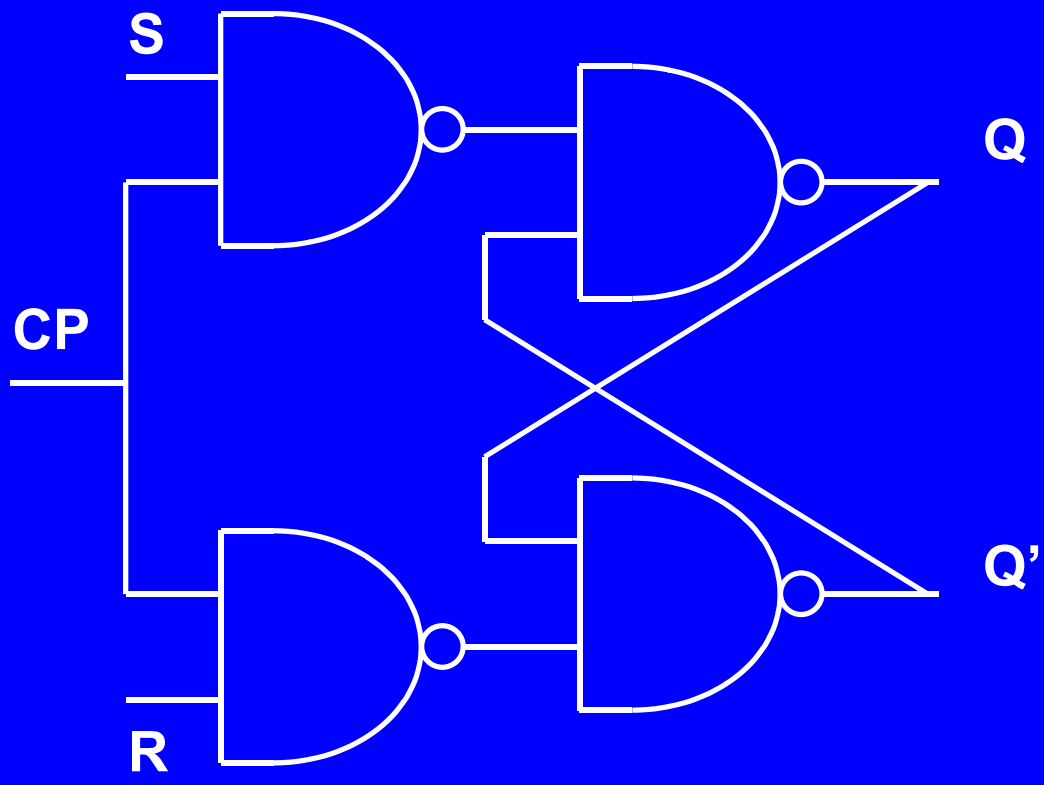


S	R	Q	Q'
1	0	0	1
1	1	0	1
0	1	1	0
1	1	1	0
0	0	1	1

Clocked SR latch

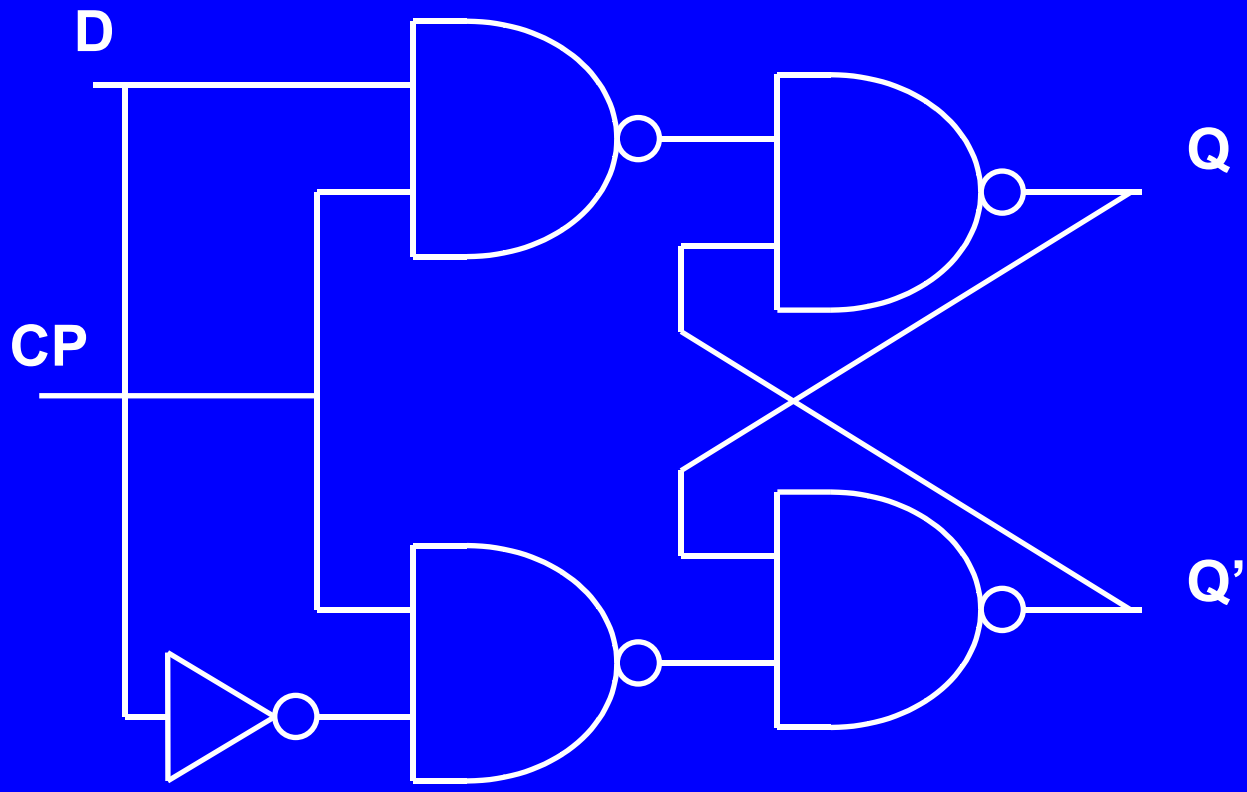


Clocked SR latch



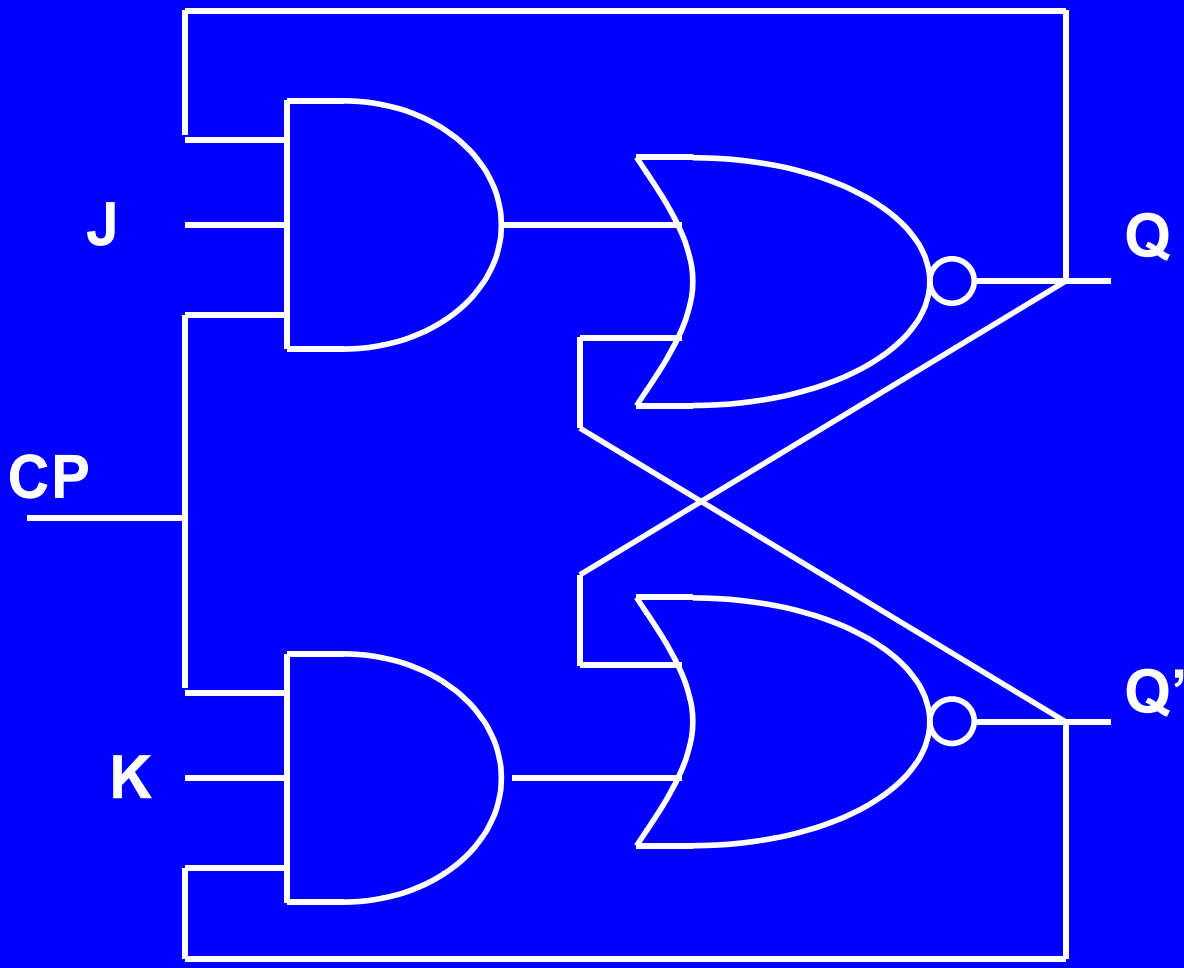
Q	S	R	Q(t+1)
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	X
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	X

Clocked D latch



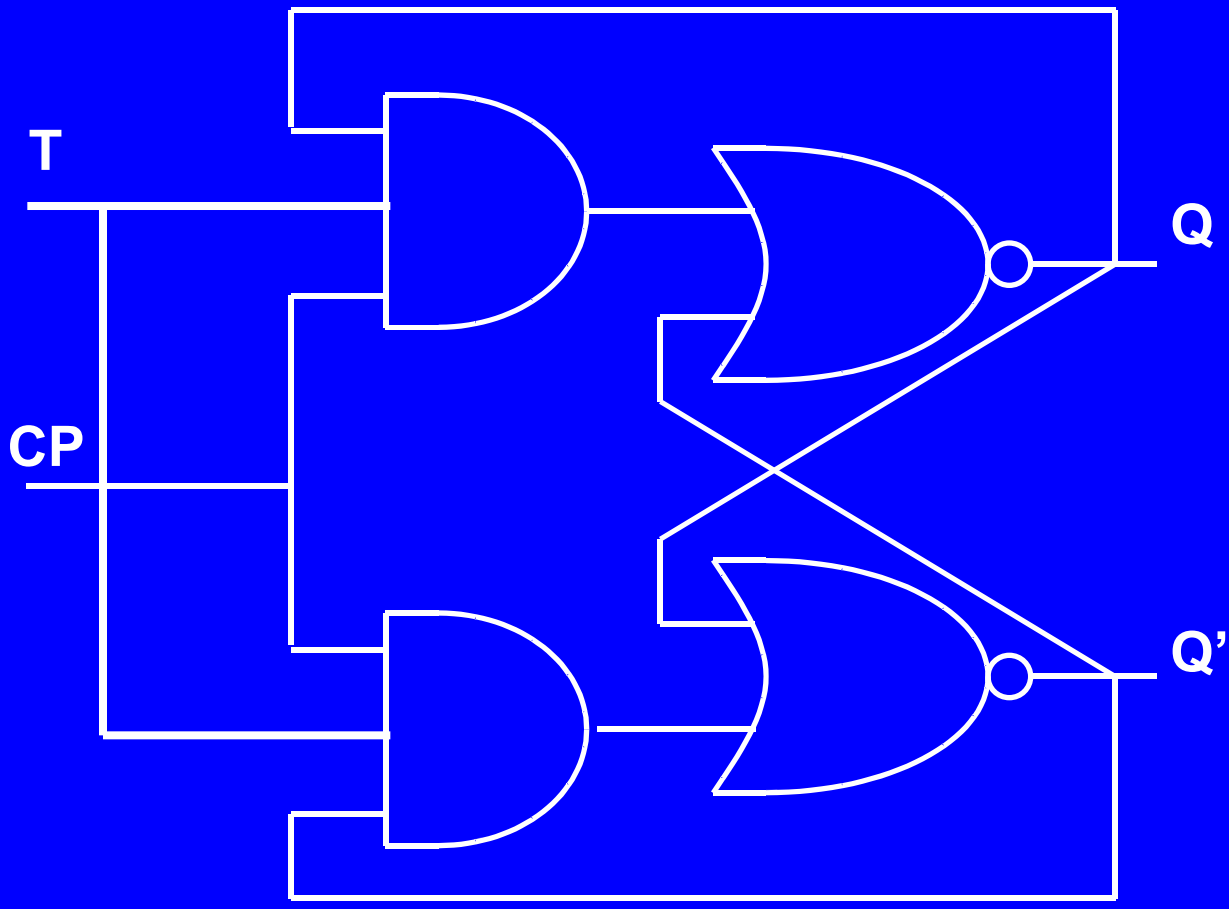
Q	D	Q(t+1)
0	0	0
0	1	1
1	0	0
1	1	1

Clocked JK latch



Q	J	K	Q(t+1)
0	0	0	0
0	0	1	0
0	1	0	1
0	1	1	1
1	0	0	1
1	0	1	0
1	1	0	1
1	1	1	0

Clocked T latch



Q	T	Q(t+1)
0	0	0
0	1	1
1	0	1
1	1	0

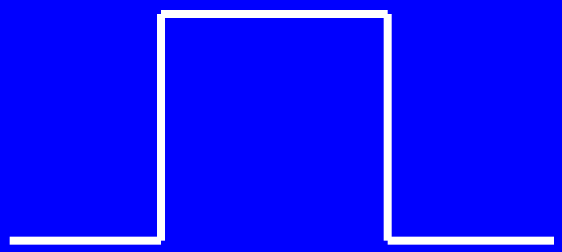
Types of sequential elements

- Latches
  - level-sensitive
  - edge triggered
- Flip-flops

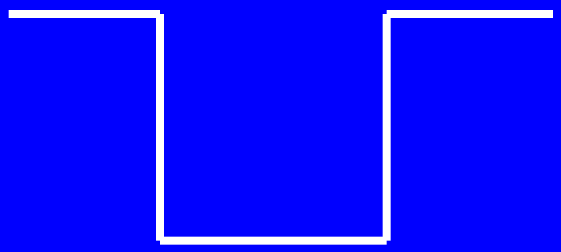
- With synchronous/asynchronous reset or enable

Timing

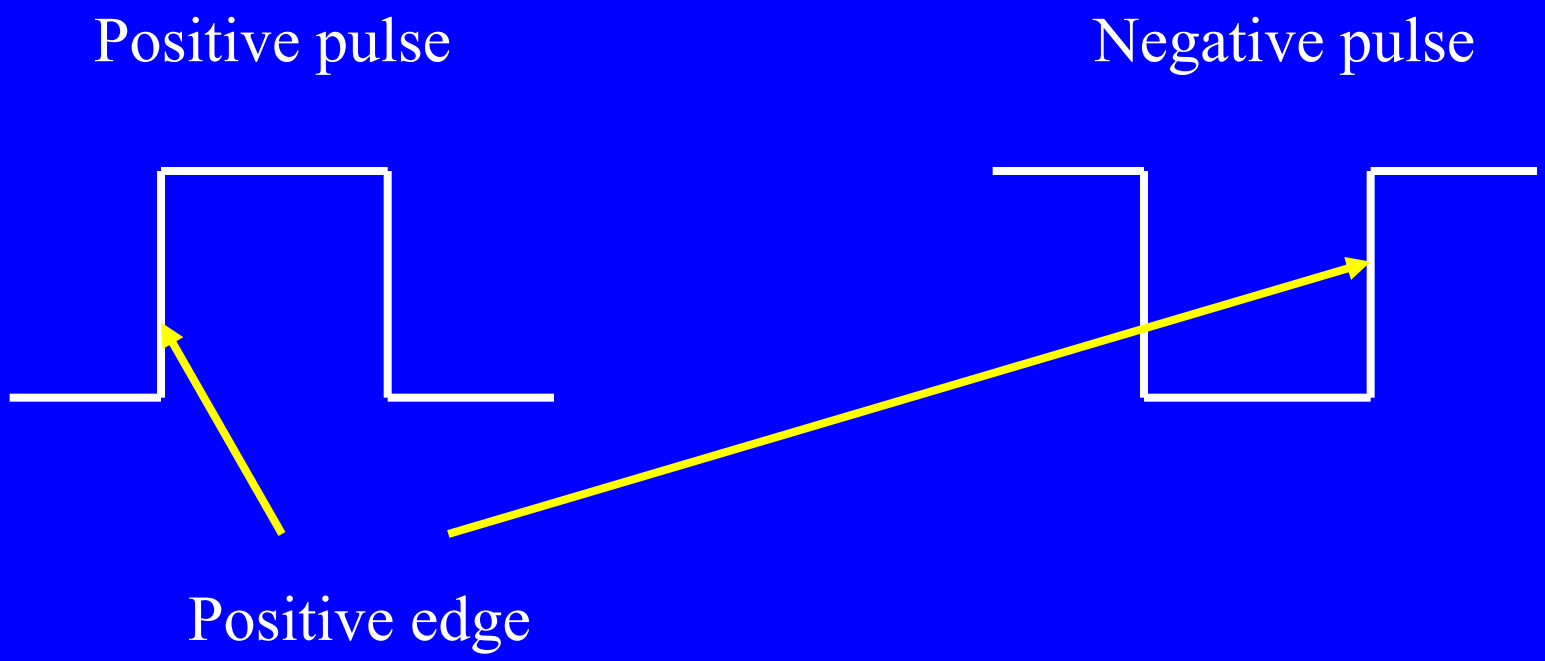
Positive pulse



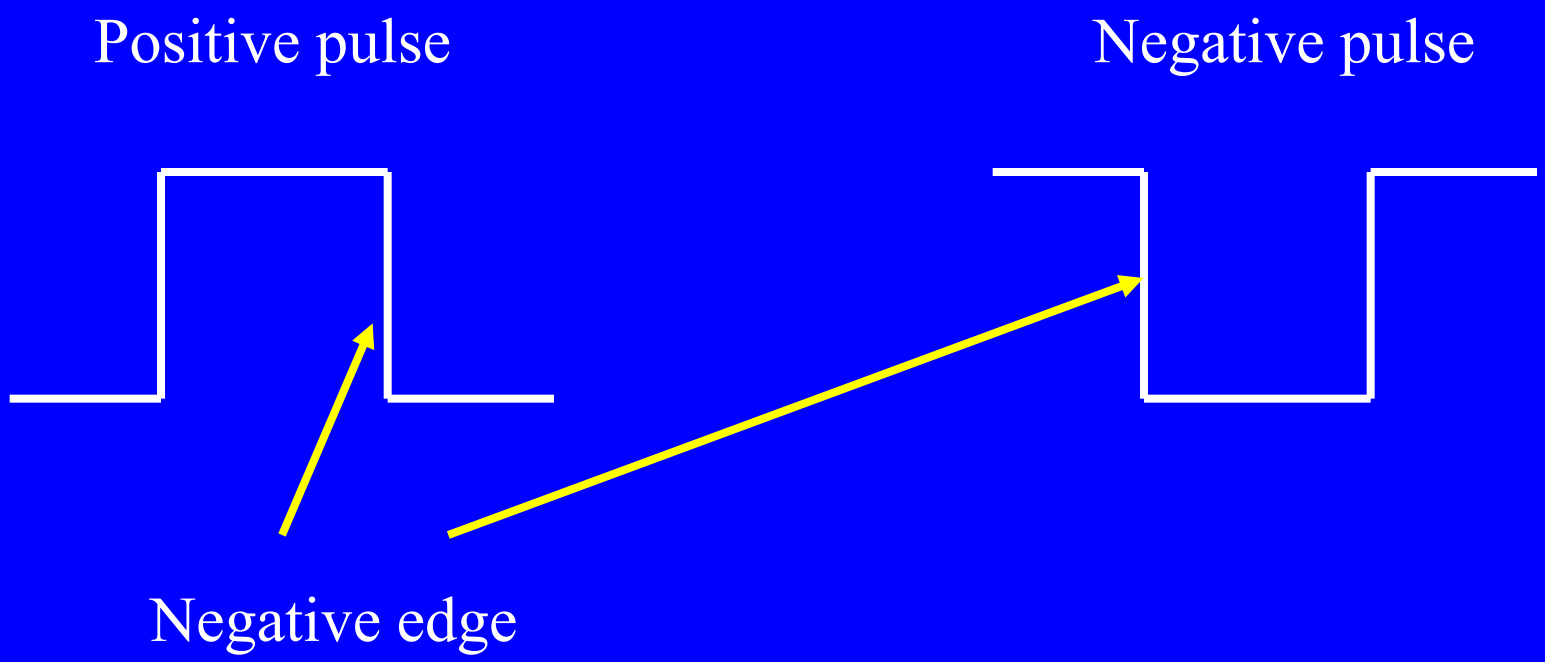
Negative pulse

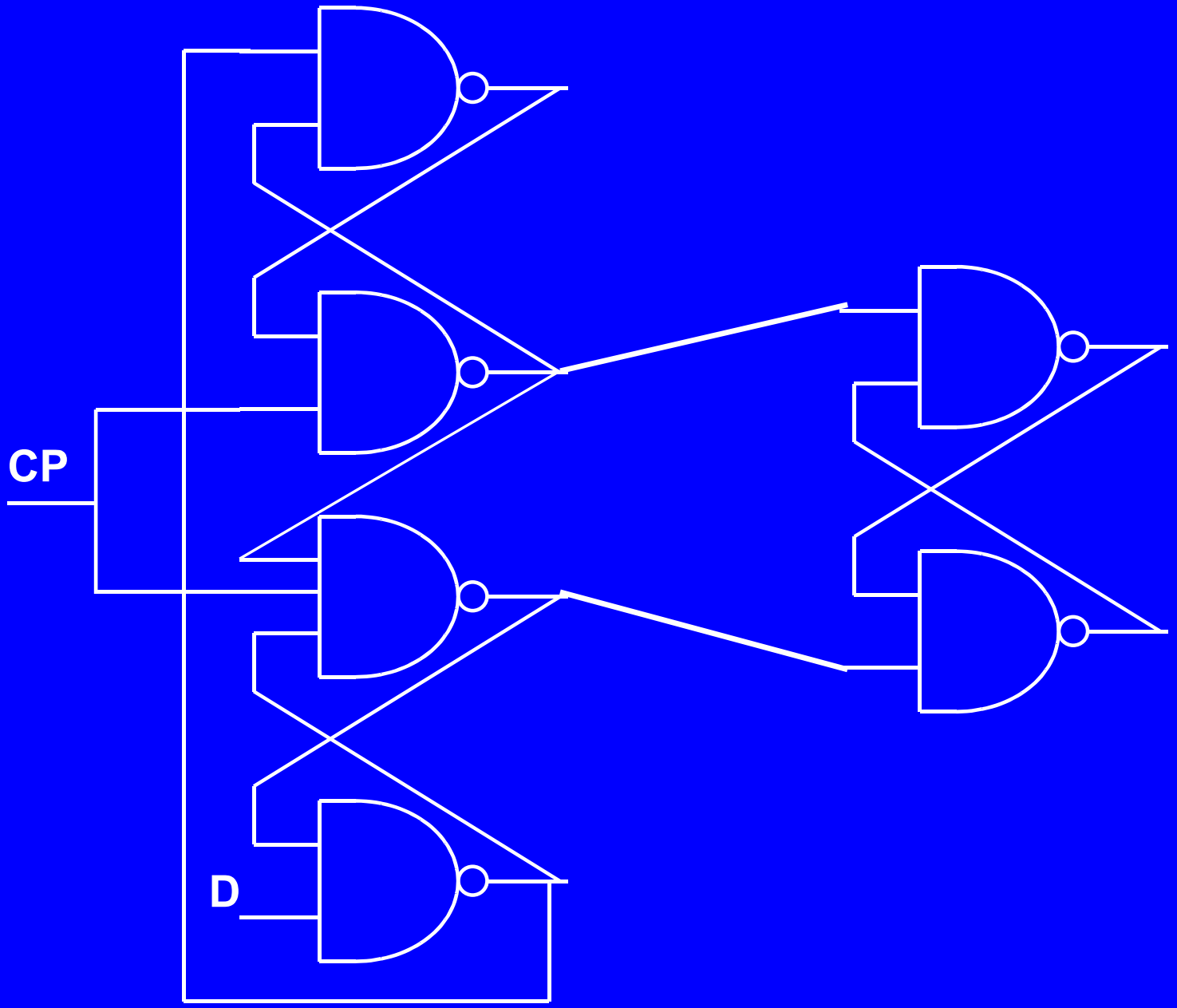


Timing



Timing

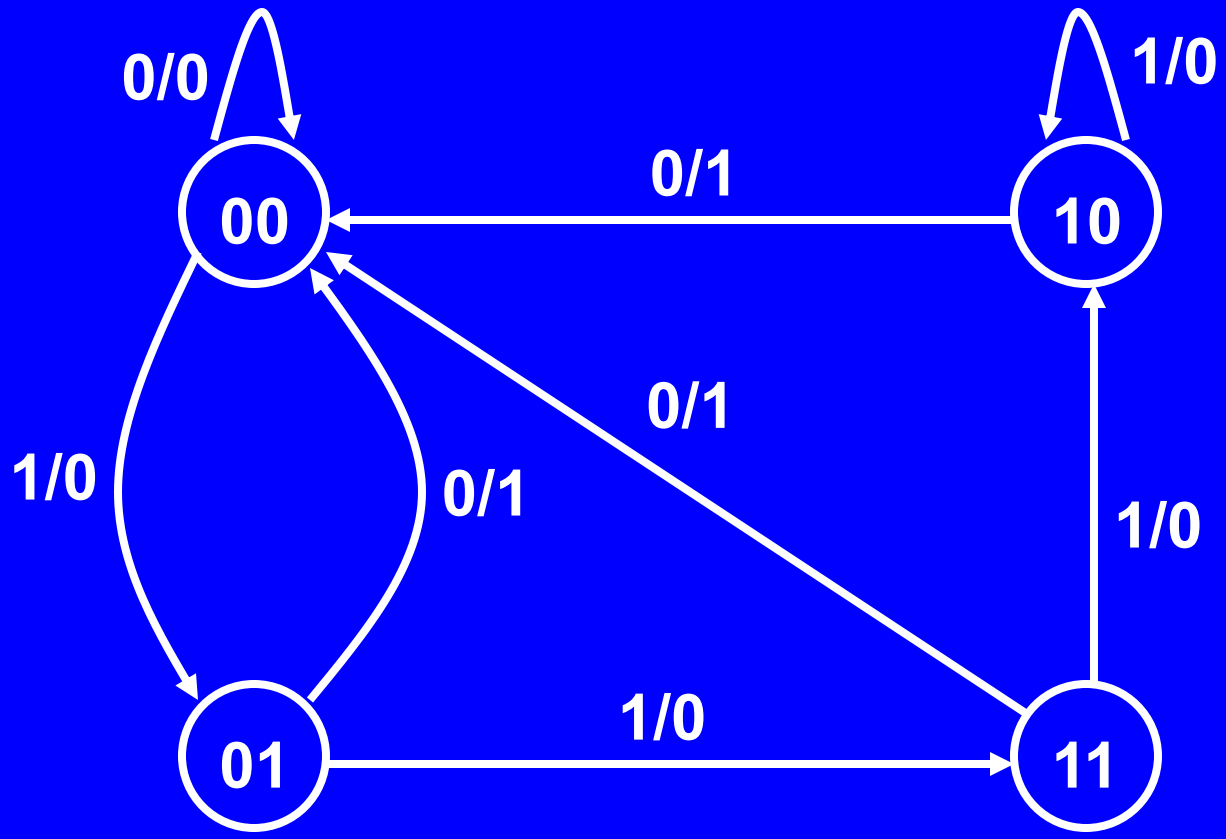



CP
D

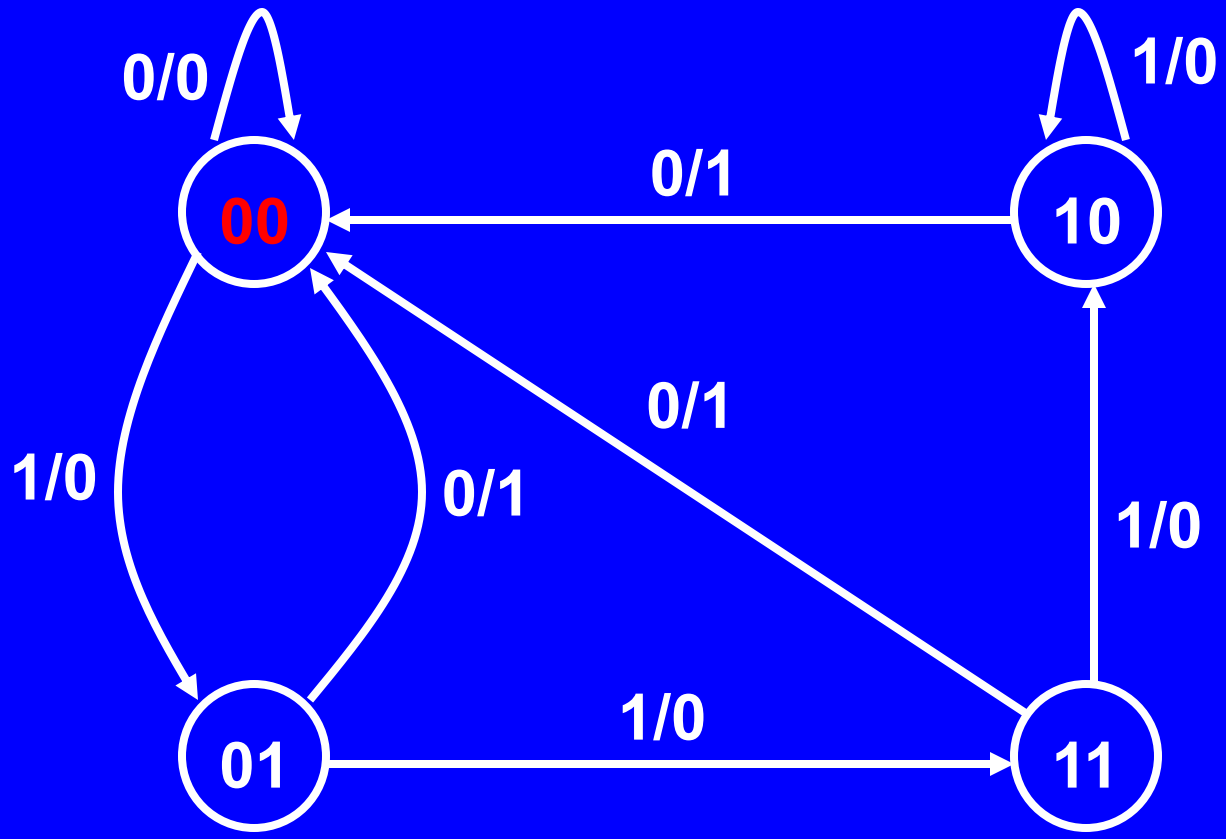
State table

Current A	Current B	Input X	Next A	Next B	Output Y
0	0	0	0	0	0
0	0	1	0	1	0
0	1	0	0	0	1
0	1	1	1	1	0
1	0	0	0	0	1
1	0	1	1	0	0
1	1	0	0	0	1
1	1	1	1	0	0

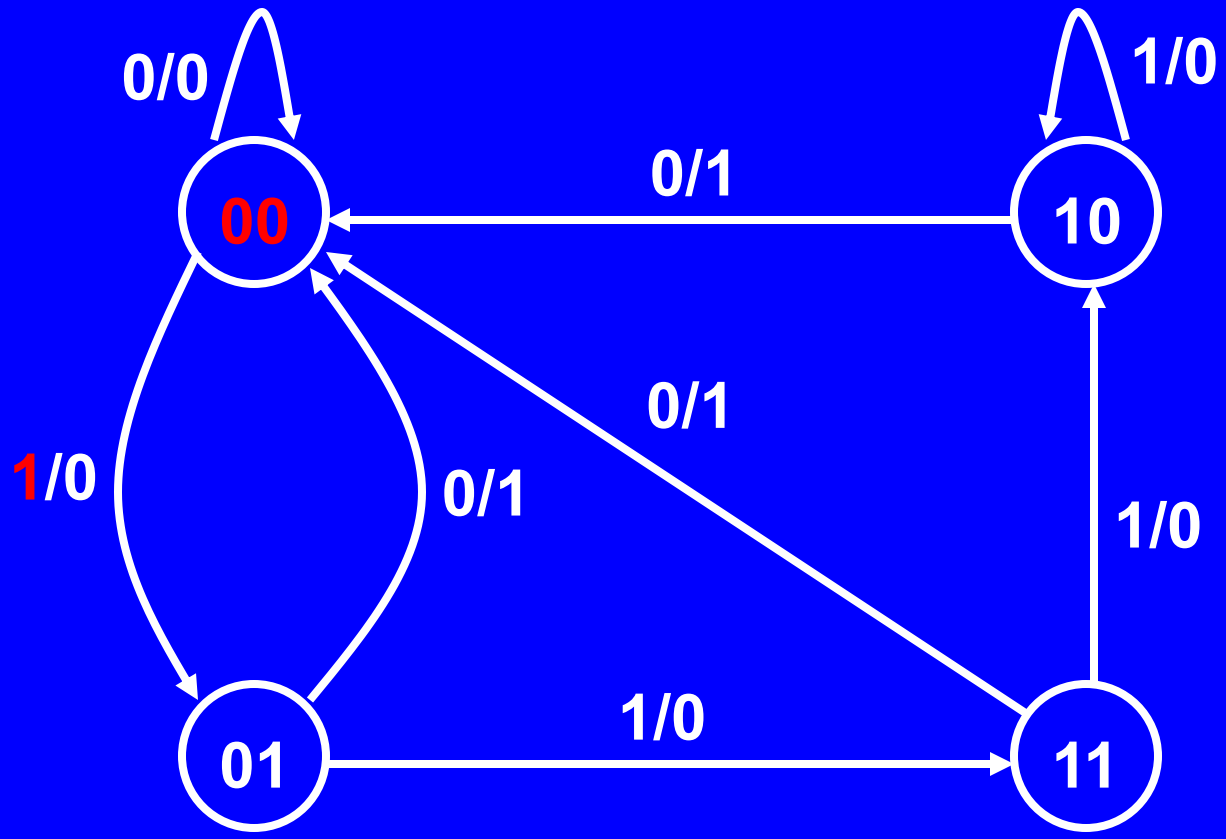
State diagram



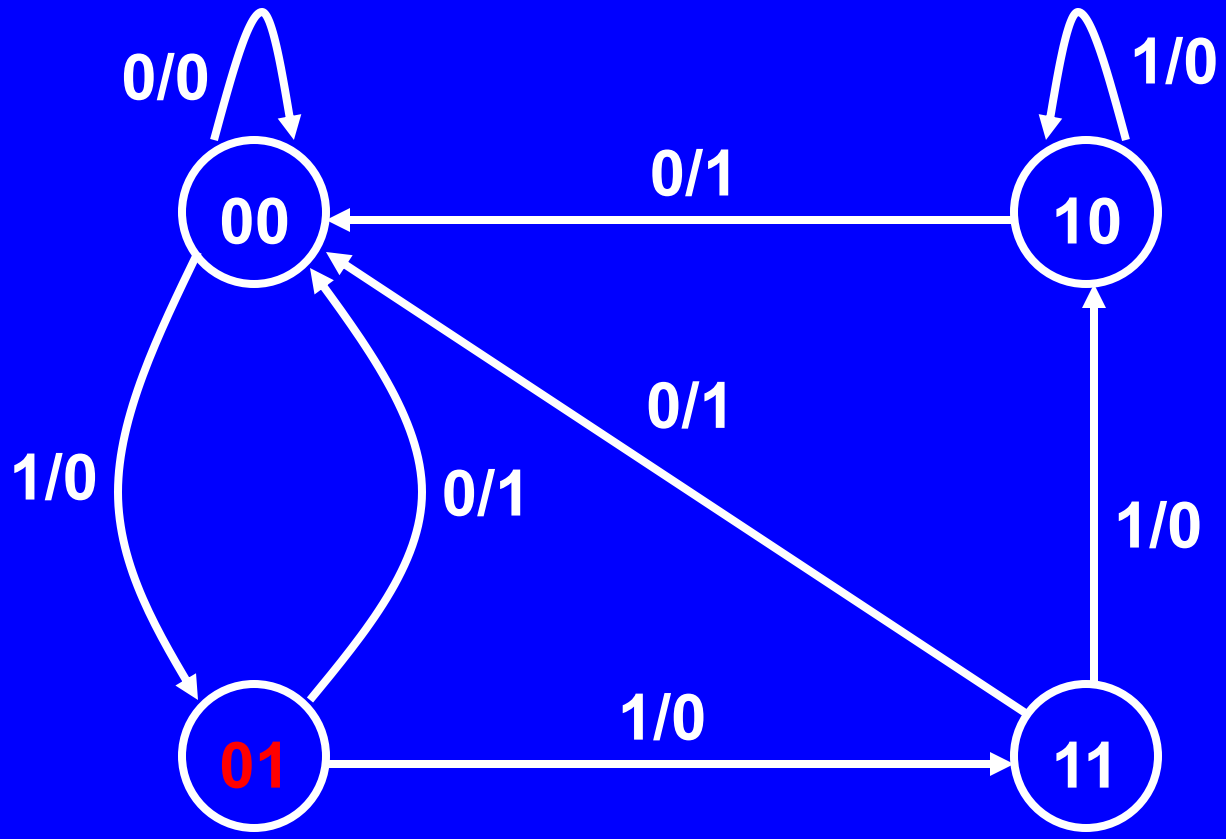
State diagram



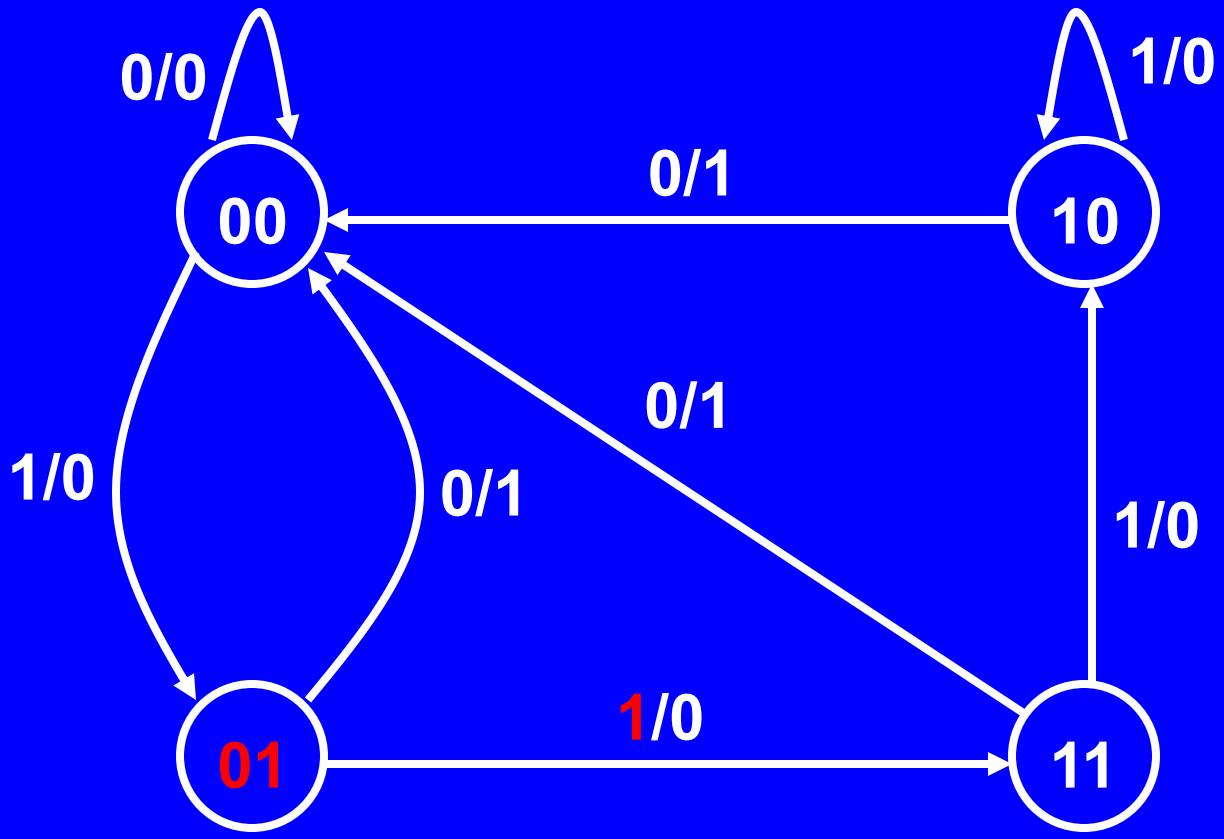
State diagram



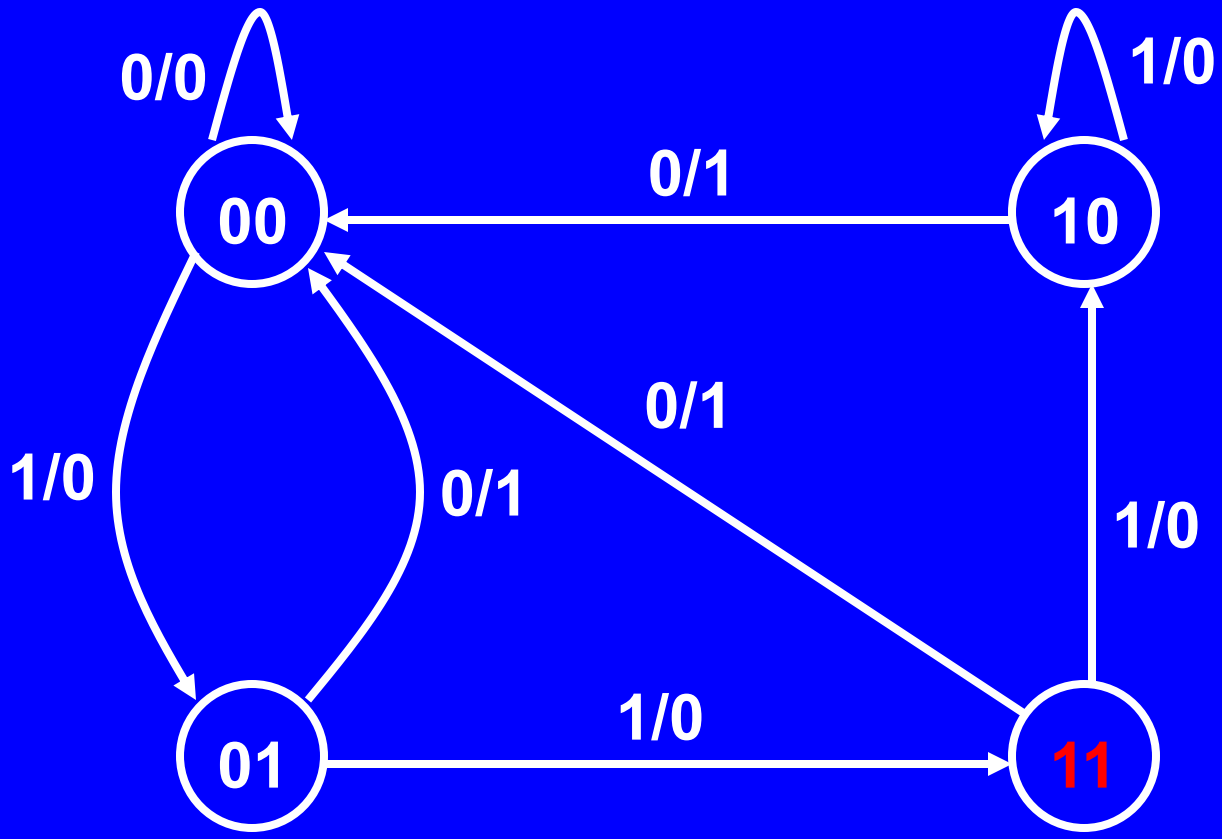
State diagram



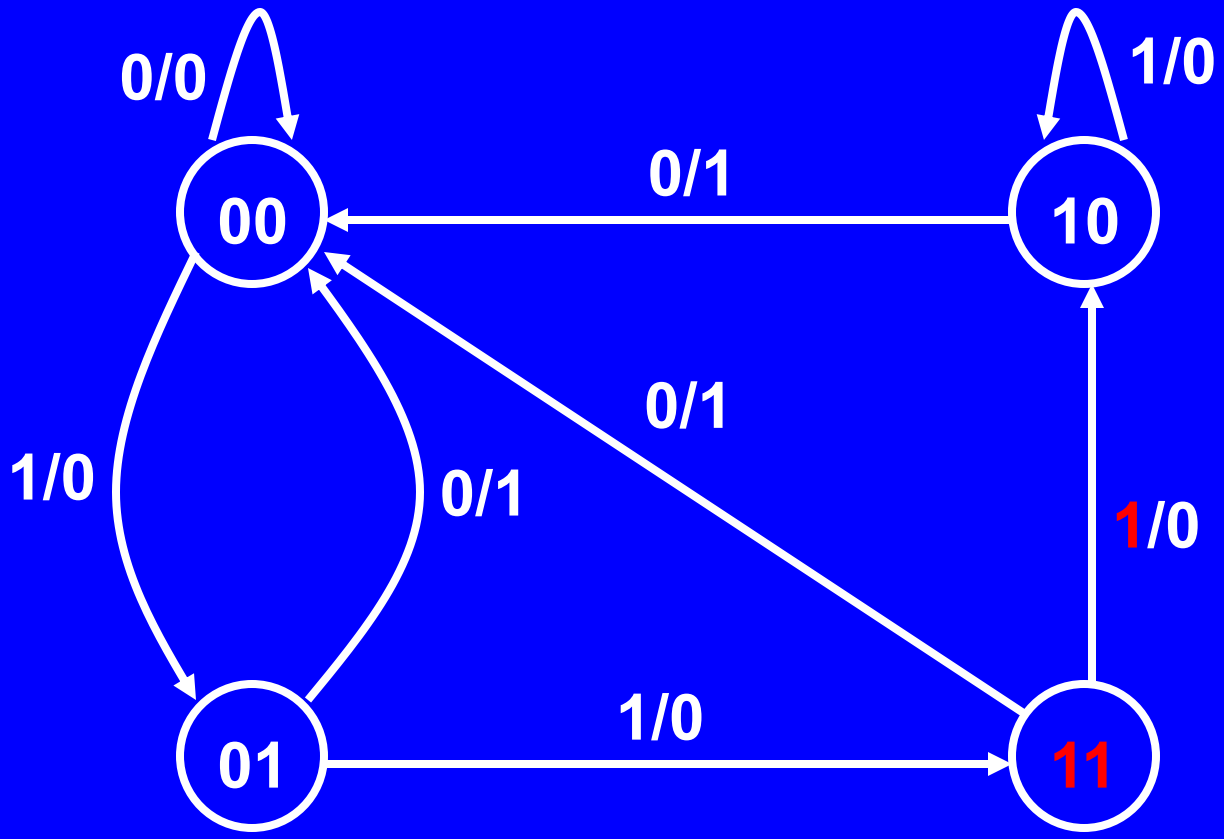
State diagram



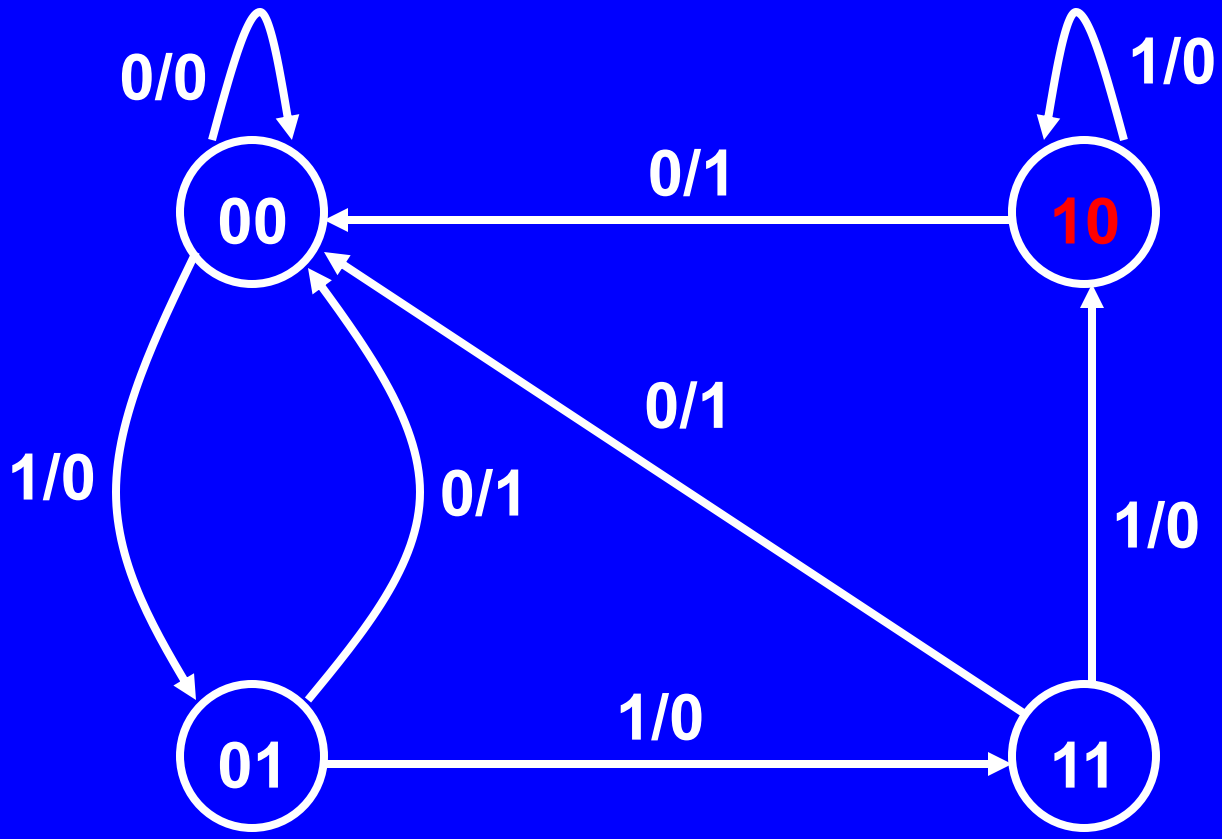
State diagram



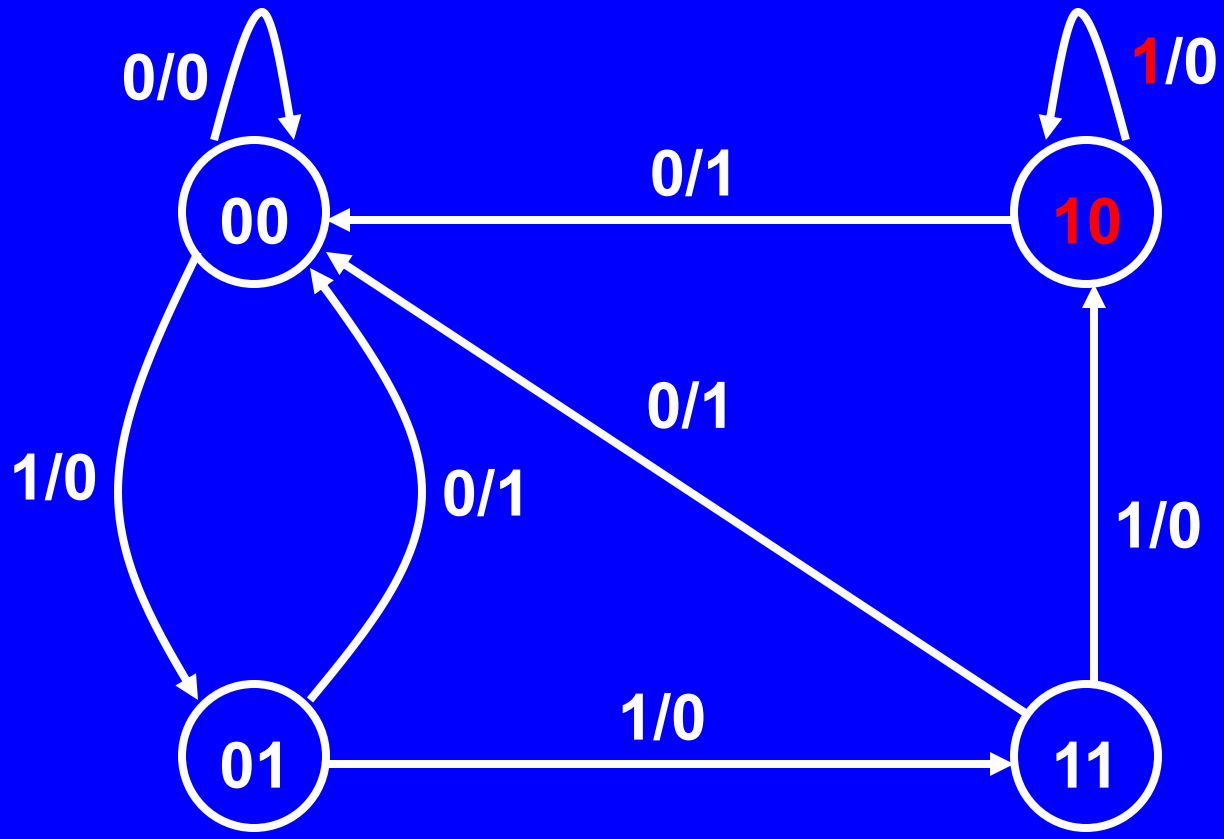
State diagram



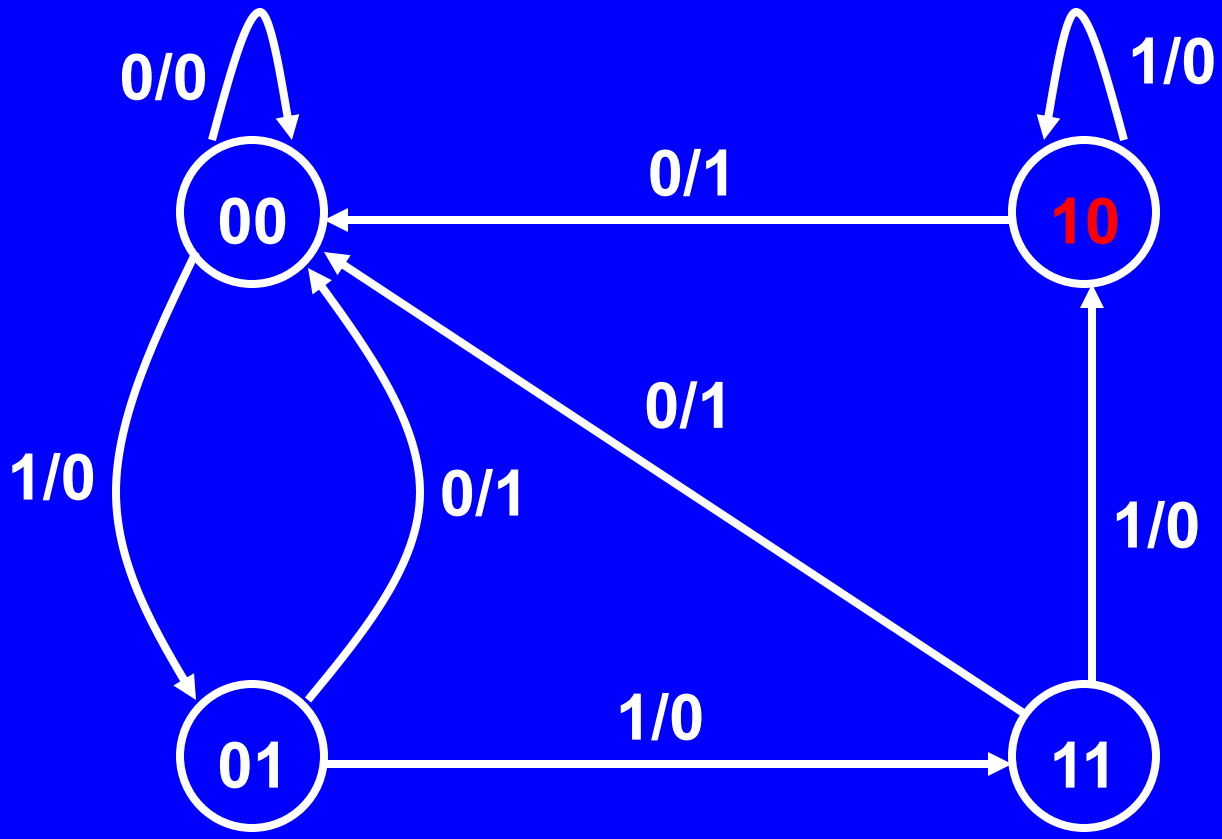
State diagram



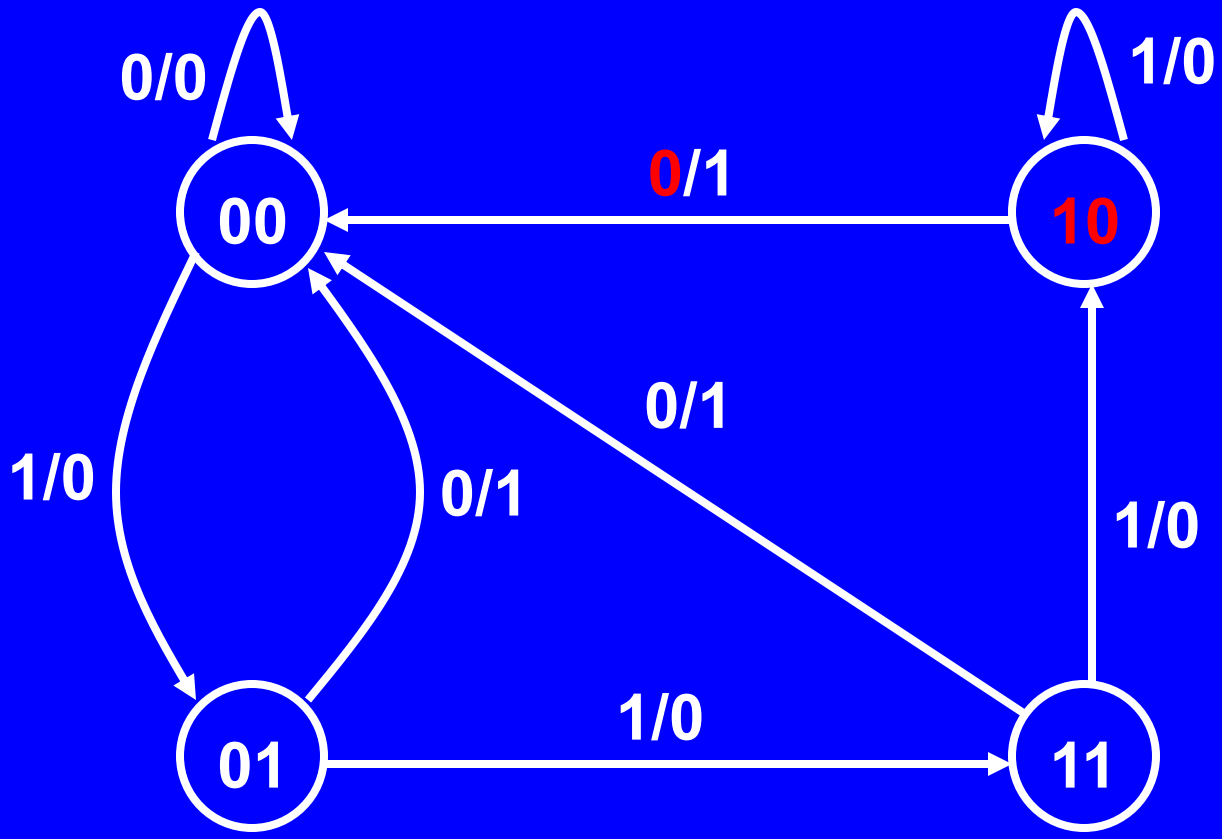
State diagram



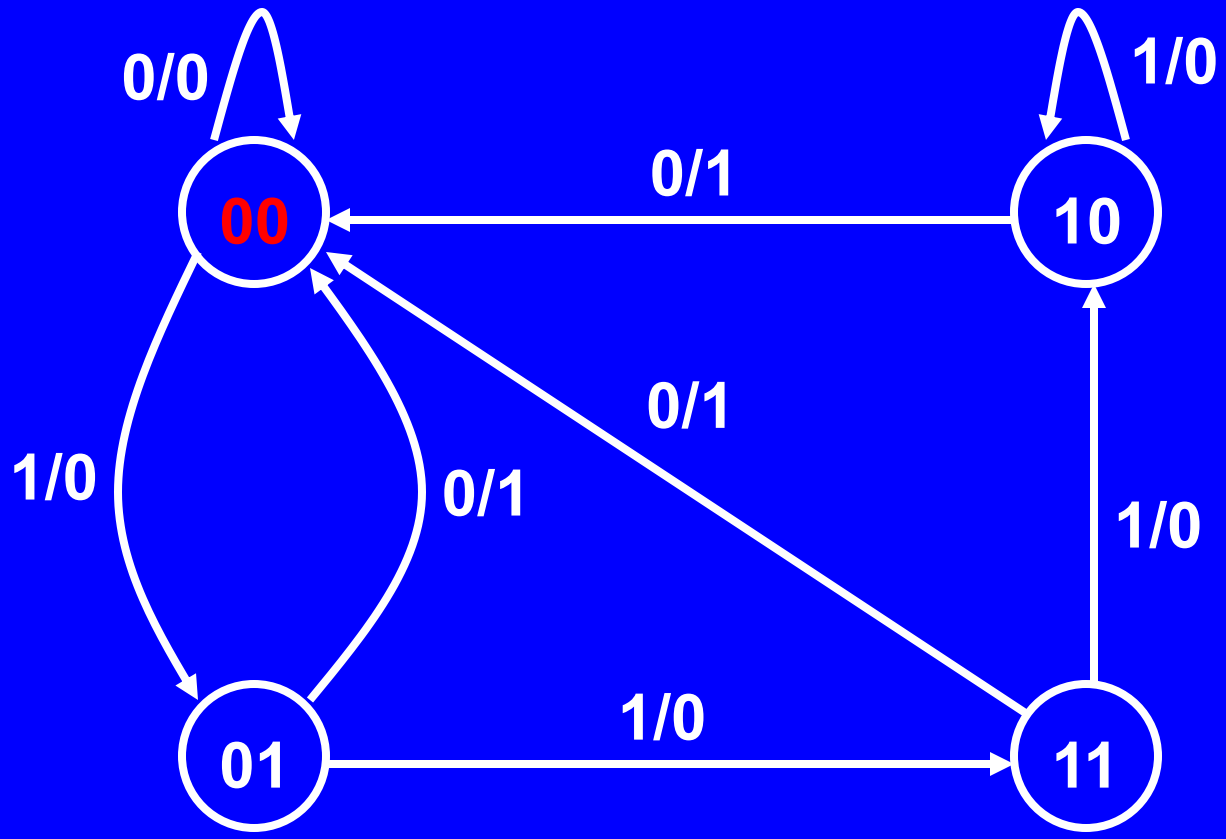
State diagram



State diagram



State diagram



Excitation tables

Q(t)	Q(t+1)	S	R
0	0	0	X
0	1	1	0
1	0	0	1
1	1	X	0

Q(t)	Q(t+1)	J	K
0	0	0	X
0	1	1	X
1	0	X	1
1	1	X	0

Q(t)	Q(t+1)	D
0	0	0
0	1	1
1	0	0
1	1	1

Q(t)	Q(t+1)	T
0	0	0
0	1	1
1	0	1
1	1	0

Design with D latches

Current		Input	Next		Inputs D		
A	B	X	A	B	DA	DB	Y
0	0	0	0	0	0	0	0
0	0	1	0	1	0	1	0
0	1	0	0	0	0	0	1
0	1	1	1	1	1	1	0
1	0	0	0	0	0	0	1
1	0	1	1	0	1	0	0
1	1	0	0	0	0	0	1
1	1	1	1	0	1	0	0

DA

A \ BX	00	01	11	10
0	0	0	1	0
1	0	1	1	0

DB

A \ BX	00	01	11	10
0	0	1	1	0
1	0	0	0	0

Y

A \ BX	00	01	11	10
0	0	0	0	1
1	1	0	0	1

DA

A \ BX	00	01	11	10
0	0	0	1	0
1	0	1	1	0

DA=AX+BX

DB

A \ BX	00	01	11	10
0	0	1	1	0
1	0	0	0	0

Y

A \ BX	00	01	11	10
0	0	0	0	1
1	1	0	0	1

DA

A \ BX	00	01	11	10
0	0	0	1	0
1	0	1	1	0

DA=AX+BX

DB=A'X

DB

A \ BX	00	01	11	10
0	0	1	1	0
1	0	0	0	0

Y

A \ BX	00	01	11	10
0	0	0	0	1
1	1	0	0	1

DA

A \ BX	00	01	11	10
0	0	0	1	0
1	0	1	1	0

DA=AX+BX

DB=A'X

Y=AX'+BX

DB

A \ BX	00	01	11	10
0	0	1	1	0
1	0	0	0	0

Y

A \ BX	00	01	11	10
0	0	0	0	1
1	1	0	0	1

Excitation tables

Q(t)	Q(t+1)	S	R
0	0	0	X
0	1	1	0
1	0	0	1
1	1	X	0

Q(t)	Q(t+1)	J	K
0	0	0	X
0	1	1	X
1	0	X	1
1	1	X	0

Q(t)	Q(t+1)	D
0	0	0
0	1	1
1	0	0
1	1	1

Q(t)	Q(t+1)	T
0	0	0
0	1	1
1	0	1
1	1	0

Design with JK latches

Q(t)	Q(t+1)	J	K
0	0	0	X
0	1	1	X
1	0	X	1
1	1	X	0

Current		Input	Next		Inputs JK			
A	B	X	A	B	JA	KA	JB	KB
0	0	0	0	0	0	X	0	X
0	0	1	0	1	0	X	1	X
0	1	0	0	0	0	X	X	1
0	1	1	1	1	1	X	X	0
1	0	0	0	0	X	1	0	X
1	0	1	1	0	X	0	0	X
1	1	0	0	0	X	1	X	1
1	1	1	1	0	X	0	X	1

JA

A \ BX	00	01	11	10
0	0	0	1	0
1	X	X	X	X

KA

A \ BX	00	01	11	10
0	X	X	X	X
1	1	0	0	1

JB

A \ BX	00	01	11	10
0	0	1	X	X
1	0	0	X	X

KB

A \ BX	00	01	11	10
0	X	X	0	1
1	X	X	1	1

JA

A \ BX	00	01	11	10
0	0	0	1	0
1	X	X	X	X

JA=BX

KA

A \ BX	00	01	11	10
0	X	X	X	X
1	1	0	0	1

KA=X’

JB

A \ BX	00	01	11	10
0	0	1	X	X
1	0	0	X	X

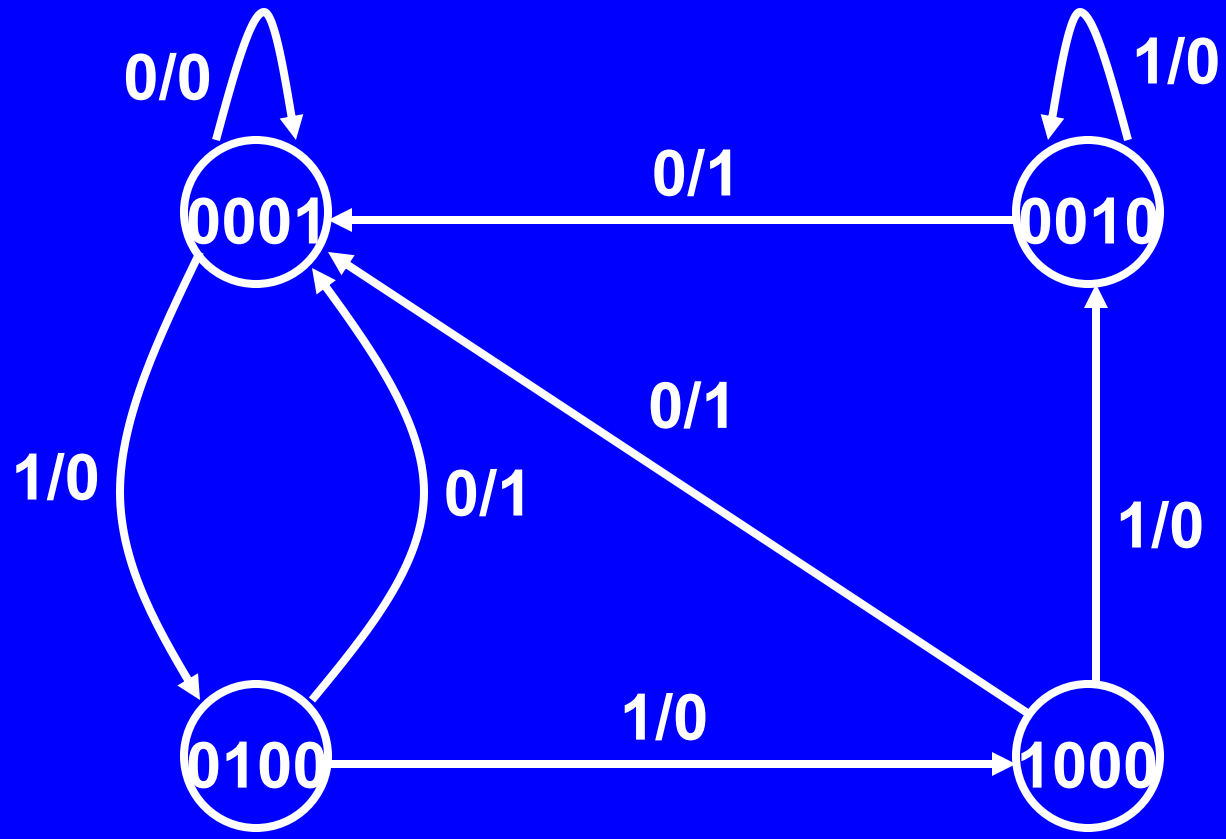
JB=A’X

KB

A \ BX	00	01	11	10
0	X	X	0	1
1	X	X	1	1

KB=A+X’

State diagram for one-hot design



One-hot design

Current					Next			
A	B	C	D	X	A	B	C	D
0	0	0	1	0	0	0	0	1
0	0	0	1	1	0	1	0	0
0	0	1	0	0	0	0	0	1
0	0	1	0	1	0	0	1	0
0	1	0	0	0	0	0	0	1
0	1	0	0	1	1	0	0	0
1	0	0	0	0	0	0	0	1
1	0	0	0	1	0	0	1	0

One-hot design

Current					Next			
A	B	C	D	X	A	B	C	D
0	0	0	1	0	0	0	0	1
0	0	0	1	1	0	1	0	0
0	0	1	0	0	0	0	0	1
0	0	1	0	1	0	0	1	0
0	1	0	0	0	0	0	0	1
0	1	0	0	1	1	0	0	0
1	0	0	0	0	0	0	0	1
1	0	0	0	1	0	0	1	0

DA=BX

One-hot design

Current					Next			
A	B	C	D	X	A	B	C	D
0	0	0	1	0	0	0	0	1
0	0	0	1	1	0	1	0	0
0	0	1	0	0	0	0	0	1
0	0	1	0	1	0	0	1	0
0	1	0	0	0	0	0	0	1
0	1	0	0	1	1	0	0	0
1	0	0	0	0	0	0	0	1
1	0	0	0	1	0	0	1	0

DA=BX

DB=DX

One-hot design

Current					Next			
A	B	C	D	X	A	B	C	D
0	0	0	1	0	0	0	0	1
0	0	0	1	1	0	1	0	0
0	0	1	0	0	0	0	0	1
0	0	1	0	1	0	0	1	0
0	1	0	0	0	0	0	0	1
0	1	0	0	1	1	0	0	0
1	0	0	0	0	0	0	0	1
1	0	0	0	1	0	0	1	0

DA=BX

DB=DX

DC=CX+AX

One-hot design

Current					Next			
A	B	C	D	X	A	B	C	D
0	0	0	1	0	0	0	0	1
0	0	0	1	1	0	1	0	0
0	0	1	0	0	0	0	0	1
0	0	1	0	1	0	0	1	0
0	1	0	0	0	0	0	0	1
0	1	0	0	1	1	0	0	0
1	0	0	0	0	0	0	0	1
1	0	0	0	1	0	0	1	0

DA=BX

DB=DX

DC=(C+A)X

One-hot design

Current					Next			
A	B	C	D	X	A	B	C	D
0	0	0	1	0	0	0	0	1
0	0	0	1	1	0	1	0	0
0	0	1	0	0	0	0	0	1
0	0	1	0	1	0	0	1	0
0	1	0	0	0	0	0	0	1
0	1	0	0	1	1	0	0	0
1	0	0	0	0	0	0	0	1
1	0	0	0	1	0	0	1	0

DA=BX

DB=DX

DC=(C+A)X

DD=AX'+BX'
+CX'+DX'

One-hot design

Current					Next			
A	B	C	D	X	A	B	C	D
0	0	0	1	0	0	0	0	1
0	0	0	1	1	0	1	0	0
0	0	1	0	0	0	0	0	1
0	0	1	0	1	0	0	1	0
0	1	0	0	0	0	0	0	1
0	1	0	0	1	1	0	0	0
1	0	0	0	0	0	0	0	1
1	0	0	0	1	0	0	1	0

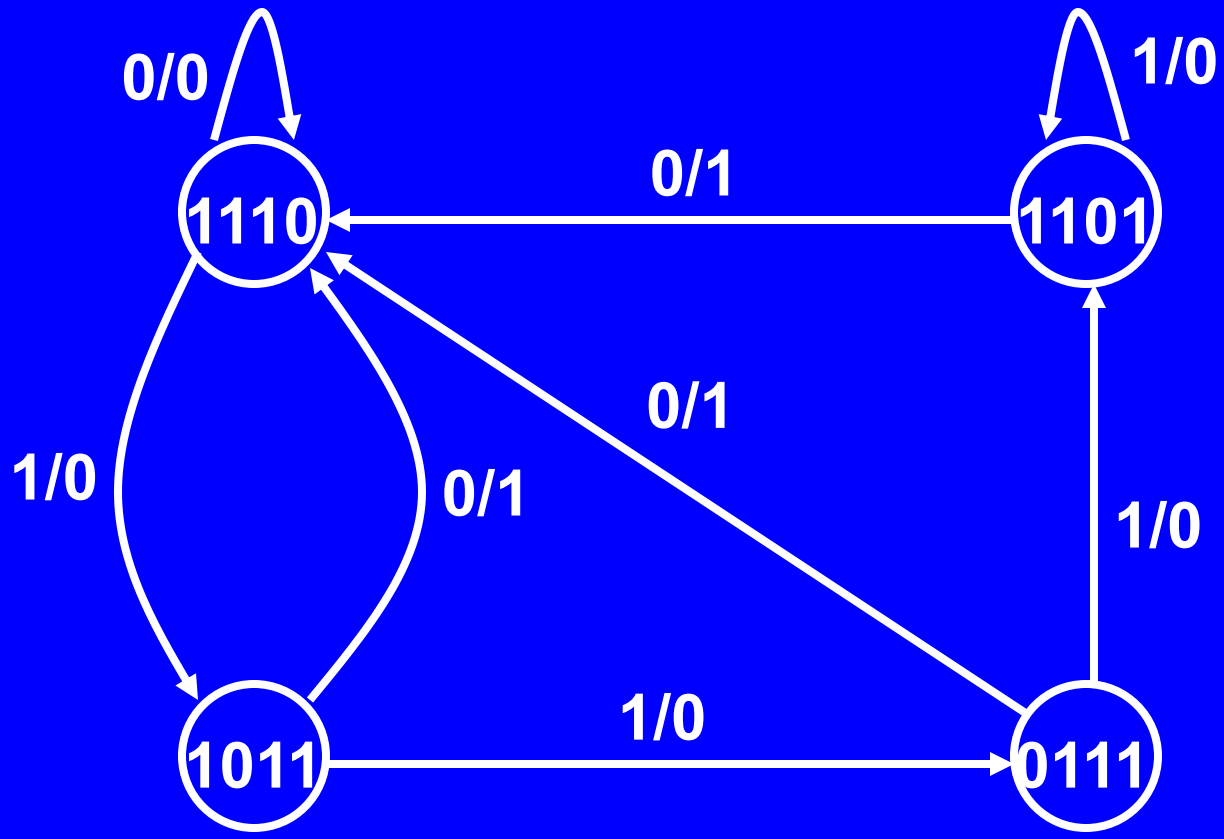
DA=BX

DB=DX

DC=(C+A)X

DD=X’

State diagram for one-cold design



One-cold design

Current					Next			
A	B	C	D	X	A	B	C	D
1	1	1	0	0	1	1	1	0
1	1	1	0	1	1	0	1	1
1	1	0	1	0	1	1	1	0
1	1	0	1	1	1	1	0	1
1	0	1	1	0	1	1	1	0
1	0	1	1	1	0	1	1	1
0	1	1	1	0	1	1	1	0
0	1	1	1	1	1	1	0	1

One-cold design

Current					Next			
A	B	C	D	X	A	B	C	D
1	1	1	0	0	1	1	1	0
1	1	1	0	1	1	0	1	1
1	1	0	1	0	1	1	1	0
1	1	0	1	1	1	1	0	1
1	0	1	1	0	1	1	1	0
1	0	1	1	1	0	1	1	1
0	1	1	1	0	1	1	1	0
0	1	1	1	1	1	1	0	1

DA=B+X’

One-cold design

Current					Next			
A	B	C	D	X	A	B	C	D
1	1	1	0	0	1	1	1	0
1	1	1	0	1	1	0	1	1
1	1	0	1	0	1	1	1	0
1	1	0	1	1	1	1	0	1
1	0	1	1	0	1	1	1	0
1	0	1	1	1	0	1	1	1
0	1	1	1	0	1	1	1	0
0	1	1	1	1	1	1	0	1

DA=B+X’

DB=D+X’

One-cold design

Current					Next			
A	B	C	D	X	A	B	C	D
1	1	1	0	0	1	1	1	0
1	1	1	0	1	1	0	1	1
1	1	0	1	0	1	1	1	0
1	1	0	1	1	1	1	0	1
1	0	1	1	0	1	1	1	0
1	0	1	1	1	0	1	1	1
0	1	1	1	0	1	1	1	0
0	1	1	1	1	1	1	0	1

DA=B+X’

DB=D+X’

DC=(C+X’)
(A+X’)

One-cold design

Current					Next			
A	B	C	D	X	A	B	C	D
1	1	1	0	0	1	1	1	0
1	1	1	0	1	1	0	1	1
1	1	0	1	0	1	1	1	0
1	1	0	1	1	1	1	0	1
1	0	1	1	0	1	1	1	0
1	0	1	1	1	0	1	1	1
0	1	1	1	0	1	1	1	0
0	1	1	1	1	1	1	0	1

DA=B+X’

DB=D+X’

DC=X’+AC

One-cold design

Current					Next			
A	B	C	D	X	A	B	C	D
1	1	1	0	0	1	1	1	0
1	1	1	0	1	1	0	1	1
1	1	0	1	0	1	1	1	0
1	1	0	1	1	1	1	0	1
1	0	1	1	0	1	1	1	0
1	0	1	1	1	0	1	1	1
0	1	1	1	0	1	1	1	0
0	1	1	1	1	1	1	0	1

DA=B+X’

DB=D+X’

DC=X’+AC

DD=X