Binary Encoding

How do we convert from binary to decimal in general?

B2	B1	B0		decimal
0	0	0		0
0	0	1		1
0	1	0		2
0	1	1		3
1	0	0		4
1	0	1		5
1	1	0		6
1	1	1		7

Binary to Decimal Conversion

$$value = B_0 + B_1 * 2^1 + B_2 * 2^2 + B_3 * 2^3 + \ldots$$

$$value = \sum_{i=0}^{N-1} B_i * 2^i$$

How do we convert from decimal to binary?

Decimal to Binary Conversion

```
int value;

For each i: B[i] = 0

while(value > 0) {
    if(remainder of value / 2 is 1) {
        B[i] = 1;
    }
    value = value / 2;
}
```

Time

Until now: we have ignored the issue of time

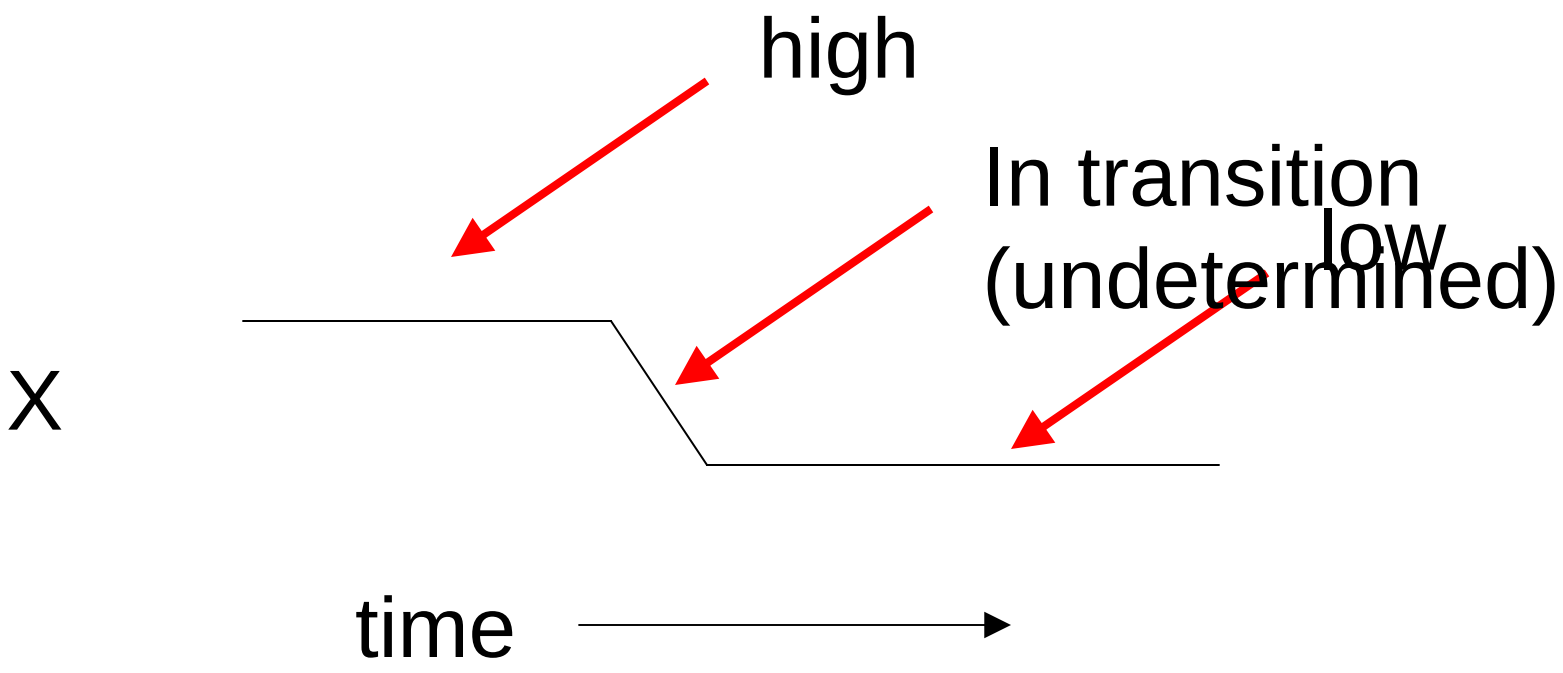
- We assumed that our digital logic circuits perform their computations instantaneously
- Our digital logic circuits have been "stateless"
  - Once you present a new input, they forget everything about previous inputs
  - We call this type of digital system **combinatorial logic**

Time

In reality, time is an important issue:

- Even our logic gates induce a small amount of delay (on the order of a few nanoseconds)
- For much of what we do – we actually want our circuits to have some form of memory

Timing Notation

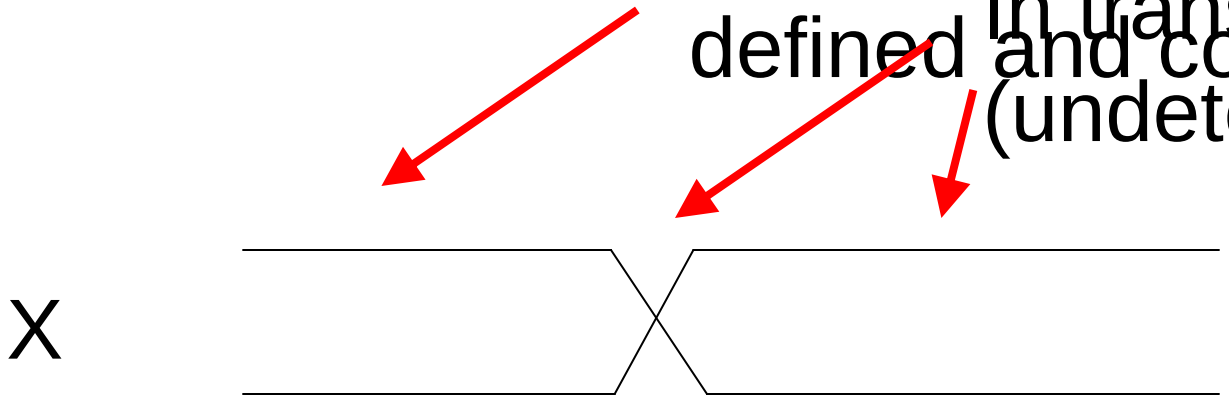


Timing Notation

Either high or low (but well defined and constant)

In transition

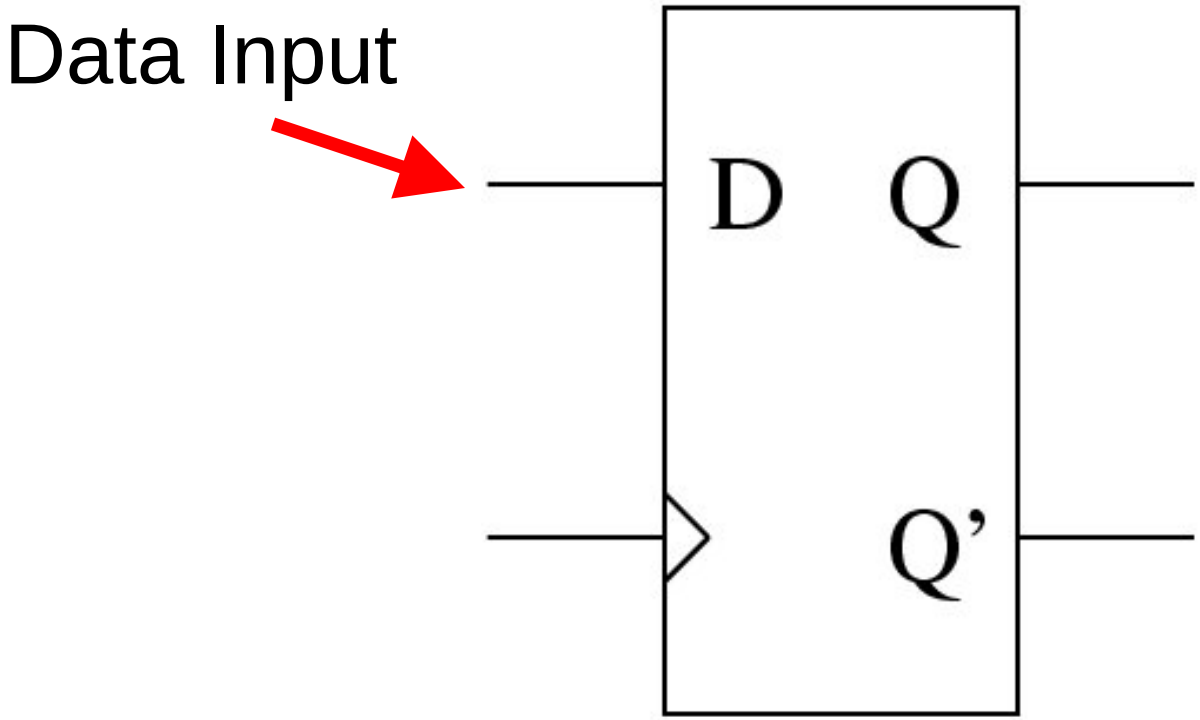
(undetermined)



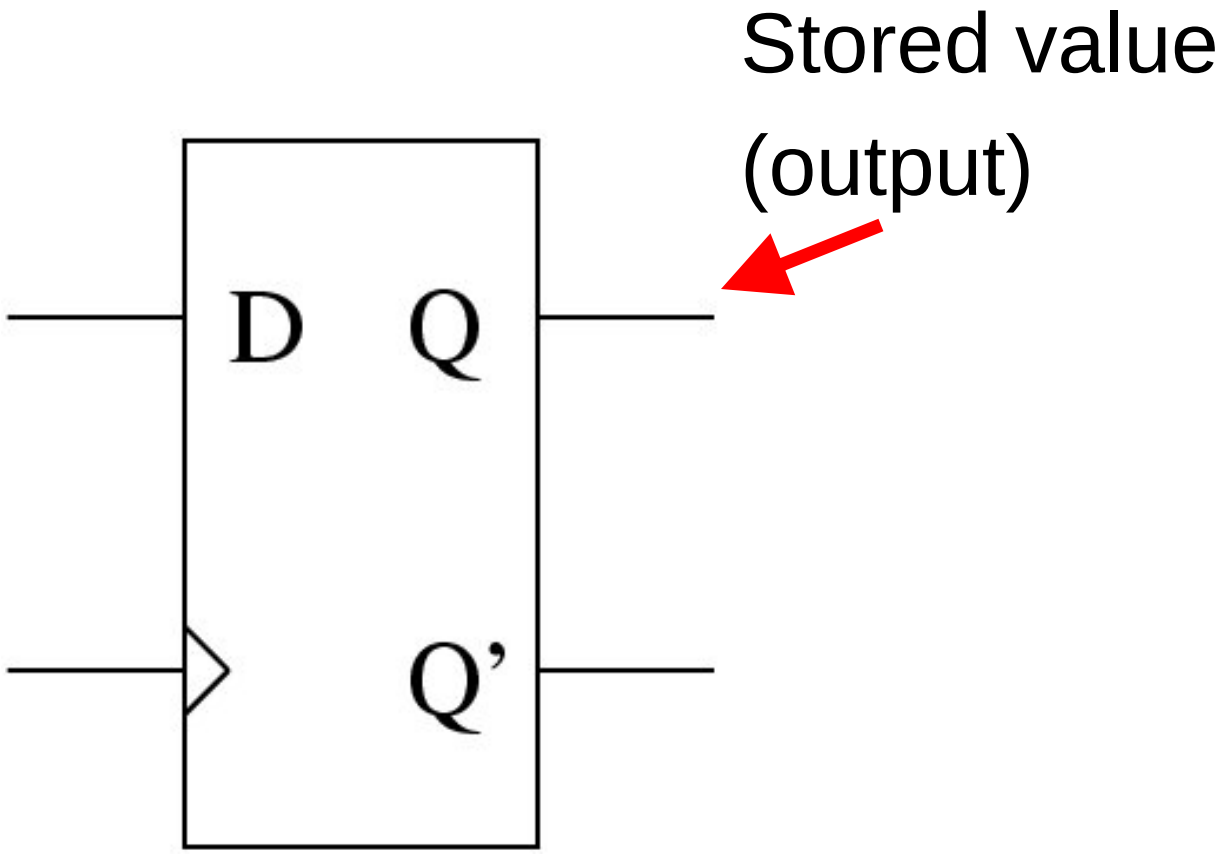
time

low

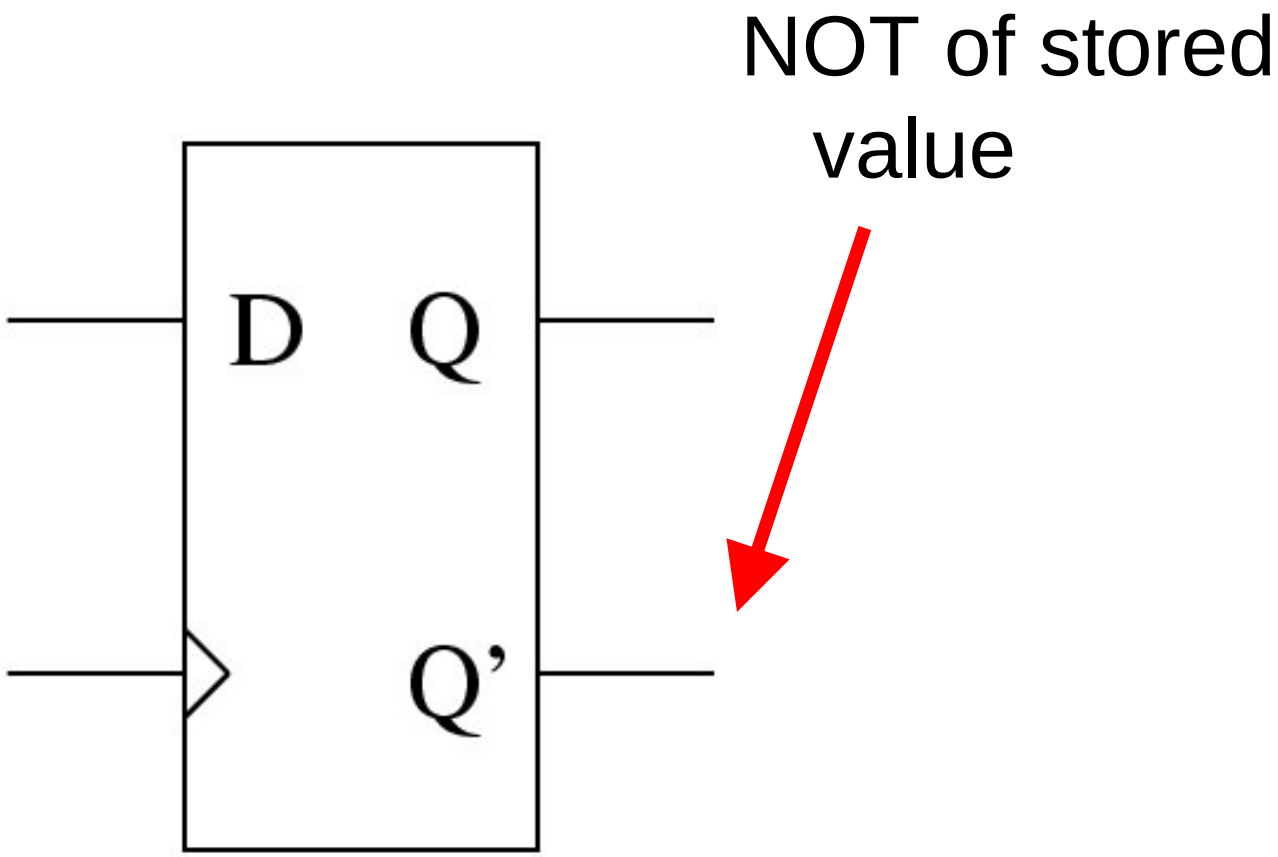
D Flip Flops



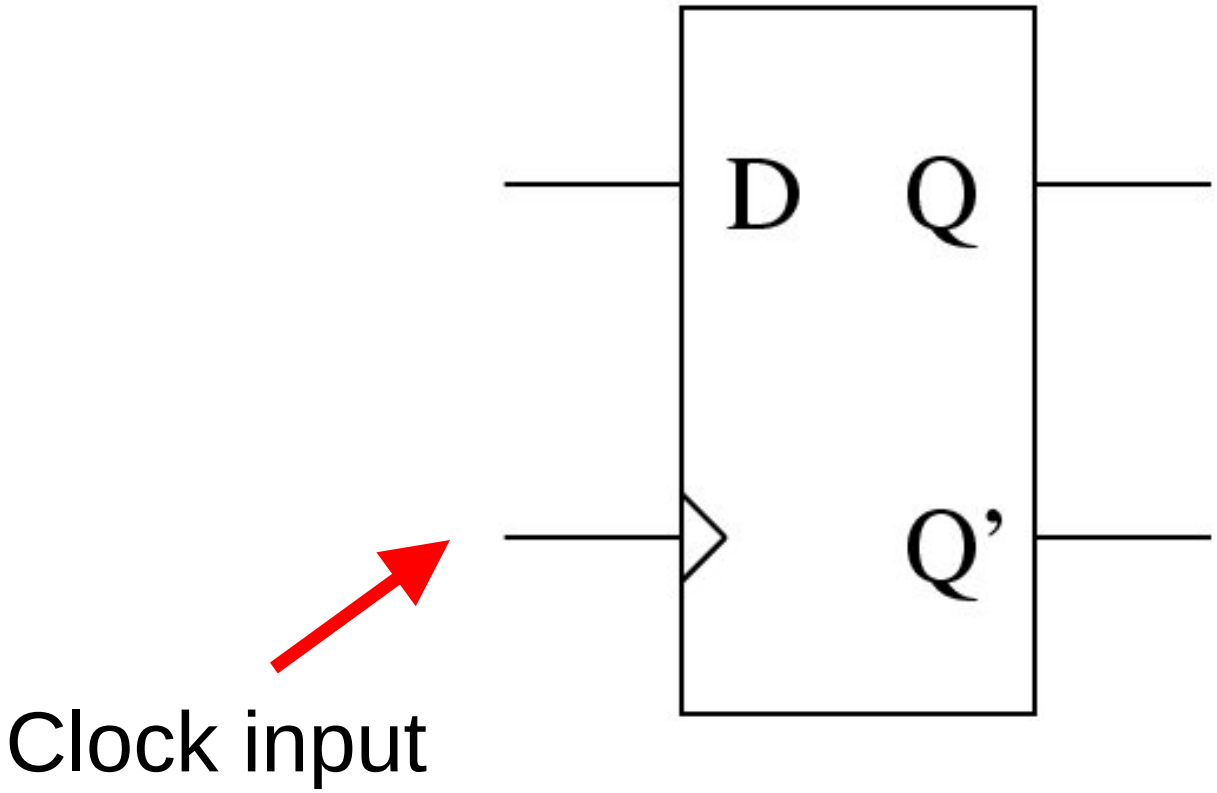
D Flip Flops



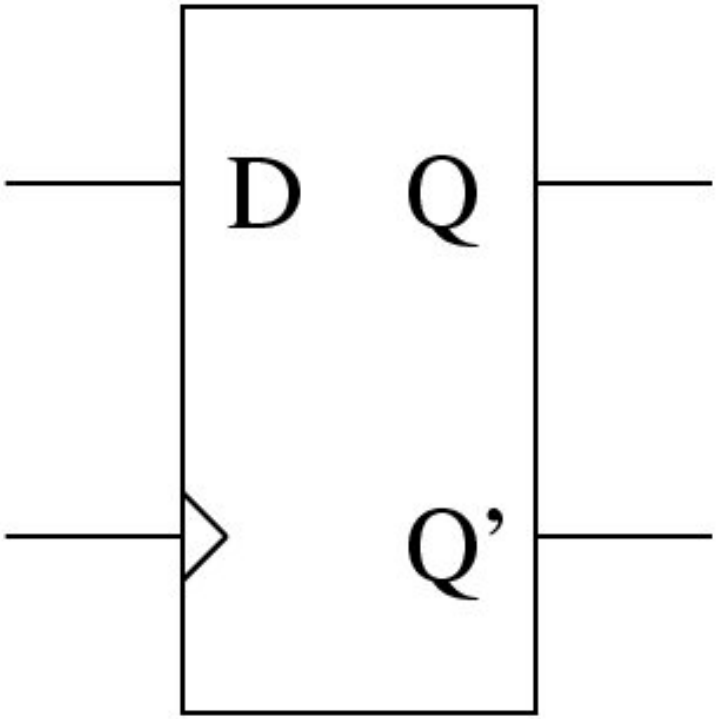
D Flip Flops



D Flip Flops

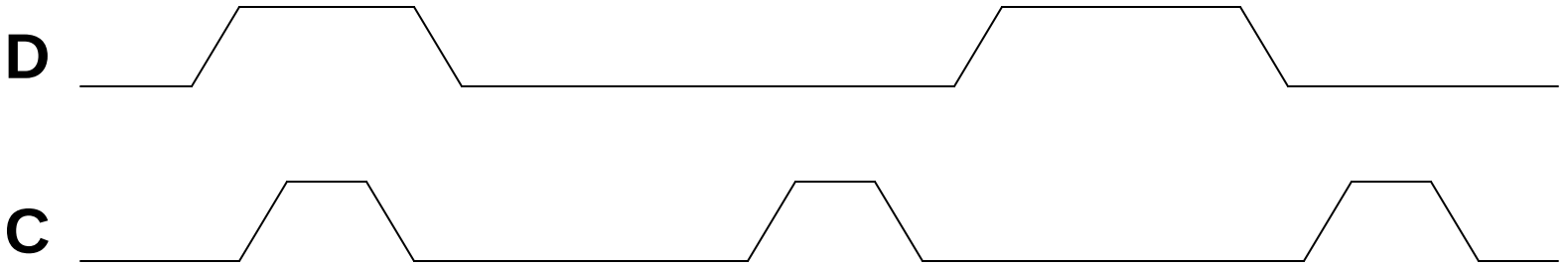


D Flip Flops



When the clock transitions from high to low:
the value of D is stored

D Flip Flop

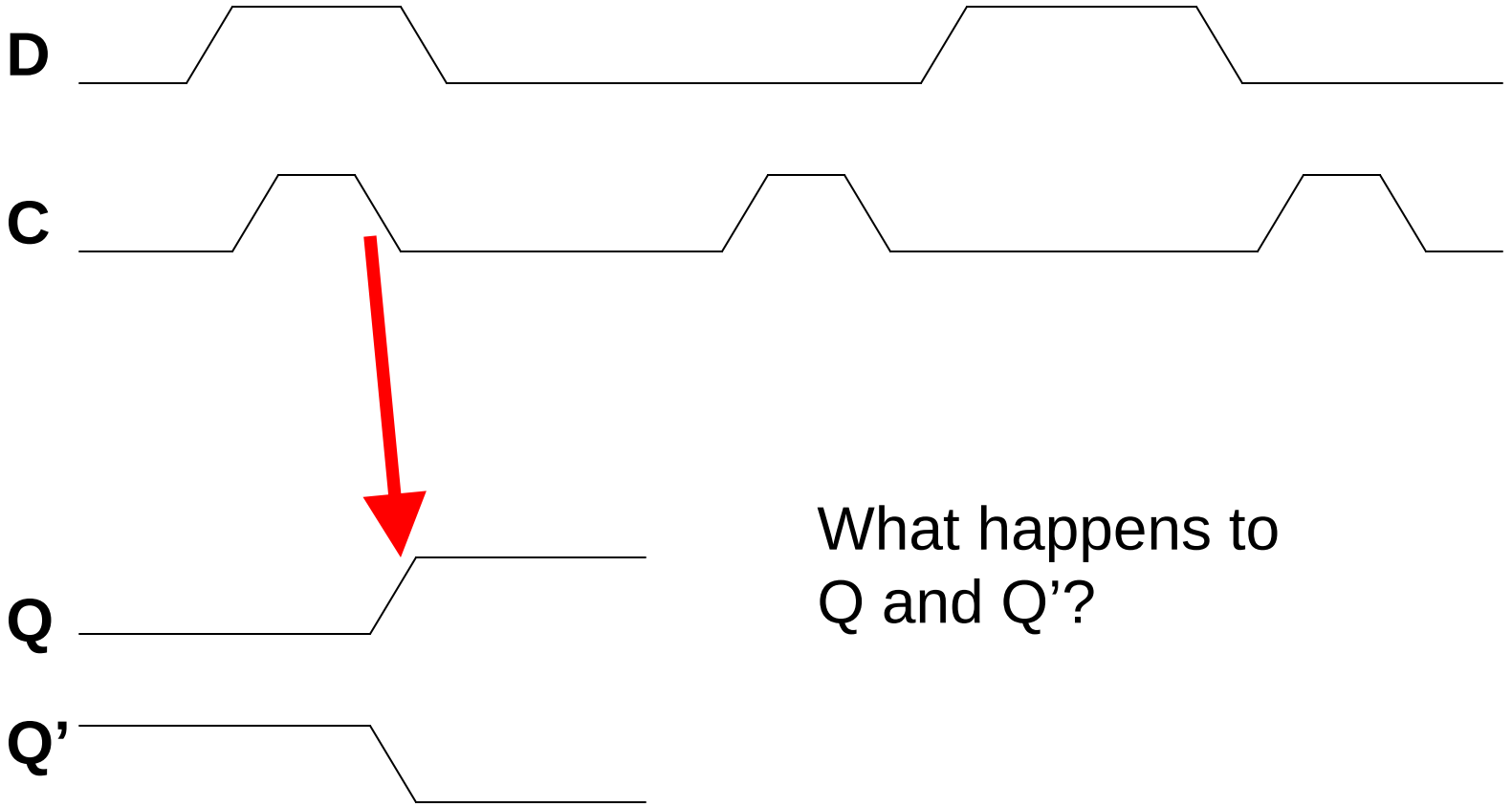


Q

Q'

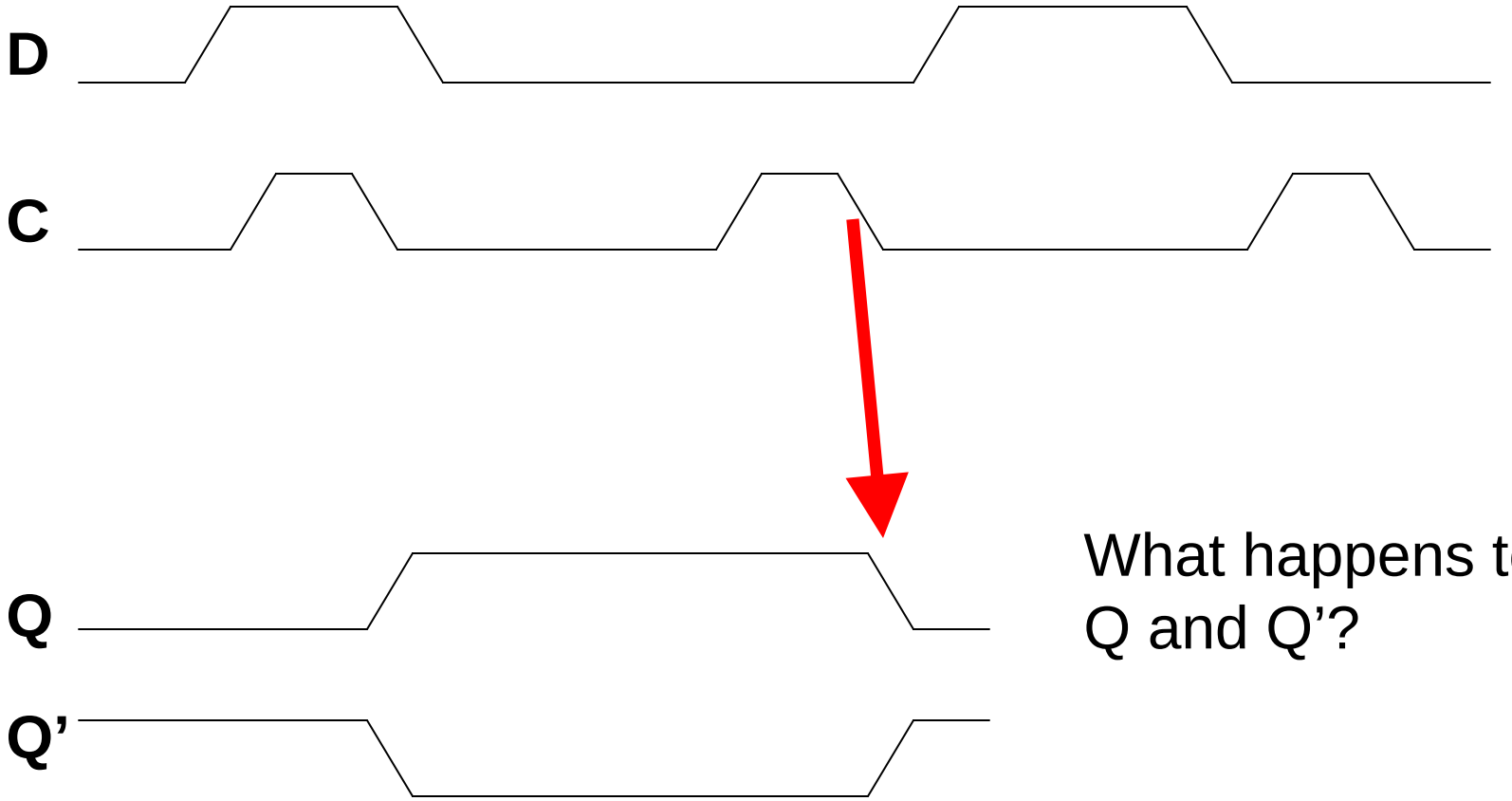
What happens to
Q and Q'?

D Flip Flop



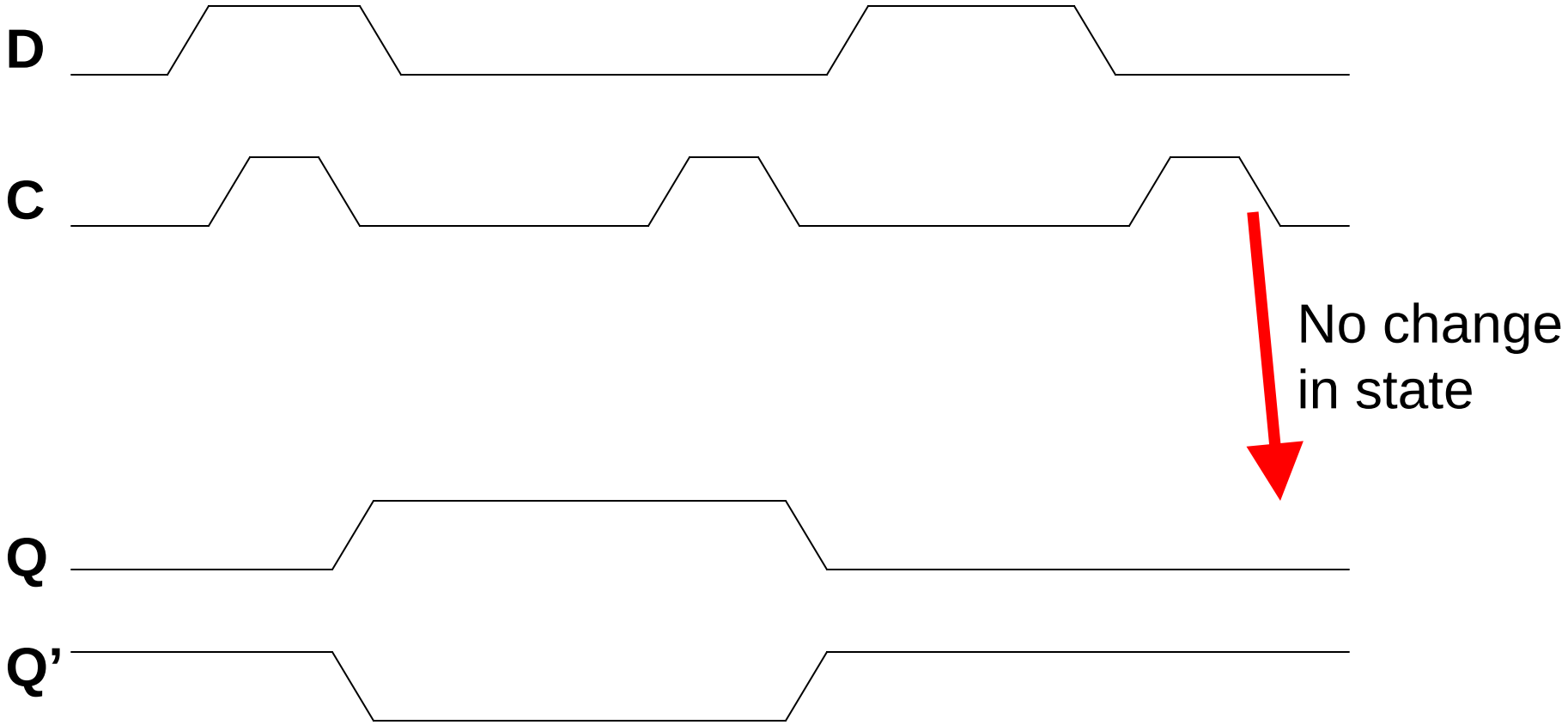
What happens to
Q and Q'?

D Flip Flop



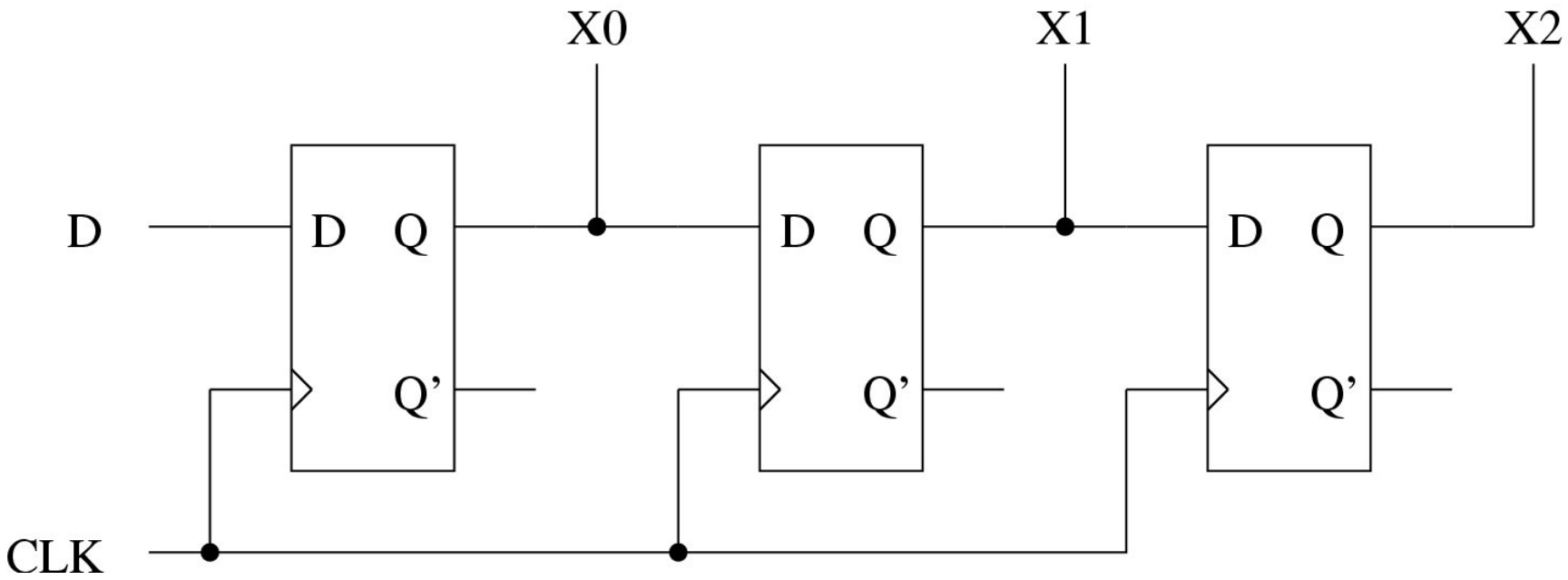
What happens to Q and Q'?

D Flip Flop



An Application of D Flip Flops

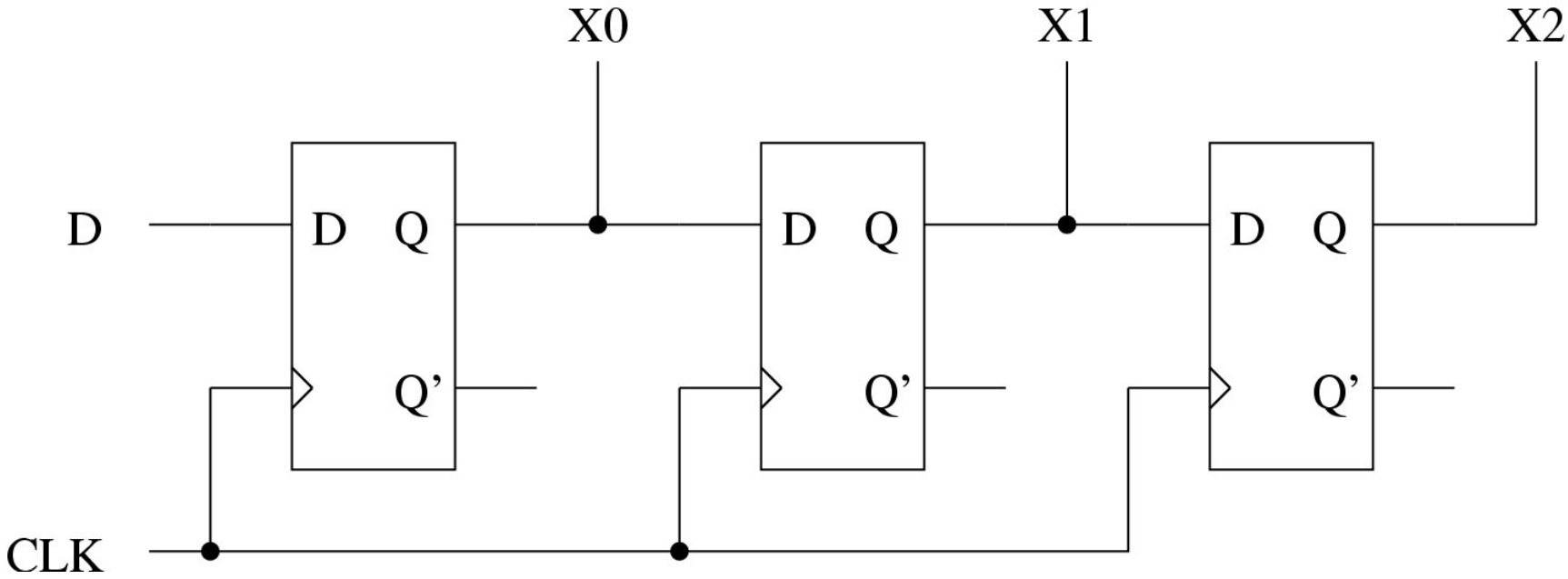
What does this circuit do?



Shift Register

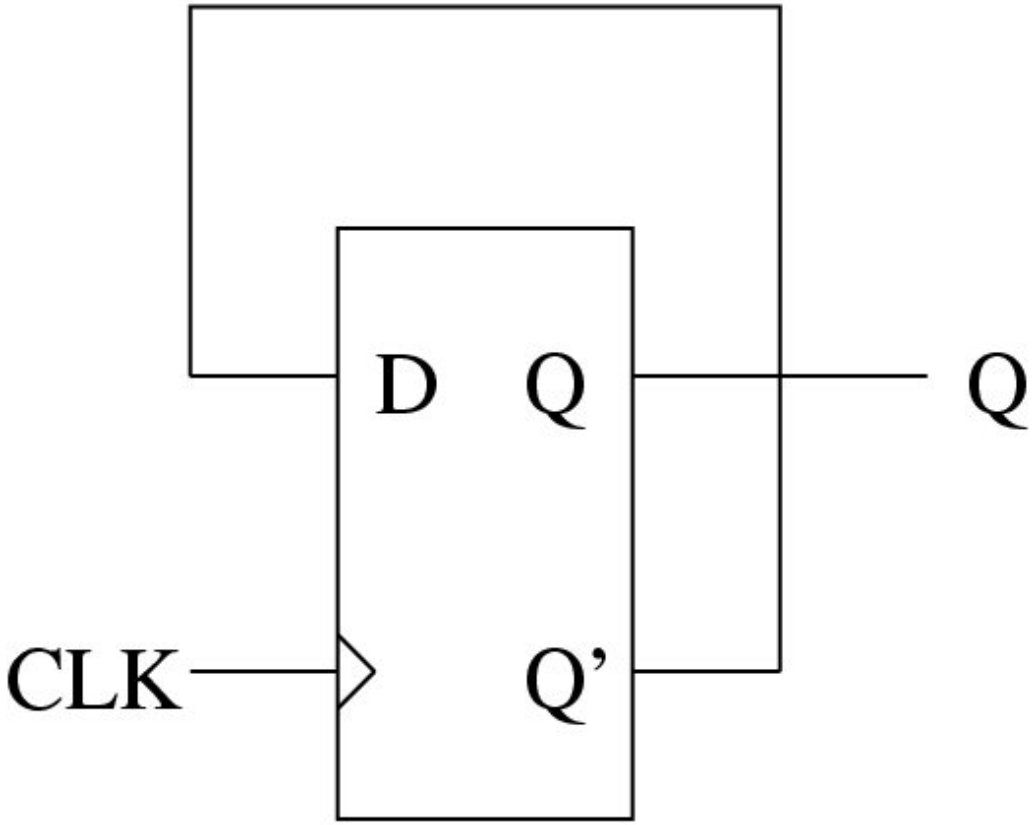
On each clock transition from high to low:

- X0 takes on the current value of D
- X1 becomes the old value of X0
- X2 becomes the old value of X1



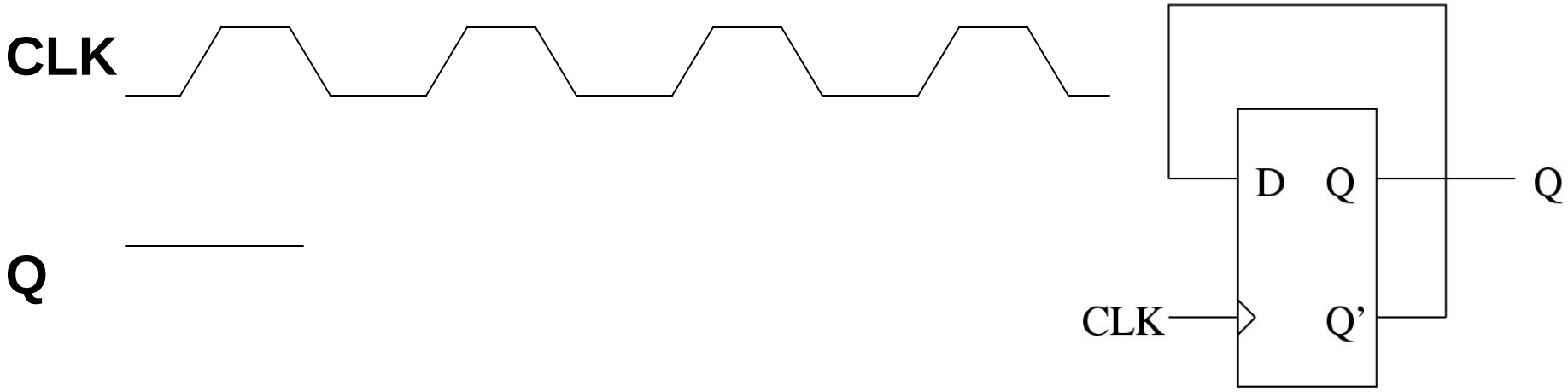
Another D Flip Flop Circuit

How does this circuit behave?



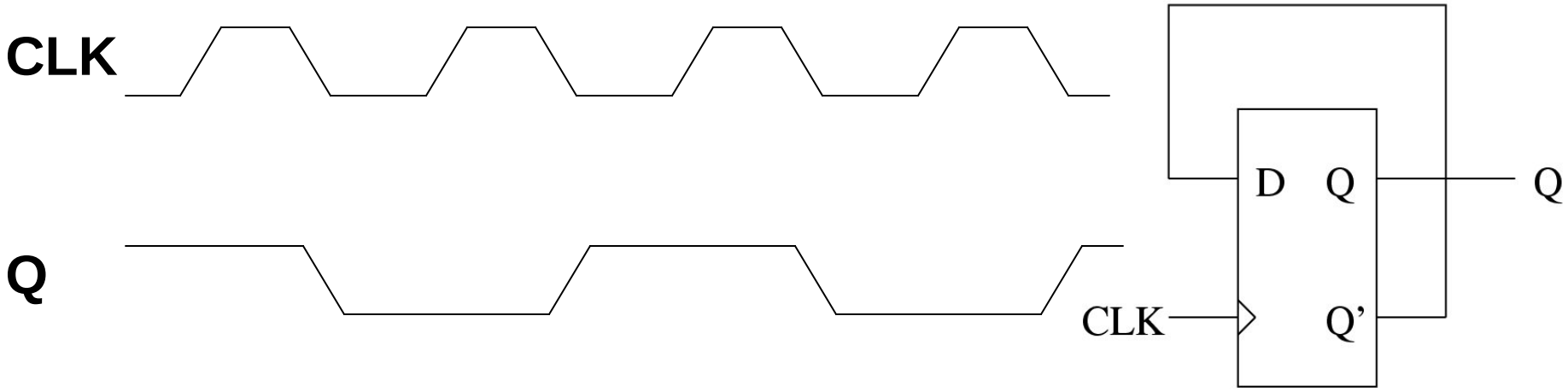
Another D Flip Flop Circuit

How does this circuit behave?



Frequency Divider

Q flips state on every downward edge of the clock



Binary Counter

How would we build a circuit that counts the number of clock ticks that have gone by?

Q2	Q1	Q0
0	0	0
0	0	1
0	1	0
0	1	1
1	0	0
1	0	1
1	1	0
1	1	1

Binary Counter

How would we build a circuit that counts the number of clock ticks that have gone by?

Combinatorial circuit design: for a given set of input Q values, output the D's for the next number in the sequence

Q2	Q1	Q0
0	0	0
0	0	1
0	1	0
0	1	1
1	0	0
1	0	1
1	1	0
1	1	1