How do we convert from binary to decimal in general?

<table>
<thead>
<tr>
<th>B2</th>
<th>B1</th>
<th>B0</th>
<th>decimal</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<tr>
<td>0</td>
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<td>0</td>
<td>4</td>
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<td>0</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
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<td>1</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>7</td>
</tr>
</tbody>
</table>
Binary to Decimal Conversion

\[
\text{value} = B_0 + B_1 \times 2^1 + B_2 \times 2^2 + B_3 \times 2^3 + \ldots
\]

\[
\text{value} = \sum_{i=0}^{N-1} B_i \times 2^i
\]

How do we convert from decimal to binary?
Decimal to Binary Conversion

```java
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

In transition (undetermined)
Timing Notation

Either high or low (but well defined and constant)
In transition (undetermined)

X

______

time

______

low
D Flip Flops

Stored value
(output)
D Flip Flops

NOT of stored value
D Flip Flops

Clock input
D Flip Flops

When the clock transitions from high to low: the value of D is stored
What happens to Q and Q’?
What happens to $Q$ and $Q'$?
D Flip Flop

What happens to Q and Q'?
D Flip Flop

D

C

Q

Q'

No change in state
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?

CLK

Q

CLK

Q'
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?

<table>
<thead>
<tr>
<th>Q2</th>
<th>Q1</th>
<th>Q0</th>
</tr>
</thead>
<tbody>
<tr>
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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

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