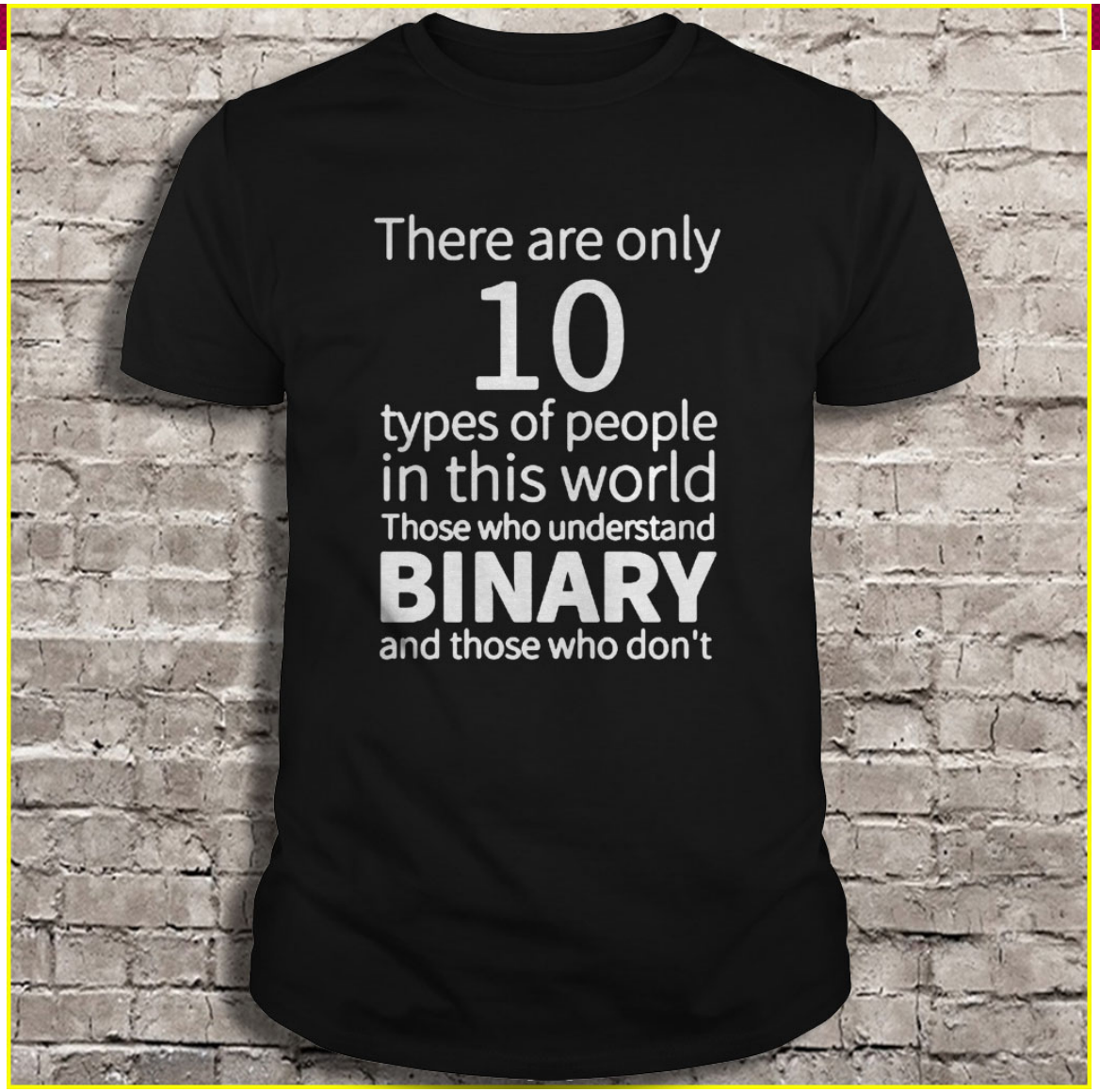
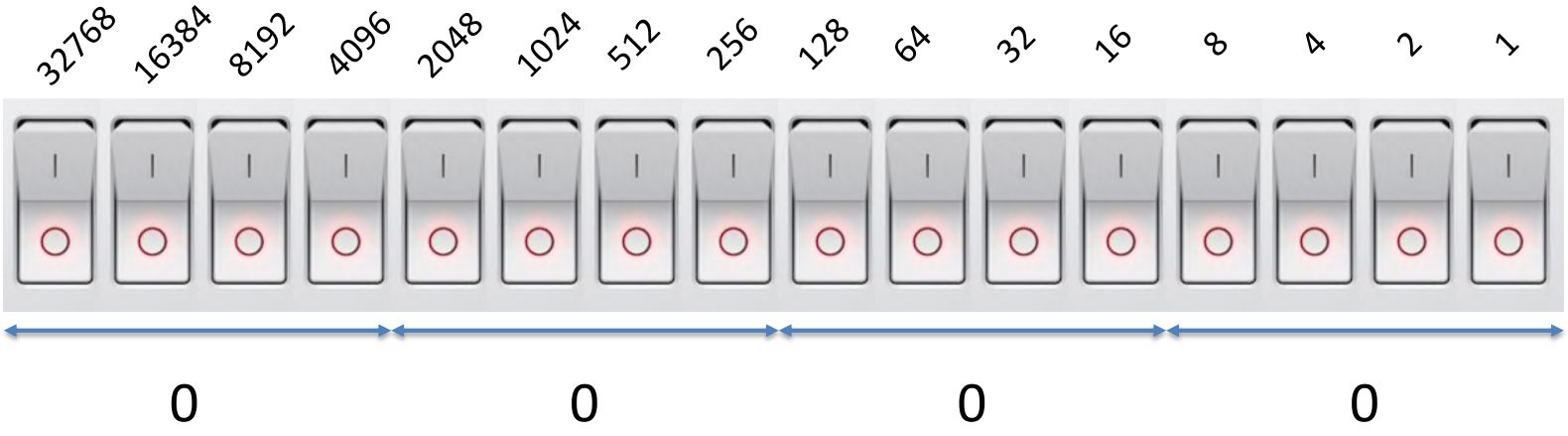
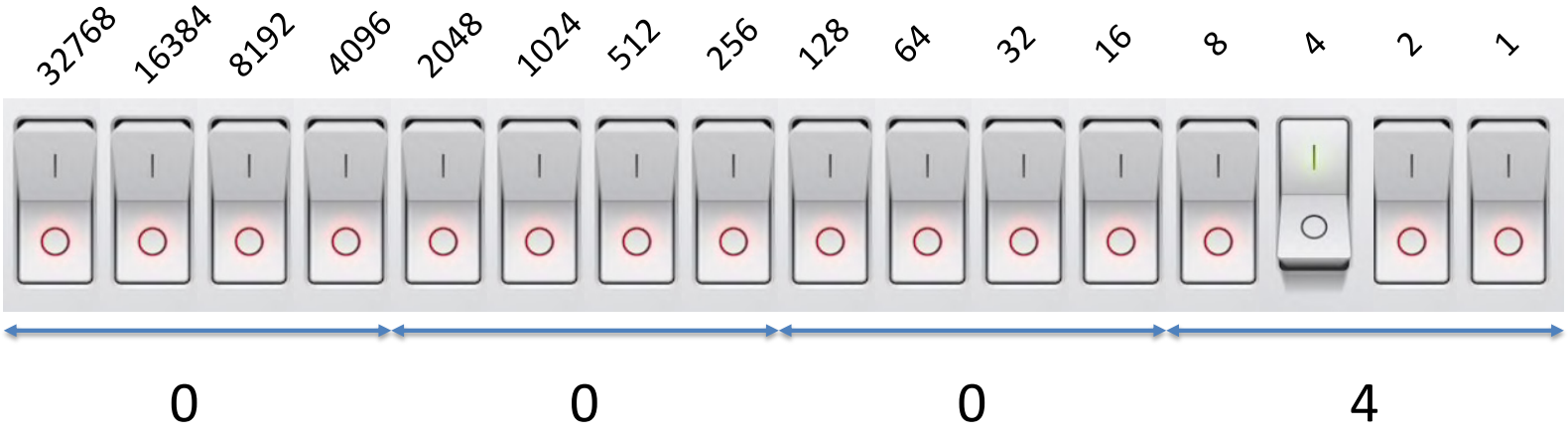
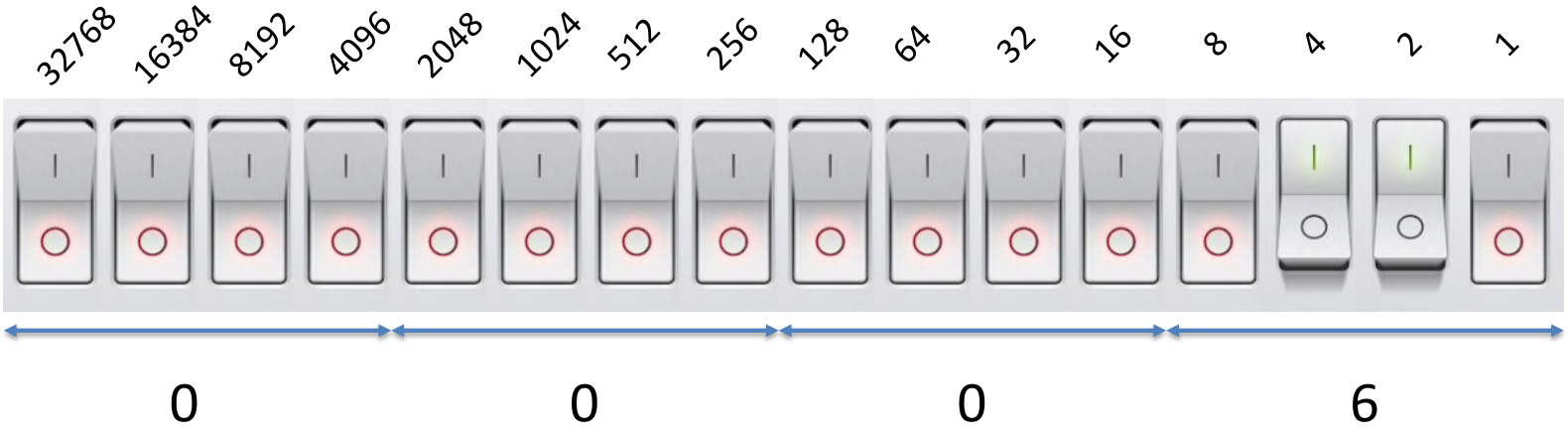
BINARY


There are only
10
types of people
in this world
Those who understand
BINARY
and those who don't

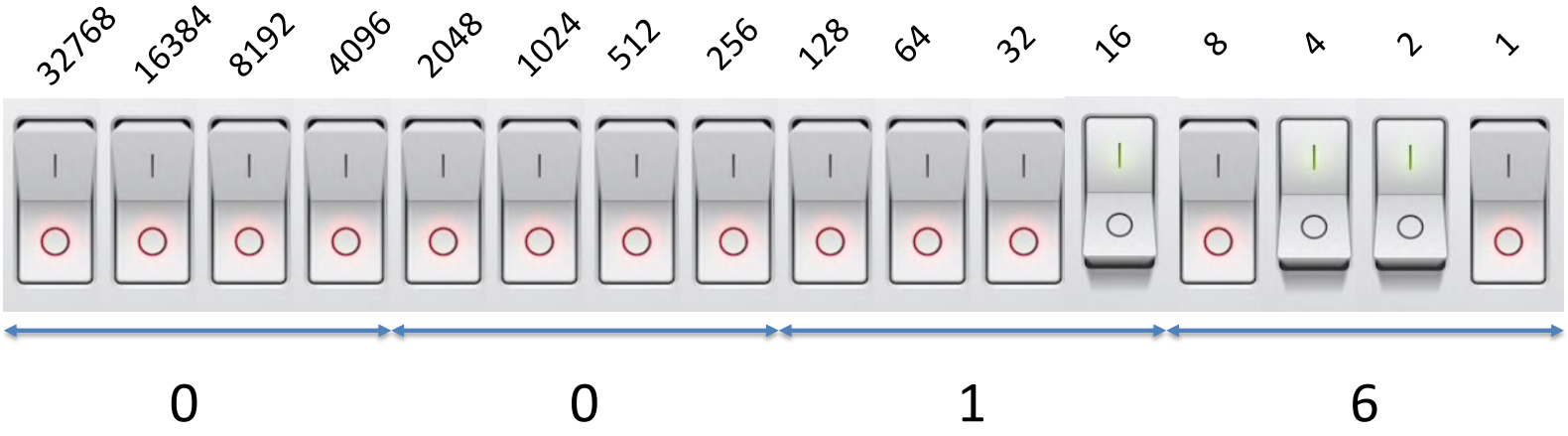

32768
16384
8192
4096
2048
1024
512
256
128
64
32
16
8
4
2
1
0
0
0
0
0



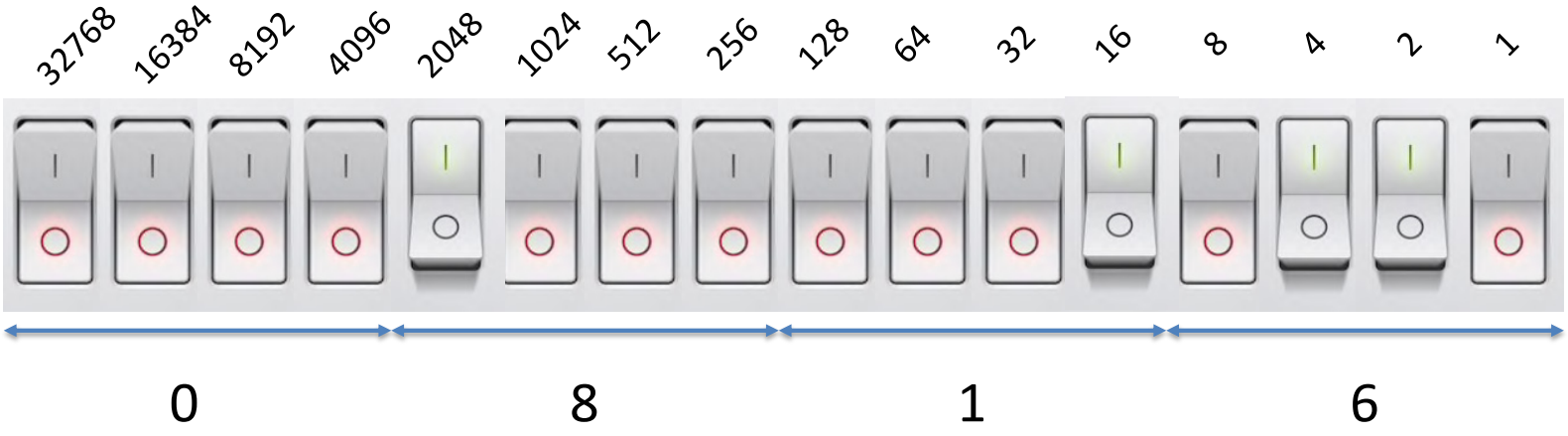
4_{10}



6_{10}



22_{10}



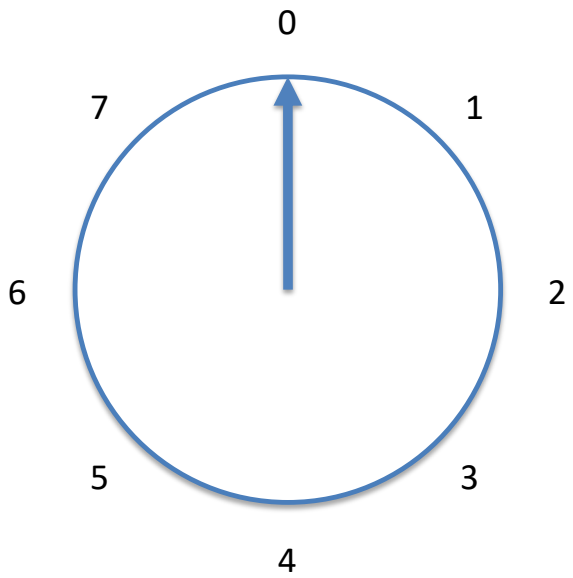
2070_{10}

HOW TO REPRESENT NEGATIVE NUMBERS?

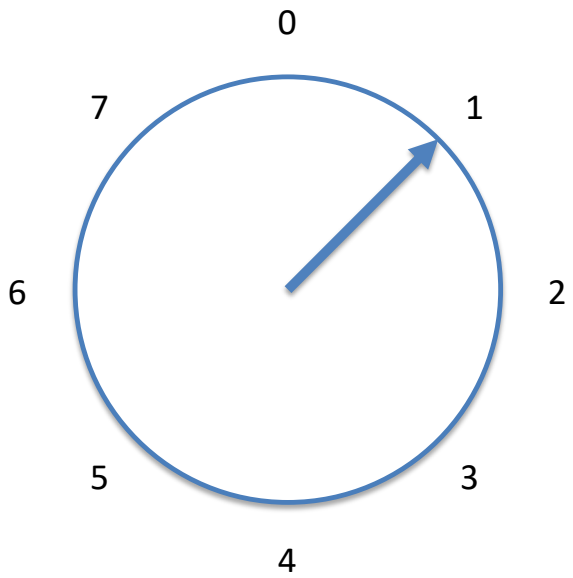
People have tried many things:

1. Using the most significant bit (MSB) as the sign bit: Sign-Magnitude
   - `0101` = $+5_{10}$
   - `1101` = -5_{10}
2. Inverting all bits: 1's Complement
   - `0101` = $+5_{10}$
   - `1010` = -5_{10}
3. Etc.
4. To explain, we need the concept of modular arithmetic

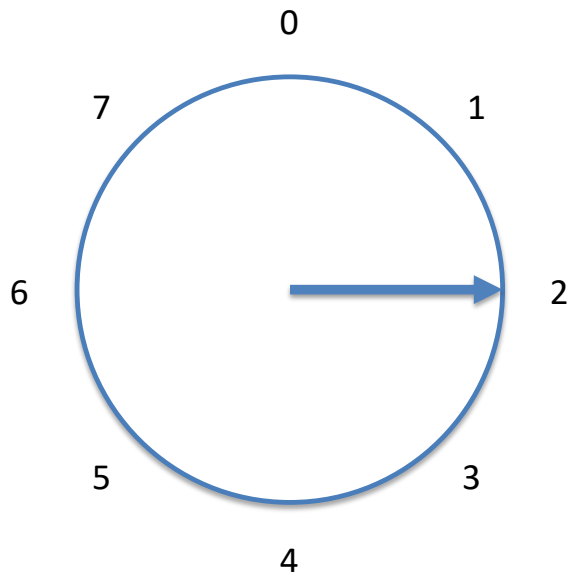
MODULAR ARITHMETIC IS LIKE A CLOCK.



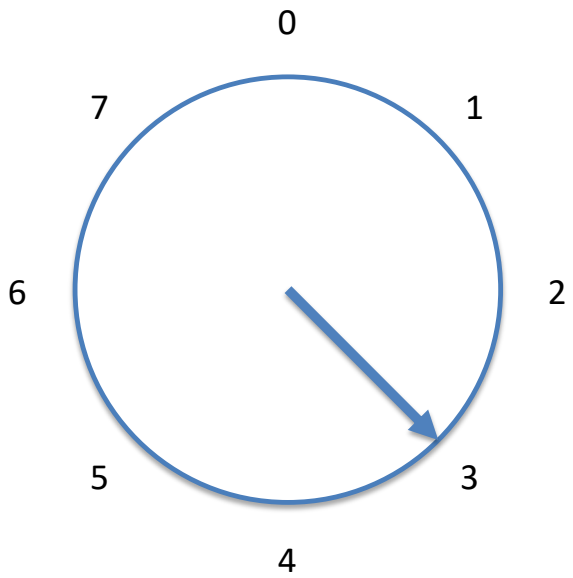
MODULAR ARITHMETIC IS LIKE A CLOCK.



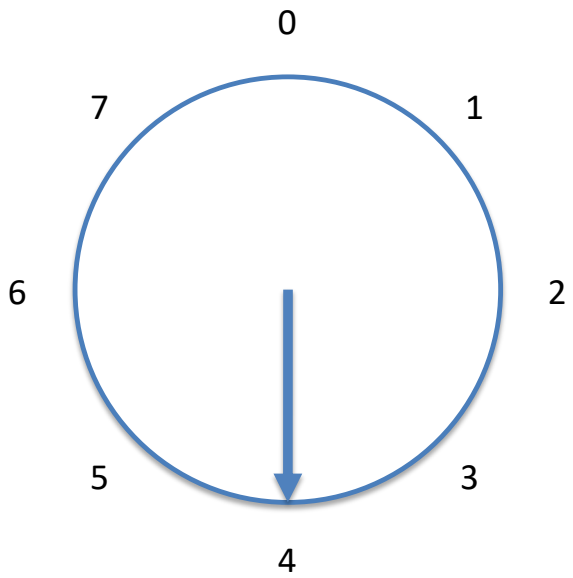
MODULAR ARITHMETIC IS LIKE A CLOCK.



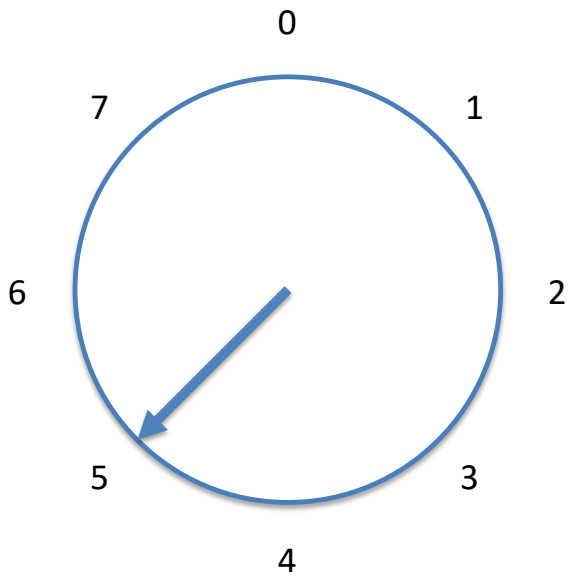
MODULAR ARITHMETIC IS LIKE A CLOCK.



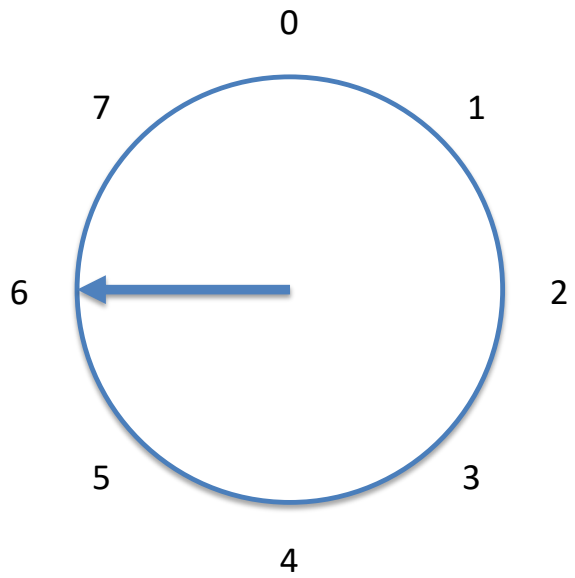
MODULAR ARITHMETIC IS LIKE A CLOCK.



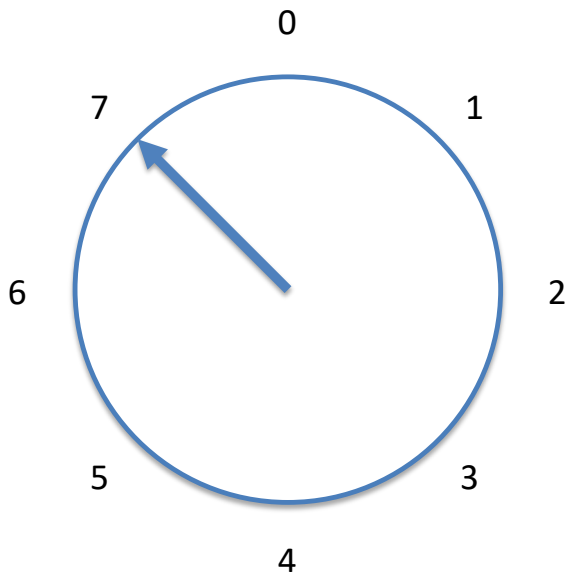
MODULAR ARITHMETIC IS LIKE A CLOCK.



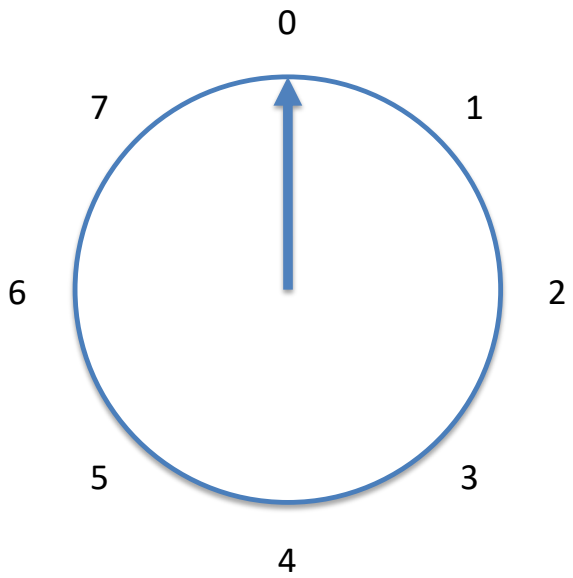
MODULAR ARITHMETIC IS LIKE A CLOCK.



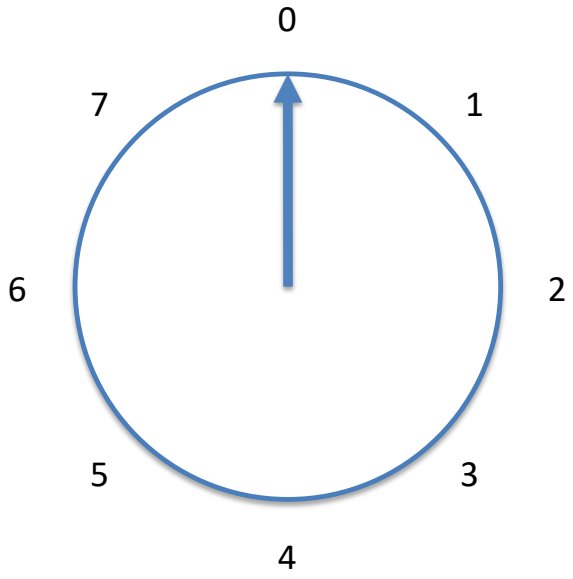
MODULAR ARITHMETIC IS LIKE A CLOCK.



MODULAR ARITHMETIC IS LIKE A CLOCK.



MODULAR ARITHMETIC IS LIKE A CLOCK.



Now you try: What is 3+7 MOD 8?

$$\begin{array}{rll} & 0\ 1\ 1 & = 3_{10} \\ + & 1\ 1\ 1 & = 7_{10} \\ \hline & 1\ 0\ 1\ 0 & = 10_{10} \\ \text{MOD 8:} & 0\ 1\ 0 & = 2_{10}\text{!!!} \end{array}$$

7 is a NEGATIVE NUMBER in MOD8 arithmetic!!!

2'S COMPLEMENT

To Convert a Positive Number into its 2's Complement (Negative):

1. Invert all bits in the target number
2. Add 1

2_{10} 0 1 0

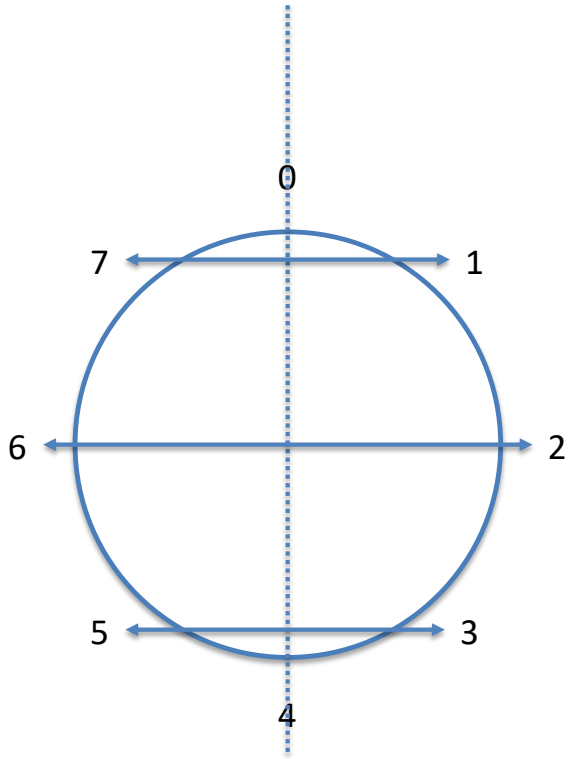
↓

1 0 1

\+ 1

-2_{10} 1 1 0

MODULAR ARITHMETIC IS LIKE A CLOCK.



2's Complement works because we are reflecting across the line that separates positive numbers from negative numbers.

2'S COMPLEMENT: EXAMPLE W/ MOD 2^{16} ARITH

```
 D     8     7     E
1101  1000  0111  1110
```

Is this number negative or positive?

Negative! Because MSB = 1

One's: Invert All Bits

```
 2     7     8     1
0010  0111  1000  0001
```

Two's: Add 1 to One's

```
 2     7     8     2
0010  0111  1000  0010
```

```
  1 1 1 1
    D 8 7 E
+   2 7 8 2
-----------
1 0 0 0 0
```

Drop most significant bit because we are doing arithmetic mod 2^{16}

2'S COMPLEMENT: EXAMPLE W/ MOD 2^{16} ARITH

```
 1     6     A     F
0001  0110  1010  1111
```

Is this number negative or positive?

Positive! Because MSB = 0

One's: Invert All Bits

```
 E     9     5     0
1110  1001  0101  0000
```

Two's: Add 1 to One's

```
 E     9     5     1
1110  1001  0101  0001
```

```
  1111
   16AF
 + E951
 ------
 10000
```

Drop most significant bit because we are doing arithmetic mod 2^{16}