CS107 Lecture 3

Bits and Bytes, Integer Representations, Overflow

Reading: Bryant & O'Hallaron, Ch. 2.2-2.3 (skim)

Ed Discussion: https://edstem.org/us/courses/65949/discussion/5359785

Overflow

If you exceed the **maximum** value of your bit representation, you *wrap around* or *overflow* back to the **smallest** bit representation.

```
0b1111 + 0b1 =  0b0000
0b1111 + 0b10 = 0b0001
```

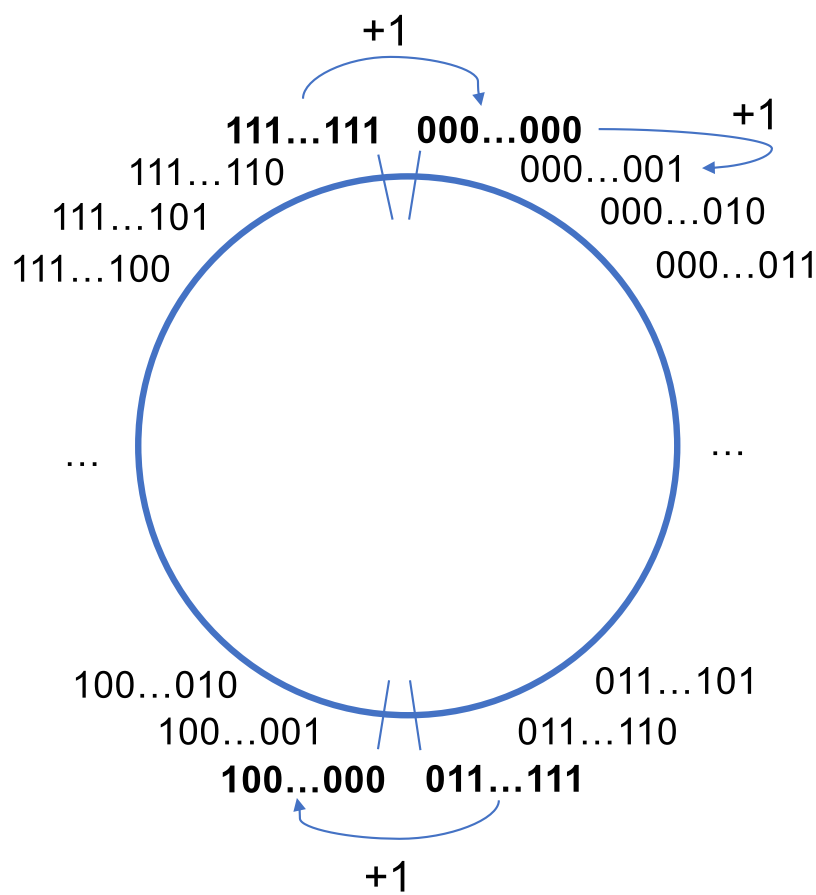
If you go below the **minimum** value of your bit representation, you *wrap around* or *overflow* (or rather, *underflow*) back to the **largest** bit representation.

```
0b0000 - 0b1 =  0b1111
0b0000 - 0b10 = 0b1110
```

Min and Max Integer Values

Type	Size	Minimum	Maximum
char	1	-128 (**SCHAR_MIN**)	127 (**SCHAR_MAX**)
unsigned char	1	0	255 (**UCHAR_MAX**)
short	2	-32768 (**SHRT_MIN**)	32767 (**SHRT_MAX**)
unsigned short	2	0	65535 (**USHRT_MAX**)
int	4	-2147483648 (**INT_MIN**)	2147483647 (**INT_MAX**)
unsigned int	4	0	4294967295 (**UINT_MAX**)
long	8	-9223372036854775808 (**LONG_MIN**)	9223372036854775807 (**LONG_MAX**)
unsigned long	8	0	18446744073709551615 (**ULONG_MAX**)

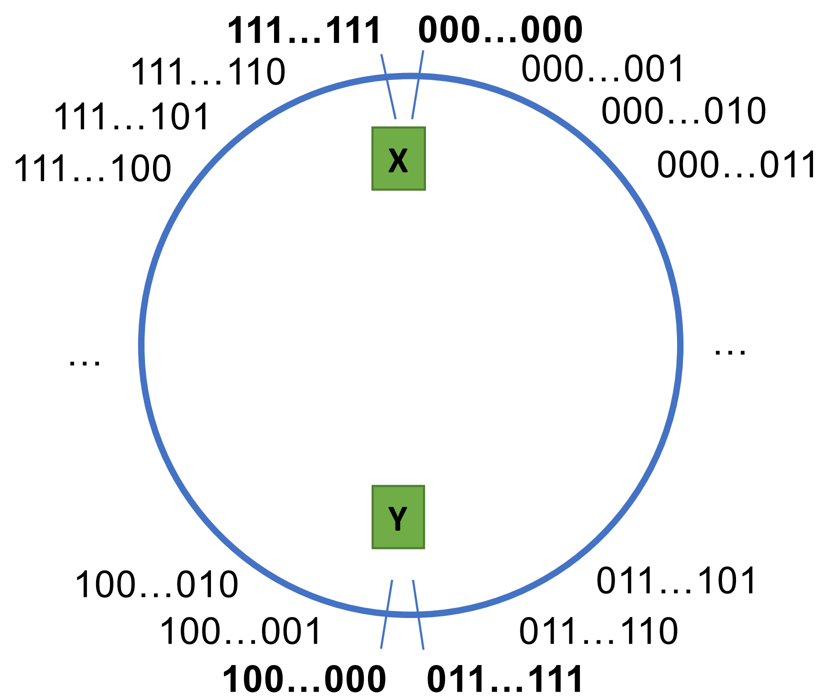
Overflow


+1
111…111
000…000
+1
111…110
000…001
111…101
000…010
111…100
000…011
…
…
100…010
011…101
100…001
011…110
100…000
011…111
+1

Overflow

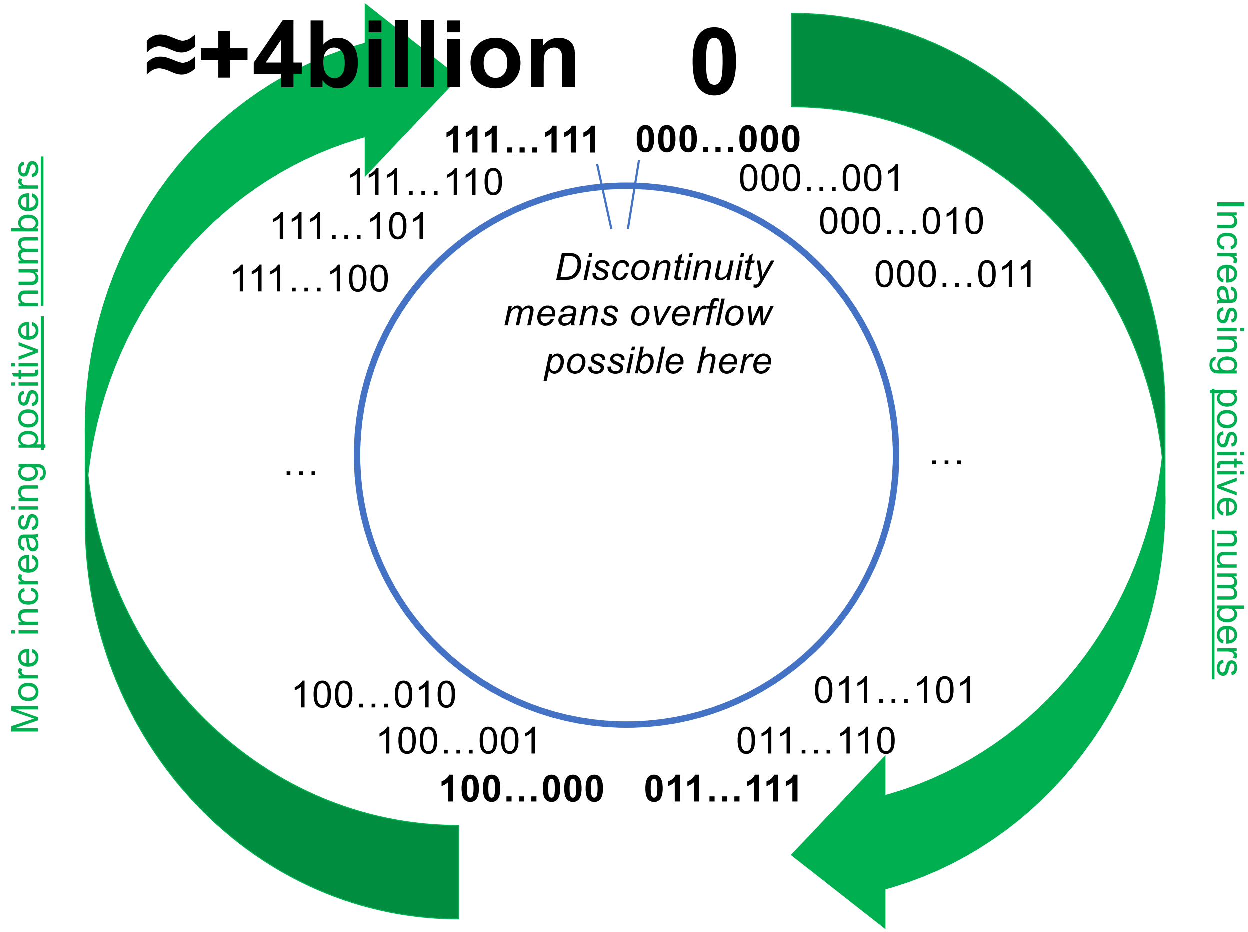
At which points can overflow occur for signed and unsigned int? *(assume binary values shown are all 32 bits)*

A. Signed and unsigned can both overflow at points X and Y
B. Signed can overflow only at X, unsigned only at Y
C. Signed can overflow only at Y, unsigned only at X
D. Signed can overflow at X and Y, unsigned only at X
E. Other

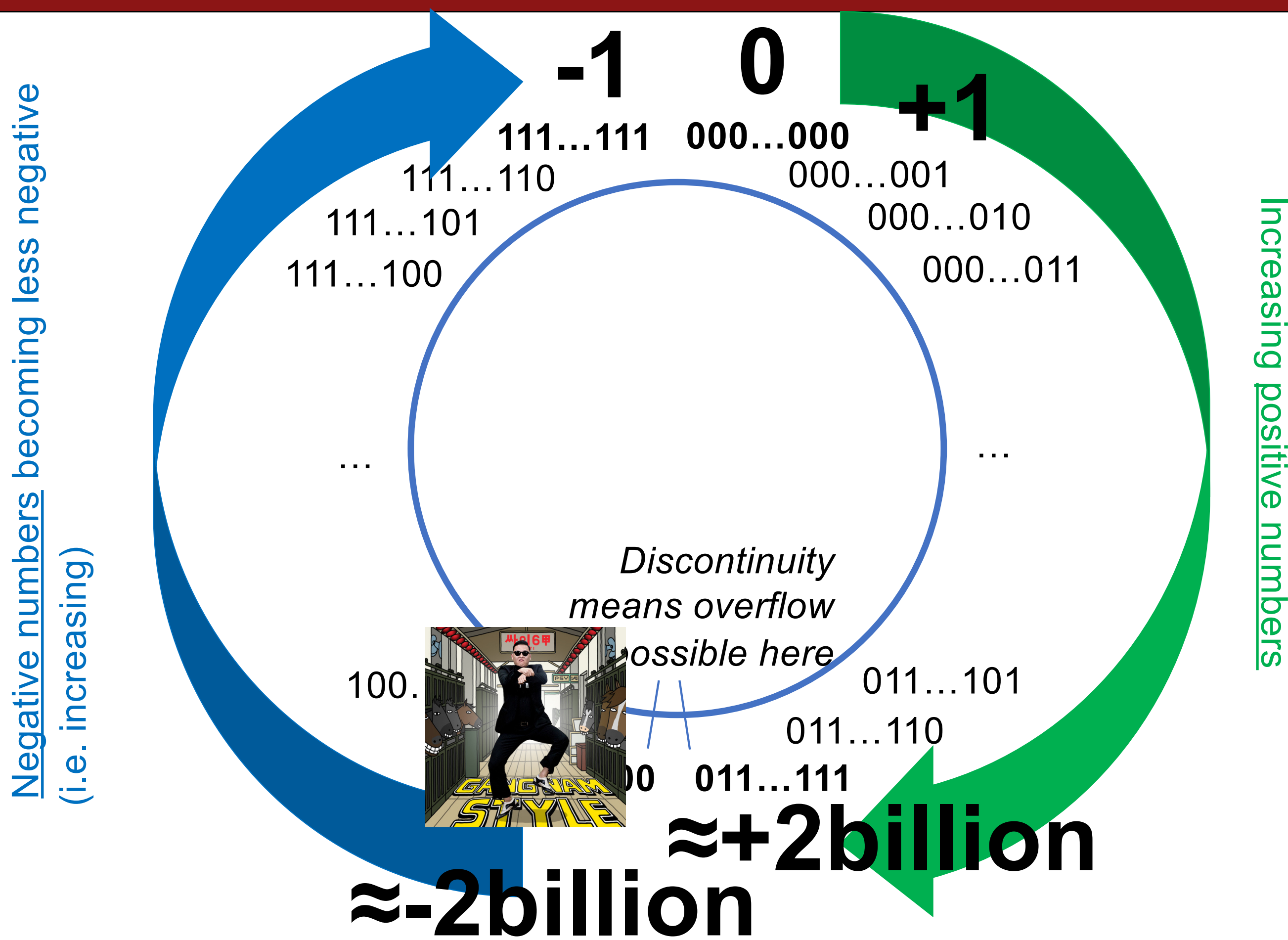


<u>**Key Idea:** Overflow means *discontinuity*</u>

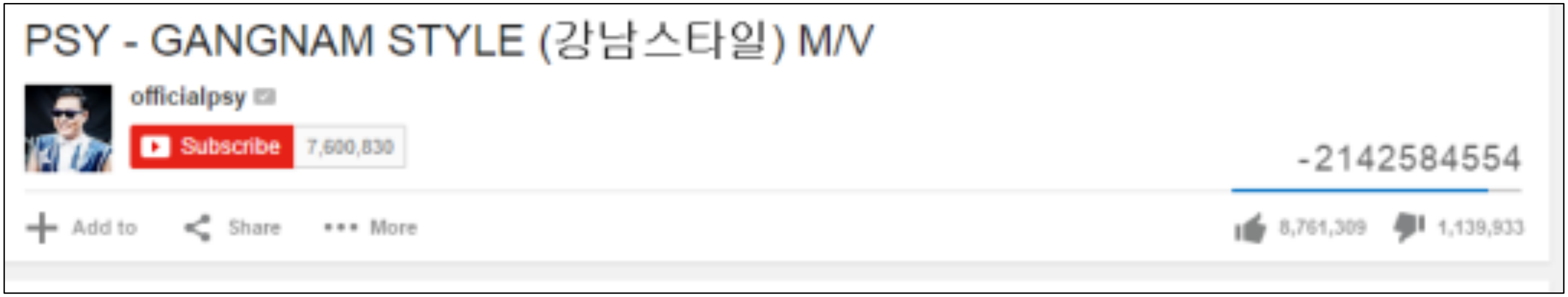
Unsigned Integers



Signed Numbers



Overflow In Practice: PSY



YouTube: "We never thought a video would be watched in numbers greater than a 32-bit integer (up to 2,147,483,647 views), but that was before we met PSY. 'Gangnam Style' has been viewed so many times we had to upgrade to a 64-bit integer (9,223,372,036,854,775,808)!" [link]

"We saw this coming a couple months ago and updated our systems to prepare for it" [link]

Overflow In Practice: Timestamps

Many systems store timestamps as **the number of seconds since Jan. 1, 1970,** in a **signed 32-bit integer**.

- **Problem:** the latest timestamp that can be represented this way is 3:14:07 UTC on January 13, 2038!

Overflow in Practice:

- Pacman Level 256
- Make sure to reboot Boeing Dreamliners every 248 days
- Comair/Delta airline had to cancel thousands of flights days before Christmas
- Reported vulnerability CVE-2019-3857 in libssh2 may allow a hacker to remotely execute code
- Donkey Kong Kill Screen

Recap

- Bits and Bytes
- Hexadecimal
- Integer Representations
- Unsigned Integers
- Signed Integers
- Overflow

Lecture 3 takeaway: computers represent everything in binary. We must determine how to represent our numbers (e.g., base-10 numbers) in a binary format so a computer can manipulate them. Finite representations come with limitations.

Monday: How can we manipulate individual bits and bytes?

Extra Practice

Practice: Two's Complement

Fill in the below table:

It's easier to compute base-10 for positive numbers, so use two's complement first if negative.

	`char x = ____;`		`char y = -x;`	
	decimal	binary	decimal	binary
1.		0b1111 1100		
2.		0b0001 1000		
3.		0b0010 0100		
4.		0b1101 1111		

Practice: Two’s Complement

Fill in the below table:

It’s easier to compute base-10 for positive numbers, so use two’s complement first if negative.

	`char x = ____;`		`char y = -x;`	
	decimal	binary	decimal	binary
1.	-4	0b1111 1100	4	0b0000 0100
2.		0b0001 1000		
3.		0b0010 0100		
4.		0b1101 1111		

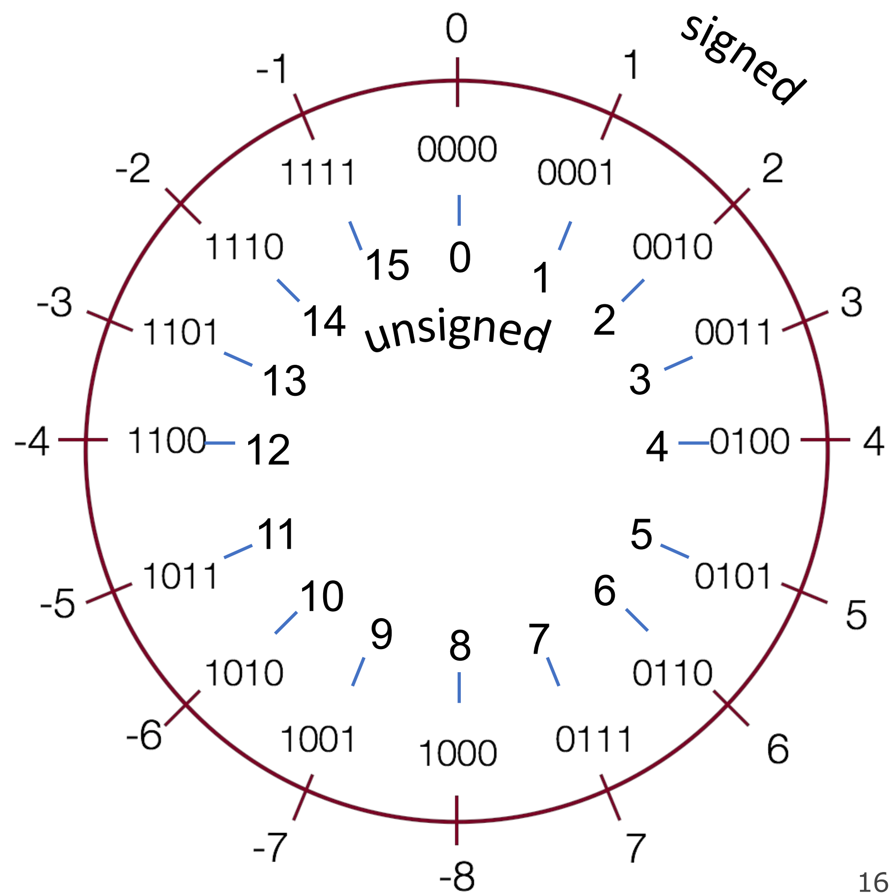
Practice: Two's Complement

Fill in the below table:

It's easier to compute base-10 for positive numbers, so use two's complement first if negative.

	`char x = ____;`		`char y = -x;`	
	decimal	binary	decimal	binary
1.	-4	0b1111 1100	4	0b0000 0100
2.	24	0b0001 1000	-24	0b1110 1000
3.	36	0b0010 0100	-36	0b1101 1100
4.	-33	0b1101 1111	33	0b0010 0001

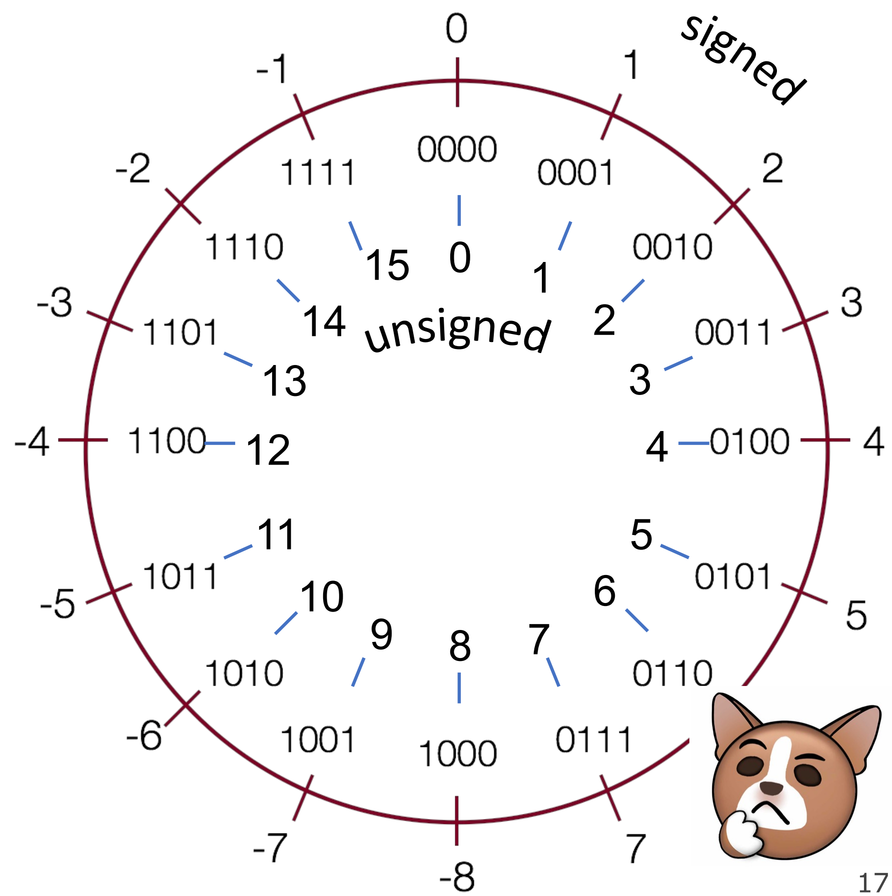
Signed vs. Unsigned Integers



Underspecified question

What is the following base-2 number in base-10?

`0b1101`

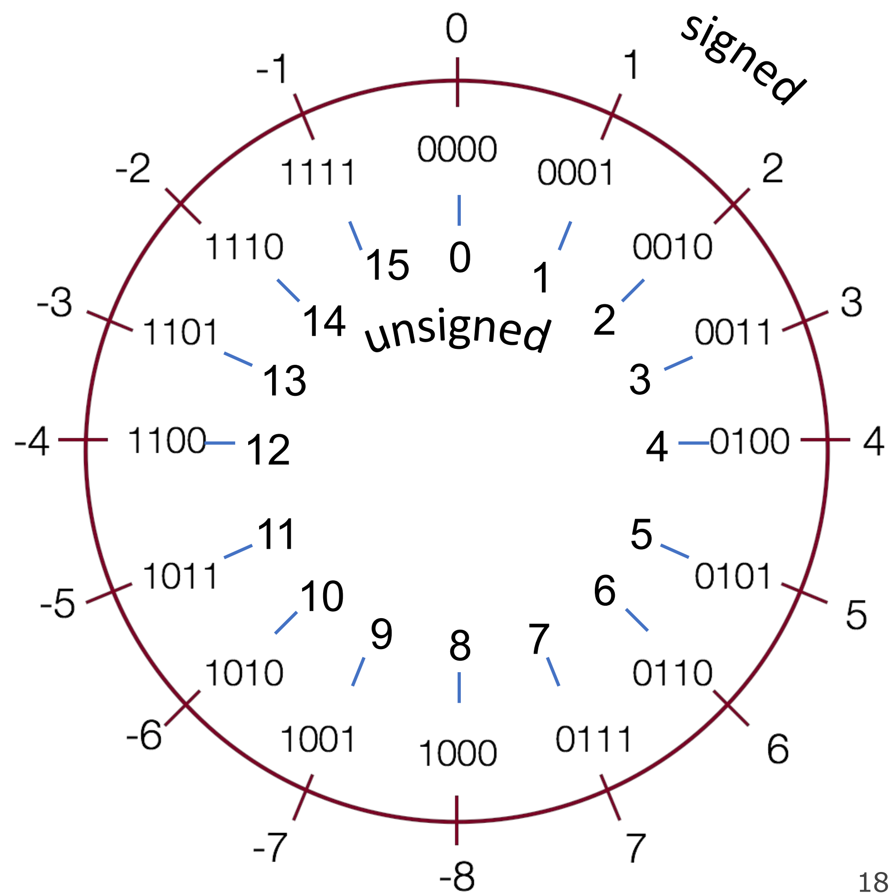


Underspecified question

What is the following base-2 number in base-10?

`0b1101`

If 4-bit signed: -3
If 4-bit unsigned: 13
If >4-bit signed or unsigned: 13

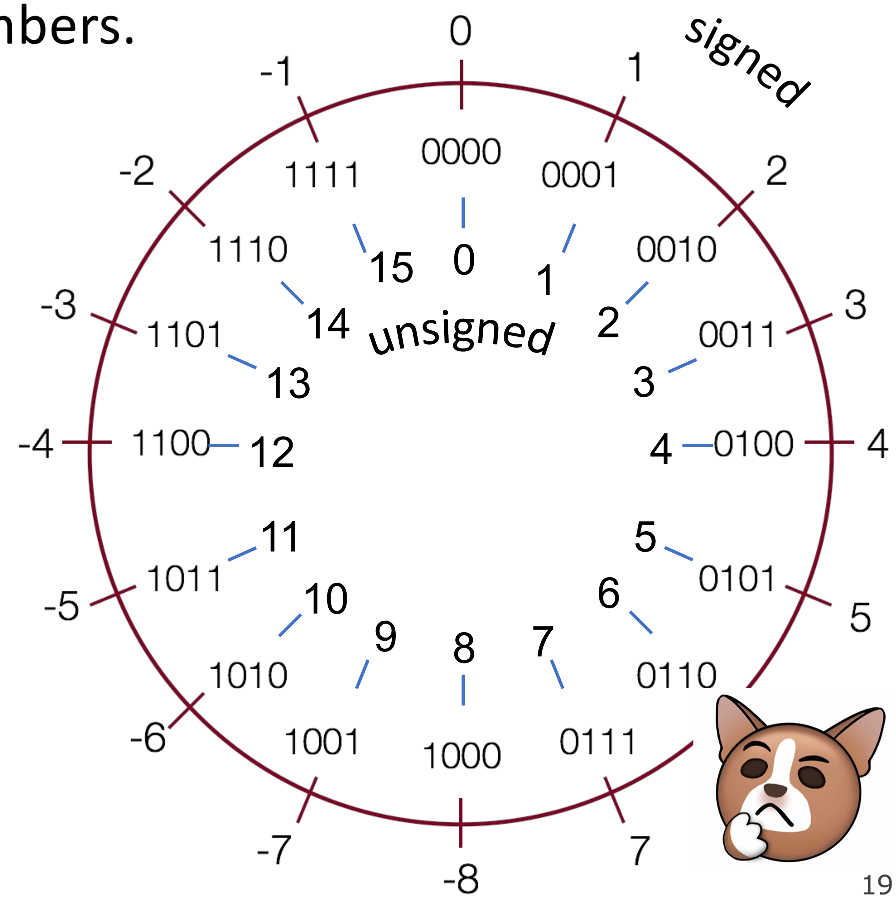


You need to know the type to determine the number! (Note by default, numeric constants in C are `signed ints`)

Overflow

- What is happening here? Assume 4-bit numbers.

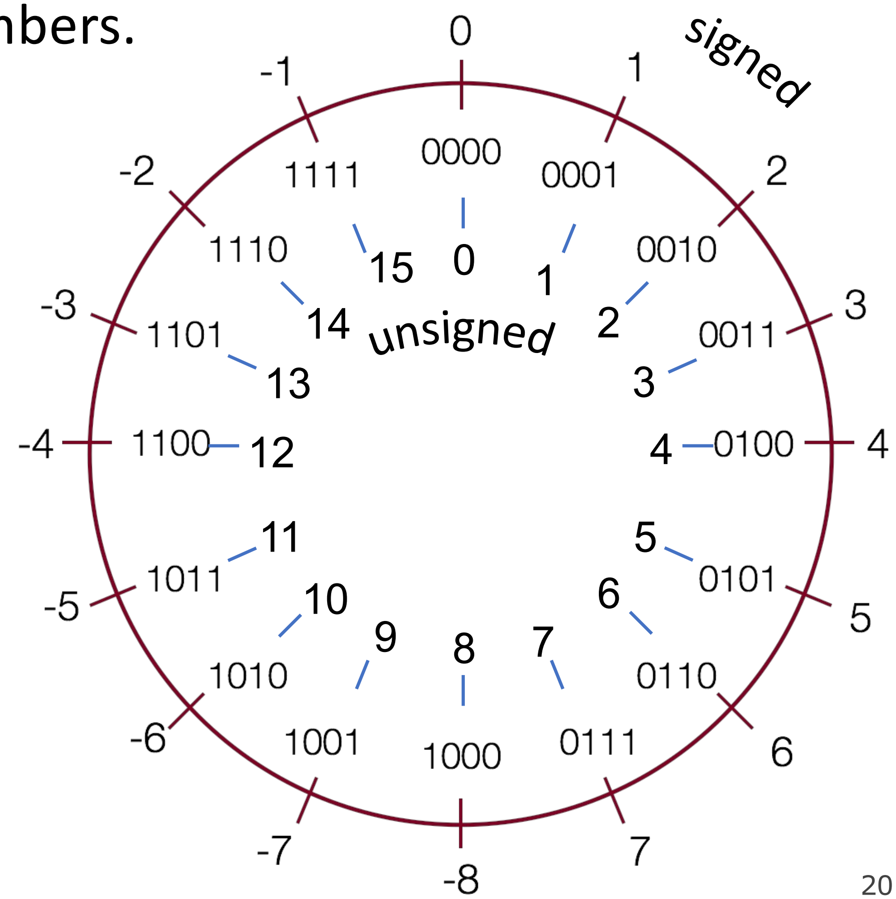
```
  0b1101
+ 0b0100
```



Overflow

- What is happening here? Assume 4-bit numbers.

```
  0b1101
+ 0b0100
```



Signed	Unsigned
`-3 + 4 = 1`	`13 + 4 = 1`
No overflow	Overflow

Limits and Comparisons

1. What is the…

	Largest unsigned?	Largest signed?	Smallest signed?
`char`			
`int`			

Limits and Comparisons

1. What is the…

	Largest unsigned?	Largest signed?	Smallest signed?
`char`	$2^8 - 1 = 255$	$2^7 - 1 = 127$	$-2^7 = -128$
`int`	$2^{32} - 1 = 4294967296$	$2^{31} - 1 = 2147483647$	$-2^{31} = -2147483648$

These are available as UCHAR_MAX, INT_MIN, INT_MAX, etc. in the `<limits.h>` header.