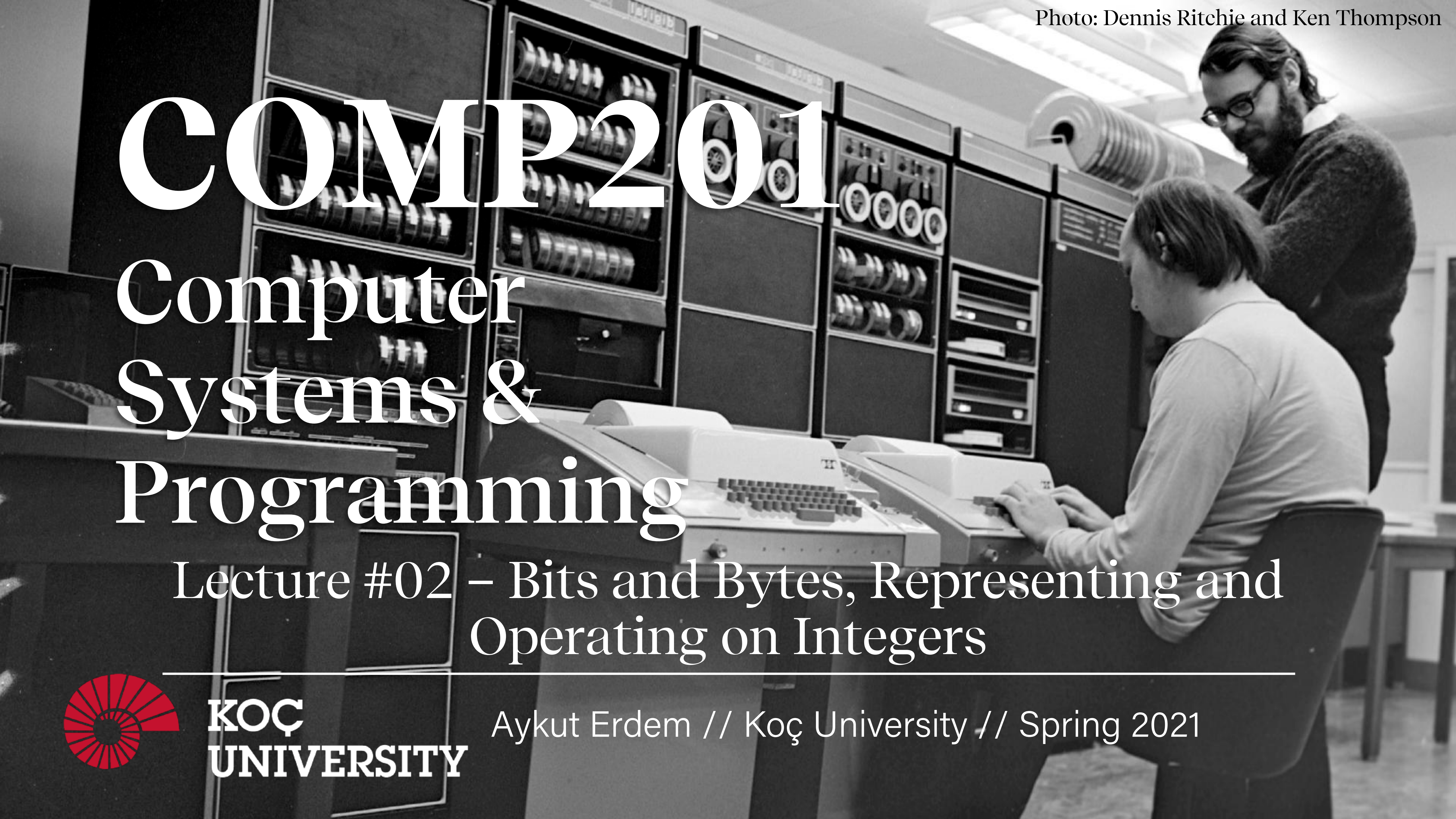

Photo: Dennis Ritchie and Ken Thompson

# COMP201

## Computer Systems & Programming

### Lecture #02 – Bits and Bytes, Representing and Operating on Integers

KOÇ UNIVERSITY

Aykut Erdem // Koç University // Spring 2021

# Plan For Today

- Bits and Bytes
- Hexadecimal
- Integer Representations
- Unsigned Integers
- Signed Integers
- Overflow
- Casting and Combining Types

**Disclaimer:** Slides for this lecture were borrowed from

—Nick Troccoli's Stanford CS107 class

# COMP201 Topic 1: How can a computer represent integer numbers?

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THE WALL STREET JOURNAL.

SHARE

# US Air, Comair Scramble To Get Back to Normal

A Wall Street Journal NEWS ROUNDUP
Dec. 27, 2004 12:01 am ET

SAVE PRINT TEXT

Air travelers on two airlines continued to face canceled flights and lost luggage after weather, worker absences and computer glitches left thousands stranded in airports over the holiday weekend. Comair Inc., a regional carrier owned by Delta Air Lines that canceled its entire schedule Saturday, resumed limited flights yesterday but said it wouldn't return to normal until midweek.

US Airways Group Inc. blamed more than 400 canceled flights and thousands of pieces of stranded luggage on large numbers of workers who called in sick, as well as on a heavy winter storm. A spokesman said the carrier had no evidence of a concerted job action, but the troubles underscore the problems low morale could cause the carrier as it struggles to emerge from bankruptcy-court protection.

It was unclear how many holiday travelers were affected, though the major disruptions appeared to be limited to US Airways and Comair. UAL Corp.'s United Airlines and Northwest Airlines reported weather difficulties in Chicago and Detroit, respectively. AMR Corp.'s American Airlines said it experienced problems due to unusual snowfall at its Dallas-Fort Worth hub over the weekend

# Demo: Unexpected Behavior

`airline.c`

# Lecture Plan

- Bits and Bytes
- Hexadecimal
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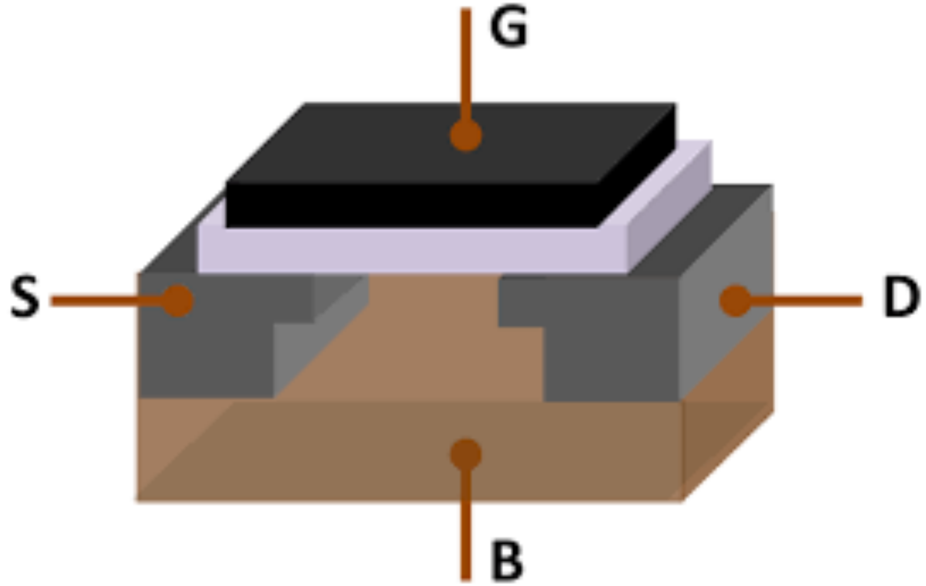
- Unsigned Integers
- Signed Integers
- Overflow
- Casting and Combining Types

0

# 1

# Bits

- Computers are built around the idea of two states: “on” and “off”. Transistors represent this in hardware, and bits represent this in software!



# One Bit At A Time

- We can combine bits, like with base-10 numbers, to represent more data. **8 bits = 1 byte**.
- Computer memory is just a large array of bytes! It is *byte-addressable*; you can't address (store location of) a bit; only a byte.
- Computers still fundamentally operate on bits; we have just gotten more creative about how to represent different data as bits!
  - Images
  - Audio
  - Video
  - Text
  - And more…

# Base 10

5 9 3 4

Digits 0-9 (0 to base-1)

# Base 10

5 9 3 4

thousands hundreds tens ones

= **5***1000 + **9***100 + **3***10 + **4***1

# Base 10

5 9 3 4

$10^3$ $10^2$ $10^1$ $10^0$

# Base 10

5 9 3 4

$10^X$: 3 2 1 0

# Base 2

1 0 1 1

$2^X$: 3 2 1 0

Digits 0-1 (*0* to *base-1*)

# Base 2

1 0 1 1

$2^3$ $2^2$ $2^1$ $2^0$

# Base 2

Most significant bit (MSB)

Least significant bit (LSB)

1 0 1 1

eights fours twos ones

= **1***8 + **0***4 + **1***2 + **1***1 = $11_{10}$

# Base 10 to Base 2

**Question:** What is 6 in base 2?

- Strategy:
  - What is the largest power of 2 $\leq 6$?

# Base 10 to Base 2

**Question:** What is 6 in base 2?

- Strategy:
  - What is the largest power of 2 ≤ 6? **$2^2$=4**

| 0 | 1 | _ | _ |
|---|---|---|---|
| $2^3$ | $2^2$ | $2^1$ | $2^0$ |

# Base 10 to Base 2

**Question:** What is 6 in base 2?

- Strategy:
  - What is the largest power of 2 ≤ 6? $\mathbf{2^2=4}$
  - Now, what is the largest power of 2 ≤ 6 – $2^2$?

| 0 | 1 | ___ | ___ |
|---|---|---|---|
| $2^3$ | $2^2$ | $2^1$ | $2^0$ |

# Base 10 to Base 2

**Question:** What is 6 in base 2?

- Strategy:
  - What is the largest power of 2 ≤ 6? **$2^2$=4**
  - Now, what is the largest power of 2 ≤ 6 – $2^2$? **$2^1$=2**

$$\underset{2^3}{\underline{\;0\;}}\quad\underset{2^2}{\underline{\;1\;}}\quad\underset{2^1}{\underline{\;1\;}}\quad\underset{2^0}{\underline{\;\;\;}}$$

# Base 10 to Base 2

**Question:** What is 6 in base 2?

- Strategy:
  - What is the largest power of 2 ≤ 6? **$2^2$=4**
  - Now, what is the largest power of 2 ≤ 6 – $2^2$? **$2^1$=2**
  - 6 – $2^2$ – $2^1$ = 0!

| 0 | 1 | 1 | _ |
|---|---|---|---|
| $2^3$ | $2^2$ | $2^1$ | $2^0$ |

# Base 10 to Base 2

**Question:** What is 6 in base 2?

- Strategy:
  - What is the largest power of 2 $\leq$ 6? **$2^2=4$**
  - Now, what is the largest power of 2 $\leq 6 - 2^2$? **$2^1=2$**
  - $6 - 2^2 - 2^1 = 0$!

$$\underset{2^3}{\underline{0}} \quad \underset{2^2}{\underline{1}} \quad \underset{2^1}{\underline{1}} \quad \underset{2^0}{\underline{0}}$$

# Base 10 to Base 2

**Question:** What is 6 in base 2?

- Strategy:
  - What is the largest power of 2 ≤ 6? **$2^2=4$**
  - Now, what is the largest power of 2 ≤ 6 – $2^2$? **$2^1=2$**
  - $6 - 2^2 - 2^1 = 0$!

| 0 | 1 | 1 | 0 |
|---|---|---|---|
| $2^3$ | $2^2$ | $2^1$ | $2^0$ |

= **0***8 + **1***4 + **1***2 + **0***1 = 6

# Practice: Base 2 to Base 10

What is the base-2 value 1010 in base-10?

a) 20
b) 101
c) 10
d) 5
e) Other

# Practice: Base 10 to Base 2

What is the base-10 value 14 in base 2?

a) 1111
b) 1110
c) 1010
d) Other

# Byte Values

- What is the minimum and maximum base-10 value a single byte (8 bits) can store?

# Byte Values

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# Byte Values

- What is the minimum and maximum base-10 value a single byte (8 bits) can store? **minimum = 0** **maximum = ?**

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| $2^x$: | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

# Byte Values

- What is the minimum and maximum base-10 value a single byte (8 bits) can store? **minimum = 0** **maximum = ?**

11111111

$2^x$: 7 6 5 4 3 2 1 0

- **Strategy 1:** $1*2^7 + 1*2^6 + 1*2^5 + 1*2^4 + 1*2^3 + 1*2^2 + 1*2^1 + 1*2^0 = 255$

# Byte Values

- What is the minimum and maximum base-10 value a single byte (8 bits) can store? **minimum = 0** **maximum = 255**

11111111

$2^x$: 7 6 5 4 3 2 1 0

- **Strategy 1:** $1*2^7 + 1*2^6 + 1*2^5 + 1*2^4 + 1*2^3 + 1*2^2 + 1*2^1 + 1*2^0 = 255$
- **Strategy 2:** $2^8 - 1 = 255$

# Multiplying by Base

$$1450 \text{ x } 10 = 1450\underline{0}$$

$$1100_2 \text{ x } 2 = 1100\underline{0}$$

*Key Idea*: inserting 0 at the end multiplies by the base!

# Dividing by Base

$$1450 \;/\; 10 = 145$$

$$1100_2 \;/\; 2 = 110$$

*Key Idea*: removing 0 at the end divides by the base!

# Lecture Plan

- Bits and Bytes
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# Hexadecimal

- When working with bits, oftentimes we have large numbers with 32 or 64 bits.
- Instead, we'll represent bits in *base-16 instead;* this is called **hexadecimal**.

$$\underbrace{0110}_{0\text{-}15}\ \underbrace{1010}_{0\text{-}15}\ \underbrace{0011}_{0\text{-}15}$$

# Hexadecimal

- When working with bits, oftentimes we have large numbers with 32 or 64 bits.
- Instead, we'll represent bits in *base-16 instead;* this is called **hexadecimal**.

0-15 0-15 0-15

Each is a base-16 digit!

# Hexadecimal

- Hexadecimal is *base-16*, so we need digits for 1-15. How do we do this?

| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | a | b | c | d | e | f |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | 10 | 11 | 12 | 13 | 14 | 15 |

# Hexadecimal

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hex digit | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Decimal value | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Binary value | 0000 | 0001 | 0010 | 0011 | 0100 | 0101 | 0110 | 0111 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Hex digit | 8 | 9 | A | B | C | D | E | F |
| Decimal value | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 |
| Binary value | 1000 | 1001 | 1010 | 1011 | 1100 | 1101 | 1110 | 1111 |

# Hexadecimal

- We distinguish hexadecimal numbers by prefixing them with **`0x`**, and binary numbers with **`0b`**.
- E.g. **`0xf5`** is **`0b11110101`**

$$\mathrm{0x}\,\underbrace{\mathrm{f}}_{1111}\;\underbrace{5}_{0101}$$

# Practice: Hexadecimal to Binary

What is **`0x173A`** in binary?

| | | | | |
|---|---|---|---|---|
| **Hexadecimal** | **1** | **7** | **3** | **A** |
| **Binary** | **0001** | **0111** | **0011** | **1010** |

# Practice: Hexadecimal to Binary

What is **`0b1111001010`** in hexadecimal? (*Hint: start from the right*)

| | | | |
|---|---|---|---|
| **Binary** | **11** | **1100** | **1010** |
| **Hexadecimal** | **3** | **C** | **A** |

# Question Break!

# Lecture Plan

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# Number Representations

- **Unsigned Integers:** positive and 0 integers. (e.g. 0, 1, 2, … 99999…
- **Signed Integers:** negative, positive and 0 integers. (e.g. …-2, -1, 0, 1,… 9999…)

- **Floating Point Numbers:** real numbers. (e,g. 0.1, -12.2, $1.5 \times 10^{12}$)

# Number Representations

- **Unsigned Integers:** positive and 0 integers. (e.g. 0, 1, 2, ... 99999...
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- **Floating Point Numbers:** real numbers. (e,g. 0.1, -12.2, $1.5 \times 10^{12}$)

More on this next week!

# Number Representations

| C Declaration | Size (Bytes) |
|---|---|
| **`int`** | **4** |
| **`double`** | **8** |
| **`float`** | **4** |
| **`char`** | **1** |
| **`char *`** | **8** |
| **`short`** | **2** |
| **`long`** | **8** |

# In The Days Of Yore…

| C Declaration | Size (Bytes) |
|---|---|
| `int` | 4 |
| `double` | 8 |
| `float` | 4 |
| `char` | 1 |
| `char *` | 4 |
| `short` | 2 |
| `long` | 4 |

# Transitioning To Larger Datatypes


- **Early 2000s:** most computers were **32-bit.** This means that pointers were **4 bytes (32 bits).**
- 32-bit pointers store a memory address from 0 to $2^{32}$-1, equaling **$2^{32}$ bytes of addressable memory**. This equals **4 Gigabytes**, meaning that 32-bit computers could have at most **4GB** of memory (RAM)!
- Because of this, computers transitioned to **64-bit.** This means that datatypes were enlarged; pointers in programs were now **64 bits.**
- 64-bit pointers store a memory address from 0 to $2^{64}$-1, equaling **$2^{64}$ bytes of addressable memory.** This equals **16 Exabytes**, meaning that 64-bit computers could have at most **1024*1024*1024 GB** of memory (RAM)!

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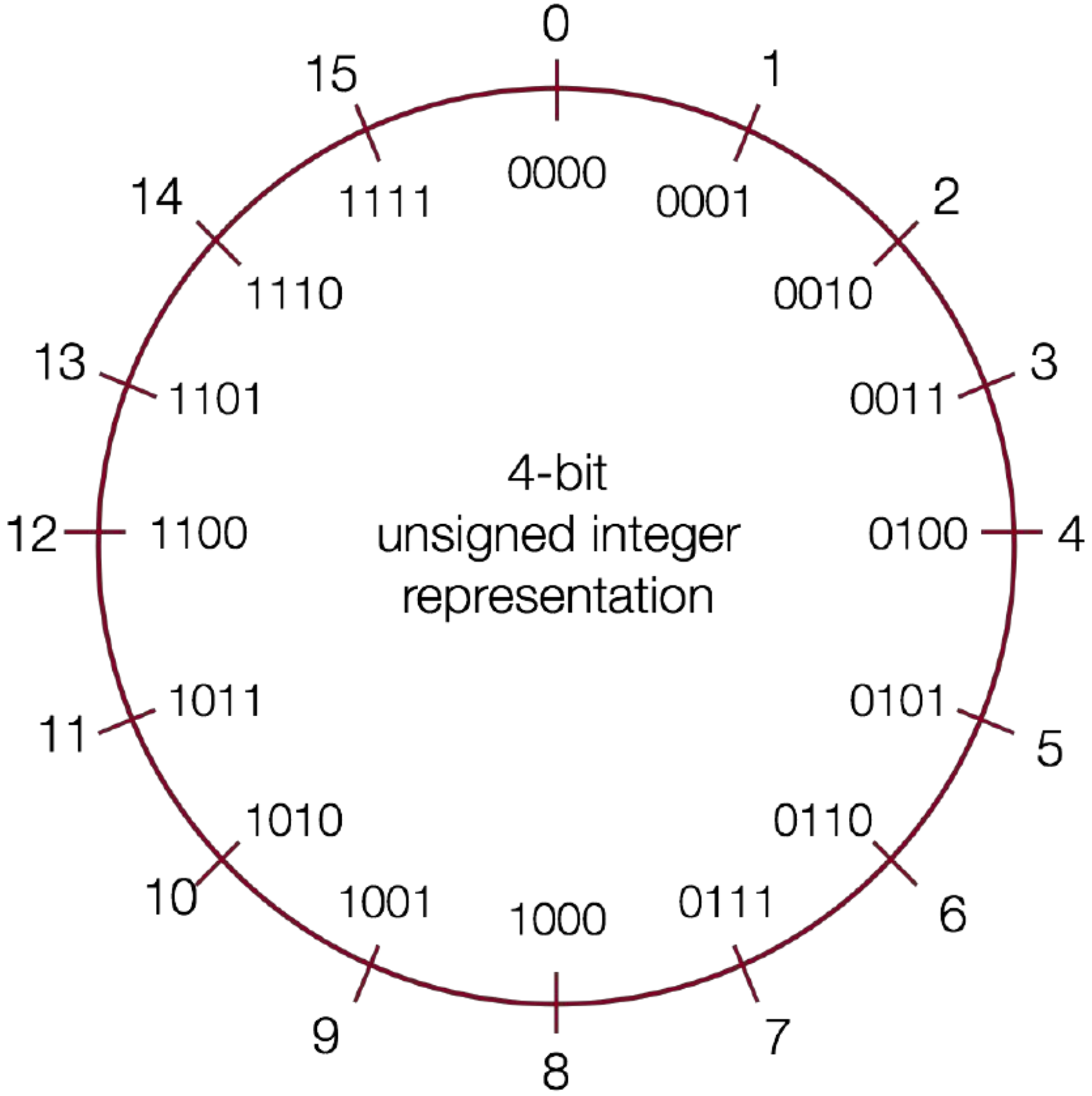
# Unsigned Integers

- An **unsigned** integer is 0 or a positive integer (no negatives).
- We have already discussed converting between decimal and binary, which is a nice 1:1 relationship. Examples:

```
0b0001 = 1
0b0101 = 5
0b1011 = 11
0b1111 = 15
```

- The range of an unsigned number is 0 → $2^w$ - 1, where $w$ is the number of bits. E.g. a 32-bit integer can represent 0 to $2^{32} - 1$ (4,294,967,295).

# Unsigned Integers



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# Signed Integers

- A **signed** integer is a negative integer, 0, or a positive integer.
- *Problem:* How can we represent negative *and* positive numbers in binary?

# Signed Integers

- A **signed** integer is a negative integer, 0, or a positive integer.
- *Problem:* How can we represent negative *and* positive numbers in binary?

**Idea**: let's reserve the *most significant bit* to store the sign.

# Sign Magnitude Representation

$$\underbrace{0}_{\text{positive}}\underbrace{110}_{6}$$

$$\underbrace{1}_{\text{negative}}\underbrace{011}_{3}$$

# Sign Magnitude Representation

$$\underbrace{0}_{\text{positive}}\underbrace{000}_{0}$$

$$\underbrace{1}_{\text{negative}}\underbrace{000}_{0}$$

# Sign Magnitude Representation

| | |
|---|---|
| 1 000 = -0 | 0 000 = 0 |
| 1 001 = -1 | 0 001 = 1 |
| 1 010 = -2 | 0 010 = 2 |
| 1 011 = -3 | 0 011 = 3 |
| 1 100 = -4 | 0 100 = 4 |
| 1 101 = -5 | 0 101 = 5 |
| 1 110 = -6 | 0 110 = 6 |
| 1 111 = -7 | 0 111 = 7 |

- We've only represented 15 of our 16 available numbers!

# Sign Magnitude Representation

- **Pro:** easy to represent, and easy to convert to/from decimal.
- **Con:** +-0 is not intuitive
- **Con:** we lose a bit that could be used to store more numbers
- **Con:** arithmetic is tricky: we need to find the sign, then maybe subtract (borrow and carry, etc.), then maybe change the sign. This complicates the hardware support for something as fundamental as addition.

Can we do better?

# A Better Idea

- Ideally, binary addition would *just work* **regardless** of whether the number is positive or negative.

$$\begin{array}{r} 0101 \\ +\ \color{red}{????} \\ \hline 0000 \end{array}$$

# A Better Idea

- Ideally, binary addition would *just work* **regardless** of whether the number is positive or negative.

$$
\begin{array}{r}
0101 \\
+\,1011 \\
\hline
0000
\end{array}
$$

# A Better Idea

- Ideally, binary addition would *just work* **regardless** of whether the number is positive or negative.

$$
\begin{array}{r}
0011 \\
+\,{\color{red}????} \\
\hline
0000
\end{array}
$$

# A Better Idea

- Ideally, binary addition would *just work* **regardless** of whether the number is positive or negative.

$$
\begin{array}{r}
0011 \\
+\ {\color{red}1101} \\
\hline
0000
\end{array}
$$

# A Better Idea

- Ideally, binary addition would *just work* **regardless** of whether the number is positive or negative.

$$\begin{array}{r} 0000 \\ +\,{\color{red}????} \\ \hline 0000 \end{array}$$

# A Better Idea

- Ideally, binary addition would *just work* **regardless** of whether the number is positive or negative.

$$
\begin{array}{r}
0000 \\
+\,{\color{red}0000} \\
\hline
0000
\end{array}
$$

# A Better Idea

| Decimal | Positive | Negative |
|---|---|---|
| 0 | 0000 | 0000 |
| 1 | 0001 | 1111 |
| 2 | 0010 | 1110 |
| 3 | 0011 | 1101 |
| 4 | 0100 | 1100 |
| 5 | 0101 | 1011 |
| 6 | 0110 | 1010 |
| 7 | 0111 | 1001 |

| Decimal | Positive | Negative |
|---|---|---|
| 8 | 1000 | 1000 |
| 9 | 1001 (same as -7!) | NA |
| 10 | 1010 (same as -6!) | NA |
| 11 | 1011 (same as -5!) | NA |
| 12 | 1100 (same as -4!) | NA |
| 13 | 1101 (same as -3!) | NA |
| 14 | 1110 (same as -2!) | NA |
| 15 | 1111 (same as -1!) | NA |

# There Seems Like a Pattern Here…

$$\begin{array}{r} 0101 \\ +\,1011 \\ \hline 0000 \end{array} \qquad \begin{array}{r} 0011 \\ +\,1101 \\ \hline 0000 \end{array} \qquad \begin{array}{r} 0000 \\ +\,0000 \\ \hline 0000 \end{array}$$

- The negative number is the positive number **inverted, plus one!**

# There Seems Like a Pattern Here…

A binary number plus its inverse is all 1s.

```
  0101
+ 1010
------
  1111
```

Add 1 to this to carry over all 1s and get 0!

```
  1111
+ 0001
------
  0000
```

# Another Trick

- To find the negative equivalent of a number, work right-to-left and write down all digits *through* when you reach a 1. Then, invert the rest of the digits.

$$\begin{array}{r} 100100 \\ +\ ?????? \\ \hline 000000 \end{array}$$

# Another Trick

- To find the negative equivalent of a number, work right-to-left and write down all digits *through* when you reach a 1. Then, invert the rest of the digits.

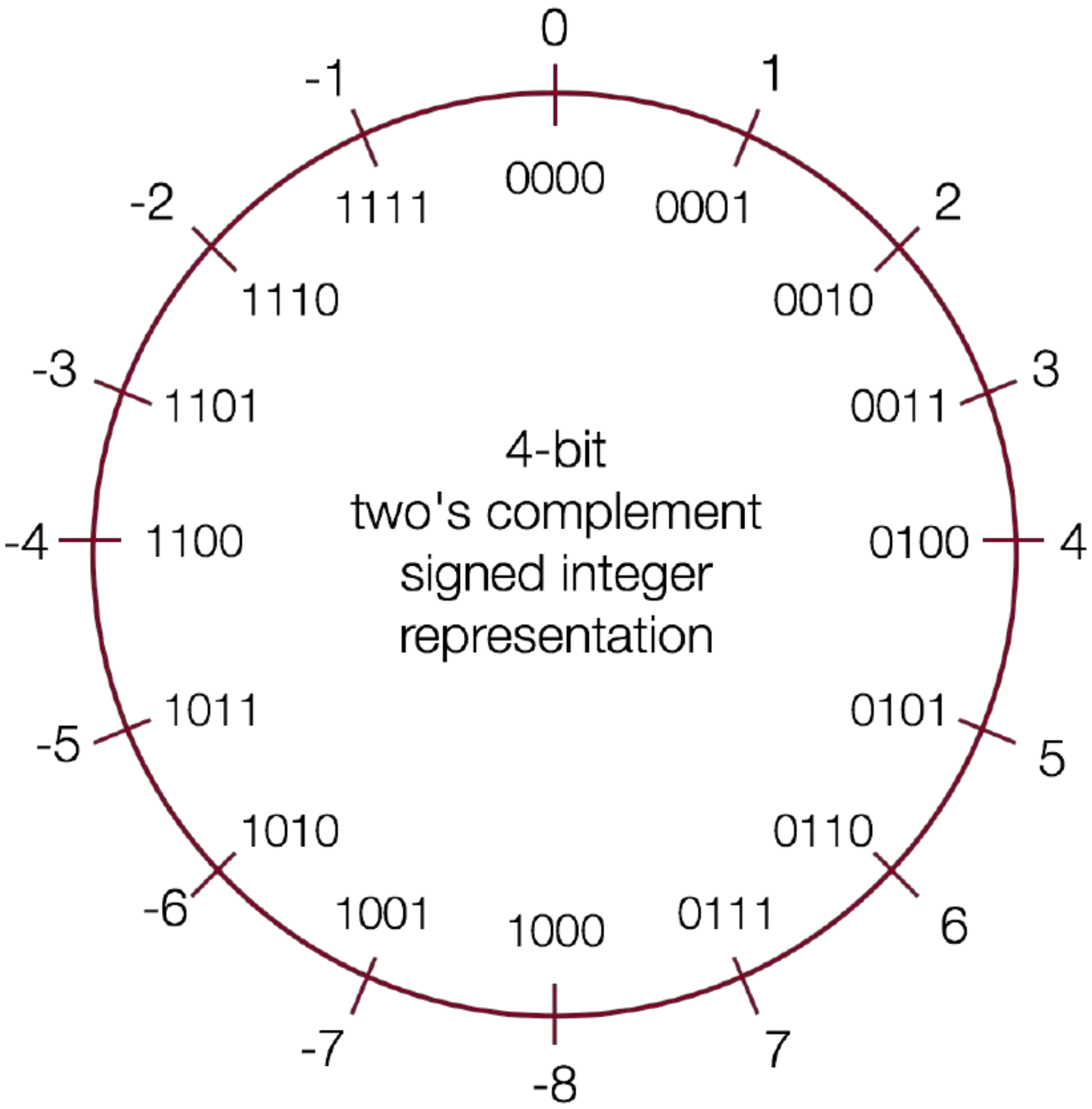
$$
\begin{array}{r}
100100 \\
+\ {\color{red}???100} \\
\hline
000000
\end{array}
$$

# Another Trick

- To find the negative equivalent of a number, work right-to-left and write down all digits *through* when you reach a 1. Then, invert the rest of the digits.

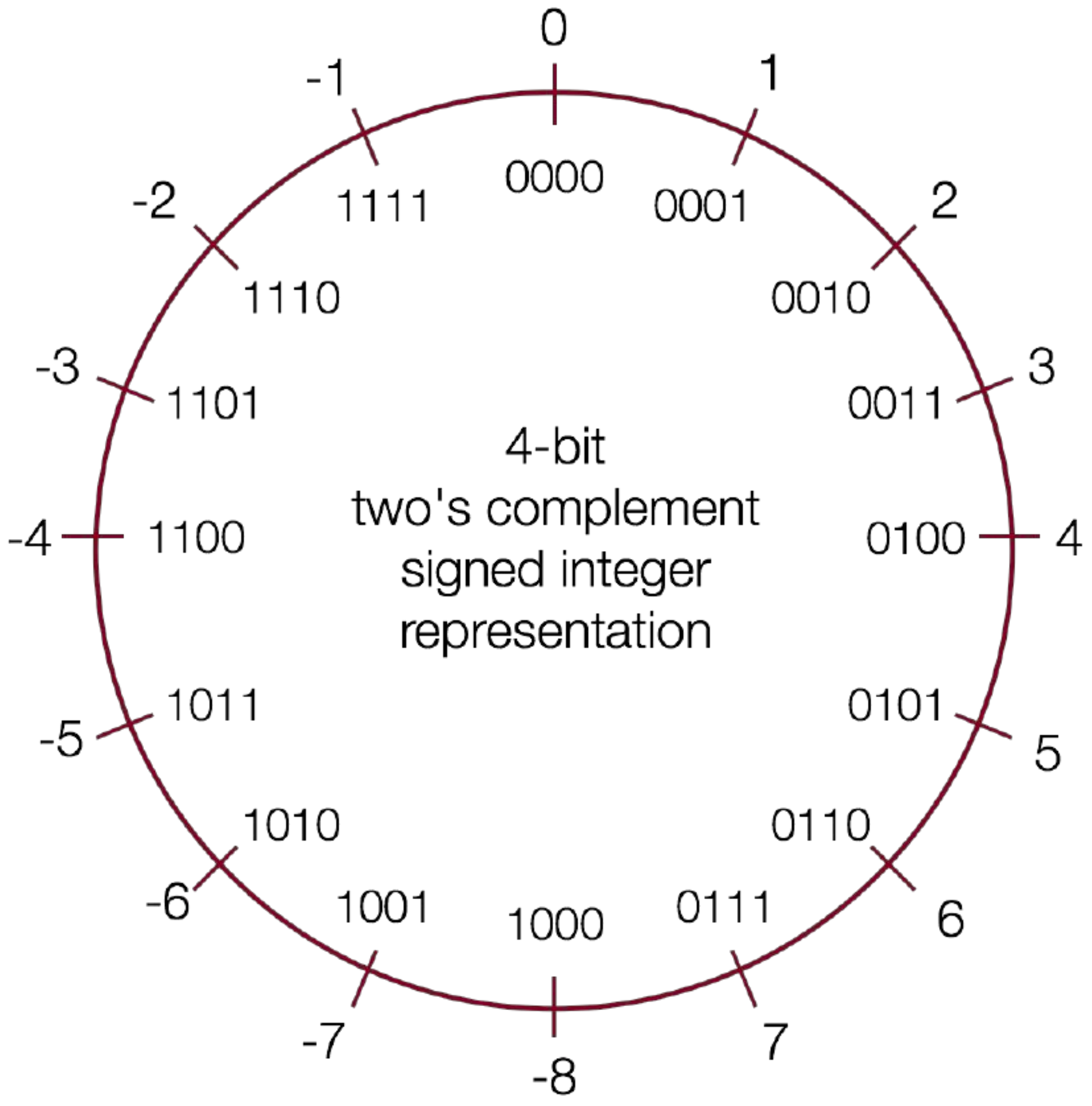
$$
\begin{array}{r}
100100 \\
+\ 011100 \\
\hline
000000
\end{array}
$$

# Two's Complement



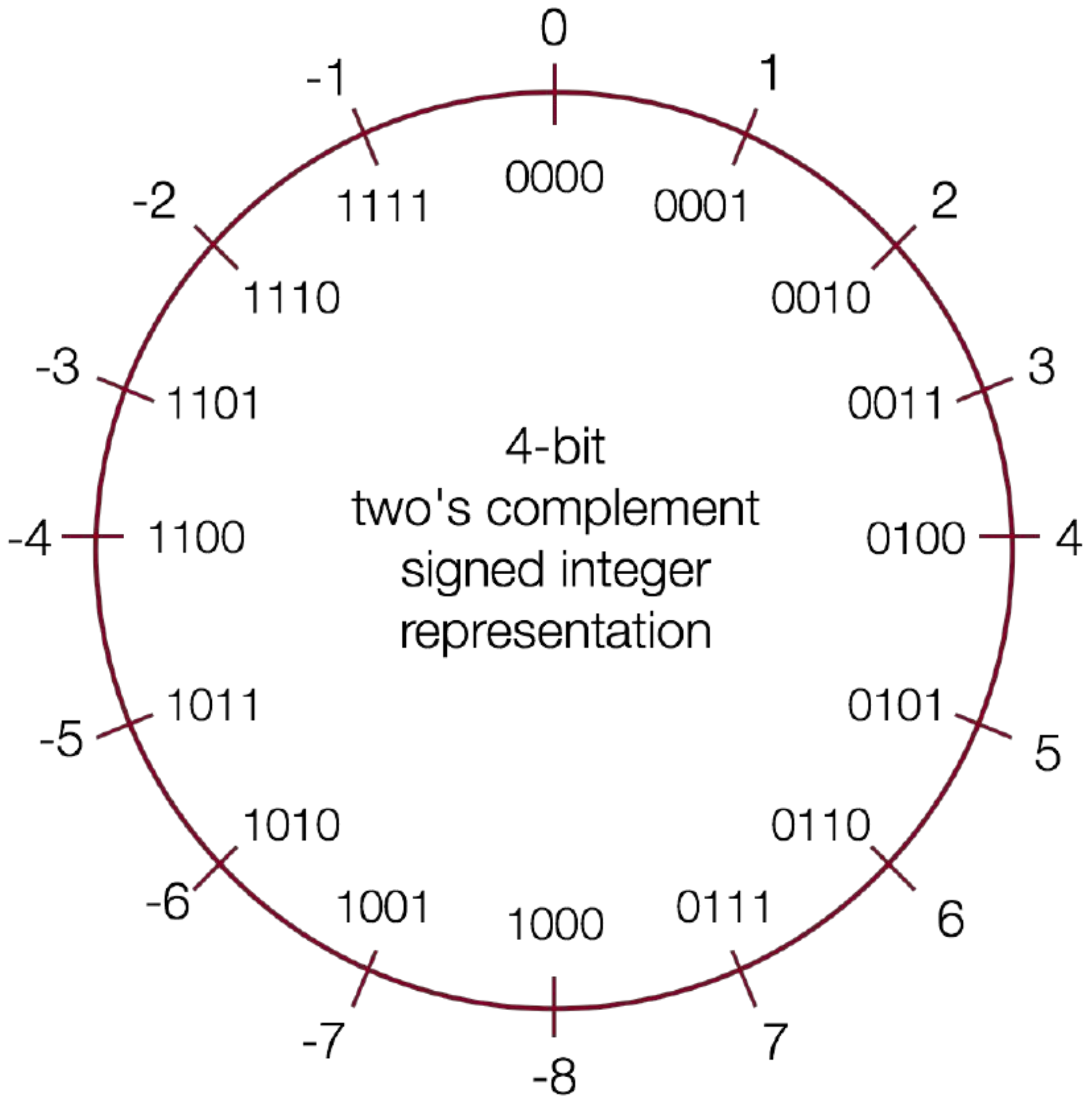
# Two's Complement

- In **two's complement**, we represent a positive number as **itself**, and its negative equivalent as the **two's complement of itself.**
- The **two's complement** of a number is the binary digits inverted, plus 1.
- This works to convert from positive to negative, **and** back from negative to positive!



# Two's Complement

- **Con:** more difficult to represent, and difficult to convert to/from decimal and between positive and negative.
- **Pro:** only 1 representation for 0!
- **Pro:** all bits are used to represent as many numbers as possible
- **Pro:** the most significant bit still indicates the sign of a number.
- **Pro:** addition works for any combination of positive and negative!



# Two's Complement

- Adding two numbers is just...adding! There is no special case needed for negatives. E.g. what is 2 + -5?

| | | |
|---|---|---|
| | 0010 | 2 |
| + | 1011 | -5 |
| | 1101 | -3 |

# Two's Complement

- Subtracting two numbers is just performing the two's complement on one of them and then adding. E.g. 4 – 5 = -1.

$$\begin{array}{rr} 0100 & 4 \\ -\,0101 & 5 \\ \hline \end{array} \longrightarrow \begin{array}{rr} 0100 & 4 \\ +\,{\color{red}1011} & -5 \\ \hline 1111 & -1 \end{array}$$

# Practice: Two's Complement

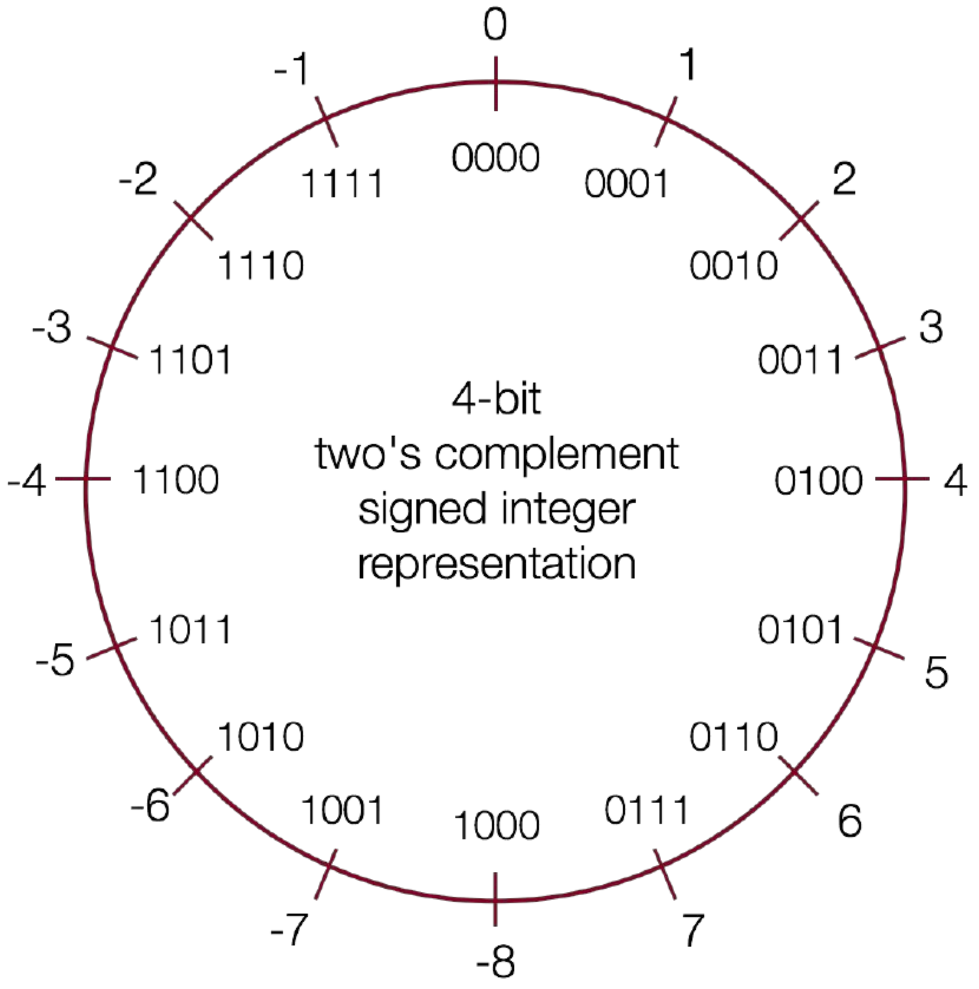
What are the negative or positive equivalents of the numbers below?

a) -4 (1100)

b) 7 (0111)

c) 3 (0011)

d) -8 (1000)



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# 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
```

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

```
0b0000 - 0b1 = 0b1111
```

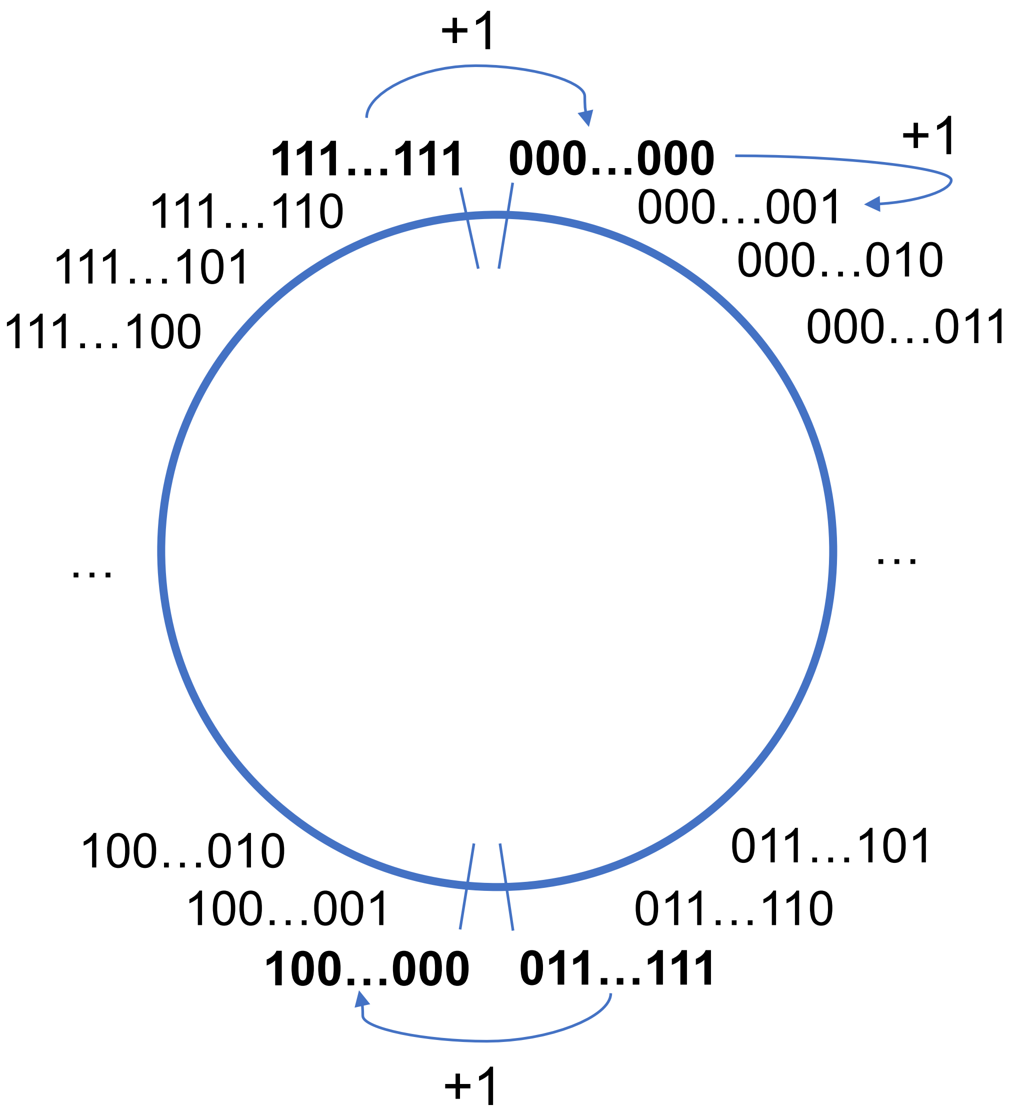
# Min and Max Integer Values

| Type | Size (Bytes) | Minimum | Maximum |
|---|---|---|---|
| `char` | 1 | -128 | 127 |
| `unsigned char` | 1 | 0 | 255 |
| `short` | 2 | -32768 | 32767 |
| `unsigned short` | 2 | 0 | 65535 |
| `int` | 4 | -2147483648 | 2147483647 |
| `unsigned int` | 4 | 0 | 4294967295 |
| `long` | 8 | -9223372036854775808 | 9223372036854775807 |
| `unsigned long` | 8 | 0 | 18446744073709551615 |

# Min and Max Integer Values

**`INT_MIN, INT_MAX, UINT_MAX, LONG_MIN, LONG_MAX, ULONG_MAX, …`**

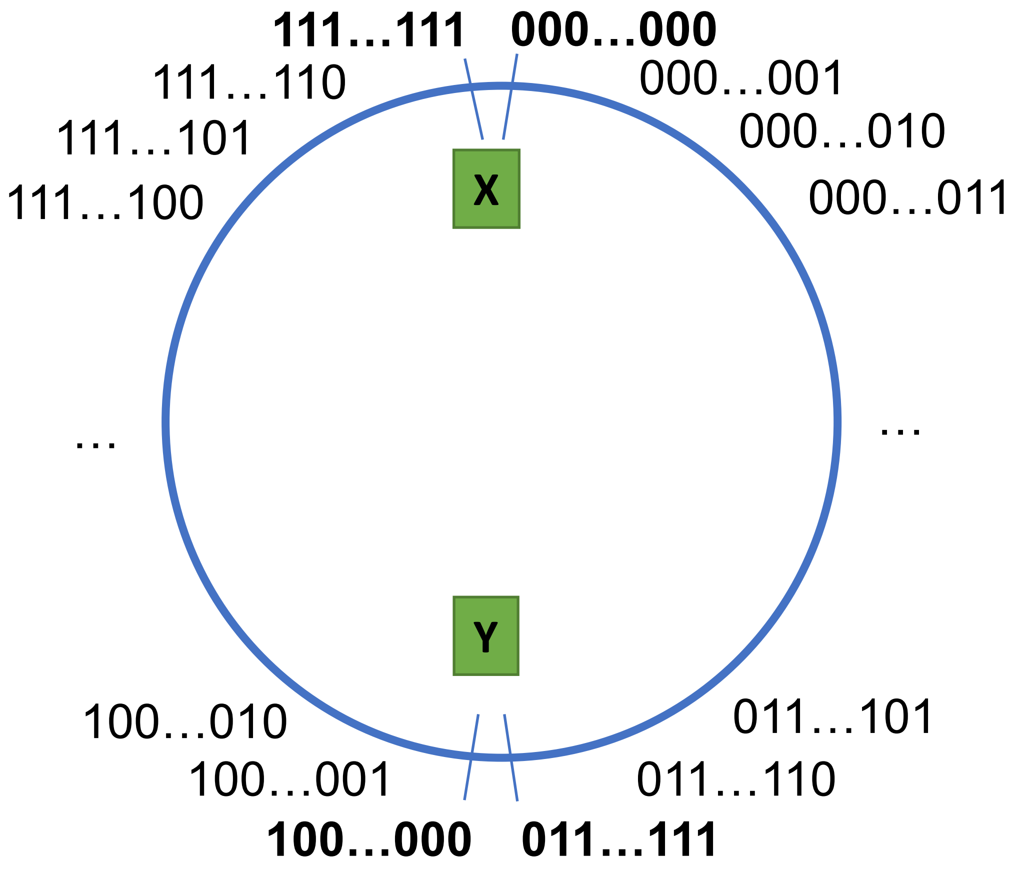
# Overflow


+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

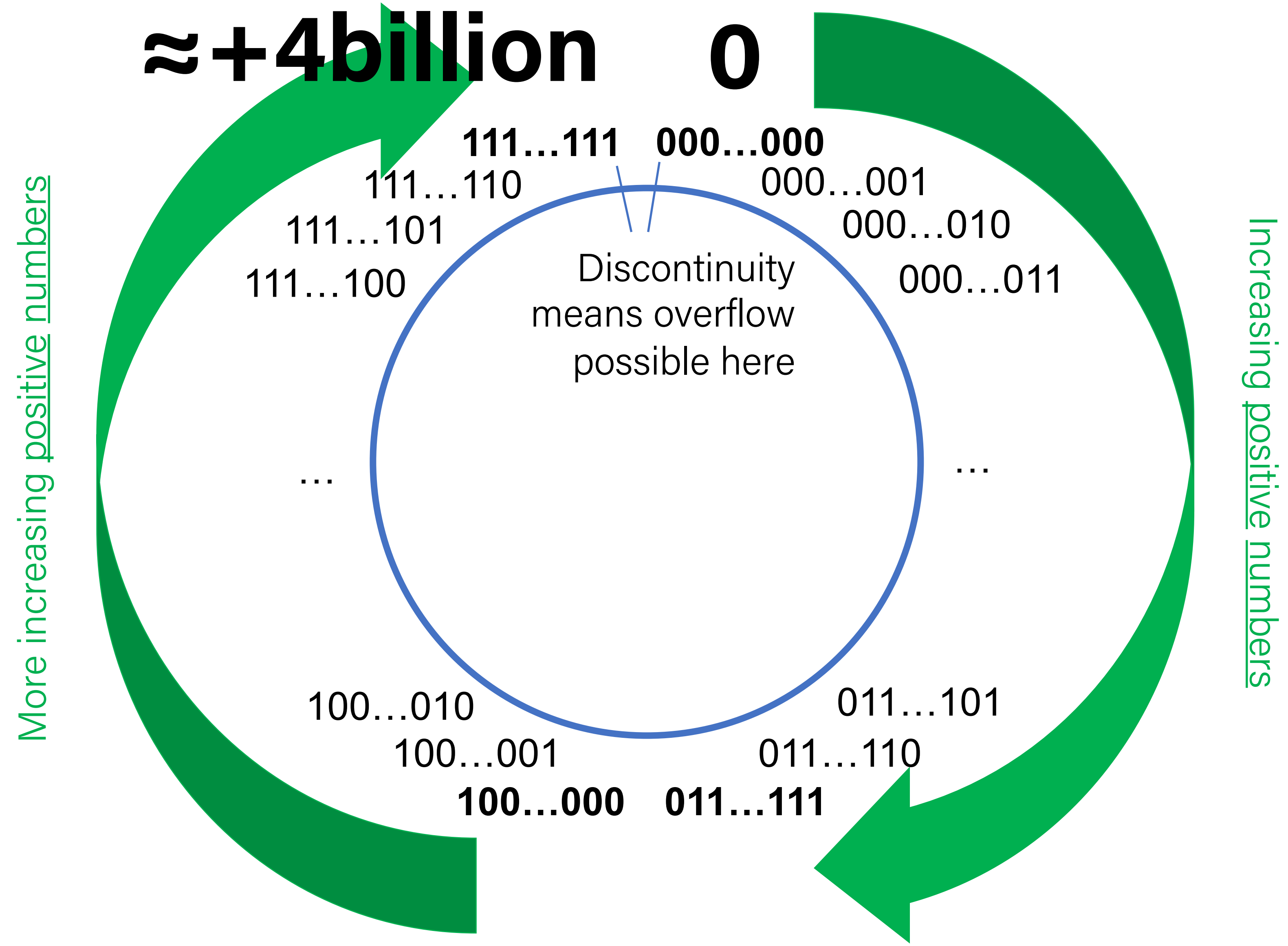
# Overflow

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

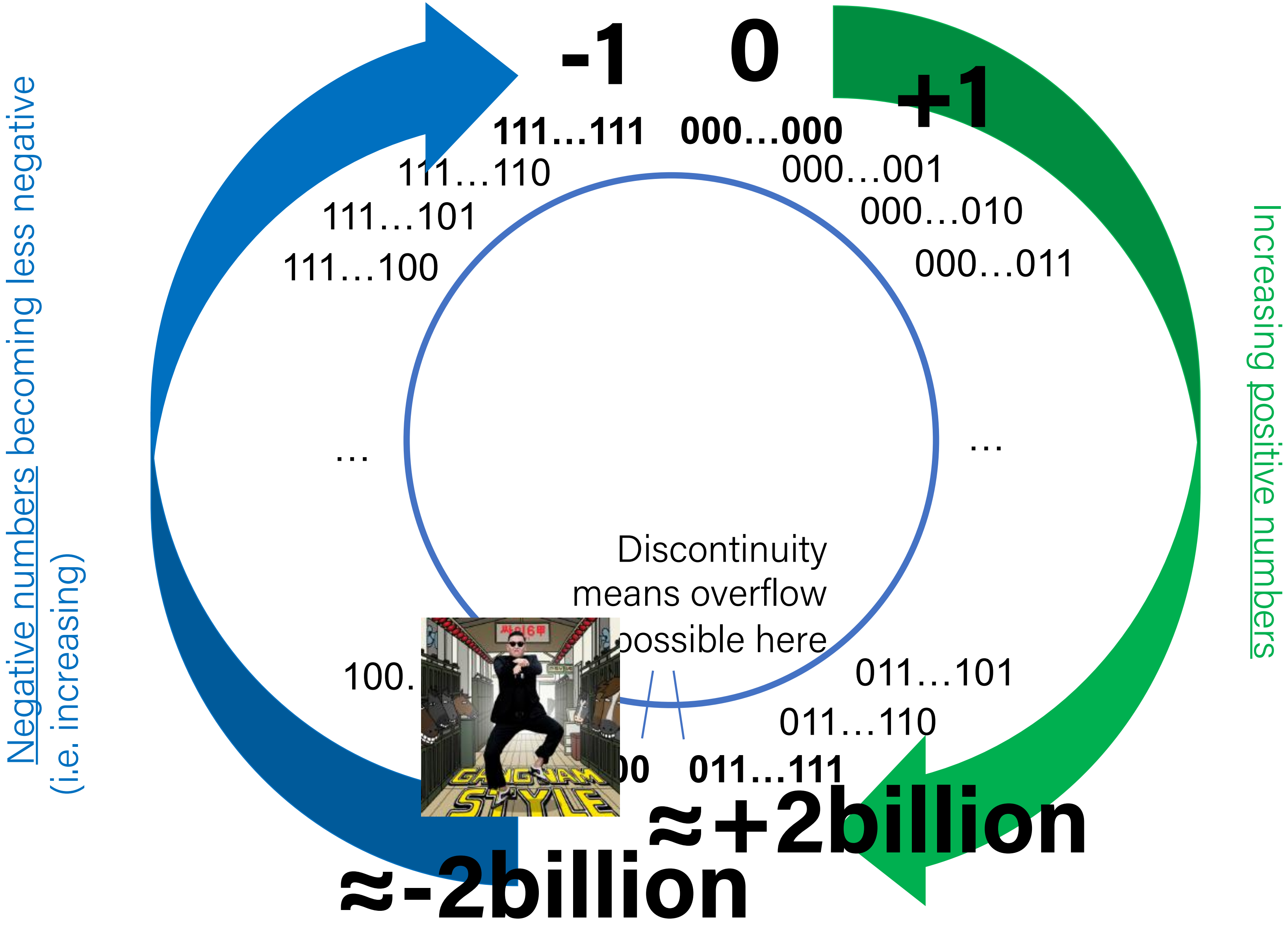
A. Signed and unsigned can both overflow at points X and Y
B. Signed can overflow only at X, unsigned only at Y
C. Signed can overflow only at Y, unsigned only at X
D. Signed can overflow at X and Y, unsigned only at X
E. Other



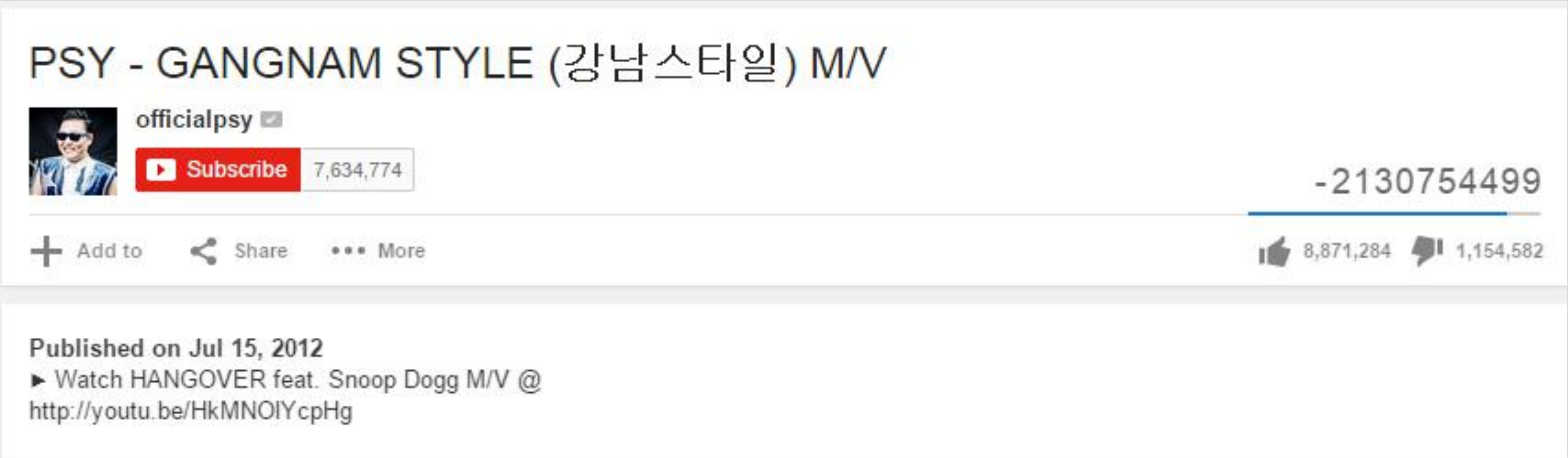
# Unsigned Integers



# Signed Numbers



# Overflow In Practice: PSY



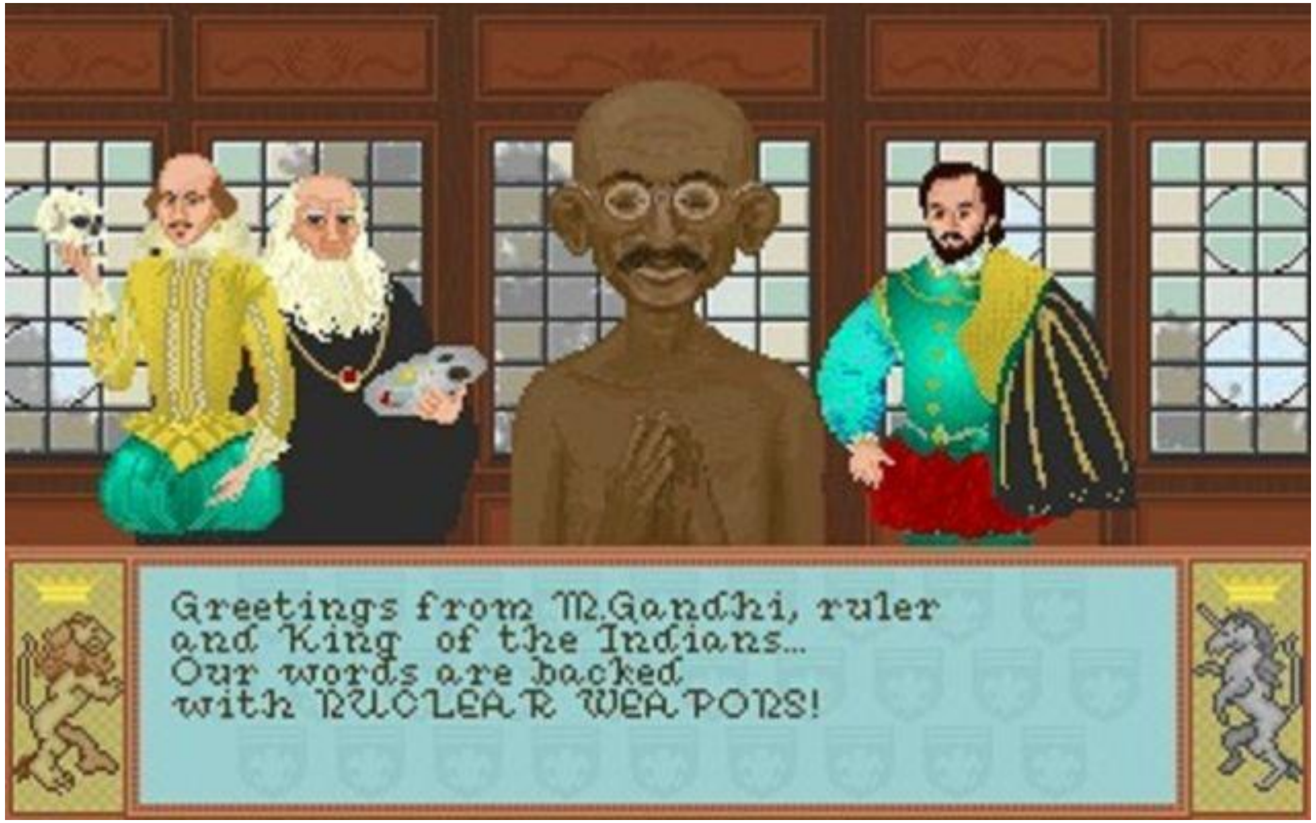

**YouTube:** “We never thought a video would be watched in numbers greater than a 32-bit integer (=2,147,483,647 views), but that was before we met PSY. "Gangnam Style" has been viewed so many times we had to upgrade to a 64-bit integer (9,223,372,036,854,775,808)!”

# 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 Jan. 13 2038!

# Overflow In Practice: Gandhi

- In the game "Civilization", each civilization leader had an "aggression" rating. Gandhi was meant to be peaceful, and had a score of 1.
- If you adopted "democracy", all players' aggression reduced by 2. Gandhi's went from 1 to **255**!
- Gandhi then became a big fan of nuclear weapons.




https://kotaku.com/why-gandhi-is-such-an-asshole-in-civilization-1653818245

# 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

# Demo Revisited: Unexpected Behavior

`airline.c`

# Lecture Plan

- Bits and Bytes
- Hexadecimal
- Integer Representations
- Unsigned Integers
- Signed Integers
- Overflow
- Casting and Combining Types

# `printf` and Integers

- There are 3 placeholders for 32-bit integers that we can use:
  - `%d`: signed 32-bit int
  - `%u`: unsigned 32-bit int
  - `%x`: hex 32-bit int
- The placeholder—not the expression filling in the placeholder—dictates what gets printed!

# Casting

- What happens at the byte level when we cast between variable types? **The bytes remain the same!** **This means they may be interpreted differently depending on the type.**

```
int v = -12345;
unsigned int uv = v;
printf("v = %d, uv = %u\n", v, uv);
```

This prints out: `"v = -12345, uv = 4294954951"`. **Why?**

# Casting

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```
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unsigned int uv = v;
printf("v = %d, uv = %u\n", v, uv);
```
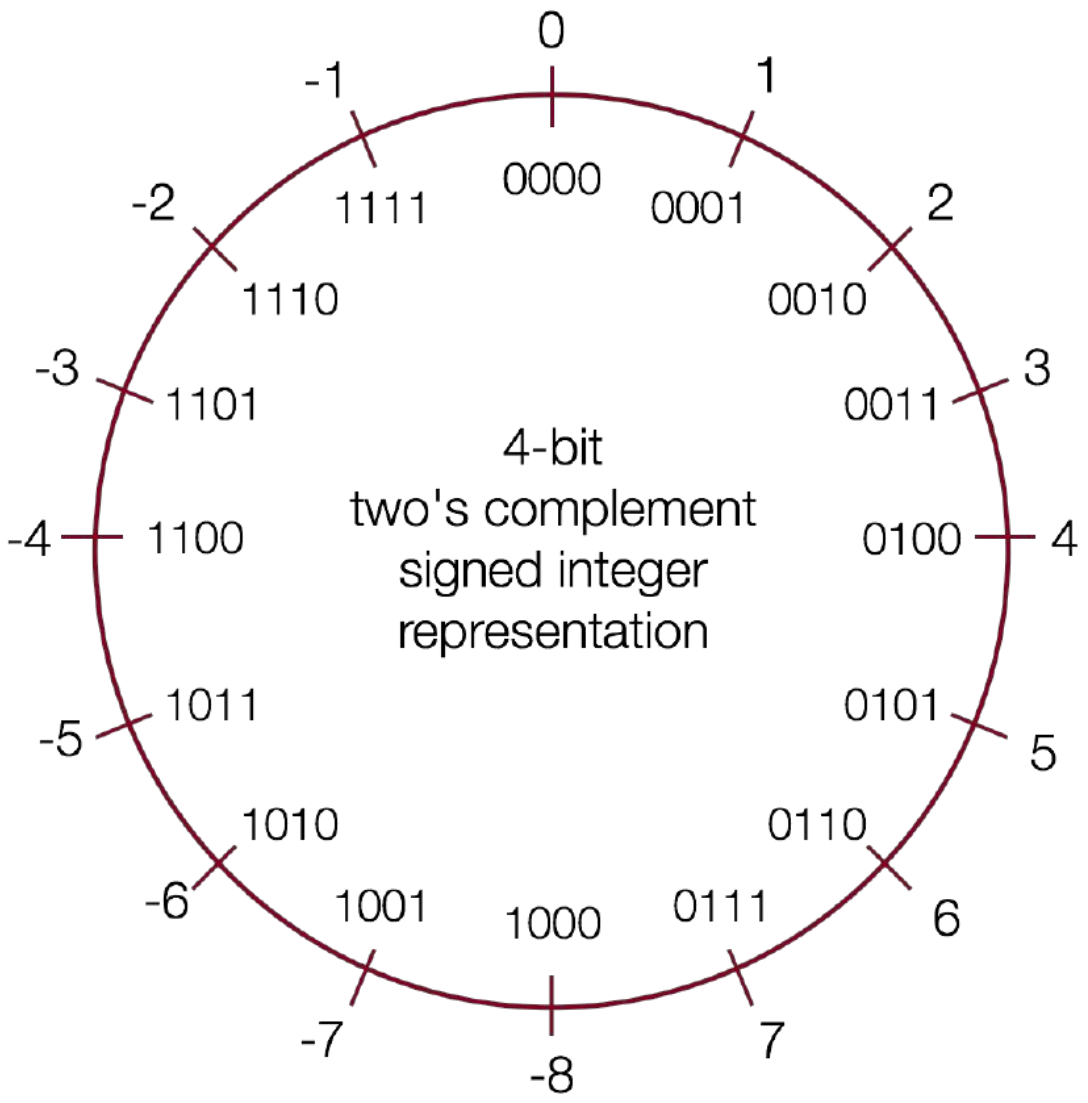

The bit representation for -12345 is
0b**11111111111111111100111111000111.**

If we treat this binary representation as a positive number, it's *huge*!

# Casting


0
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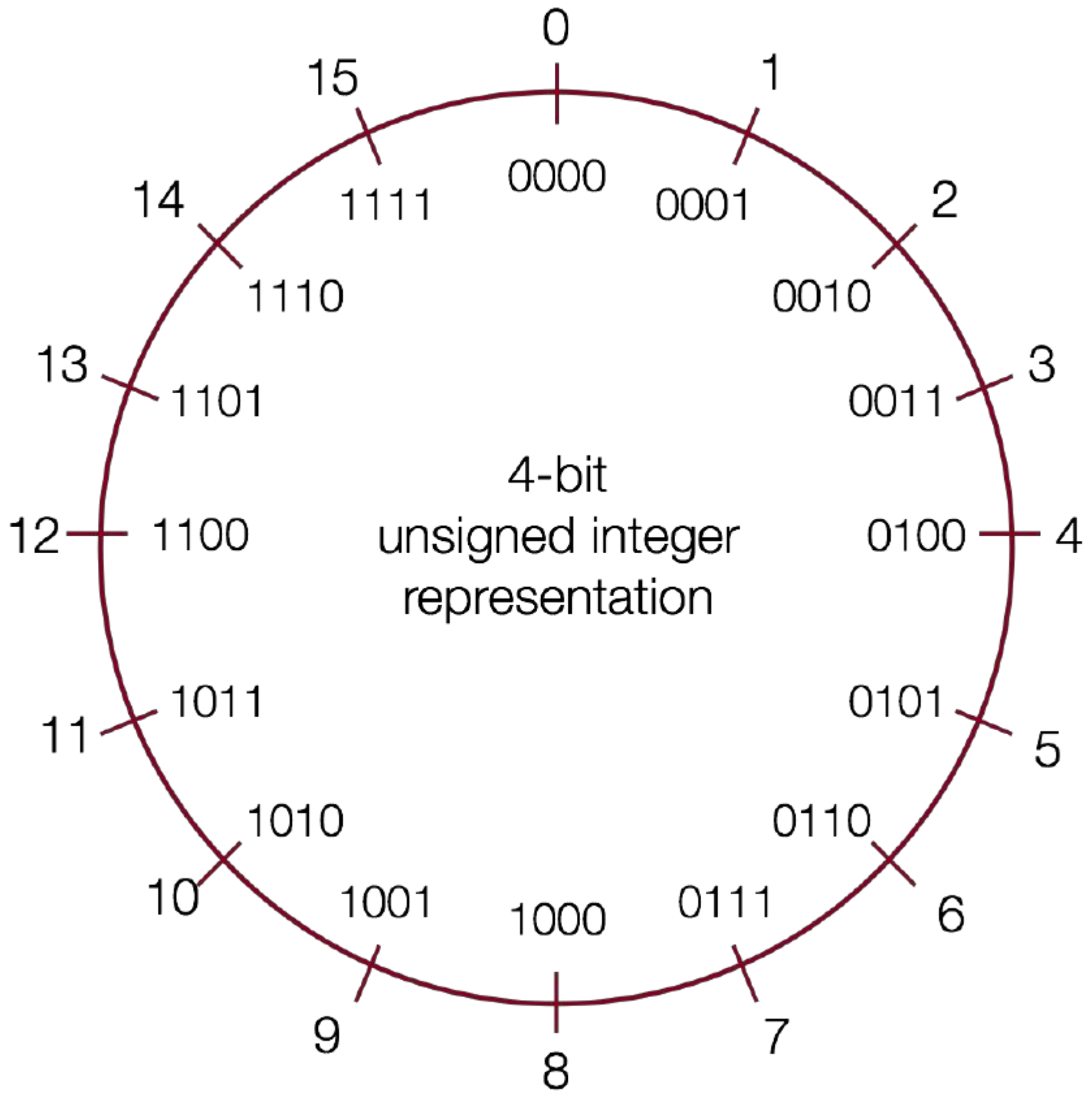
-2
1110
-1
1111
4-bit
two's complement
signed integer
representation


0
0000
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0110
7
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8
1000
9
1001
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# Comparisons Between Different Types

- **Be careful** when comparing signed and unsigned integers. **C will implicitly cast** the signed argument to unsigned, and then performs the operation assuming both numbers are non-negative.

| Expression | Type | Evaluation | Correct? |
|---|---|---|---|
| `0 == 0U` | | | |
| `-1 < 0` | | | |
| `-1 < 0U` | | | |
| `2147483647 >`<br>`-2147483647 - 1` | | | |
| `2147483647U >`<br>`-2147483647 - 1` | | | |
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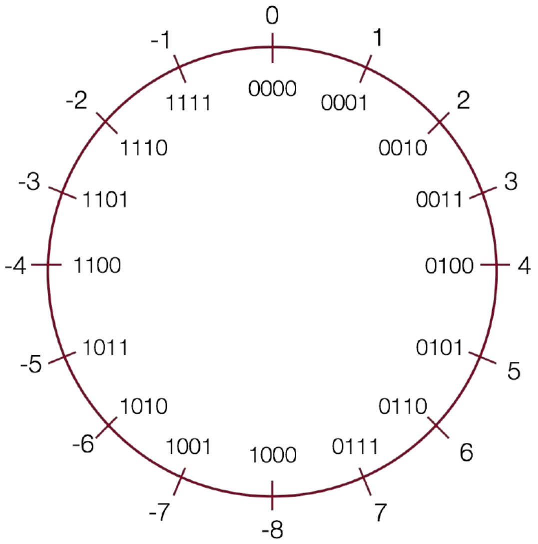

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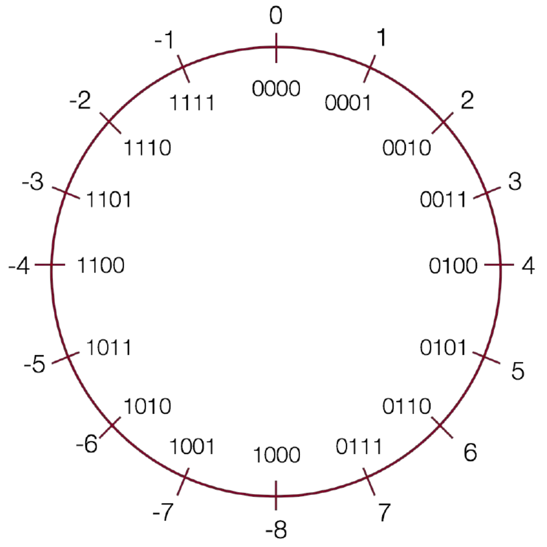

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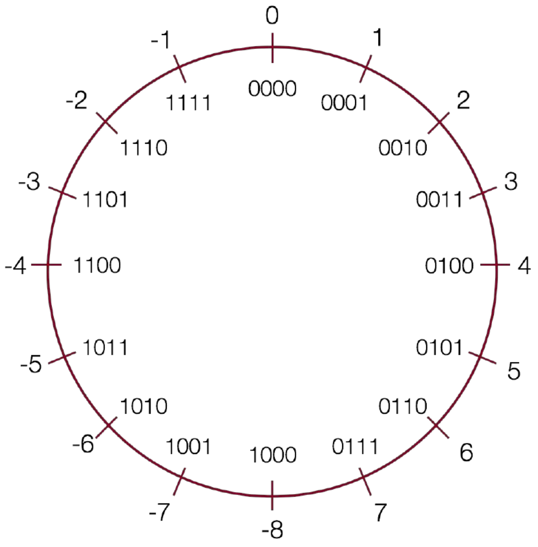

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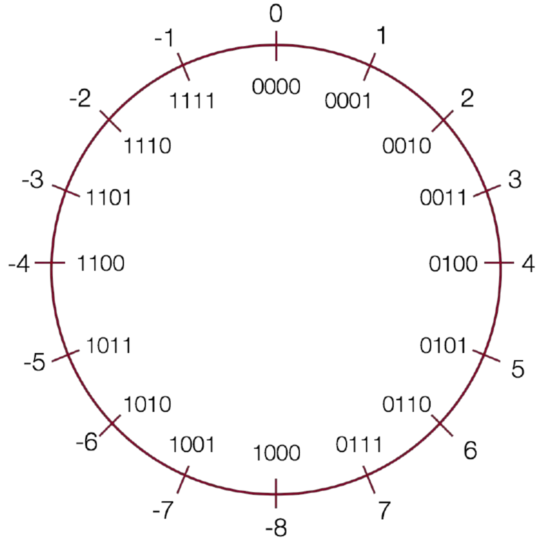


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|---|---|---|---|
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| `unsigned int` | 4 | `0` | `4294967295` |

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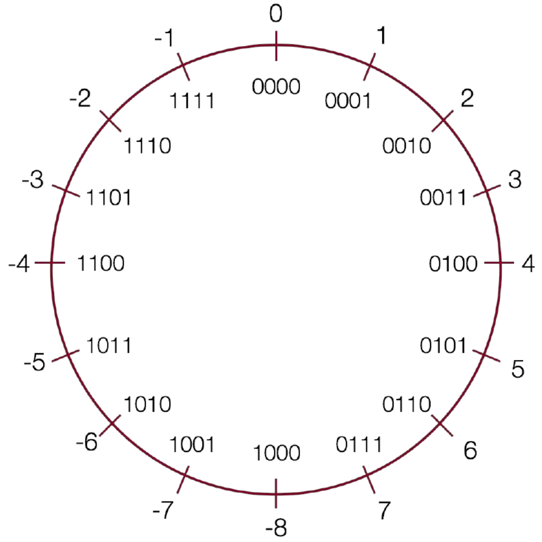


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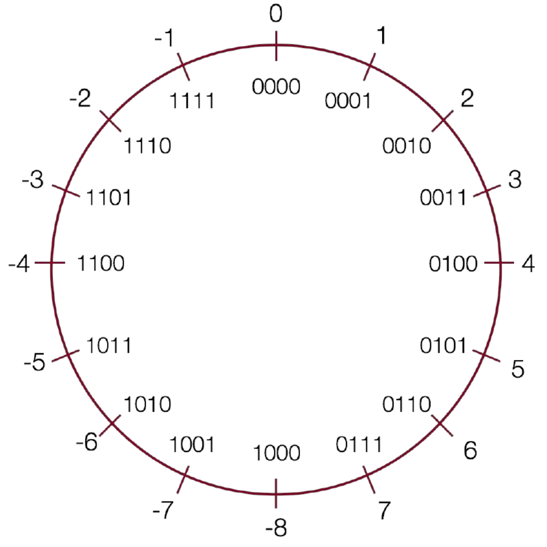


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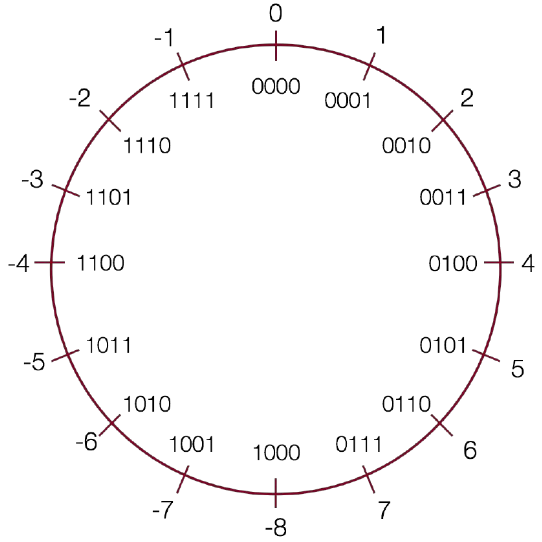


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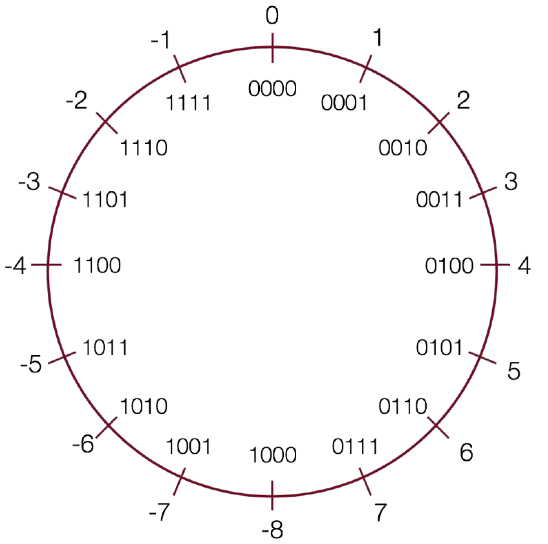


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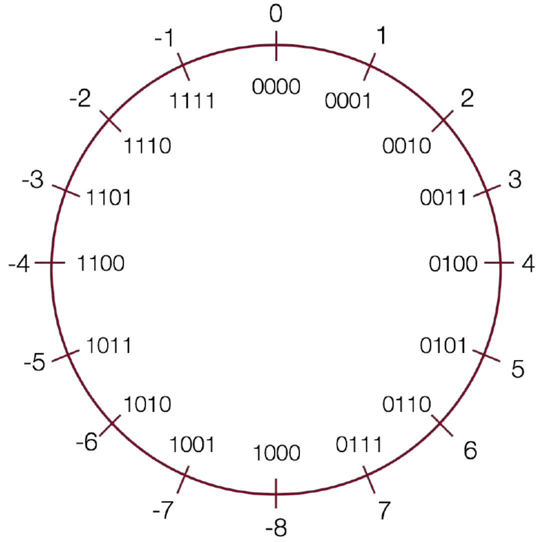


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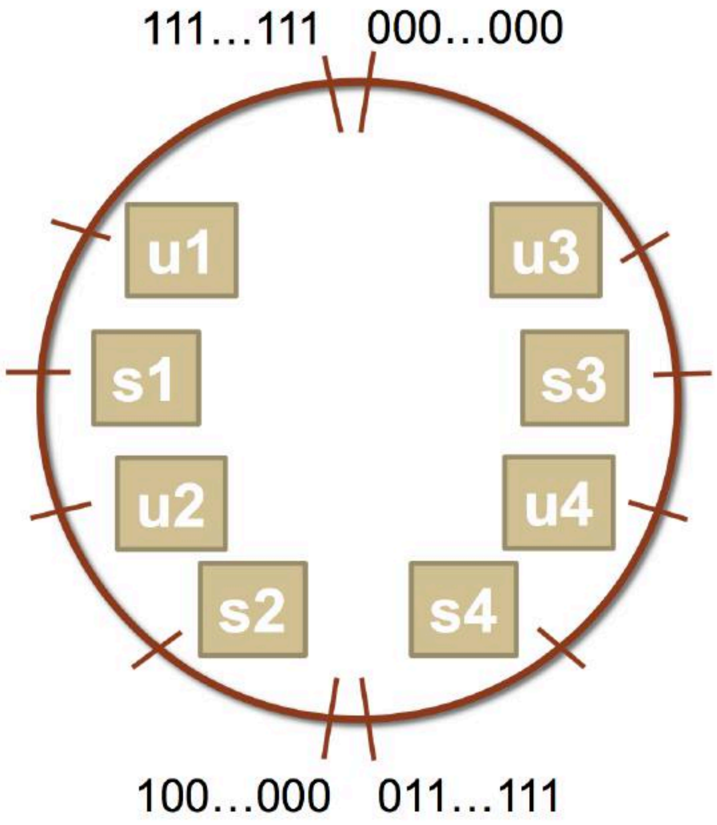
# Comparisons Between Different Types

Which many of the following statements are true? *(assume that variables are set to values that place them in the spots shown)*

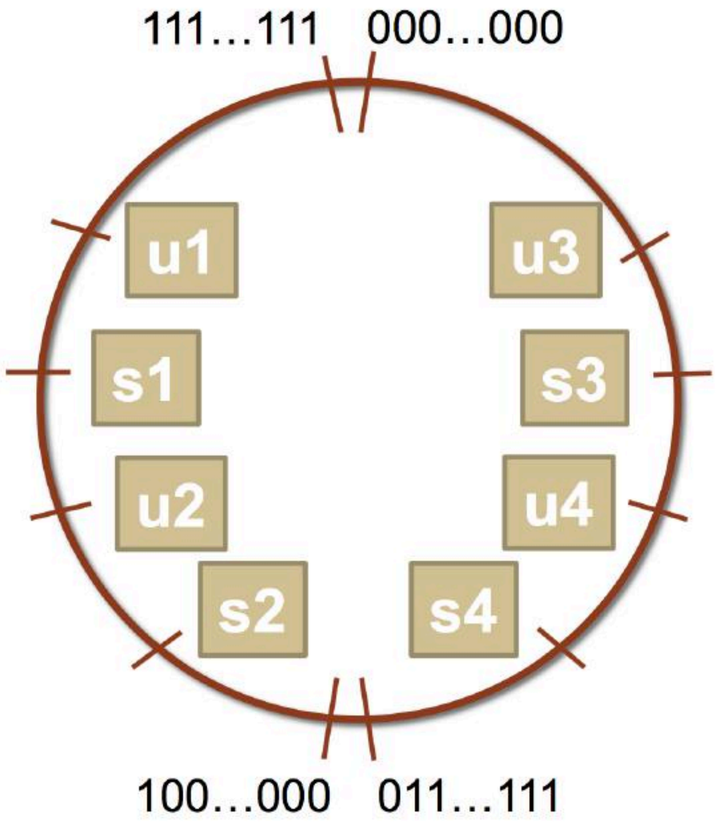
```
s3 > u3
u2 > u4
s2 > s4
s1 > s2
u1 > u2
s1 > u3
```



# Comparisons Between Different Types

Which many of the following statements are true? *(assume that variables are set to values that place them in the spots shown)*

```
s3 > u3 - true
u2 > u4
s2 > s4
s1 > s2
u1 > u2
s1 > u3
```



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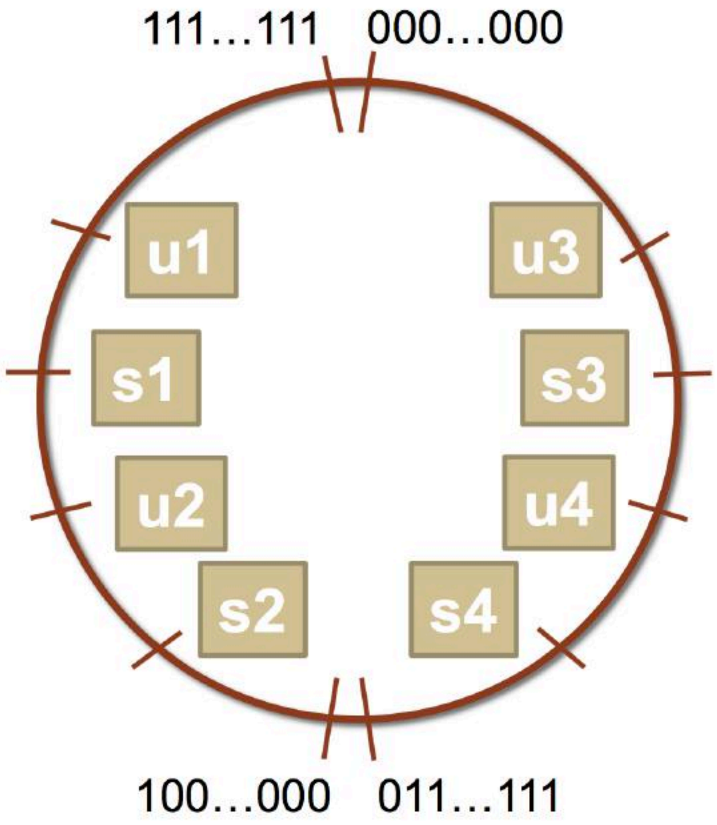

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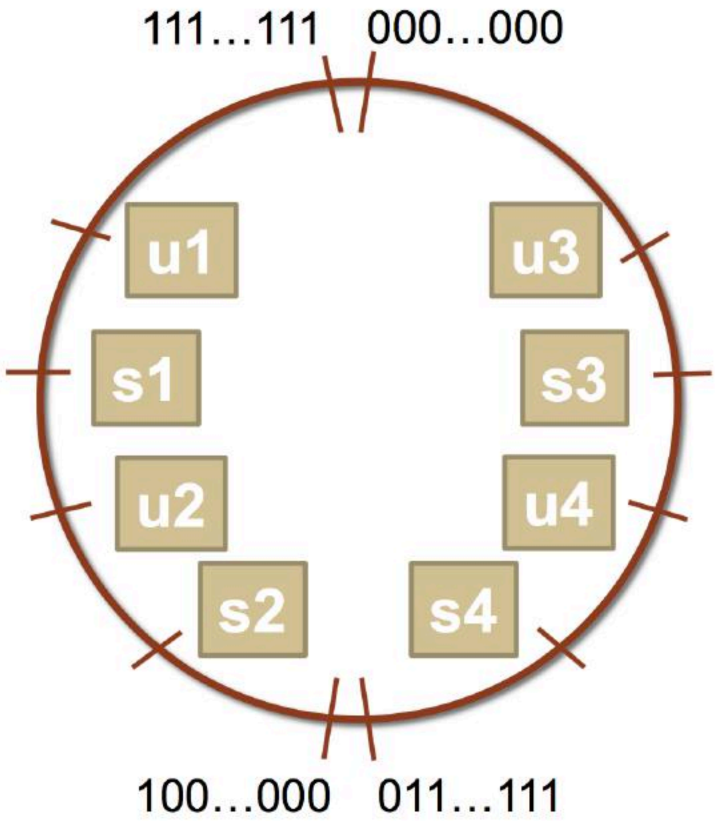

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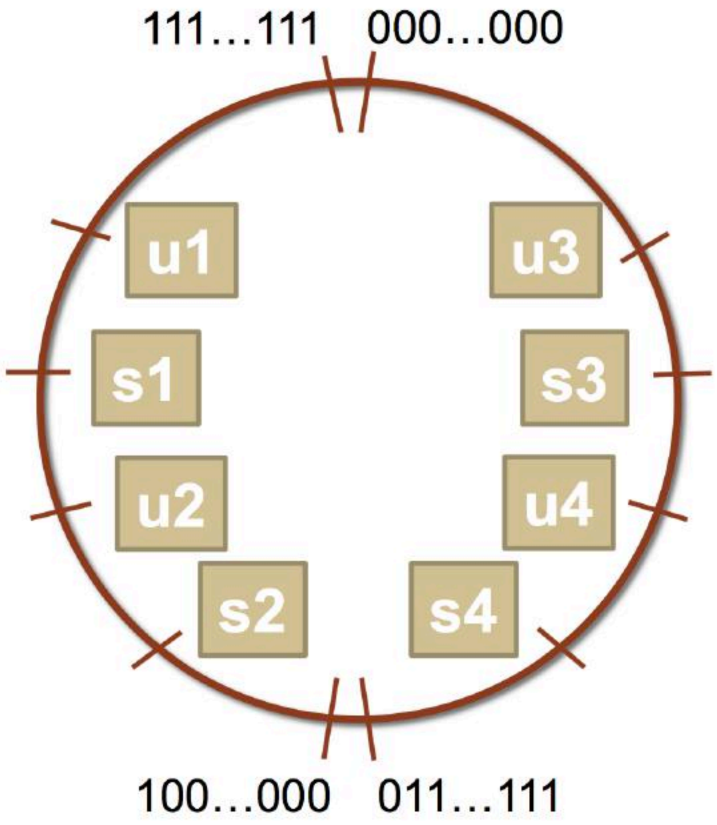

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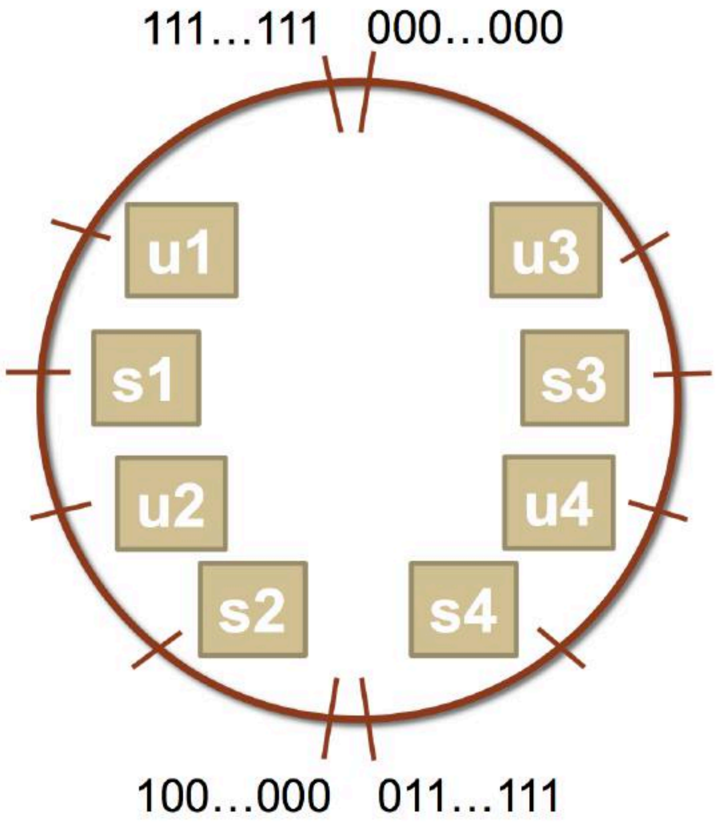

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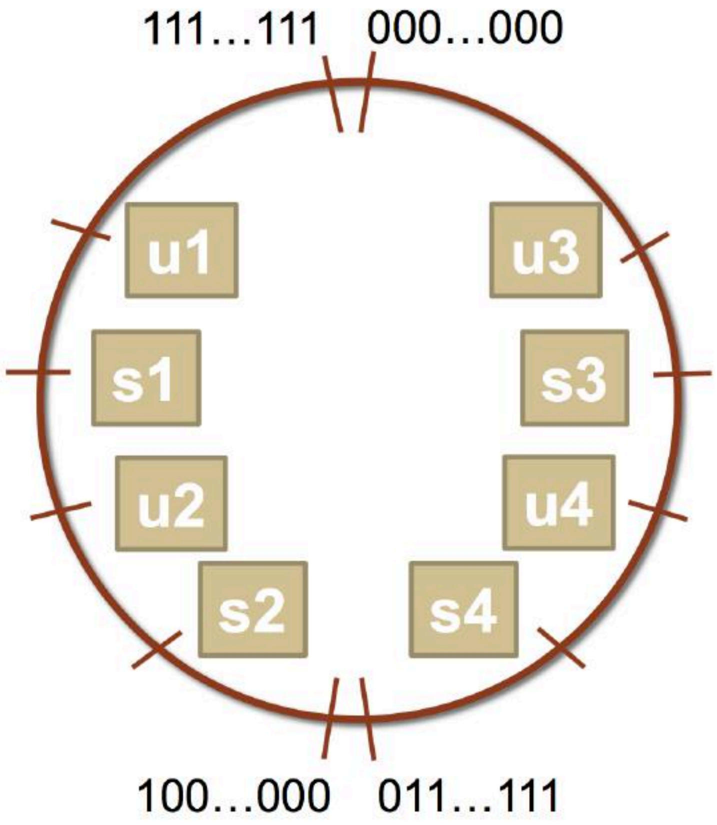

# Expanding Bit Representations

- Sometimes, we want to convert between two integers of different sizes (e.g. **`short`** to **`int`**, or **`int`** to **`long`**).
- We might not be able to convert from a bigger data type to a smaller data type, but we do want to always be able to convert from a **smaller** data type to a **bigger** data type.
- For **unsigned** values, we can add *leading zeros* to the representation ("zero extension")
- For **signed** values, we can *repeat the sign of the value* for new digits ("sign extension")
- Note: when doing <, >, <=, >= comparison between different size types, it will *promote to the larger type*.

# Expanding Bit Representation

```
unsigned short s = 4;
// short is a 16-bit format, so                           s = 0000 0000 0000 0100b

unsigned int i = s;
// conversion to 32-bit int, so i = 0000 0000 0000 0000 0000 0000 0000 0100b
```

# Expanding Bit Representation

```
short s = 4;
// short is a 16-bit format, so                     s = 0000 0000 0000 0100b

int i = s;
// conversion to 32-bit int, so i = 0000 0000 0000 0000 0000 0000 0000 0100b
```

— or —

```
short s = -4;
// short is a 16-bit format, so                     s = 1111 1111 1111 1100b

int i = s;
// conversion to 32-bit int, so i = 1111 1111 1111 1111 1111 1111 1111 1100b
```

# Truncating Bit Representation

If we want to **reduce** the bit size of a number, C *truncates* the representation and discards the *more significant bits*.

```
int x = 53191;
short sx = x;
int y = sx;
```

What happens here? Let's look at the bits in `x` (a 32-bit `int`), 53191:

**`0000 0000 0000 0000 1100 1111 1100 0111`**

When we cast `x` to a `short`, it only has 16-bits, and C *truncates* the number:

**`1100 1111 1100 0111`**

This is -12345! And when we cast `sx` back an `int`, we sign-extend the number.

**`1111 1111 1111 1111 1100 1111 1100 0111`** // still -12345

# Truncating Bit Representation

If we want to **reduce** the bit size of a number, C *truncates* the representation and discards the *more significant bits*.

```
int x = -3;
short sx = x;
int y = sx;
```

What happens here? Let's look at the bits in `x` (a 32-bit `int`), -3:

**`1111 1111 1111 1111 1111 1111 1111 1101`**

When we cast `x` to a `short`, it only has 16-bits, and C *truncates* the number:

**`1111 1111 1111 1101`**

This is -3! **If the number does fit, it will convert fine.** `y` looks like this:

**`1111 1111 1111 1111 1111 1111 1111 1101`** // still -3

# Truncating Bit Representation

If we want to **reduce** the bit size of a number, C *truncates* the representation and discards the *more significant bits*.

```
unsigned int x = 128000;
unsigned short sx = x;
unsigned int y = sx;
```

What happens here? Let's look at the bits in `x` (a 32-bit unsigned `int`), 128000:

**`0000 0000 0000 0001 1111 0100 0000 0000`**

When we cast `x` to a `short`, it only has 16-bits, and C *truncates* the number:

**`1111 0100 0000 0000`**

This is 62464! **Unsigned numbers can lose info too.** Here is what `y` looks like:

**`0000 0000 0000 0000 1111 0100 0000 0000`** // still 62464

# The `sizeof` Operator

```
long sizeof(type);
```

```
// Example
long int_size_bytes = sizeof(int);     // 4
long short_size_bytes = sizeof(short); // 2
long char_size_bytes = sizeof(char);   // 1
```

`sizeof` takes a variable type as a parameter and returns the size of that type, in bytes.

# Practice: Truncation

What are the values of `cx` for the passages of code below?

```
short x = 130; // 0b1000 0010
char cx = x;
```

```
short x = -132 // 0b1111 1111 0111 1100
char cx = x;
```

```
short x = 25; // 0b1 1001
char cx = x;
```

# Practice: Truncation

What are the values of `cx` for the passages of code below?

```
short x = 130; // 0b1000 0010
char cx = x; // -126
```

```
short x = -132 // 0b1111 1111 0111 1100
char cx = x; // 124
```

```
short x = 25; // 0b1 1001
char cx = x; // 25
```

# Practice: Truncation

What are the values of `cx` for the passages of code below?

```
short x = 390; // 0b1 1000 0110
char cx = x;
```

```
short x = -15; // 0b1111 1111 1111 0001
char cx = x;
```

# Practice: Truncation

What are the values of `cx` for the passages of code below?

```
short x = 390; // 0b1 1000 0110
char cx = x; // -122
```

```
short x = -15; // 0b1111 1111 1111 0001
char cx = x; // -15
```

# Recap

- Getting Started With C
- Bits and Bytes
- Hexadecimal
- Integer Representations
- Unsigned Integers
- Signed Integers
- Overflow
- Casting and Combining Types
- **Next time:** How can we manipulate individual bits and bytes? How can we represent floating point numbers?