# Data Representation

15-110 – Friday 09/04

# Learning Objectives

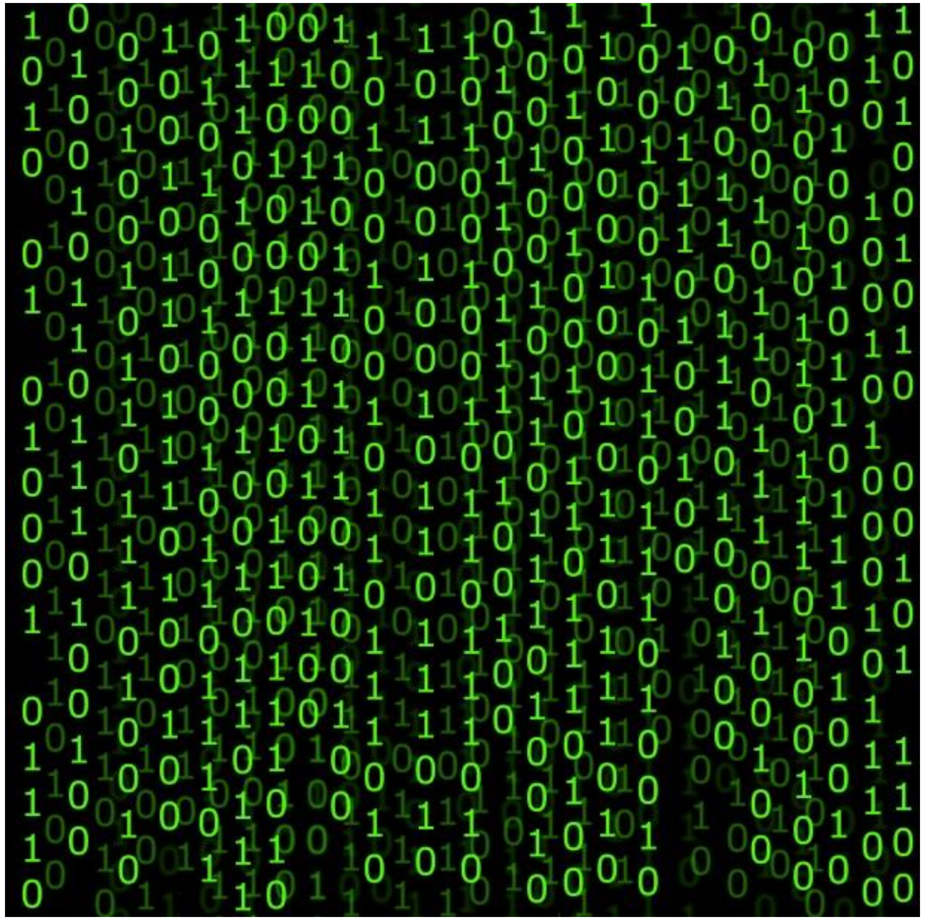
- Understand how different **number systems** can represent the same information
- Translate **binary numbers** to decimal, and vice versa
- Interpret binary numbers as abstracted types, including **colors** and **text**

# Number Systems

# Computers Run on 0s and 1s

Computers represent everything by using 0s and 1s. You've likely seen references to this before.

How can we represent text, or images, or sound with 0s and 1s? This brings us back to **abstraction**.



# Abstraction is About Representation

Recall our definition of abstraction from the first lecture:

**Abstraction** is a technique used to make complex systems manageable by reducing the amount of detail used to **represent** or interact with the system.

We'll use abstraction to translate 0s and 1s to decimal numbers, then translate those numbers to other types.

# Number Systems – Coins

A **number system** is a way of representing numbers using symbols.

One example of a number system is US currency. How much is each of the following symbols worth?

Penny
1 cent

Nickel
5 cents

Dime
10 cents

Quarter
25 cents

# Number Systems – Dollars

Alternatively, we can represent money using **dollars and cents**, in decimal form.

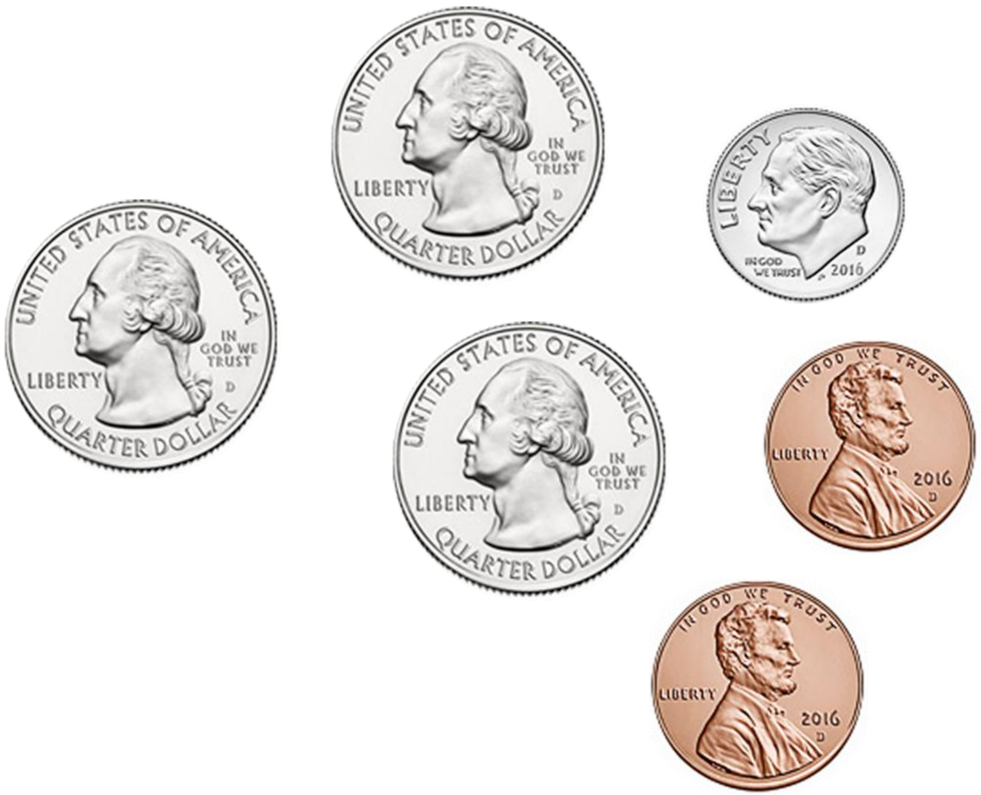
For example, a medium coffee at Tazza is **$2.65**.

# Converting Coins to Dollars

We can **convert between number systems** by translating a value from one system to the other.

For example, the coins on the left represent the same value as $0.87

Using pictures is clunky. Let's make a new representation system for coins.



# Coin Number Representation

To represent coins, we'll make a number with four digits.

The first represents quarters, the second dimes, the third nickels, and the fourth pennies.

c.3.1.0.2 =

3*$0.25 + 1*$0.10 + 0*$0.05 + 2*$0.01 =

$0.87

|  | Q | D | N | P |
|---|---|---|---|---|
| c | 3 | 1 | 0 | 2 |

# Converting Dollars to Coins

In recitation, you created an algorithm to convert money from dollars to coins, minimizing the number of coins used.

How did your algorithm work?

# Conversion Example

What is $0.59 in coin representation?

$0.59 = 2*$0.25 + 0*$0.10 + 1*$0.05 + 4*$0.01 = c.2.0.1.4

# Activity: Coin Conversion

Now try the following calculations with your discussion group:

What is c.1.1.1.2 in dollars?

What is $0.61 in coin representation?

# Number Systems – Binary

Now let's go back to computers. We can represent numbers using only 0s and 1s with the **binary number system**.

Instead of counting the number of 1s, 5s, 10s, and 25s in coins you need, count the number of 1s, 2s, 4s, and 8s.

Why these numbers? They're **powers of 2**. This is a number in **base 2**. In contrast, our usual decimal system uses base 10.

| $2^3$ **8** | $2^2$ **4** | $2^1$ **2** | $2^0$ **1** |
|---|---|---|---|
| 1 | 1 | 0 | 1 |

# Bits and Bytes

When working with binary and computers, we often refer to a set of binary values used together to represent a number.

A single binary value is called a **bit**.

A set of 8 bits is called a **byte**.

We commonly use some number of **bytes** to represent data values.

# Counting in Binary

0 =

| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

1 =

| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 |

2 =

| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 |

3 =

| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 |

4 =

| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 |

5 =

| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 |

6 =

| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 |

7 =

| 128 | 64 | 32 | 16 | 8 | 4 | 2 | 1 |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 |

# Converting Binary to Decimal

To convert a binary number to decimal, just add each power of 2 that is represented by a 1.

For example, 00011000 = 16 + 8 = 24

| **128** | **64** | **32** | **16** | **8** | **4** | **2** | **1** |
|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |

Another example:

10010001 = 128 + 16 + 1 = 145

| **128** | **64** | **32** | **16** | **8** | **4** | **2** | **1** |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 0 | 0 | 0 | 1 |

# Converting Decimal to Binary

Converting decimal to binary uses the **same process** as converting dollars to coins.

Look for the largest power of 2 that can fit in the number and subtract it from the number. Repeat with the next-largest power of 2, etc., until you reach 0.

For example, 36 = 32 + 4 = 00100100

| **128** | **64** | **32** | **16** | **8** | **4** | **2** | **1** |
|---|---|---|---|---|---|---|---|
| 0 | 0 | **1** | 0 | 0 | **1** | 0 | 0 |

Another example:

103 = 64 + 32 + 4 + 2 + 1

| **128** | **64** | **32** | **16** | **8** | **4** | **2** | **1** |
|---|---|---|---|---|---|---|---|
| 0 | **1** | **1** | 0 | 0 | **1** | **1** | **1** |

# Activity: Converting Binary

Now try converting numbers on your own.

First: what is **01011011** in decimal?

Second: what is **75** in binary?

# Abstracted Types

# Binary and Abstraction

Now that we can represent numbers using binary, we can represent **everything** computers store using binary.

We just need to use **abstraction** to interpret bits or numbers in particular ways.

Let's consider numbers, images, and text.

# Discussion: Representing Advanced Numbers

It can be helpful to think logically about how to represent a value before learning how it's done in practice. Let's do that now.

**Discuss:** We can convert binary directly into positive numbers, but how do we represent negative numbers?

**Discuss:** What about floating-point numbers? How do we represent π?

# Answer: Representing Advanced Numbers

## Negative Numbers

**Possible Approach**: reserve one bit to represent whether the number is positive or negative. Convert the rest normally.

**Actual Approach:** any integer can be viewed as either signed or unsigned. The value 11111111 is 255, but it's also -1 because 11111111 + 1 = 100000000, which becomes 00000000 if we only have 8 bits. So 11111110 is -2 (or 254), and so on.

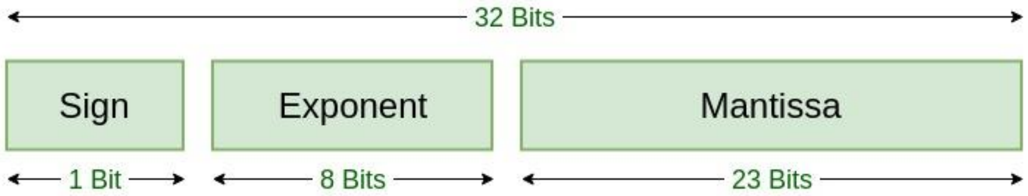
## Floating-Point Numbers

**Possible Approach:** use two bytes to represent digits before the decimal point, and two bytes to represent digits after.

**Actual Approach:** use scientific representation (0.8e+10) to move the decimal point. Some bits are for the exponent and some are for the number value (called the "mantissa").

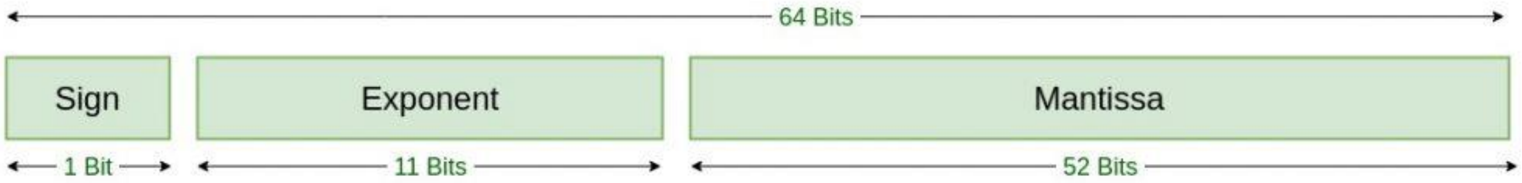
# Sidebar: 32 and 64 Bit Floating-Point Numbers

**32 Bits:**



Single Precision
IEEE 754 Floating-Point Standard

**64 Bits:**



Double Precision
IEEE 754 Floating-Point Standard

# Size of Integers

Your machine is either classified as 32-bit or 64-bit. This refers to the **size of integers** used by your computer's operating system.

The largest integer that can be represented with N bits is $2^N$-1 (why?). This means that...

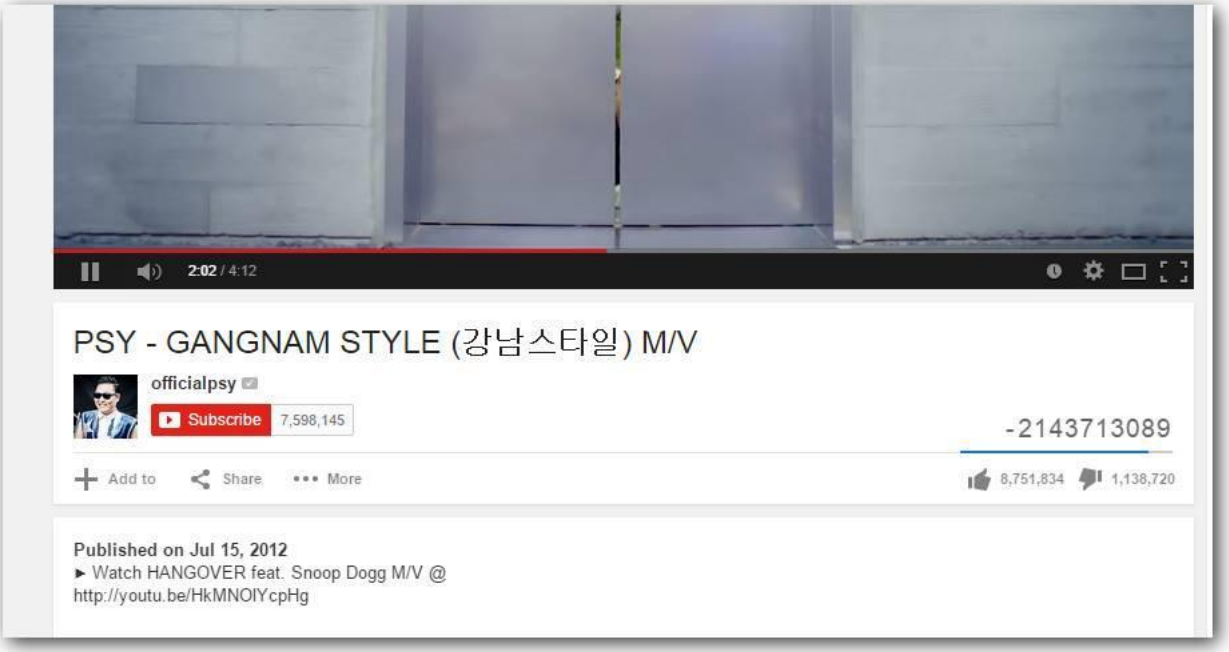
Largest int for 32 bits: 4,294,967,295 (or 2,147,483,647 with negative numbers)

Largest int for 64 bits: 18,446,744,073,709,551,615 (18.4 quintillion)

# Integer Overflow

Why does this matter?

By late 2014, the music video Gangnam Style received more than **2 billion** views. When it passed the largest positive number that could be represented with 32 bits, YouTube showed the number of views as **negative** instead!



PSY - GANGNAM STYLE (강남스타일) M/V

officialpsy

-2143713089

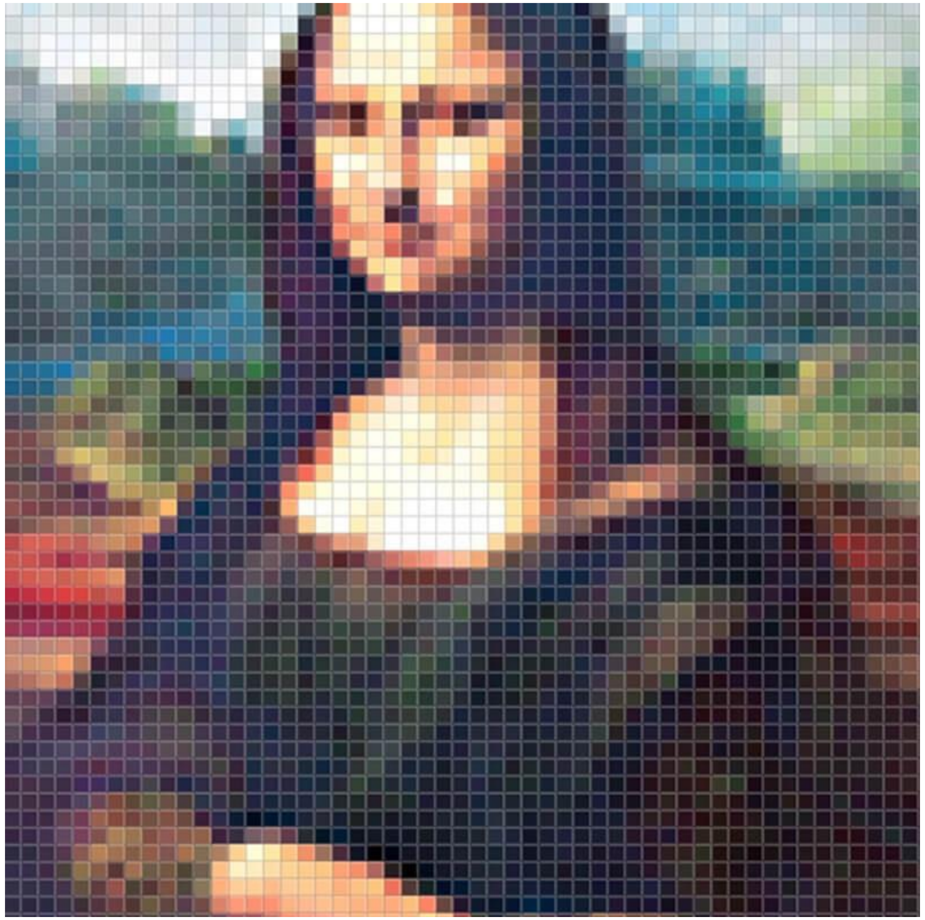
Published on Jul 15, 2012
► Watch HANGOVER feat. Snoop Dogg M/V @
http://youtu.be/HkMNOIYcpHg

Now YouTube uses a 64-bit counter instead.

# Represent Images as Grids of Colors

What if we want to represent an image? How can we convert that to numbers?

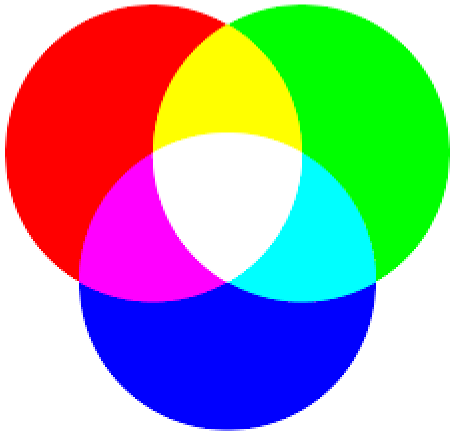
First, break the image down into a grid of colors, where each square of color has a distinct hue. A square of color in this context is called a **pixel**.



# Representing Colors in Binary

Now we just need to represent a single color (a pixel) as a number.

There are a few ways to do this, but we'll focus on **RGB**. Any color can be represented as a combination of Red, Green, and Blue.



Red, green, and blue intensity can be represented using one **byte** each, where 00000000 (0) is none and 11111111 (255) is very intense. So each pixel will require 3 bytes to encode.

Try it out here: w3schools.com/colors/colors_rgb.asp

# Example: Representing Beige

To make the campus-building beige, we'd need:

**Red = 249 = 11111001** 🟥

**Green= 228 = 11100100** 🟩

**Blue = 183 = 10110111** 🟦

**Which makes beige!** 🟨

# Represent Text as Individual Characters

Next, how do we represent text?

First, we break it down into smaller parts, like with images. In this case, we can break text down into individual **characters**.

For example, the text "Hello World" becomes

H, e, l, l, o, space, W, o, r, l, d

# Use a Lookup Table to Convert Characters

Unlike colors, characters don't have a natural connection to numbers.

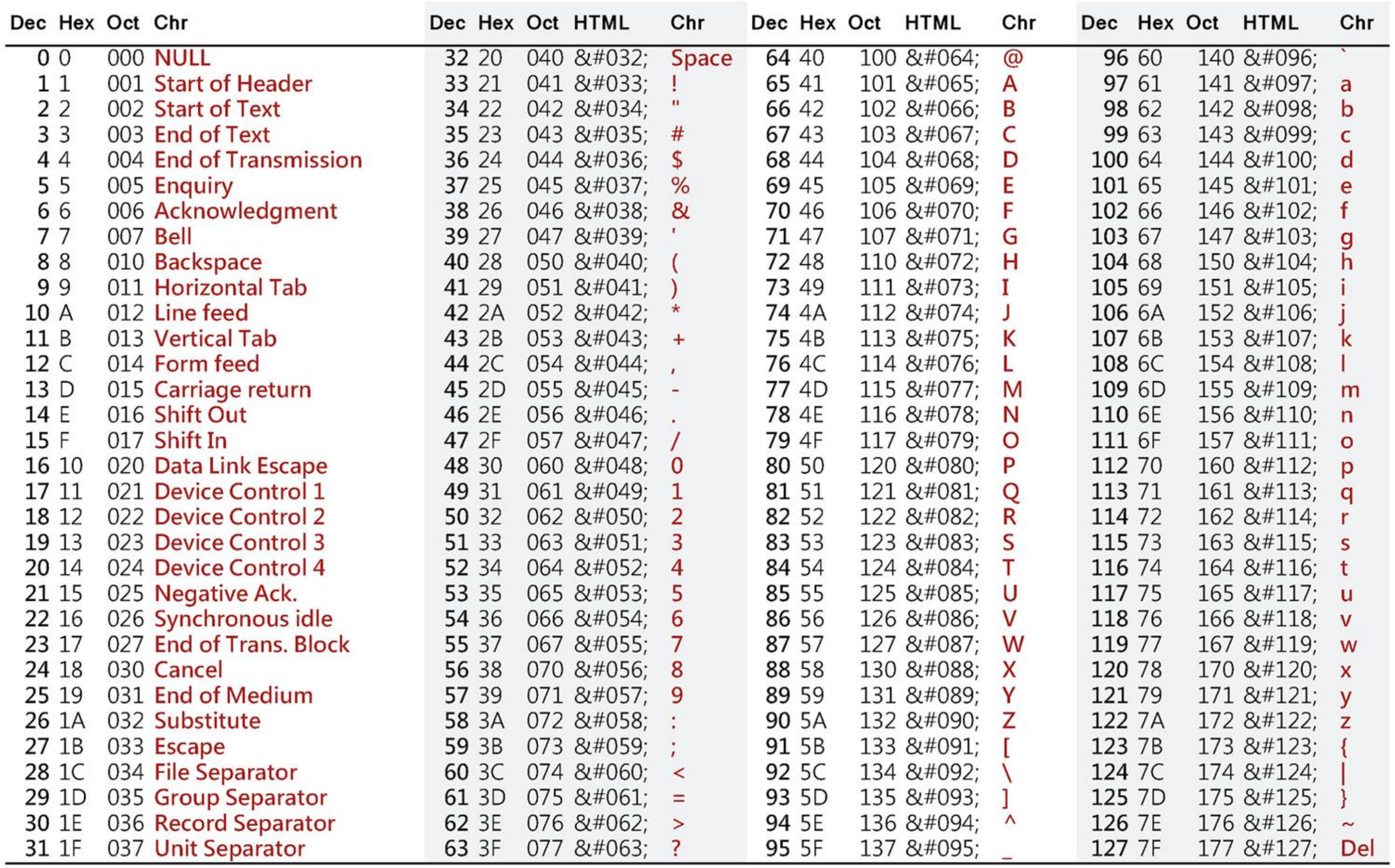
Instead, we can use a **lookup table** that maps each possible character to an integer.

As long as every computer uses the same lookup table, computers can always translate a set of numbers into the same set of characters.

# ASCII is a Simple Lookup Table

For basic characters, we can use the encoding system called ASCII. This maps the numbers 0 to 255 to characters. Therefore, one character is represented by one byte.

Check it out here: www.asciitable.com



| Dec | Hex | Oct | Chr | Dec | Hex | Oct | HTML | Chr | Dec | Hex | Oct | HTML | Chr | Dec | Hex | Oct | HTML | Chr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 000 | NULL | 32 | 20 | 040 | &#032; | Space | 64 | 40 | 100 | &#064; | @ | 96 | 60 | 140 | &#096; | ` |
| 1 | 1 | 001 | Start of Header | 33 | 21 | 041 | &#033; | ! | 65 | 41 | 101 | &#065; | A | 97 | 61 | 141 | &#097; | a |
| 2 | 2 | 002 | Start of Text | 34 | 22 | 042 | &#034; | " | 66 | 42 | 102 | &#066; | B | 98 | 62 | 142 | &#098; | b |
| 3 | 3 | 003 | End of Text | 35 | 23 | 043 | &#035; | # | 67 | 43 | 103 | &#067; | C | 99 | 63 | 143 | &#099; | c |
| 4 | 4 | 004 | End of Transmission | 36 | 24 | 044 | &#036; | $ | 68 | 44 | 104 | &#068; | D | 100 | 64 | 144 | &#100; | d |
| 5 | 5 | 005 | Enquiry | 37 | 25 | 045 | &#037; | % | 69 | 45 | 105 | &#069; | E | 101 | 65 | 145 | &#101; | e |
| 6 | 6 | 006 | Acknowledgment | 38 | 26 | 046 | &#038; | & | 70 | 46 | 106 | &#070; | F | 102 | 66 | 146 | &#102; | f |
| 7 | 7 | 007 | Bell | 39 | 27 | 047 | &#039; | ' | 71 | 47 | 107 | &#071; | G | 103 | 67 | 147 | &#103; | g |
| 8 | 8 | 010 | Backspace | 40 | 28 | 050 | &#040; | ( | 72 | 48 | 110 | &#072; | H | 104 | 68 | 150 | &#104; | h |
| 9 | 9 | 011 | Horizontal Tab | 41 | 29 | 051 | &#041; | ) | 73 | 49 | 111 | &#073; | I | 105 | 69 | 151 | &#105; | i |
| 10 | A | 012 | Line feed | 42 | 2A | 052 | &#042; | * | 74 | 4A | 112 | &#074; | J | 106 | 6A | 152 | &#106; | j |
| 11 | B | 013 | Vertical Tab | 43 | 2B | 053 | &#043; | + | 75 | 4B | 113 | &#075; | K | 107 | 6B | 153 | &#107; | k |
| 12 | C | 014 | Form feed | 44 | 2C | 054 | &#044; | , | 76 | 4C | 114 | &#076; | L | 108 | 6C | 154 | &#108; | l |
| 13 | D | 015 | Carriage return | 45 | 2D | 055 | &#045; | - | 77 | 4D | 115 | &#077; | M | 109 | 6D | 155 | &#109; | m |
| 14 | E | 016 | Shift Out | 46 | 2E | 056 | &#046; | . | 78 | 4E | 116 | &#078; | N | 110 | 6E | 156 | &#110; | n |
| 15 | F | 017 | Shift In | 47 | 2F | 057 | &#047; | / | 79 | 4F | 117 | &#079; | O | 111 | 6F | 157 | &#111; | o |
| 16 | 10 | 020 | Data Link Escape | 48 | 30 | 060 | &#048; | 0 | 80 | 50 | 120 | &#080; | P | 112 | 70 | 160 | &#112; | p |
| 17 | 11 | 021 | Device Control 1 | 49 | 31 | 061 | &#049; | 1 | 81 | 51 | 121 | &#081; | Q | 113 | 71 | 161 | &#113; | q |
| 18 | 12 | 022 | Device Control 2 | 50 | 32 | 062 | &#050; | 2 | 82 | 52 | 122 | &#082; | R | 114 | 72 | 162 | &#114; | r |
| 19 | 13 | 023 | Device Control 3 | 51 | 33 | 063 | &#051; | 3 | 83 | 53 | 123 | &#083; | S | 115 | 73 | 163 | &#115; | s |
| 20 | 14 | 024 | Device Control 4 | 52 | 34 | 064 | &#052; | 4 | 84 | 54 | 124 | &#084; | T | 116 | 74 | 164 | &#116; | t |
| 21 | 15 | 025 | Negative Ack. | 53 | 35 | 065 | &#053; | 5 | 85 | 55 | 125 | &#085; | U | 117 | 75 | 165 | &#117; | u |
| 22 | 16 | 026 | Synchronous idle | 54 | 36 | 066 | &#054; | 6 | 86 | 56 | 126 | &#086; | V | 118 | 76 | 166 | &#118; | v |
| 23 | 17 | 027 | End of Trans. Block | 55 | 37 | 067 | &#055; | 7 | 87 | 57 | 127 | &#087; | W | 119 | 77 | 167 | &#119; | w |
| 24 | 18 | 030 | Cancel | 56 | 38 | 070 | &#056; | 8 | 88 | 58 | 130 | &#088; | X | 120 | 78 | 170 | &#120; | x |
| 25 | 19 | 031 | End of Medium | 57 | 39 | 071 | &#057; | 9 | 89 | 59 | 131 | &#089; | Y | 121 | 79 | 171 | &#121; | y |
| 26 | 1A | 032 | Substitute | 58 | 3A | 072 | &#058; | : | 90 | 5A | 132 | &#090; | Z | 122 | 7A | 172 | &#122; | z |
| 27 | 1B | 033 | Escape | 59 | 3B | 073 | &#059; | ; | 91 | 5B | 133 | &#091; | [ | 123 | 7B | 173 | &#123; | { |
| 28 | 1C | 034 | File Separator | 60 | 3C | 074 | &#060; | < | 92 | 5C | 134 | &#092; | \ | 124 | 7C | 174 | &#124; | \| |
| 29 | 1D | 035 | Group Separator | 61 | 3D | 075 | &#061; | = | 93 | 5D | 135 | &#093; | ] | 125 | 7D | 175 | &#125; | } |
| 30 | 1E | 036 | Record Separator | 62 | 3E | 076 | &#062; | > | 94 | 5E | 136 | &#094; | ^ | 126 | 7E | 176 | &#126; | ~ |
| 31 | 1F | 037 | Unit Separator | 63 | 3F | 077 | &#063; | ? | 95 | 5F | 137 | &#095; | _ | 127 | 7F | 177 | &#127; | Del |

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# Translating Text to Numbers

"Hello World" =

01001000

01100101

01101100

01101100

01101111

00100000

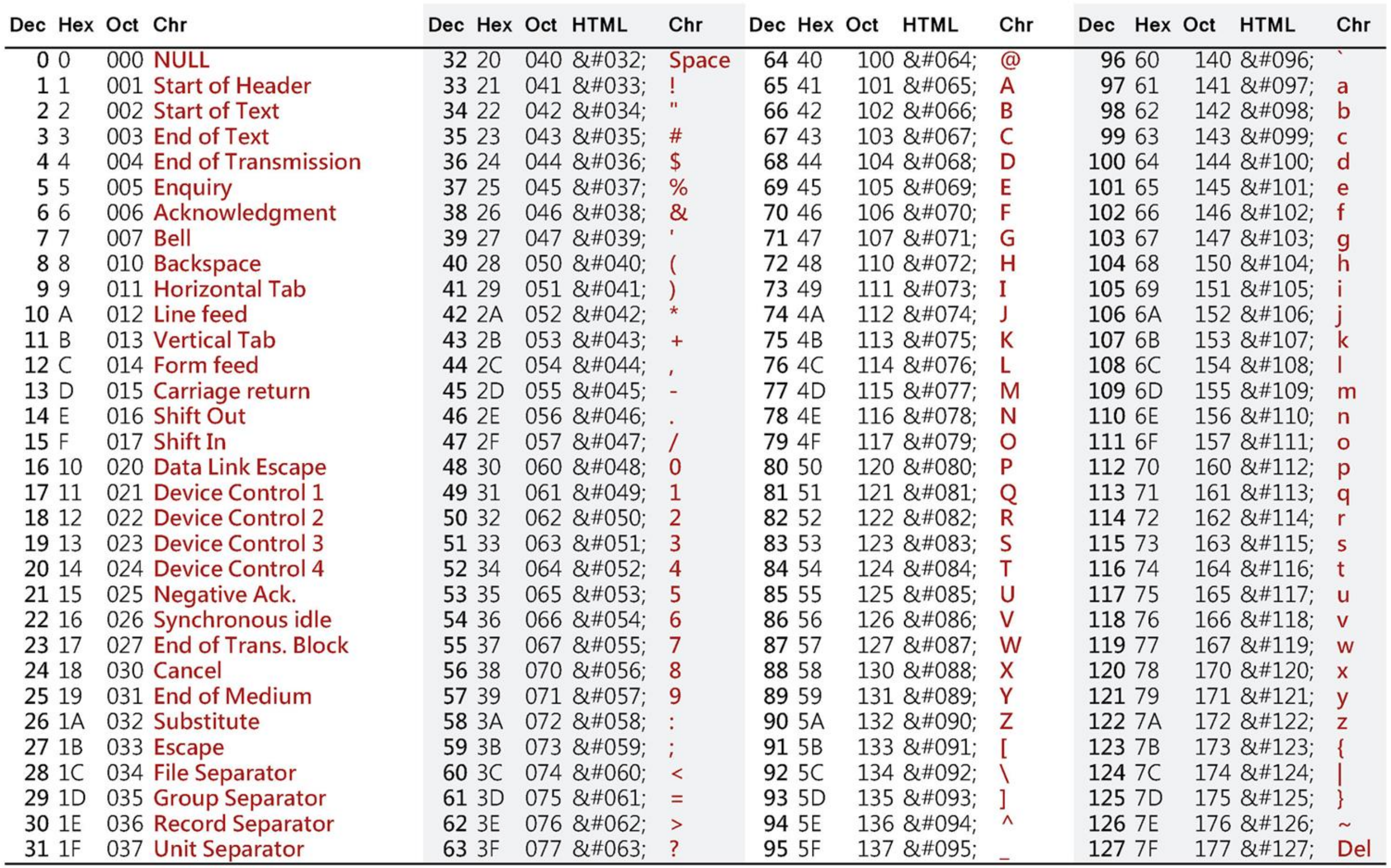
01010111

01101111

01110010

01101100

01100100



| Dec | Hex | Oct | Chr | Dec | Hex | Oct | HTML | Chr | Dec | Hex | Oct | HTML | Chr | Dec | Hex | Oct | HTML | Chr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 000 | NULL | 32 | 20 | 040 | &#032; | Space | 64 | 40 | 100 | &#064; | @ | 96 | 60 | 140 | &#096; | ` |
| 1 | 1 | 001 | Start of Header | 33 | 21 | 041 | &#033; | ! | 65 | 41 | 101 | &#065; | A | 97 | 61 | 141 | &#097; | a |
| 2 | 2 | 002 | Start of Text | 34 | 22 | 042 | &#034; | " | 66 | 42 | 102 | &#066; | B | 98 | 62 | 142 | &#098; | b |
| 3 | 3 | 003 | End of Text | 35 | 23 | 043 | &#035; | # | 67 | 43 | 103 | &#067; | C | 99 | 63 | 143 | &#099; | c |
| 4 | 4 | 004 | End of Transmission | 36 | 24 | 044 | &#036; | $ | 68 | 44 | 104 | &#068; | D | 100 | 64 | 144 | &#100; | d |
| 5 | 5 | 005 | Enquiry | 37 | 25 | 045 | &#037; | % | 69 | 45 | 105 | &#069; | E | 101 | 65 | 145 | &#101; | e |
| 6 | 6 | 006 | Acknowledgment | 38 | 26 | 046 | &#038; | & | 70 | 46 | 106 | &#070; | F | 102 | 66 | 146 | &#102; | f |
| 7 | 7 | 007 | Bell | 39 | 27 | 047 | &#039; | ' | 71 | 47 | 107 | &#071; | G | 103 | 67 | 147 | &#103; | g |
| 8 | 8 | 010 | Backspace | 40 | 28 | 050 | &#040; | ( | 72 | 48 | 110 | &#072; | H | 104 | 68 | 150 | &#104; | h |
| 9 | 9 | 011 | Horizontal Tab | 41 | 29 | 051 | &#041; | ) | 73 | 49 | 111 | &#073; | I | 105 | 69 | 151 | &#105; | i |
| 10 | A | 012 | Line feed | 42 | 2A | 052 | &#042; | * | 74 | 4A | 112 | &#074; | J | 106 | 6A | 152 | &#106; | j |
| 11 | B | 013 | Vertical Tab | 43 | 2B | 053 | &#043; | + | 75 | 4B | 113 | &#075; | K | 107 | 6B | 153 | &#107; | k |
| 12 | C | 014 | Form feed | 44 | 2C | 054 | &#044; | , | 76 | 4C | 114 | &#076; | L | 108 | 6C | 154 | &#108; | l |
| 13 | D | 015 | Carriage return | 45 | 2D | 055 | &#045; | - | 77 | 4D | 115 | &#077; | M | 109 | 6D | 155 | &#109; | m |
| 14 | E | 016 | Shift Out | 46 | 2E | 056 | &#046; | . | 78 | 4E | 116 | &#078; | N | 110 | 6E | 156 | &#110; | n |
| 15 | F | 017 | Shift In | 47 | 2F | 057 | &#047; | / | 79 | 4F | 117 | &#079; | O | 111 | 6F | 157 | &#111; | o |
| 16 | 10 | 020 | Data Link Escape | 48 | 30 | 060 | &#048; | 0 | 80 | 50 | 120 | &#080; | P | 112 | 70 | 160 | &#112; | p |
| 17 | 11 | 021 | Device Control 1 | 49 | 31 | 061 | &#049; | 1 | 81 | 51 | 121 | &#081; | Q | 113 | 71 | 161 | &#113; | q |
| 18 | 12 | 022 | Device Control 2 | 50 | 32 | 062 | &#050; | 2 | 82 | 52 | 122 | &#082; | R | 114 | 72 | 162 | &#114; | r |
| 19 | 13 | 023 | Device Control 3 | 51 | 33 | 063 | &#051; | 3 | 83 | 53 | 123 | &#083; | S | 115 | 73 | 163 | &#115; | s |
| 20 | 14 | 024 | Device Control 4 | 52 | 34 | 064 | &#052; | 4 | 84 | 54 | 124 | &#084; | T | 116 | 74 | 164 | &#116; | t |
| 21 | 15 | 025 | Negative Ack. | 53 | 35 | 065 | &#053; | 5 | 85 | 55 | 125 | &#085; | U | 117 | 75 | 165 | &#117; | u |
| 22 | 16 | 026 | Synchronous idle | 54 | 36 | 066 | &#054; | 6 | 86 | 56 | 126 | &#086; | V | 118 | 76 | 166 | &#118; | v |
| 23 | 17 | 027 | End of Trans. Block | 55 | 37 | 067 | &#055; | 7 | 87 | 57 | 127 | &#087; | W | 119 | 77 | 167 | &#119; | w |
| 24 | 18 | 030 | Cancel | 56 | 38 | 070 | &#056; | 8 | 88 | 58 | 130 | &#088; | X | 120 | 78 | 170 | &#120; | x |
| 25 | 19 | 031 | End of Medium | 57 | 39 | 071 | &#057; | 9 | 89 | 59 | 131 | &#089; | Y | 121 | 79 | 171 | &#121; | y |
| 26 | 1A | 032 | Substitute | 58 | 3A | 072 | &#058; | : | 90 | 5A | 132 | &#090; | Z | 122 | 7A | 172 | &#122; | z |
| 27 | 1B | 033 | Escape | 59 | 3B | 073 | &#059; | ; | 91 | 5B | 133 | &#091; | [ | 123 | 7B | 173 | &#123; | { |
| 28 | 1C | 034 | File Separator | 60 | 3C | 074 | &#060; | < | 92 | 5C | 134 | &#092; | \ | 124 | 7C | 174 | &#124; | \| |
| 29 | 1D | 035 | Group Separator | 61 | 3D | 075 | &#061; | = | 93 | 5D | 135 | &#093; | ] | 125 | 7D | 175 | &#125; | } |
| 30 | 1E | 036 | Record Separator | 62 | 3E | 076 | &#062; | > | 94 | 5E | 136 | &#094; | ^ | 126 | 7E | 176 | &#126; | ~ |
| 31 | 1F | 037 | Unit Separator | 63 | 3F | 077 | &#063; | ? | 95 | 5F | 137 | &#095; | _ | 127 | 7F | 177 | &#127; | Del |

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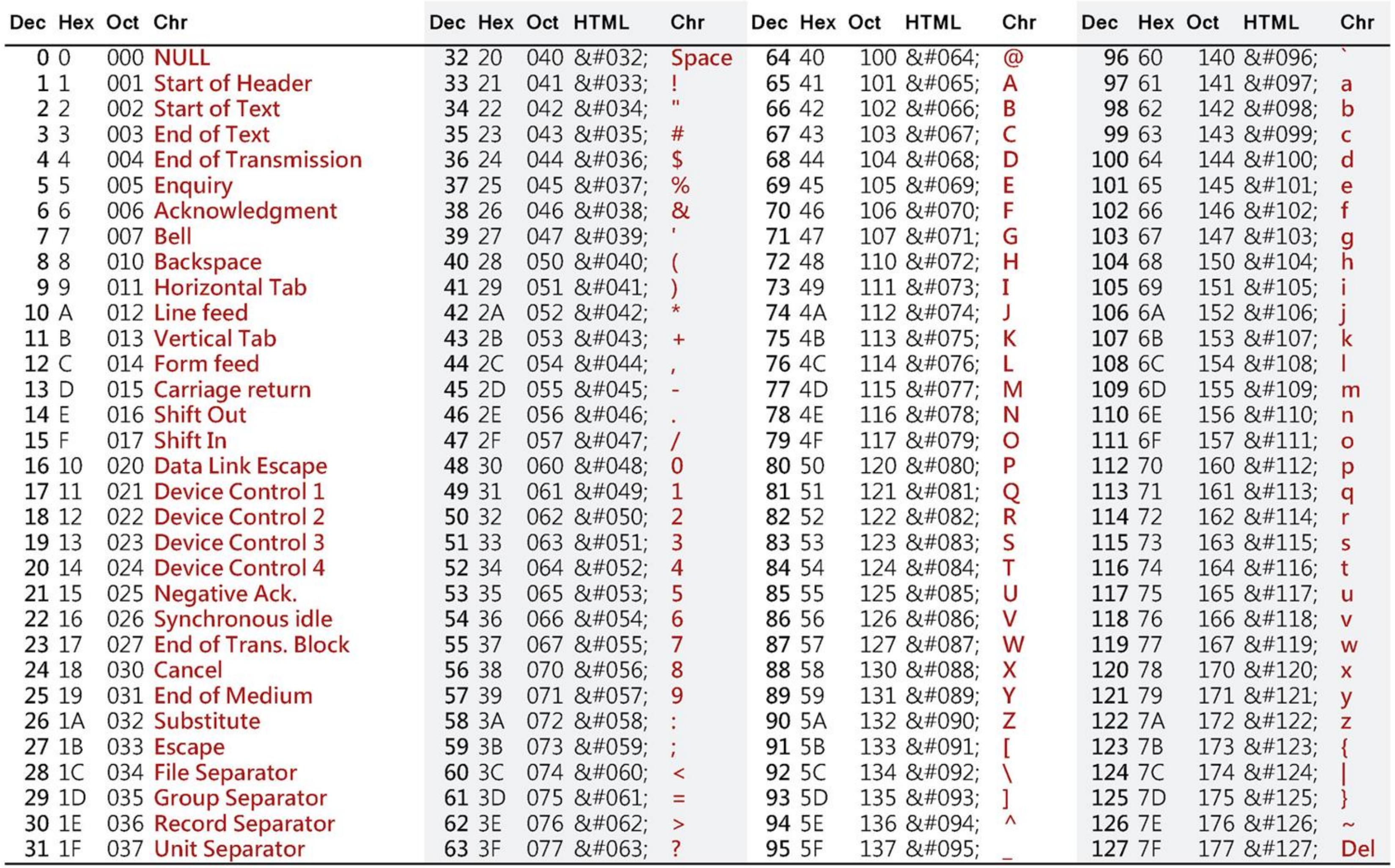
# Activity: Binary to Text

**You do:** translate the following binary into ASCII text.

01011001

01100001

01111001



| Dec | Hex | Oct | Chr | Dec | Hex | Oct | HTML | Chr | Dec | Hex | Oct | HTML | Chr | Dec | Hex | Oct | HTML | Chr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 000 | NULL | 32 | 20 | 040 | &#032; | Space | 64 | 40 | 100 | &#064; | @ | 96 | 60 | 140 | &#096; | ` |
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| 5 | 5 | 005 | Enquiry | 37 | 25 | 045 | &#037; | % | 69 | 45 | 105 | &#069; | E | 101 | 65 | 145 | &#101; | e |
| 6 | 6 | 006 | Acknowledgment | 38 | 26 | 046 | &#038; | & | 70 | 46 | 106 | &#070; | F | 102 | 66 | 146 | &#102; | f |
| 7 | 7 | 007 | Bell | 39 | 27 | 047 | &#039; | ' | 71 | 47 | 107 | &#071; | G | 103 | 67 | 147 | &#103; | g |
| 8 | 8 | 010 | Backspace | 40 | 28 | 050 | &#040; | ( | 72 | 48 | 110 | &#072; | H | 104 | 68 | 150 | &#104; | h |
| 9 | 9 | 011 | Horizontal Tab | 41 | 29 | 051 | &#041; | ) | 73 | 49 | 111 | &#073; | I | 105 | 69 | 151 | &#105; | i |
| 10 | A | 012 | Line feed | 42 | 2A | 052 | &#042; | * | 74 | 4A | 112 | &#074; | J | 106 | 6A | 152 | &#106; | j |
| 11 | B | 013 | Vertical Tab | 43 | 2B | 053 | &#043; | + | 75 | 4B | 113 | &#075; | K | 107 | 6B | 153 | &#107; | k |
| 12 | C | 014 | Form feed | 44 | 2C | 054 | &#044; | , | 76 | 4C | 114 | &#076; | L | 108 | 6C | 154 | &#108; | l |
| 13 | D | 015 | Carriage return | 45 | 2D | 055 | &#045; | - | 77 | 4D | 115 | &#077; | M | 109 | 6D | 155 | &#109; | m |
| 14 | E | 016 | Shift Out | 46 | 2E | 056 | &#046; | . | 78 | 4E | 116 | &#078; | N | 110 | 6E | 156 | &#110; | n |
| 15 | F | 017 | Shift In | 47 | 2F | 057 | &#047; | / | 79 | 4F | 117 | &#079; | O | 111 | 6F | 157 | &#111; | o |
| 16 | 10 | 020 | Data Link Escape | 48 | 30 | 060 | &#048; | 0 | 80 | 50 | 120 | &#080; | P | 112 | 70 | 160 | &#112; | p |
| 17 | 11 | 021 | Device Control 1 | 49 | 31 | 061 | &#049; | 1 | 81 | 51 | 121 | &#081; | Q | 113 | 71 | 161 | &#113; | q |
| 18 | 12 | 022 | Device Control 2 | 50 | 32 | 062 | &#050; | 2 | 82 | 52 | 122 | &#082; | R | 114 | 72 | 162 | &#114; | r |
| 19 | 13 | 023 | Device Control 3 | 51 | 33 | 063 | &#051; | 3 | 83 | 53 | 123 | &#083; | S | 115 | 73 | 163 | &#115; | s |
| 20 | 14 | 024 | Device Control 4 | 52 | 34 | 064 | &#052; | 4 | 84 | 54 | 124 | &#084; | T | 116 | 74 | 164 | &#116; | t |
| 21 | 15 | 025 | Negative Ack. | 53 | 35 | 065 | &#053; | 5 | 85 | 55 | 125 | &#085; | U | 117 | 75 | 165 | &#117; | u |
| 22 | 16 | 026 | Synchronous idle | 54 | 36 | 066 | &#054; | 6 | 86 | 56 | 126 | &#086; | V | 118 | 76 | 166 | &#118; | v |
| 23 | 17 | 027 | End of Trans. Block | 55 | 37 | 067 | &#055; | 7 | 87 | 57 | 127 | &#087; | W | 119 | 77 | 167 | &#119; | w |
| 24 | 18 | 030 | Cancel | 56 | 38 | 070 | &#056; | 8 | 88 | 58 | 130 | &#088; | X | 120 | 78 | 170 | &#120; | x |
| 25 | 19 | 031 | End of Medium | 57 | 39 | 071 | &#057; | 9 | 89 | 59 | 131 | &#089; | Y | 121 | 79 | 171 | &#121; | y |
| 26 | 1A | 032 | Substitute | 58 | 3A | 072 | &#058; | : | 90 | 5A | 132 | &#090; | Z | 122 | 7A | 172 | &#122; | z |
| 27 | 1B | 033 | Escape | 59 | 3B | 073 | &#059; | ; | 91 | 5B | 133 | &#091; | [ | 123 | 7B | 173 | &#123; | { |
| 28 | 1C | 034 | File Separator | 60 | 3C | 074 | &#060; | < | 92 | 5C | 134 | &#092; | \ | 124 | 7C | 174 | &#124; | \| |
| 29 | 1D | 035 | Group Separator | 61 | 3D | 075 | &#061; | = | 93 | 5D | 135 | &#093; | ] | 125 | 7D | 175 | &#125; | } |
| 30 | 1E | 036 | Record Separator | 62 | 3E | 076 | &#062; | > | 94 | 5E | 136 | &#094; | ^ | 126 | 7E | 176 | &#126; | ~ |
| 31 | 1F | 037 | Unit Separator | 63 | 3F | 077 | &#063; | ? | 95 | 5F | 137 | &#095; | _ | 127 | 7F | 177 | &#127; | Del |

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# For More Characters, Use Unicode

There are plenty of characters that aren't available in ASCII (characters from non-English languages, advanced symbols, emoji...).

The Unicode system represents every character that can be typed into a computer. It uses up to 5 bytes, which can represent up to 1 trillion characters!

Find all the Unicode characters here: [www.unicode-table.com](www.unicode-table.com)

# Sidebar: Fun Facts

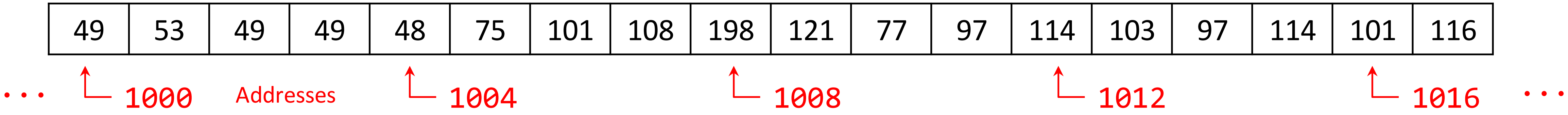
**Fun Fact #1:** .txt and .py files are encoded using just ASCII (or Unicode). But .docx and .pdf files have extra encoding information, since they are more than just text.

**Fun Fact #2:** the Unicode Consortium gets to decide which new Emoji are added to the table. Anyone can submit a request for a new Emoji!

# Computer Memory is Stored as Binary

Your computer keeps track of saved data and all the information it needs to run in its **memory**, which is represented as binary. You can think about your computer's memory as a really long list of bits, where each bit can be set to 0 or 1. But usually we think in terms of bytes, which are groups of 8 bits.

Every byte in your computer has an **address**, which the computer uses to look it up.



| | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 49 | 53 | 49 | 49 | 48 | 75 | 101 | 108 | 198 | 121 | 77 | 97 | 114 | 103 | 97 | 114 | 101 | 116 |

# Binary Values Depend on Interpretation

When you open a file on your computer, the application reads the associated binary and **interprets** the binary values based on the file encoding it expects.

You can attempt to open **any file** using **any program**, if you change the filetype extension to fool the program. Some programs may crash, and others will show nonsense, because the binary isn't being interpreted correctly.

**Example:** try changing a .docx filetype to .txt, then open it in a plain text editor.

# We Use Lots of Bytes!

In modern computing, we use a **lot** of bytes to represent information.

**Smartphone Memory:** 64 gigabytes = 64 **billion** bytes

**Google databases:** Over 100 million gigabytes = 100 **quadrillion** bytes!

**CMU Wifi:** 15 **million** bytes per second

# Sidebar: Compression Reduces Size

Transferring bytes between computers takes time. To save time, we often apply **compression algorithms**, which reduce the number of bytes needed to represent a thing. This can be done in two ways: lossless or lossy.

In **lossless** compression, no information is lost. When you undo the compression, you get back exactly the same data as the original version. This is done by mapping short keys to longer patterns.

Images, videos, and music often use **lossy** algorithms to get much greater compression, to as little as 10% of the original size! These algorithms reduce information by removing details that we can't perceive. However, adding more compression reduces the quality of the image, video, or audio recording.

JPEG (images), MPEG (video), and MP3 (audio) are common file formats that use lossy compression. GIF files use lossless compression.

# Learning Objectives

- Understand how different **number systems** can represent the same information

- Translate **binary numbers** to decimal, and vice versa

- Interpret binary numbers as abstracted types, including **colors** and **text**

- **Feedback form: https://bit.ly/110-feedback**