Digital Representation of Information

Digital encoding of information means the data is stored in discrete units -- effectively numbers -- and it is contrasted with analog encoding which uses a physical quantity, e.g. charge, varying over a continuous range. Digital is better.
How Digital Works

- The physical world is analog -- sound comes from pushing air with a certain energy at a certain rate, etc
- By measuring a phenomenon one derives a value (number) of the phenomenon at that moment
- Sampling -- taking many measurements at uniform intervals -- gives a series of numbers, the digital form

Digital audio:
44,100 sample/s
2 bytes/sample
2 channels, L&R
176,400 B/s
635 MB/hour

0.0 .8 .7 0 -.8 -.9 -.2 .8 .9 .2 -.7 -1 -.4 .6 1 .4 -.5 -1 -.5 .4 …
Digital Data

- Digital samples capture the basic structure of analog data, but it can be inaccurate due to limited precision.

- Or sampling rate

Low rate

High rate
Two Advantages of Digital Data

- A computer can “compute on” digital data, enhancing it to remove noise, artifacts of imprecision, etc.

- Digital data can be transmitted and replicated exactly
  - The numbers are the complete representation of data
  - Assuring each number is duplicated or transmitted accurately, means the data is exact

\[0.8 0.7 0.8 0.9 0.2 0.8 0.9 0.2 0.7 1.1 0.4 0.6 1.4 0.5 1.5 1.5 4\ldots\]
\[0.8 0.7 0.8 0.9 0.2 0.8 0.9 0.2 0.7 1.1 0.4 0.6 1.4 0.5 1.5 1.5 4\ldots\]
Some Information Is Discrete

- Keyboard characters can be represented exactly
- Imagine you and your friend are prohibited from talking -- it's too noisy? -- and so you use dice to encode the letters and punctuation to communicate

With two dice there are $6 \times 6 = 36$ encodings, not enough for 26 letters, 10 numerals and punctuation. Three dice would give $6 \times 6 \times 6 = 216$ representations, too many. So, you dump the numerals. Order matters: row then col!
Character Encodings

- Keyboard characters are encoded into a byte or two
- ASCII is one of many encodings of the characters
- A byte (8 bits) permits 256 things to be represented

ASCII, pronounced AS·key, stands for American Standard Code for Information Interchange
Encoding The Number

- Information is often stored by charge or magnetic field
  Schematic diagram of magnetic spots, say on a disk

- Its presence or absence can be detected, leading to a natural association with 1 and 0 to the states, motivating the use of binary numbers

Binary is counting on your fists instead of your fingers
Decimal and Binary

- **Decimal**
  - Symbols: 0, 1, …, 9
- **Binary**
  - Symbols: 0, 1

**Base**

- **Decimal**: 10
- **Binary**: 2

**Number xyz**

- **Decimal**: \(x \cdot 10^2 + y \cdot 10^1 + z \cdot 10^0\)
- **Binary**: \(x \cdot 2^2 + y \cdot 2^1 + z \cdot 2^0\)

**Ex: 101**

- **Decimal**: \(1 \cdot 10^2 + 0 \cdot 10^1 + 1 \cdot 10^0\)
- **Binary**: \(1 \cdot 2^2 + 0 \cdot 2^1 + 1 \cdot 2^0\)

**Place Value**

- **101**: 5

**Powers**

- **Decimal**: 1, 10, 100, 1000, …
- **Binary**: 1, 2, 4, 8, 16, 32, 64, …

**What binary numbers are:** 1000₂, 1010₂ and 1111₂

- Use a subscript to indicate the number base, e.g. \(5_{10} = 101_2\)

Binary works just like decimal, except that the base is 2.
Adding Is Familiar

- To add in binary use the same technique (algorithm), but restrict yourself to 0 and 1 … everything else works the same way

\[
\begin{array}{cccc}
1 & 1 & 0 & 0 \\
1 & 1 & 0 & 1 \\
1 & 1 & 0 & 1 \\
\end{array}
\begin{aligned}
11 & 0 & 1 & 1 & 0 & 1 \\
11 & 1 & 0 & 1 & 0 & 1 \\
11 & 0 & 1 & 1 & 0 & 1 \\
\end{aligned}
\begin{array}{c}
1 \\
51 \\
58 \\
109 \\
\end{array}
\]

- Binary is pretty tedious for humans because there are so many digits … circuitry benefits however because it uses the two states (on/off) efficiently

A sequence of b bits can represent \(2^b\) things, e.g. 0 to \(2^b-1\)
Picture Elements (Pixels)

- The phosphor on the screen naturally displays the on/off property of binary
  - Suitable for one color (B&W) video
  - The bits in memory are streamed out on the screen in “raster” order, like a standard TV
- For a color display, three (basic) colors of light must be displayed: red, green and blue (RGB)
  - Requires three different numbers, e.g. one byte each
  - Range of colors is determined by the intensity of each component
  - When all three values are at their maximum, the color is white, and when they are at their minimum the color is black
Color Control

- Select the color palette from an application and play
- Notice when values are equal -- gray results
The way that bits represent information is determined by how we interpret the bits …

As separate bytes these are: 104, 181, 56
As ASCII these bytes are: h, ₪, 7
As a 24 bit integer these bytes are: 6,862,136
As a color value the bytes are

The bytes can be interpreted in an unlimited number of ways
Digital representation can be faithfully replicated and transmitted

It’s common to “compute” on a digital representation

The binary digits (bits) 0 and 1 are a natural way to interpret the presence or absence of a phenomenon

Binary numbers and arithmetic are like decimal except they are limited to the two numerals 0 and 1

Bits are bits -- what they mean depends on how we interpret their meaning … sometimes they are numbers, sometimes letters, sometimes sound, sometimes color, ...