Chapter 1. Digital Data Representation and Communication

Part I

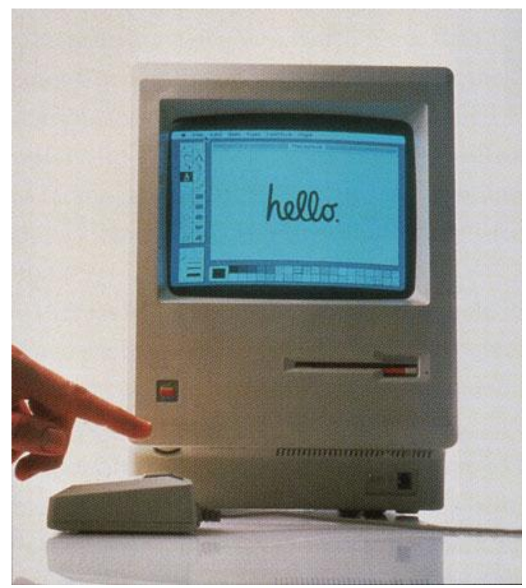
Department of Computer Science
National Tsing Hua University

Introduction

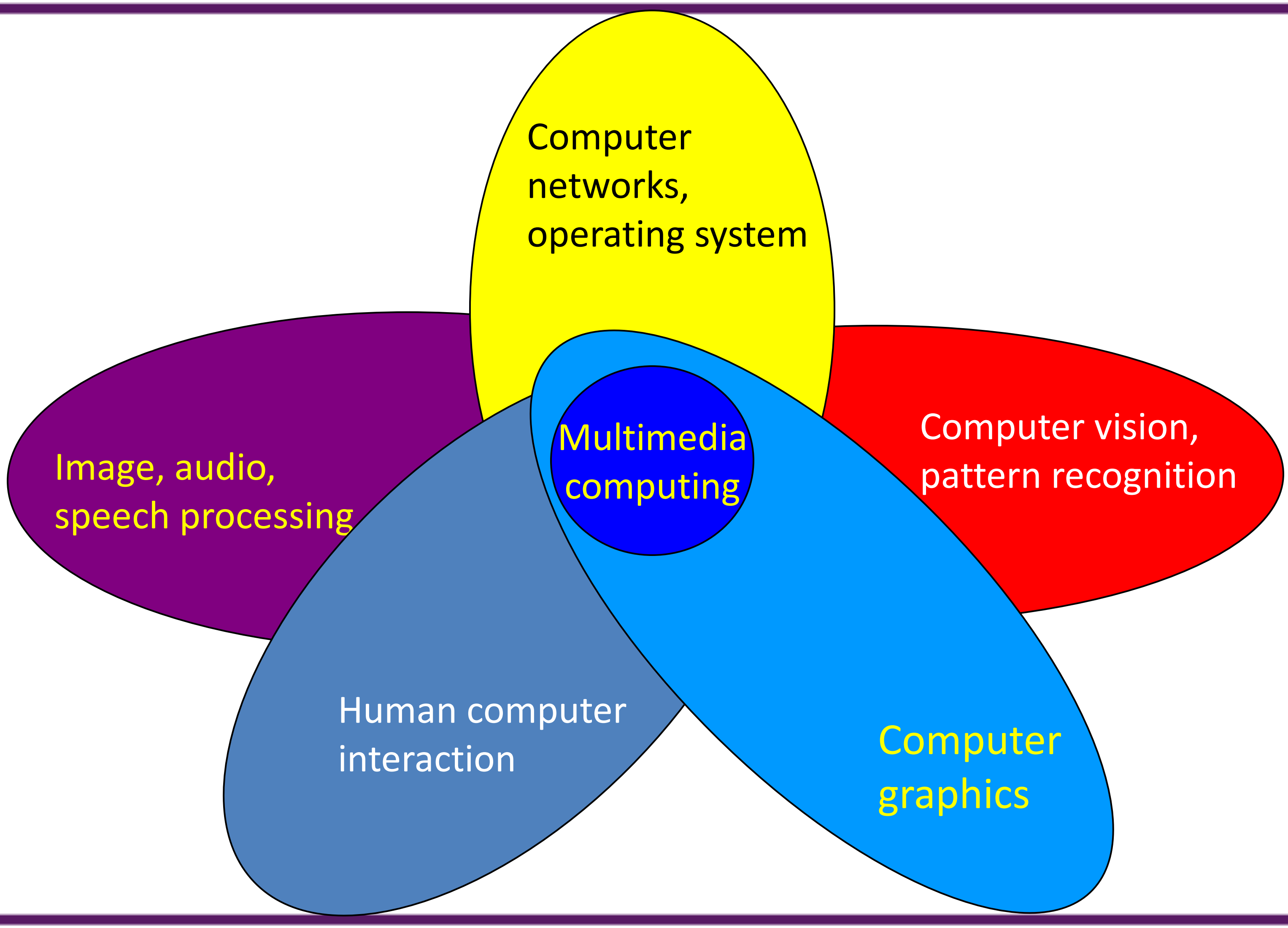
- Digital media is multimedia driven by computers. You can see it, hear it, maybe even touch it, and certainly interact with it.
- What draws most people to a study of digital media is the satisfaction of making something that communicates, entertains, or teaches.
- We consider the topics in digital media work—choosing color modes, compressing files, identifying aliased frequencies, filtering, transforming, and creatively editing.
- We present the mathematical and algorithmic procedures upon which the tools are built.

What is Multimedia?

- "Multimedia" has no strict definition.
- In our context, multimedia indicates the computer technology (multimedia computing) for more efficient communication by using different media types:
  - Text
  - Audio and speech
  - Images
  - Graphics
  - Video



Multimedia is Multidisciplinary



Example Multimedia Systems

Chronoscope: Musée d'Orsay

The *Chronoscope* application spreads out an artist's works on a timeline. Paintings by different artists of the same period can be studied side-by-side to explore the cross-fertilization of ideas. Based on impressionist paintings from 1848 to 1914, in the collection of the *Musée d'Orsay* in Paris, France. Interface: Matthew Hodges. Content: Musée d'Orsay, Paris, France.

Chronoscope in MIT's Project Athena

Example Multimedia Systems

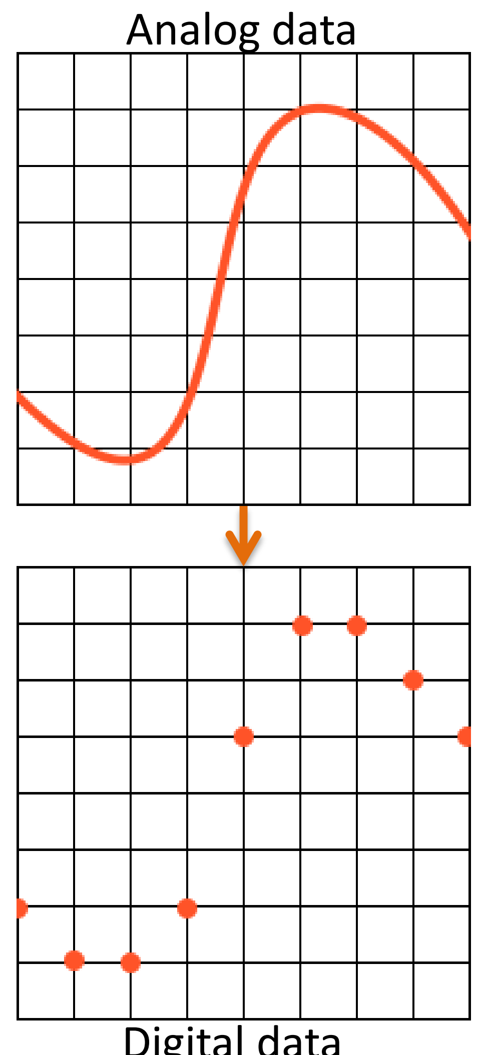
Navigation Learning Environment

The *Navigation Learning Environment* is a complex simulation designed to teach the basics of coastal navigation with "surrogate travel" techniques. The software can render a view in any direction from the pilot's perspective, using a database of 360-degree panoramas. Maps and charts help to set a course, while a throttle control determines the rate at which the boat's position is updated. Interface and content: Matthew Hodges.

Navigation Learning Environment in MIT's Project Athena

Analog and digital data

- Analog data
  - Takes on continuous values
  - E.g. voice, video
- Digital data
  - Takes on discrete values
  - E.g. text, integer
- Converting the continuous phenomena of images, sound, and motion into a discrete representation that can be handled by a computer is called ***analog-to-digital conversion***.

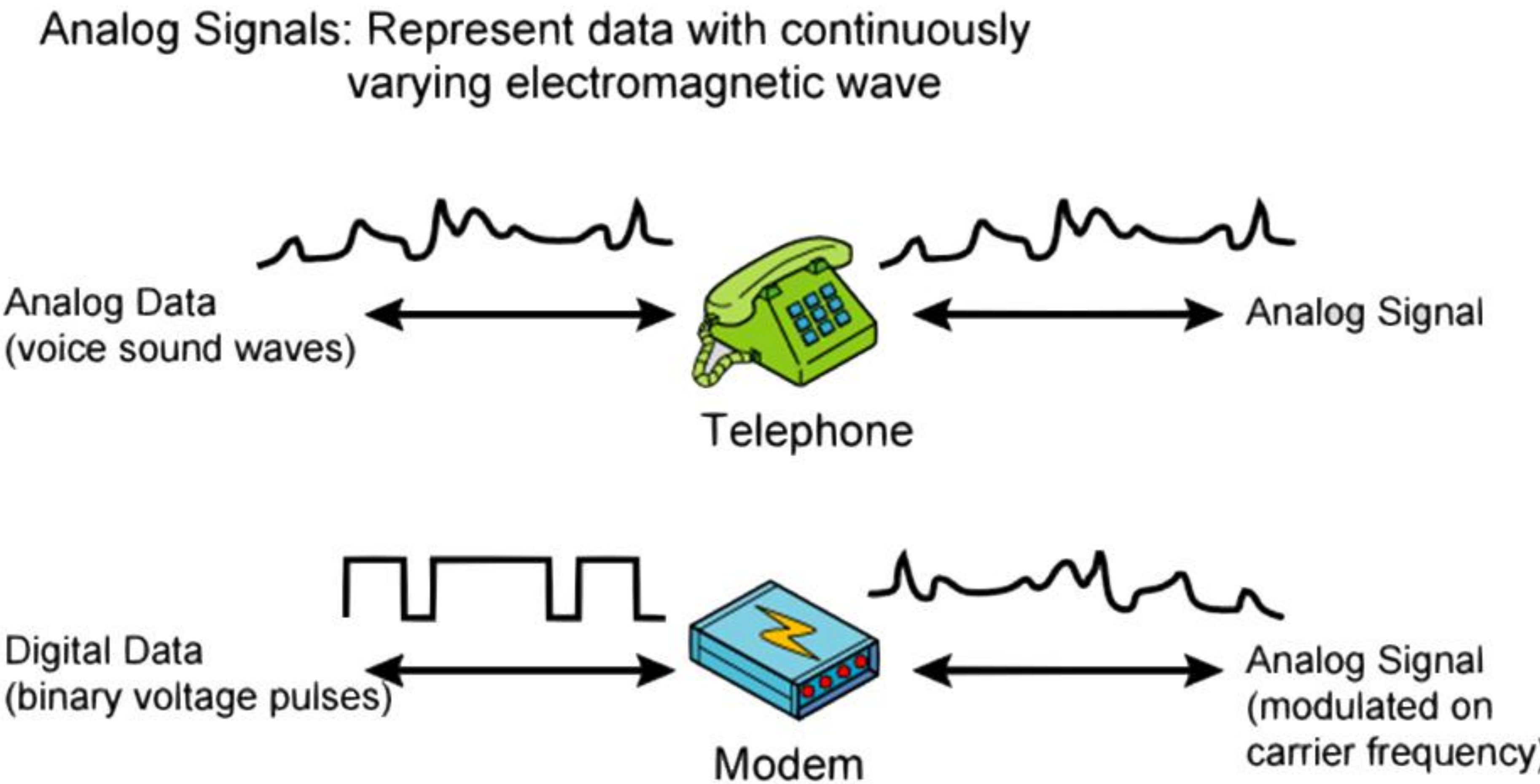


Analog data compared with digital data

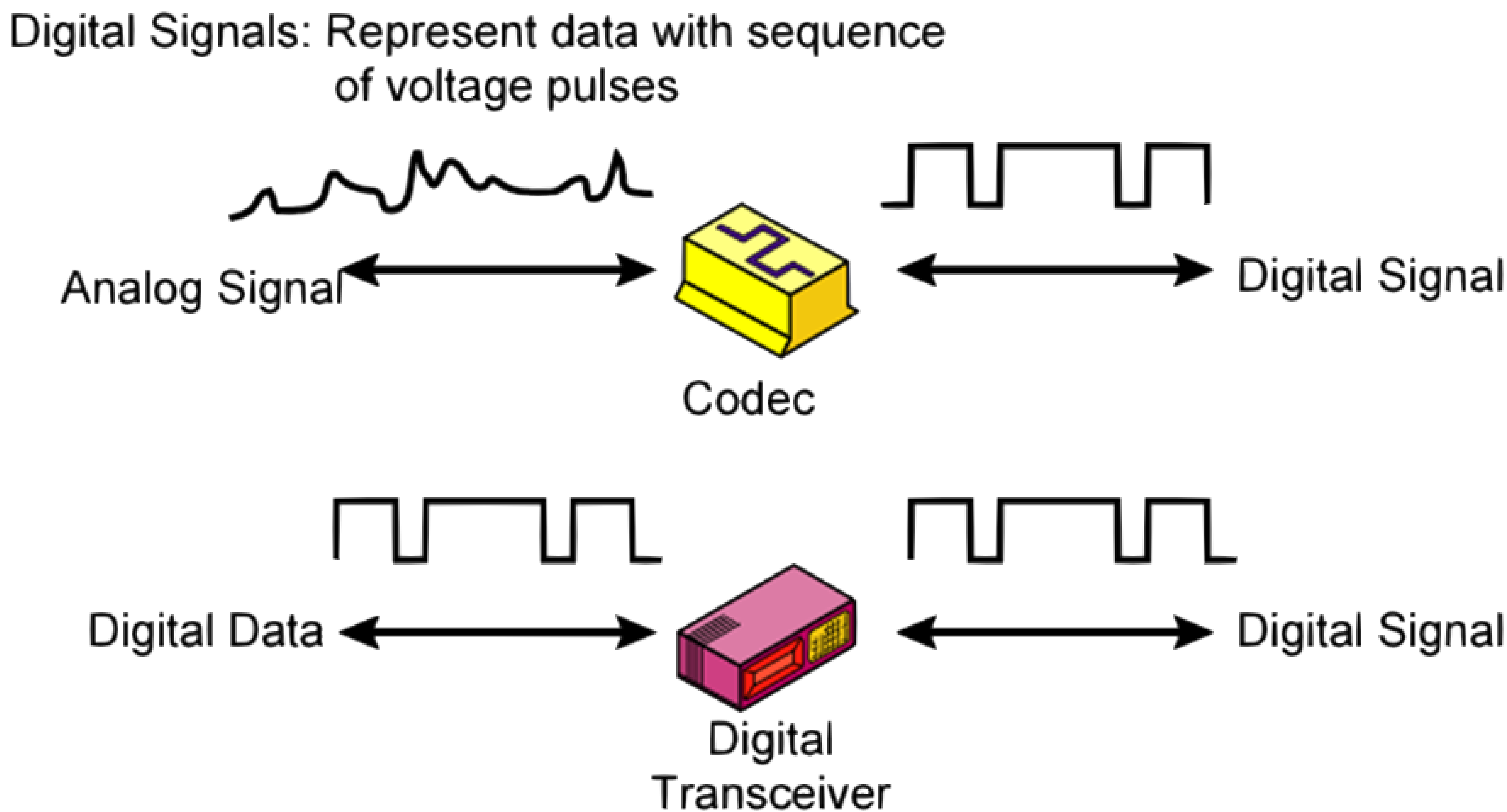
- Analog data > digital data
  - More information -> more precise and better quality
- Digital data > Analog data
  - Size -> communicated more compactly
  - Reliably -> less affected by noise when transmitted

- **Computers** can **only** work with **digital data**.

Analog Signals Carrying Analog and Digital Data

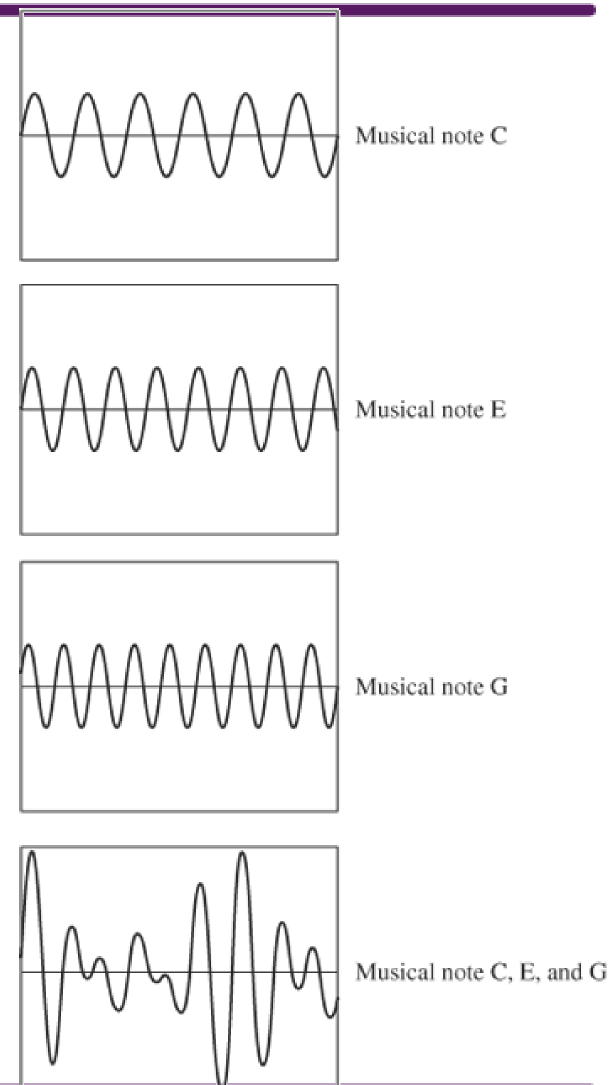


Digital Signals Carrying Analog and Digital Data

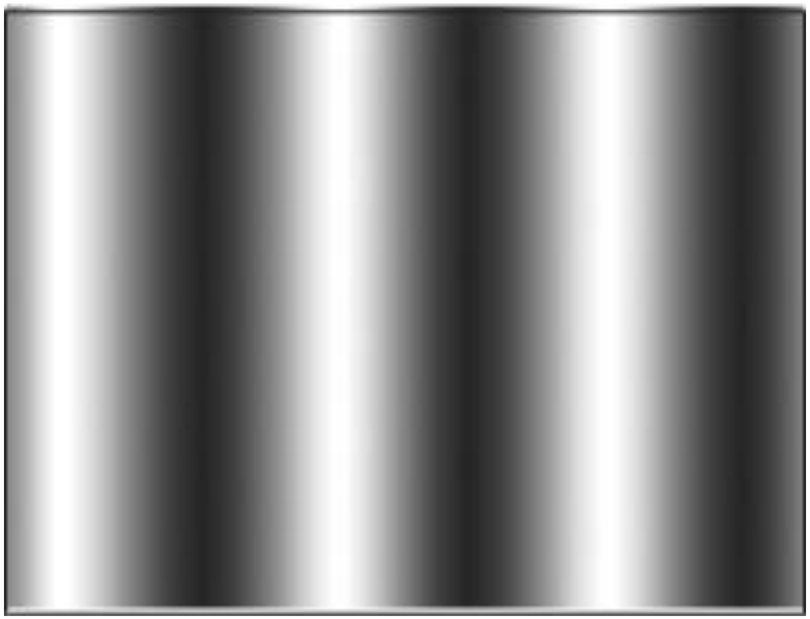


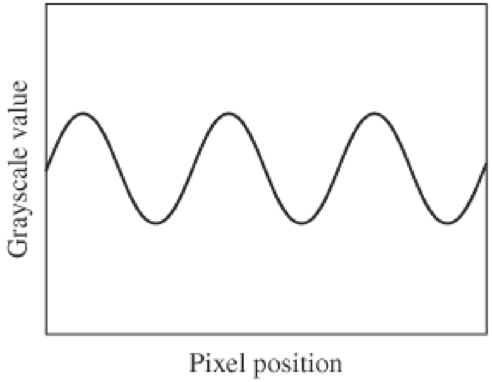
Fourier transform

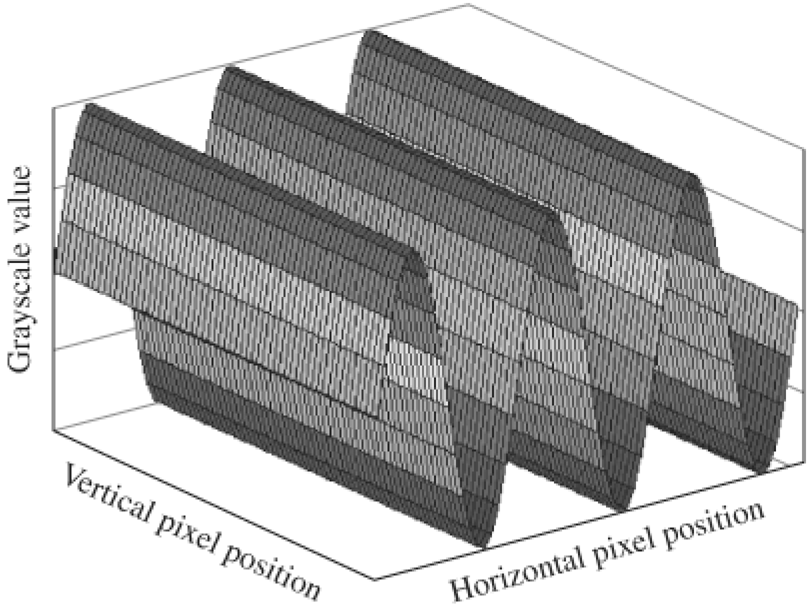
- Fourier analysis shows that any periodic signal can be decomposed into an infinite sum of sinusoidal waveforms.
- Fourier transform makes it possible to store a complex sound wave in digital form, determine the wave's frequency components, and filter out components that are not wanted.



An example of grayscale image





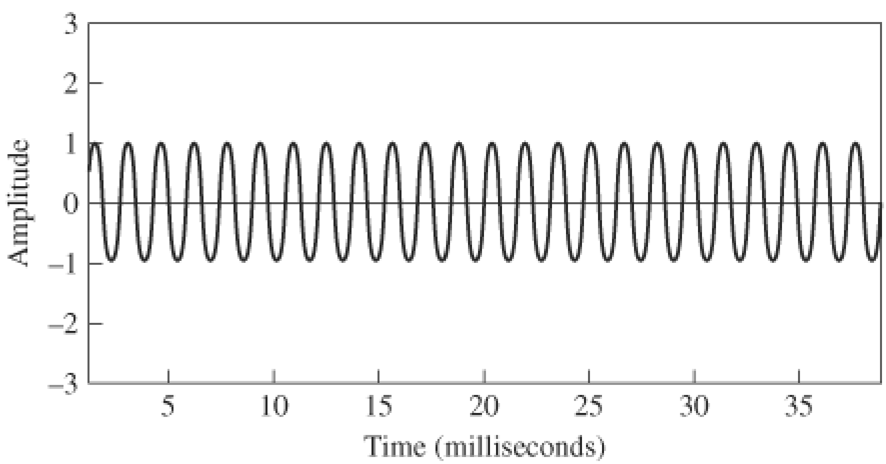


A/D Conversion

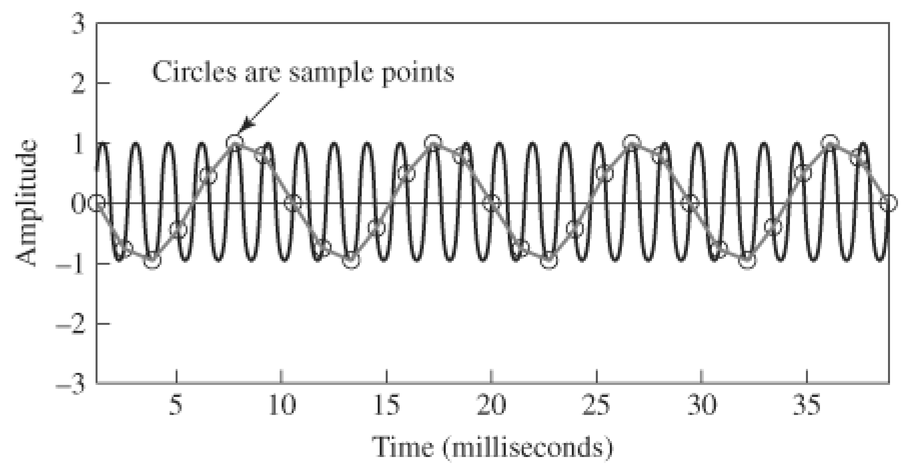
- Analog-to-digital conversion requires two steps: ***sampling*** and ***quantization***.
- The first step, sampling, chooses discrete points at which to measure a continuous phenomenon (***signal***).
- For images, the sample points are evenly separated in space. For sound, the sample points are evenly separated in time.
- The number of samples taken per unit time or unit space is called the ***sampling rate*** or, alternatively, the ***resolution***.
- The second step, quantization, requires that each sample be represented in a fixed number of bits, called the ***bit depth***. The bit depth limits the precision with which each sample can be represented.

Sampling and Aliasing

- ***Undersampling:*** sampling rate does not keep up with the rate of change in the signal.
- ***Aliasing*** in a digital signal arises from undersampling and results in the sampled discrete signal cannot reconstruct the original source signal.



Audio wave at 637 Hz



637 Hz audio wave sampled at 770 Hz

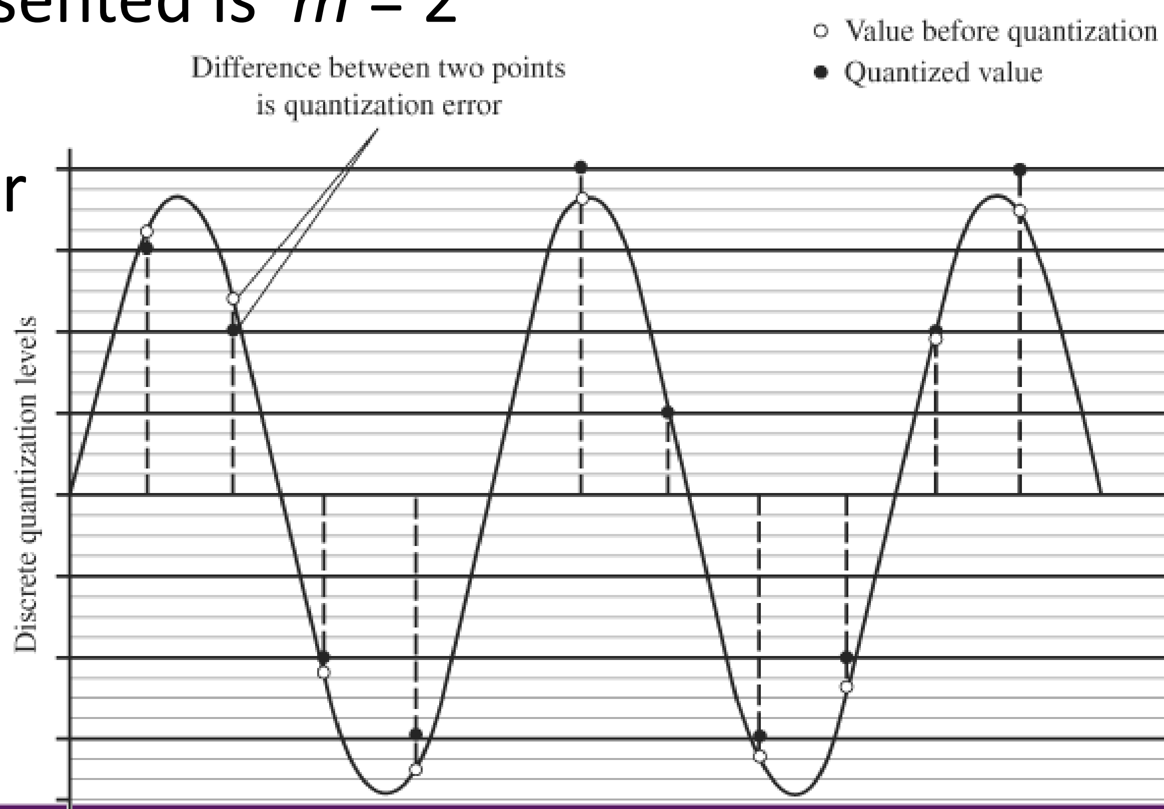
Nyquist theorem

- The Nyquist theorem specifies the sampling rate needed for a given spatial or temporal frequency.
- To guarantee that no aliasing will occur, you must use a sampling rate that is greater than twice the maximal frequency in the signal being sampled.
- Let f be the frequency of a sine wave. Let r be the minimum sampling rate that can be used in the digitization process such that the resulting digitized wave is not aliased. Then the ***Nyquist frequency*** r is

$$r = 2f$$

Quantization

- Let n be the number of bits used to quantize a digital sample. Then the maximum number of different values that can be represented is $m = 2^n$
- Quantization error



SNR and SQNR

- Signal-to-noise ratio (SNR) can generally be defined as the ratio of the meaningful content of a signal versus the associated noise.
- In analog data communication, SNR is defined as the ratio of the average power in the signal versus the power in the noise level.
- For a digitized signal, the signal-to-noise ratio is defined as the ratio of the maximum sample value versus the maximum quantization error. This can also be called ***signal-to-quantization-noise ratio*** (***SQNR***)

SQNR and Dynamic Range

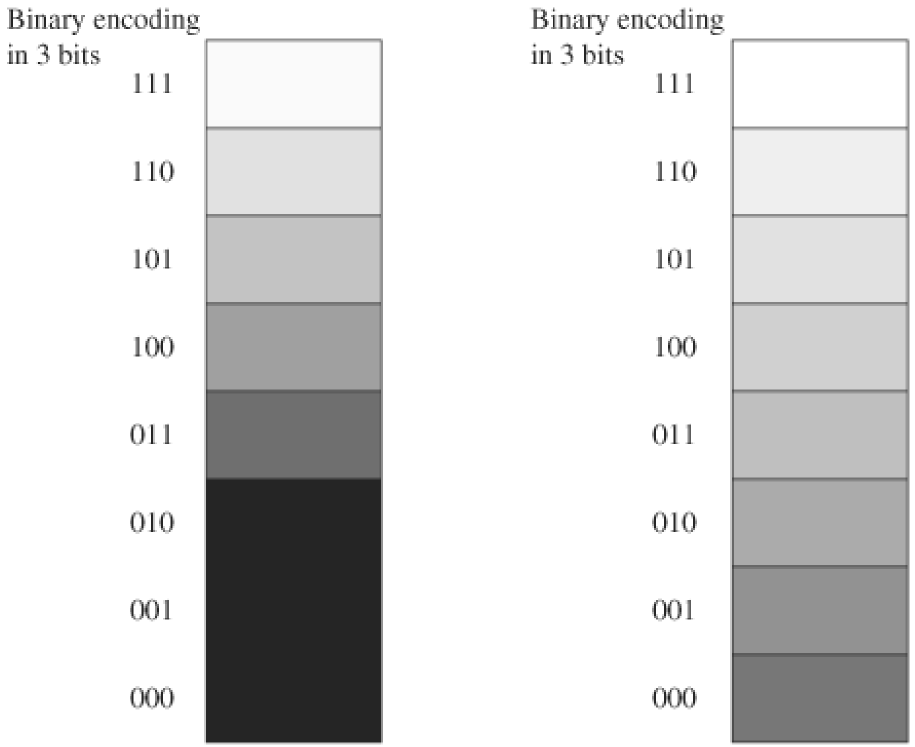
- Let *n* be the bit depth of a digitized media, Then the ***SQNR*** is

$$SQNR = 20 \log_{10}(2^n) \quad \text{(in dB)}$$

- Signal-to-quantization-noise ratio is directly related to ***dynamic range***.
- Dynamic range, informally defined, is the ratio of the largest-amplitude sound (or color, for digital images) and the smallest that can be represented with a given bit depth.

Dynamic Range

- With three bits, you have eight colors. You can spread these colors out over a wide range or a narrow range.
- In either case, the dynamic range is the same, dictated by the bit depth, which determines the maximum error possible (resulting from rounding to available colors) relative to the range of colors represented.



The image of Barbara

Aliasing due to sampling