EBU5303

Multimedia Fundamentals

Digitisation

Agenda

- Sound and images are analogue phenomena that can be represented by complex waveforms
- They must be digitised to be handled by computers: sampling and quantisation
- Sampling and quantisation rates determine the size of the digitised data

Reading

http://burg.cs.wfu.edu/TheScienceOfDigitalMedia/Chapter1/Ch1ScienceOfDigitalMedia.pdf

1.2 Analog to Digital Conversion

1.3 Data Storage

Learning Objectives (digitisation)

- Understand the difference between analog and discrete phenomena.
- Understand how images and sound can be represented as sinusoidal waveforms.
- Understand how sinusoidal functions can be summed to create more complex waveforms.
- Understand how undersampling leads to aliasing.
- Understand how quantisation leads to quantisation error.
- Understand and be able to apply the equation for signal-to-noise ratio.
- Be able to calculate the storage space needed for digital images, audio, and video files given basic parameters.
- Know the storage capacity of common storage media.

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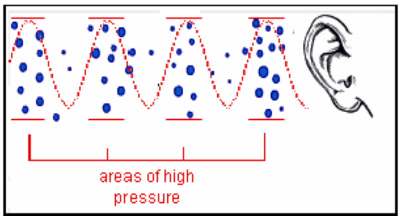
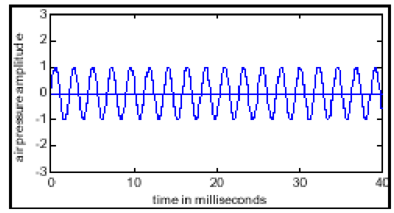
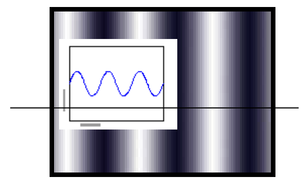
Analogue versus discrete phenomena

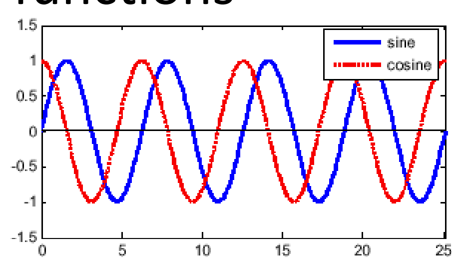
Sound and images in the analogue domain







Sinusoidal functions



- cycle
- wavelength (m)
- f = frequency (Hz)
- T = period (s) = 1/f
- A = amplitude
- ω = angular frequency (rad/s) = $2\pi f$
- ϕ = phase

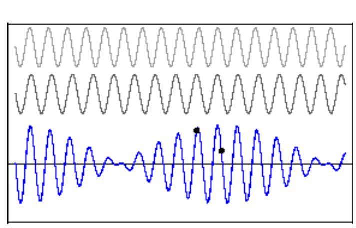
$$s(t) = A \sin(\omega t + \phi)$$

Exercise

What is the sine function representing a sound wave with a frequency of f = 440 Hz?

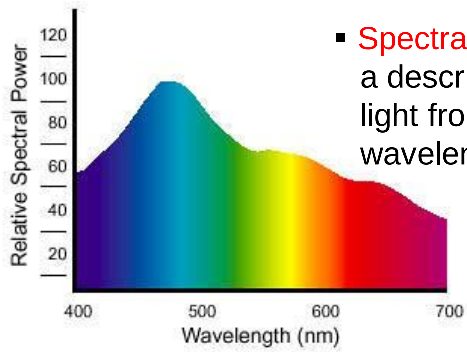
Complex Waveforms

- Most waveforms are complex, i.e. their shape is the result of adding 2 or more waveforms.
- Each complex waveform may be described as the sum of a number of simple sine waves, each with a particular amplitude, frequency (or wavelength) and phase.



Example: Visible Light

- The wavelengths of visible light lie roughly between 400 nm and 700 nm.

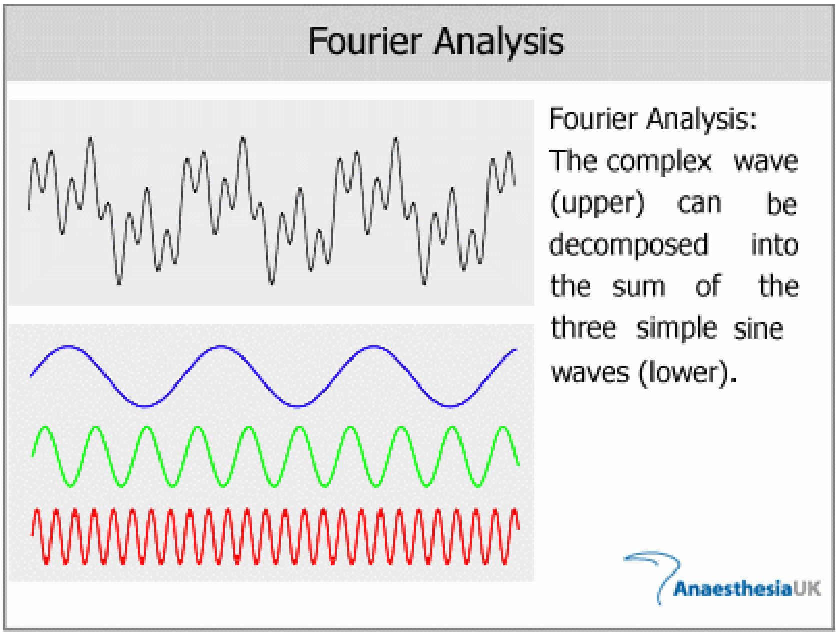


- Spectral Power Distribution (SPD): a description of how the intensity of light from some source varies with wavelength.

Fourier analysis

- Fourier analysis attempts to represent a set of data with a series of sines and cosines with different periods, amplitudes, and phases.
- This representation is done by a mathematical process called a transform : the data measurements in the time domain are *transformed* into the period or frequency domain.

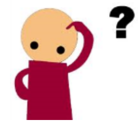
$$F(\nu) = \int f(t) exp(i2\pi\nu t) dt$$



Summary so far …

- Sound and light (colours and images) are analogue phenomena
- They can be represented by complex waveforms
- Individual components (sine waves) can be extracted from a complex waveform by Fourier analysis

Questions…



- What kind of sound is represented by a completely regular sine wave ?
- What does the frequency of a wave tell us about the sound it represents ?
- What does the amplitude of a wave tell us about the sound it represents ?
- What information is contained in the wavelength of a light ray ?

Agenda

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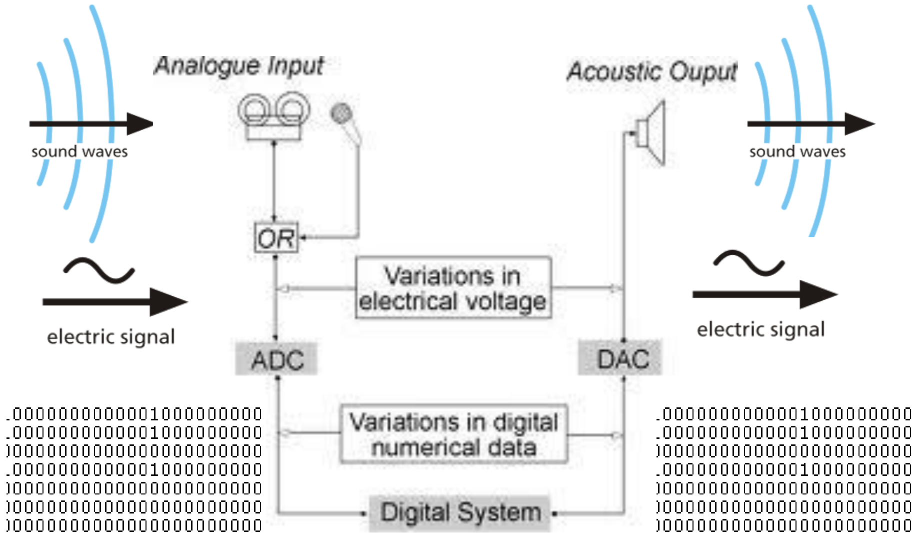
Analogue-to-digital conversion



Analogue-to-digital conversion

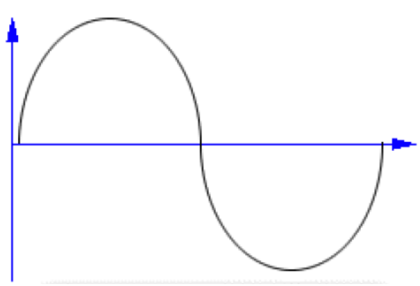
= converting the continuous phenomena of images, sound, and motion into a discrete representation that can be handled by a computer.

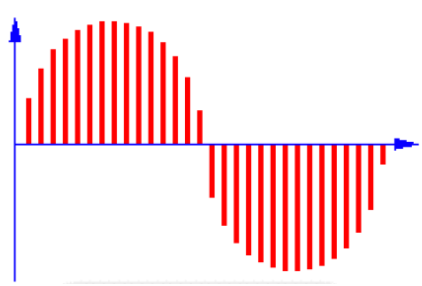
- Digitised pictures and sound can now be captured in fine detail.
- Digital data communication is less vulnerable to noise than is analogue.
- Digital data can be communicated more compactly than analogue… when compressed!

Sampling

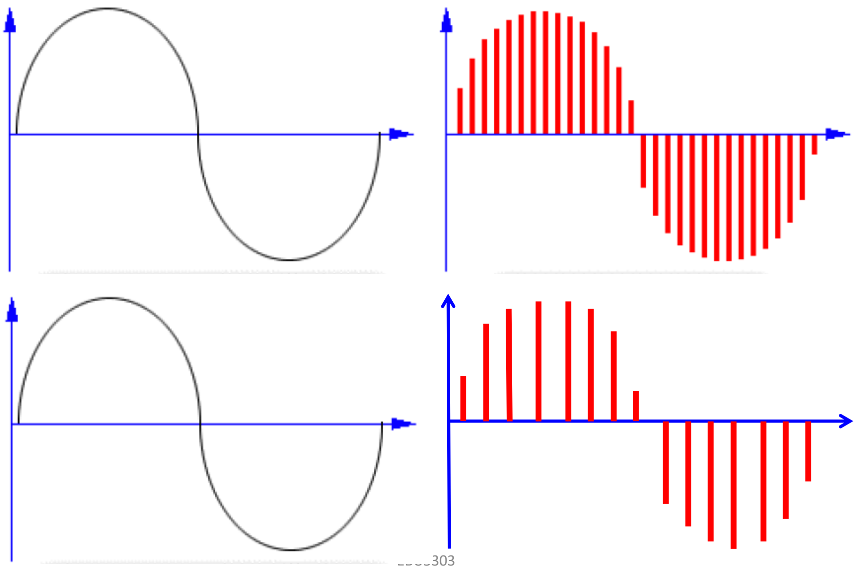
- Sampling chooses discrete points at which to measure a continuous phenomenon (a *signal*).
- In the case of images, the sample points are evenly separated in space.
- In the case of sound, the sample points are evenly separated in time.
- The number of samples taken per unit time or unit space is called the ***sampling rate.***

Sampling





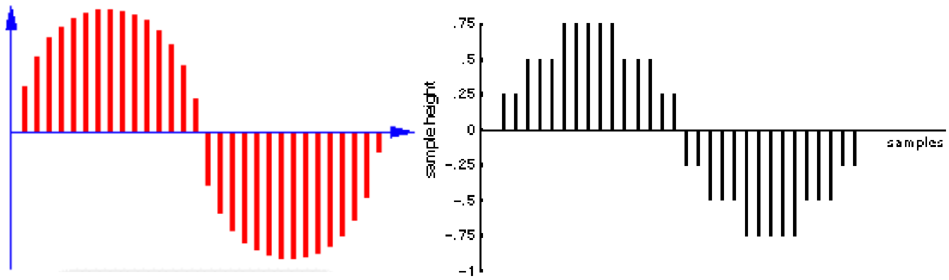
Sampling



Quantisation

- Quantisation requires that each sample be represented in a fixed number of bits, called the ***sample size*** or the ***bit depth***.
- In the case of an image, the bit depth is called the ***color depth****.*
- The bit depth limits the precision with which each sample can be represented.

Quantisation

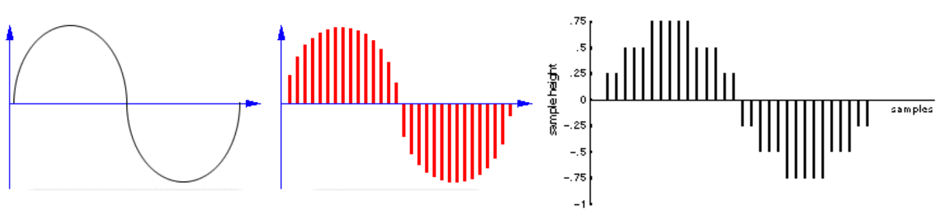


Let *n* be the number of bits used to quantize a digital sample. Then the maximum number of different values that can be represented, m, is

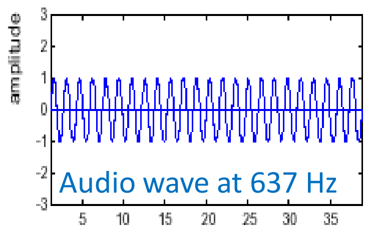
$$m = 2^n$$

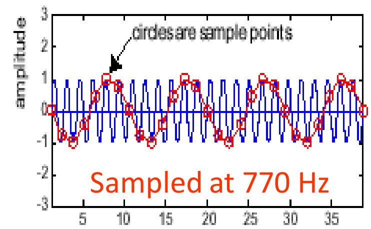
Sampling + Quantisation

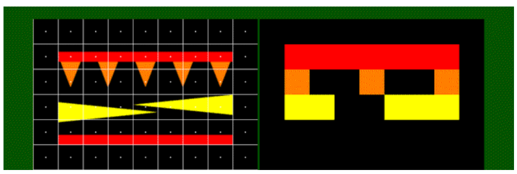
- The sampling rate relates directly to the frequency of a wave.
- Quantization, on the other hand, relates more closely to the amplitude of a wave.

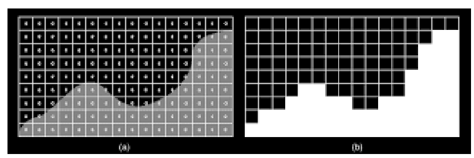


Aliasing (sampling error)









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Nyquist theorem

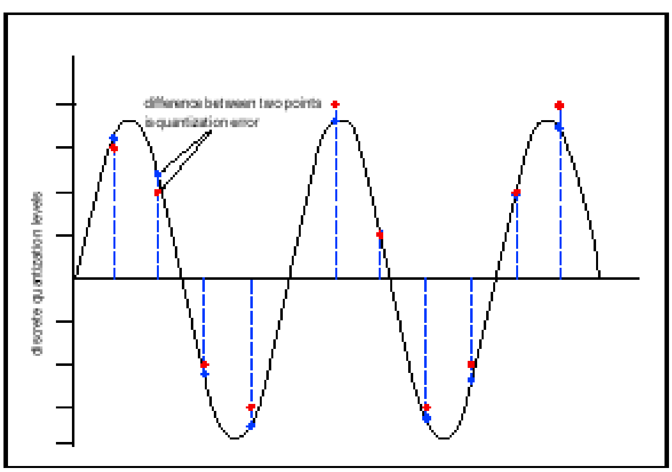
Sample twice as often as the highest frequency you want to capture

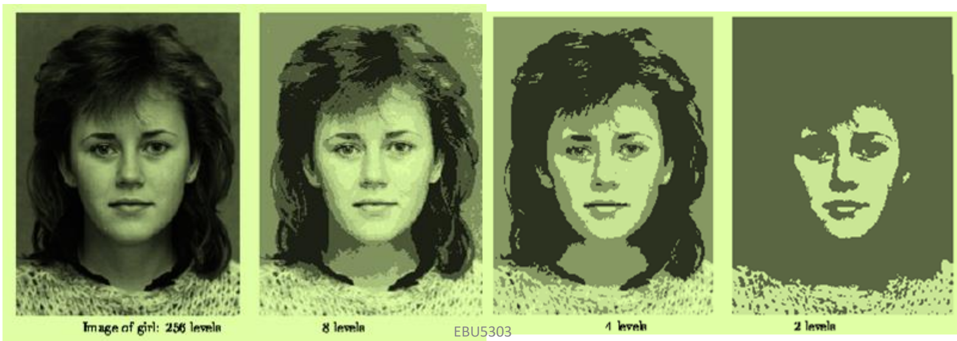
Let *f* be the frequency of a sine wave. Let *r* be the minimum sampling rate that can be used in the digitisation process such that the resulting digitised wave is not aliased. Then:

$$r = 2\,f$$

r is called the ***Nyquist rate***.

Quantisation error





Signal to Noise Ratio (SNR)

- SNR: 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 digitised image or sound, SNR, also called ***signal-to-quantisation-noise ratio*** (***SQNR***), is defined as the ratio of the maximum sample value versus the maximum quantisation error.

$$SQNR = 20 \log_{10}\left(\frac{\max(quantization\ value)}{\max(quantization\ error)}\right)$$

SQNR

- SQNR is measured in decibels.
- SQNR is directly related to ***dynamic range:*** the ratio of the largest sound amplitude (or color, for images) and the smallest that can be represented with a given bit depth.

Let *n* be the bit depth of a digitised media file (e.g. digital audio). Then the signal-to-quantisation noise ratio ***SQNR*** is:

$$SQNR = 20 \log_{10}(2^n)$$

Summary so far …

- Analogue sounds and images must be digitised
- Digitisation includes two processes: sampling and quantisation
- Undersampling causes aliasing (the original data cannot be reproduced)
- Quantisation errors cause loss of details and determine the Signal to Quantisation Noise ratio
- The Nyquist theorem helps us choose an adequate sampling rate

Exercise

If you are recording an audio file and you expect that the highest frequency in the file will be 10,000 Hz, what is the minimum sampling rate you should use to ensure that you will not get audio aliasing?

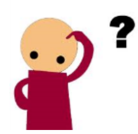
Exercise

The number of possible colours in an image is determined by the quantisation rate. How many different colours can be represented with 12 bits?

Exercise

Prove that, if we double the number of bits used to hold a quantised value, then we square the number of quantisation levels.

Question



You have a digital image in 8 bit colour which lacks the subtle gradations from one colour to the next that you would like to see. Is this a matter of aliasing or quantisation error? Explain.

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Data size (example): audio file

Sampling rate: 44.1 kHh (44,100 samples/s)
Quantisation rate: 32 bits per sample (16 for each of two stereo channels)
Number of minutes: 1 minute
Total number of bits:

44,100 * 32 * 60 = 84,672,000 bits
84,672,000 bits = 10,584,000 bytes

File size: ~ 10.58 Mbytes for 1 minute
Data rate of the file: ~ 1.41 Mbits/s

Data size : image file

Example:
Sampling: 1024 pixels x 768 pixels (samples)
Bits per pixel: 24

1024 x 768 = 786,432 pixels
786,432 x 24 = 18,874,368 bits

18,874,368 / 8 = 2,359,296 bytes
File size ~ 2.36 MB

Data size : video file

Sampling: 720 pixels x 480 pixels
Bits per pixel: 24
Frame rate : 30 frames/s
Length: 1 minute
Audio : 44,1 KHz, 32 bits

pixels per frame : 720 x 480 = 345,600 pixels
bits per frame : 345,600 x 24 = 8,294,400 bits
Video images size/s : 8,294,400 x 30 = 248,832,000 bits
Total video image size : 248,832,000 x 60 = 14,929,920,000 bits

Data size : video file

Sampling: 720 pixels x 480 pixels
Bits per pixel: 24
Frame rate : 30 frames/s
Length: 1 minute
Audio : 44,1 KHz, 32 bits

Audio size/s : 44,100 x 32 = 1,411,200 bits
Total audio size : 1,411,200 x 60 = 84,672,000 bits

Total video size : images + audio = 15,014,592,000 bits
File size ~ 1.88 GB !!!

Storage Media

Storage medium	Maximum capacity
Portable Media	
CD (Compact Disk)	700 MB
DVD (Digital Versatile Disc or Digital Video Disk), standard one sided	4.7 GB standard; 8.5 GB dual-layered
DVD video or high capacity	17–27 GB
Memory stick or card	8 GB
HD-DVD (High Definition DVD), standard one-sided	15 GB standard; 30 GB dual-layered
Blu-ray Disk	25 GB standard; 50 GB dual-layered
Flash drive	64 GB
Permanent Media	
Hard disk drive	1 terabyte (1000 GB)

Exercise

Compute the number of bytes needed for 1 minute of video that has 720 x 576 pixels per frame, 25 frames per second, 3 bytes per pixel, and CD-quality stereo audio.

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