Sensors

- Static monocular reflectance data (monochromic or color)
  - Films
  - Video cameras (with tapes)
  - Digital cameras (with memory)
- Motion sequences (camcorders)
- Stereo (2 cameras)
- Range data (Range finder)
- Non-visual sensory data
  - infrared (IR)
  - ultraviolet (UV)
  - Microwaves
- Audio
- Inertial
- Many more
The Electromagnetic Spectrum

- The whole electromagnetic spectrum is used by “imagers”

The Human Eye

Source: National Eye Institute.
Film, Video, Digital Cameras

- Black and White (Reflectance data only)
- Color (Reflectance data in three bands - red, green, blue)

Color Images

‘Dimensions’ of an Image
- Spatial (x,y)
- Spectra (number of components)
- Radiometric (number of bits/channel)
- Temporal (t)

Pixel
Across the EM Spectrum

Crab Nebula

Captions: Map of the distribution of positions towards the center of the Milky Way Galaxy, including the newly discovered outburst “cloud.” The brightest feature corresponds to the center of the Galaxy. The horizontal structure lies along the plane of the Galaxy. The outburst “cloud” is located above the galactic center.

Courtesy: B. B. Davis (University of California, Berkeley) and W. A. Forrest (Northwestern University)

Across the EM Spectrum

Mobile Vehicle and Cargo Inspection System (VACIS®)

Gamma rays are typically waves of frequencies greater than $10^{19}$ Hz

Gamma rays can penetrate nearly all materials and are therefore difficult to detect

Courtesy: Science Applications International Corporation (SAIC)
Across the EM Spectrum

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Courtesy: Science Applications International Corporation (SAIC)
Across the EM Spectrum

- Medical X-Rays

![Medical X-Ray Images]

Across the EM Spectrum

- From X-Ray images to 3D Models: CT Scans

![CT Scans Example]
Across the EM Spectrum

- Chandra X-Ray Satellite

Across the EM Spectrum

- Flower Patterns in Ultraviolet
Across the EM Spectrum

- Messier 101 (Pinwheel Galaxy) in Ultraviolet

- Traditional images
Across the EM Spectrum

- Non-traditional Use of Visible Light:

Across the EM Spectrum

- Scanning Laser Rangefinder
Across the EM Spectrum

• IR: Near, Medium, Far (~heat)
Across the EM Spectrum

- IR: Finding chlorophyll - the green coloring matter of plants that functions in photosynthesis

Across the EM Spectrum

- (Un)Common uses of Microwaves

CD Movie
Exploding Water Movie
Across the EM Spectrum

• Microwave Imaging: Synthetic Aperture Radar

San Fernando Valley

Tibet: Lhasa River

Athens, Greece

Thailand: Phang Hoei Range

Red: L-band (24cm)
Green: C-band (6 cm)
Blue:C/L

Across the EM Spectrum

• Radar in Depth: Interferometric Synthetic Aperture Radar - IFSAR

(elevation)

Yakutat Bay, Alaska
Across the EM Spectrum

• Low Altitude IFSAR

Across the EM Spectrum

• Radio Waves (images of cosmos from radio telescopes)
Stereo Vision

• Single Camera (no stereo)
Stereo Vision

Stereo Images

• A Short Digression
Stereo X-Ray

Mosaics

• A mosaic is created from several images
Mosaics

• Stabilized Video

Mosaics

• Depth from a Video Sequence (single camera)
Why is Vision Difficult?

- Natural Variation in Object Classes:
  - Color, texture, size, shape, parts, and relations
- Variations in the Imaging Process
  - Lighting (highlights, shadows, brightness, contrast)
  - Projective distortion, point of view, occlusion
  - Noise, sensor and optical characteristics
- Massive Amounts of Data
  - 1 minute of 1024x768 color video = 4.2 gigabytes (Uncompressed)

The Need for Knowledge
The Figure Revealed

The Effect of Context

THE CHT
The Effect of Context - 2

Context - Continue

• ….a collection of objects:
Context - Continue

• The objects as hats:

Context - Continue

• And as something else.....
Vision System Components

• …at the low (image) level, we need
  • Ways of generating initial descriptions of the image data
  • Method for extracting features of these descriptions
  • Ways of representing these descriptions and features
  • Usually, cannot initially make use of general world knowledge

Vision System Components

• …at the intermediate level, we need
  • Symbolic representations of the initial descriptions
  • Ways of generating more abstract descriptions from the initial ones (grouping)
  • Ways of accessing relevant portions of the knowledge base
  • Ways of controlling the processing
  • Intermediate level processes should be capable of being used top-down (knowledge-directed) or bottom-up (data-directed)
Vision System Components

- at the high (interpretation) level, we need
  - Ways of **representing** world knowledge
    - Objects
    - Object parts
    - Expected scenarios (relations)
    - Specializations
  - Mechanisms for **Interferencing**
    - Beliefs
    - Partial matches
  - **Control** Information
  - **Representations** of
    - Partial interpretations
    - Competing interpretations
    - Relationship to the image descriptions

Audio
Audio Signals

• Sound is created by the motion of air particles in space
• A microphone converts this motion into an electrical signal
• Remember the “hello” wave:

Properties of audio signals

• Audio signals have frequency components that are complex
  • In other words, most audio signals are made up of many different frequencies, combining to make the sound we recognize
  • The standard for human voice is taken to vary from about 100 Hz to 3000 Hz
  • Piano: Concert A above Middle C is 440 Hz
  • Lowest audible frequency for humans is around 20 Hz (a low, rumbling bass note)
  • Highest audible frequency is 20 kHz (beyond the range of most humans)
• Notice the faster rate at which the ear can detect stimulus changes compared to the eye (ear can detect rates up to 20,000 per second, eye can detect only 50 times per second)
• This needs to be taken into account when converting audio information into digital form—we need to use far more samples per second of information for audio

Period, Frequency & Amplitude

• Frequency (f), measured in Hertz (Hz) refers to the rate of repetition of the signal
  • If the frequency of a signal is 2Hz, then 2 cycles of the wave are completed per second
• Period, measured in seconds (s) is the time it takes to complete one cycle of the wave
• Frequency and period are Inversely Proportional:
  • T=1/f
  • f=1/T
Period, Frequency & Amplitude

- If the frequency of the signal is 2Hz, then the period is 0.5 s (i.e. it takes 0.5 seconds for the wave to complete one cycle)
- Amplitude is the magnitude of the signal at a given point in time. This could be volts, etc..
  - Amplitude relates to volume
  - Louder sounds have greater vertical displacement of sound wave

\[
\text{Period}: T = 10 \text{ ms (micosecond)}
\]

\[
\text{Frequency} : f = \frac{1}{10 \cdot 10^{-3}} = 100 \text{ Hz}
\]
Signal with twice the frequency

Period: \( T = 5 \text{ ms} \)

Frequency: \( f = \frac{1}{(5 \times 10^{-3})} = 200 \text{ Hz} \)

Notice the period is half the value as before

Notice the frequency is twice the value as before

Sine waves with various frequencies:

http://www.mindspring.com/~scottr/zmusic/
Multipliers

The following are the common multipliers used for audio characteristics such as period (T) and frequency (f):

- Giga (G) $10^9$ 1,000,000,000.
- Mega (M) $10^6$ 1,000,000.
- Kilo (k) $10^3$ 1,000.
- milli (m) $10^{-3}$ .001
- micro (µ) $10^{-6}$ .000001
- nano (n) $10^{-9}$ .000000001

For example, KHz = KiloHertz = 1000 Hz
ms = millisecond = 1/1000 = .001 seconds

Audio Signal Components
Frequency composition (spectrum) of a signal

The different frequency components which are added together to produce a complex waveform are called the frequency spectrum of that waveform.

Sound Wave Vs. Frequency Spectrum

- Fortunately, we do not need to know the specific frequency content of a signal to digitize it.
- We only need to know the highest frequency signal in a sample
Digitizing Audio Signals

• We know continuous images are digitized first by dividing the image into a certain number of pixels, then determining the brightness level of each pixel and finally assigning a code of certain length to each pixel.
• A similar procedure is used to digitize audio signals.
• The first step is called “sampling” where the waveform is sampled at certain intervals.
• The second step, called “quantization,” involves rounding off the continuous values of the audio samples so they can be represented by a finite number of bits.

Two step process for digitizing audio

- Continuous function of time
- Infinite amount of information
- Must choose particular instants of time
Sampling Rate

The sampling rate determines how many values of the signal we choose to retain.

- Sampling Interval (T)
  - Amount of time separating the samples
  - Also called sampling period
- Sampling Rate (f)
  - Number of samples per second
  - Also called sampling frequency

Digital Telephone Example

- In a digital telephone system, the speech signal is sampled 8,000 Hz. What is the sampling period?

\[ T_s = \frac{1}{f_s} \]
\[ T_s = \frac{1}{8000} \]
\[ T_s = .000125 = 1.25 \times 10^{-4} = 125 \mu s \]
Sampling Frequency

How often do you sample?
The sampling rate depends on the signal's highest frequency (for baseband)

- Harry Nyquist, working at Bell Labs developed what has become known as the Nyquist Sampling Theorem:
  - In order to be 'perfectly' represented by its samples, a signal must be sampled at a sampling rate (also called sampling frequency) equal to \textit{at least} twice its highest frequency component

- Or: \( f_s = 2f \)

- Note that \( f_s \) here is frequency of sampling, not the frequency of the sample

Sampling Rate Examples

- Take Concert A: 440 Hz
  - What would be the minimum sampling rate needed to accurately capture this signal?
  - \( f_s = 2 \times 440 \text{ Hz} = 880 \text{ Hz} \)

- Take your telephone \( \rightarrow \) used for voice, mostly
  - Highest voice component is: 3000 Hz
  - Minimum sampling rate: \( f_s = 2 \times 3000 \text{ Hz} = 6000 \text{ Hz} \)
  - Real telephone digitization is done at 8000 Hz sampling rate (supporting a 4 kHz bandwidth). Why? Remember that Nyquist said “equal to \textit{at least} twice…”
Undersampling and Oversampling

• Undersampling
  • Sampling at an inadequate frequency rate
  • Aliased into new form - Aliasing
  • Loses information in the original signal

• Oversampling
  • Sampling at a rate higher than minimum rate
  • More values to digitize and process
  • Increases the amount of storage and transmission
  • COST $$

Effects of Undersampling

Original waveform

Reconstructed waveform
Reconstructing Audio from Samples

- After receiving the signal, it is necessary to reconstruct it in order to hear it.

- The signal is reconstructed from its samples.

- Exact reconstruction is possible if the sampling rate is sufficiently high enough.

A short section of a speech waveform (highest frequency component is 3KHz)

Reconstructed speech waveform with 1 KHz sampling rate (note the resulting waveform does not resemble original waveform)
Reconstructed speech waveform with 5 KHz sampling rate (the resulting waveform starts resembling the original waveform)

Reconstructed speech waveform with 10 KHz sampling rate (the resulting waveform highly resembles the original waveform)

Questions?