Image Processing and Analysis

3 stages:

**Image Restoration** - correcting errors and distortion.
  - Warping and correcting systematic distortion related to viewing geometry
  - Correcting "drop outs", striping and other instrument noise
  - Applying corrections to compensate for atmospheric absorption & radiance

**Image Enhancement** - emphasizing the information that is of interest
  - Spatial Filtering to enhance or suppress features on the basis of size
  - Contrast enhancement to emphasize subtle tonal variations.

**Image Analysis** - extracting specific information for subsequent analyses
  - Principal component transformations
  - Multispectral classification
  - Temporal Variation

What is an Image? An image is an array of numbers.

A sensor (e.g. AVHRR) on board a platform (e.g. Nimbus 7) measures some quantity (e.g. spectral reflectance) at a particular spatial resolution (e.g. 1.1 km) and spectral resolution (e.g. 0.5 µm) at a point on the target (e.g. Earth) surface. This quantity is stored as a number of some finite precision (e.g. 8 bit). Various corrections are applied to the number (e.g. atmospheric path radiance, deskewing) to minimize the components of the signal that are not related to the properties of the target. These numbers may then be represented visually on an image by assigning a color or gray level to each number.

- The numbers are referred to as DN's (digital numbers) and are often rescaled from the actual reflectance (or radiance) to a “normalized” value within the precision of the measurement (e.g. 0-255 for 8 bit data).
- Within an image, each DN is assigned to a unique location determined by its line or sample (row) number and pixel (column) number.
- Each individual point is called a pixel (picture element) and is assigned a color or brightness value.
- These individual points correspond to locations on the target (e.g. Earth) surface and are generally projected into an equally spaced rectangular
array using some transformation (e.g. Universal Transverse Mercator) that maps points from the surface of a sphere (or oblate spheroid) onto a plane. • All projections introduce some kind of geometric distortion.

The dimension of the array determines the type of image:

**Scalar** images are derived from a single 2D array of numbers representing a single quantity (e.g. gravity or elevation) measured at different locations.

**Vector** images are derived from a series of 2D arrays of numbers representing different bands (e.g. ranges of λ) of information measured at the same points on the earth surface. Each band of a vector image can be considered a separate scalar image.

**Sampling and Resolution** - determine the information content of an image. The **Sampling Theorem** states that *it is necessary to sample at twice the frequency of the shortest wavelength of interest*. This is often referred to as the **Nyquist Frequency**. While sampling at the Nyquist frequency does not guarantee an accurate description of the shortest wavelength (depending on the phase of the signal - see the bottom of the first panel) in the signal, sampling at less than the Nyquist frequency guarantees that the information at this wavelength will be lost or distorted. Undersampling results in a phenomenon called **Aliasing** in which short wavelength features are sampled at different phases and appear as longer wavelength features in the sampled signal. *Avoid aliasing at all costs.*

Oversampling a signal wastes bandwidth if no additional information is gained but undersampling is worse if it introduces distortion that corrupts other parts of the signal. It is generally preferable to oversample (within reason) than to introduce artifacts. It is often possible to avoid both extremes, *if you understand the signal you are trying to sample*. The examples below show the progression from heavy oversampling to serious undersampling. Notice the difference between the various representations of the sinusoidal signal resulting from different sampling frequencies.

*Going from The Bad {gratuitous oversampling (below)}*
...to The Good \{	extit{optimal sampling preserving amplitude \\& phase (thin line above)}\}

...to The Ugly \{	extit{undersampling resulting in increasing distortion (below)}\}
Image Enhancement - involves changing the brightness value or color of some or all of the pixels in an image in order to emphasize features of interest or de-emphasize something that obscure features of interest.

2 categories of image enhancement

Point Operations - assigning a new value to a pixel based only on its previous value (eg. contrast enhancement by stretching and histogram equalization).

Neighborhood Operations - assigning a new value to a pixel based on the values of its neighbors (eg. sharpening, smoothing, edge enhancement).

Filtering

Images contain features of different scales ranging from broad trends to fine textures. It is frequently useful to separate information information on the basis of its spatial scale. This is referred to as spatial filtering.

• Like EM radiation, spatial scale can also be thought of in terms of wavelength ($\lambda$).

Broad scale features are said to be long wavelength while Smaller scale features are referred to as short wavelength.

The distribution of information with respect to its wavelength is given by the Power Spectrum of an image. A power spectrum is a statistical estimate that can be computed using a transformation (known as a Fourier Transform) in which the variance of an image is described as a function of frequency (or wavelength).

There are 3 basic types of filters:

Low Pass filters remove ("cut") high frequency (short $\lambda$) information to enhance ("pass") low frequency (long $\lambda$) information. Used to remove noise and emphasize regional features. Also known as smoothing filters.

High Pass filters remove long $\lambda$ information to enhance short $\lambda$ information. Used to emphasize edges, fine detail or texture.
Also known as sharpening filters.

**Band Pass** filter removes both low and high frequency information to enhance a specific intermediate band of information.

Filtering can be accomplished in 2 ways:

**Frequency domain filtering** involves *Fourier transforming* the data so that its information is represented by its frequency, removing unwanted information at specific wavelengths and then transforming the filtered information back to the spatial (image) domain.

**Image domain filtering** uses a *convolution operator* (or filter) to compute a moving average in which each data point is replaced by some linear combination of itself and its neighboring data points.

When a filter is convolved with an image, the *weights* of the filter are multiplied with the input value of the target pixel and the neighboring pixels, the results of all the multiplications are added up and the sum is the new output value of the pixel.

*Smoothing (low pass) filters* usually have weights that lie between 0 and 1 so that their sum adds up to 1. This assures that the output values will be within the range of the input values and facilitates comparison between the filtered and unfiltered images.

In general, the wider a low pass filter (greater # of weights), the smoother the result will be.

*Sharpening (high pass) filters* often have weights with both positive and negative values. This results in the calculation of a difference (or *gradient*) between neighboring pixels and accentuates edges and short λ information.

Examples of filters

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<tr>
<th>Smoothing</th>
<th>Sharpening</th>
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A simple (but unelegant) way to high pass filter a signal is to subtract a smoothed version of the signal from the original signal.