# REMOTE SENSING

Digital Image Processing

# OVERVIEW

# INTRODUCTION

Remotely sensed data acquired in or converted to digital format are most often subject to analyses and information extraction using image processing techniques developed over the past 50 years. The process encompasses a myriad of algorithms that an analyst can apply to get meaningful information from an image.

Remote sensing instruments (or sensors) detect and record electromagnetic (EM) energy. There are two types of sensor systems, *active sensors* and *passive sensors*. Data may be acquired in single (panchromatic) or multiple (multi-/hyperspectral) bands of the EM spectrum. In either case, the data appear in a matrix of *x-columns* by *y-rows*, with each square of the matrix referenced as a *pixel* and having a gray-scale value that indicates the EM energy recorded for that pixel (commonly referred to as the *brightness value* (BV)). The range of BVs recorded in each band across the image is dependent on the radiometric resolution of the sensor system (e.g., values ranging from 0 to 255 would be recorded for a sensor system with an 8-bit radiometric resolution).

Most remote sensing studies are based on developing deterministic relationships between the EM signals recorded in various bands of the spectrum and the chemical or biophysical properties of the features being investigated.

# IMAGE QUALITY ASSESSMENT: BASIC STATISTICS AND HISTOGRAM ANALYSIS

Errors (or noise) are introduced into the data by numerous factors, such as the environment (e.g., atmospheric scattering), random or systematic malfunction of the sensor system (e.g., an uncalibrated detector creates striping), or improper processing of the raw data prior to actual data analysis. (e.g., inaccurate analog-to-digital conversion). Therefore, one of the initial tasks of an image analyst should be to assess its quality and statistical characteristics. This is normally accomplished by

- Examining the frequency of occurrence of individual BVs in the image displayed in a histogram
- Sample visual analysis of individual pixel BVs at specific locations or within a geographic area
- Computing univariate descriptive statistics to determine if there are unusual anomalies in the image data
- Computing multivariate statistics to determine the amount of between-band correlation (e.g., to identify redundancy)

# IMAGE QUALITY ASSESSMENT: BASIC STATISTICS AND HISTOGRAM ANALYSIS

Basic statistics: mean, standard deviation, and variance.
These statistics provide information about the range of BVs in each band, the relationship of the BVs in each band, the representation of spectral characteristics of features being examined, and an indicator of values that can be used for image enhancement (e.g., a histogram stretch using minimum–maximum values in a given band).
For an in-depth analysis, other statistical measures, such as variance and *correlation*, may be required to provide insight into the data quality and redundancy.

Remote sensing–derived spectral measurements for each pixel often change together in some predictable fashion because objects or features exhibit spectral behavioural patterns across the bands. For example, clear deep water would have low, steadily declining BVs across the blue, green, and red portions of the spectrum until it reaches near zero in the near-infrared (NIR). If there is no relationship between the BVs in one band and that of another for a given pixel, it may imply that the values are mutually independent, or there may be an anomalous observation for a given feature (e.g., sedimentation present in deep water).

# IMAGE QUALITY ASSESSMENT: BASIC STATISTICS AND HISTOGRAM ANALYSIS

In most cases, spectral measurements of individual pixels may not be independent, and a measure of their mutual interaction is reflected in the *covariance* or the joint variation of two variables about their common mean.

$$r_{k,l} = \frac{\mathrm{COV}_{k,l}}{s_k s_l}$$

If we square the correlation coefficient, we obtain the *sample coefficient of determination* ( $r^2$), which expresses the proportion of the total variation in the values of "band *l*" that can be accounted for or explained by a linear relationship with the values of the random variable "band *k*." Thus, a correlation coefficient ($r_{kl}$) of 0.70 results in an $R^2$ value of 0.49, meaning that 49% of the total variation of the values of "band *l*" in the sample is accounted for by a linear relationship with values of "band *k*."

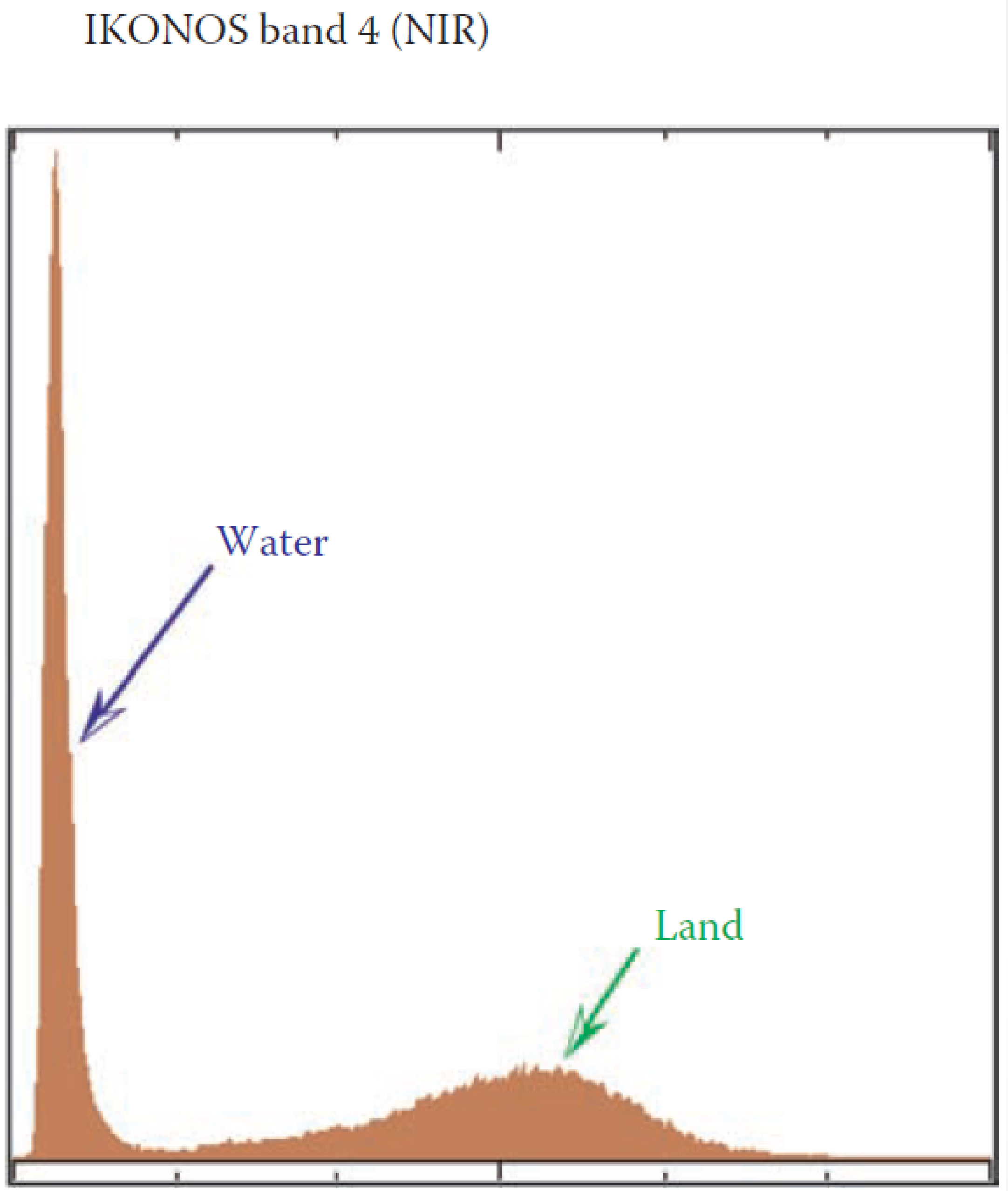
Furthermore, the correlation and covariance information can be used for analysis by advanced image processing functions such as principal component analysis (PCA) and image classification.

# IMAGE QUALITY ASSESSMENT: BASIC STATISTICS AND HISTOGRAM ANALYSIS

A histogram is the most fundamental and useful graphical representation of information content in an image. It tabulates frequencies of occurrences of each BV, display them graphically, and provides information on *contrast* within each band.

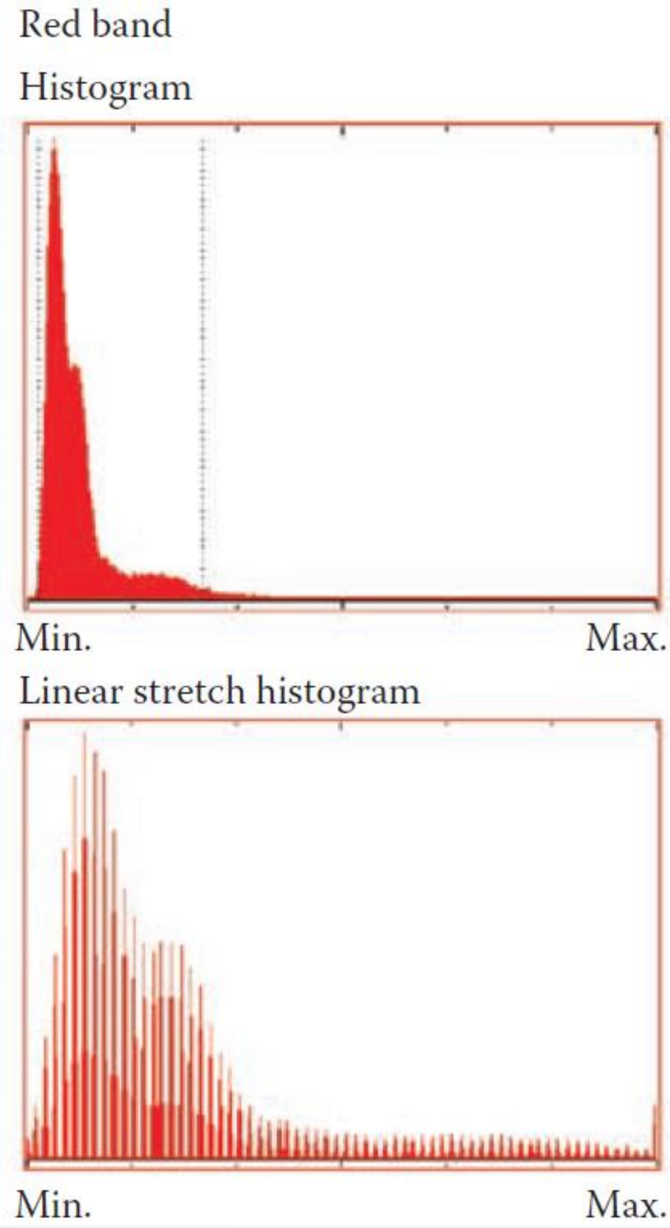
histograms may provide the user with information on the quality of the image (e.g., high-contrast, low-contrast, bimodal, and multimodal) and are often used to enhance imagery

# IMAGE QUALITY ASSESSMENT: BASIC STATISTICS AND HISTOGRAM ANALYSIS

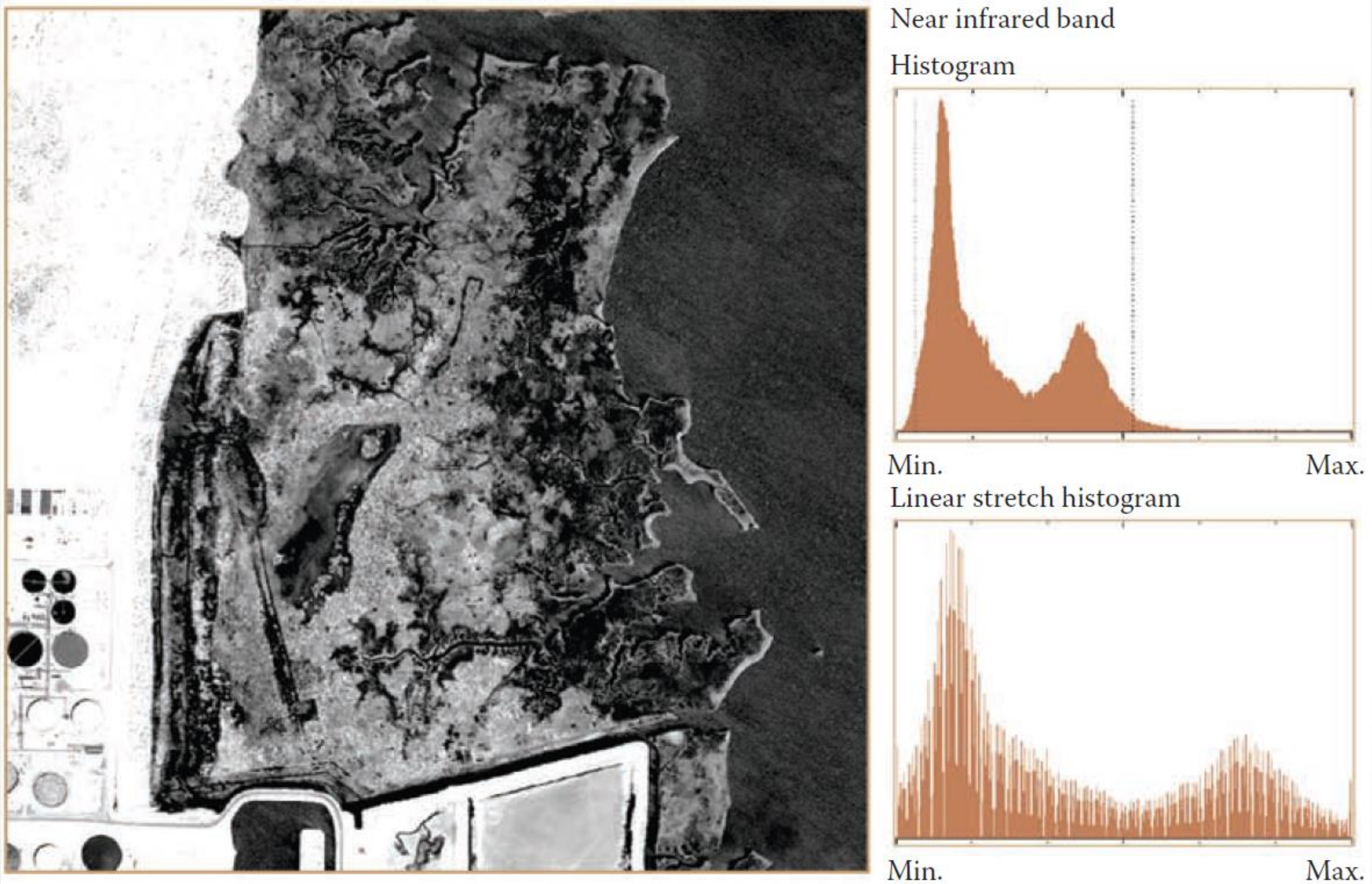



Histogram of the near-infrared band (band 4) of the IKONOS sensor system. The near-infrared band is useful for land/water delineation, and this is evident in the histogram where clear deep water pixels have very low reflectivity while the land pixels record higher BVs in the band.

# IMAGE QUALITY ASSESSMENT: BASIC STATISTICS AND HISTOGRAM ANALYSIS



# IMAGE QUALITY ASSESSMENT: BASIC STATISTICS AND HISTOGRAM ANALYSIS



# IMAGE ENHANCEMENT

- image reduction
- magnification
- spatial and spectral profiles
- image contrasting,
- density slicing
- composite generation

| Image Enhancement Technique | Effect on Image | Example of Application |
|---|---|---|
| Image magnification | Zooms into the area of interest or closer observation of feature | |
| Image reduction | Zooms out either partially or completely from an image to provide a large-area perspective | Enable a geographic or spatial analysis of an entire landscape |
| Spatial profiles | Draw a transect across the area of interest | Changes in features across the transect (e.g., forest to grasslands, to water) |
| Spectral profiles | Draw a transect across the area of interest | Changes in spectral signature observed along the transect as variations in features occur |
| Density slicing | Color coding a band based on BV ranges | Highlight specific features or a rapid visualization of potential land cover observed in the selected band |
| Image composites | Representation of land cover features in various colors based on the band combinations used | Geologic highlighting of a mineral may use a combination of certain bands based on the spectral properties of that mineral |

Higher-order image enhancement techniques include band rationing, spatial filtering, edge enhancement, and spectral image transformation.

# IMAGE ENHANCEMENT

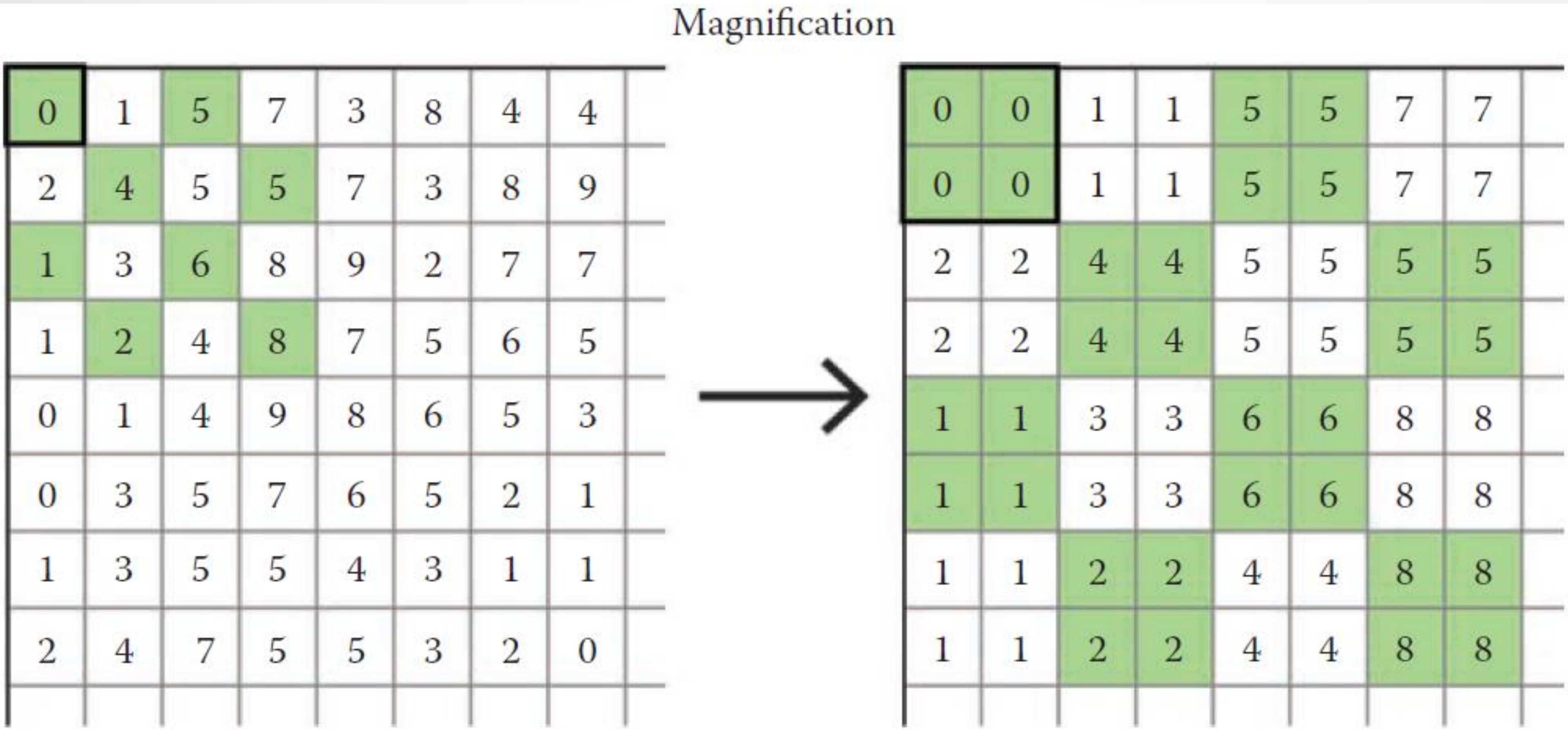
Reduction

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 1 | 5 | 7 | 3 | 8 | 4 | 4 |
| 2 | 4 | 5 | 5 | 7 | 3 | 8 | 9 |
| 1 | 3 | 6 | 8 | 9 | 2 | 7 | 7 |
| 1 | 2 | 4 | 8 | 7 | 5 | 6 | 5 |
| 0 | 1 | 4 | 9 | 8 | 6 | 5 | 3 |
| 0 | 3 | 5 | 7 | 6 | 5 | 2 | 1 |
| 1 | 3 | 5 | 5 | 4 | 3 | 1 | 1 |
| 2 | 4 | 7 | 5 | 5 | 3 | 2 | 0 |

→

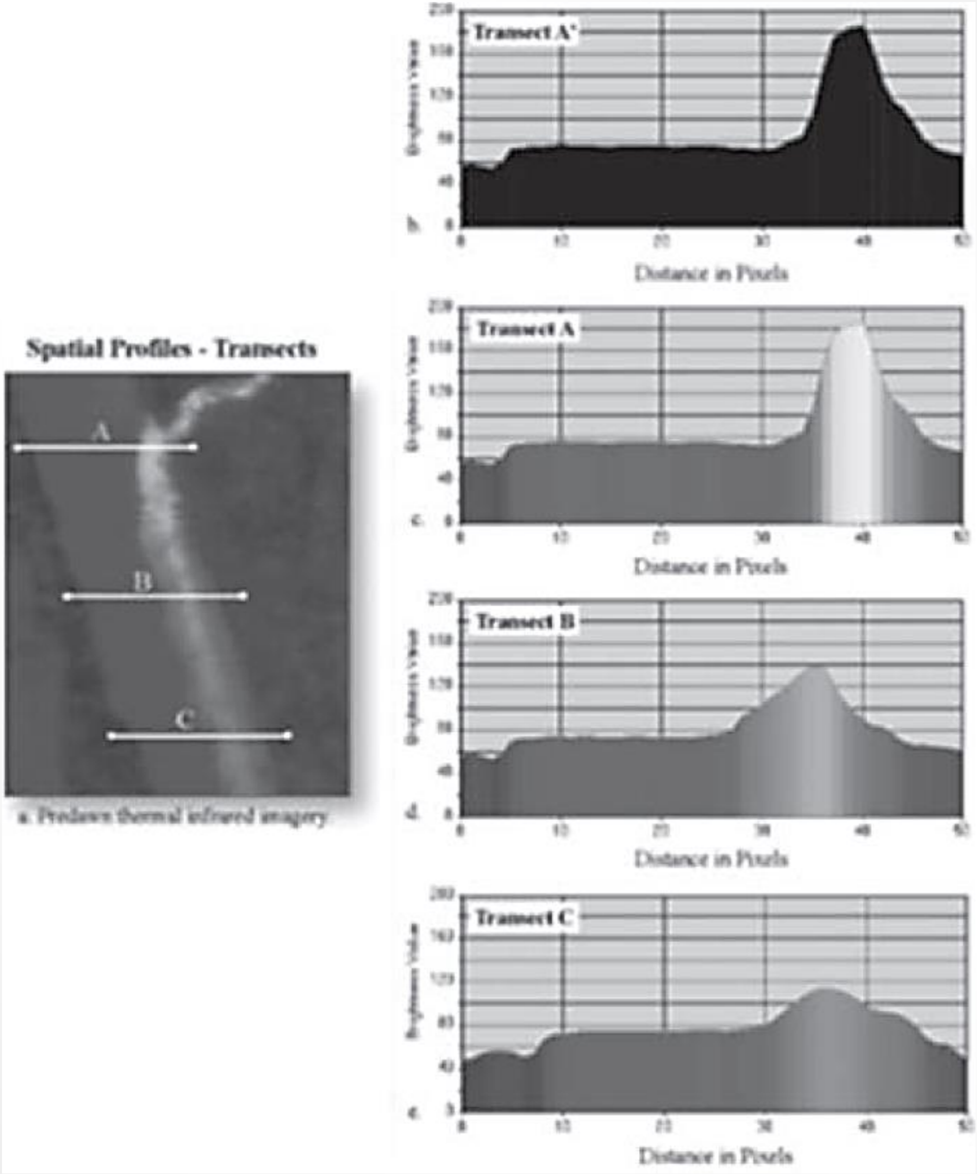
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 0 | 5 | 3 | 4 | - | - | - | - |
| 1 | 6 | 9 | 7 | - | - | - | - |
| 0 | 4 | 8 | 5 | - | - | - | - |
| 1 | 5 | 4 | 1 | - | - | - | - |
| - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - |
| - | - | - | - | - | - | - | - |

# IMAGE ENHANCEMENT



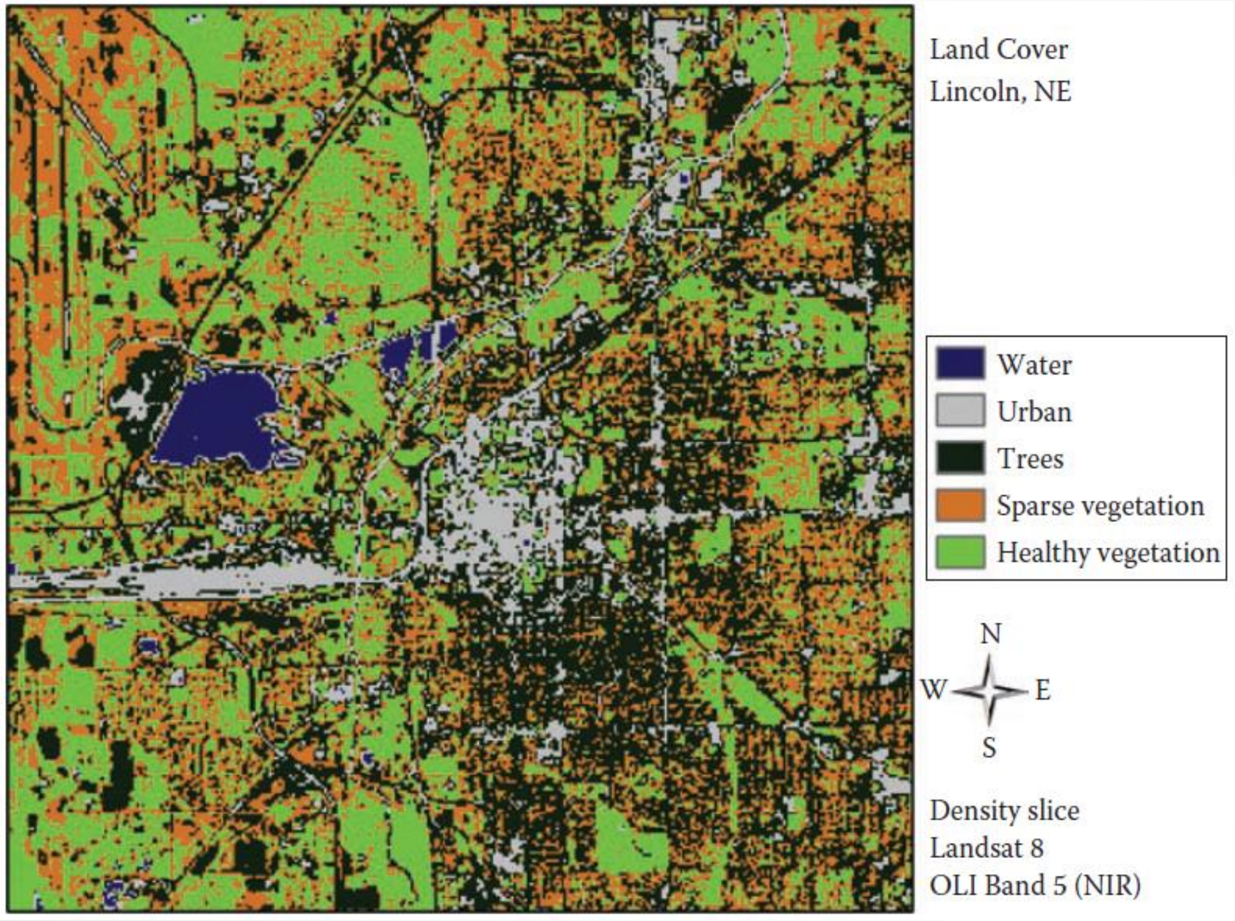
# IMAGE ENHANCEMENT

The further understanding of the image landscape by deriving *spatial* and *spectral* profiles along user-specified transects. The pixels that lie along that transect can be measured and displayed to compare the spectral (BVs) or spatial differences (coordinate space). Multiple transects may be used to determine spatial patterns or trends. Transects can also be used to assist in density slicing an image or a portion of it.



# IMAGE ENHANCEMENT

Density slicing is a pseudocolor enhancement technique normally applied to a single-band monochrome. It is considered an effective way of highlighting different but apparently homogeneous areas within an image by *slicing* the range of grayscale values (e.g., 0–255) and assigning different colors to each of those slices. This technique is often used in conjunction with a vegetation index (VI), such as the Normalized Difference Vegetation Index (NDVI) to highlight variations in the density of biomass.



# IMAGE ENHANCEMENT

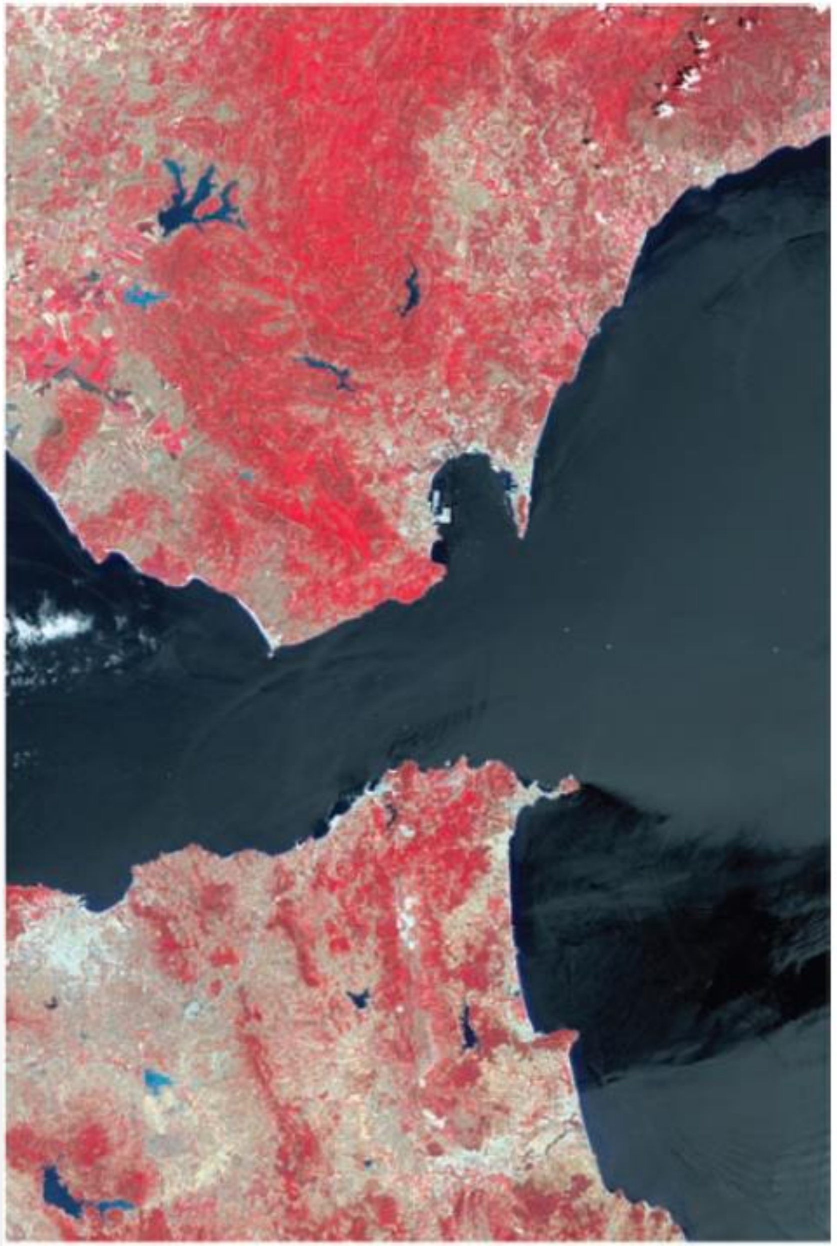
Composite generation. This method utilizes the three planes of a computer's display device (red (R), green (G), and blue (B)) and allows the analyst to place different bands of a multispectral image into various planes.

For example, to generate a true colour composite from Landsat Operational Land Imager (OLI) image, one would insert bands 4, 3, and 2 into the R, G, and B planes, respectively, thus generating a true colour image.

# IMAGE ENHANCEMENT

Composite generation. Similarly, to display a false colour composite of the same image, OLI bands 5, 4, and 3 would be placed in the R, G, and B planes.

In Figure, the NIR band (OLI band 5) is placed into the red plane of the display and is often used for vegetation analysis because of high spectral reflectance of vegetation in the near and mid-infrared portions of the spectrum.



# IMAGE PREPROCESSING

Image pre-processing is a preparatory phase that, in principle, improves image quality as the basis for later analyses that will extract information from the image. Often known as image restoration, the process produces a corrected image that is as close as possible, both geometrically and radiometrically, to the radiant energy characteristics of the actual scene. This requires that internal and external errors be determined and corrected for. Internal errors are created by the sensor itself and are generally systematic and stationary (i.e., predictable and constant).

# IMAGE PREPROCESSING

**Radiometric Correction**

Atmospheric correction can be divided into two types: (1) absolute and (2) relative.

Absolute radiometric corrections turn the BVs into scaled surface reflectance values and attempt to model the atmosphere, as it would exist at the time of image acquisition.

Atmospheric CORrection Now (ACORN) by ImSpec (2002)

ATmospheric REMoval (ATREM) program by the University of Colorado (1986)

Fast Line-of-Sight Atmospheric Analysis of Spectral Hypercubes (FLAASH) by Exelis (formerly Research Systems, 2003)

Initial data for the models:
spectral profile
atmospheric properties for that date and time

# IMAGE PREPROCESSING

## Radiometric Correction

Relative atmospheric correction is often used if an analyst wants to normalize the BV among the various bands of a single scene or normalize multi-date imagery to a single/standard scene selected among the dataset.
An example of the former method is to examine the observed BVs in an area of shadow or for a very dark object (such as a large clear lake or an asphalt surface) and determine the minimum value. 

Multi-date image normalization techniques involve the selection of a base image and then transforming the spectral characteristics of all other images to have the same radiometric scale as the base image. The method involves the selection of pseudo-invariant features (i.e., radiometric ground control points (GCPs)) from the base image, identifying the BVs of the same features across all the multidate imagery and normalizing them to the base image.
The landscape elements such as slope and aspect can cause radiometric distortion of the signal received by the sensor system.
Four topographic correction methods, (1) cosine correction, (2) Minnaert correction, (3) statistical–empirical correction, and (4) C-correction. Each correction method is based on illumination and requires a digital elevation model (DEM).

# IMAGE PREPROCESSING

## Radiometric Correction

Noise in an image may be due to irregularities or errors that occur in the sensor response and/or data recording and transmission. Common forms of noise include systematic striping or banding and dropped lines.

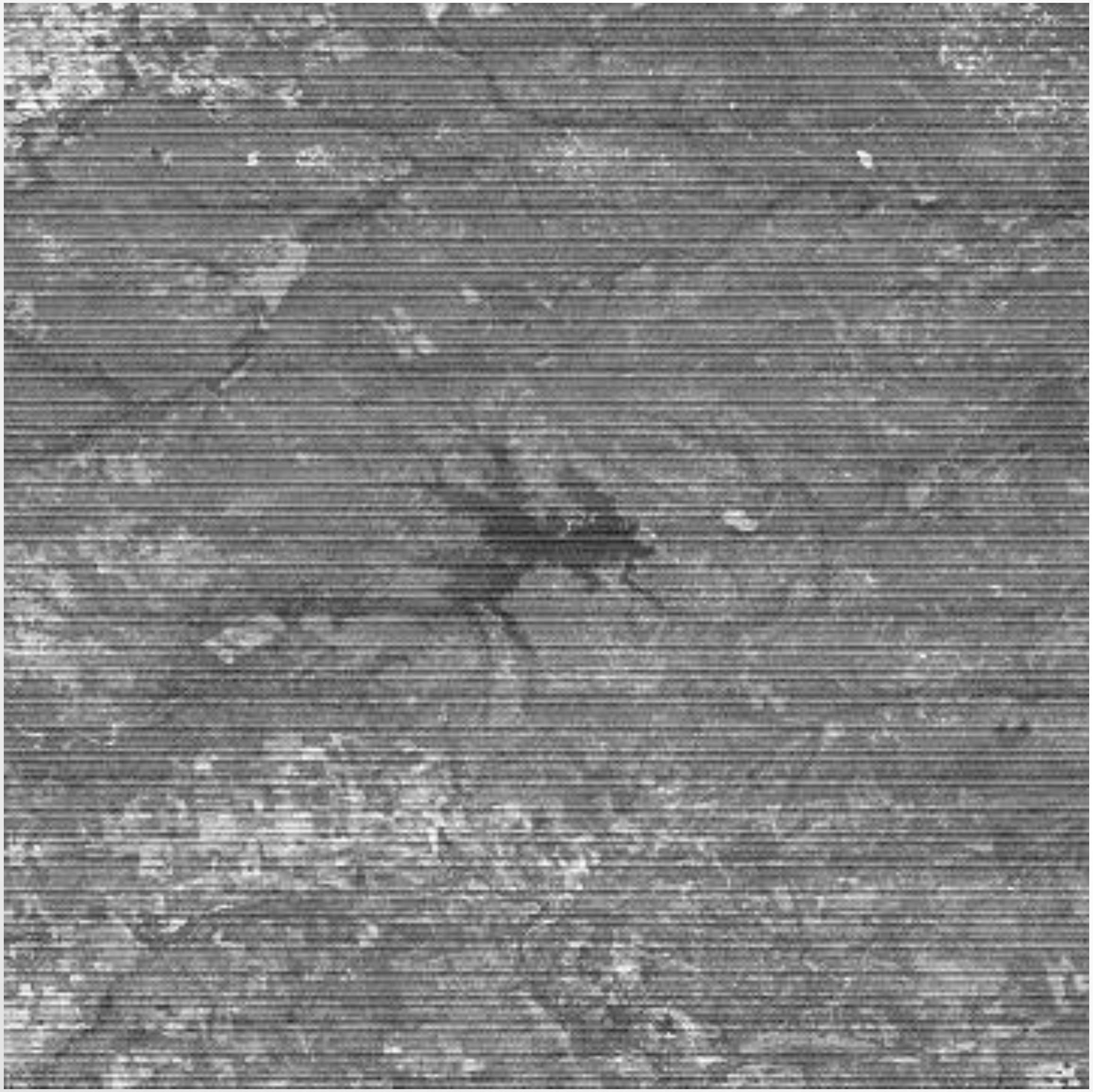
Early Landsat MSS data had substantial striping due to variations and drift in the response over time of the six MSS detectors. The *drift* was different for each of the six detectors, causing the same brightness to be represented differently by

each detector. The overall appearance was thus a *striped* effect. The corrective process made a relative correction among the six sensors to bring their apparent values in line with each other.

Dropped lines occur when there are system errors that result in missing or defective data along a scan line and is often *corrected* by replacing the line with the pixel values in the line above or below, or with the average of the two.

# IMAGE PREPROCESSING

## Radiometric Correction



# IMAGE PREPROCESSING

**Geometric Correction**

The stability of a remote sensing platform, the curvature of the earth, sensor orientation, topography, and other factors cause geometric distortion in an image.

*Geometrically corrected* imagery can be used to extract accurate distance, area, and direction (bearing) information

Remotely sensed imagery collected from airborne or spaceborne sensors contains internal and external geometric errors systematic (predictable) or nonsystematic (random),

# IMAGE PREPROCESSING

Unlike in both analogue and analytical photogrammetry, where basically only one functional relationship between the image and object space is identified, in digital photogrammetry ***two sensor models*** can be distinguished.

***physical*** or ***rigorous sensor model*** that is anchored on the basic collinearity condition

***generalized*** or ***replacement sensor model*** that can be applied in digital photogrammetry

Majority of the generalized sensor models employ geometries, such as projective geometry, that are different from the central perspective geometry
used in classical photogrammetry.

# IMAGE PREPROCESSING

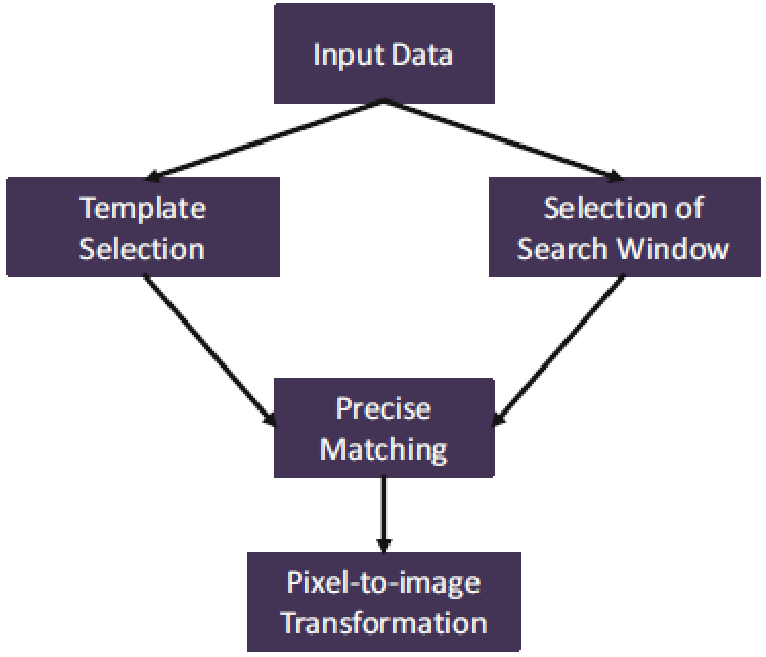
## AUTOMATED PHOTOGRAMMETRIC MAPPING

### Interior Orientation

Interior orientation allows for the transformation of pixel coordinates to equivalent photo coordinates and, using camera calibration data, to reconstruct, if necessary, the geometry of the bundle that generated a single image.

(1) Transformation from the digital image pixel coordinate system to the photo coordinate system defined by the fiducial marks, and

(2) Estimation of the interior orientation parameters through camera calibration.

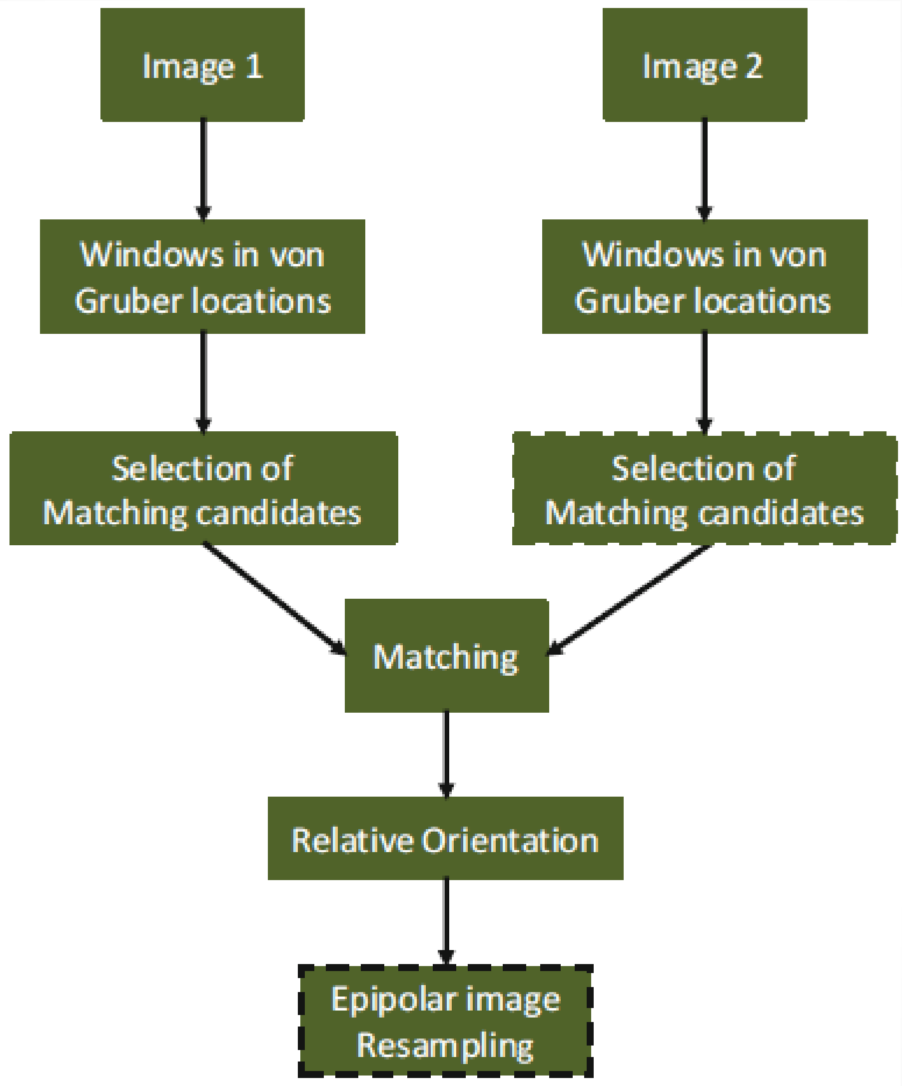



(a) Typical workflow of an automated interior orientation module

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Relative Orientation




(b) Automated conjugate point measurement in a stereopair

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Aerial Triangulation

Modern DPWs implement aerial triangulation using least squares bundle adjustment algorithms, along with integrating robust estimation techniques. This allows for a rigorous and high quality triangulated solution to be obtained, in addition to the automatic detection of blunders in the measurements. Two different types of measurements can be distinguished using DPWs, namely;

(1) Automatic point measurements that automatically produces numerous measurements of conjugate image points. In order to handle aerial triangulation computational needs, matching tools have been extended from stereo- to multi-stage application. Furthermore, it is possible to match features automatically to better than ±0.1 pixel.

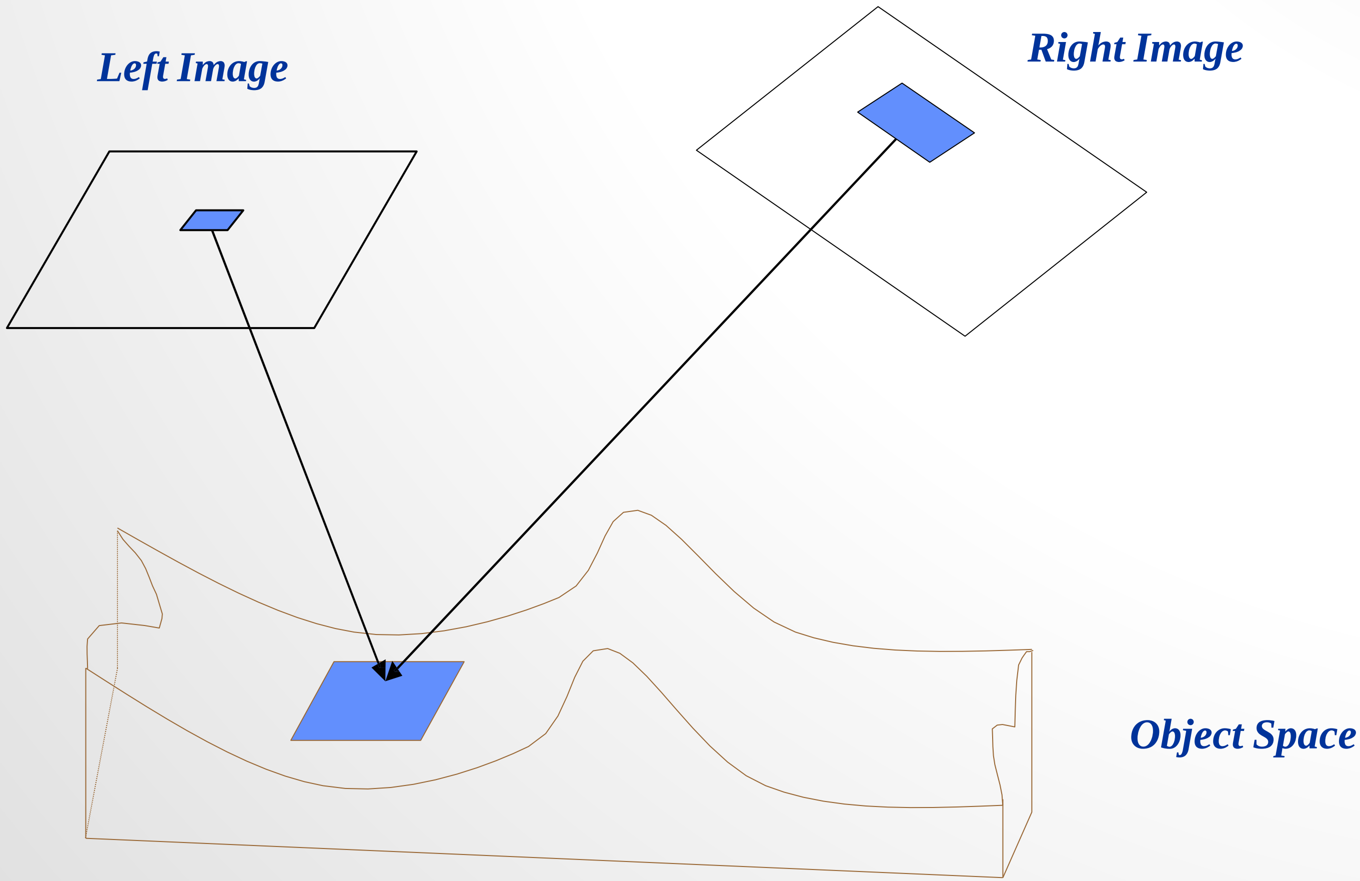
(2) Interactive point measurements which allow for user-controlled measurements for the identification and measurement of specific points of interest e.g., ground control points in a semi-automatic manner.

# IMAGE PREPROCESSING

## Photogrammetric Procedures

### Image Registration: Objective

- Aims at geometrically aligning two or more images so that corresponding pixels and/or their derivatives (e.g., edges, corner points) representing the same underlying structure in object space may be integrated/fused.



# IMAGE PREPROCESSING

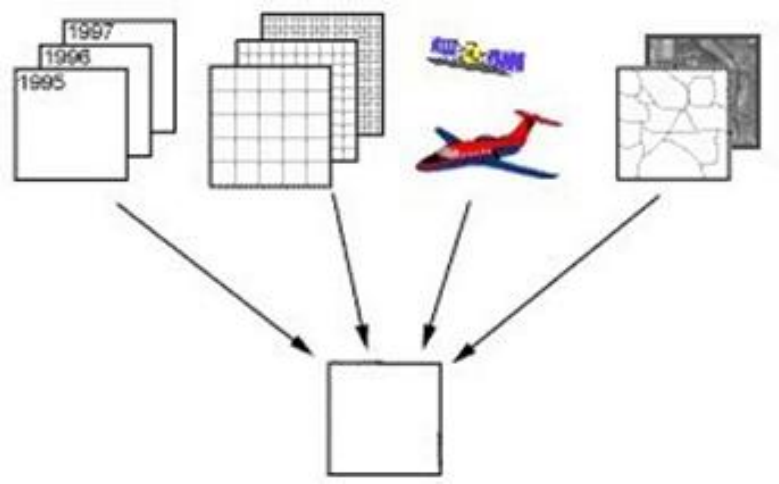
## Photogrammetric Procedures

### Image Registration: Motivation

- Integrating information gathered by *different sensors.*
- Finding changes in images captured at *different times* (updating & monitoring purposes).
- Inferring three dimensional information from two dimensional imagery where either the camera or the object in the scene has moved.
- Model based object recognition.

Data Integration: Fundamentally involves combining/merging data from multiple sources in an effort to extract better and/or more information.

- **Multi-temporal**
- **Multi-resolution**
- **Multi-sensor**
- **Multi-type**




Change Detection: Accurate image registration of multi-sensor datasets captured at different times is a prerequisite for a reliable change detection procedure.

# IMAGE PREPROCESSING

## Photogrammetric Procedures

### Image Registration Paradigm

Primitives

Transformation Function

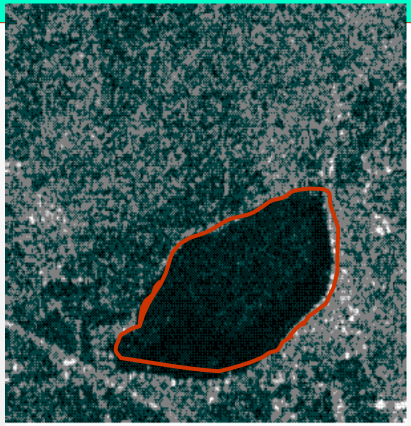
Similarity Measure

Matching Strategy

**Primitives**

**The domain in which information for matching is extracted for the registration process.**

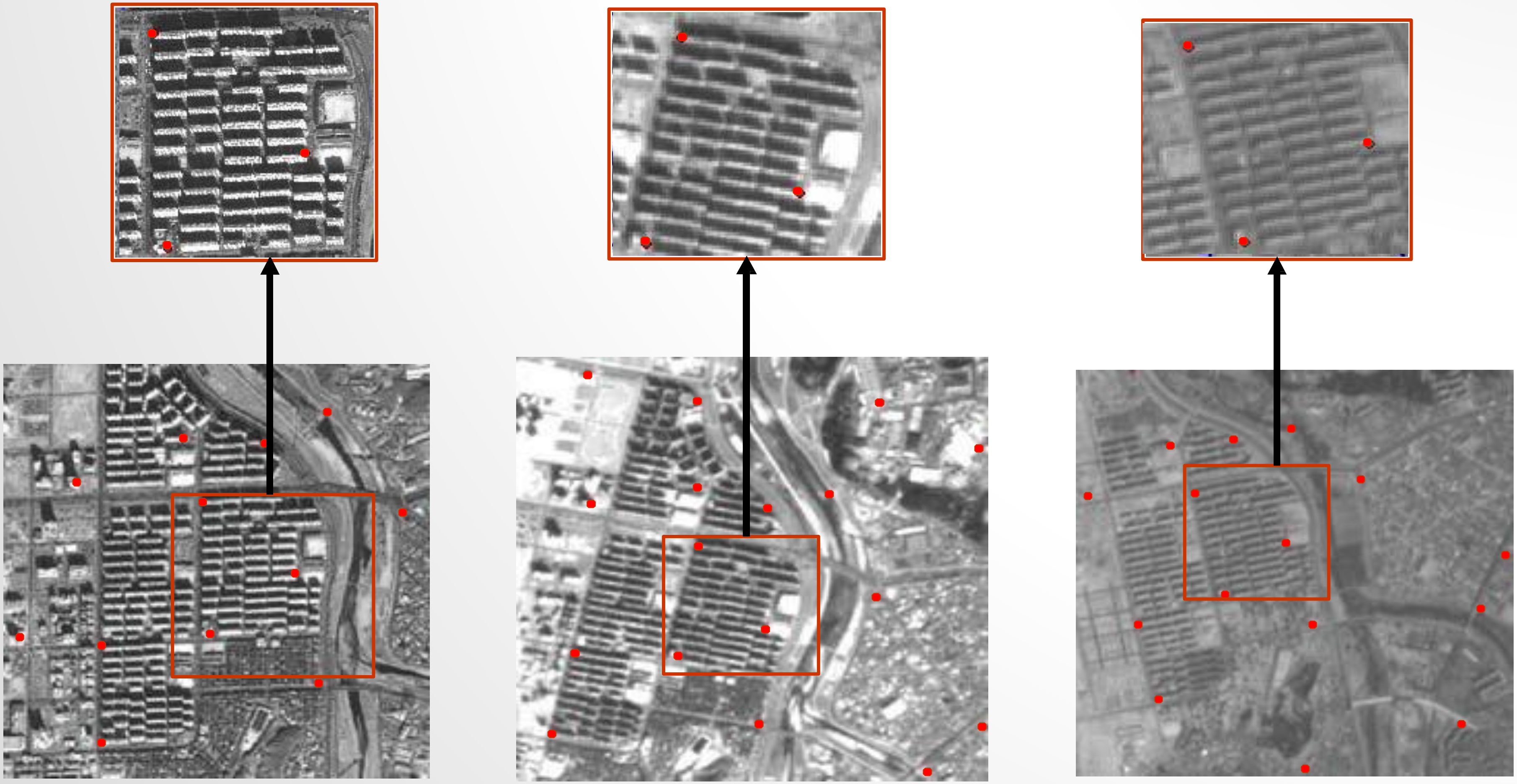
- **Distinct Points**
- **Linear Features**
- **Homogeneous Regions**



# IMAGE PREPROCESSING

## Photogrammetric Procedures

### Image Registration: Point Primitives



IKONOS (1m) KOMPSAT (6m) SPOT (10m)

# IMAGE PREPROCESSING

## Photogrammetric Procedures

## Image Registration Paradigm

Primitives

↓

Transformation Function

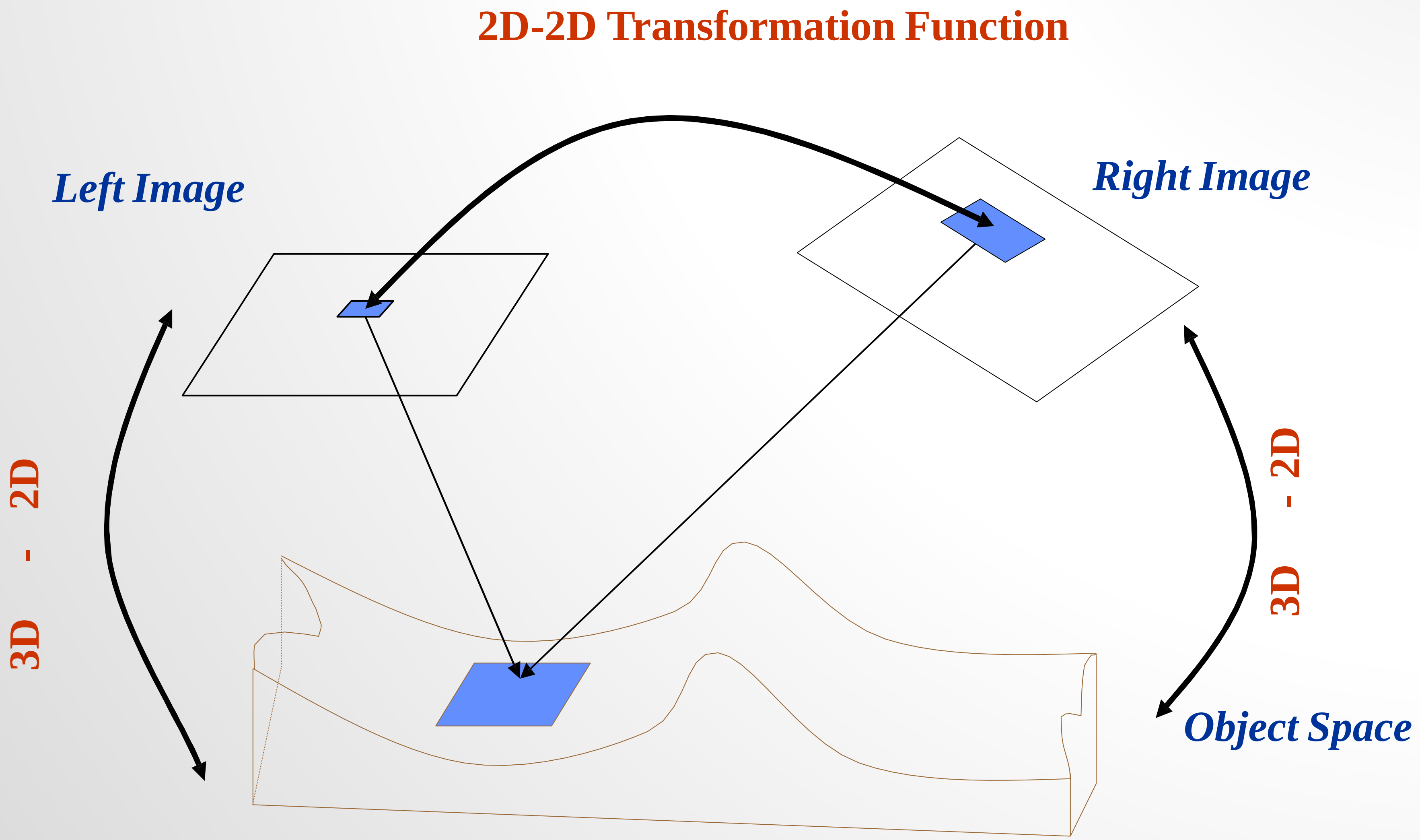
↓

**Establishing the mathematical function that relates geometric attributes of corresponding primitives.**

# IMAGE PREPROCESSING

## Photogrammetric Procedures

### Transformation Function



# IMAGE PREPROCESSING

## Photogrammetric Procedures

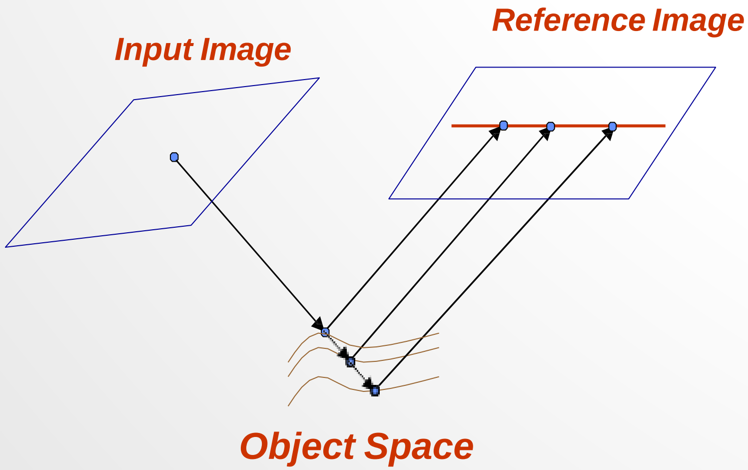
### Transformation Function: Rigorous Models

3-D → 2-D

$$x = x_p - c\frac{r_{11}(X - X_0) + r_{21}(Y - Y_0) + r_{31}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)}$$

$$y = y_p - c\frac{r_{12}(X - X_0) + r_{22}(Y - Y_0) + r_{32}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)}$$

2-D → 2-D




- Without having a DEM, we can not establish a mathematical relationship between conjugate points in overlapping images.

# IMAGE PREPROCESSING

## Photogrammetric Procedures

### Transformation Function: Approximate Models

**Approximate Models**

**Parallel Projection (2D-affine)**

$$x = B_1 X + B_2 Y + B_3 Z + B_4$$

$$y = B_5 X + B_6 Y + B_7 Z + B_8$$

$$\boxed{Z = a_0 + a_1 \cdot X + a_2 \cdot Y}$$

**Standard Affine**

$$x = C_1 X + C_2 Y + C_3$$

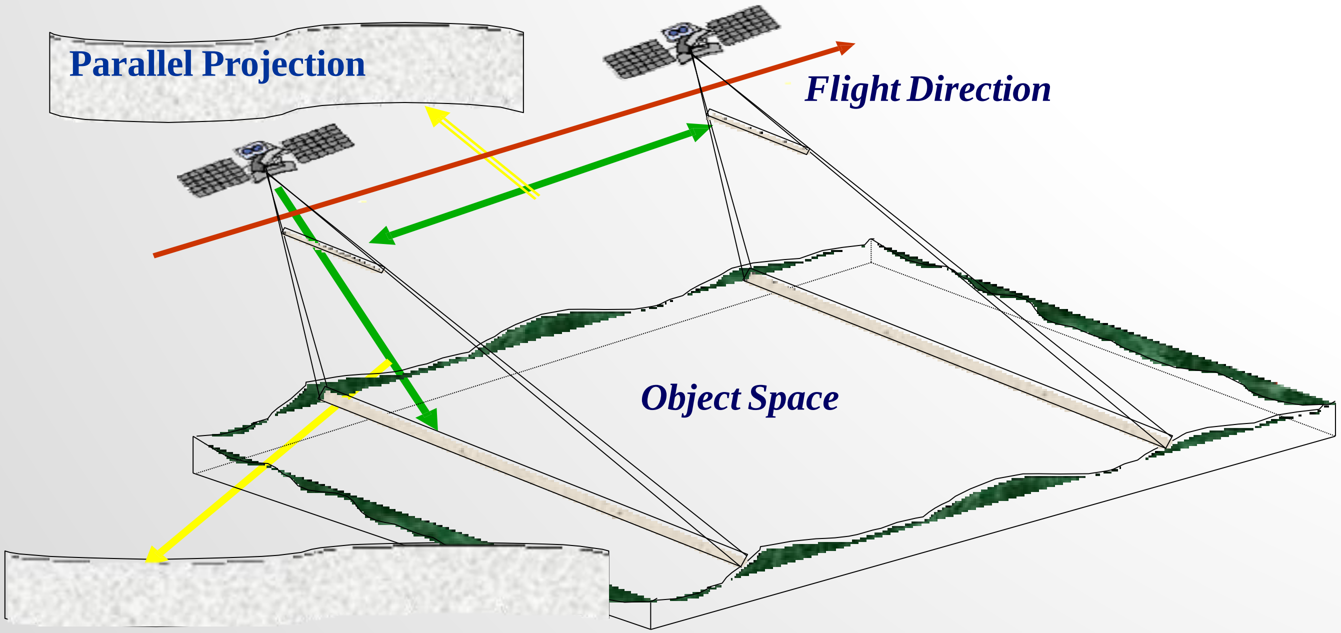
$$y = C_4 X + C_5 Y + C_6$$

$$\boxed{C_1 = C_5 \;\&\; C_2 = -C_4}$$

**2D-Similarity**

$$x = C_1 X - C_2 Y + C_3$$

$$y = C_2 X + C_1 Y + C_6$$

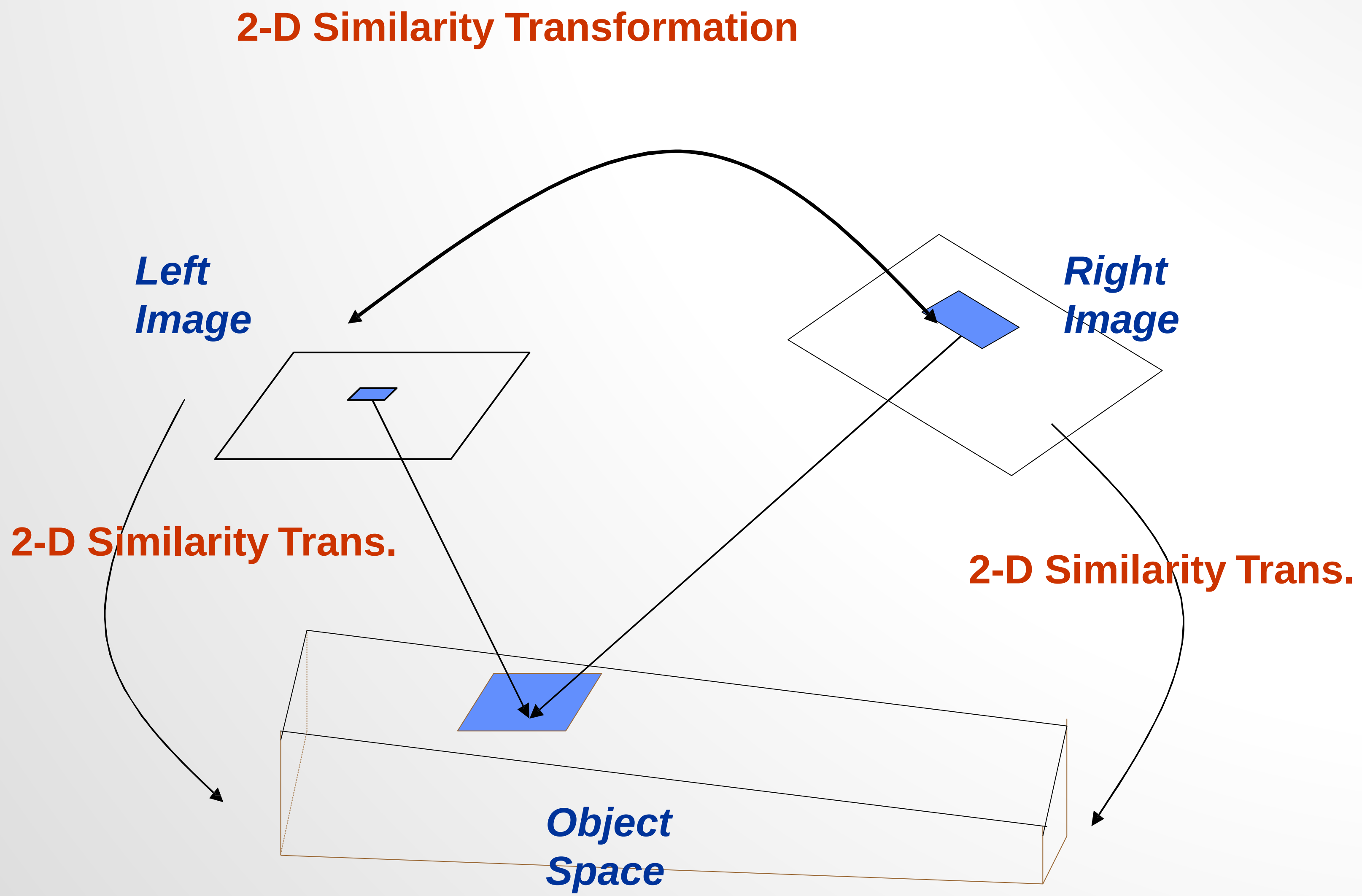



- **High Altitude**
- **Narrow AFOV**
- **Planar Surface**
- **Parallel Image-Object**

# IMAGE PREPROCESSING

## Photogrammetric Procedures

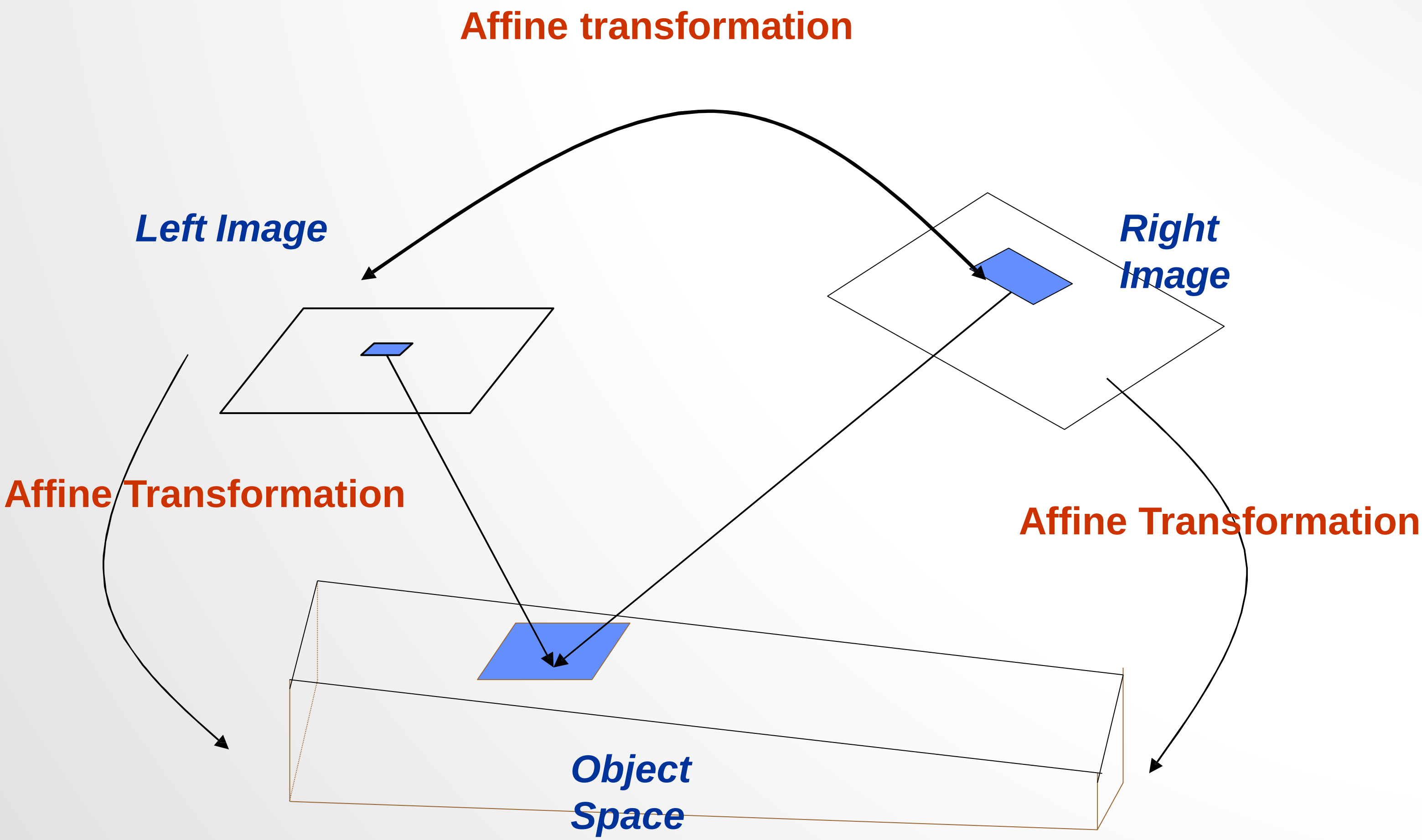
**2-D similarity Transformation  Transitive Property**



# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Affine Transformation Transitive Property



# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Image Registration Paradigm

Primitives

↓

Transformation Function

↓

**Similarity Measure**

↓

**Establish the necessary measures that describe the degree of similarity between selected primitives.**

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Geometric Similarity measure

- Mathematically describe the fact that conjugate primitives should coincide with each other after applying the proper registration transformation function.
- The geometric similarity measure depends on:
  - The selected registration primitives (e.g., points, linear features, or homogenous regions).
  - The registration transformation function (e.g., 2-D similarity or affine transformation).

$$x_r - f_{g_x}(x_i, y_i) = 0$$

$$y_r - f_{g_y}(x_i, y_i) = 0$$

- Where $f_{g_x}$ & $f_{g_y}$ represent the registration transformation function.

- For 2-D similarity, the geometric similarity measure is described as follows

$$x_r - a_0 \quad - a \; x_i + b \; y_i = 0$$

$$y_r - b_0 \quad - b \; x_i - a \; y_i = 0$$

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Radiometric Similarity Measure

- Describe the degree of similarity between the grey level distribution functions at the vicinity of the selected primitives.
- The radiometric similarity measure is important for automatic identification of conjugate primitives.
- The correlation coefficient can be used to describe the radiometric similarity of point primitives.
  - For imagery with equivalent spatial resolution.

*Correlation Coefficient*

- Assuming that:
  - $g_r(x, y)$ is the gray value function at the vicinity of a selected point in the reference image.
  - $g_i(x, y)$ is the gray value function at the vicinity of the corresponding point in the input image.
  - (nxm) is the size of the analyzed windows centered at the selected points in the reference and input images.
- Then, the cross correlation coefficient (radiometric similarity measure) can be computed as follows:

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

## Correlation Coefficient

$$\overline{g_r} = \frac{\sum_{j=1}^{n}\sum_{k=1}^{m} g_r(x_j, y_k)}{n\ m}$$

$$\overline{g_i} = \frac{\sum_{j=1}^{n}\sum_{k=1}^{m} g_i(x_j, y_k)}{n\ m}$$

$$\sigma_r = \sqrt{\frac{\sum_{j=1}^{n}\sum_{k=1}^{m} [g_r(x_j, y_k) - \overline{g_r}]^2}{n\ m - 1}}$$

$$\sigma_i = \sqrt{\frac{\sum_{j=1}^{n}\sum_{k=1}^{m} [g_i(x_j, y_k) - \overline{g_i}]^2}{n\ m - 1}}$$

$$\sigma_{ri} = \frac{\sum_{j=1}^{n}\sum_{k=1}^{m} [\{g_r(x_j, y_k) - \overline{g_r}\}\ \{g_i(x_j, y_k) - \overline{g_i}\}]}{n\ m - 1}$$

$$\rho = \frac{\sigma_{ri}}{\sigma_r\ \sigma_i}$$

- The correlation coefficient factor might take values that range from -1 to +1.
- $\rho = 0$ indicates no similarity at all.
- $\rho = -1$ indicates an inverse similarity (e.g. similarity between the diapositive and the negative of the same image).
- $\rho = 1$ indicates a perfect match (the highest similarity possible).

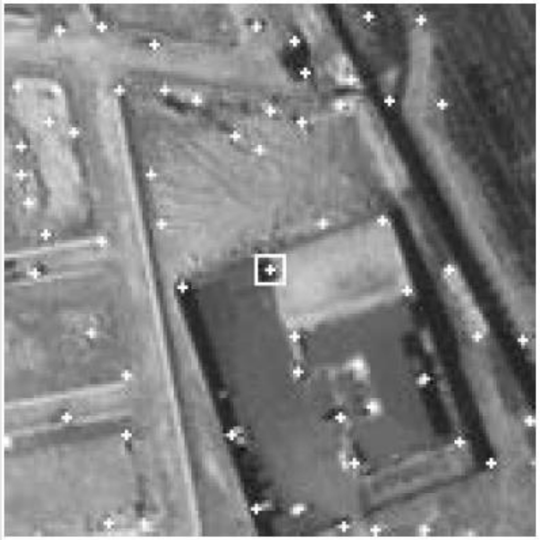
# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

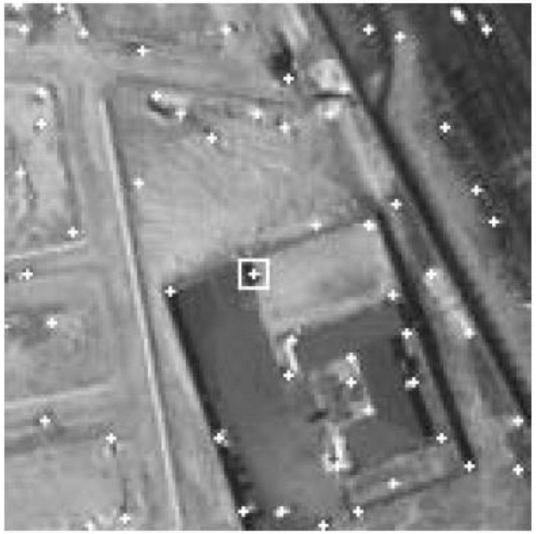
### Radiometric Similarity Measure

Reference Image

Input Image



Using a 7x7 window: $\rho = 0.8$



Using a 7x7 window: $\rho = 0.65$

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Image Registration Paradigm

Primitives

↓

Transformation Function

↓

Similarity Measure

↓

**Matching Strategy**

**Control the process of identifying and assessing the quality of automatically matched points.**

# IMAGE PREPROCESSING

## IMAGE MATCHING

Two basic image matching methods can be distinguished

***Area-based matching***. In this method, a search pattern is determined for the feature to be matched. This is then passed over a search window in the conjugate image, with the aim of identifying pixels with similar digital composition as the search pattern. More specifically, the cross correlation between the search pattern and the iterative search windows is compared.

For the pattern matrix, the standard error in gray level variation is given by

$$\sigma' = \sqrt{\left(\frac{1}{n-1}\right)\sum (\mathrm{d}'_{ij} - \mathrm{d}')^2}$$

where the mean of the gray value differences $\mathrm{d}' = \frac{1}{n}\sum_1^n \mathrm{d}'_{ij}$

Similarly, for the search window the standard error in gray level disparity is given by

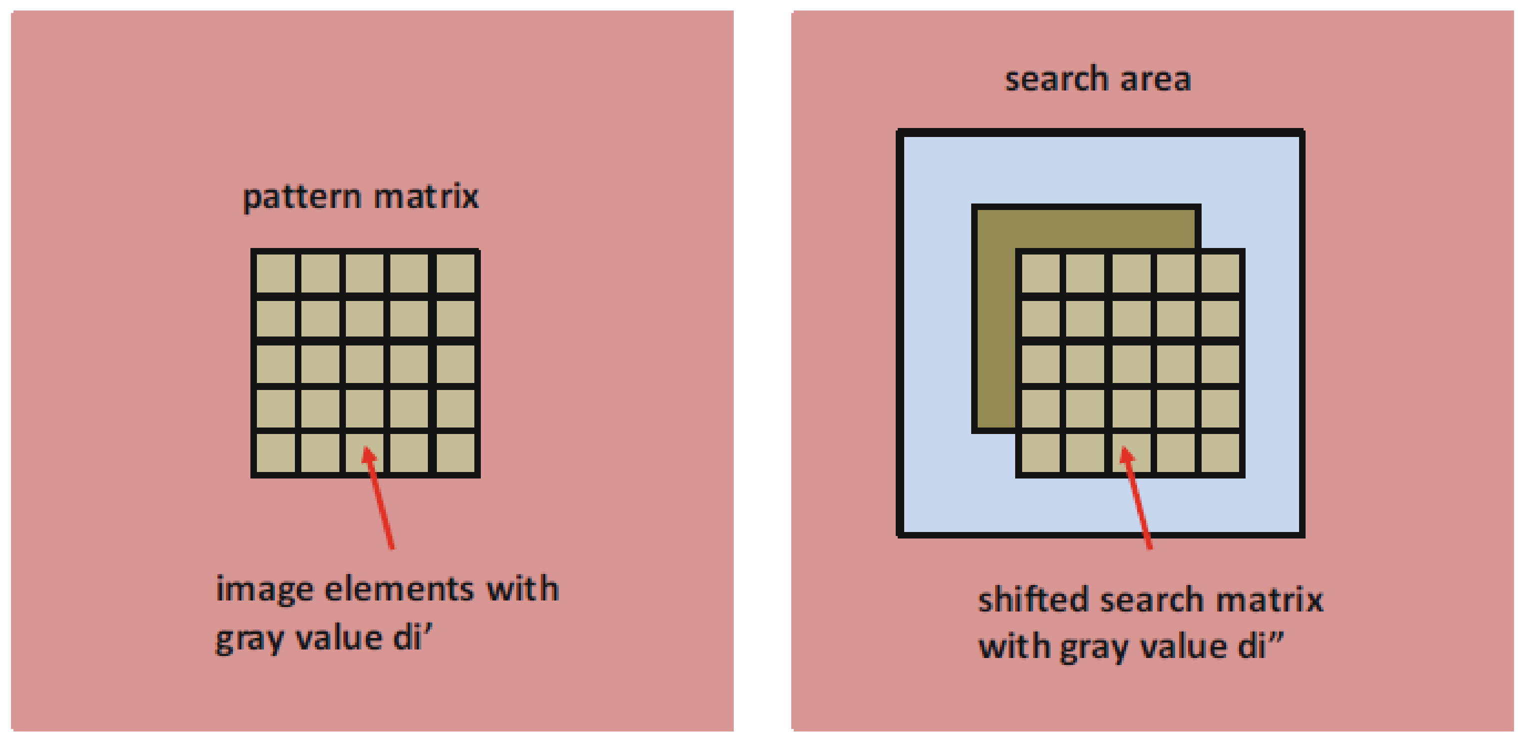
$$\sigma'' = \sqrt{\left(\frac{1}{n-1}\right)\sum (\mathrm{d}''_{ij} - \mathrm{d}'')^2}$$

$$Covr_{ij} = \frac{1}{n}\sum \mathrm{d}'_{ij} \cdot \mathrm{d}''_{ij}$$

$$r_{ij} = \frac{Covr_{ij}}{\sigma' \cdot \sigma''}$$

# IMAGE PREPROCESSING

## IMAGE MATCHING




(a) Image pattern (b) Search window

# IMAGE PREPROCESSING

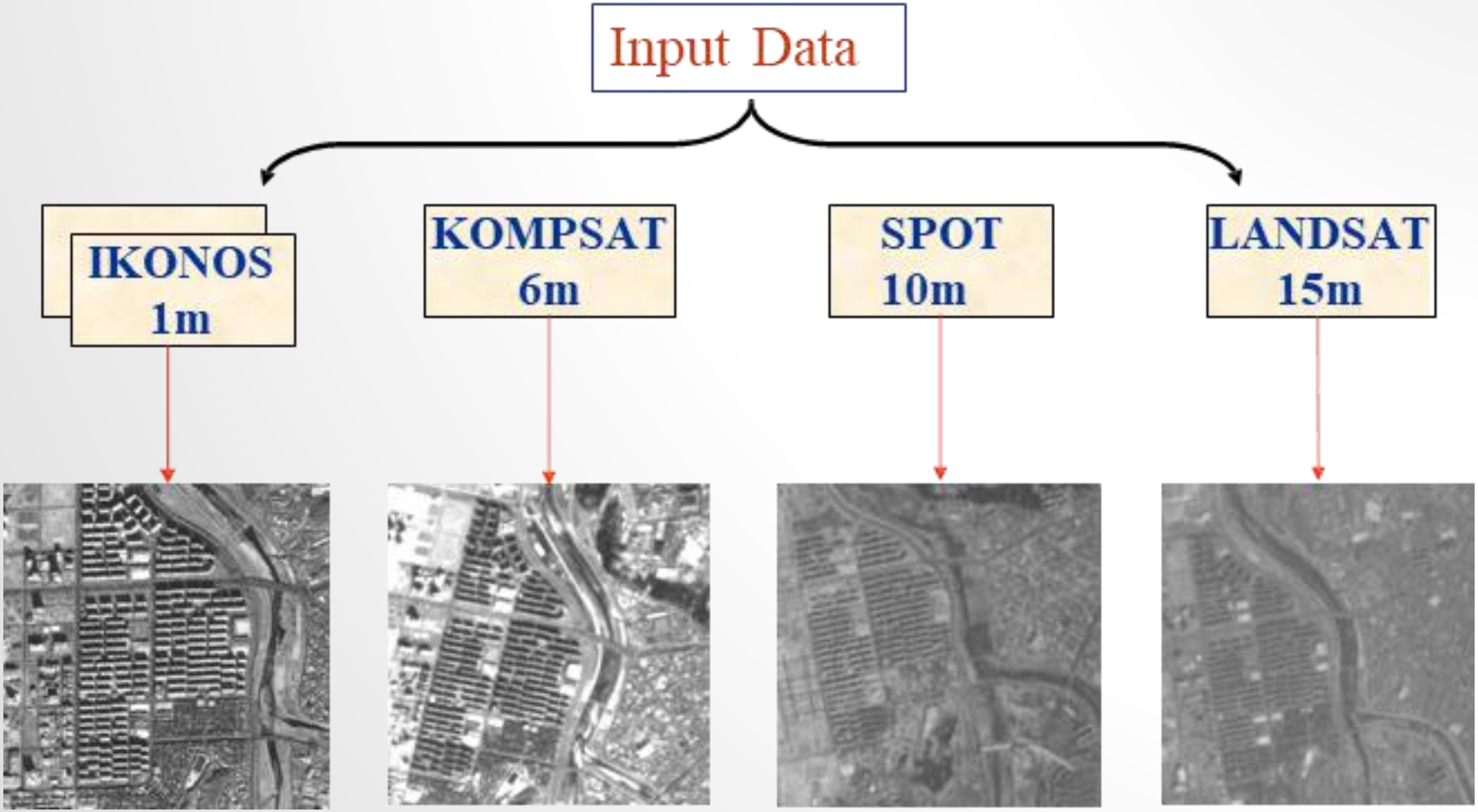
## IMAGE MATCHING

***Feature-based matching***. This is suitable for imagery with many discontinuous features like rivers, roads etc. As the name suggests, feature-based matching is premised on the detection and identification of image features which possess distinct gray value characteristics, either individually or collectively. These may include features comprising of noticeable primitives, such as points, line segments, etc., and/or interest points of high gray value variance, such as bright spots, sharp corners, etc. Different operators e.g., ***Sobel***, ***Moravec***, ***Förstner*** etc., may be employed to support feature-based matching.

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

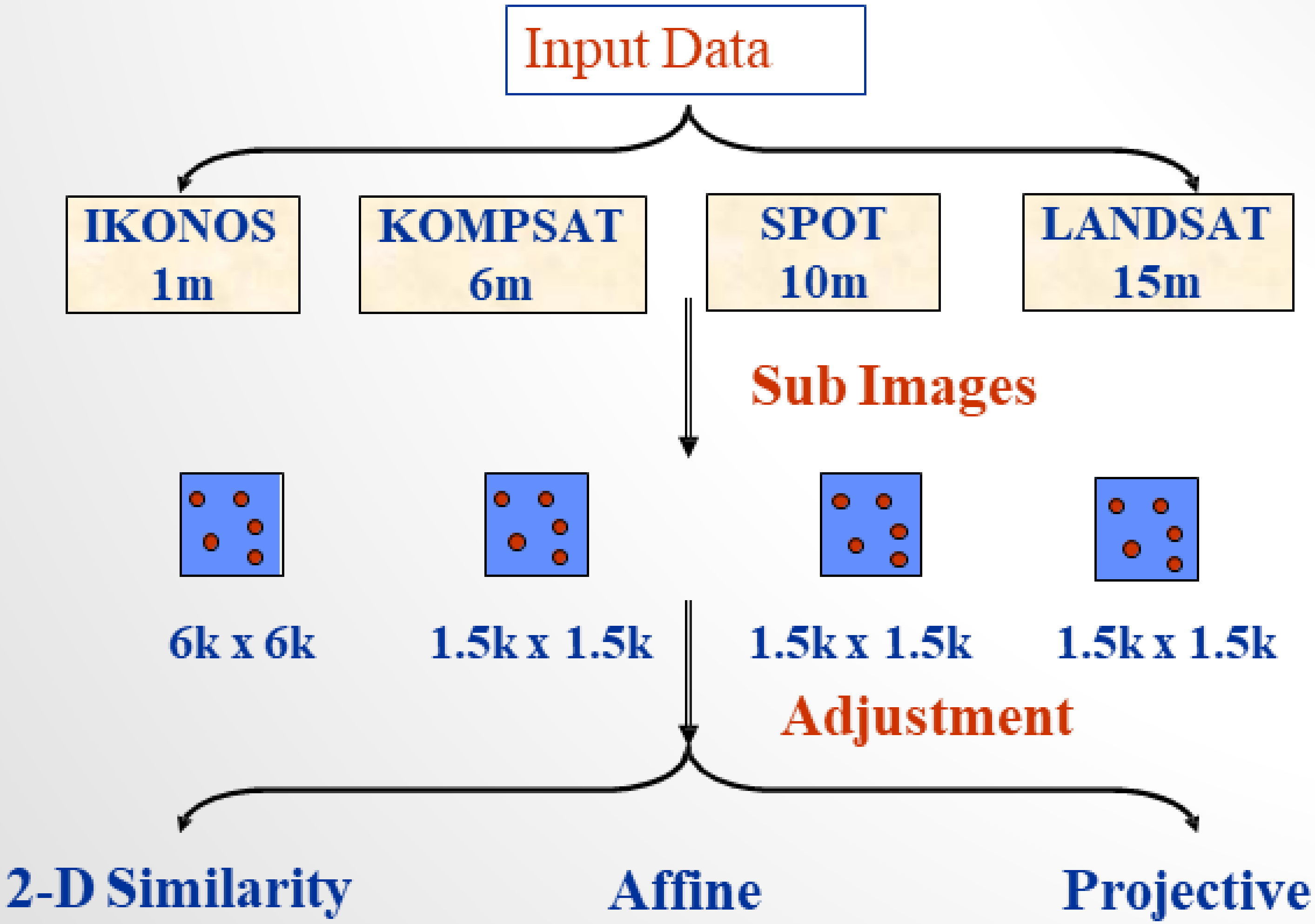
### Image Registration: Example



# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

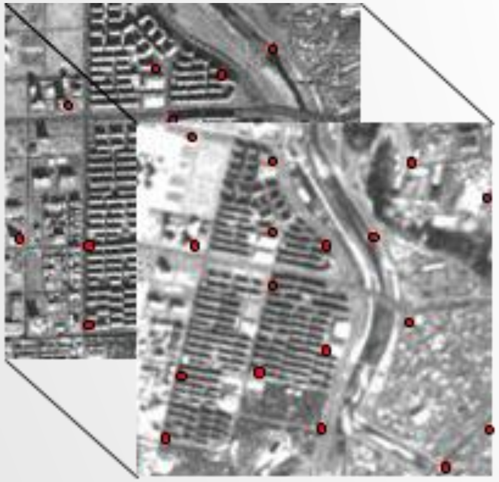
### Image Registration: Example



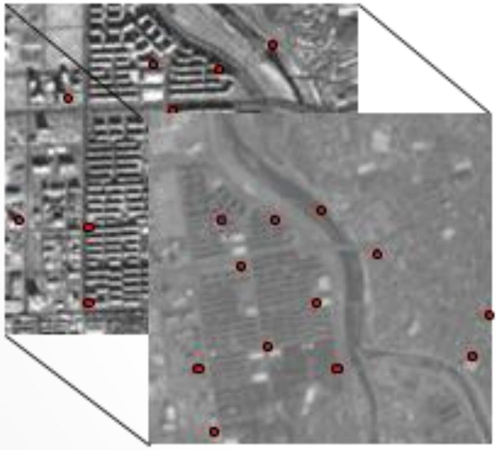
# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

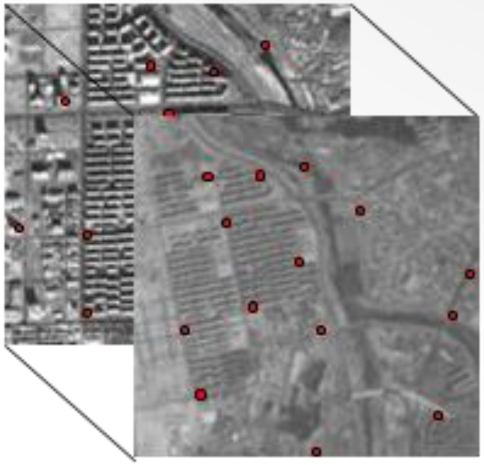
### Image Registration: Example



IKONOS-KOMPSAT



IKONOS-SPOT



IKONOS-LANDSAT

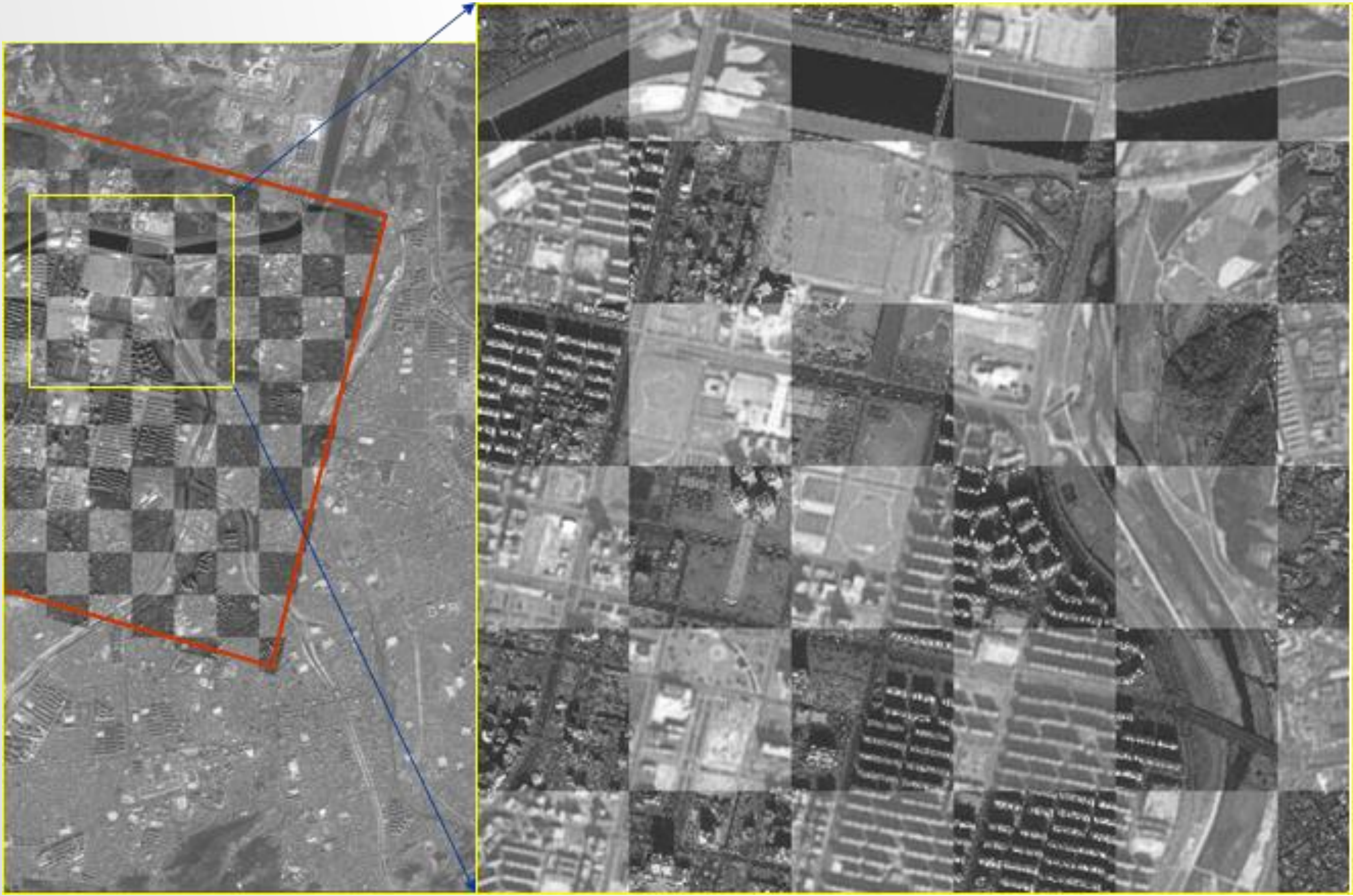
**Estimated Variance Component**

| | Similarity | Affine |
|---|---|---|
| Ikonos - Kompsat | 4.615409 | 2.224918 |
| Ikonos - Spot | 7.669094 | 6.602059 |
| Ikonos - Landsat | 7.487283 | 6.506330 |

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### IKONOS – KOMPSAT Mosaic



# IMAGE PREPROCESSING

## KOMPSAT – SPOT Mosaic

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Image Registration & Change Detection

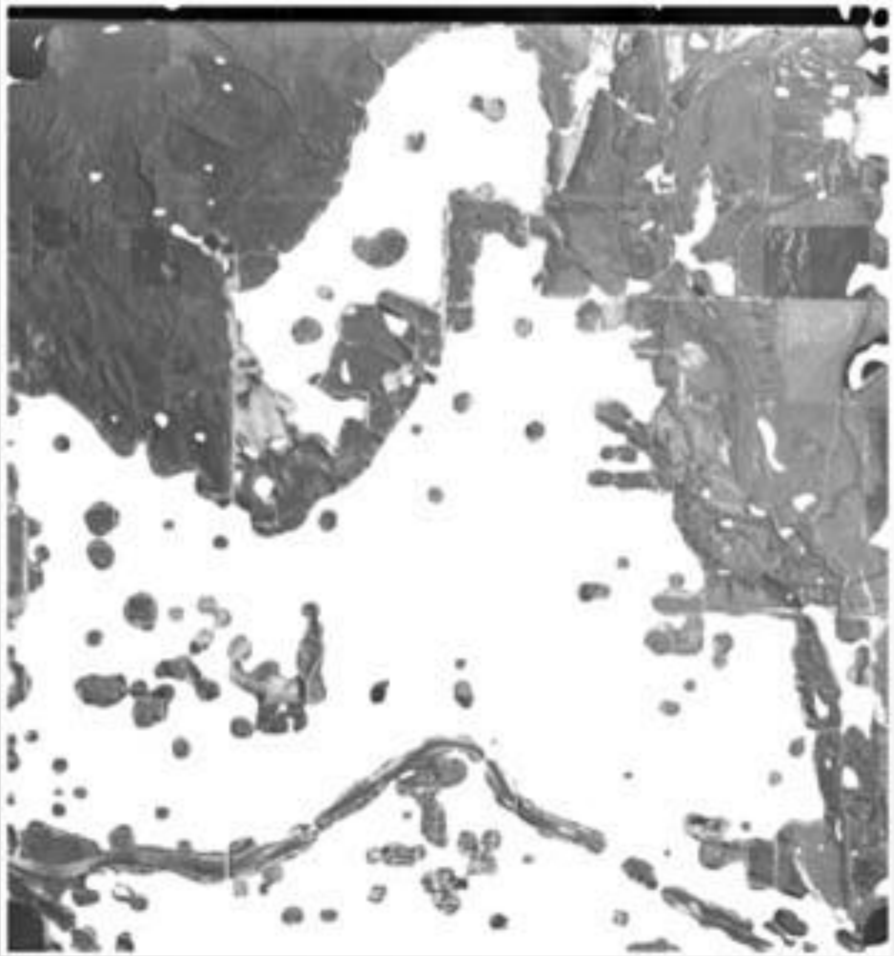
Calgary, 1956

Calgary, 1999

# IMAGE PREPROCESSING

## Photogrammetric Procedures

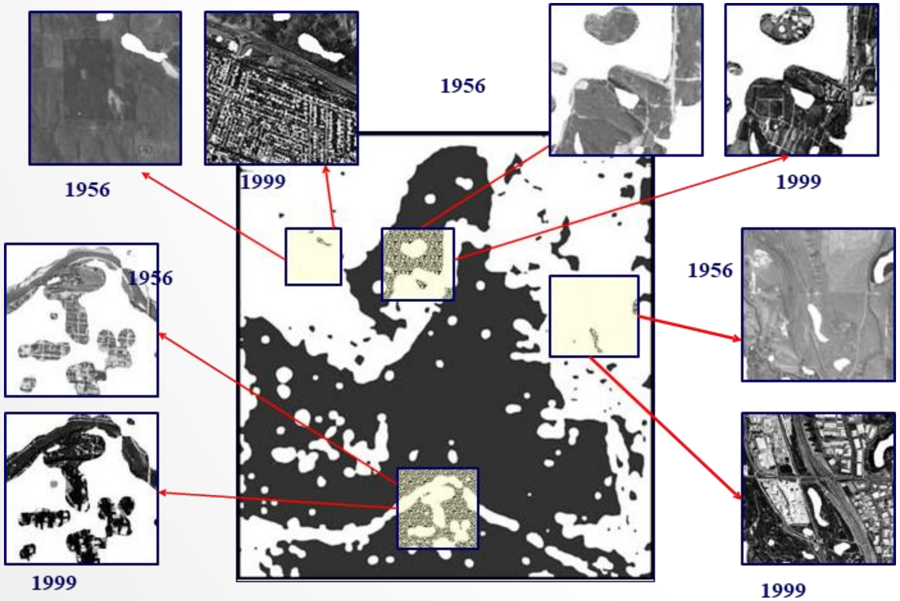
### Image Registration & Change Detection

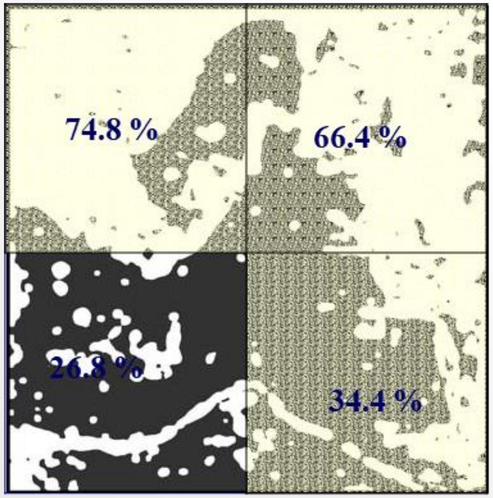


# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Change Detection: (Quantitative Measurements)

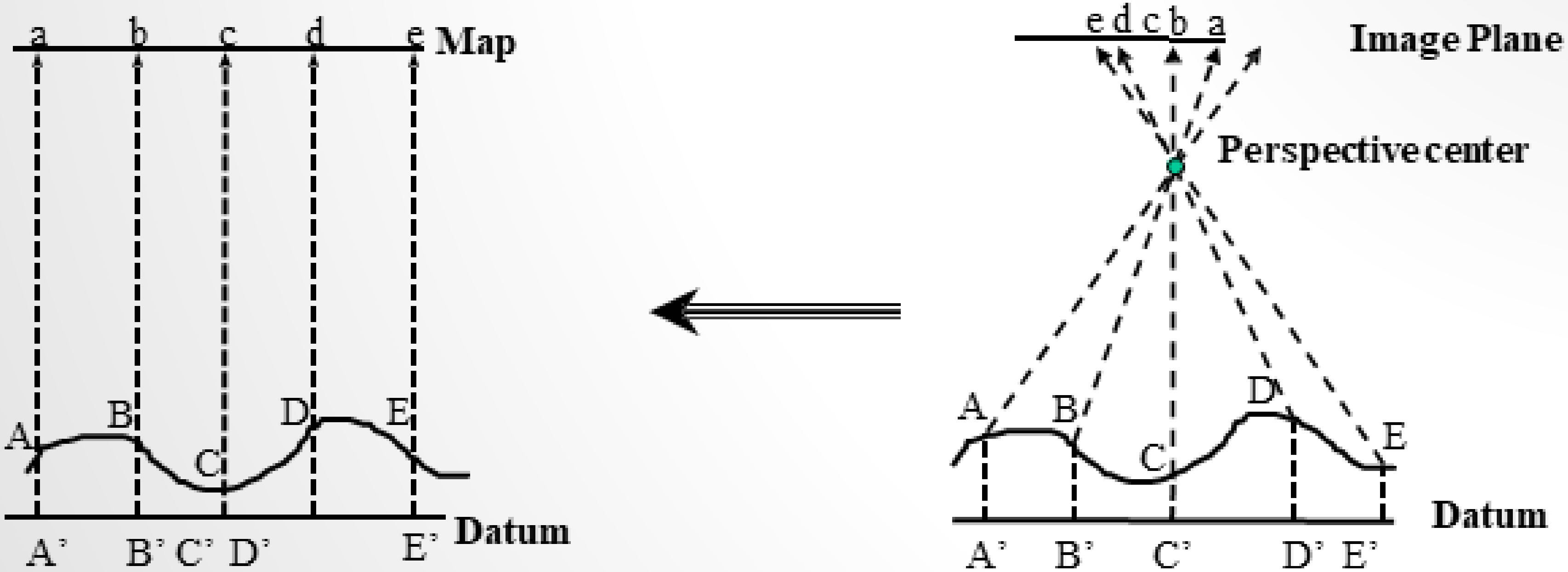


# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Ortho-Photo Generation



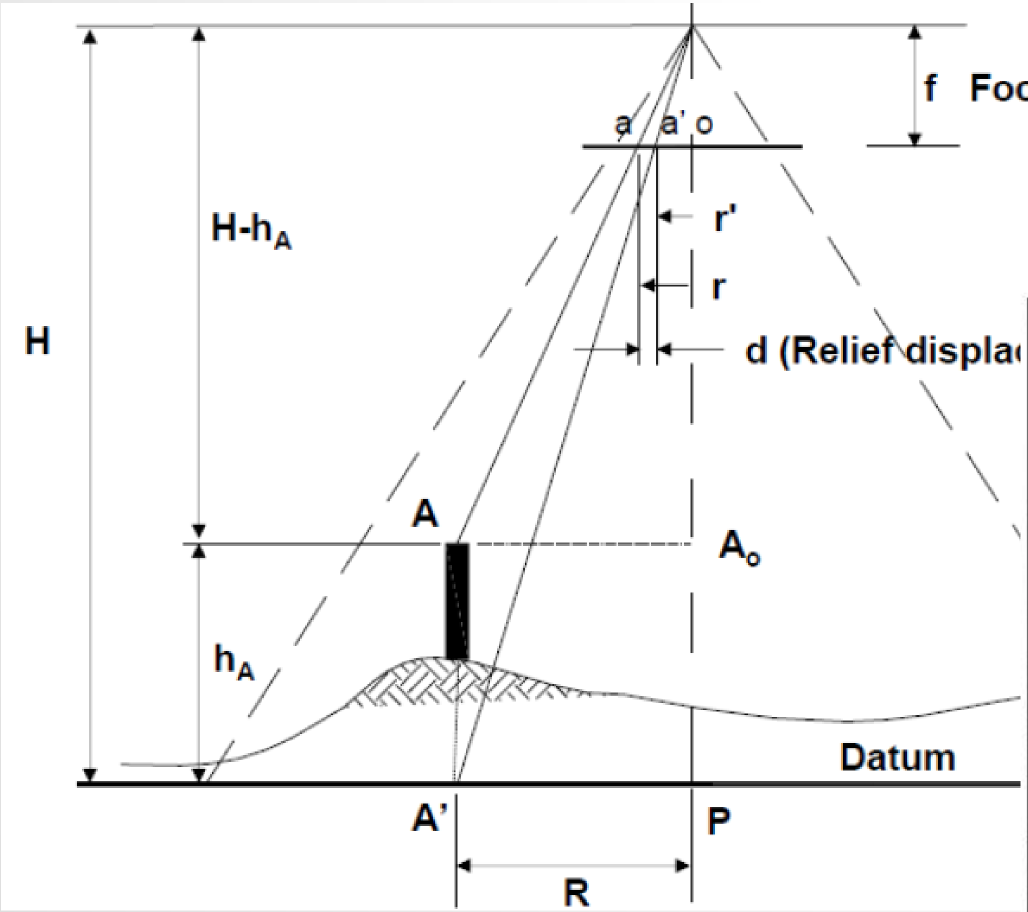

- Orthogonal projection.
- Uniform scale.
- No relief displacement.

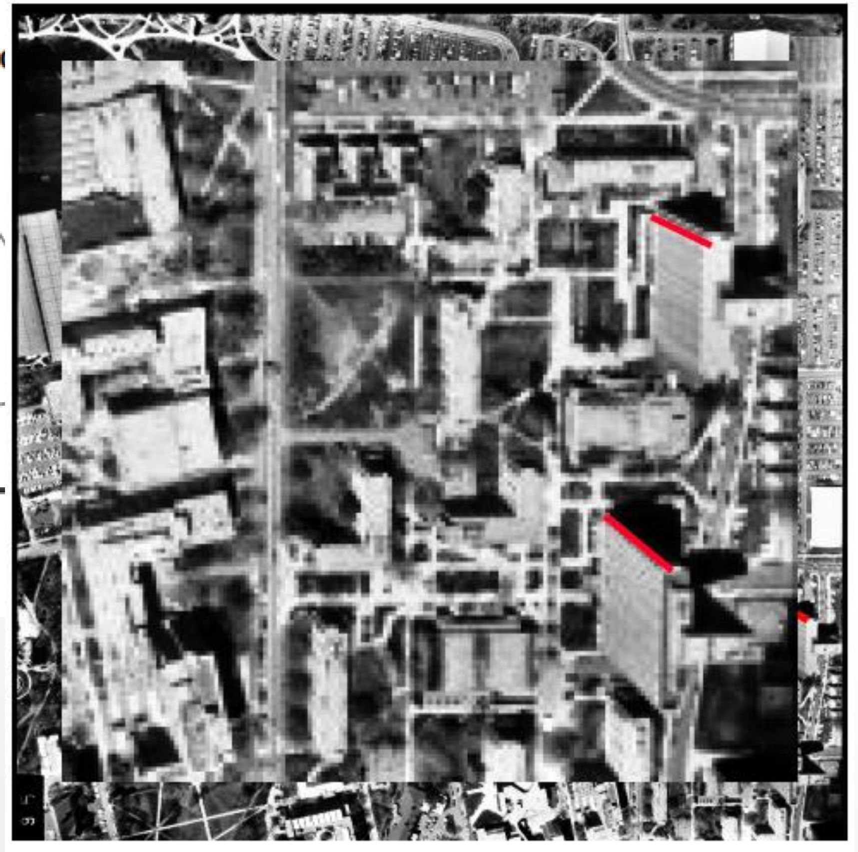
- Perspective projection.
- Non-uniform scale.
- Relief displacement.

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Relief Displacement



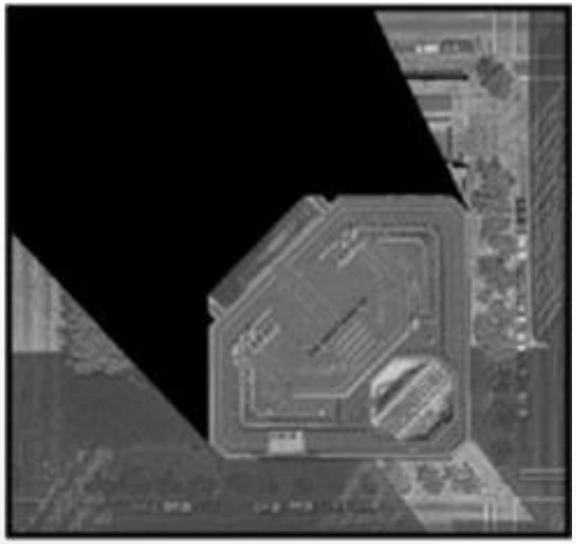



# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Ortho-Photo

- Characteristics:
  - Relief displacement free image.
  - Image which has the same characteristics of a map.
    - Orthogonal (parallel) projection.
    - Uniform scale.
    - No relief displacement.



# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Ortho-Photos: Advantages

- They have the same characteristics of a map but with more features.
- The user can draw lines and measure distances without the need for stereo-plotters.
- Cheap alternatives for maps (for developing countries).
- They can be generated automatically.
- They are important for GIS applications.

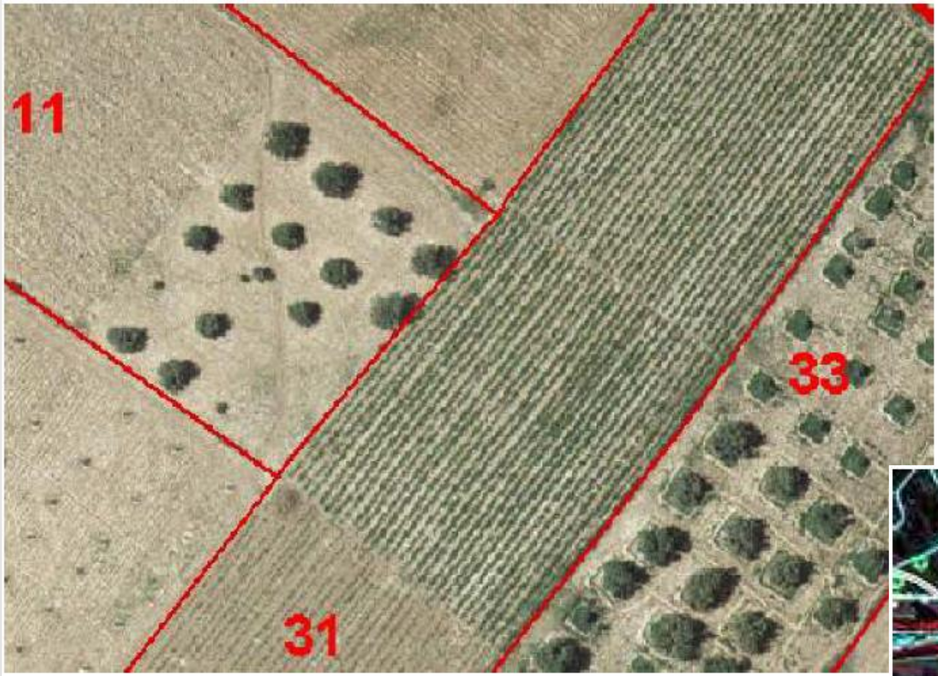

- Perspective Image

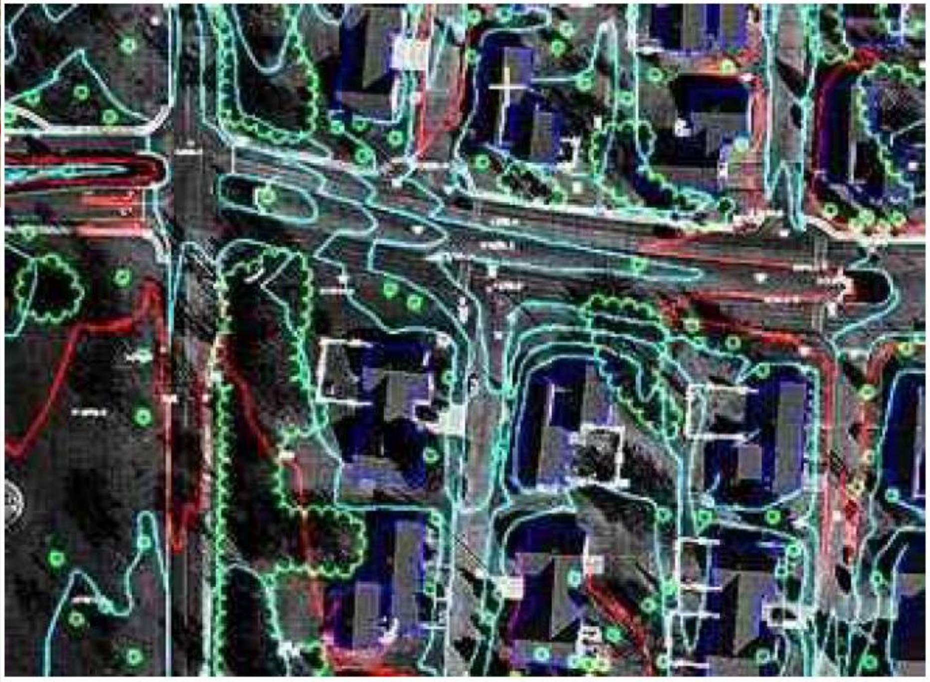
- Ortho-Photo

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Ortho-Photo Application: Example



# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Ortho-Photos: Applications & Generation

- Applications include:
  - Parcel mapping and tax assessment,
  - Infrastructure management,
  - Resource analysis,
  - Drainage studies,
  - E-911 operations mapping.
- Ortho-photos are generated from aerial and satellite images through a process known as ortho-rectification.

- Aerial imagery and satellite scenes do not show features in their correct locations due to displacements caused by the tilt of the sensor and terrain relief.
- Ortho-rectification transforms the central projection of the photograph into an orthogonal view of the ground, thereby removing the distorting effects of tilt and terrain relief.

# IMAGE PREPROCESSING

## Digital Image Rectification

- Generation of an ortho-photo map from an aerial photograph requires information on:
  - The internal characteristics of the camera (IOP).
  - The location of the camera ($X_o$, $Y_o$, $Z_o$).
  - Camera orientation in space ($\omega$, $\varphi$, $\kappa$).
  - Digital elevation model.
- If the terrain is flat, the above information may not be required.
  - In such situations, ortho-photos can be produced by a process called *polynomial rectification* that only removes the effect of tilt using few control points.

**Tilted Image**

**Rectified Image**

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Polynomial Rectification

- Mainly used for relatively flat terrain (to remove the effect of the tilt).
- It uses Ground Control Points (GCPs) to relate the ortho-photo and the image coordinate systems.
- The degree of the polynomial depends on the number of available GCPs and the nature of the terrain.
- More GCPs yield more accurate rectified imagery.
- Polynomial rectification is completely independent from the geometry of the imaging system.
  - Therefore, it can be used for both satellite and aerial images.
- It is more often used for satellite images due to the following reasons:
  - Geometry and distortions in satellite imagery are sometimes difficult to model,
  - The relief displacement due to the topography of the Earth is relatively small compared to the flying height of the satellite.

$$x = \sum_{i=0}^{N} \sum_{j=0}^{N-i} a_{ij} X^i Y^j$$

$$y = \sum_{i=0}^{N} \sum_{j=0}^{N-i} b_{ij} X^i Y^j$$

$$x = a_{00} + a_{10} X + a_{01} Y + a_{20} X^2 + a_{11} XY + a_{02} Y^2$$
$$= a_0 + a_1 X + a_2 Y + a_3 X^2 + a_4 XY + a_5 Y^2$$

$$y = b_{00} + b_{10} X + b_{01} Y + b_{20} X^2 + b_{11} XY + b_{02} Y^2$$
$$= b_o + b_1 X + b_2 Y + b_3 X^2 + b_4 XY + b_5 Y^2$$

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Polynomial Rectification: Final Remarks

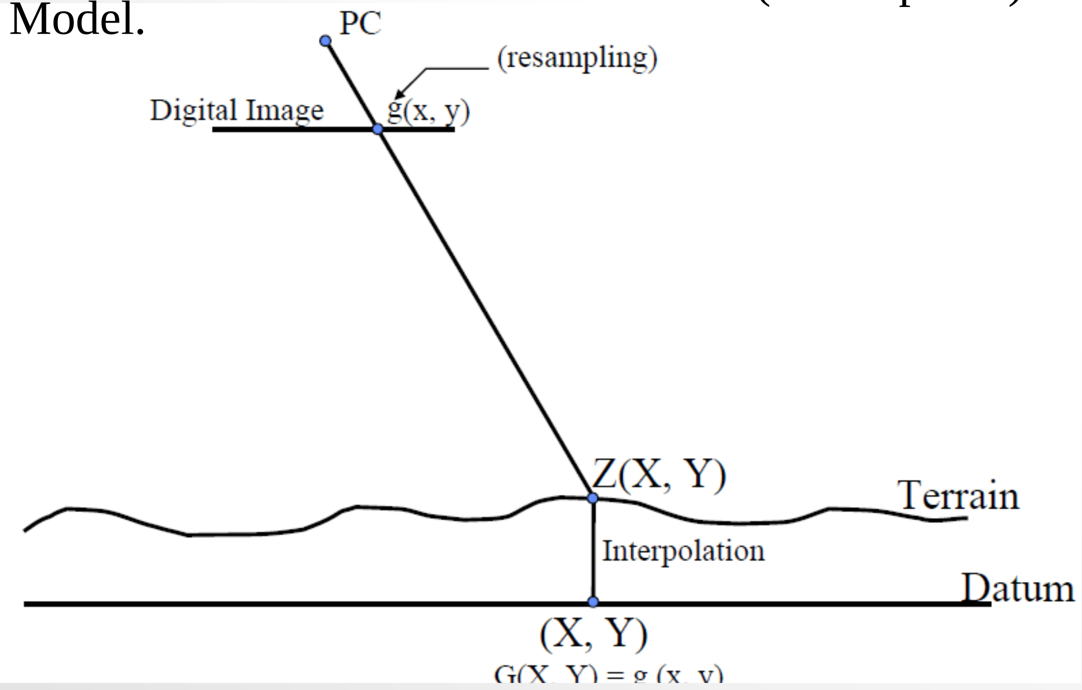
- Advantages:
  - Fast and easy to implement.
  - Can use cheap scanners (for scanning aerial images).
  - Can use maps to determine the coordinates of GCP.
  - No need for the sensor model.
- Disadvantages:
  - Less accurate (does not use the sensor model).
  - Not applicable for aerial imagery over urban areas.
  - No specific procedure for determining the optimum polynomial order.

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Differential Rectification

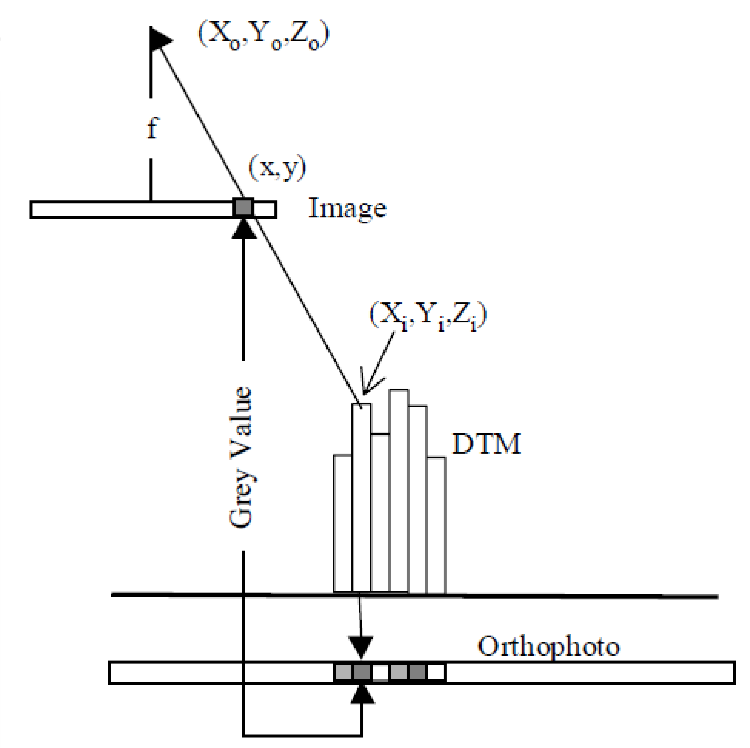
- The objective of differential rectification is the assignment of grey values from the image (usually aerial image) to each cell within the ortho-photo.
- After the rectification, both the elevation and the grey/color values are stored at the same location along the datum.
- Input:
  - Digital Image.
  - EOP of that image.
  - IOP of the used camera.
  - Digital Elevation Model.
- Output:
  - Digital image which has the same characteristics of a map (Ortho-photo).



# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Differential Rectification

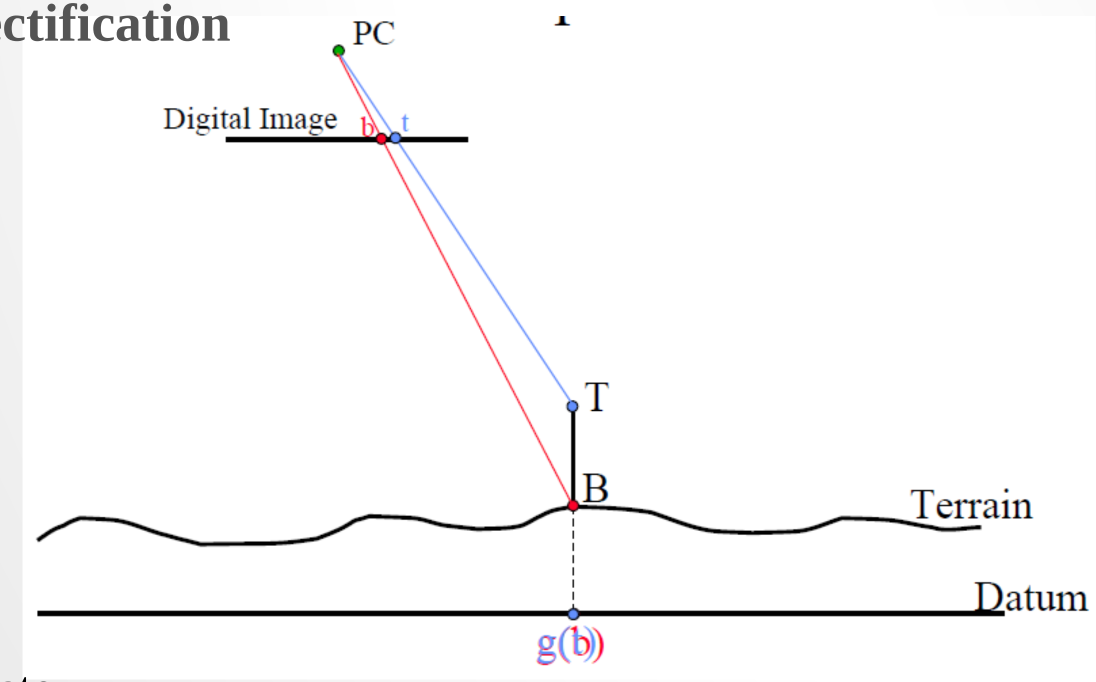



- Procedure:
  - Define a uniform grid over the ortho-photo plane (datum).
  - For each grid element (X, Y) in the ortho-photo plane, interpolate for the corresponding elevation → Z(X, Y).
  - Using the EOP and IOP together with the collinearity equations find the corresponding image point (x, y).
  - Find g(x, y) using one of the resampling techniques.
  - G(X, Y) = g(x, y).
  - Repeat the above procedure for all the pixels in the ortho-photo plane.

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Differential Rectification

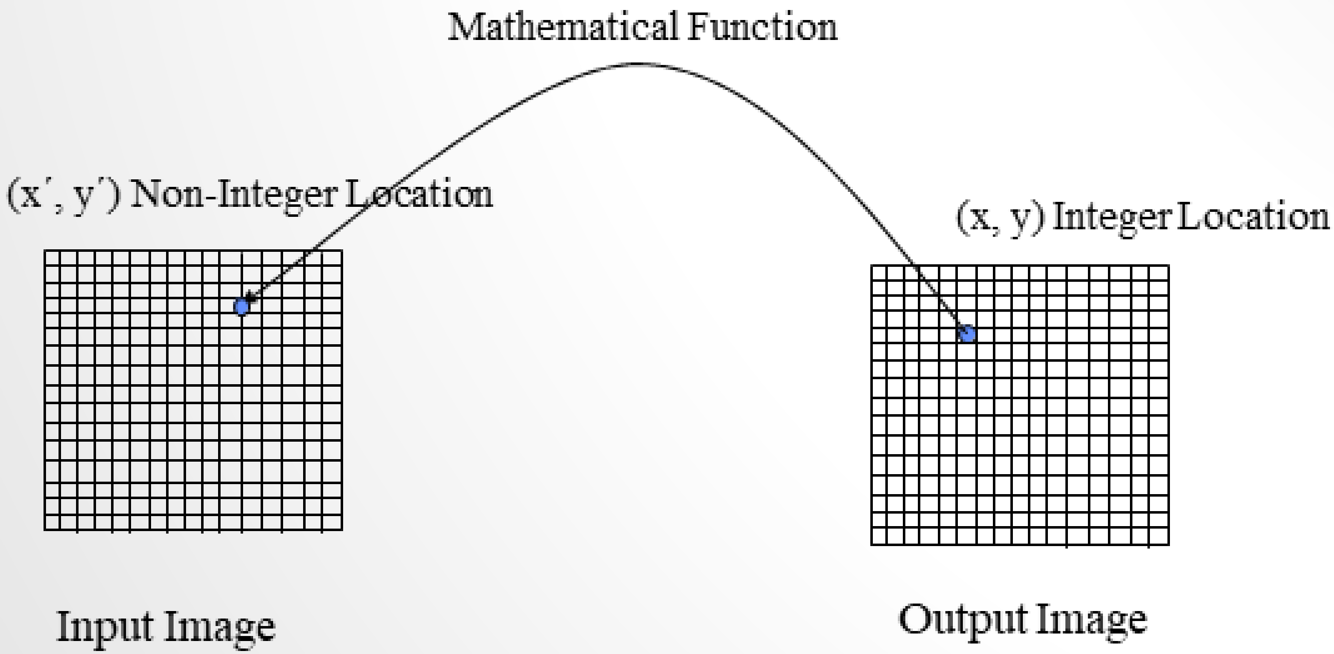



- Advantages:
  - More accurate.
  - Uses the sensor model.
  - Applicable for satellite and aerial imagery.
- Disadvantages:
  - Requires DTM.
  - Needs expensive scanner.
  - Requires the sensor model.
  - Computationally expensive.

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Geometric Image Transformation




- Image rotation.
- Image to image registration.
- Image rectification (ortho-photo generation).
- Image normalization according to epipolar geometry.

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Geometric Image Transformation

$$\begin{bmatrix} x' \\ y' \end{bmatrix} = \begin{bmatrix} \cos\alpha & \sin\alpha \\ -\sin\alpha & \cos\alpha \end{bmatrix} \begin{bmatrix} x \\ y \end{bmatrix}$$

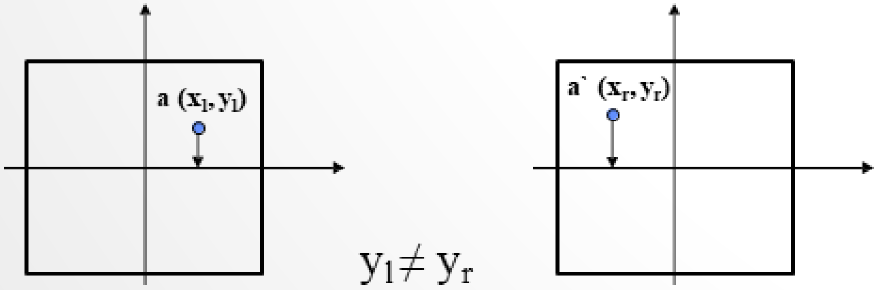
**Image rotation**

$\alpha$ - *Rotation angle*

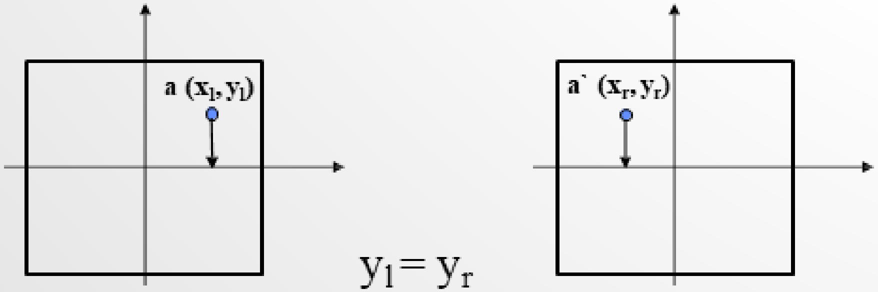
$(x', y')$ *input image coordinates* (*non* – integer)

$(x, y)$ *output image coordinates* (integer)

### Normalized Image Generation




Input Stereo-Pair

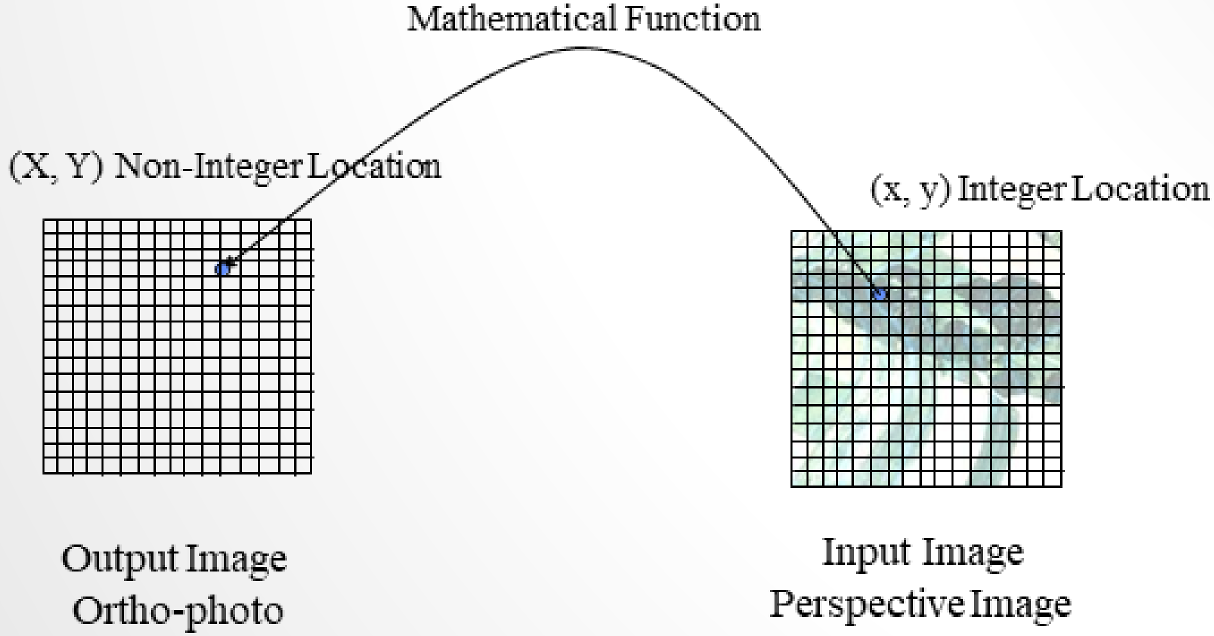



Output Stereo-Pair

# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

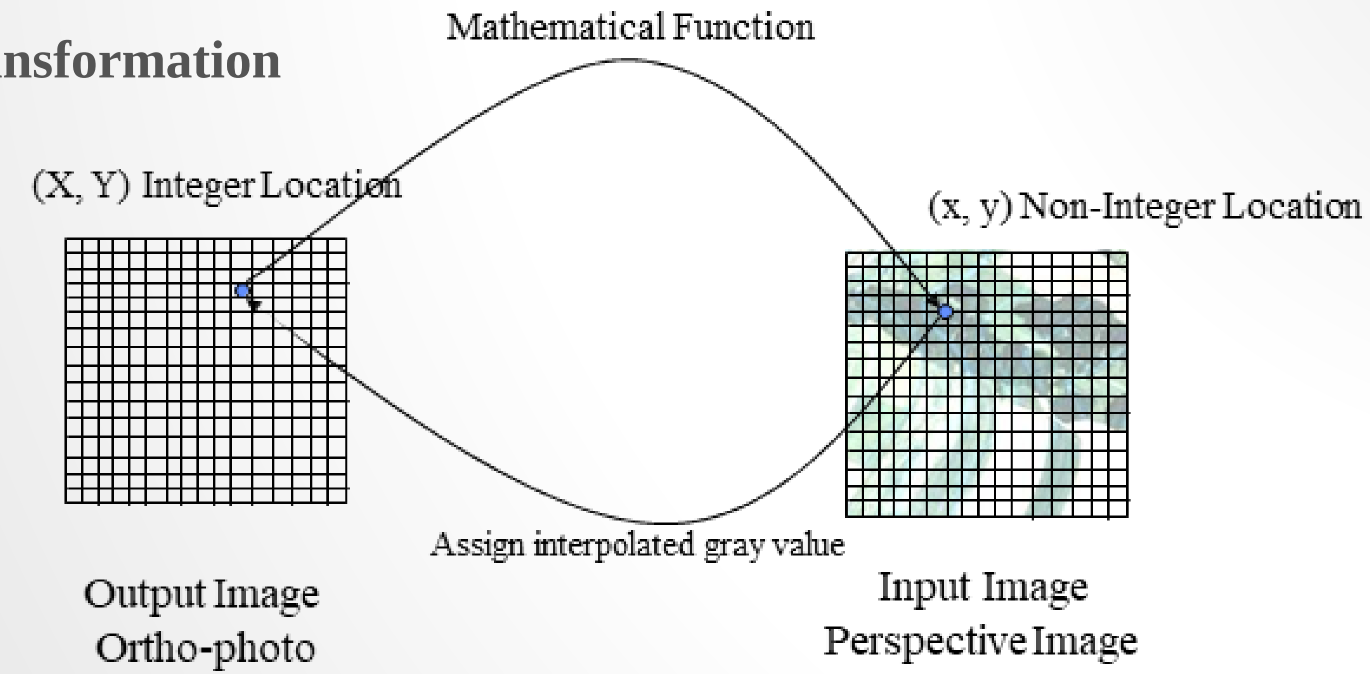
### Direct Transformation




- Assign the pixel gray/color value to the nearest ortho-photo cell.
- Transformation from the image coordinates (x,y) to the ortho-photo coordinates (X,Y).
- Assign the pixel gray/color value to the nearest ortho-photo cell.
- Advantages:
  - Grey/color values of the image will not change.
- Disadvantages:
  - Not all the ortho-photo cells will be assigned a gray/color value from the image and therefore their gray/color values have to be interpolated from neighboring cells.

# IMAGE PREPROCESSING
## PHOTOGRAMMETRIC PROCEDURES

### Indirect Transformation




- Estimate the gray/color value using interpolation / resampling techniques (e.g. nearest neighbor).

- Transformation from the ortho-photo coordinates (X,Y) to the image coordinates (x,y).
- Estimate the gray/color value using interpolation / resampling techniques (e.g. nearest neighbor).
- Assign the interpolated gray/color value to the transformed ortho-photo cell.
- Advantages:
  - Every ortho-photo cell will get a gray/color value.
- Disadvantages:
  - Interpolating the gray/color value is time consuming.
  - The gray/color values of the final rectified images might not be the same as those of the original image (due to interpolation).

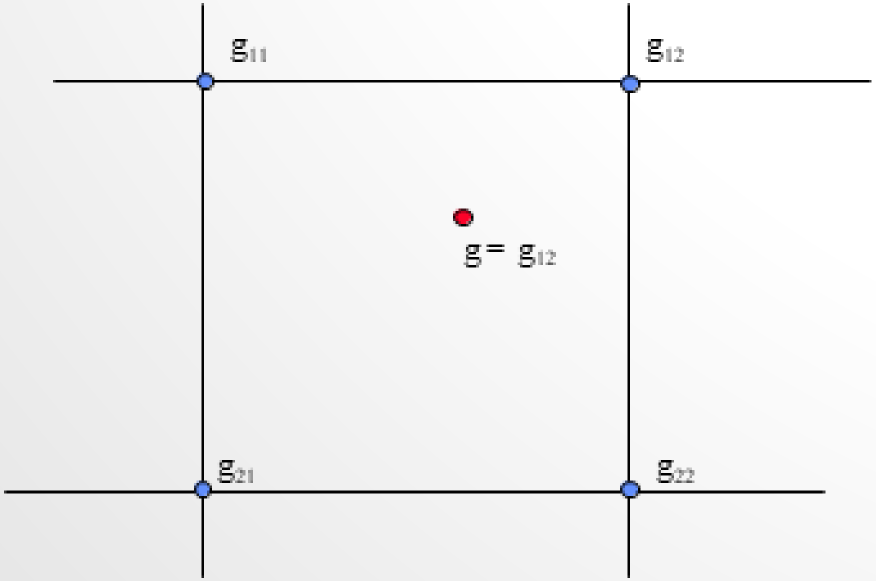
# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Image Resampling

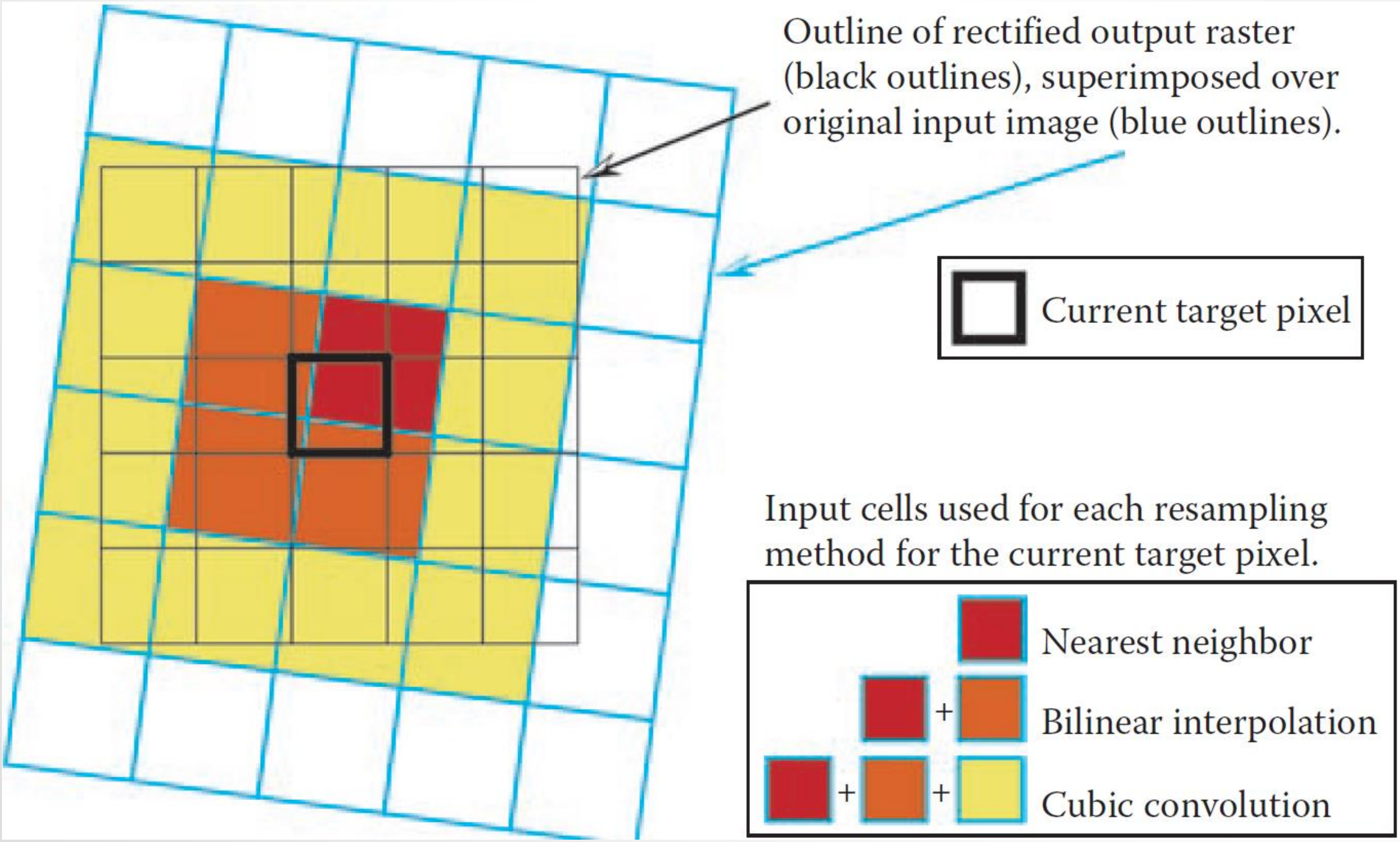
- Objective:
  - compute g(x′, y′) for non-integer (x′, y′).
- Alternatives:
  - Nearest Neighbor algorithm.
  - Bilinear interpolation.
  - Bi-cubic convolution.

### Nearest Neighbor Resampling



# IMAGE PREPROCESSING

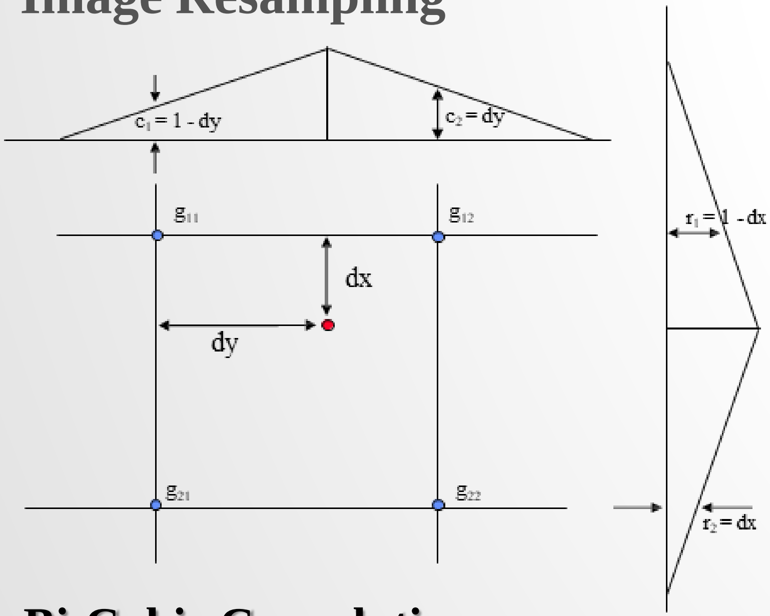
## PHOTOGRAMMETRIC PROCEDURES



# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

### Image Resampling

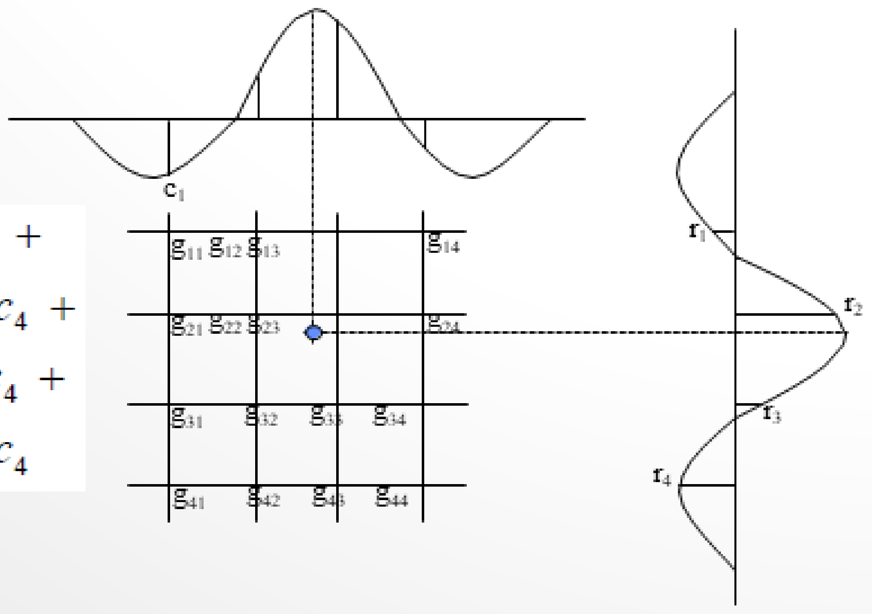



### Bilinear Resampling

$$g = g_{11}\, r_1\, c_1 + g_{12}\, r_1\, c_2 + g_{21}\, r_2\, c_1 + g_{22}\, r_2\, c_2$$

### Bi-Cubic Convolution

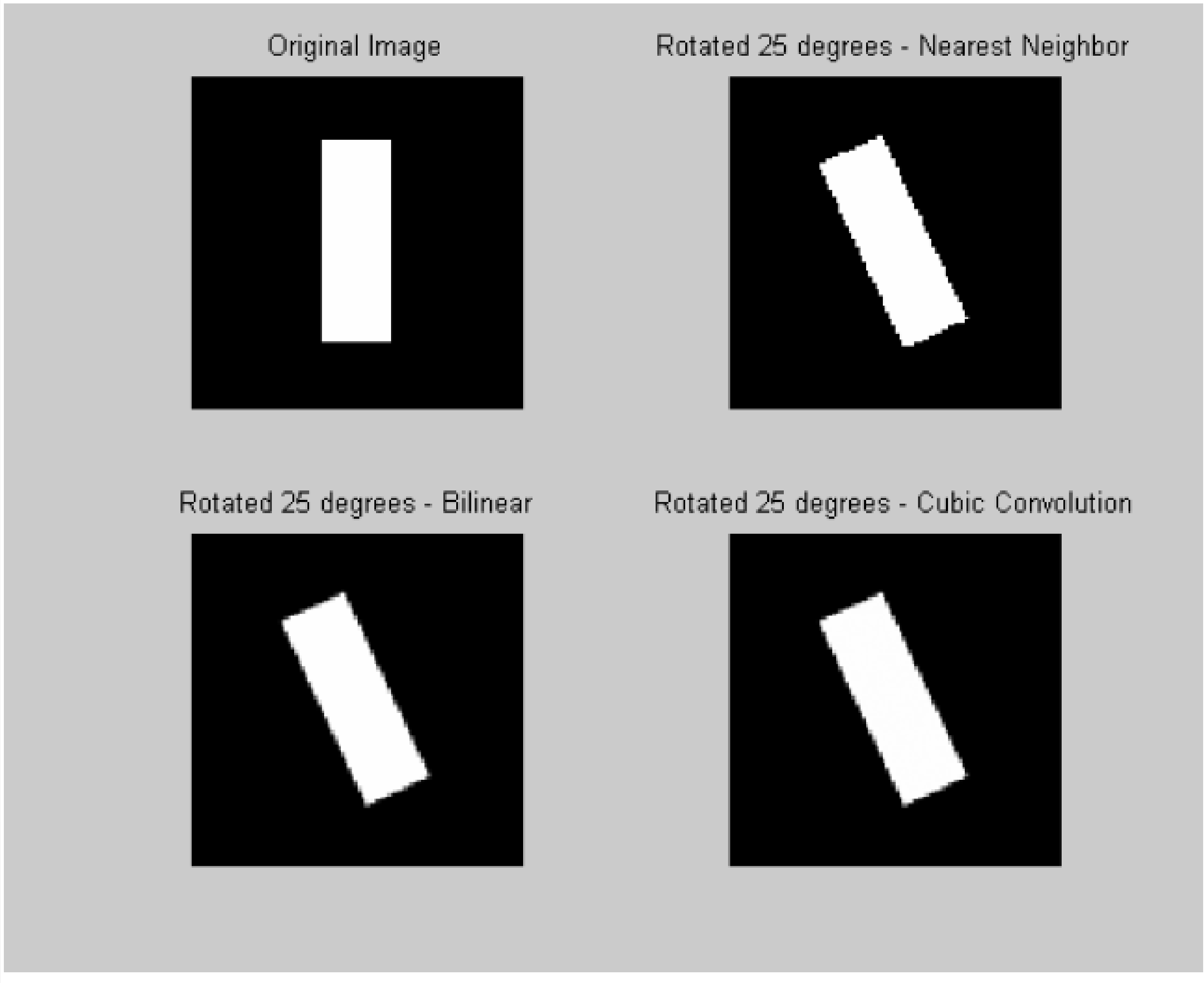
$$\begin{aligned} g = \quad & g_{11}\, r_1\, c_1 + g_{12}\, r_1\, c_2 + g_{13}\, r_1\, c_3 + g_{14}\, r_1\, c_4 + \\ & g_{21}\, r_2\, c_1 + g_{22}\, r_2\, c_2 + g_{23}\, r_2\, c_3 + g_{24}\, r_2\, c_4 + \\ & g_{31}\, r_3\, c_1 + g_{32}\, r_3\, c_2 + g_{33}\, r_3\, c_3 + g_{34}\, r_3\, c_4 + \\ & g_{41}\, r_4\, c_1 + g_{42}\, r_4\, c_2 + g_{43}\, r_4\, c_3 + g_{44}\, r_4\, c_4 \end{aligned}$$



# IMAGE PREPROCESSING

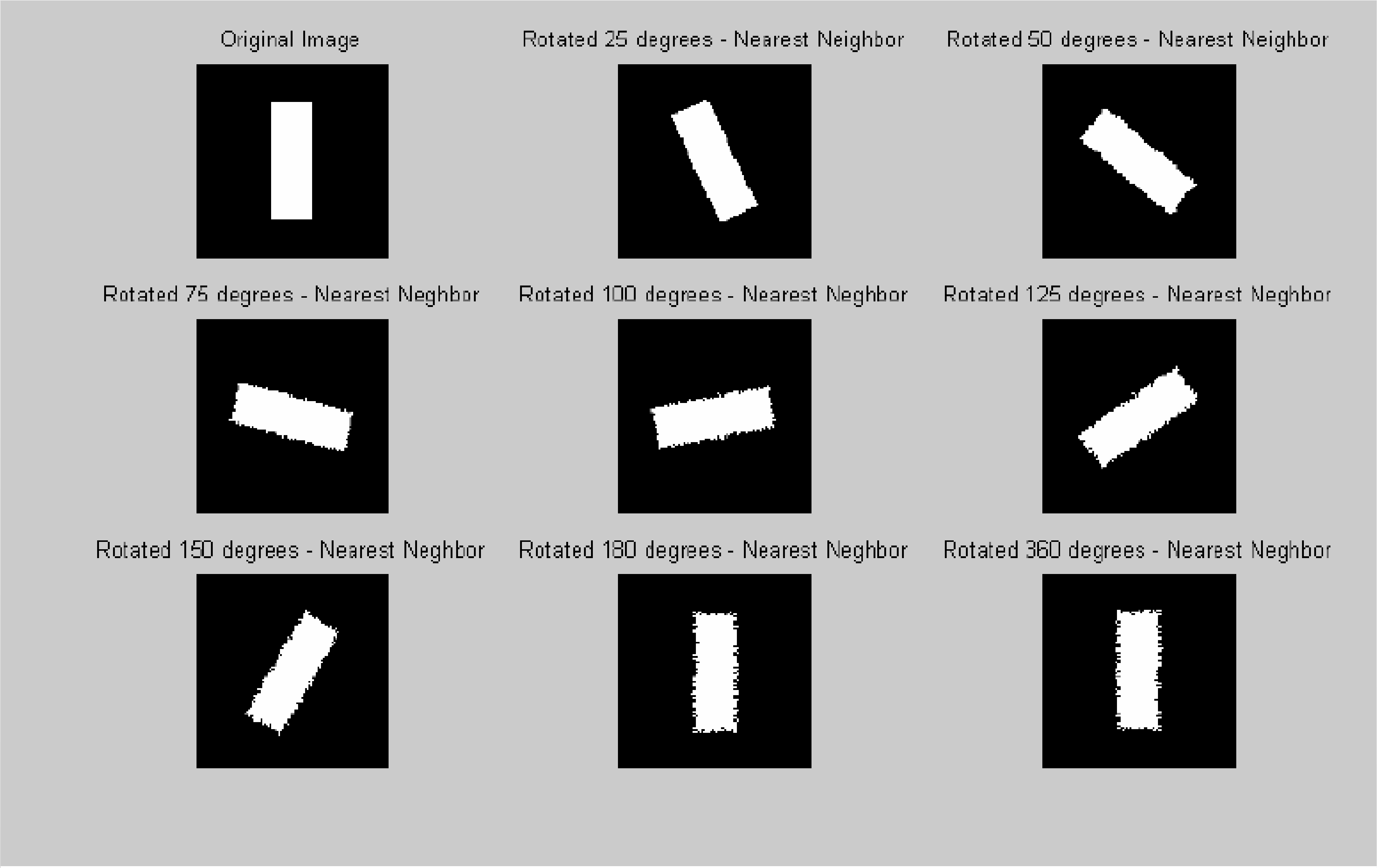
## PHOTOGRAMMETRIC PROCEDURES

### Example (Image Rotation)



# IMAGE PREPROCESSING

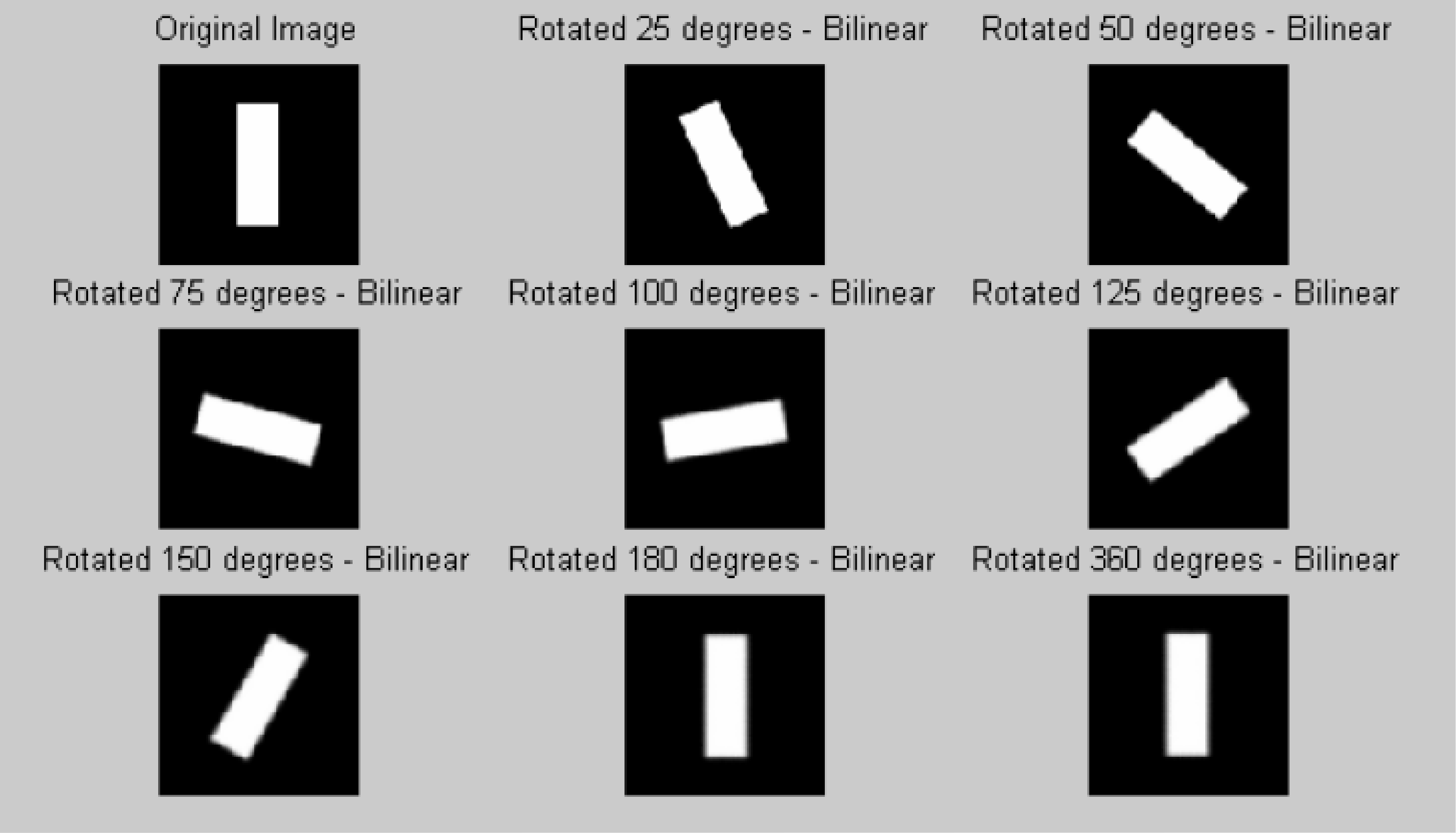
## Nearest Neighbor Resampling



# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

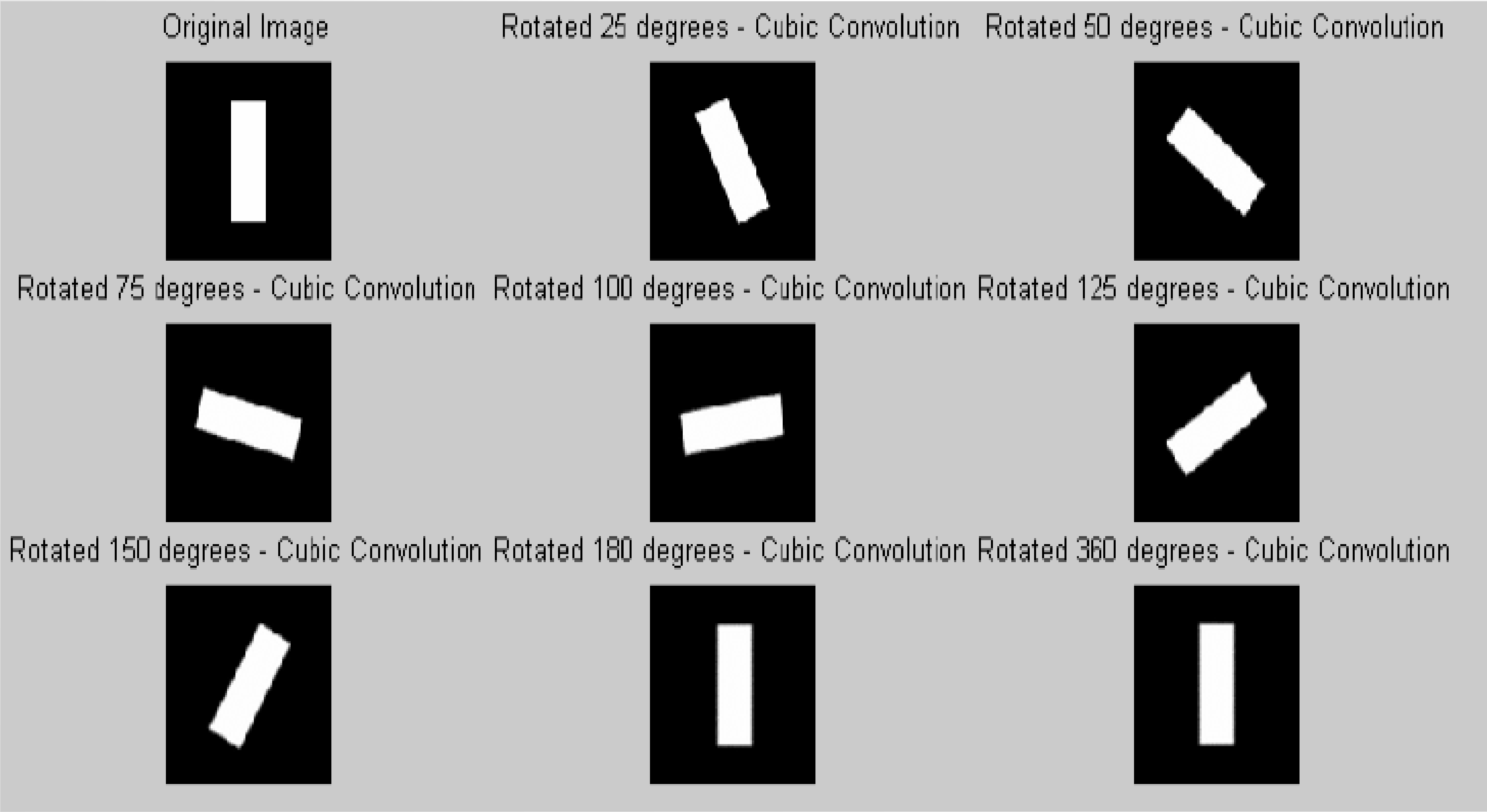
### Bilinear Resampling



# IMAGE PREPROCESSING

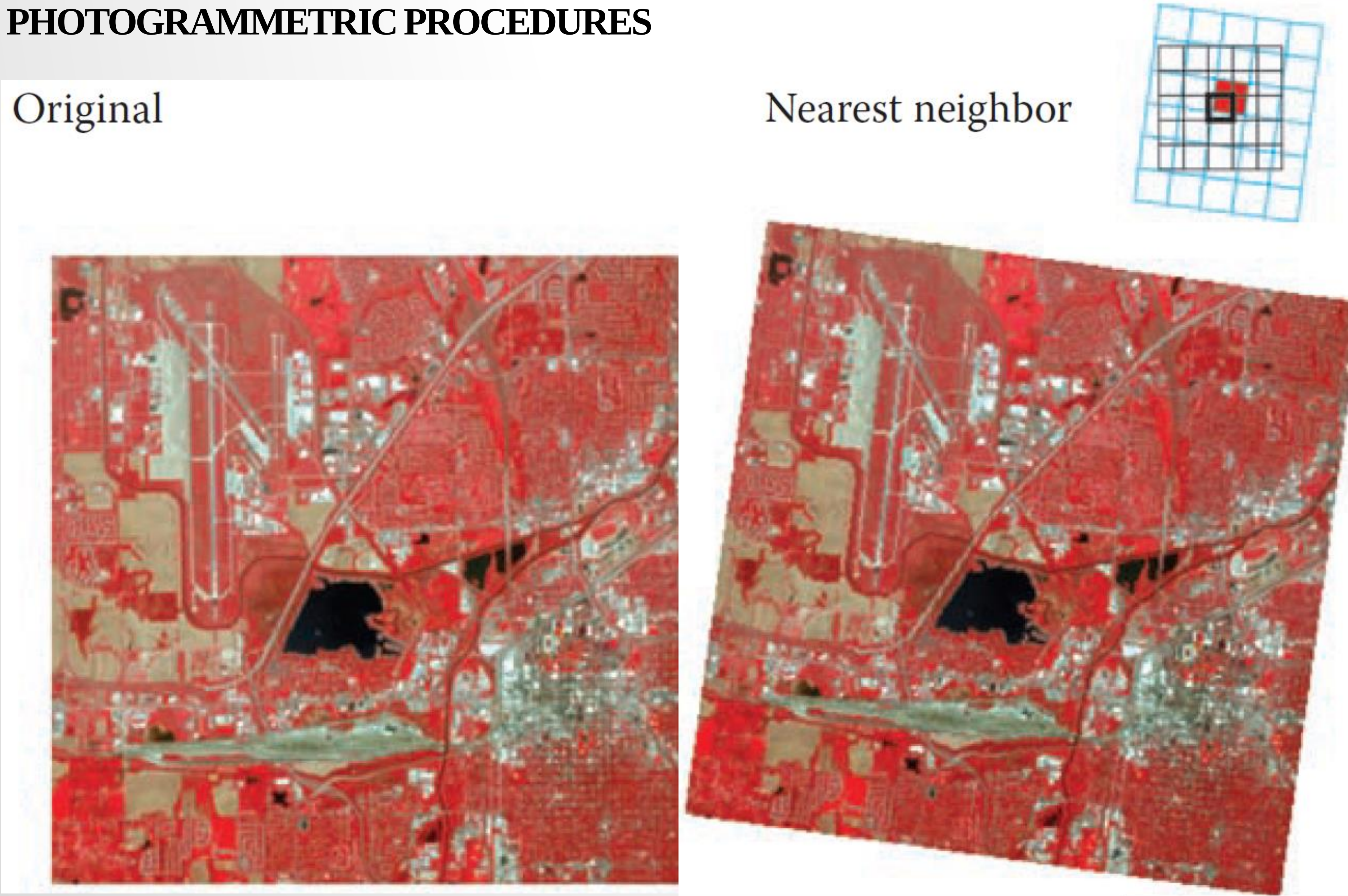
## PHOTOGRAMMETRIC PROCEDURES

### Bi-Cubic Convolution



# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

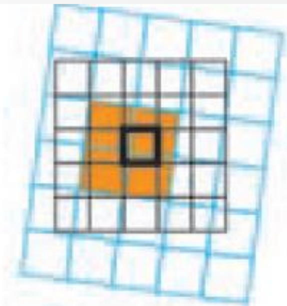


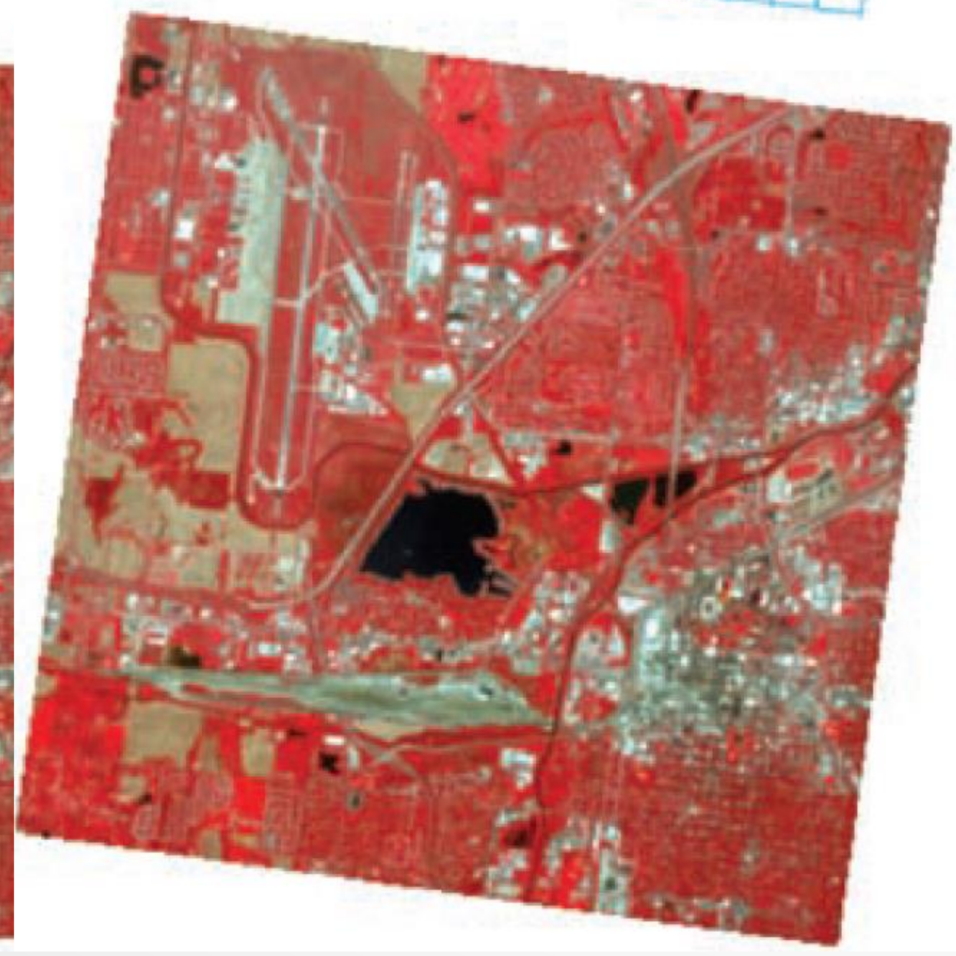
# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

Original

Bilinear interpolation



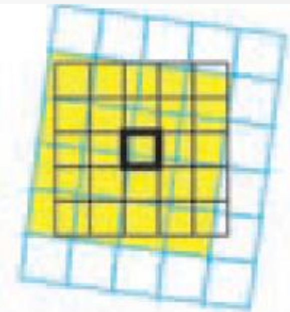


# IMAGE PREPROCESSING

## PHOTOGRAMMETRIC PROCEDURES

Original

Cubic convolution



# IMAGE PREPROCESSING

## Resampling: Final Remarks

| Intensity Interpolation Technique | Pixels Used for Interpolation | Advantages | Disadvantages |
|---|---|---|---|
| Nearest neighbor | 1 | Maintains data integrity<br>Not computationally intensive | Blocky appearance |
| Bilinear interpolation | 4 | Minimal disruption to data integrity<br>Smooth appearance | Contrast may be reduced<br>BVs are interpolated |
| Cubic convolution | 16 | Improved appearance | BVs are highly manipulated |

- Geometric Characteristics:
  - Cubic → Best.
  - Bilinear → Good.
  - Nearest Neighbor → Poor.
- Radiometric Characteristics:
  - Cubic → Poor.
  - Bilinear → Good.
  - Nearest Neighbor → Best.
- Execution Time:
  - Cubic → Slow.
  - Bilinear → Relatively Fast.
  - Nearest Neighbor → Fast.