Signal Theory Methods in Multispectral Remote Sensing

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- Brief History of the field
- Some fundamentals of remote information
- Outline of spectral analysis methodology

Brief History

REMOTE SENSING OF THE EARTH

Atmosphere - Oceans - Land

1957 - Sputnik

1958 - National Space Act - NASA formed

1960 - TIROS I

1960 - 1980 Some 40 Earth Observational Satellites Flown

1967 NRC Summer Study on Useful Applications of Earth-Oriented Satellites

Panels on:

- Agriculture, Forestry, Geography
- Geology
- Hydrology
- Meteorology
- Oceanography

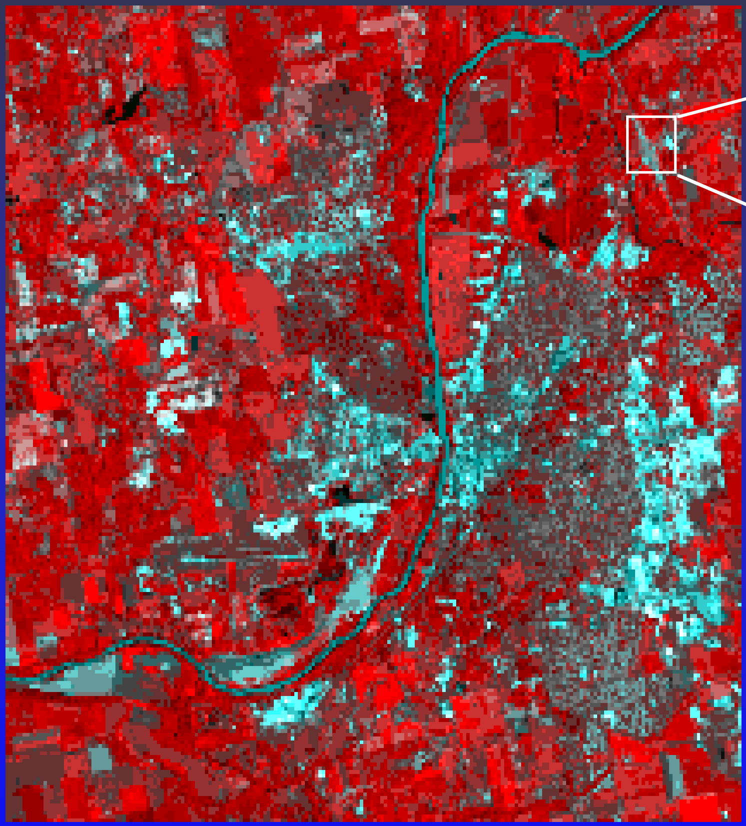
- Broadcasting
- Points-to-point Communication

- Point-to-point Communication

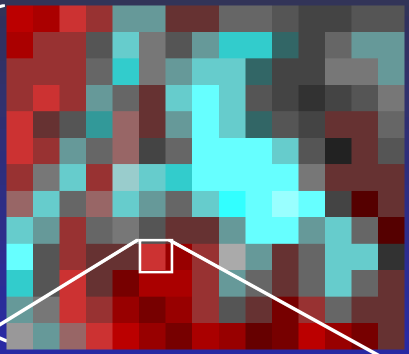
- Navigation & Traffic Control

- Sensors & Data Systems
- Geodesy & Cartography
- Economic Analysis
- Systems for Remote Sensing Information and Distribution

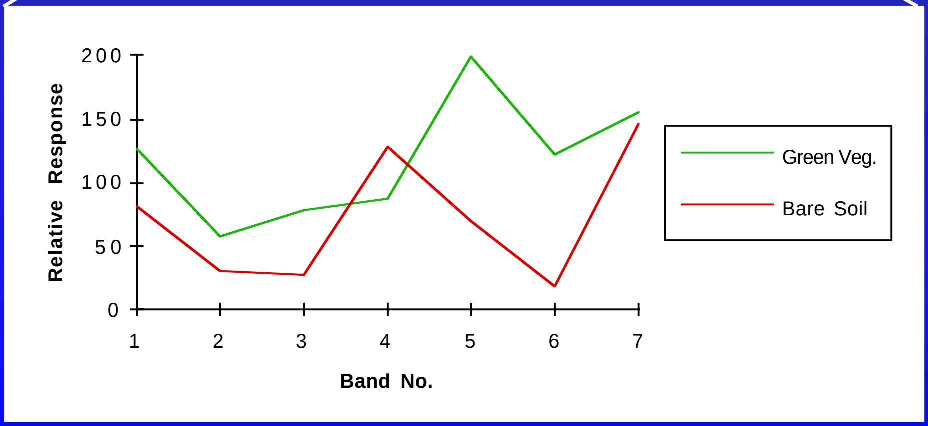
The Multispectral Concept



Thematic Mapper
Simulated Color IR Image



Enlarged 10 Times



Thematic Map Generation

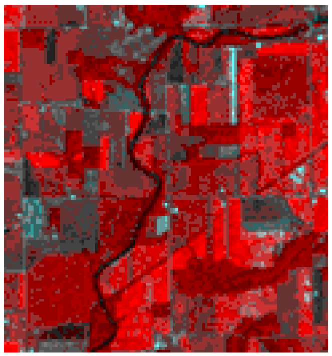
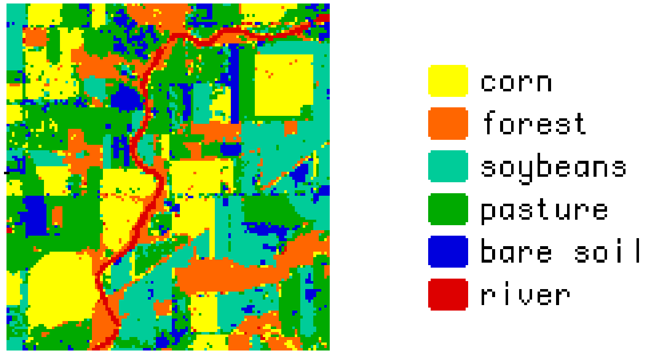


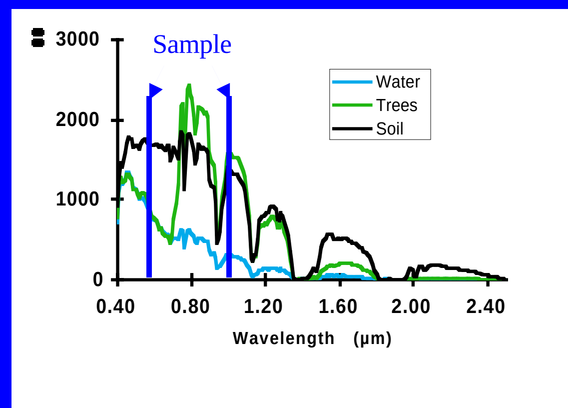
Image Data



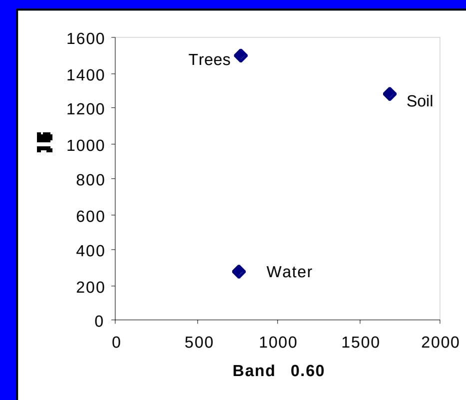
Thematic Map

Data Representations

Image Space



Spectral Space

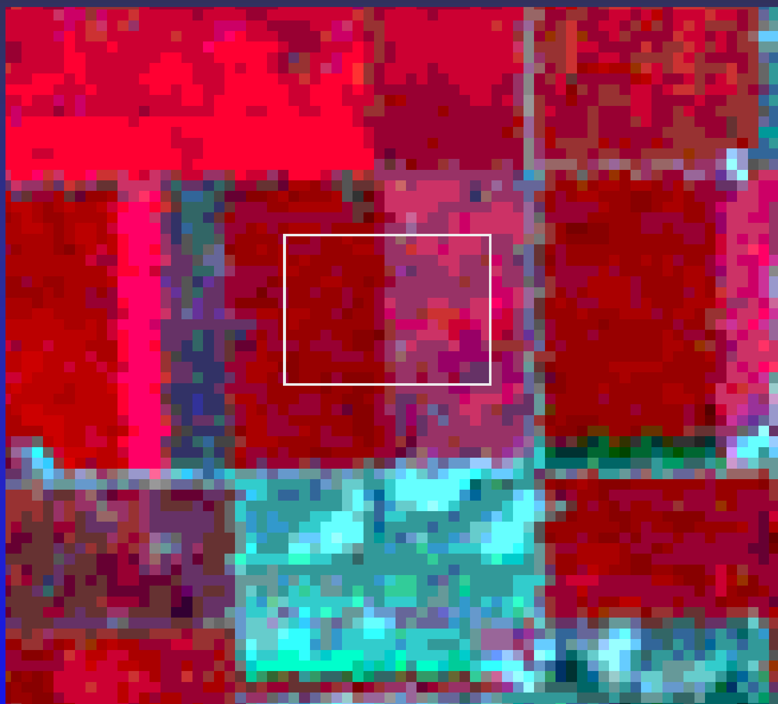


Feature Space

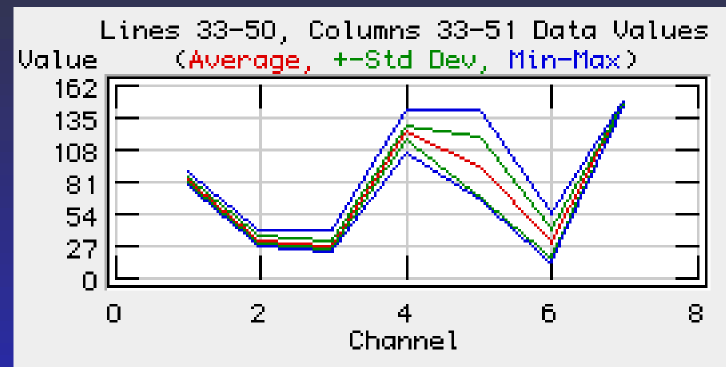
- Image Space - Geographic Orientation
- Spectral Space - Relate to Physical Basis for Response
- Feature Space - For Use in Pattern Analysis

Example Data Presentations

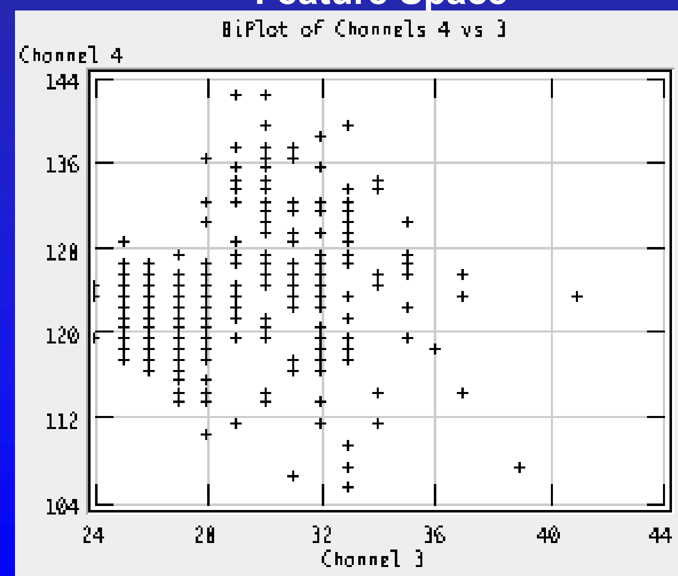
Image Space



Spectral Space

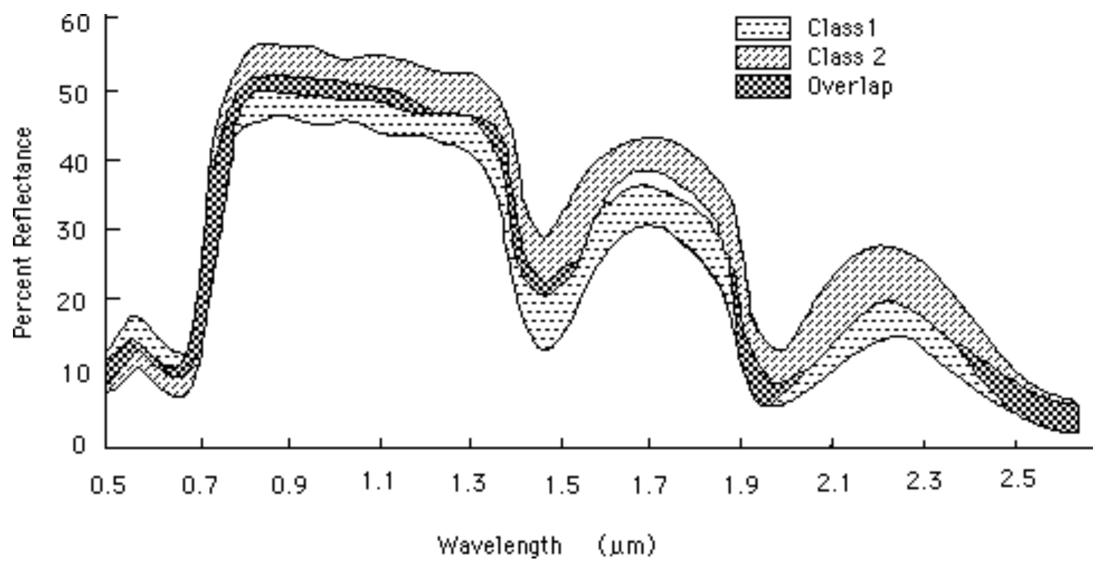


Feature Space

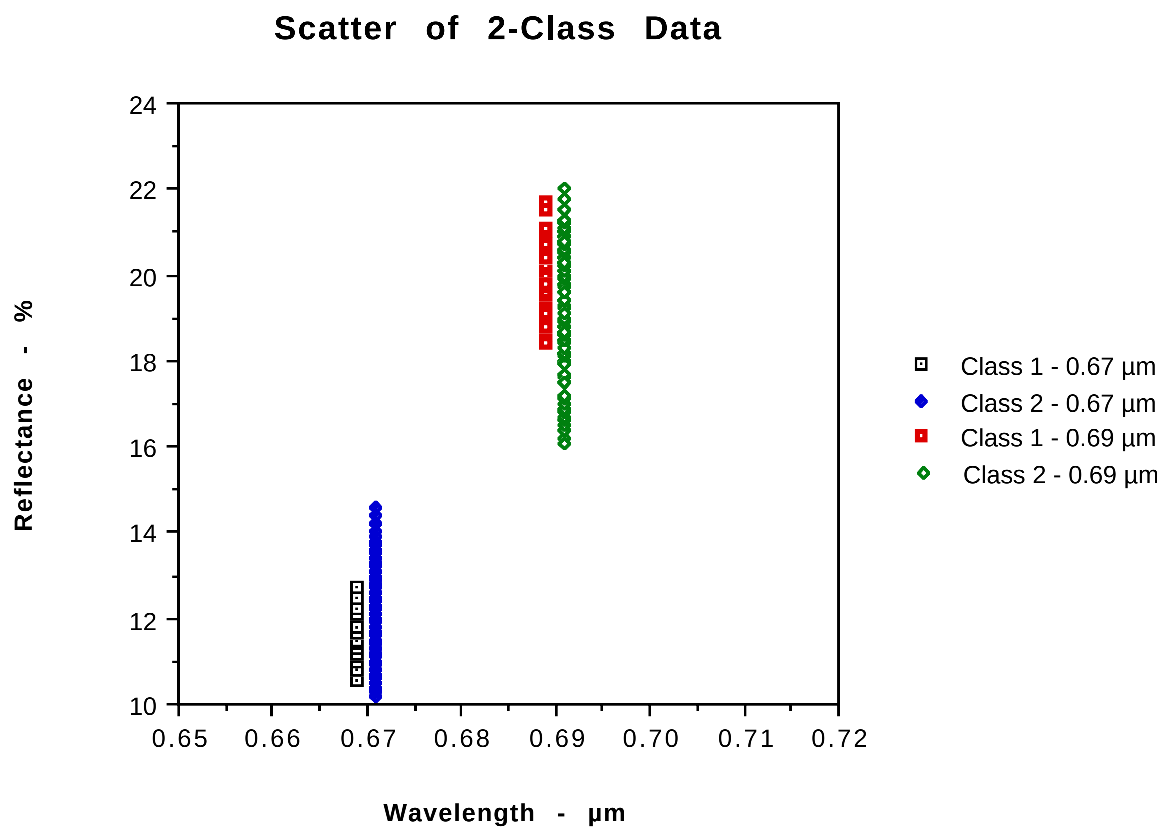


Vegetation in Spectral Space

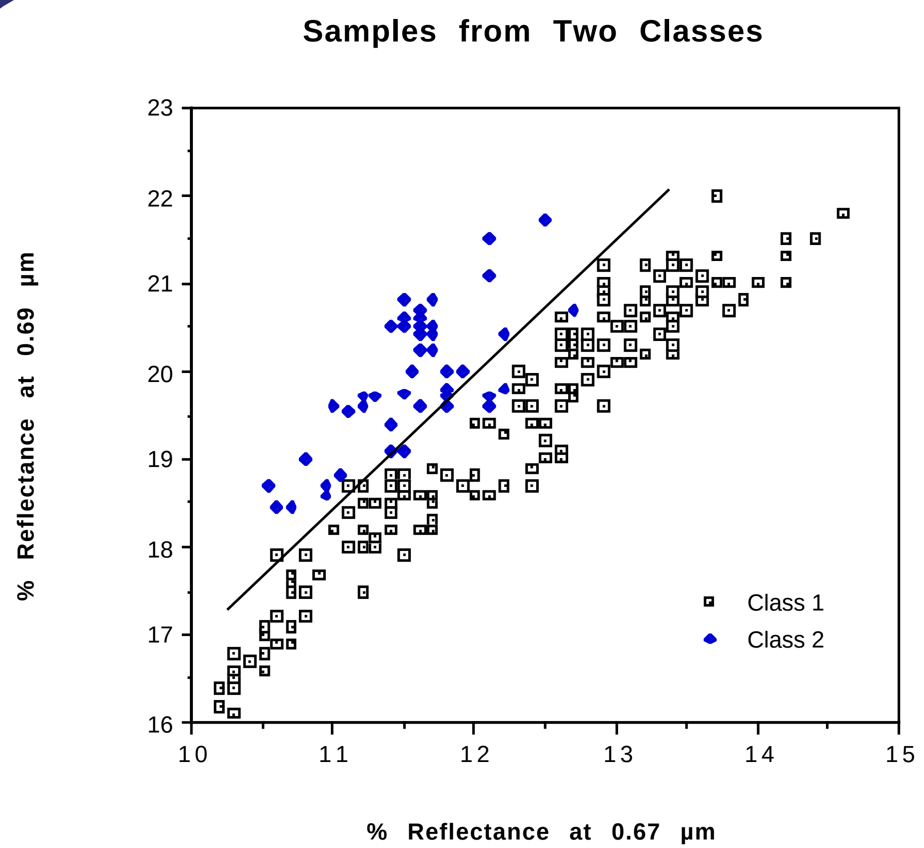
Laboratory Data: Two classes of vegetation



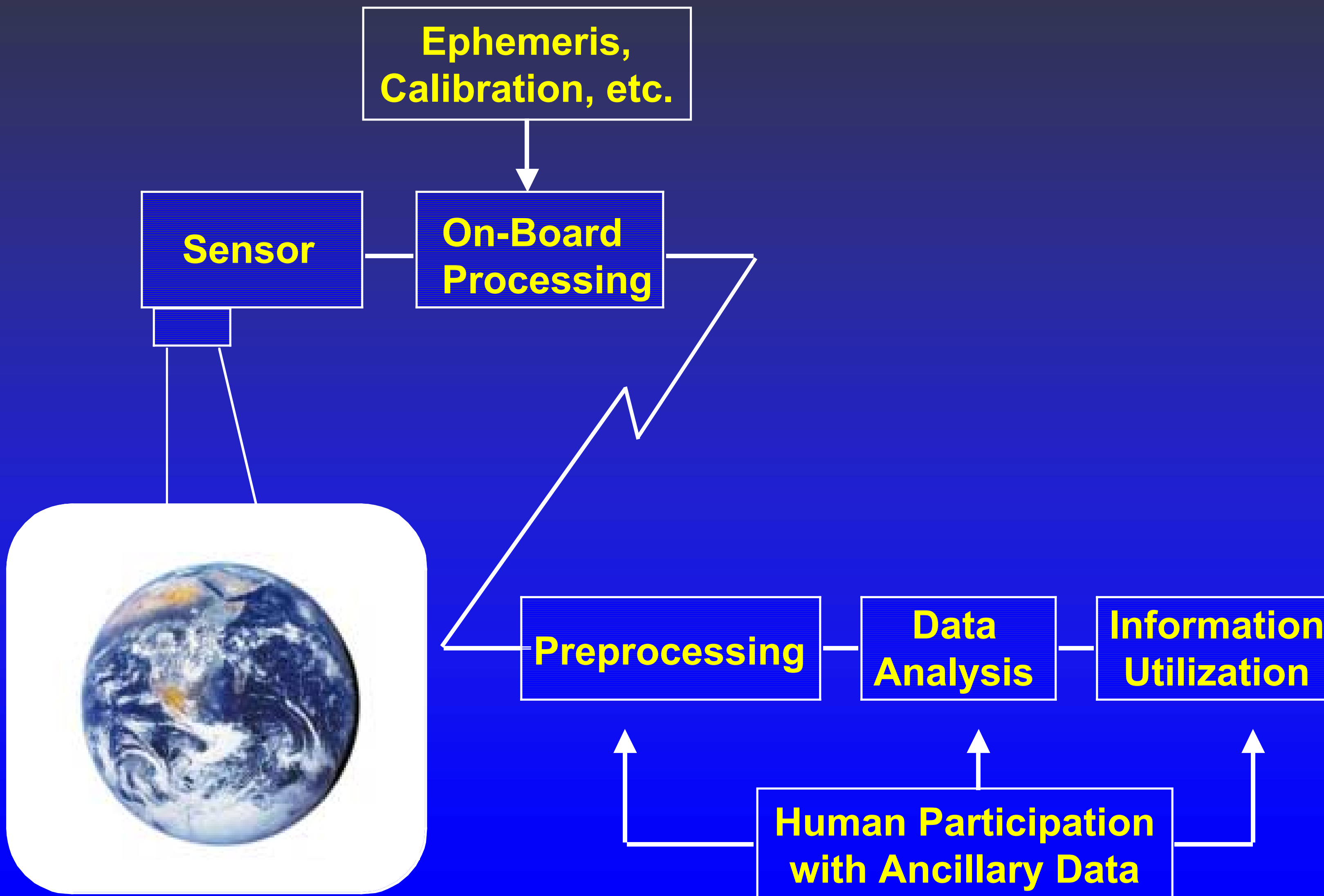
Scatter Plots of Reflectance



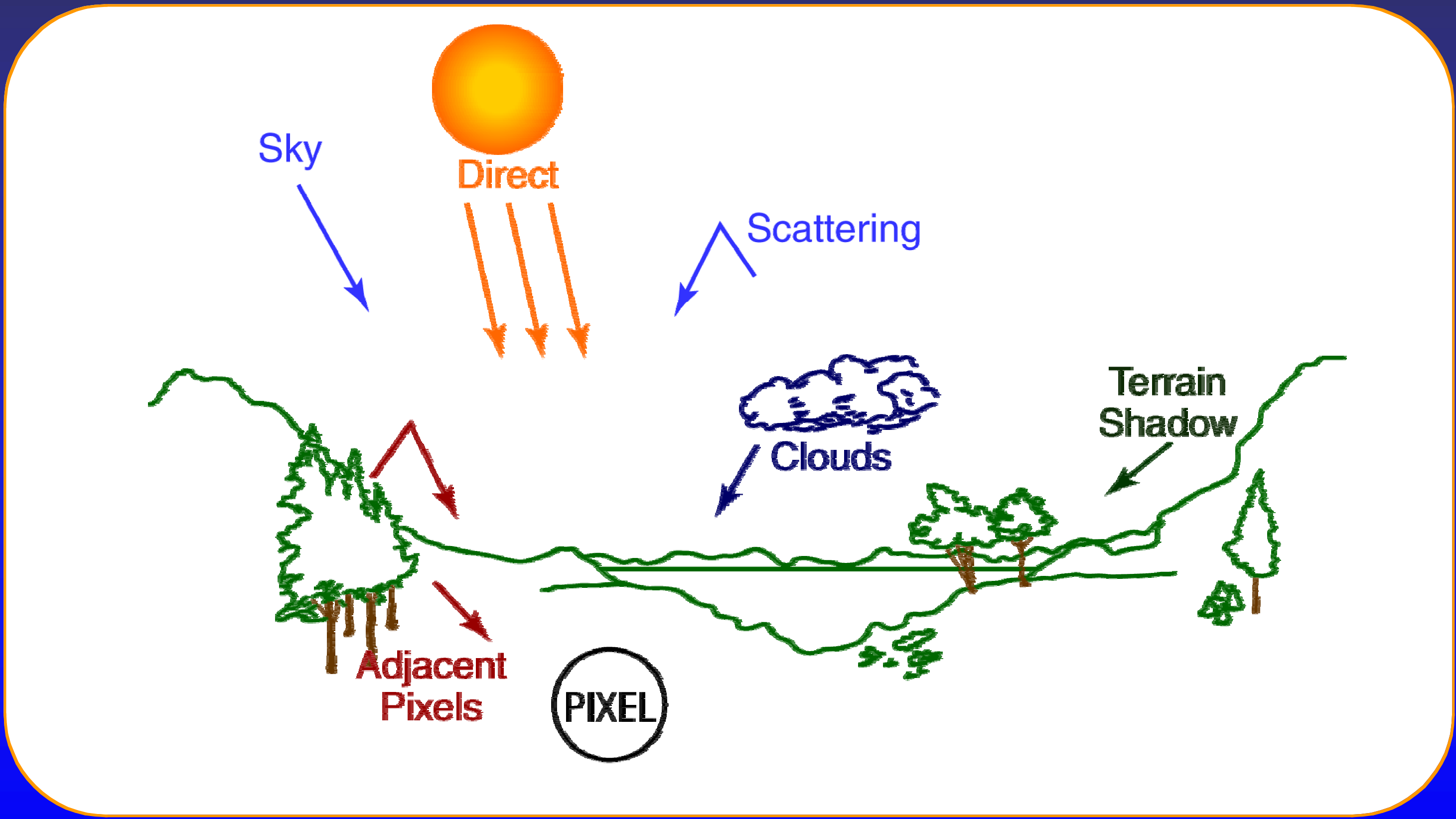
Vegetation in Feature Space



Systems View

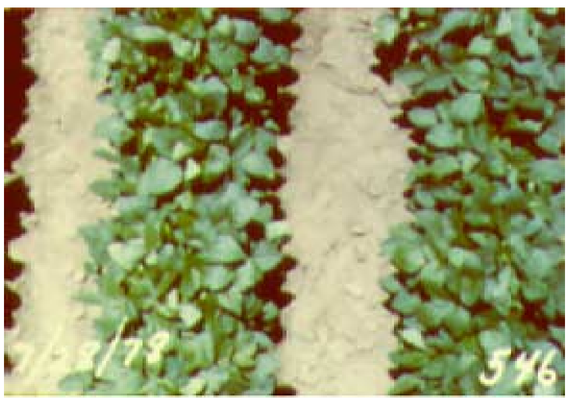


Scene Effects on Pixel

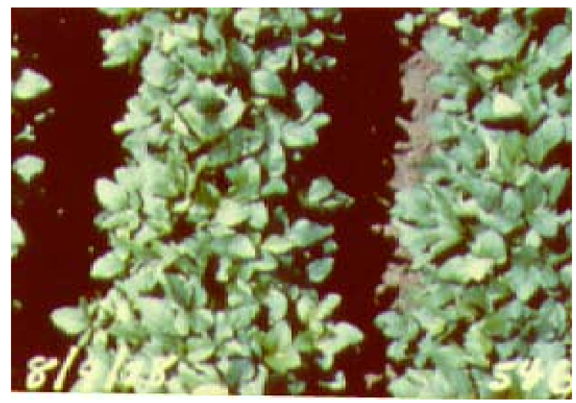


Sun Angle/View Angle Effects

Soybeans - 91 cm rows

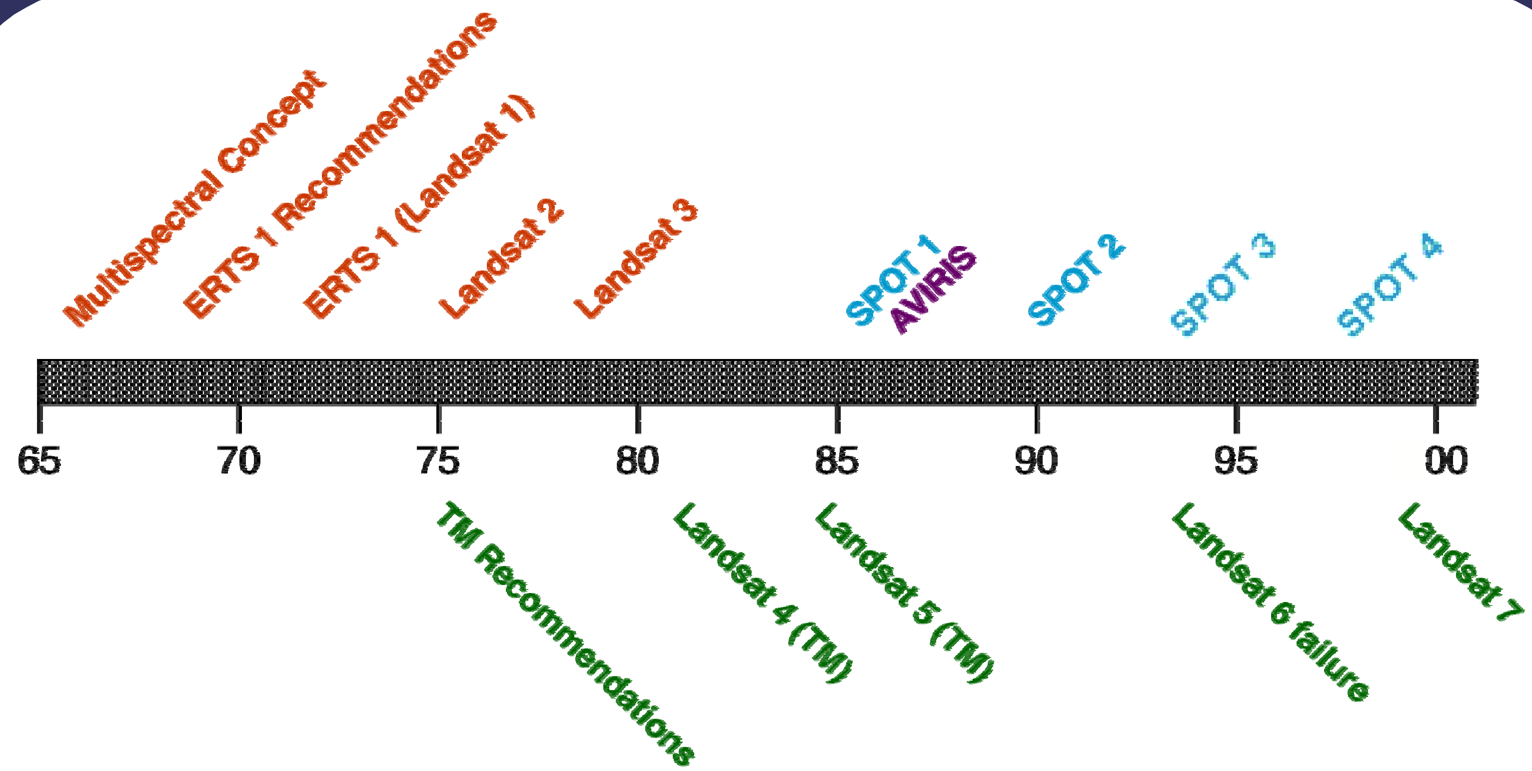


12:25 PM



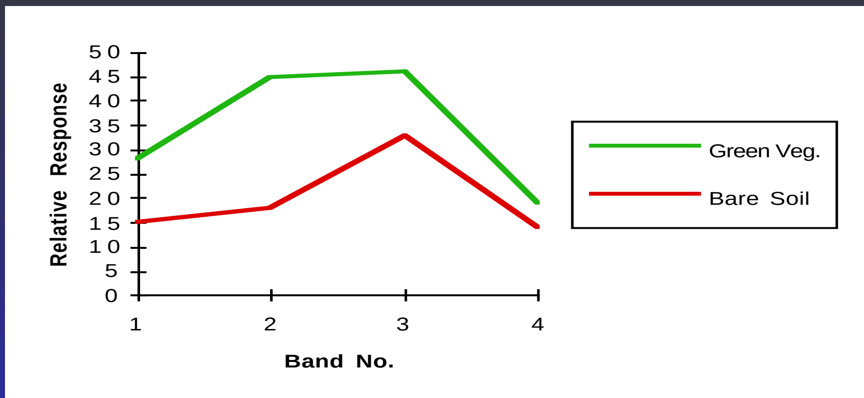
10:50 AM

Brief History-Land Remote Sensing



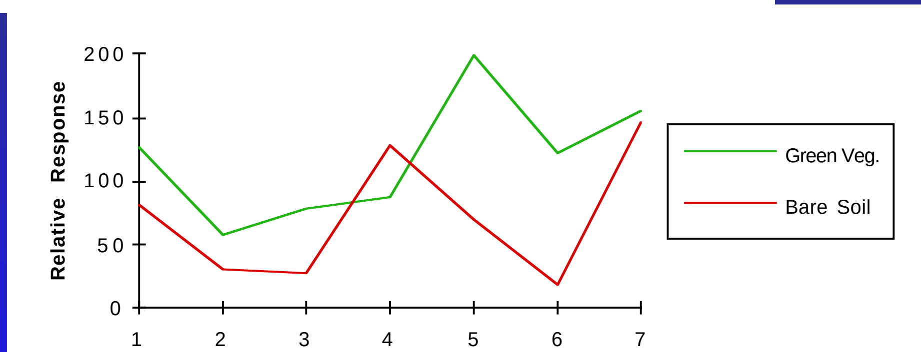
Three Generations of Sensors

MSS
1968



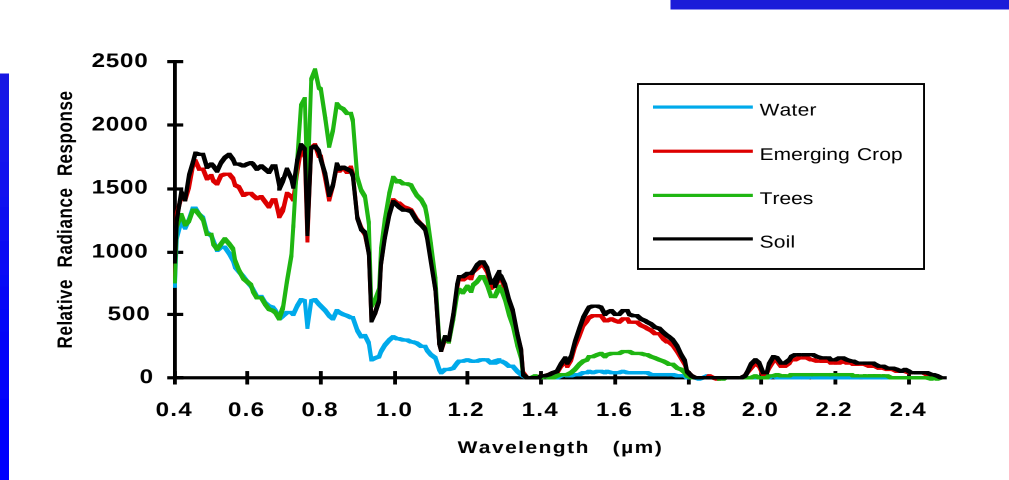
6-bit data
80 m pixels
4 bands

TM
1975



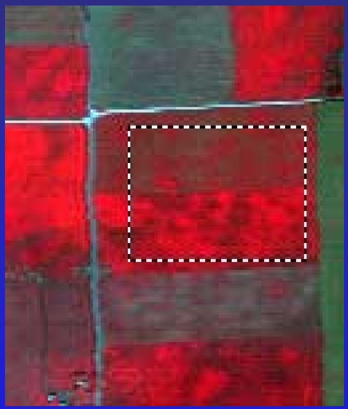
8-bit data
30 m pixels
7 bands

Hyperspectral
1986

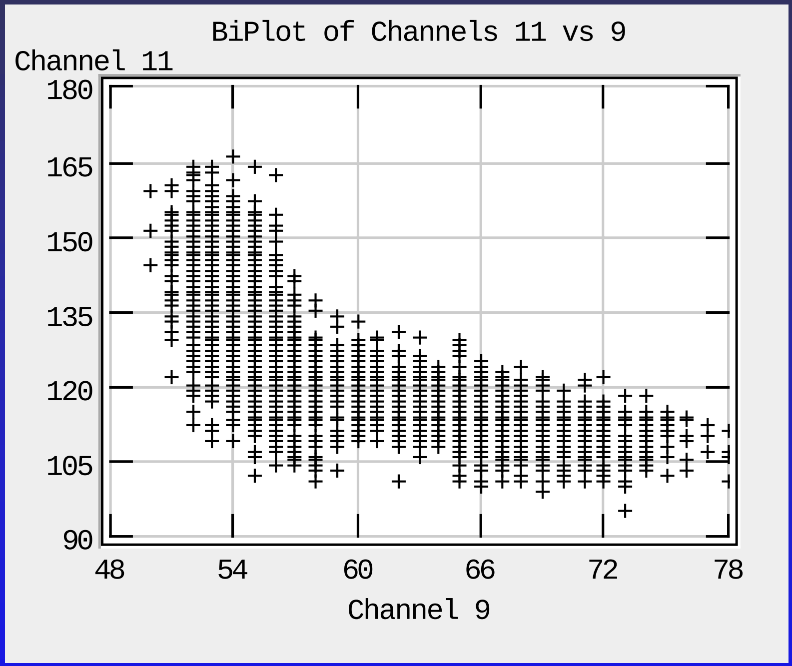


10-bit data
20 m pixels
≈ 200 bands

Scatter Plot for Typical Data



Agricultural Area



- 8-bit data in 2 bands = $(2^8)^2$ = 65,536 cells
- About 3000 pixels in 1000 occupied cells

Hyperspectral Data - A Simple Example

- Assume 10 bit data in a 100 dimensional space.
- That is $(1024)^{100} \approx 10^{300}$ discrete locations

Even for a data set of 10^6 pixels, the probability of any two pixels lying in the same discrete location is vanishingly small.

Thus, in theory, everything is separable from everything.

But how?

Southern Corn Leaf Blight

SCLB Lesions

Infection begins at the bottom of the plant

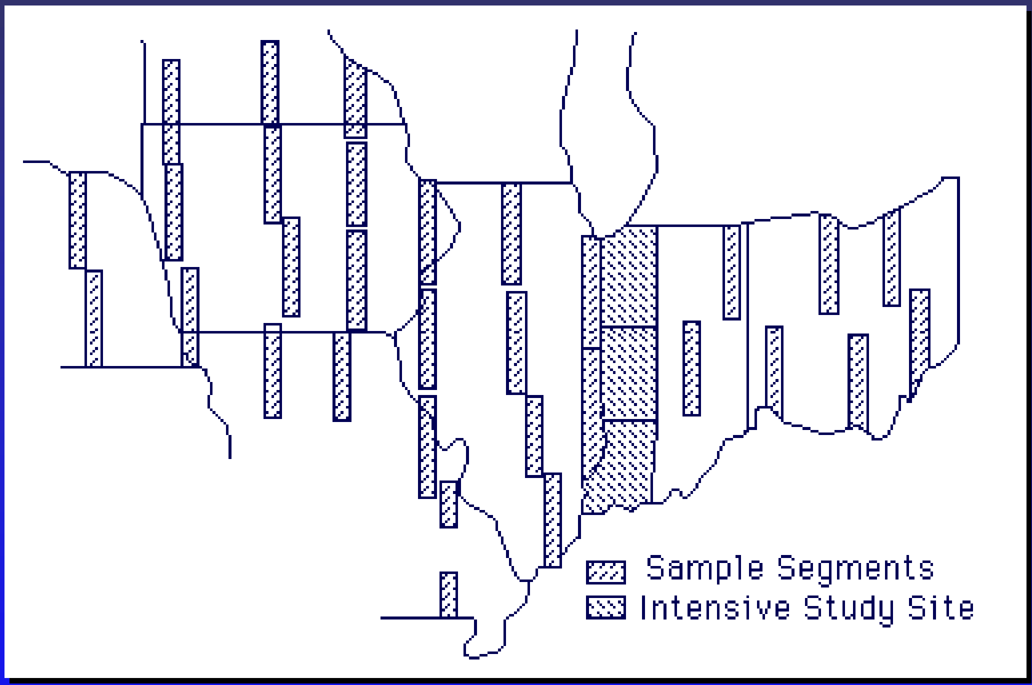
Blight Stages

Healthy Plants

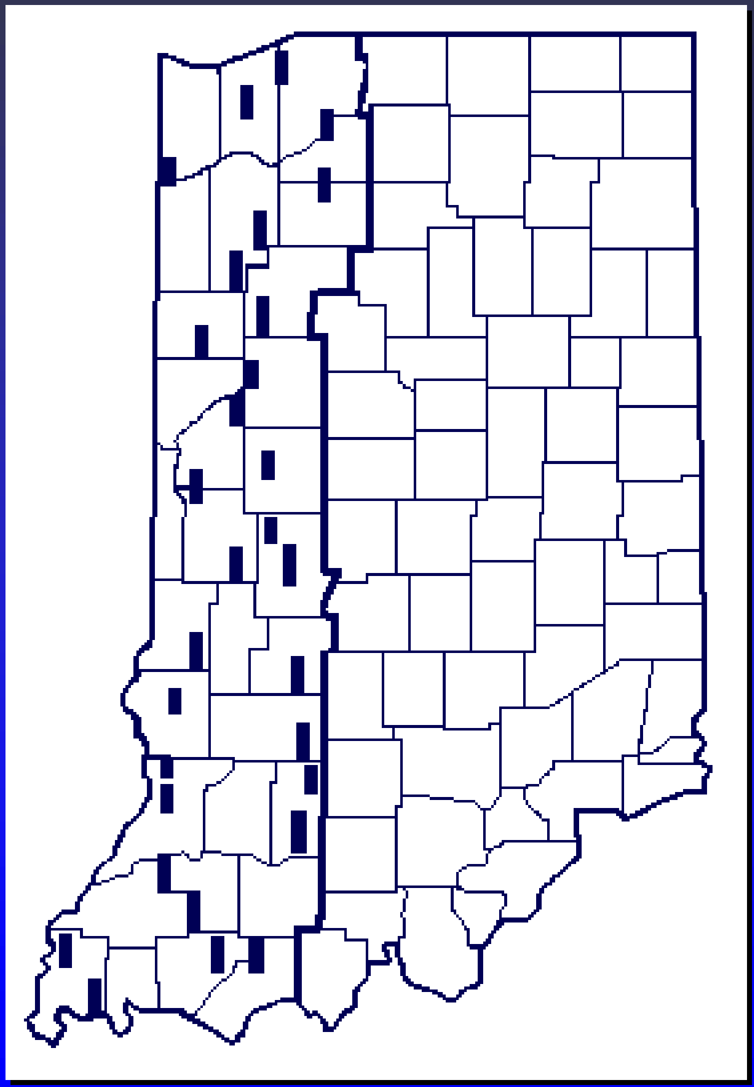
Moderate Blight

Severe Blight

1971 Corn Blight Watch Experiment Flightlines

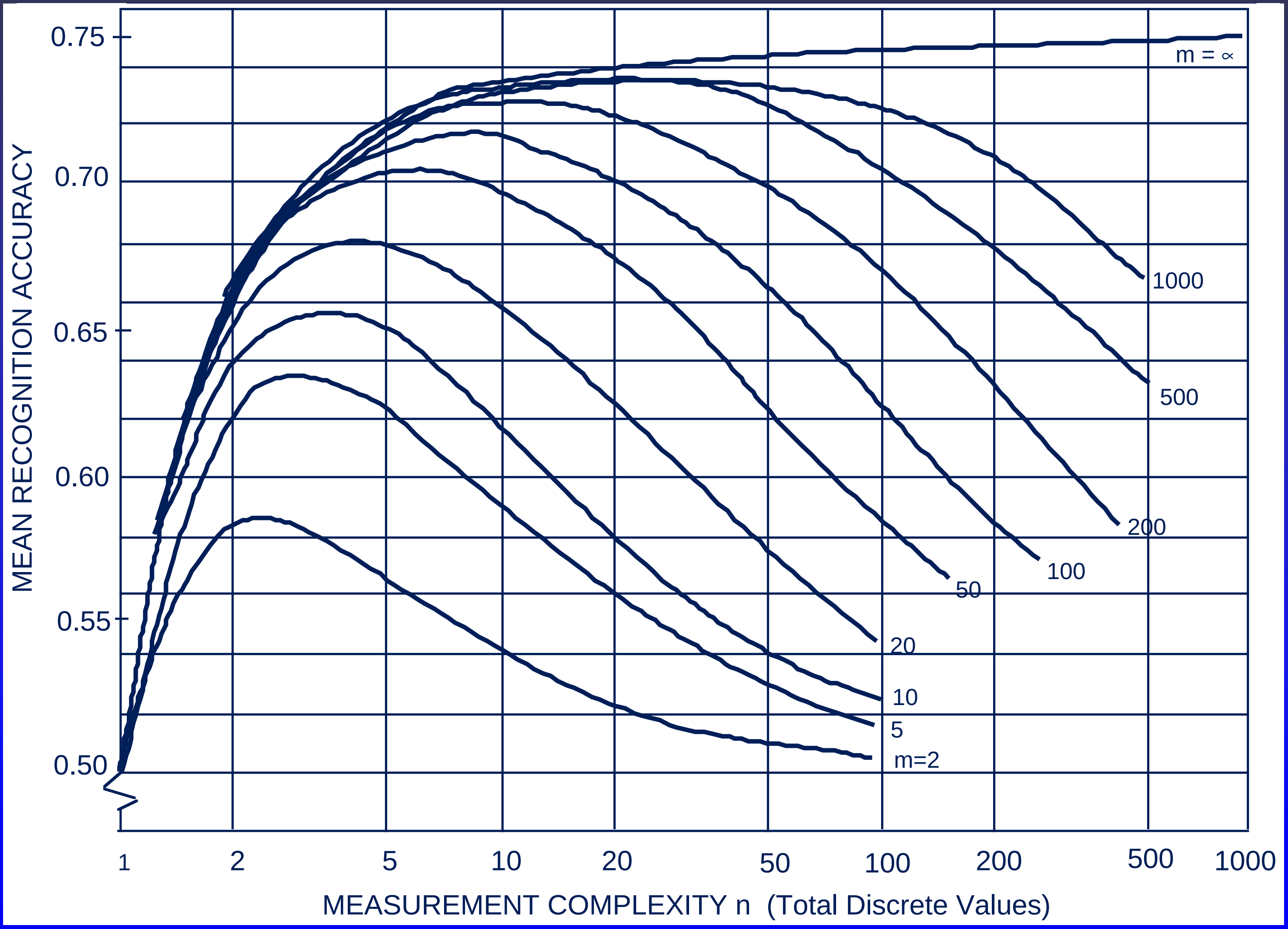


1971 CBWE Intensive Area Flightlines



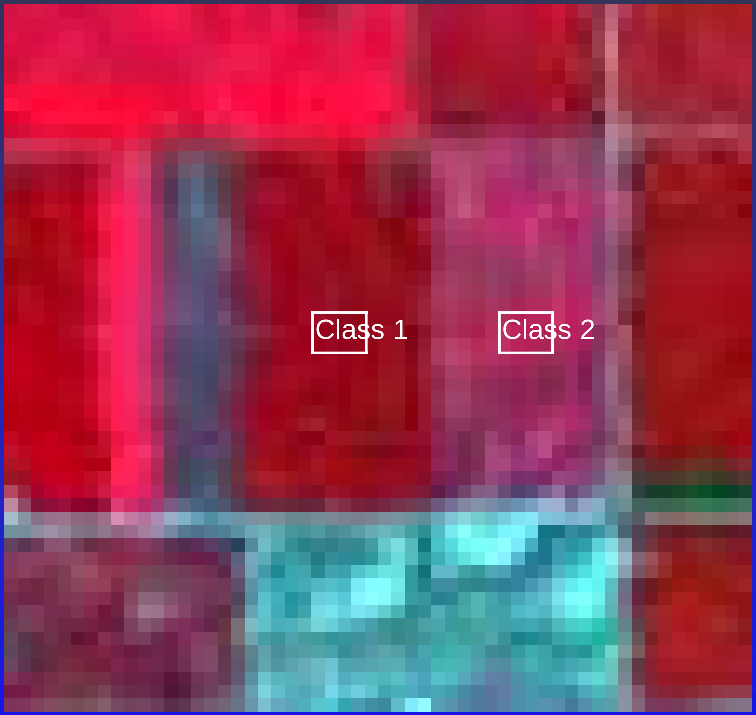
- All segments flown & analyzed every two weeks throughout the growing season with a 13 band scanner
- Discrimination successful into three stages of blight:
  - ✓Little or none
  - ✓Moderate
  - ✓Severe

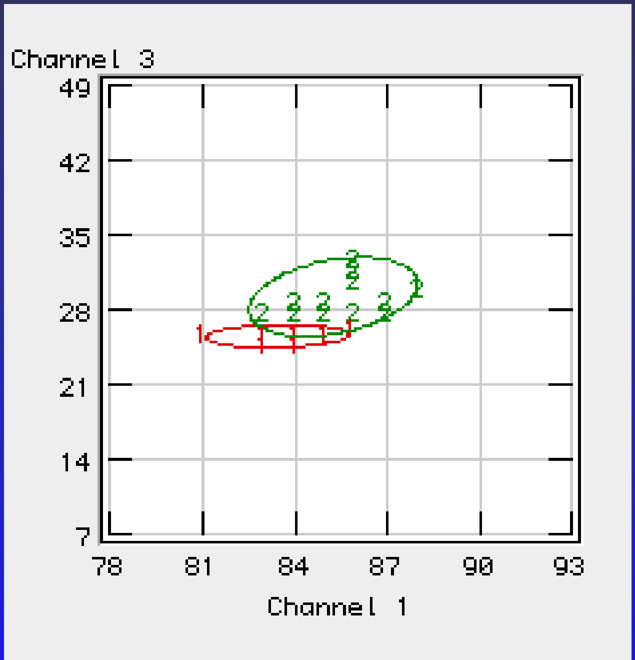
Hughes Effect



G.F. Hughes, "On the mean accuracy of statistical pattern recognizers," IEEE Trans. Inform. Theory., Vol IT-14, pp. 55-63, 1968.

Estimation Error - A Simple Example
12 Pixel Training





$$\mu_1 = \begin{bmatrix} 83.4 \\ 25.7 \end{bmatrix} \qquad \mu_2 = \begin{bmatrix} 85.2 \\ 29.3 \end{bmatrix}$$

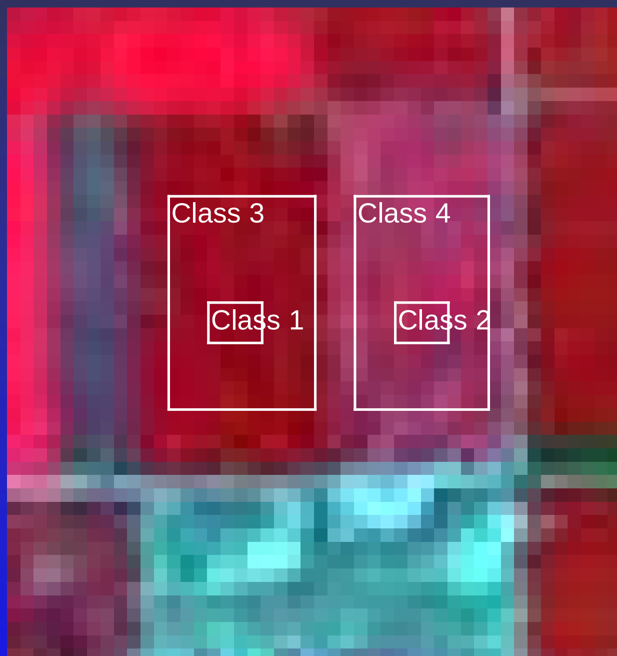
$$\Sigma_1 = \begin{bmatrix} 1.17 & \\ 0.06 & 0.24 \end{bmatrix} \qquad \Sigma_2 = \begin{bmatrix} 1.66 & \\ 0.73 & 2.97 \end{bmatrix}$$

$\rho_1 = 0.11$ $\qquad$ $\rho_2 = 0.33$

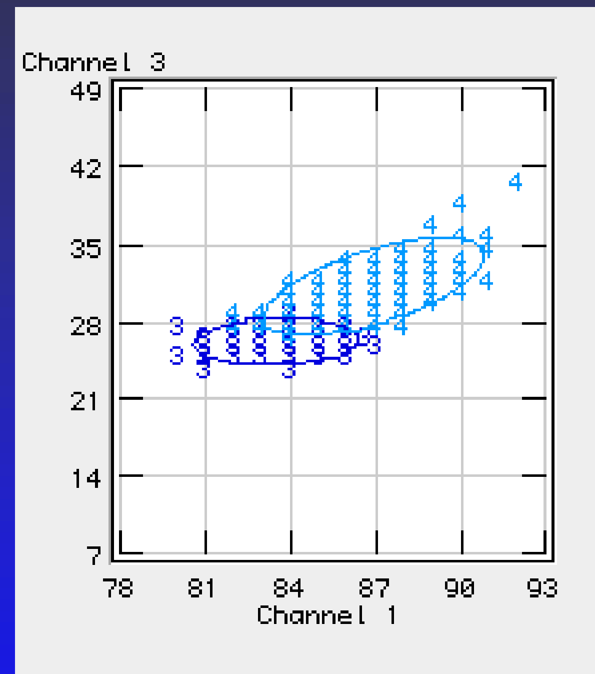
$$\rho_{13} = \frac{\sigma_{13}}{\sqrt{\sigma_1^2 \sigma_3^2}}$$

$$-1 \le \boldsymbol{\rho}_{jk} \le +1$$

Estimation Error - A Simple Example
200 Pixel Training



200 pixel training



12 pixel training

$$\mu_3 = \begin{bmatrix} 83.5 \\ 26.2 \end{bmatrix} \qquad \mu_4 = \begin{bmatrix} 86.9 \\ 31.2 \end{bmatrix}$$

$$\Sigma_3 = \begin{bmatrix} 1.86 & \\ 0.13 & 1.00 \end{bmatrix} \qquad \Sigma_4 = \begin{bmatrix} 3.31 & \\ 2.42 & 4.43 \end{bmatrix}$$

$$\rho_3 = 0.09 \qquad \rho_4 = 0.63$$

$$\mu_1 = \begin{bmatrix} 83.4 \\ 25.7 \end{bmatrix} \qquad \mu_2 = \begin{bmatrix} 85.2 \\ 29.3 \end{bmatrix}$$

$$\Sigma_1 = \begin{bmatrix} 1.17 & \\ 0.06 & 0.24 \end{bmatrix} \qquad \Sigma_2 = \begin{bmatrix} 1.66 & \\ 0.73 & 2.97 \end{bmatrix}$$

$$\rho_1 = 0.11 \qquad \rho_2 = 0.33$$

Estimation Error - A Simple Example
Some Conclusions

- Mean Vector - A First Order Statistic
- Covariance Matrix - A Second Order Statistic
- To Perfectly Represent an Arbitrary Distribution Would Require Statistics of All Orders.
- The Number of Samples Required for Acceptable Estimation Error Grows Rapidly With Order.
- With Typical (Finite) Numbers of Training Samples

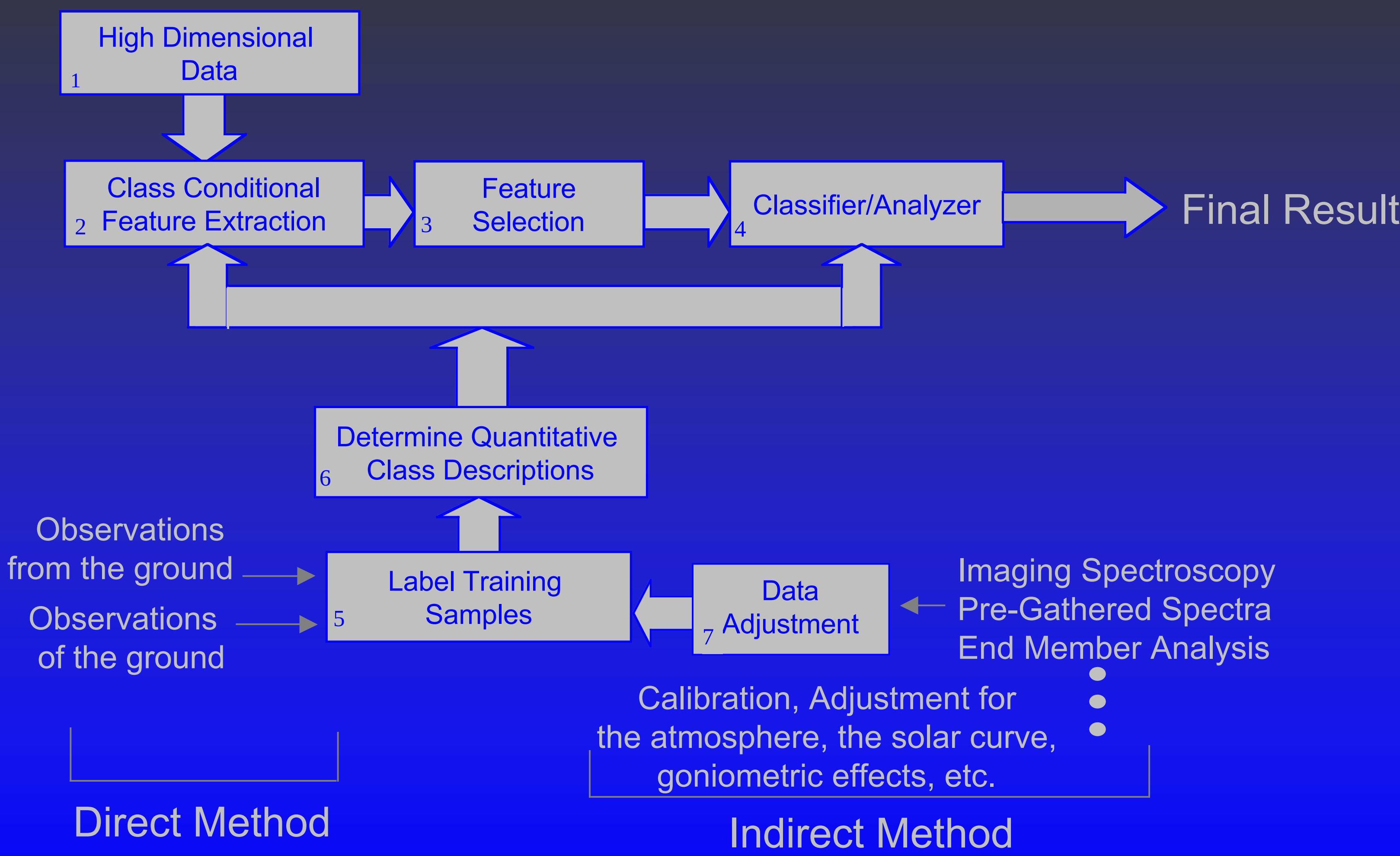
  - First Order Statistics Can Usually Be Estimated Satisfactorily.

  - Second Order Statistics Are More Problematic But Usually Acceptable.

  - Statistics Beyond Second Order Are Usually Unusable.

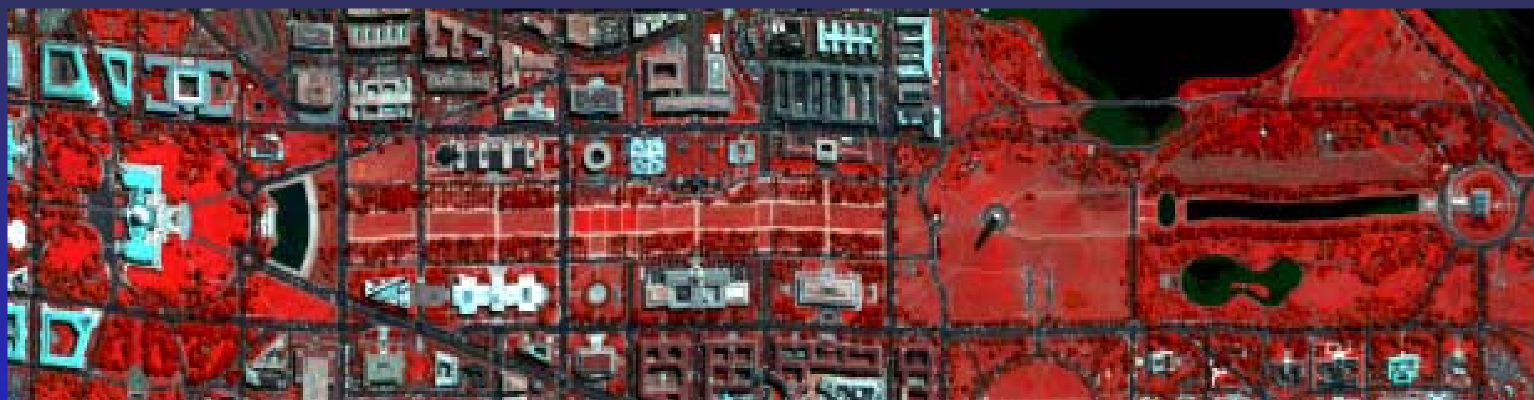
- Thus complex classes must be modeled by a (small) collection of estimated density functions, i.e. subclasses.

Analysis System



An exhaustive, separable, informational value list of classes is key. Subclasses may be necessary to adequately model all classes.

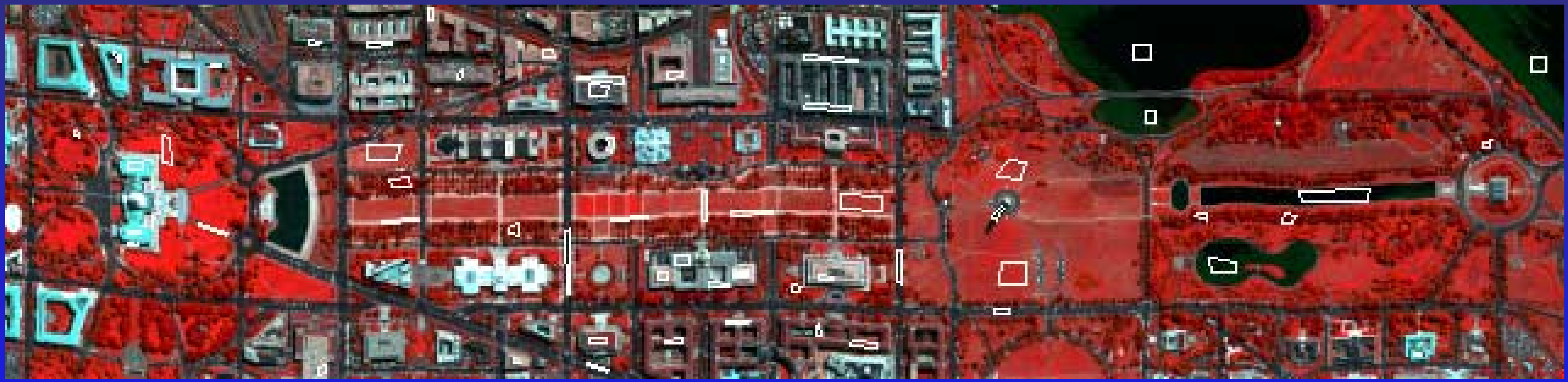
Hyperspectral Image of DC Mall



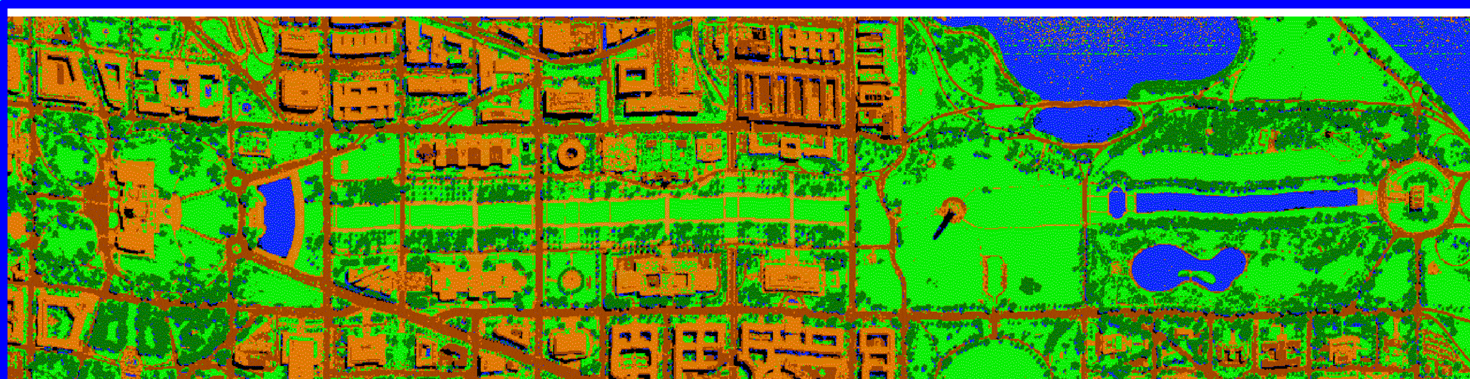
HYDICE Airborne System
1208 Scan Lines, 307 Pixels/Scan Line
210 Spectral Bands in 0.4-2.4 µm Region
155 Megabytes of Data
(Not yet Geometrically Corrected)

Define Desired Classes

Training areas designated by polygons outlined in white



Thematic Map of DC Mall



Legend

- **Roofs**
- **Streets**
- **Grass**
- **Trees**
- **Paths**
- **Water**
- **Shadows**

Operation	CPU Time (sec.)	Analyst Time
Display Image	18	
Define Classes		< 20 min.
Feature Extraction	12	
Reformat	67	
Initial Classification	34	
Inspect and Mod. Training		≈ 5 min.
Final Classification	33	
Total	**164 sec = 2.7 min.**	**≈ 25 min.**

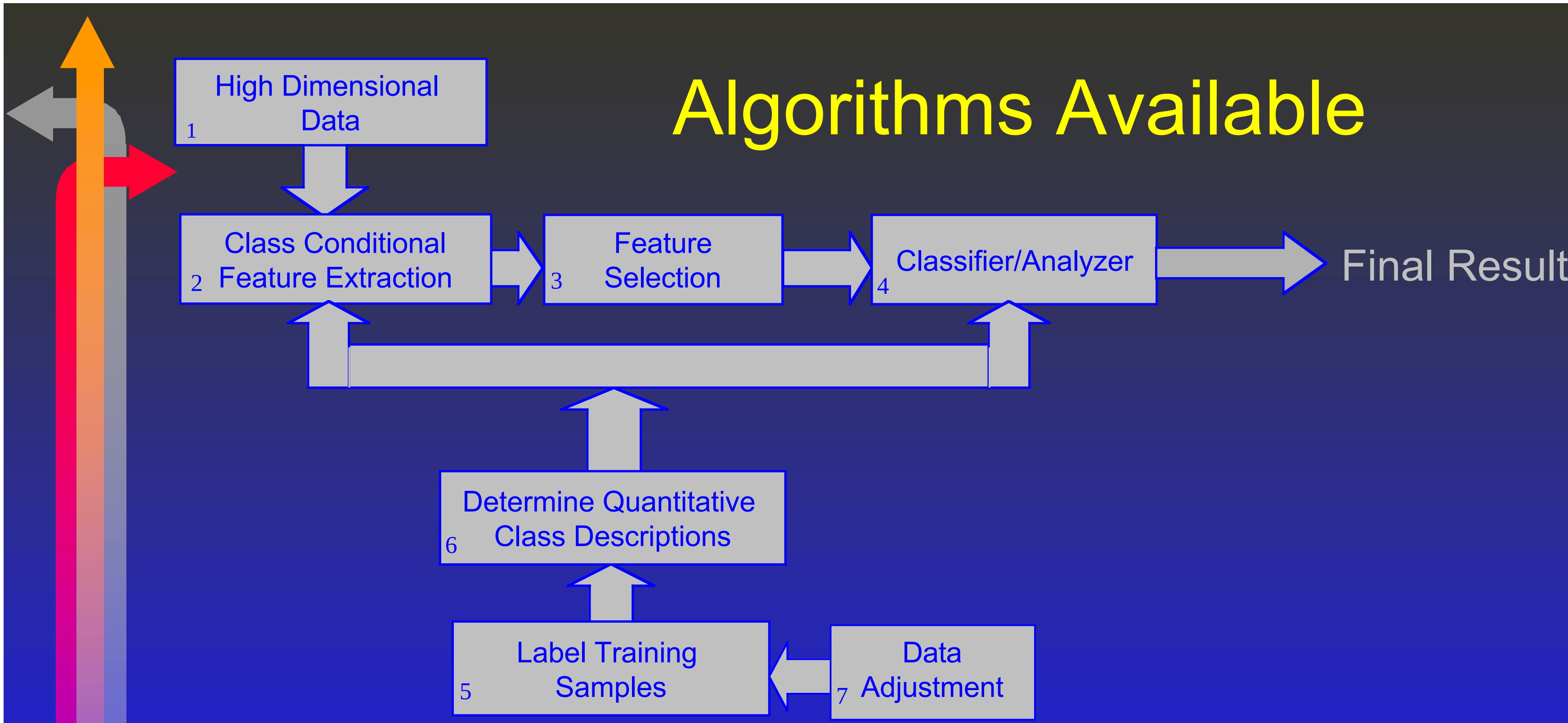
(No preprocessing involved)

MultiSpec©

- **Import Data (**Binary or ASCII**)**
- **Histogram & Display Images**
- **Cluster (**Single Pass or Iterative**)**
- **Define Classes (**Rectangular, Polygonal**)**
- **Feature Definition (**Subsets, or Optimal Subspaces**)**
- **Statistics Enhancement (**Via Labeled & Unlabeled**)**
- **Classification (**Spectral or Spectral/Spatial**)**
- **Results Display (**Thematic and Tabular**)**
- **Utility Functions (**Graph Spectra, Scatter Diagrams, Principal Components, Ratios, Add Bands, Mosaicing, Changing Geometry, Visualization aids, etc.**)**

Available via WWW at:
http://dynamo.ecn.purdue.edu/~biehl/MultiSpec/
Additional documentation via WWW at:
http://dynamo.ecn.purdue.edu/~landgreb/publications.html

Algorithms Available



Algorithm	Box
Discriminant Analysis Feature Extraction (DAFE)	2
Decision Boundary Feature Extraction (DBFE)	2
Nonparametric Weighted Feature Extraction (NWFE)	2
Projection Pursuit	2
Feature Selection	3
Maximum Likelihood Classification Algorithms	4
Clustering (Unsupervised Classification)	5
LOOC	6
Statistics Enhancement	6

Textbook Synopsis

Signal Theory Methods in Multispectral Remote Sensing

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To be published by John Wiley and Sons, Inc, January 8, 2003

Part I. A Brief Overview

Chapter 1. Introduction and overview of the multispectral approach

Part II. The Basics for Conventional Multispectral Data

Chapter 2. Measurements and Sensor System Fundamentals

Chapter 3. Fundamental Concepts of Pattern Recognition

Part III. Additional Details

Chapters on: Training A Classifier, Hyperspectral Data Characteristics, Feature Definition, A Data Analysis Paradigm & Examples, Use of Spatial Variations, Noise in Remote Sensing Systems, Multispectral Image Data Preprocessing

Appendix: An Outline of Probability Theory

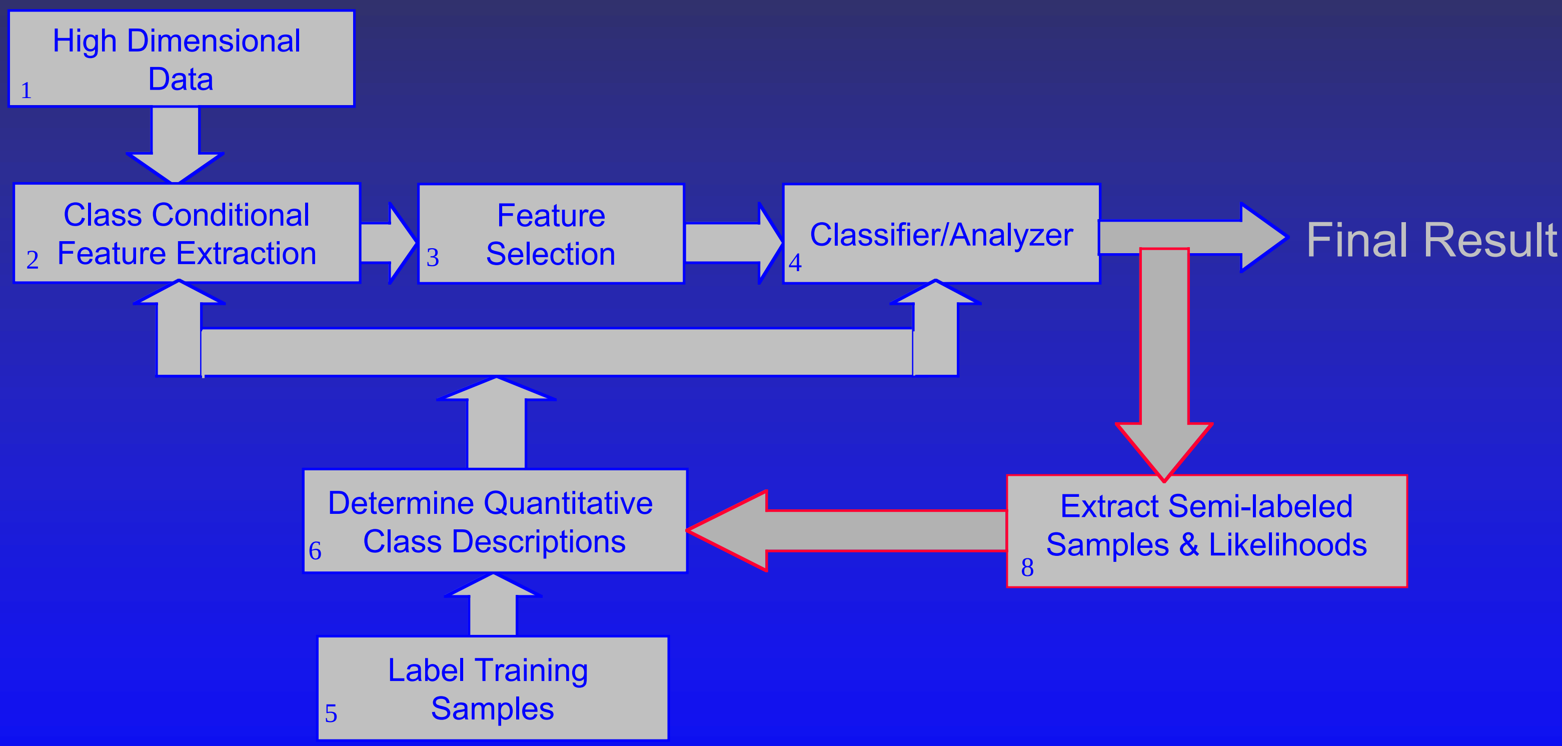
Exercises

Student Compact Disc

Color Figures of text material
MultiSpec-based projects

Analysis System

The primary limitation is estimation error due to finite training.



Use the classified samples which have high likelihood as additional training samples.