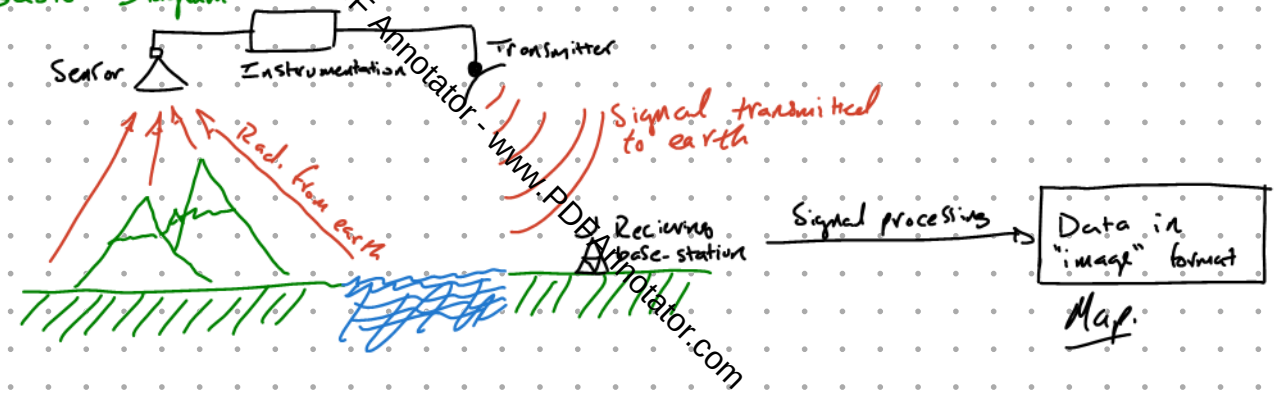
Image Data Analysis - IDA

Lesson One

In remote sensing energy radiating from the earth's surface is measured using sensors mounted on an aircraft, satellite, or other airborne object.

The measurements allow one to construct an image of the landscape/earth's surface.

Basic Diagram:



The energy collected by the sensor can come from a number of sources, giving rise to two types of sensor:

- Energy radiated from the earth as a result of the sun's radiation.
- Energy radiated from the earth as a result of it's own temperature (Blackbody)

} Passive sensing

- Energy radiated due to illumination by an artificial source (laser/radar/etc.)

} Active sensing

} Images produced in (usually) digital format.

The most important parameter involved in remote sensing is, ultimately, the wavelength of the radiation.

For Passive sensors: $\lambda = 0.4\mu m \rightarrow 12\mu m$ (visible/IR)

$\lambda = 30m \rightarrow 300mm$ (microwave)

For active sensors:

Excitation, $\lambda \approx 355nm$ ($\approx$ UV)
Measurement, $\lambda = 0.4\mu m \rightarrow 12\mu m$ (visible/IR) } Laser Fluorosensors

SAR (Synthetic Aperture Radar)
/SLAR (Side Looking Airborne Radar) } λ = {Ka, K, Ku, X, C, S, L Bands} Radar Sensors

Lesson One - Introduction to Data Sources in Remote Sensing

Introduction to Data Sources in Remote Sensing

Intro to Data Sources
Characteristics of Digital Image Data
Remote Sensing Data Products and Processing
Wavelengths of Interest, Active, and Passive Systems
Technical characteristics of Digital Image Data
Eg.: Landsat 7 Datasets (1999 - Present)
Eg.: Lansat 5 Images (1984 - 2013)

Spectral Ranges Commonly Used in Remote Sensing
Radiation Energy from Different Hot Bodies / Black Bodies
Eg.: OLI and TIRS sensors on LandSat 8 (2013 - Present) & LandSat 9 (2021 - Present)

Electromagnetic Radiation Scattering

Remote Sensing Platforms

Different kinds of platforms and Applications
Sun-synchronous Low Earth Orbits
Satellite and Aircraft Imaging Technologies
Spectral Resolution: Convential vs Spectrometric Imaging

Image Data Sources in the Microwave Region

Side Looking Airborne Radar - SLAR
Synthetic Aperture Radar - SAR

Spatial Data Sources in General

Types of Spatial Data
Data Formats
Use of Colour in Remote Sensing Images
Multispectral Raster Image Formats

Lesson Two - Error Correction and Registration of Image Data

Error Correction and Registration of Image Data

Image Data Acquisition
Sources of Error in the (data-driven) Image Analysis Pipeline
Sources of Error in the Remote Sensing Data

Sources of Radiometric Distortion in Remote Sensing Data

Types of Radiometric Distortion
The Effect of Atmosphere on Radiation
Radiometric Quantity Definitions
Absorption and Scattering by the Atmosphere
The Effect of Atmosphere on Radiation Cont..
Further Radiometric Quantity Definitions
Atmospheric Effects on Remote Sensing Imagery
Instrumentation Errors
Striping (or Banding) Artifacts (Along Swath Direction)

Correction of Radiometric Distortion

- Correction of Atmospheric Effects
- Correction of Instrumentation Errors

Sources of Geometric Distortion in Remote Sensing Data

- Sources of Geometric Distortion
- Basic Image Formation Geometry
- Earth Rotation Effects
- Panoramic Distortion
- Earth Curvature
- Scan Time Skew
- Variations in Platform Altitude, Velocity, and Attitude
- Aspect Ratio Distortion
- Sensor Scan Non-Linearities
- Non-systemic and Systematic Distortion

Correction of Geometric Distortion

- General Aspects
- use of Mapping Polynomials for Image Correction
  - Mapping Polynomials and Ground Control Points
  - Resampling
  - Interpolation
  - Choice of Control Points
  - Eg.: Map-Landsat MSS Registration
- Mathematical Modelling
  - Aspect Ratio Correction
  - Earth Rotation Skew Correction
  - Image Orientation to North-South
  - Correction of Panoramic Effects
  - Combining the corrections

Image Registration

- Geo-referencing and Geo-coding
- Image to Image Registration
- Control Point Localisation by Windowed Image Correlation
- Example of Im.-Im. Registration (Manual GCP Selection - SSDA)
- Image to Image (Affine) Registration in the Frequency Domain
- Control Point Registration by Automated Feature Extraction and Matching
- Example of Im.-Im. Registration (Automated Feature Based)

Lesson Three - Multispectral Transformations of Image Data

Introduction

The Principle Components Transformation

The Mean Vector and Covariance Matrix
An example
A Zero Correlation, Rotational Transform
An example (cont...)
Practical Considerations
Real Example
A Second Real Example
A Third Real Example: Landsat Thematic Mapper
Remarks about the Principle Components Transform
The Effects of an Origin Shift
Applications of Principal Components in Image Enhancement and Display
The Taylor Method of Contrast Enhancement (Decorrelation stretch)
Decorrelation Stretch Example One
Decorrelation Stretch Example Two
Other Applications of Principle Components Analysis

Lecture Four - The Interpretation of Digital Image Data

Approaches to Interpretation
The Classic View of Complementarity
Pixel-Wise Classification
Pixel-Wise Classification in the Pattern Space
Multi-Spectral Pattern Space: Information vs Spectral Classes

Object-Wise Detection / Classification
The Current "Interpretability" Perspective

Definition and Types of Machine Learning
Machine Learning Overview
Applications of Machine Learning
Imaging and Beyond
Classification and Beyond

Image Interpretation Domains: Beyond Remote Sensing
UnSupervised Classification
Supervised Classification
Steps in Supervised Classification
Measuring the Success and Performance for Classification
Typical Issues in Machine Learning
Overfitting and Underfitting
Generalisation and Capacity
Model Capacity
Bias and Variance
Overall Picture

Lesson Five - Supervised (Statistical) Classification Techniques

Maximum Likelihood Classification

- Bayes' Classification
- The Maximum Likelihood Decision Rule
- Multivariate Normal Class Models
- Decision Surfaces
- Thresholds
- Number of Training Pixels Required for Each Class
- A Simple Illustration

Gaussian Mixture Models

Minimum Distance and Parallel-Piped Classification

- The Case of Limited Training Data
- Minimum Distance Classifier: The Discriminant Function
- Remarks on Minimum Distance Classification
- Decision Surfaces - Example
- Remarks on Minimum Distance Classification
- Parallel-Piped Classification
- Classification Time Comparison of the classifiers

Context Classification

- The Concept of Spatial Context
- Context Classification by Image Pre-Processing
- Post Classification Filtering
- Probabilistic Label Relaxation
  - The Basic Algorithm
  - The Neighbourhood Function
  - Determining the Compatibility Coefficients
  - The Final Step
    - Stopping the Process
    - Propagation Control
  - Example One
  - Example Two

- Handling Spatial Context by Markov Random Fields
- Comparative Example

Lesson Six - Supervised Non-Parametric Classification: Geometric Approaches

- Introduction

The kNN (Nearest Neighbour) Classifier

Non-Parametric Methods from a Geometric Basis: Linear Discrimination

- Concept of a Weight Vector
- Testing Class Membership
- Training a Linear Classifier in the Weight Space
- Setting the Correction Increment

Support Vector Classifiers

Linearly Seperable Classes
Overlapping Classes - The Use of Slack Variables
Linear Inseparability
The Use of Kernel Functions
Example
Popular Kernels

Binary vs Multicategory Classification

Binary Classification - The Threshold Logic Unit
Multicategory Classification
Networks of Classifiers - Solution of Non-Linear Problems
SVM Application: Kernel Selection and Multicategory Stategy
SVM Application: Examples

Networks of Classifiers: The Neural Network Approach

The Neural Network Approach
The Processing Element
Training the Neural Networks - Backpropagation
Choosing the Network Parameters

Committees of Classifiers: Ensemble Classification

Problem Statement and Decision Logics
Bagging
Boosting: AdaBoost

Committees of Classifiers: Random Forests

The Idea of Ensembling Multistage Classifiers
Decision Tree Classifiers
CART - Classification And Regression Trees
Random Forests

Lesson Seven - Clustering and Unsupervised Classification

Back to the General Problem of Delineation of Spectral Classes

Similarity Metrics and Clustering Criteria

How many Clusters? - Similarity Metrics and Clustering Criteria

The Iterative Optimisation (Migrating Means, K-Means) Clustering Algorithm

The Basic Algorithm
Isodata - Mergings, Deletions, and Splitting Elongated Clusters
Choice of Initial Cluster Centres
Clustering Cost

Unsupervised Classification and Cluster Maps - Examples

Unsupervised Classification and Cluster Maps
Clustering Example

A Single Pass Clustering Technique

Single Pass Algorithm
Advantages and Limitations
Skip Generation Parameter
Variations on the Single Pass Algorithm
Example

Agglomerative Hierarchical Clustering

Clustering by Histogram Peak Selection

Lesson Eight - From Shallow to Deep Neural Networks

Main Resources & Related Courses

Knowledge Base vs Representation Learning

Feed-Forward Neural Networks...
The Mammalian Visual Cortex is Hierarchical
Multilayer Perceptron (MLP)
Representation (Feature) Learning Perspective of MLP
Activation (Non-Linear) Functions, g()
Training an MLP (and a Function)
MLP Expressiveness
Number of Neurons
Example One: Expressiveness
Example Two: Binary Case and Complexity

Universal Approximation Theorems
Approximation Capability (Expressiveness): The Width or Depth Dilemma

Outputs and Loss Functions

Loss Function
Task Dependency of Output and Loss Functions
Image Classification
Binary Classification - Bernoulli Distribution - BCE
Multiclass Classification - Categorical Distribution - CE Loss
Multiclass Classification - Categorical Distribution - Softmax Output
Summary: Classification Deep Neural Networks

Activation Functions

Sigmoid
Tanh
Rectified Linear Unit (ReLU)
Leaky ReLU
Exponential Linear Units (ELU)
Maxout

Lesson Nine - Convolutional Neural Networks

- Introduction
- Notation
- Fully Connected vs Convolutional Layers
- Downsampling
  - Pooling
  - Strided Convolution
- Receptive Field Algorithm
- Fully Connected Layers
- Convolutional Network Example
- Upsampling
- Max Unpooling
- Dilated Convolution
  - Gridding Effects
  - Architectures
- Some Remarks about CNNs

Lesson Ten - AI and Deep Learning for Medical Image Analysis

- Intro - Main Issues / Challenges
- Data Driven Approach
- Evaluation Metrics
- Applications and Case Studies
  - Medical Image Classification
  - Medical Image Segmentation and Detection
  - Higher Dimensionality Data
- Interpretability, Fairness, Ethics