Lesson: Pixels vs. object-based paradigm

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African Population and Health Research Center

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Nuffic meet the world

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The pixel-based and object-based paradigm in image classification

Adapted from Taïs Grippa – CIVIS Summer School 2021

Based on inputs of Taïs GRIPPA (ULB), Moritz LENNERT (ULB), Eleonore WOLFF (ULB), Stefan LANG (PLUS).

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I. Introduction
II. Spatial unit to classify: Pixel or Object ?
III. Image segmentation and Object-based image analysis (OBIA)
IV. Measure of interpretation criteria: classification features

I. Introduction

What is the purpose of image classification?

Image classification

- The aim of image classification/analysis is to extract meaningful information from (e.g., earth observation) images
- The most common (geo)information extracted from remote sensing earth observation data is land cover

Image interpretation

False colour composite

Try to answer this question:

- What do you see on this image ?

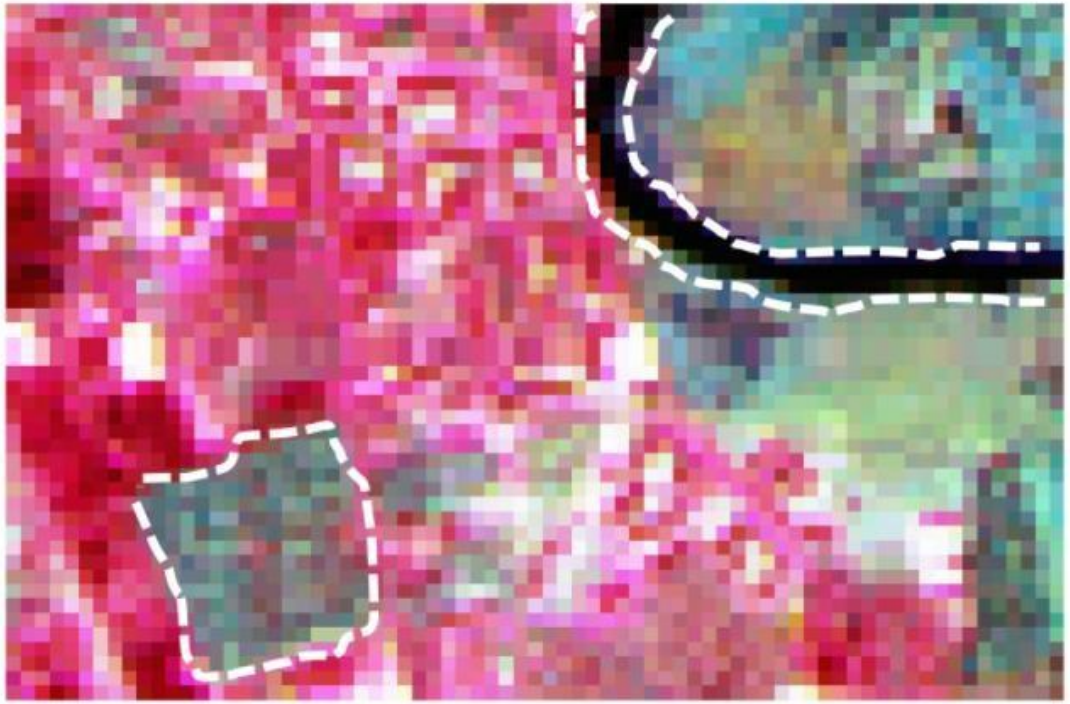
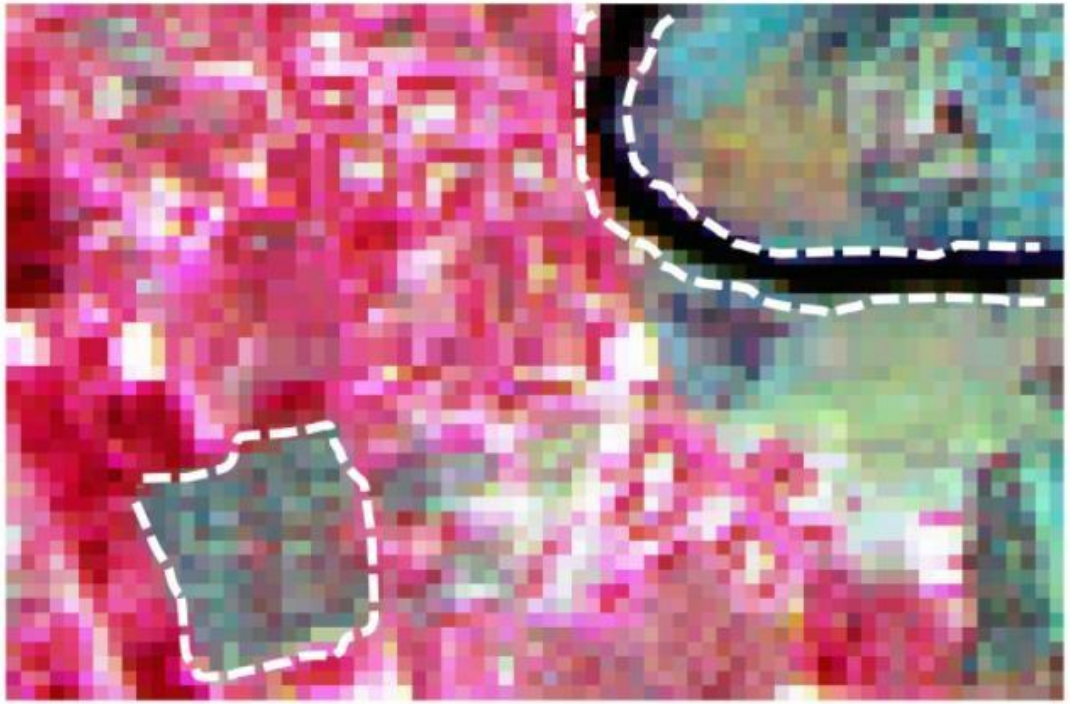


Image interpretation

False colour composite

Try to answer these two questions:

- What do you see on this image ?
- Which information do you rely on to take you decision ?



Spatial matters

- Spatial information is as important as spectral information to identify real-world object in image analysis.

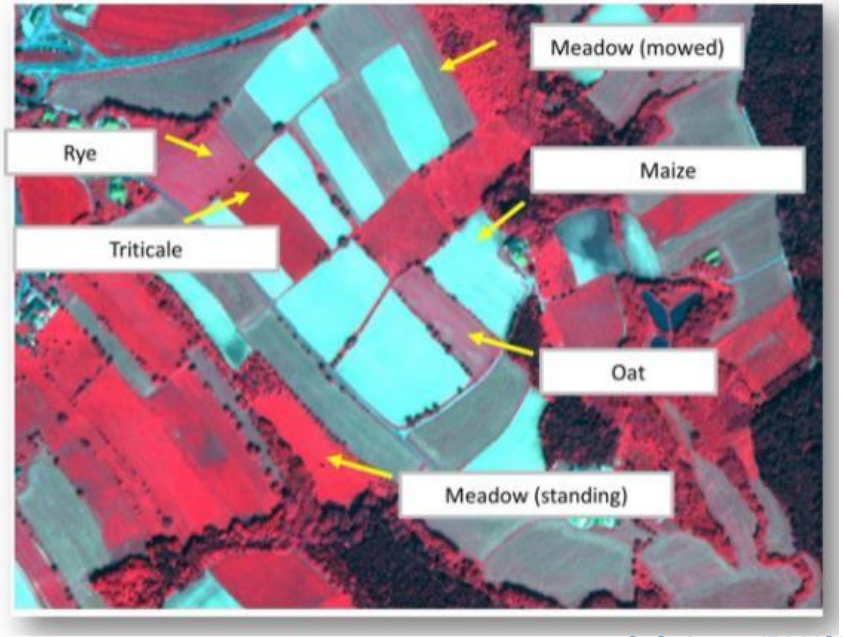
Spectral

Red pixels = Active vegetation

Spatial

Smooth = Agricultural fields

Bumpy = Deciduous forest



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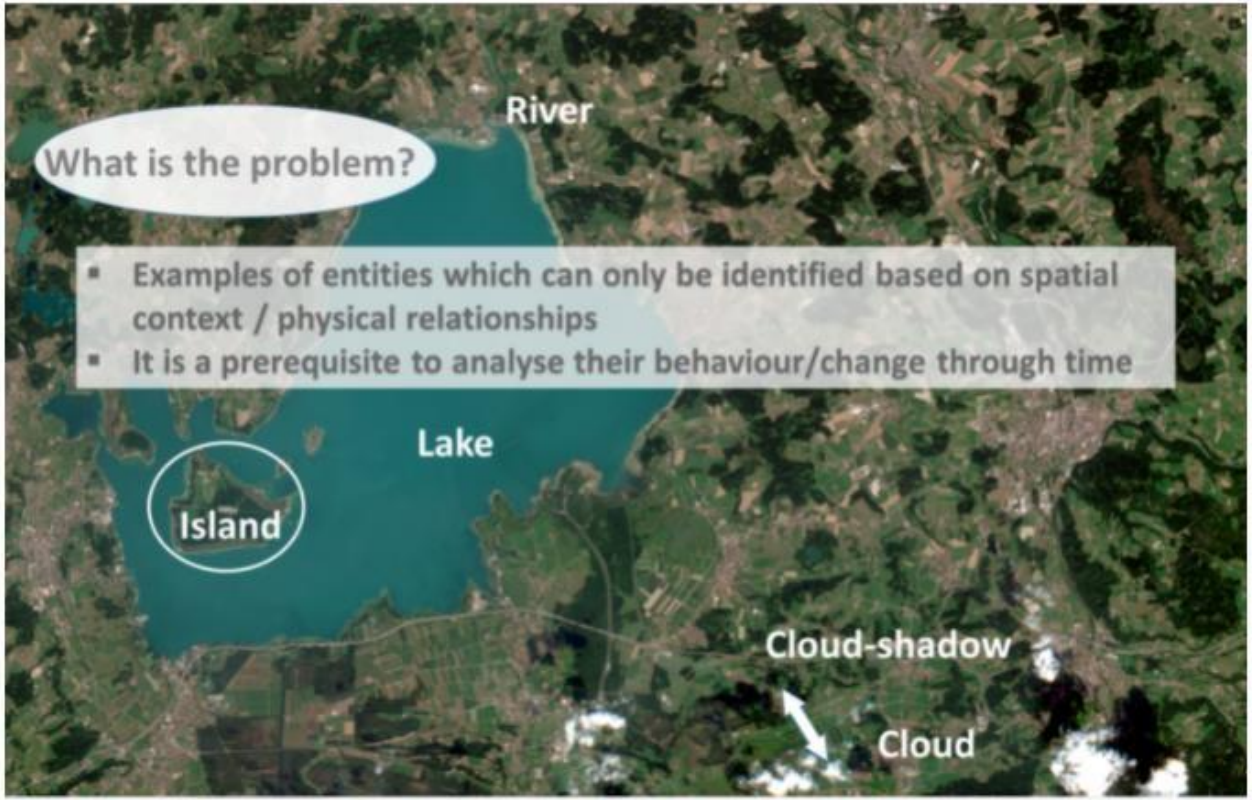
Spatial matters

- Lake >< River
- Land >< Island
- Shadow



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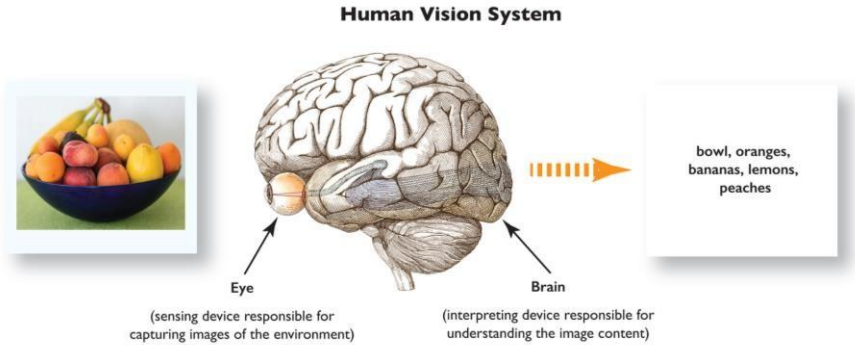
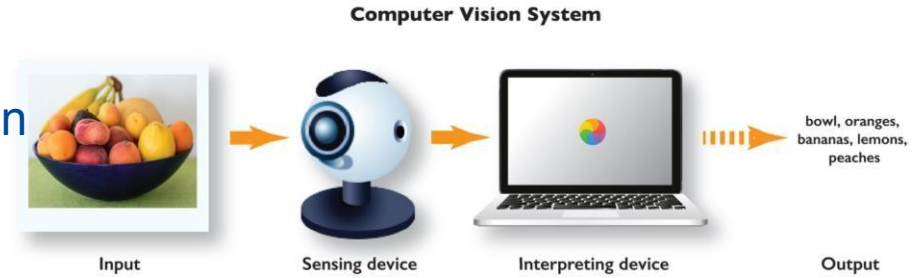
Human v.s. Computer

- Human visual system
  - highly complex and powerful allowing precision and nuance in interpretation
  - very tedious and inefficient when dealing with large amounts of data



- Computer vision system
  - Possibility to automatize extraction



CHALLENGE
Replicate the interpretation capacity of the human brain

What is the problem with pixel-based ?

Information available at pixel level:

- Spectral value of pixel (-> Tone/color)
- Pseudo bands like NDVI indices etc..
  (-> Tone/color)
- Coordinates from pixel (-> location)

Other important criteria of interpretation are not available directly at pixel-based level, such as Shape / Size / Texture / Association / Site

Simple spatial information

Complex spatial information

II. Spatial unit to classify: Pixel or Object ?

Spatial unit: Pixel or Object ?

- The spatial resolution has an impact on the kind of object of interest we can classify in the image.

Spatial unit: Pixel or Object ?

- Understanding the relation between the spatial resolution of the image and the size of elements we expect to map is important to understand why the object-based approach could be useful.

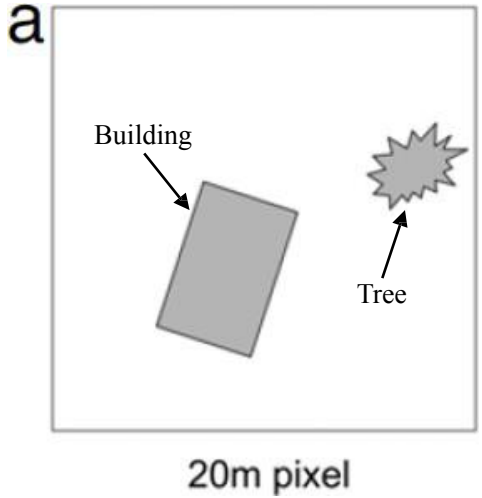
Spatial unit: Pixel or Object ?

How to classify correctly this building made of multiple pixels ?

How to identify the different classes mixed in this pixel ?

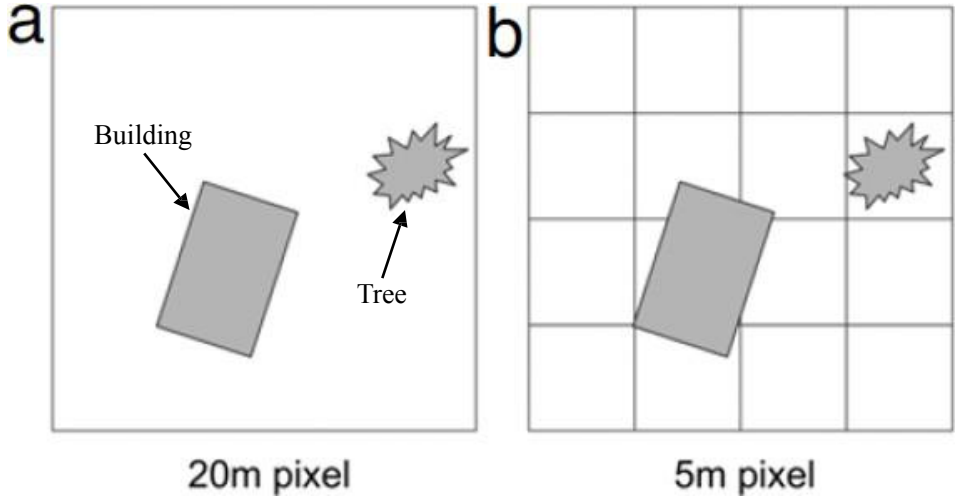
Spatial unit: Pixel or Object ?

a) Mixed pixel: Several geographical objects in the same pixel =>
Mixed spectral responses, no clear delineation of the objects and difficult to classify



Spatial unit: Pixel or Object ?

b) Some mixed pixels and some pure. Here, the spatial resolution starts to be equivalent to the size of some geographical objects but not all



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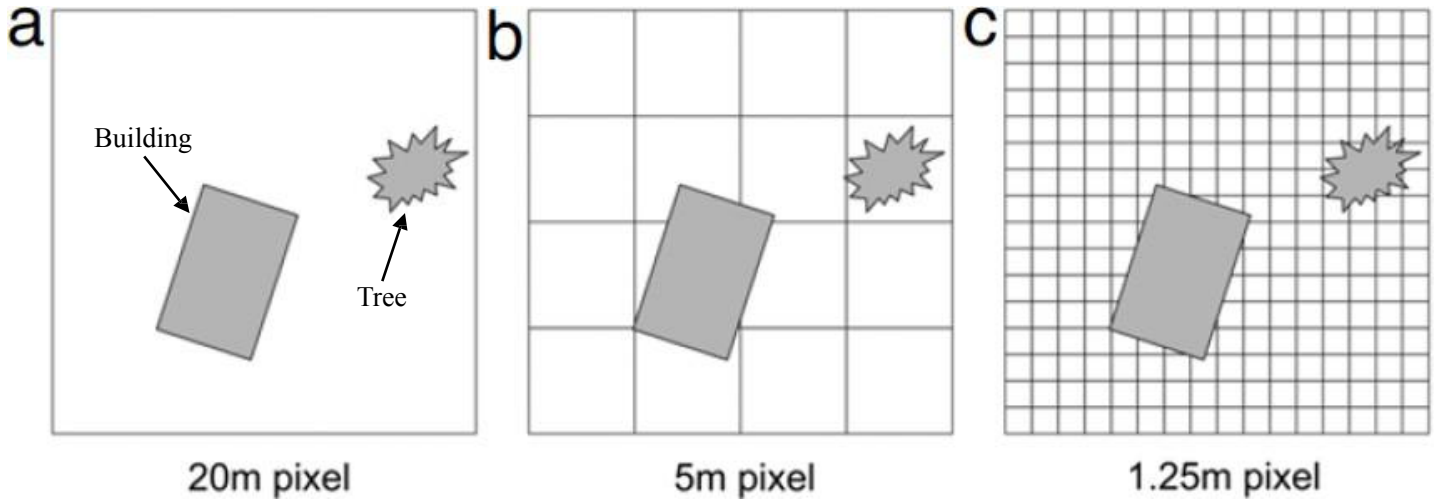
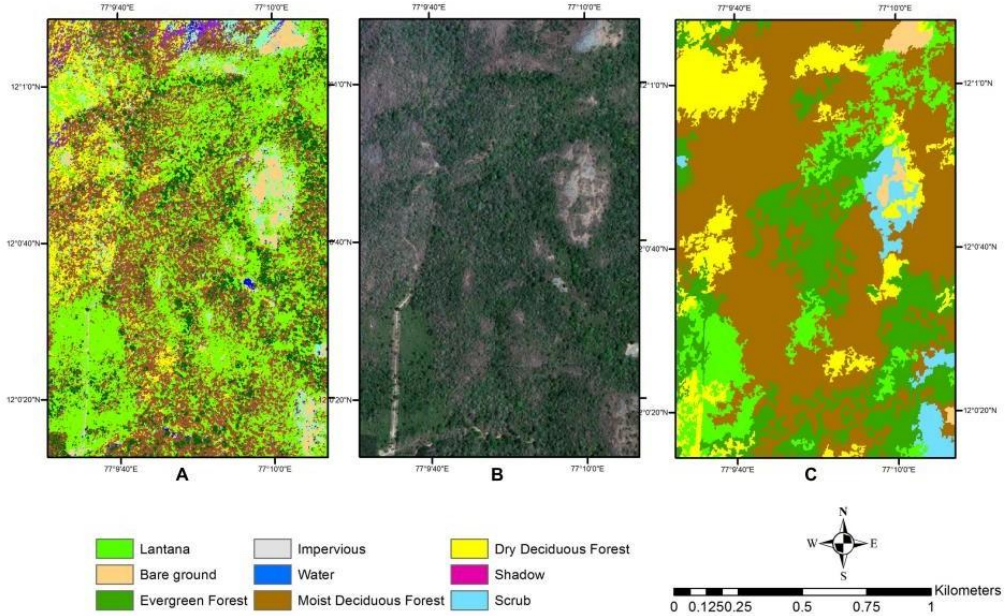
Spatial unit: Pixel or Object ?

c) Single geographical objects are composed of multiple pixels => Could be a problem in pixel-based approach (salt-and-pepper)



Salt-and-pepper effect

A common issue with pixel-based classification, that is not present in object-based approaches (which give more homogenous regions)



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Spatial unit: Pixel or Object ?

When the size of objects of interest tends to be larger than the image's pixel size, the object-based approach start to make sense

Why to chose an object-based paradigm

- If objects of interest are composed of multiple pixels
- If size and shape features are useful for distinguishing different classes (ex: bare soil <> unpaved road ; Lake <> River)

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III. Image segmentation and Object-based image analysis (OBIA)

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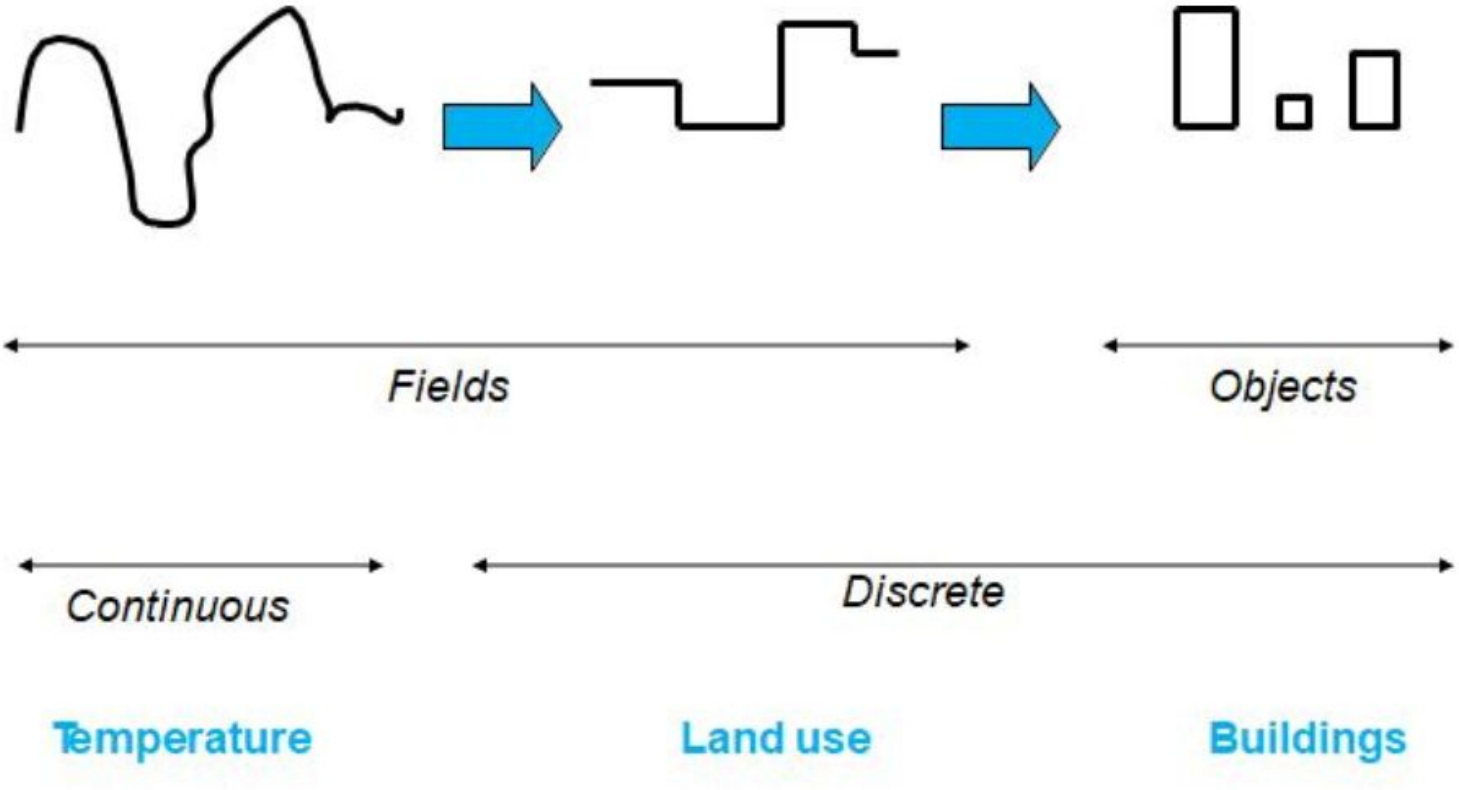
Geographic Phenomena



Object-based image analysis (OBIA)

Object representation
Vector model

Clear boundaries, unique and unambiguous content, allows queries

Stores interpretations, facts

Imaged representation
Raster data model

No boundaries, no semantic content, only spectral values, allows different interpretations

Stores (pseudo-continuous) measurements

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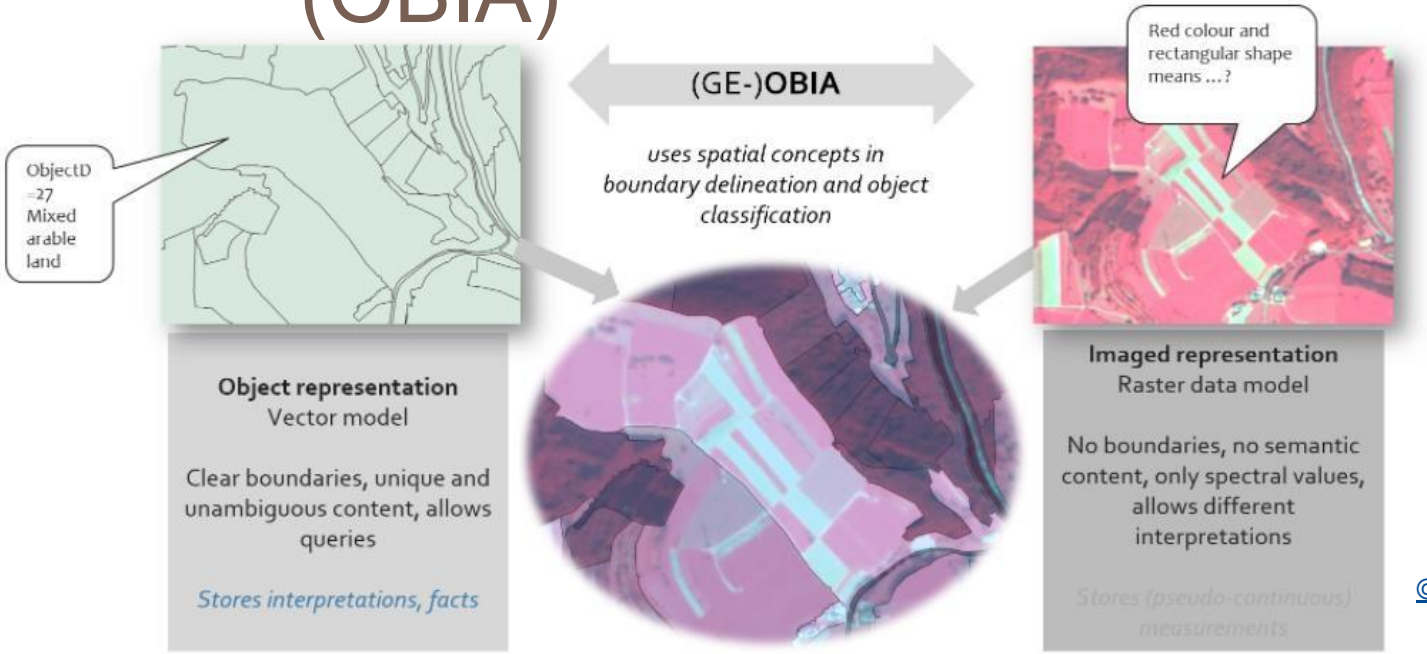
- Vector model and raster model are two different paradigms in data management

Object-based image analysis (OBIA)



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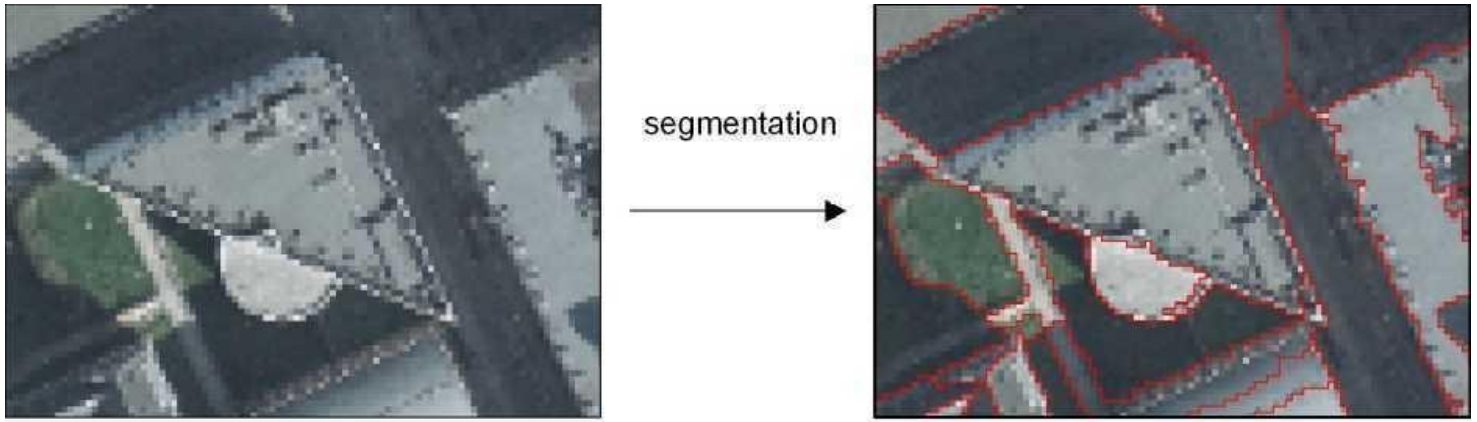
- GEOBIA is an image classification paradigm leveraging the object representation model to analyze raster data
- Creates bridge between GIS (mainly vector + spatial analysis) and remote sensing (raster)

Object-based image analysis (OBIA)

- Image data does not store boundaries, but boundaries can be extracted from images using **segmentation** techniques



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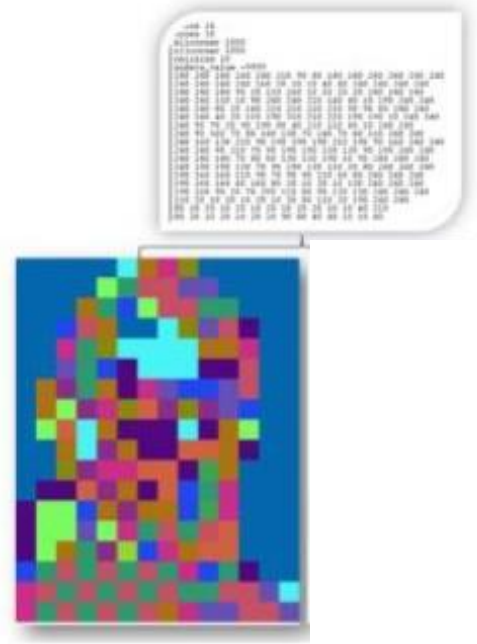
How segmentation works ?

- Can you identify the content of this image?



A simple image matrix is converted to random colours (left). When using graduated grey shades it reveals a familiar pattern (right). © S. Lang (PLUS)

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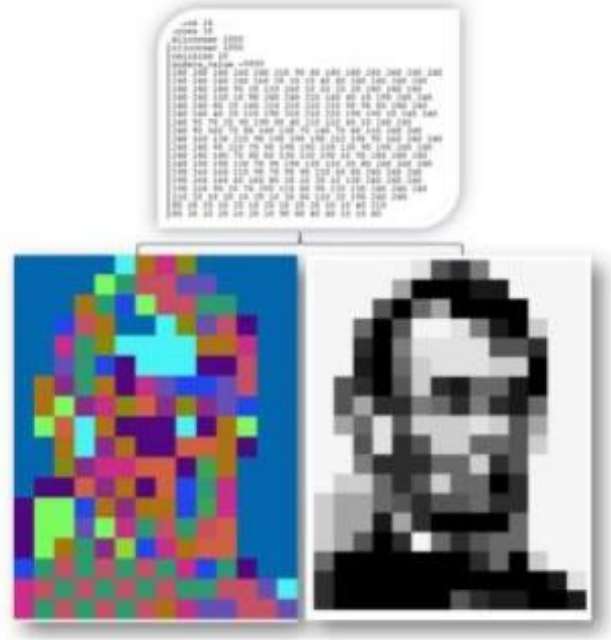
How segmentation works ?

- Can you identify the content of this image? And now ?
- How do we know that some pixels should belong to the same object ?

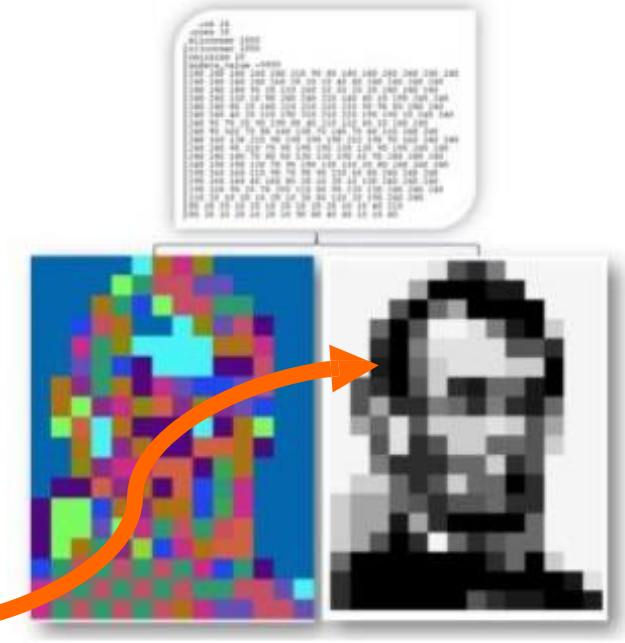


A simple image matrix is converted to random colours (left). When using graduated grey shades it reveals a familiar pattern (right).

How segmentation works ?

- Can you identify the content of this image? And now ?
- How do we know that some pixels should belong to the same object ?

Pixels belonging to the hair all have dark color and are close to each other
=> Spatial auto-correlation



A simple image matrix is converted to random colours (left). When using graduated grey shades it reveals a familiar pattern (right). © S. Lang, PLUS

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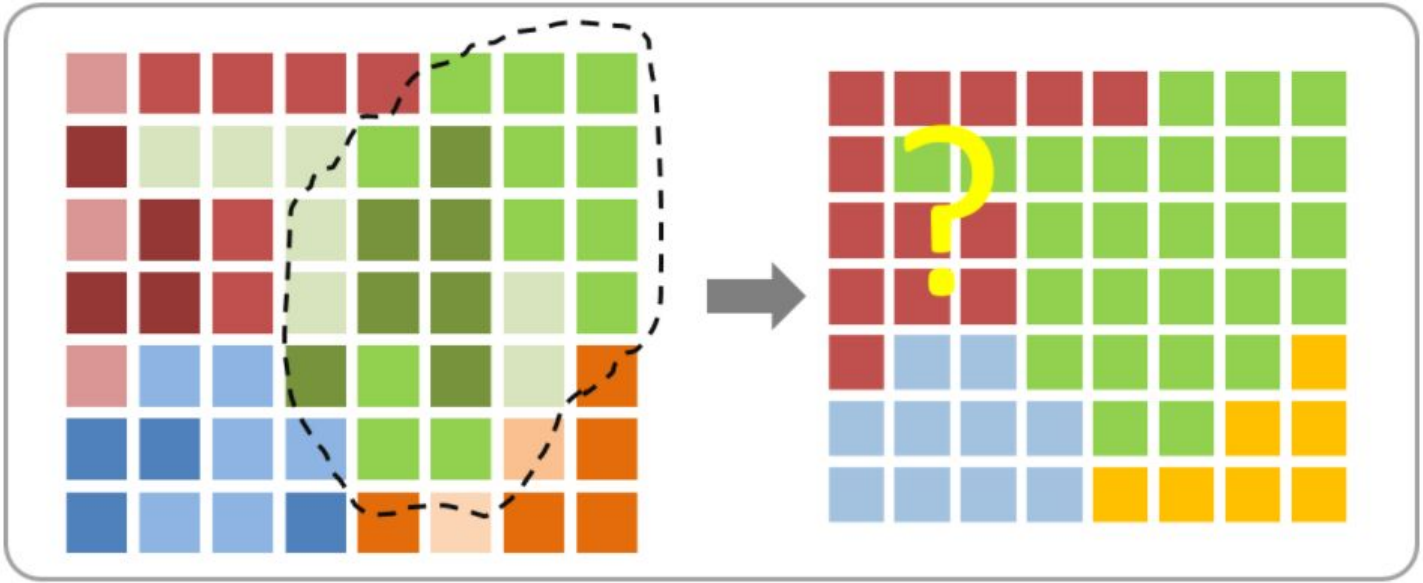
How segmentation works ?

“Everything is related to everything else, but near things are more related than distant things.”

Tobler’s first law of geography



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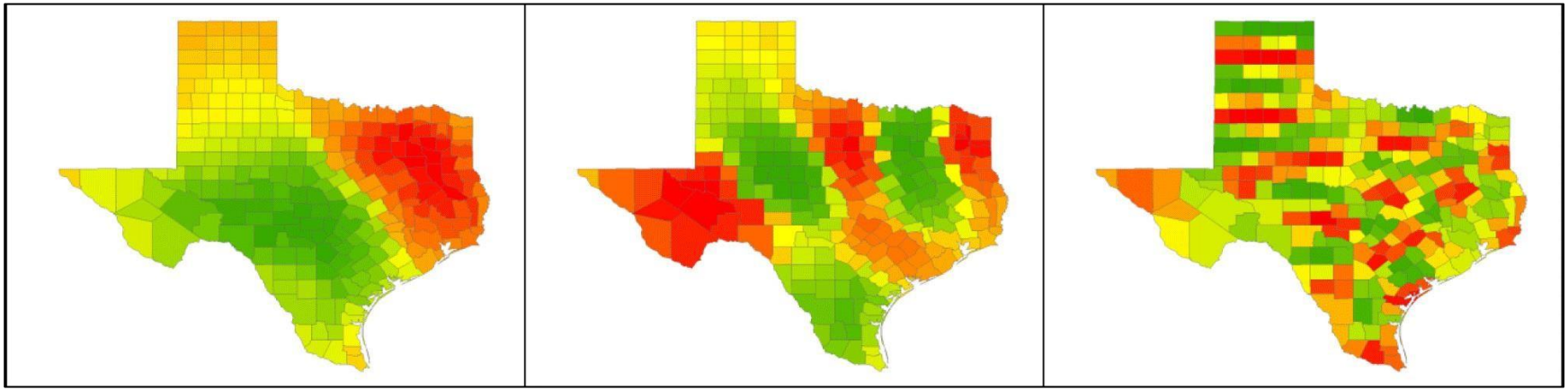
How segmentation works ?

- Measures of spatial autocorrelation: Morans' I, Geary's C

I > 0 = Clustered 0 = Random I < 0 = Dispersed



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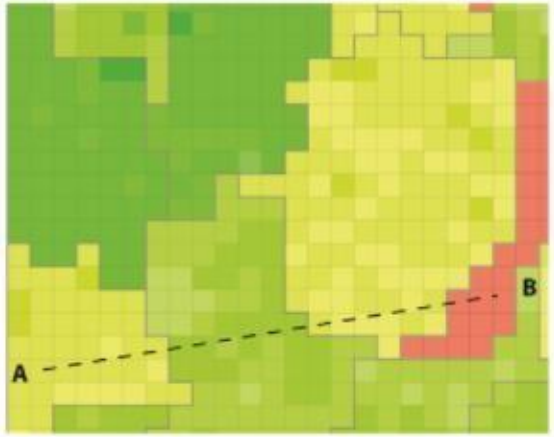
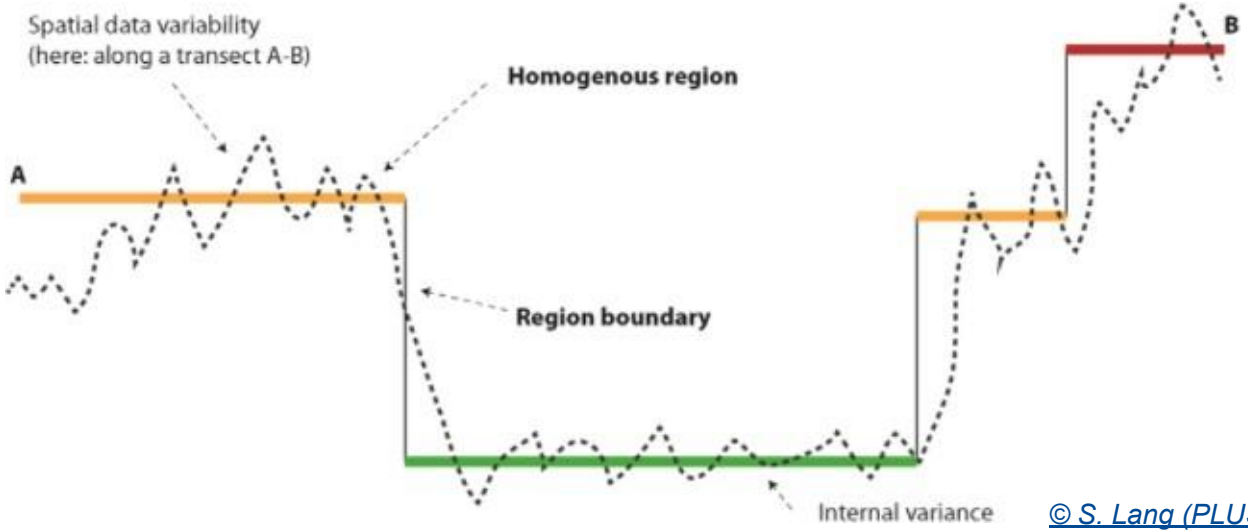
How segmentation works ?

- Spatial auto-correlation is a fundamental principle in image analysis
- The Human vision system relies on breaks in spatial auto-correlation to decide if pixels belong together and form “objects”
- The good news : We can measure that with our computers !
- Segmentation = Grouping neighboring pixels with similar values

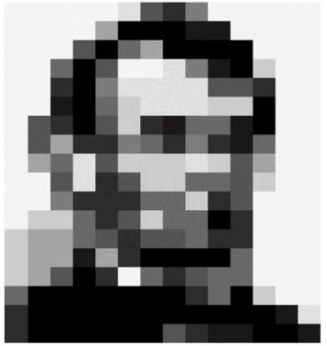
How segmentation works ?

- Objects are regions homogenous in terms of spectral values
- Region boundaries occur when spectral values change suddenly

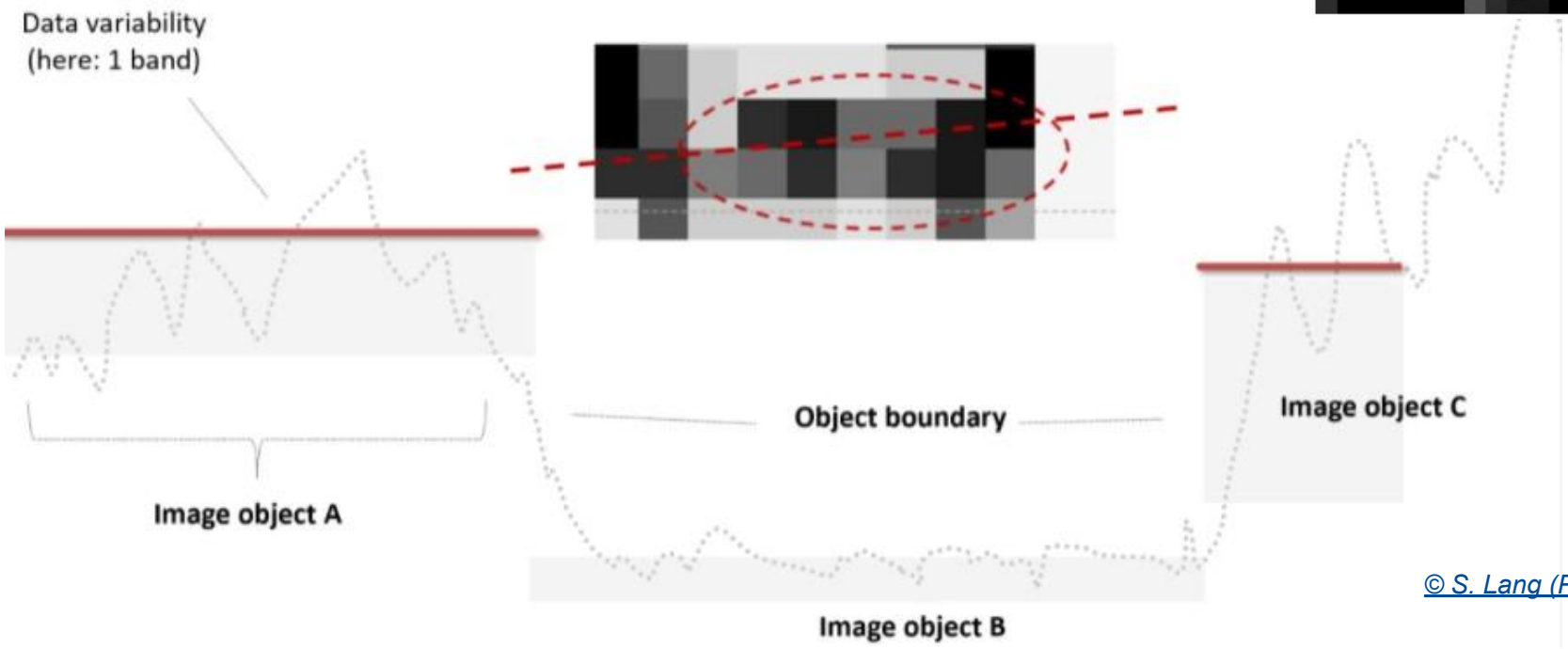




How segmentation works ?



- Grayscale segmentation



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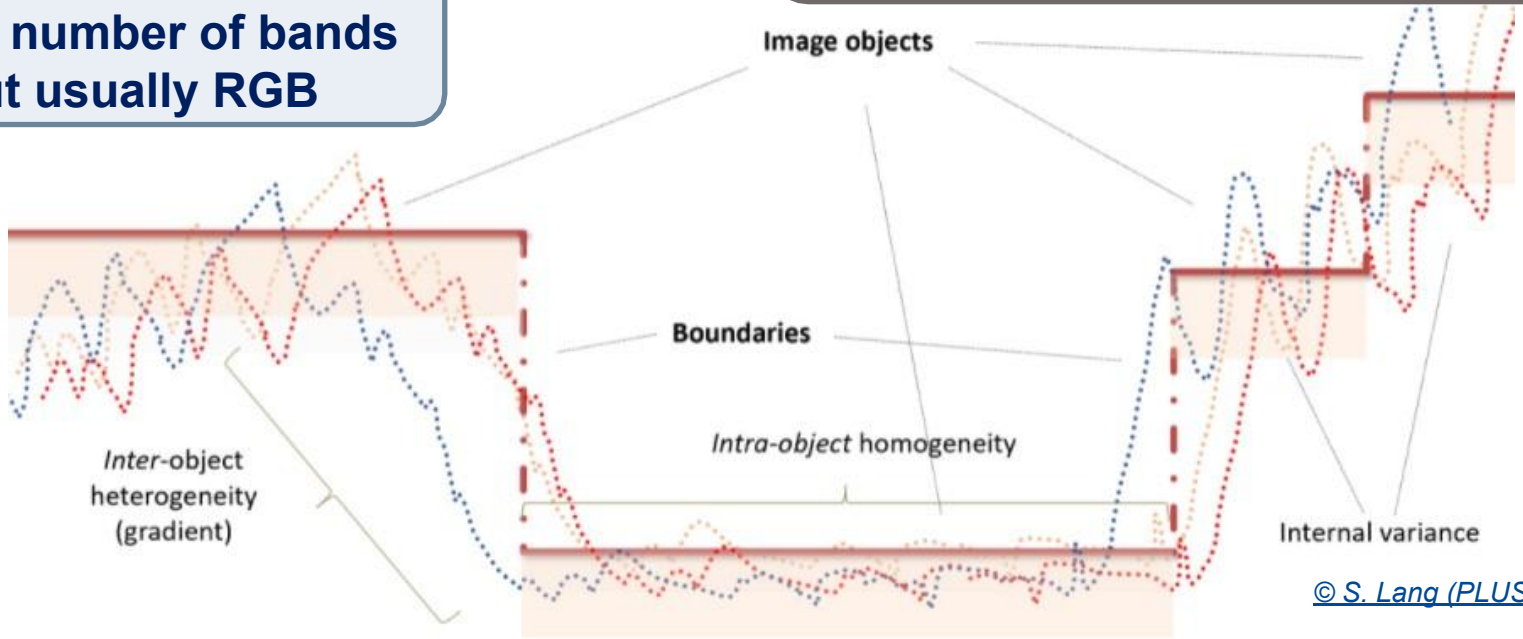
How segmentation works ?

- Multispectral segmentation

No theoretical limitation of the number of bands but usually RGB

- **Theoretically not limited to spectral (e.g. height value)**
- **More bands = Heavier processing**



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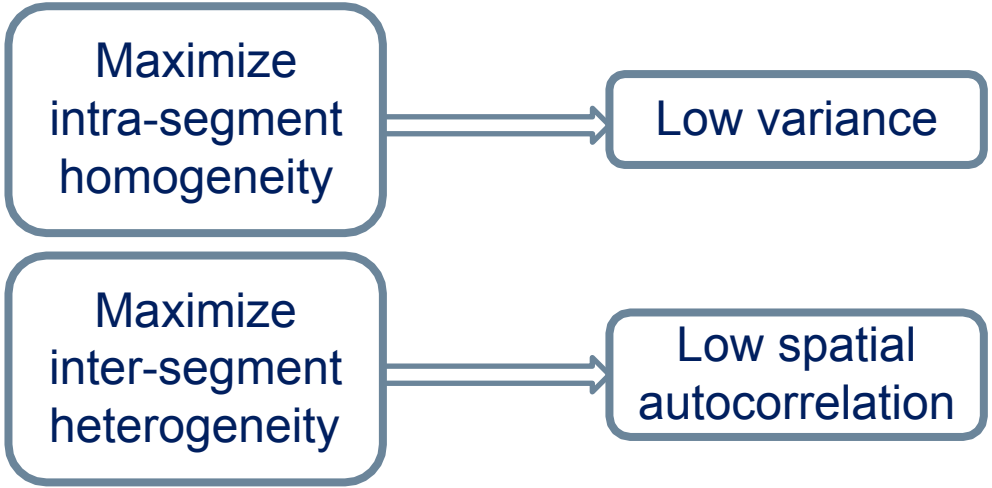
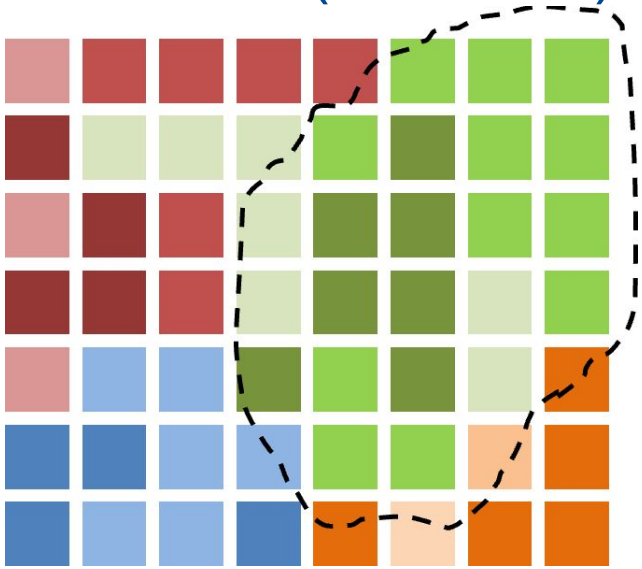
How segmentation works ?

- How to measure goodness of the segmentation ?
- The result of the segmentation should maximize the uniformity of single objects and the difference between adjacent objects (Haralick, 1985)



How segmentation works ?

- Spectral homogeneity may be not the only criteria desired
  - Size (min/max) / Compactness / etc…



Ambiguous case (considering spectral homogeneity vs. compactness of region)

Segmentation is not trivial

- Segmentation = image object creation by grouping contiguous and similar pixels

- Segmentation results should correspond as much as possible to objects of interest, but it is rarely perfect –> Look for trade-off.
- (Very) non optimal segmentation can dramatically affect the results of the classification

Segmentation is not trivial

Ideally, we would like each building of this image represented in one segment.

By varying the segmentation parameters, we achieve very different results.

Segmentation is not trivial

Example of **over-segmentation** :

Too many segments for a single real-world object

Threshold (GRASS GIS): 0.005

Segmentation is not trivial

Example of **under-segmentation** :

Several real-world objects for a single segment

Threshold (GRASS GIS): 0.005

Segmentation is not trivial

Example of **trade-off** :

Good compromise between over-segmentation and under-segmentation

Threshold (GRASS GIS): 0.005

Choice of segmentation parameter

How can optimal segmentation parameters be selected ?

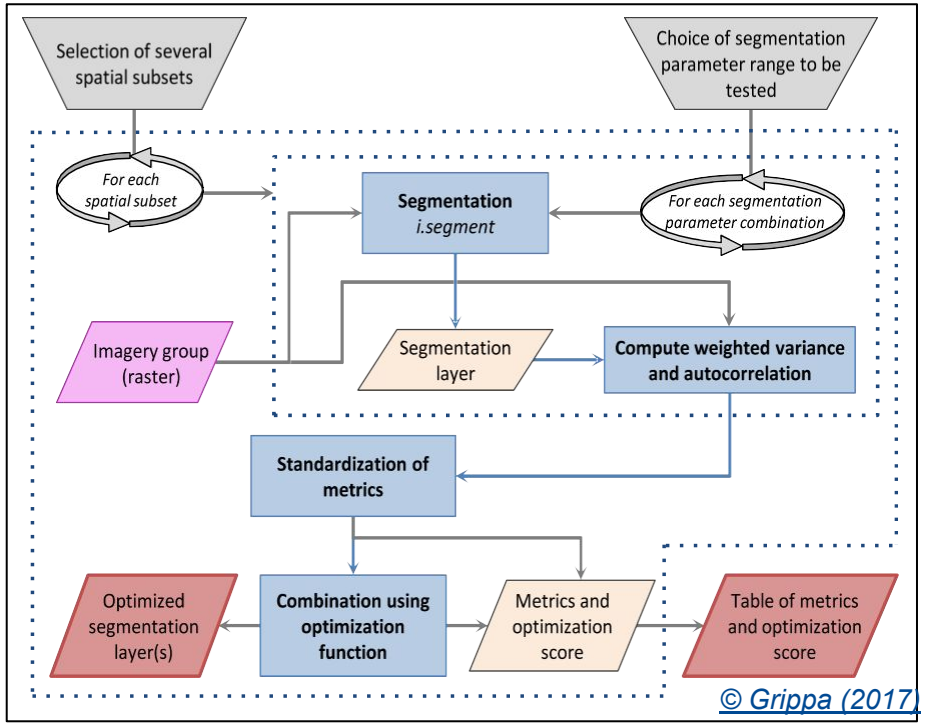
- Manually with trial-and-error attempts, in order to iteratively tune segmentation parameters, to produce expected segments
- Automated segmentation parameter optimization
  - Supervised: with available reference polygons Need a priori knowledge
  - Unsupervised (USPO – Unsupervised segmentation parameter optimization): relying on image statistics only → Without a-priori knowledge. Available in GRASS GIS (free) or eCognition (Proprietary)

Choice of segmentation parameter

Unsupervised segmentation parameter optimization (USPO)

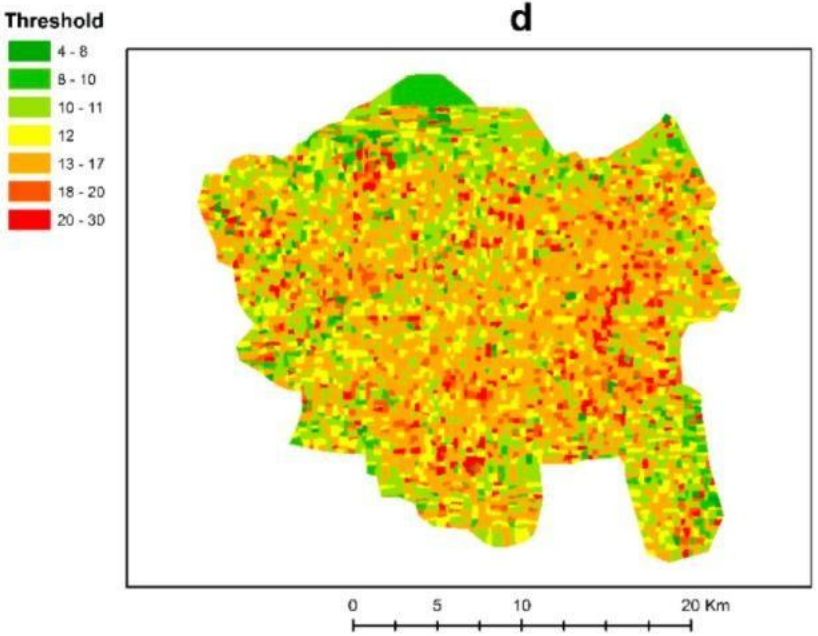
Optimal combination of segmentation parameters

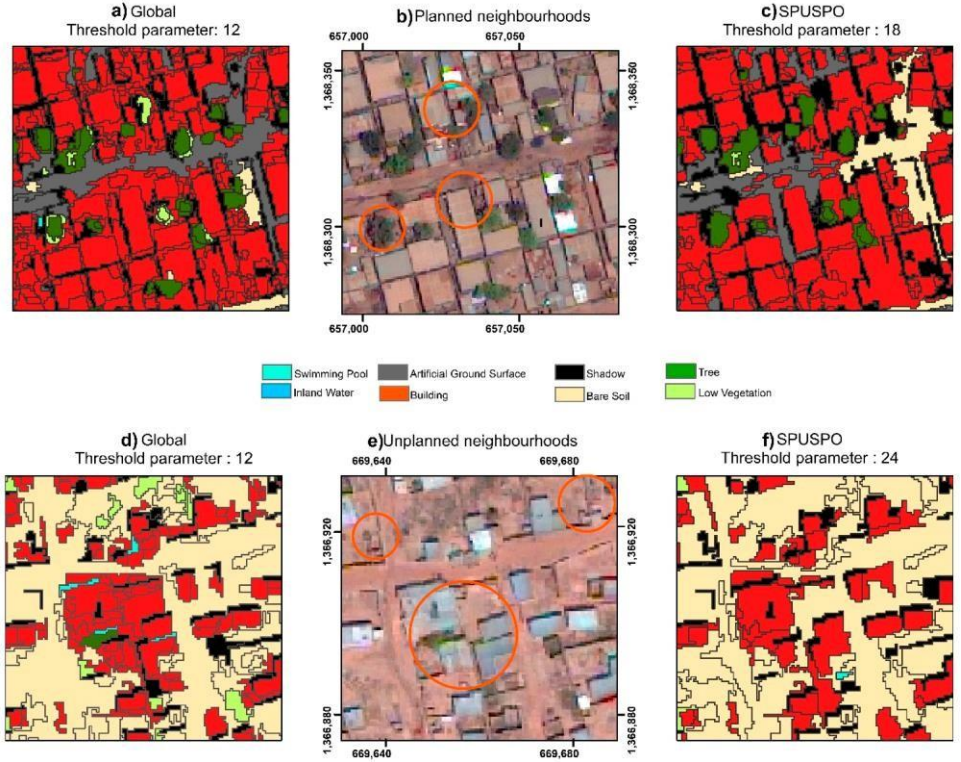
```
i.segment.uspo --overwrite group=opt_ndvi output=- regions=regio
Working on region region1
Best values:
Region  Thresh  MinSize Optimization
region1 0.04    10      0.653504551875
region1 0.05    5       0.630122188453
region1 0.05    10      0.625265005352
region,threshold,minsize,variance,spatial_autocorrelation,optimi
region1,0.01,10,4377.22722523,0.532769242846,0.351638838413
region1,0.01,5,2696.86551632,0.635491416839,0.0
region1,0.02,10,4545.24538704,0.473494476948,0.491350274845
region1,0.03,10,5262.27878218,0.400250406719,0.605730523328
region1,0.02,5,2993.14278476,0.563103596719,0.270353765406
region1,0.04,10,6352.80005026,0.325995624944,0.653504551875
region1,0.03,5,3921.94612895,0.476527715668,0.495265334997
```



Choice of segmentation parameter

Variation of optimal segmentation parameters in the area of interest





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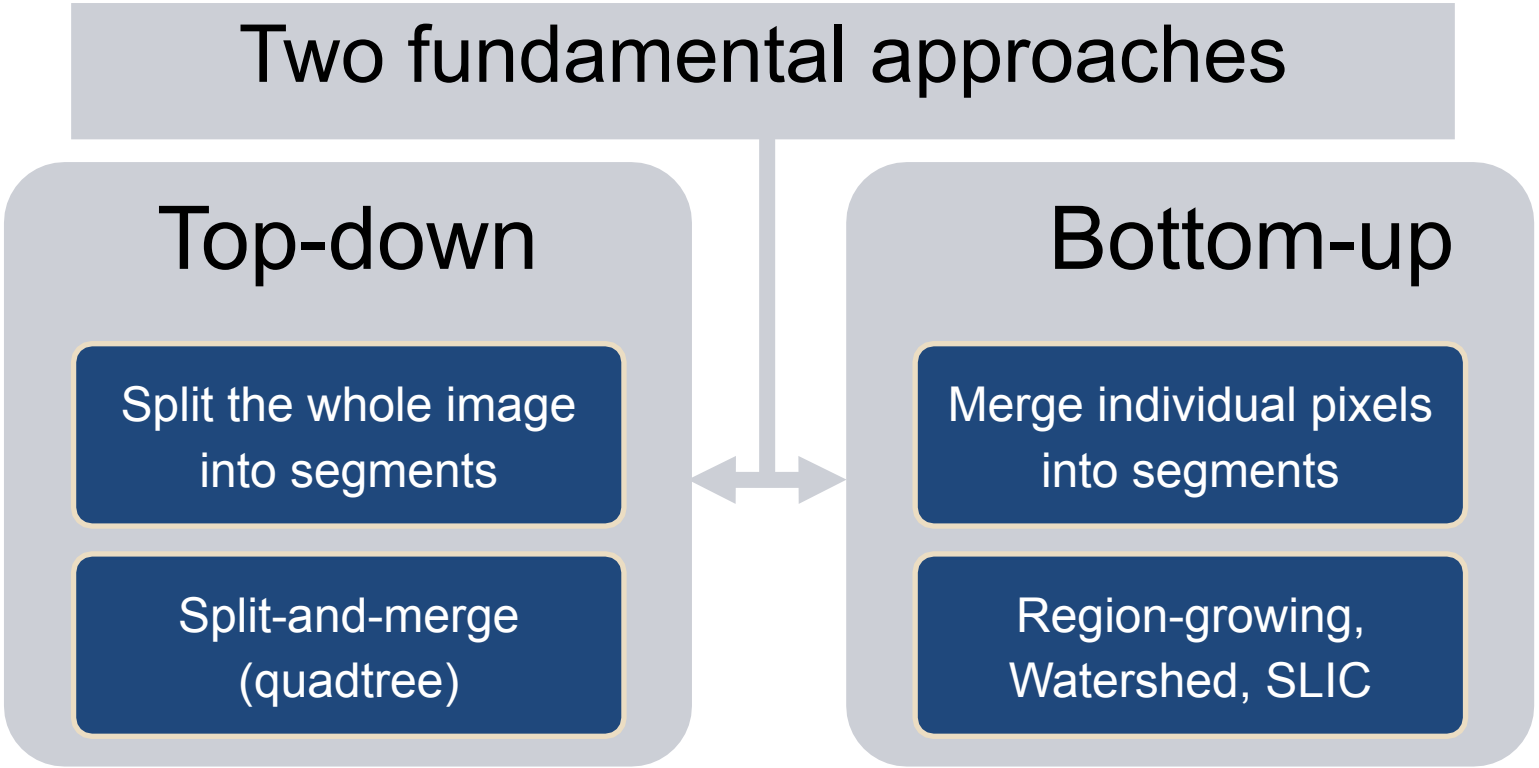
Segmentation algorithms



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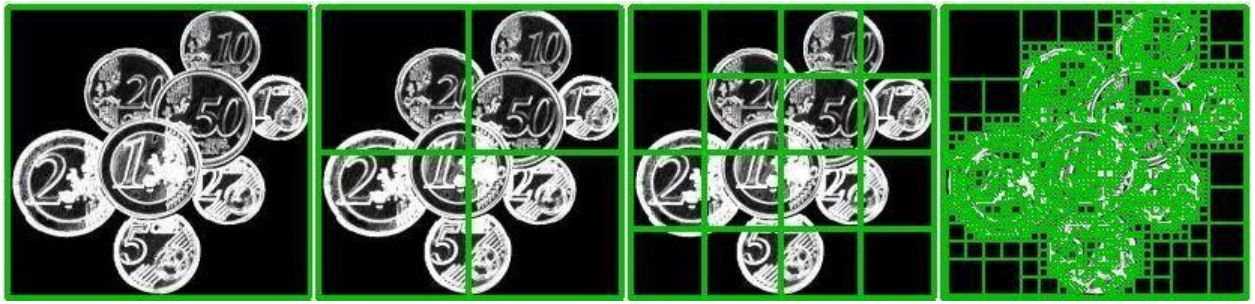
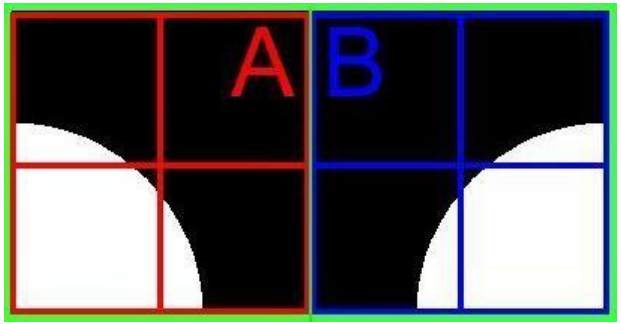
Segmentation algorithms

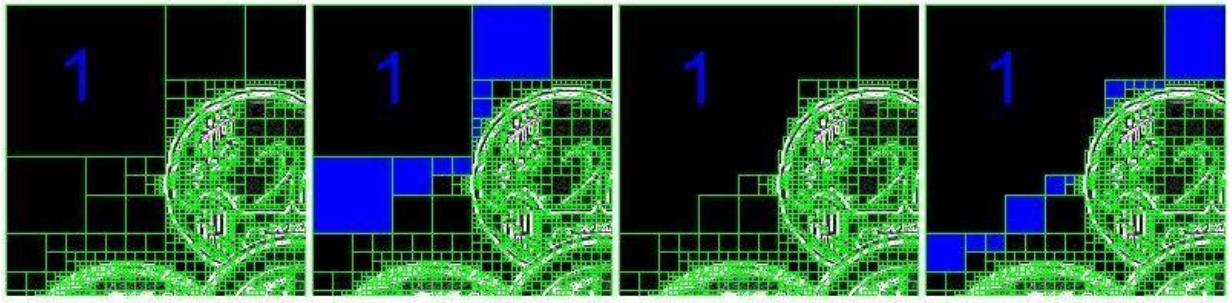
- Split-and-merge



1) Split

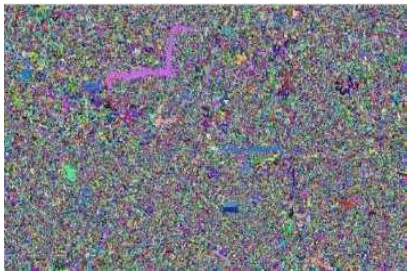
2) Merge





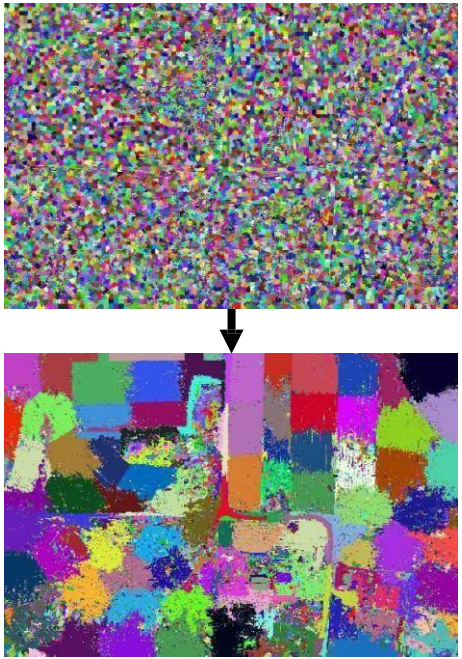
Segmentation algorithms

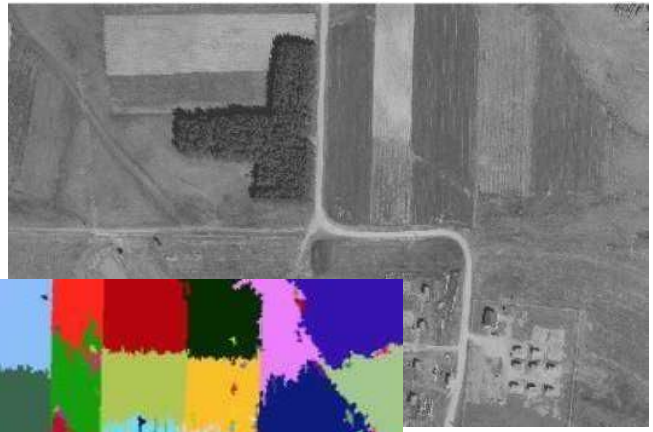
- Region-growing

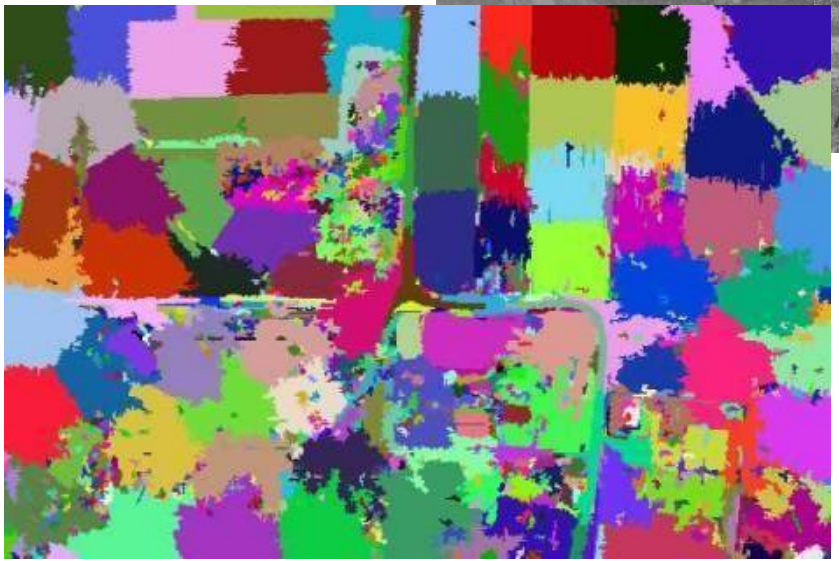


Segmentation algorithms

- SLIC Superpixels *(Statistical clustering based on K-means)*







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Important remark about segmentation

- Most of the time it is impossible to have a perfect segmentation.
- It is usually preferable to have slightly over-segmented objects because these could still be correctly classified during the classification step.
- Under-segmented objects contain several land cover classes, which affects the classification and means that it could never correspond to reality

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Important remark about segmentation

Working under the object-based paradigm does not mean we should rely on the vector model.

- Vector data are very heavy and slow to query when dealing with millions of segments.
- Raster model is much more efficient. Segment IDs can be stored in each pixel belonging to the same object and segment statistics stored in a text file
  - E.g., CSV file ready-to-use for machine learning implementation using R or Python >< Attribute table of vector layer which need format conversion