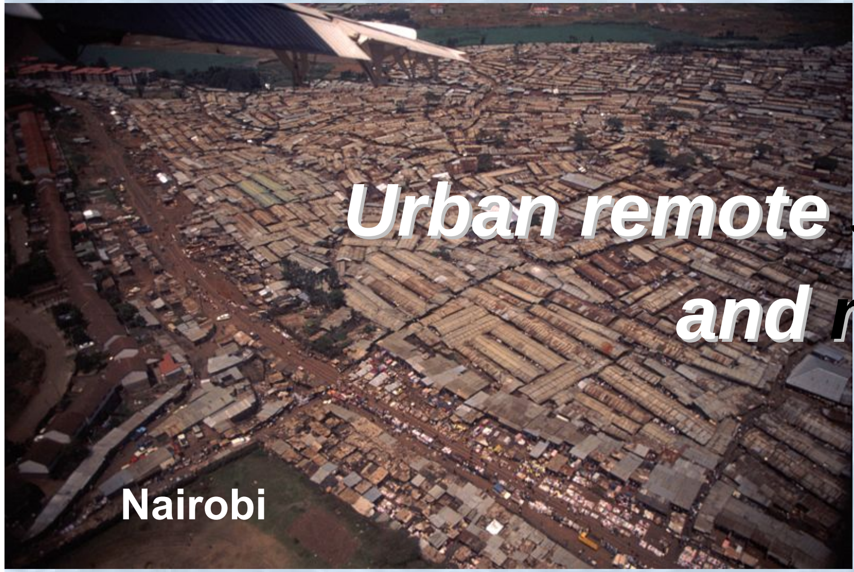
From Slums detection to slum definition …

Urban remote sensing: recent technological and methodological developments



Christiane Weber

CNRS – Strasbourg – France

Christiane.weber@lorraine.u-strasbg.fr

Laboratoire
Image et Ville UMR 7011

UNIVERSITÉ LOUIS PASTEUR STRASBOURG

CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE

Presentation

Context

Satellite imagery

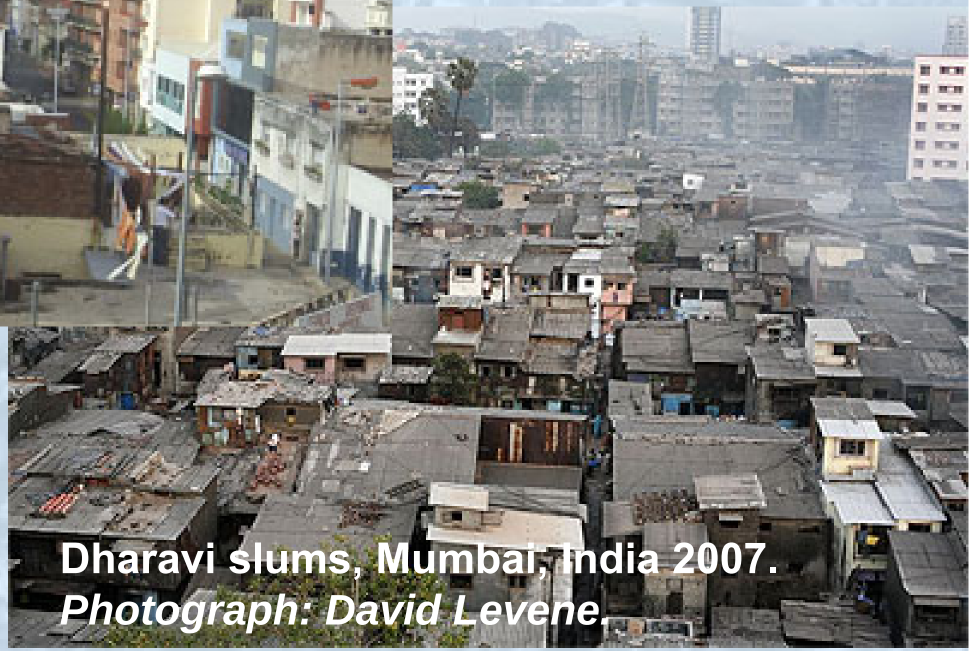
Detection & Extraction

Identification & Analyse

Slums detection towards slums definition

Direct link?

Relevant spatial characteristics?


Dharavi slums, Mumbai, India 2007.
Photograph: David Levene.

Detection: constrains

Various situations

Informal settlements on slopes

Chaotic structures without networks

Elevation and regular forms

Diversity of materials

Size of elements and surrounding buildings

➔ **Variety of situations, difficulty to generalize**

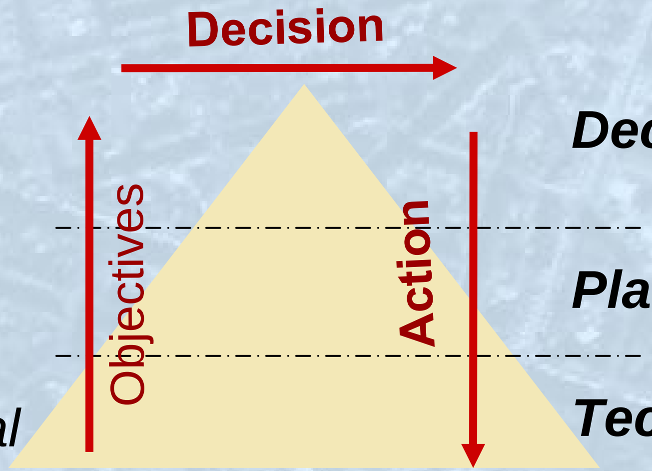
Context: Urban specificities

Urban management:

Strategic — ***Decision makers***

Tactical — ***Planners***

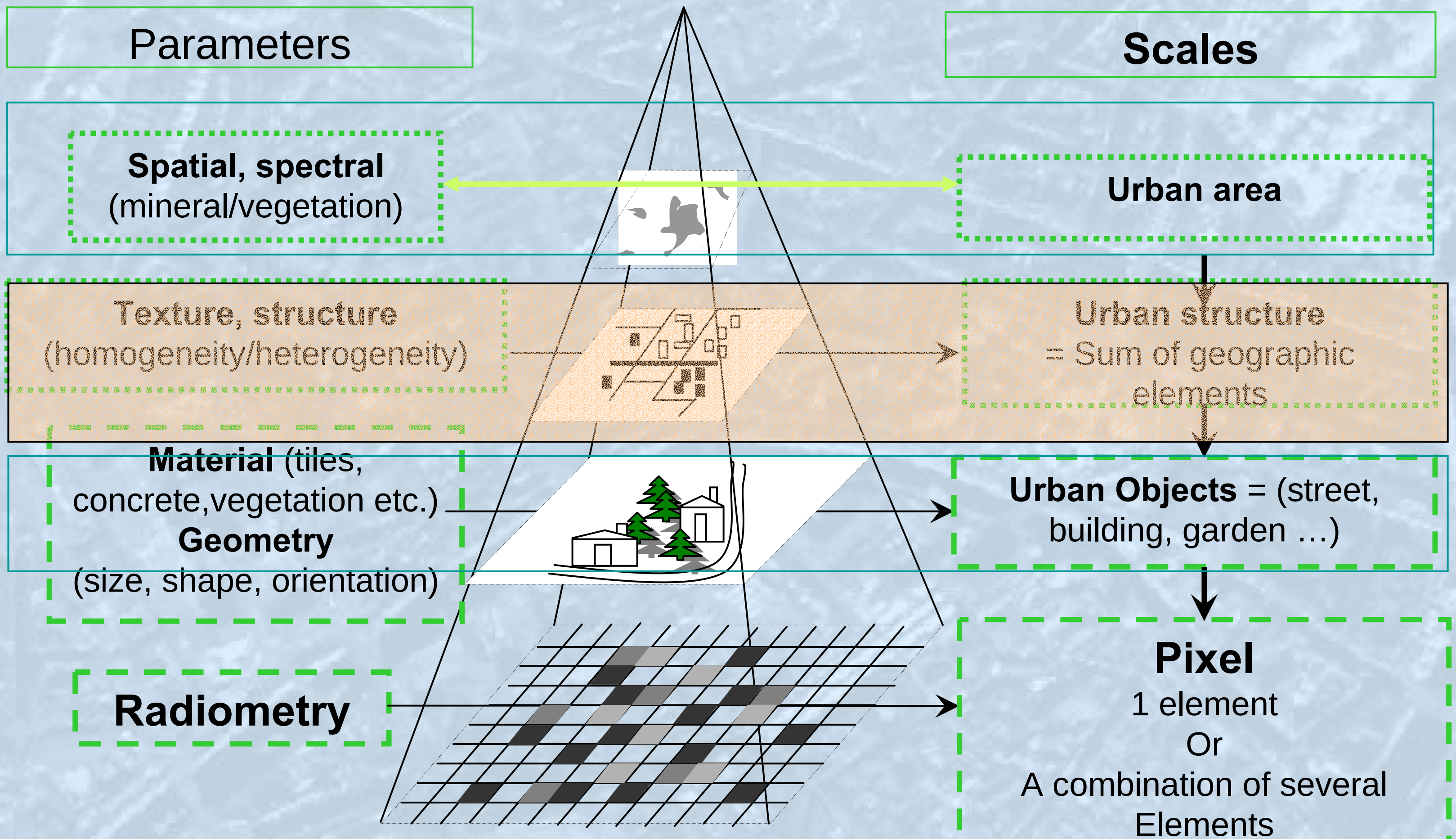
Operationnal — ***Technicians***



Urban management = - need of various types of information
- at various scales

Niveau I	Global level	> 1/25 000e
Niveau II	Urban Planning	du 1/5 000e au 1/10 000e
Niveau III	Urban mapping	du 1/1000e au 1/2000e
Niveau IV	Technical applications	du 1/200e au 1/500e

Context: Urban specificities



(TRAN, 2007 d'après ARMAND, 1986)

➔ Information extraction at various levels (urban area, urban structu, urban object) with HSR images?

Context: Detection

Scale ➔ Spatial resolution

Environment ➔ Spectral resolution, GIS data (ancillary)

Object ➔ Spatial & spectral resolution, GIS data (ancillary)

What can we do?

Detection & Extraction

1) Very high spatial resolution? (or multi-resolution solution)
2) RS usual image processing concepts or morphological concepts or knowledge based concepts?

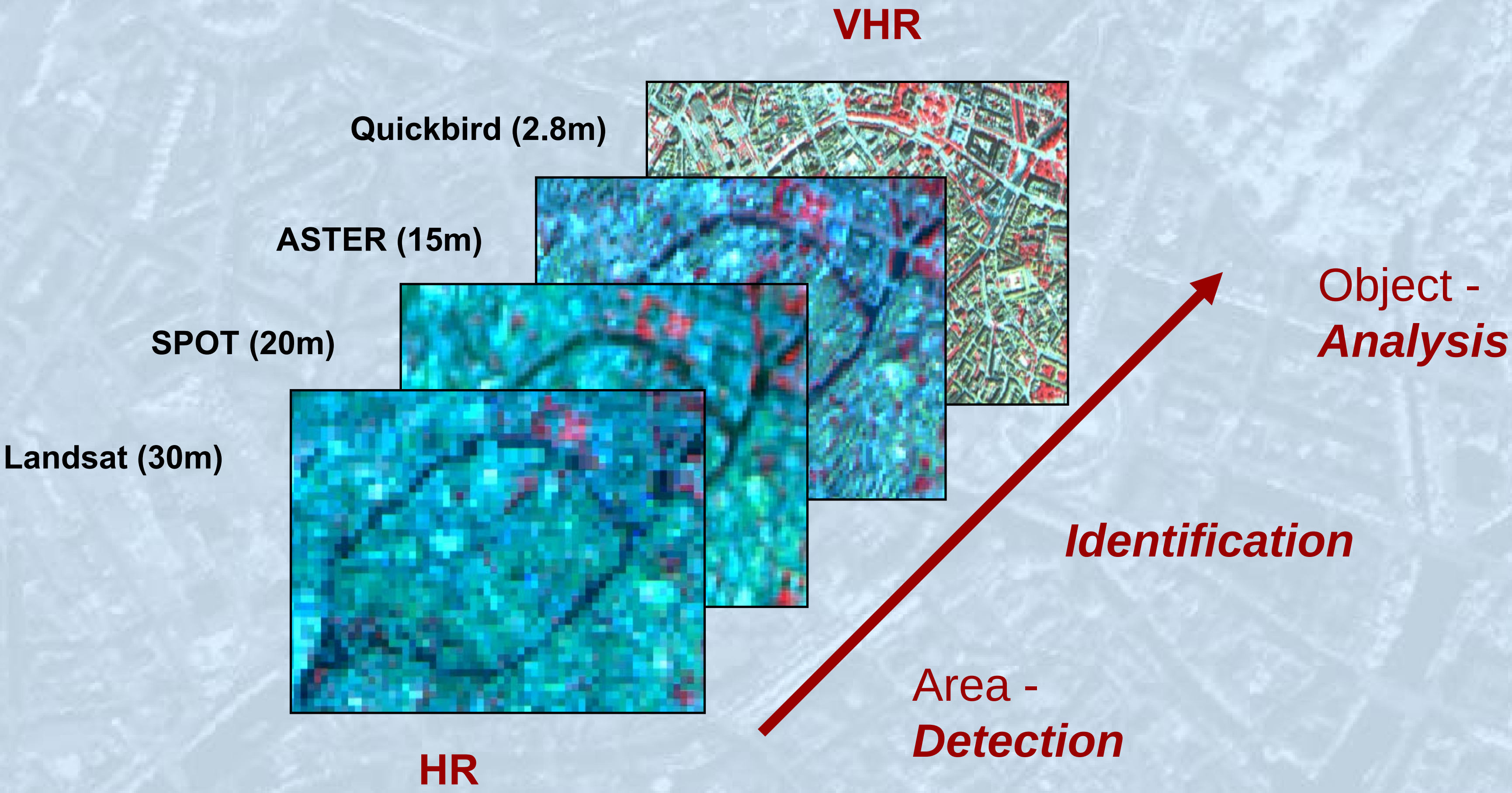
Identification & Analyse

3) GIS integration?
4) Methodological efficiency?

Satellite imagery

Detection capacities

Increasing availability of satellite images



Urban purposes ➔ The use of several sources of data is often required to identify urban elements

New paradigm ?

- **From pixel to object**

  changing classical rules

  defining optimal spatial resolution

- **From object to region**

  adding more (different) knowledge:

  ancillary data, logical or spatial rules …

Detection: new paradigms

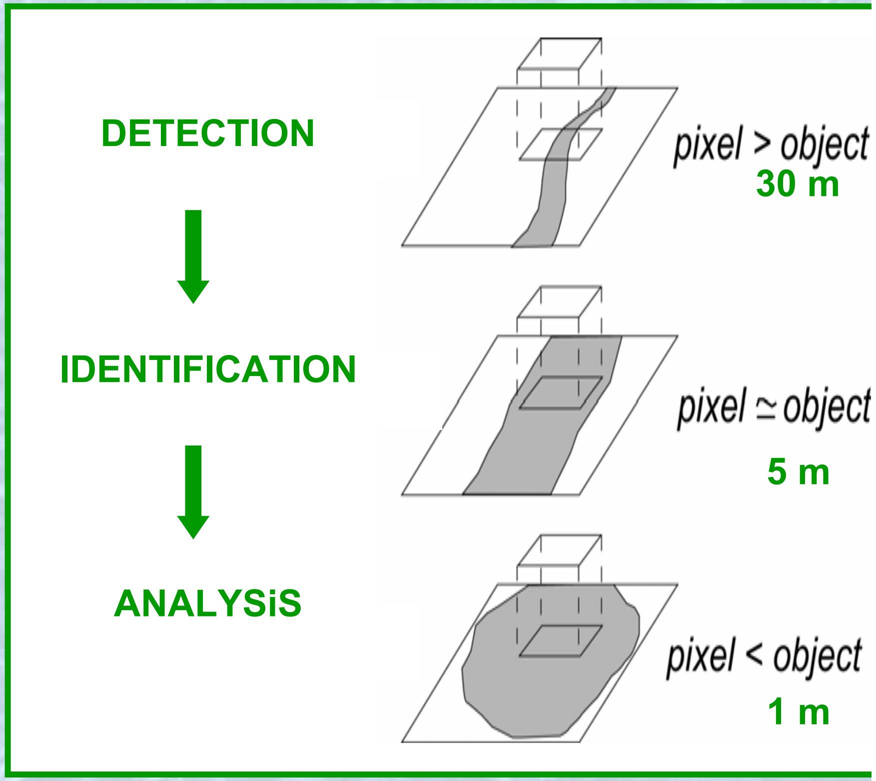
Modification of semantic signification of spectral values

⬇

Inappropriate usual classification methods

⬇

The use of spectral information is no more suffisant



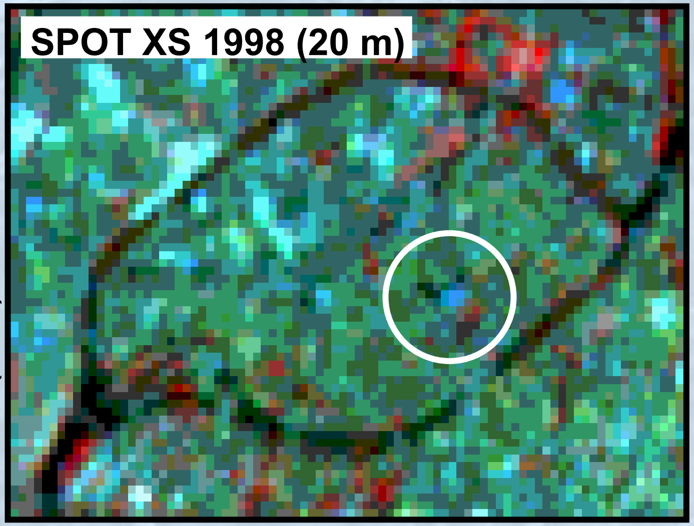
HR	➡	**VHR**
pixel	➡	**objet**

Detection: characteristics

Applications regarding spatial resolution

Spatial Resolution	Applications
VHR : 0.5 -1.5 mètre	**Identification, cartography of objects (cars, trees, urban materials…)** Classification of vegetal species and strata Detection of small grassland areas
HRS : 1.5 - 5 mètres	**Distinction of buildings** **Identification, cartography of objects (constructions)** Classification of strata and shrubby areas Detection small areas, plants diseases, small agricultural areas
HRS : 5 - 10 mètres	**Location/cartography of buildings, roads, agricultural lands, streets** Classification of vegetation strata Distinction of vegetation species, plants disease Classification of land parcels
HRS : 10 -20 mètres	**Location et geometry of large infrastructures (airports, city centres, suburbs, commercial malls, industrial.areas)** Global classification

Detection: characteristics



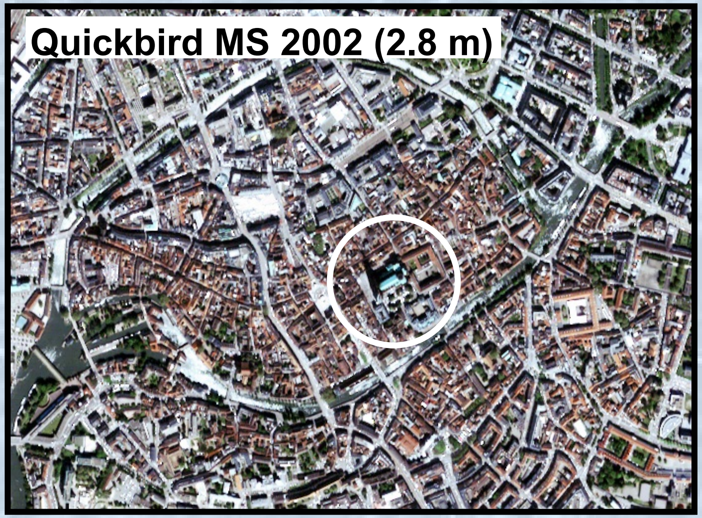
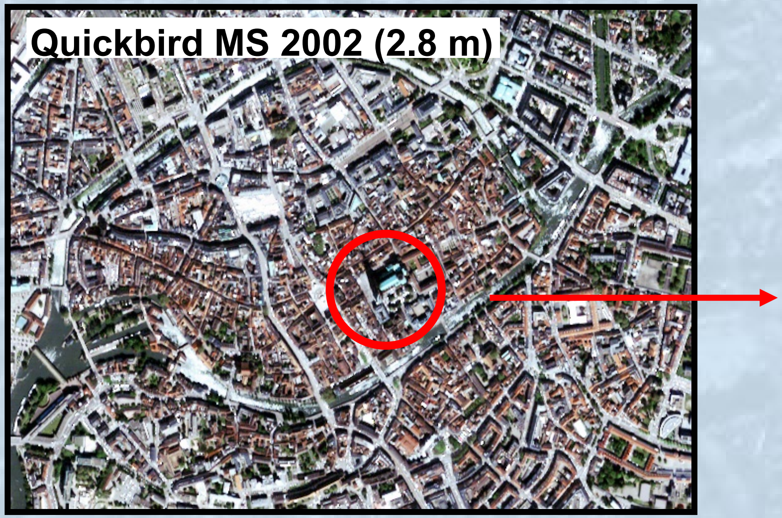


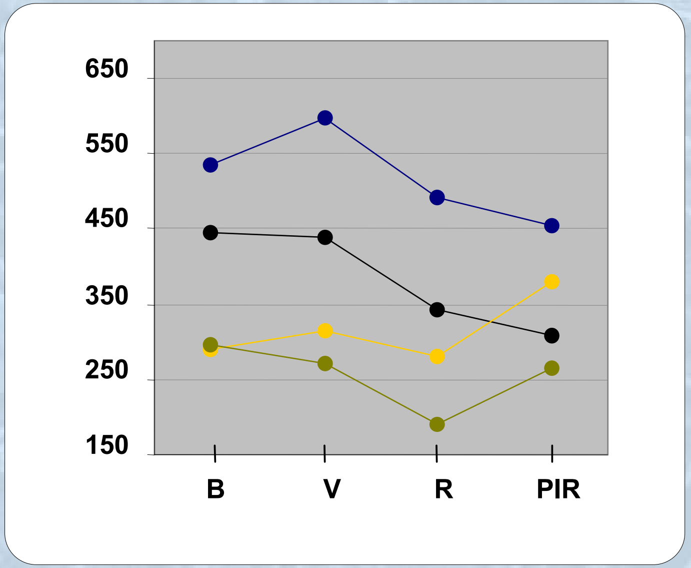
Image heterogeneity increase



Detection: characteristics

- **Same object type composed with various material,**

versus same material for various objects



Ex : Buldings with different roofs material

Detection & Extraction approache

1. **Integrate spatial** or **structural information**
   - Optimal spatial resolution
   - Local contextual information, relationships
   - Extraction and integration of knowledge

Integrate spatial or structural informatio

1. **Definition of an Optimum Spatial Resolution?**

Minimal resolution **/ Functional** resolution

Protocole: identification of the objects

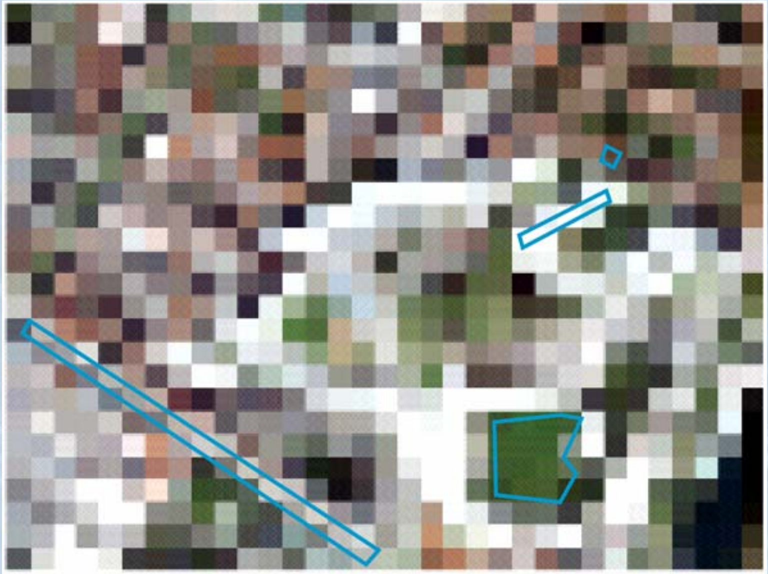
Pixel = 0.8 m

Integrate spatial or structural informatio

1. Definition of an Optimum Spatial Resolution?

Protocole : - identification of the objects

- variance analysis at different spatial resolutions



Integrate spatial or structural informatio

1. Definition of a Optimum Spatial Résolution?

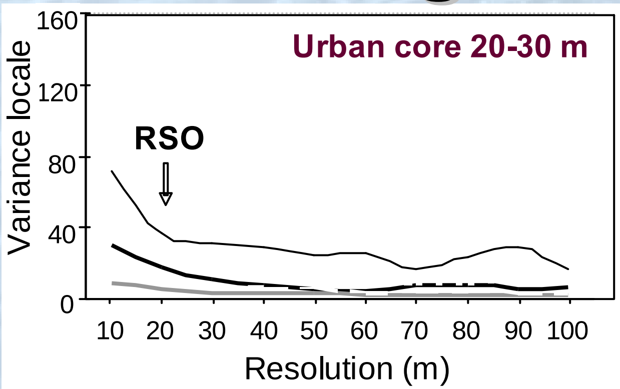
Minimal resolution / **Functional** resolution

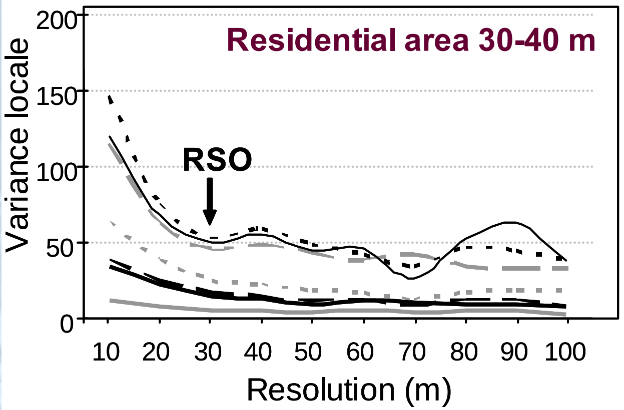
Results :

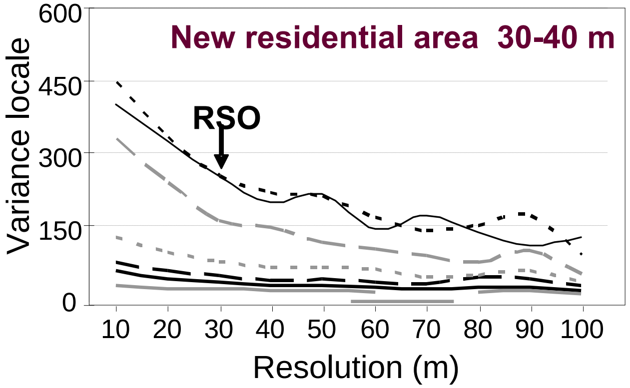
- **areas type « grassland »**
  < = 0.8- 5 m 0.8 - 1m
- **objets type « building »** (rectangular
  = 2 - 3 m 0.8 - 3m
- **objets type « road »** (linear)
  = 0.8 - 1 m 1 - 2m
- **objets type « residential building »**
  (square)
  = 0.8 - 5 m 0.8 - 3m

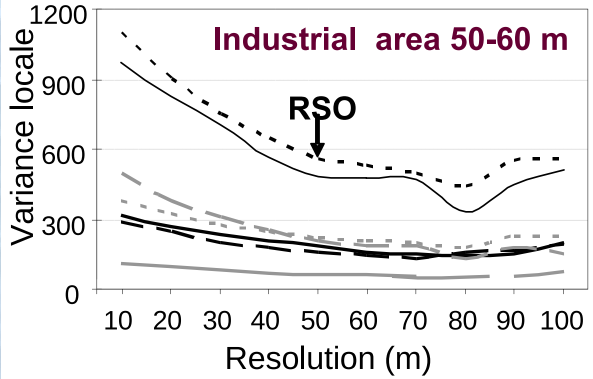
Pixel = 0.8 m

Integrate spatial or structural information









LANDSAT ETM+ fusion 15 m

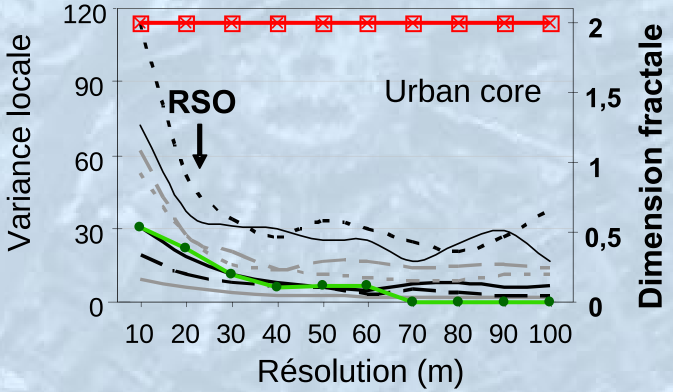
- ETM1
- ETM2
- ETM3
- ETM4
- ETM5
- ETM7
- Pan-SPOT

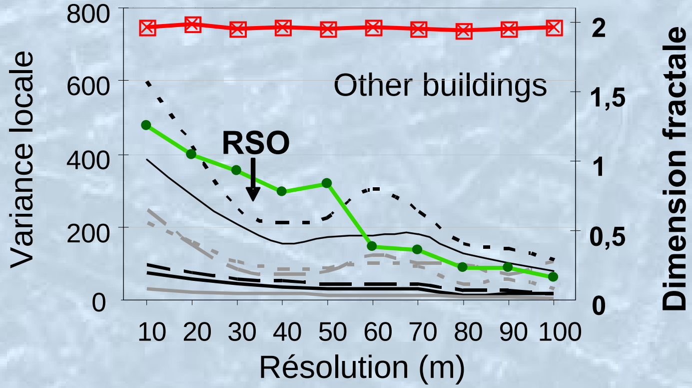
Da Nang Vietnam

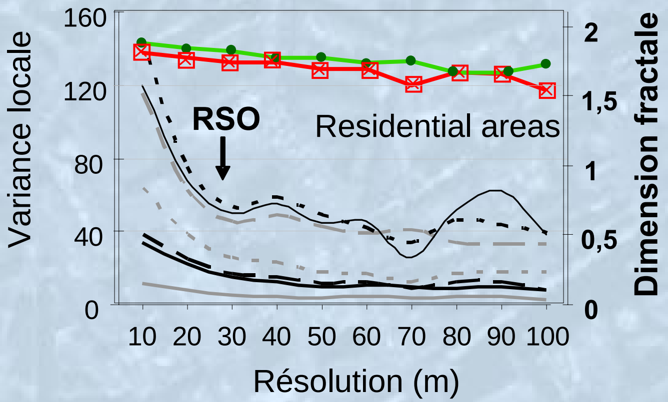
(D. Bin Tran Thi, 2007)

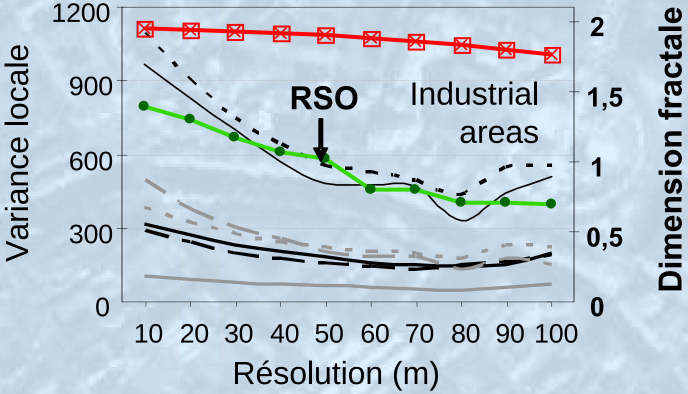
(Images : Google Earth)

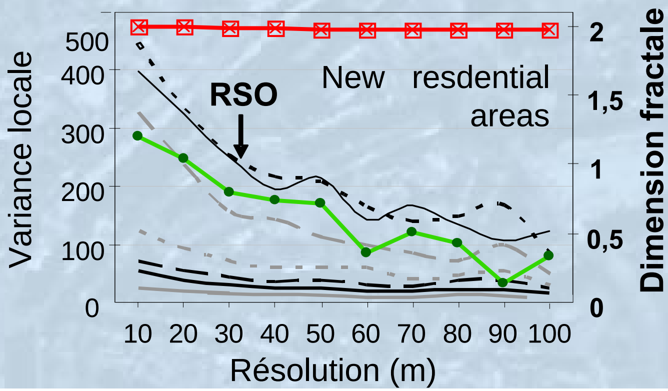
Integrate spatial or structural informatio







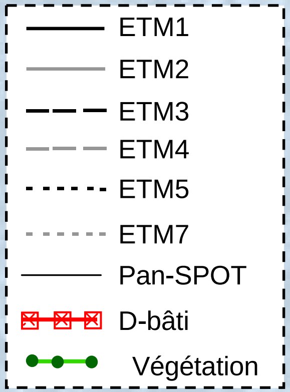




D Dimension

0 = heterogeneity

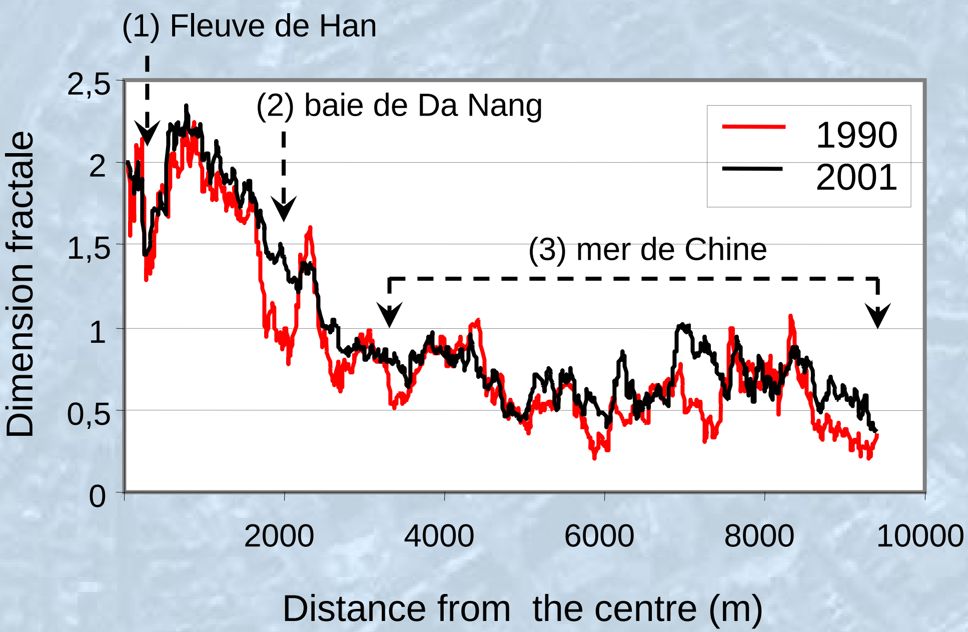
2 = homogeneity

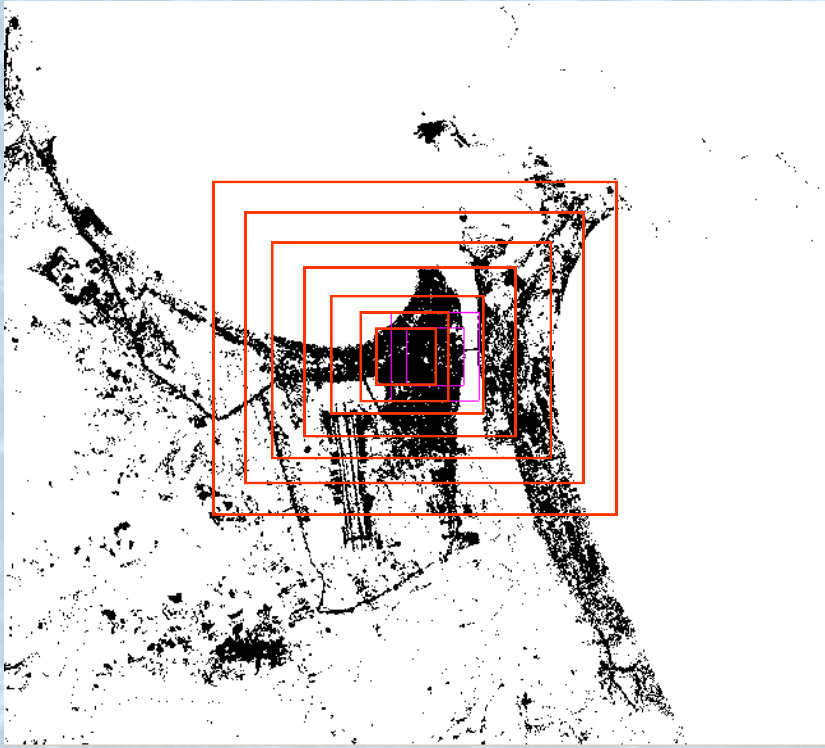


➔ Fractale dimension « D » to identify build areas

Integrate spatial or structural informatio

Fractal behavior of Da Nang 1990 et 2001





➔Two processes : densification and urban sprawl

➔ Physical obstacles

Integrate spatial or structural informatio

LULC categories Level 4	Urban categories	D - Surface correlation measures	
		1990	2001
Urban core	Very dense	**1,73 – 1,89**	**1,86 – 1,94**
Less densely urbanized	dense	**0,96 – 1,73**	**1,64 – 1,85**
Residential areas	less dense	**0 - 1,63**	**1,32 – 1,59**
	Surbubs	**< 1,0**	**< 1,3**

Fractal behavior of Da Nang 1990 et 2001

Image processing improvemen

2. **Improve the results of traditional extraction methods**
   - Combining spectral data with measures of texture or mathematical morphology
   - Developing new algorithms probabilities, soft classifiers
   - **Combining ancillary data and expert knowledge**

Image processing improvements

Combining spectral data with measures of **texture** or **mathematical morphology** or **ancillary data**

Development of **new algorithms using**

(i) *a priori* **probabilities** or *a posteriori* processing known as “soft classifier”, based on Bayesian probabilities or fuzzy set theorie or believes theorie

(ii) **combining ancillary data and expert knowledge (AI)**: machine learning, ontology, data mining

Combining ancillary data an
expert knowledg

) To integrate spatial or **structural information**

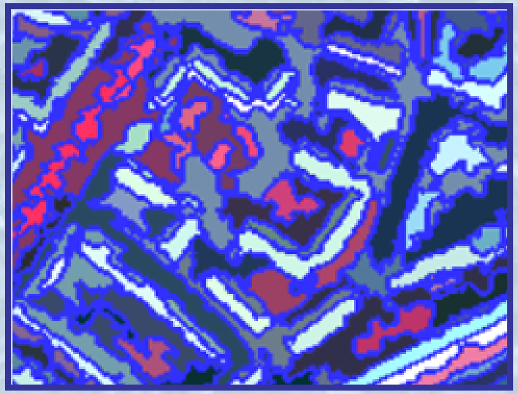
Local contextual information
(Geometry and spatial relationships)

Urban Objects

1 →

Characteristics

Segmentation "regions"

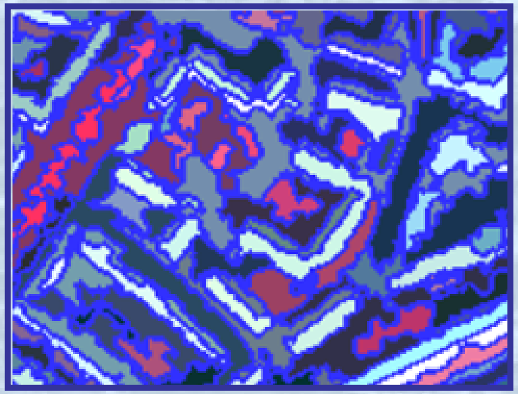


Combining ancillary data an
expert knowledg

Urban Objects

1

Characteristics



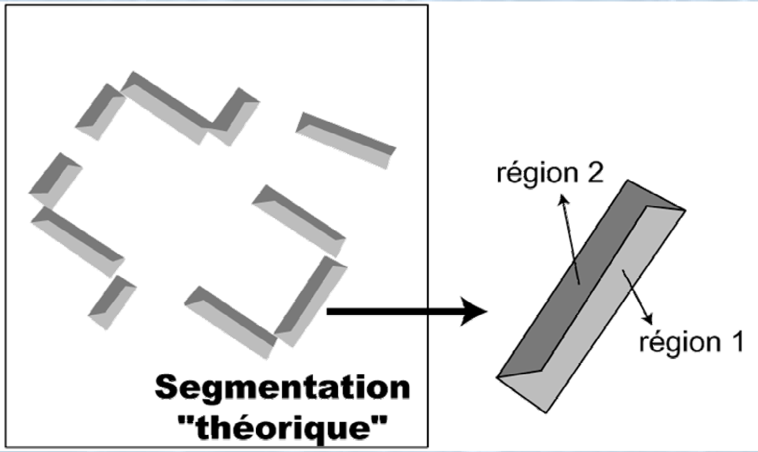
3 relevant criteria :

(a) Spectral values

(b) dimensions and shap

(c) Spatial relationships

© BD Ortho (IGN, 1998)

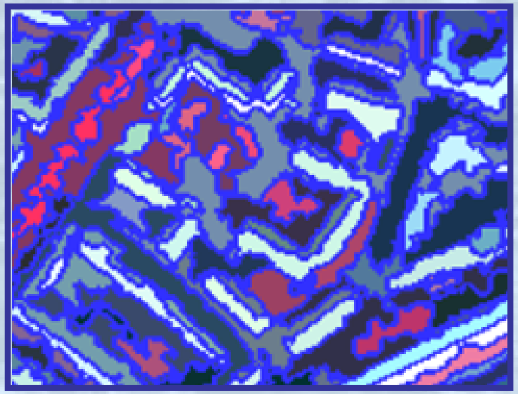


Combining ancillary data and expert knowledg

Urban Objects

1

Characteristics

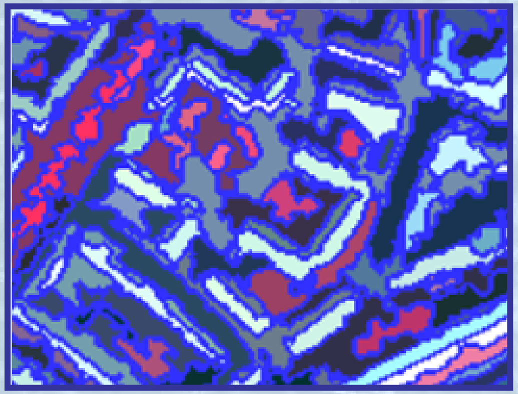


Relevant criteria :

Rules definition

« If a region has spectral characteristics associated to a roof with rectangular shape and is linked with a second region having the same characteristics, then regions 1 and 2 are agregated into one, labelled as « building ».

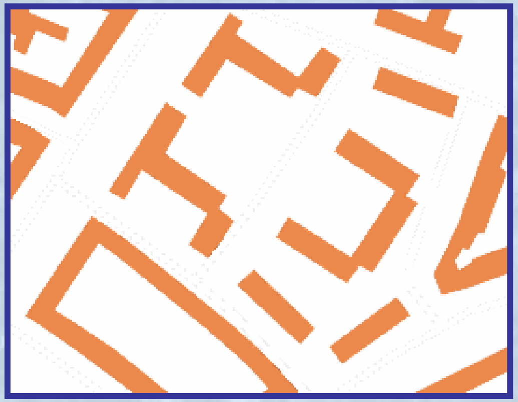
Combining ancillary data an
expert knowledg



Urban Objects

1

Characteristics



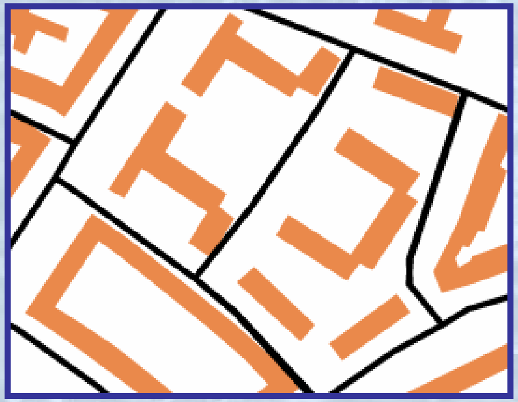
Relevant criteria

Rules definition

Integration
and classification

Object analysis

Combining ancillary data an
expert knowledg



Urban Objects

1 *Rules for object definition*

Characteristics

2

Functionnal or biophysic characteristics (1/10 000ᵉ)

7 aggregation criteria

- Buildings
- Open space
- Linearity
- Parallelism

Rules for object recognition

Combining ancillary data an
expert knowledg

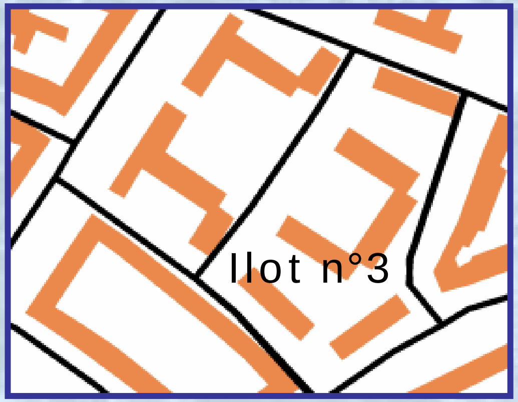
Urban Objects

↓ 1

Characteristics

↓ 2

Functionnal or biophysic characteristics (1/10 000e)



Recognition rules definition

=

Multicriteria attributs

Ilot n°3

critère n°1 : 70% de surfaces artificialisées

critère n°2 : bâtiments de type (dense - tuile)

critère n°3 : pas d'orientations définies

critère n°4 : distance entre bâtiments nulle

critère n°5 : alignement non-identifiable

critère n°6 : 14% espace vide - forme carré IH = 0.63

critère n°7 : 6% arbre + 4% pelouse + 20% route

➔ **Tissu urbain moyennement dense**

Combining ancillary data and expert knowledg

Satellite Image

↓

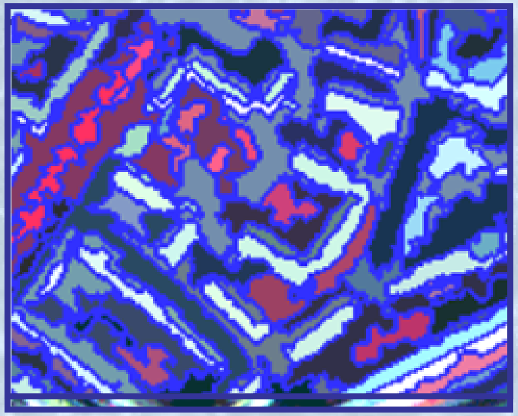
Regions

↓ ①

Characteristics

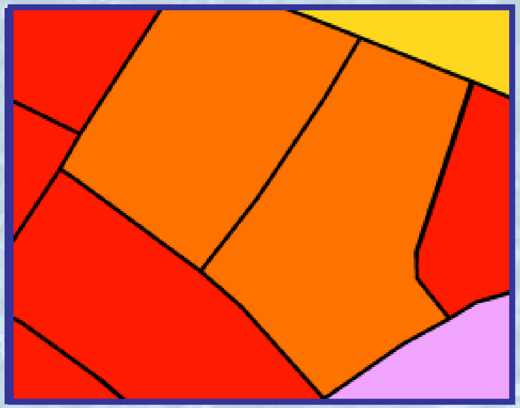
↓ ②

Functionnal or
biophysic characteristics
(1/10 000e)



Extraction of knowledge:
« More than the numerical values..

↓



Combining ancillary data and expert knowledge

Extraction and integration of Knowledge

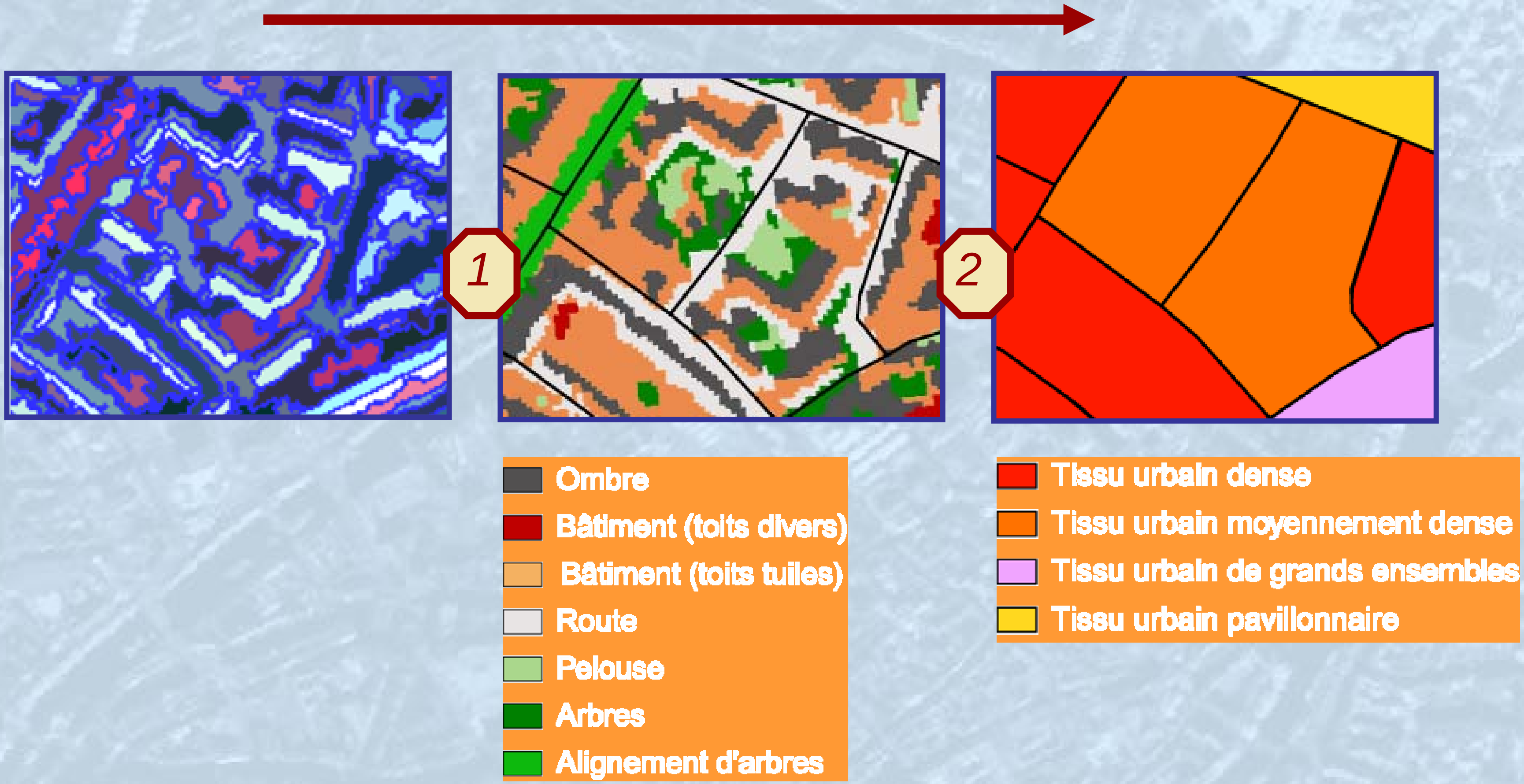


Image processing improvemen

3. Focus on the **development of knowledge extraction**
   Formalization of the knowledge
   Urban ontology, data mining approaches …
   Learning tools

(*Fodomust project: ANR resp. P Gançarski)*

Focus on the development of knowledg extraction - Formalizatior

What kind of knowledge is useful to identify the urban objects in the images?

- **Domain:** End-users needs / typology
- **Expert attributs:** color, shape, size, texture, spatial relationships ...

How to acquire this knowledge ?

➔ **Learning methods**

Focus on the **development of knowledge extraction**
« concept definition

Classifiers:

Quantitative approaches or artificial neural network, collaborative or genetic classifiers, AI approaches

Questions ?

Number of classes
Results assessment
Choice of « attributs »

« Concept » definition:

set of attributs relevant for classification

Focus on the **development of knowledge extraction**

« concept definition

Geographic Object

Image Object

Complex Object

= spatial organisation of image objects, simple or composite

Simple

= one element

Composite

= some elements

Tree

Group of trees

Park

Focus on the development of knowledge extraction - Spatial Ontology

How to describe clearly the objects of the domain in an understandable language?

Identify objects to be extracted => 'concepts inventory'

Definition of these concepts => attributes

⇨ **Design of a 'spatial ontology'**

Dictionary of geographic objects

Translation into an understandable language *(Protege2000)*

Focus on the development of knowledg extraction - Spatial Ontolog

Objects Dictionary

Fiche 1 : Pavillon

A. Identification de l'objet

Type	Nom de l'objet :	Type d'objet élémentaire	Type d'objet « image »	Résolution
Polygone	*Pavillon*	*Bâtiment*	*Objet image simple*	THR1

B. Description de l'objet dans le monde réel

B.1 Définition textuelle

L'objet « pavillon » ou « maison individuelle » appartient à la catégorie d'objets élémentaires « bâtiment ». Il désigne une construction durable destinée à abriter l'activité humaine reliée à l'habitat.

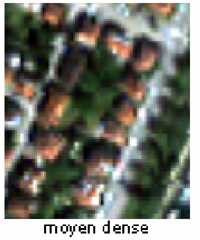
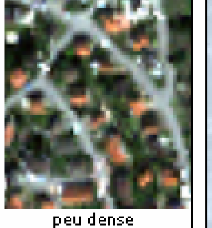
La portée de cette définition est restreinte par les critères suivants. En général, un pavillon :

- est situé dans un îlot physique (domaine privé) ;
- a une emprise au sol d'au moins 12 m² ;

Ces critères visent à exclure notamment les abribus, les aubettes, les remises à outil, cabanes de jardin etc. de la définition de l'objet « pavillon ».

Le pavillon ou maison individuelle est le plus souvent organisée en lotissement ou cité (cf. objet construit).

B.2 Illustration graphique : THR

	THR1 – QB MS (2.8 m)		
- *Pavillon*	 dense	 moyen dense	 peu dense

Emprise d'un bâtiment sur une image satellite

C. Description de l'objet dans l'image

C.1 Nature de l'objet

Objet physique – objet image simple identifiable à THR1

C.2. Définition textuelle

L'objet «pavillon » ou « maison individuelle » est représenté graphiquement par un polygone dont la surface correspond à l'emprise au sol du bâtiment.

C.3. Principales relations

Adjacence	Objets de type « végétation » Objets de type « autre route »
Alignement	oui
Distance entre barycentre = relation de voisinage	Faible = appartenance à une cité ouvrière Moyenne Elevée
inclusion	TU pavillonnaire HR1 et HR2

C.4. Attributs

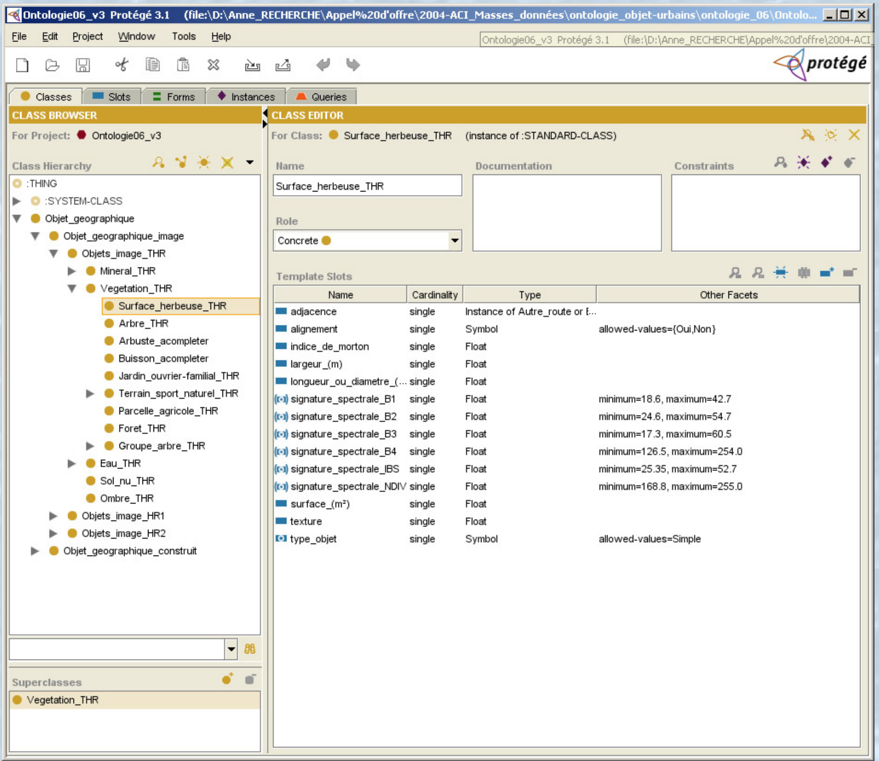
	Mineral – types possibles		
Signature spectrale	Blanc B1 : [56,6–255] avec histogramme de 0 à 255 B2 : [58,6 – 255] B3 : [36,6 – 255] B4 : [20,5 – 254,8] IBS : [55 – 255] NDVI : [16 – 65,25]	Gris B1 : [19,3–60] avec histogramme de 0 à 255 B2 : [14,3 – 60] B3 : [17,6 – 67] B4 : [14 – 67,3] IBS : [11,6 – 56,3] NDVI : [28 – 99]	Orange B1 : [21,7– 62,35] avec histogramme de 0 à 255 B2 : [19,4 – 80,15] B3 : [29,7 – 135,1] B4 : [34,8 – 139] IBS : [14,6 – 60,1] NDVI : [50,2 – 108,3]
Longueur ou diamètre (m)	13 à 61		
Largeur (m)	/		
Périmètre	36 à 92		
Surface (m²)	82 à 437		
Indice de Miller	0,56 à 0,78		
Surface Poly Convex (Sc)	82 à 485		
Surface/Sc	0,85 à 1		

Indice de Morton	0.51 à 0.63
Texture (variance)	homogène

Focus on the development of knowledg
extraction - Spatial Ontolo

Spatial Ontology

=> Written in an « open-source » software

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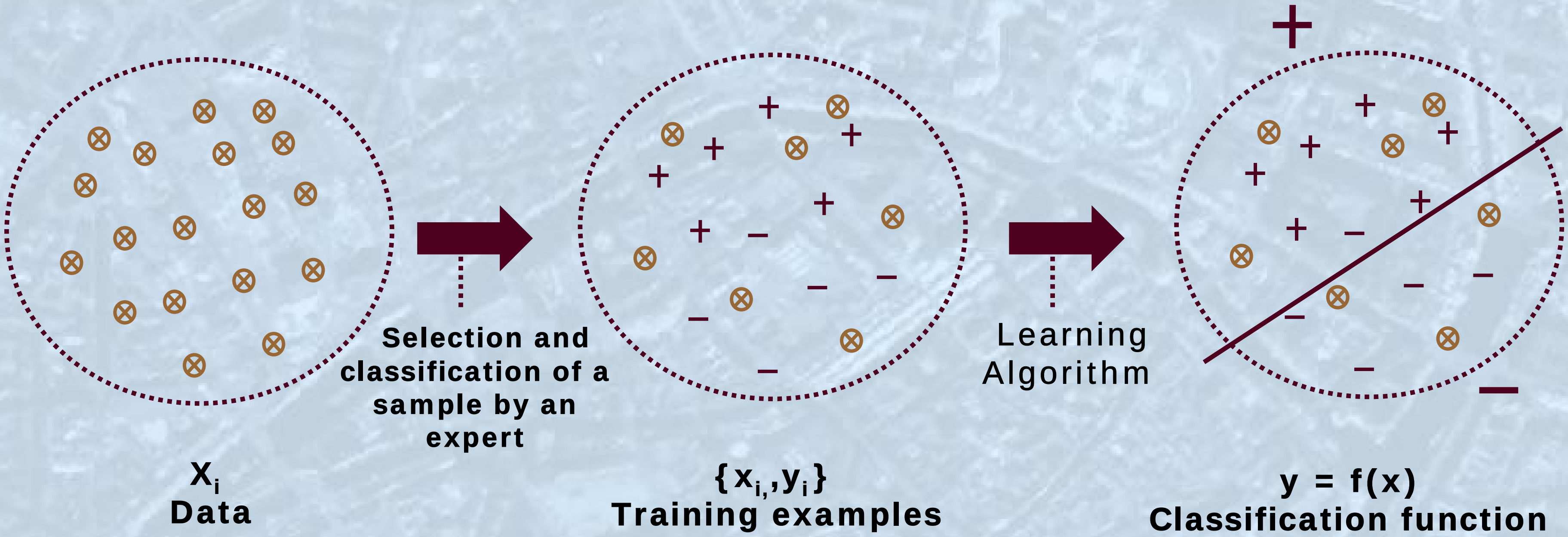
  </rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:ID="Habitat_collectif_carre_gris">
  <rdfs:subClassOf>
    <owl:Class rdf:about="#Habitat_collectif_gris"/>
  </rdfs:subClassOf>
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty>
        <owl:ObjectProperty rdf:about="#adjacence"/>
      </owl:onProperty>
      <owl:allValuesFrom>
        <owl:Class>
          <owl:unionOf rdf:parseType="Collection">
            <owl:Class rdf:about="#Autre_route"/>
            <owl:Class rdf:ID="Vegetation_THR"/>
          </owl:unionOf>
        </owl:Class>
      </owl:allValuesFrom>
    </owl:Restriction>
```

« open-source » software (Protege 2000)

Focus on the development of knowledg extraction - Learning to

Supervised Machine Learning

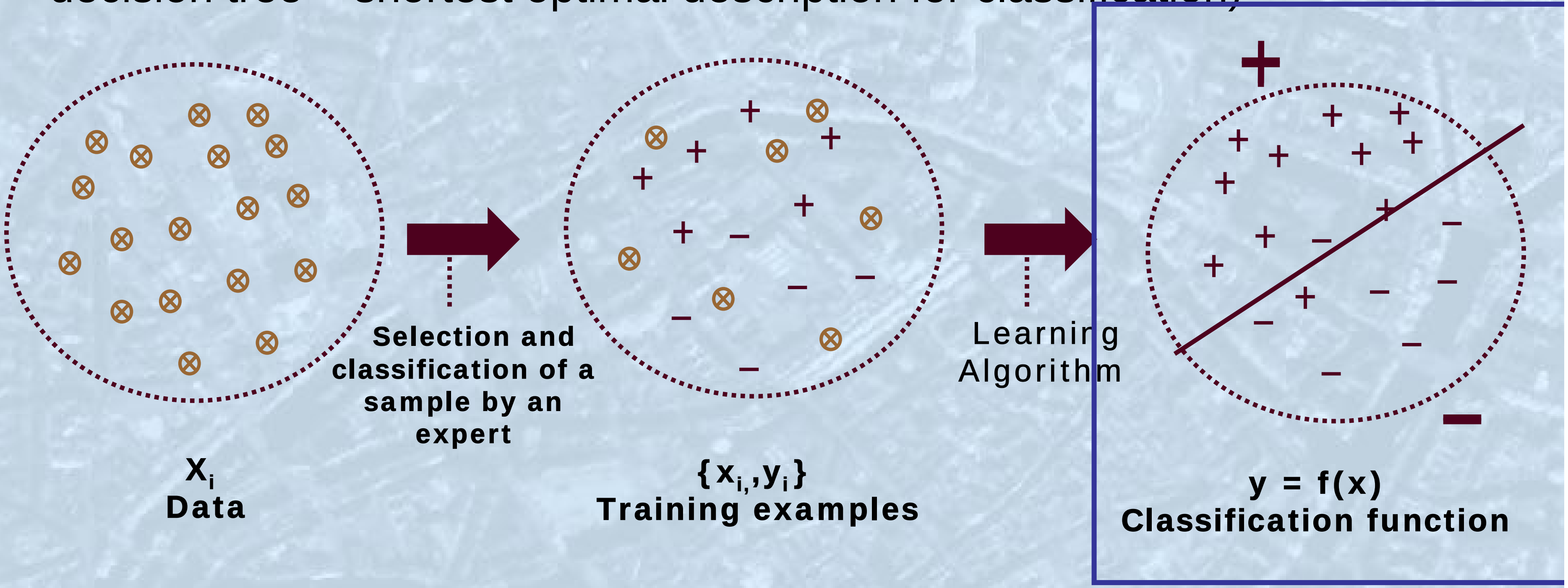
- **Learning *from examples* given by the expert:** description and classes



Focus on the development of knowledg extraction - Learning to

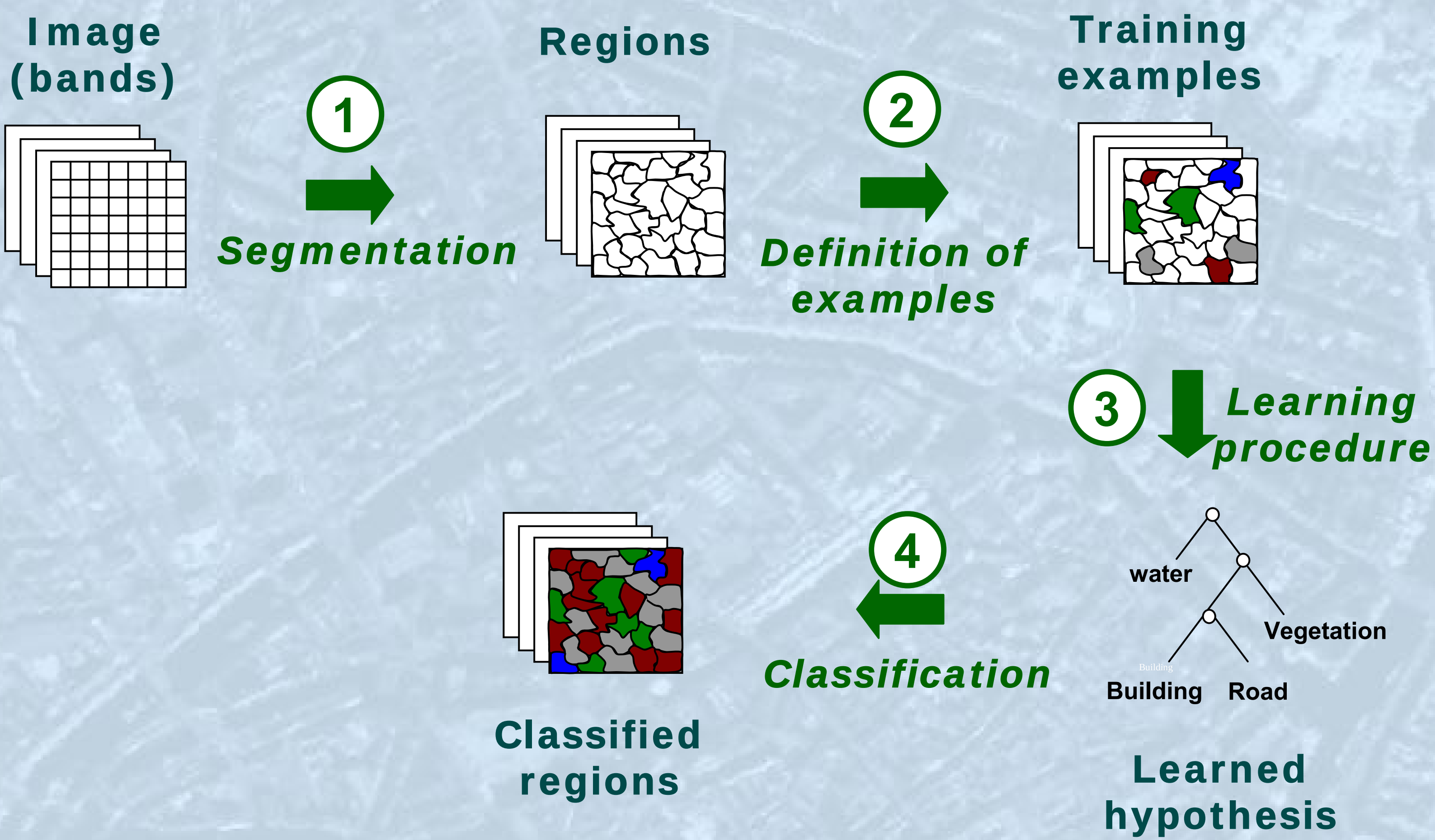
Supervised Machine Learning

- **Learning *from examples* given by the expert:** description and classes built the rules from these examples to explain the classification from the description
- **Apply the rules** (C4.5 algorithm [Quinlan 93] symbolic algorithm providing a decision tree > shortest optimal description for classification)



Focus on the development of knowledg extraction - Learning to

Steps of the **rules acquisition** process



Experiments (

1 Segmentation

A region growing approach (*eCognition* software)

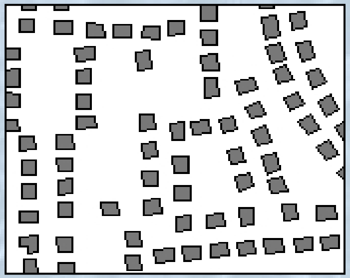
Use of ancillary data to constrain the segmentation procedure and obtain homogeneous regions

➡ Vector data from Topographic database: BDTopo (IGN) – metric precision

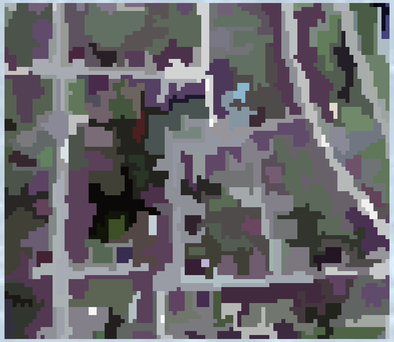
Experiments (1)

1 Segmentation

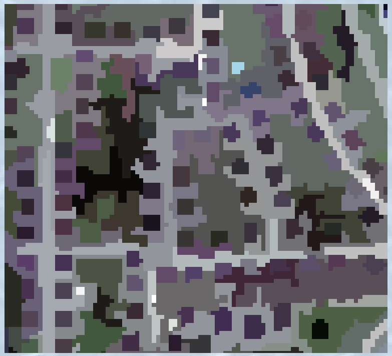
Image



Vector data



Segmentation without ancillary data



Segmentation with ancillary data

Experiments (1)

② **Definition of Training examples**

Retained classes:

Level 1

Level 2

Level 3

Description of examples with spectral features

Description of examples with spatial and contextual features

Experiments (1)

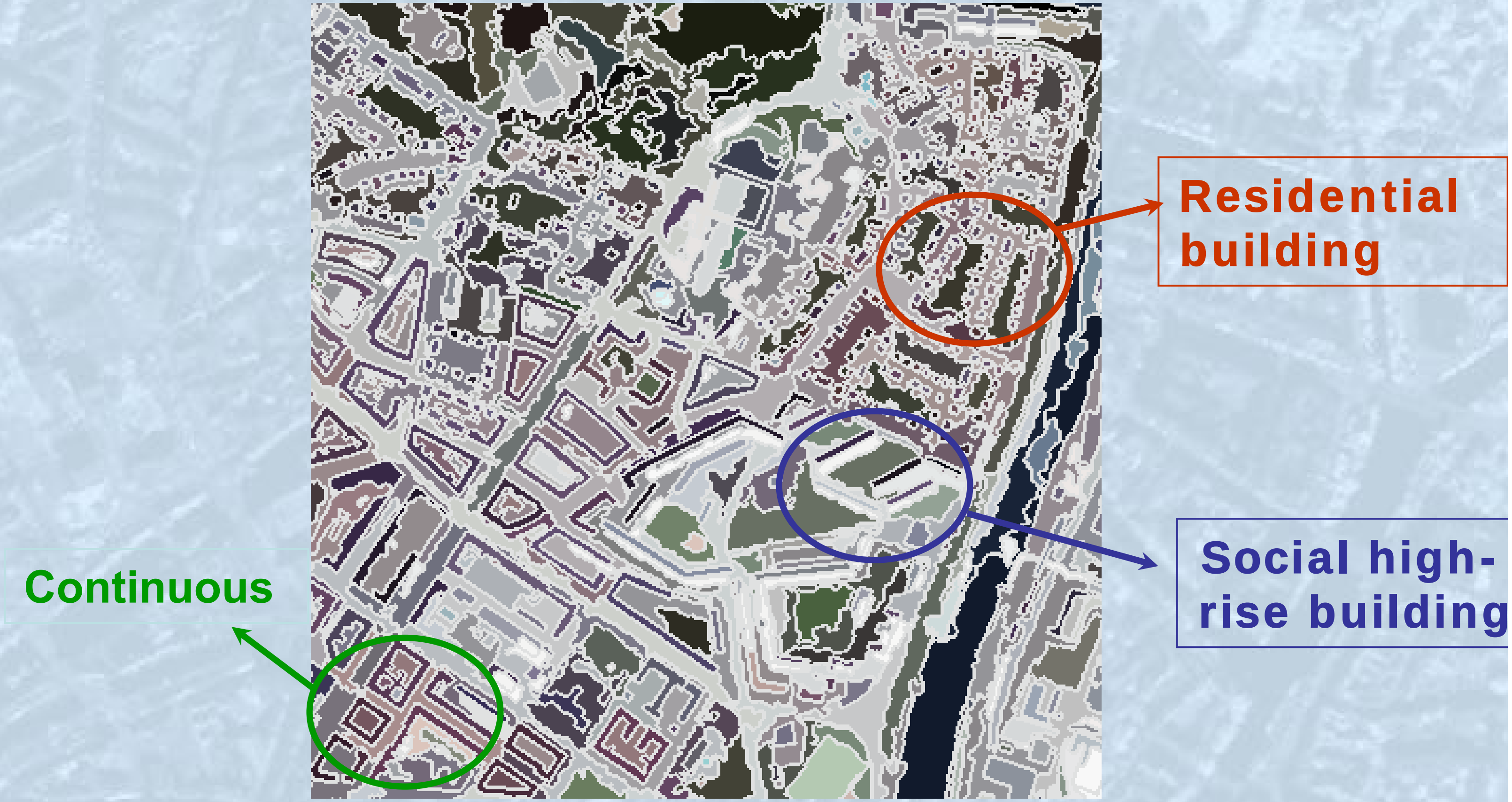
② **Definition of Training examples**

- **Spectral features:**
  - **- 4 bands (R,G,B,NIR): mean by region**
  - **- 2 index (NDVI, SBI): mean by region**

- **Spatial and contextual features:**
  - **- perimeter**
  - **- area**
  - **- diameter**
  - **- compacity (Miller's index)**
  - **- solidity (convexity)**
  - **- % of vegetation around buildings (20m)**

Experiments (1)

② **Definition of Training examples zones**

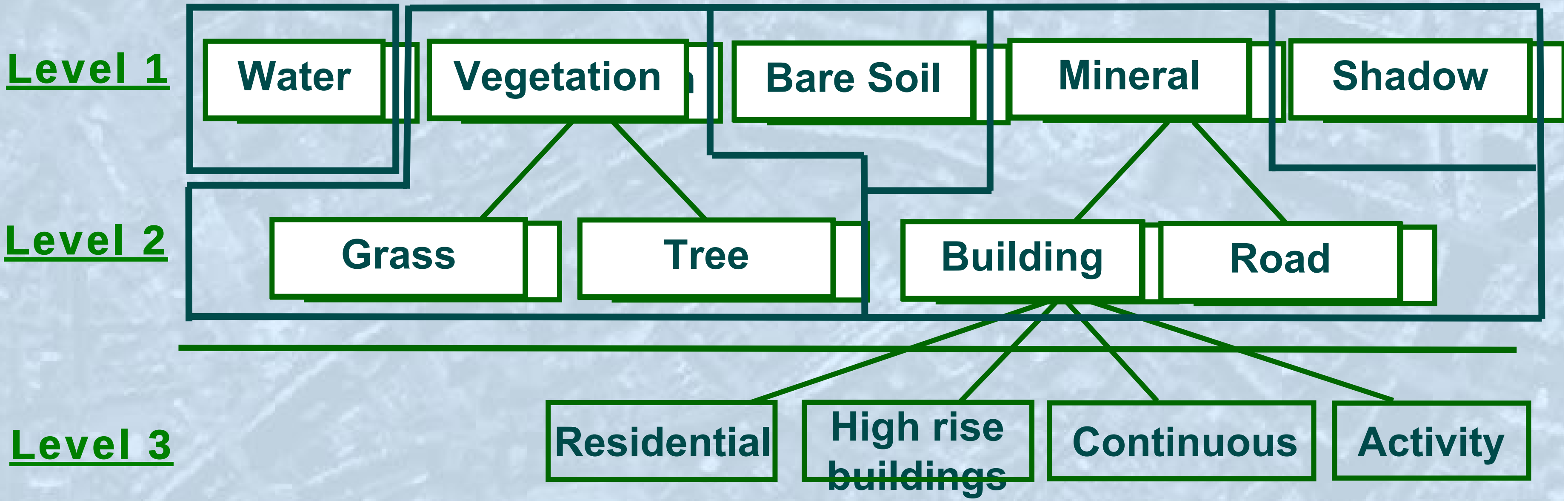


Segmented image

Experiments (1)

③ **Learning procedure**

- **Several steps:**



Experiments (1)

3 Learning procedure

- Learned Rules:

```
SPECTRAL RULES: Entire range of values [0…255]

Class Hierarchy - Level 1:

Rule 1: IF NDVI < 38.23 and IBS > 14.67 THEN Class = Water
        ELSE Class = Non Water
Rule 2: IF NDVI > 169.14 THEN Class = Vegetation
        ELSE Class = Non Vegetation
Rule 3: IF GREEN < 15.65 THEN Class = Shadow
        ELSE Class = Non Shadow
Rule 4: IF NIR > 59.25 and BLUE < 57.86 THEN Class = Bare Soil
        IF RED > 101.24 THEN Class = Bare Soil
        ELSE Class = Mineral

Class Hierarchy - Level 2:

Rule 5: IF 60.2 < BLUE < 130.8 THEN Class = Road
        ELSE Class = Building
Rule 6: IF GREEN > 30.4 THEN Class = Grass

        ELSE Class = Tree
```

Experiments (1)

3 Learning procedure

Learned Rules:

```
SPATIAL RULES: Entire range of values [0…255]

Class Hierarchy - Level 3:

Rule 7: IF AREA > 5203 m² and IM > 0.3 THEN Class = Building of A.
        IF AREA < 436.8  THEN Class = Residential B.
        IF AREA < 1254.9 THEN Class = Collective B.
        IF PV > 11.9 and AREA < 1803.2 THEN Class = Collective B.
        IF IS < 0.43 THEN Class = Collective Building
        ELSE Class = Continuous Built-up Area
```

Experiments (

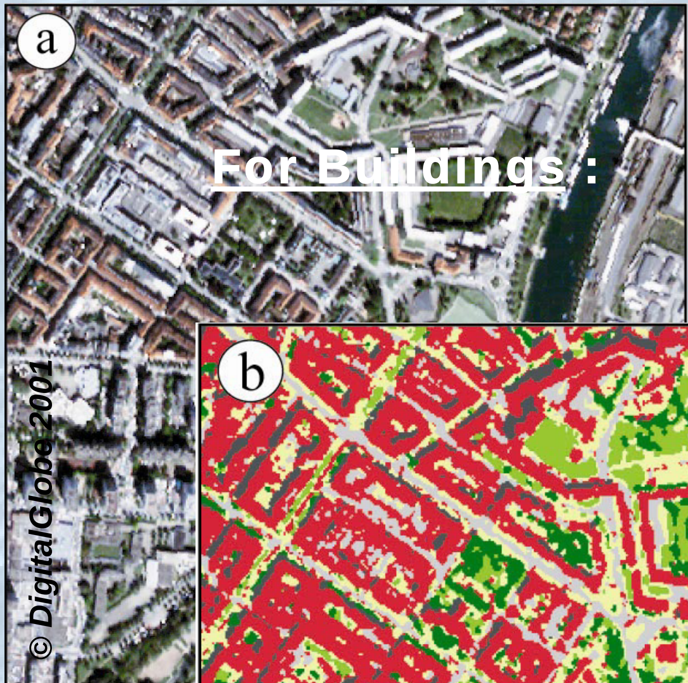
4 Classification

- Water
- Tree
- Grass
- Shadow
- Road
- Building

Experiments (

How to integrate ? Exemple QB MS

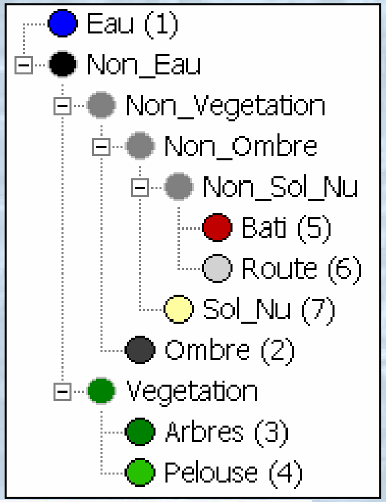
(eCognition)

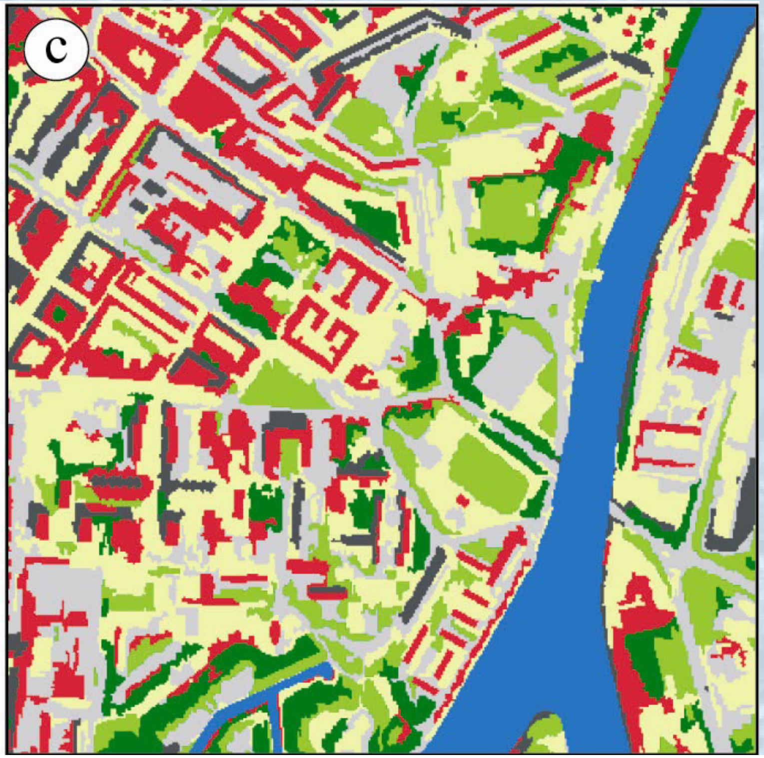


Global Accuracy : 79,7 %
Kappa : 75,5 %

For Buildings :

Global Accuracy : 80,2 %
Kappa : 79 %





Experiments (

Results Analyses:

- Enhancement of the classification results (> 5%)
- Rely on the segmentation quality
- Influence of identification order of the objects
- Influence of the integration approach of the knowledge rules

Slums detection towards slums definition

Detection versus *SLUM* definitio

- **Detection**
  - Scale
    - Environment
    - Structure
    - Object

- **Definition**
  - Criteria
    - Poverty
    - Water accessibility
    - …
  - Measurements
    - Surveys
    - …

Direct link?

Relevant spatial characteristic

Detection versus *SLUM* definitio

Detection & Extraction → **Analyse & Identification**

Urban element

> Urban element:

- "Pencil house" (Vietnam)
- "Bloc" (Mexico)
- …

Environment characteristics

- vegetation?, water, slope ?
- Network?
- Risk?
- …

Urban production mode

- "Selfmade" house
- Community action
- Urgency
- …

Social characteristics

- Poverty
- Water Access
- Unemployment
- …

Detection versus *SLUM* definition

Detection & Extraction

Scale: HR or/and VHR ➔ availability, cost, date

Methodology:
structure ➔ heterogeneous, dense, without network
specific geometry or morphology dimensions
spectral ➔ Material :adapted spectral library?
spatial ➔ratio between resolution/objectives/means

Generalisation:
Ontology ➔ to de defined (ground survey and comparison); *dictionary* adapted to the country or continent
concept definition ➔ experiments with ancillary data (spatial relationships, contextual features…)
environmental characteristics (slopes, watershed, derelict areas…)
rules ➔ to be defined

Detection versus *SLUM* rules definition

Relevant criteria :

Spectral & geometry

Spectral values (material)

Structure characteristics (morphological or fractal dimension)

Dimensions and shape (urban fabric)

Spatial relationships:

Open space

Linearity or orientation

Distance between the buildings

Parallelism

Environment Rules:

« If the element is located on a slope (n%) or in a watershed or floodable area or over the water pressure capacities than the location might be potential for a slum location”

Object Rules:

« If the element is characterised by these Spectral footprint types (x1, xn) and if the density is > 75% and the element belongs to this Urban fabric type than it can be characterized As potential slum habitat »

From slums detection to slum definition

Multidisciplinary issues: task groups

Step by step procedure

- Need ground truth investigations
- Need to know the urban model production
- Need to test the design of a specific dictionary

Thank you ...

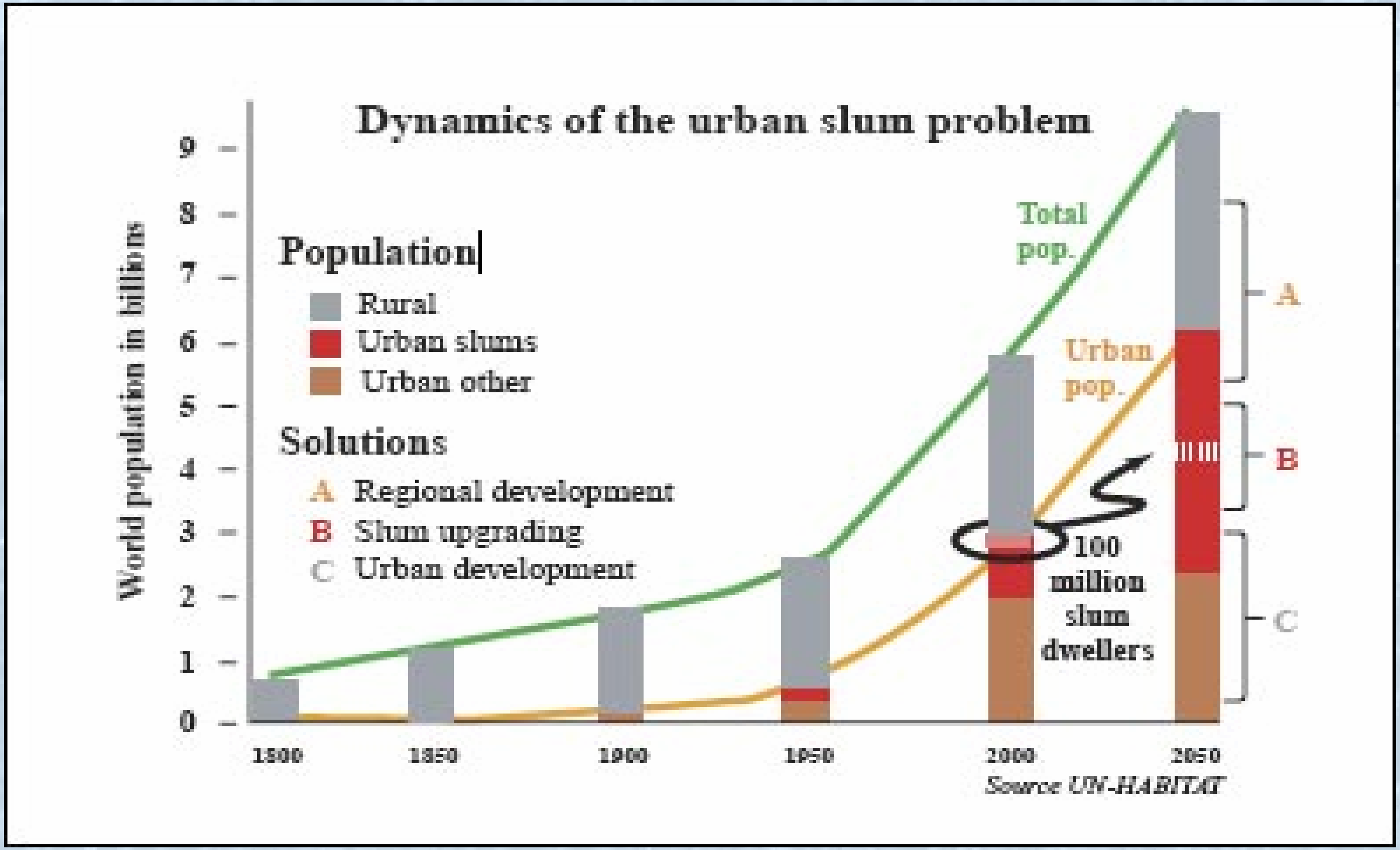
Focus on the development of knowledg extraction - Learning to

Supervised Machine Learning

- Learning ***from examples***

Use of the C4.5 algorithm [Quinlan 93]:
symbolic algorithm providing a decision tree > shortest optimal description for classification using the concept of information Entropy

Context…



Dynamics of the urban slum problem
World population in billions
0
1
2
3
4
5
6
7
8
9
Population
Rural
Urban slums
Urban other
Solutions
A Regional development
B Slum upgrading
C Urban development
Total pop.
Urban pop.
100 million slum dwellers
A
B
C
1800
1850
1900
1950
2000
2050
Source UN-HABITAT

Integrate spatial or structural information

Spectral Fusion

➡ **Complementarity of high spatial and spectral information**