Use of knowledge in a classification process to extract urban objects

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Summary

- Context
- Objective
- Ontologies applied to images
- Construction of an urban ontology oriented 'image'
- Use of the ontology in a classification process => matching procedure
- Experiments on VHR imagery
- Conclusions and perspectives
Context

- Needs of up-to-date and multiscale information
- Automatic acquisition is complex, difficult and time-consuming
- High and very high resolution images are potential sources of information
Context

- Image interpretation
- Object-oriented method based on the used of domain-knowledge

Image (bands) → Semantic Gap

Low-level descriptors (spectral response, texture, …)

Segmentation → Regions

High-level descriptors (shape, index, context, …)

Rules definition

Landcover/landuse

NDVI = 168
Area = 20.5
IH = 0.65
Objective

- Major issue = domain knowledge formalization and exploitation
- Construction of an urban ontology in 3 steps:
  - Step 1: Phase of specification
  - Step 2: Phase of conceptualisation
  - Step 3: Phase of formalisation
- Matching process between regions and concepts
- Experiments on VHR imagery

=> multi-scale mapping of urban area (from 1/100,000 to 1/10,000)
Ontologies applied to images

- **Definition (Gruber, 1993)**

  A 'simplified view of the world which is represented for specific purpose' .... a 'result of a consensus in an user community to clarify the communication' (Gruber, 1993)

- **Domain-dependent ontology**

  = landcover/use analysis in urban and peri-urban areas based on aerial or satellite images

- **From high to very high resolution images**

  - Quickbird (2.8m)
  - ASTER (15m)
  - SPOT (20m)
  - Landsat (30m)
  - Landsat (30m)
Ontology oriented 'images'

1. Phase of specification

- **Inventory of semantic objects** used by experts in urban management for mapping urban area (from 1/100,000 to 1/10,000)

- **Terminological analysis** of existing typologies and nomenclatures (western cities)

- Range of products to map urban area from 1/100,000 to 1/25,000 but not at 1/10,000

- Utility of VHR images (1m) to **propose a typology** adapted to map urban area at 1/10,000 ….

- …based on urban objects in **GIS platform** and definition of the **minimal spatial resolution** of urban object identification
Ontology oriented 'images'

1. Phase of specification

- **Extract of the nomenclature** for mapping urban area (from 1/100,000 to 1/10,000)

<table>
<thead>
<tr>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
<th>Level 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/100,000</td>
<td>1/100,000 to 1/50,000</td>
<td>1/50,000 to 1/25,000</td>
<td>1/25,000</td>
<td>1/10,000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discontinuous urban fabric</td>
<td>Individual houses</td>
<td>Low density of individual houses</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Medium density of individual houses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Collective building</td>
<td></td>
<td>High density of individual houses</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mixed</td>
<td></td>
<td>Building with less than 4 floors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Specific urban surfaces</td>
<td></td>
<td>Building with more than 4 floors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Specific urban surfaces</td>
<td></td>
<td>Mixed (houses and building)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Cemetery</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Surfaces with military buildings</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Surfaces with scholar buildings</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Surfaces with hospital buildings</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Others surfaces</td>
</tr>
</tbody>
</table>

JIGOT – Strasbourg 26&27 novembre 2007
Ontology oriented 'images'

2. Phase of conceptualisation

- From a lexicon of thematic classes to a taxonomy of concepts
- Definition of 'Image Objects' and 'built Objects'

[Diagram showing the hierarchy of urban objects, 'Image' object (IO), 'Built' object (BO), single (OIs) and aggregate (OIl) objects, with examples of a tree, a tree line, and a park.]
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2. Phase of conceptualisation

- 'Image object' (IO) stored in a dictionary with:
  - Name and textual definition
  - Representation in a GIS database
  - Range of spatial resolution at which the object is identifiable
  - Type of IO (single, aggregate)
  - Thematic code
  - Color code
  - Radiometric measures (some objects)
  - Graphic illustration (orthophoto)
  - Low-level descriptors in images

\[
\text{Satellites images} \quad \{ \begin{array}{ccc}
\text{Real world} \\
\end{array} \}
\]
Ontology oriented 'images'

2. Phase of conceptualisation

- **Low-level descriptors**

<table>
<thead>
<tr>
<th>Descriptors</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral reflectance</td>
<td>Range of observed values in 4 spectral bands: Blue (B) – Green (G) – Red (R) – near-infrared (NIR)</td>
</tr>
<tr>
<td>Normalized Difference Vegetation Index (NDVI)</td>
<td>Range of observed values of NDVI</td>
</tr>
<tr>
<td>Soil Brightness Index (BI)</td>
<td>Range of observed values of BI</td>
</tr>
<tr>
<td>Shape properties</td>
<td>Range of observed values of area, perimeter, elongation, diameter, compactness (Miller index), and solidity</td>
</tr>
<tr>
<td>Texture</td>
<td>Range of observed values of the homogeneity index and of the variance derived from the co-occurrence grey-level matrix (Haralick, 1973)</td>
</tr>
<tr>
<td>Context (or relationships)</td>
<td>Adjacency, inclusion, composition, neighbourhood</td>
</tr>
</tbody>
</table>
Example

Fiche 1 : Pavillon

A. Identification de l’objet

<table>
<thead>
<tr>
<th>Type</th>
<th>Nom de l’objet</th>
<th>Type d’objet élémentaire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polygone</td>
<td>Pavillon</td>
<td>Bâtiment</td>
</tr>
</tbody>
</table>

B. Description de l’objet dans le monde réel

B.1 Définition textuelle

L’objet « pavillon » ou « maison individuelle » appartient à la catégorie II et il désigne une construction durable destinée à abriter l’activité humaine. La poêlée de cette définition est restreinte par les critères suivants. En effet, le pavillon est situé dans un lot physique (domaine privé) ; Il a une emprise au sol de moins de 12 m². Ces critères visent à exclure notamment les abri-kiosks, les abri-kiosks, les abri-kiosks, les abri-kiosks, les abri-kiosks, les abri-kiosks, les abri-kiosks, les abri-kiosks.

Le pavillon ou maison individuelle est le plus souvent organisé en lot de 3 à 6 maisons. Il est possible de le décrire de manière plus précise en utilisant des critères tels que la surface, la longueur ou la hauteur de l’emprise.

B.2 Illustration graphique : THR

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

<table>
<thead>
<tr>
<th>Adjacence</th>
<th>Objets de type « vegetation »</th>
<th>Objets de type « autre route »</th>
</tr>
</thead>
<tbody>
<tr>
<td>oui</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Alignement</th>
<th>Faible = appartenance à une côte ouvrière</th>
<th>Moyenne = surface</th>
<th>Elevée = surface</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Distance entre barycentre</th>
<th>Relation de voisinage</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Faible = appartenance à une côte ouvrière</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Inclusion</th>
<th>TU pavillonnaire HR1 et HR2</th>
</tr>
</thead>
</table>

C.4. Attributs

<table>
<thead>
<tr>
<th>Signatures spécifiques</th>
<th>Blanc</th>
<th>Gris</th>
<th>Orange</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1 : [56,6-56.25]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>avec histogramme de 0 à 255</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B2 : [56,6-56.25]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>avec histogramme de 0 à 255</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B3 : [56,0-256]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B4 : [20,5-254,6]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IBS : [16-56.25]</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NDVI : [56-95.25]</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Longueur ou diamètre (m) | 19 à 51 |
| Largeur (m) | 7 |
| Pente (m) | 36 à 92 |
| Surface (m²) | 0,57 à 3,42 |
| Indice de Millier | 0,86 à 0,88 |
| Surface Poly Convex (S0) | 82 à 478 |
| Surface/S0 | 0,85 à 1 |

| Indice de Morton | 0,51 à 0,83 |
| Texture (variance) | homogène |

Emprise d’un bâtiment sur une image satellitaire
Ontology oriented 'images'

3. Phase of formalisation

- Modelling and implementing the knowledge in a computer-usable form

- Extract of the ontology:

  - 91 concepts, 20 attributes, depth (6)

  - For each concept = a label

    'Orange_house' = individual houses with orange roof tiles
Ontology oriented 'images'

3. Phase of formalisation

- Example of the concept 'Orange_House':

<table>
<thead>
<tr>
<th>Class</th>
<th>Attribute name</th>
<th>Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>spectral</td>
<td>spectral_signature_Blue</td>
<td>[21.7-62.3]</td>
</tr>
<tr>
<td></td>
<td>spectral_signature_Green</td>
<td>[19.4-80.1]</td>
</tr>
<tr>
<td></td>
<td>spectral_signature_Red</td>
<td>[29.7-135.1]</td>
</tr>
<tr>
<td></td>
<td>spectral_signature_NearInfaRed</td>
<td>[34.8-139]</td>
</tr>
<tr>
<td></td>
<td>spectral_signature_SBI</td>
<td>[14.6-60.1]</td>
</tr>
<tr>
<td></td>
<td>spectral_signature_NDVI</td>
<td>[50.2-108]</td>
</tr>
<tr>
<td>spatial</td>
<td>diameter(m)</td>
<td>[13-61]</td>
</tr>
<tr>
<td></td>
<td>area (m$^2$)</td>
<td>[10-600]</td>
</tr>
<tr>
<td></td>
<td>perimeter (m)</td>
<td>[28-116]</td>
</tr>
<tr>
<td></td>
<td>elongation (m)</td>
<td>[1-3.1]</td>
</tr>
<tr>
<td></td>
<td>Miller index</td>
<td>[0.5-0.8]</td>
</tr>
<tr>
<td></td>
<td>Solidity index</td>
<td>[0.85-1]</td>
</tr>
</tbody>
</table>
Matching process

Step 1: Matching score

- based on a similarity measure between the features of a region and the characteristics of a the concepts

- with a local component representing the inner properties of the concept and a global component evaluating the pertinence in the hierarchy of concepts

Degree of validity:
Let $\text{Valid}(a,C,R)$ be the validity degree of an attribute 'a' between a region R and a concept C

$$
\text{Valid}(a,C,R) = \begin{cases}
1 & \text{if } V'_R(a) \in [\min(V_C(a)); \max(V_C(a))] \\
\frac{V'_R(a)}{\min(V_C(a))} & \text{if } V'_R(a) < \min(V_C(a)) \\
\frac{\max(V_C(a))}{V'_R(a)} & \text{if } V'_R(a) > \max(V_C(a))
\end{cases}
$$

Example:

Region's values:
- 51
- 114
- 216

Accepted values:
- 0
- 89
- 178
- 255

Concept Orange_House
spectral_signature_blue

Valid = 0.57
Valid = 1.0
Valid = 0.82
Matching process

Step 1: Matching score

- The **local similarity** measure compares the features of a region with the attributes of a concept

  **Local similarity:**

  Let be \( \text{Sim}_\alpha(R,C) \) the local similarity between a region \( R \) and a concept \( C \) using the attributes of each class in \( \alpha \).

  \[
  \text{Sim}_\alpha(R,C) = \frac{\sum_{a \in F_\alpha(C)} \omega(a,C) \text{Valid}(a,C,R)}{\sum_{a \in F_\alpha(C)} \omega(a,C)}
  \]

- The **global score measure** evaluates the pertinence of the matching in the hierarchy of concepts

  **Matching score:**

  Let \( \text{Score}_\alpha(R,C) \) be the matching score between a region \( R \) and a concept \( C \), and \( P(C) \) be the path starting from the root of the ontology and ending at the concept \( C \).

  \[
  \text{Score}_\alpha(R,C) = \frac{\sum_{C_j \in P(C)} \rho(C_j) \text{Sim}_\alpha(R,C_j)}{\sum_{C_j \in P(C)} \rho(C_j)}
  \]

  \( \rho \) is the depth of the concepts
Matching process

Step 2: Navigation in the ontology

- **Objective** = navigate in the ontology to find the best concept(s) according to the score for a region

- **Level-wise algorithm developed** to navigate in the ontology using heuristics to reduce the search space

- **With two thresholds**:
  - \( \text{maxDepth} \) is the exploration maximal depth (e.g. the degree of detail)
  - \( \text{minScore} \) is the minimal value of the matching score between a region and a concept to allocate the corresponding label to the region
Matching process

Step 2: Navigation algorithm

Algorithm 1 Navigation algorithm of the ontology.

Input: a region $R$, an ontology $(\Theta, \Phi, \forall C(a), \ldots)$, a set of attribute classes $(\alpha)$, $\text{maxDepth}$ and $\text{minScore}$.
Output: the best label(s) and the matching score value.

$$\text{depth} = 1; \quad \text{scoreMax} = \text{minScore}$$

$L_\alpha(R) = \emptyset$

$\mathcal{RC} = \{\text{root}\}; \quad \text{scoreDepth} = 0; \quad \text{bestsDepth} = \emptyset$

while $(\mathcal{RC} \neq \emptyset \text{ and } \text{depth} \leq \text{maxDepth})$ do

$\text{scoreDepth} = 0; \quad \text{Best} = \emptyset$

for all $C \in \mathcal{RC}$ do

$s = \text{Score}_\alpha(R, C)$;

if $(s == \text{scoreMax})$ then

$L_\alpha(R) += \{C\}$;

end if

if $(s > \text{scoreMax})$ then

$L_\alpha(R) = \{C\}; \quad \text{scoreMax} = s$

end if

if $(s == \text{scoreDepth})$ then

$\text{bestsDepth} += \{C\}$;

end if

If $(s > \text{scoreDepth})$ then

$\text{bestsDepth} = \{C\}; \quad \text{scoreDepth} = s$

end if

end for

$\mathcal{RC} = \emptyset$

for all $C_j \in \text{bestsDepth}$ do

$\mathcal{RC} = \mathcal{RC} \cup \{C_i | C_i \preceq C_j\}$;

end for

$\text{depth} += 1$

end while

return $\{L_\alpha(R), \text{score}\}$
Experiments on VHR images

- Area of Strasbourg (France) – urban fabric with individual houses
- Quickbird image (pan-sharpened image with 0.7m spatial resolution) with four spectral bands
- Test only with some concepts (vegetation, water, orange house, road)
- Validation with a manually labeled map
Experiments on VHR images

Step 1: Segmentation

- Importance of the algorithm of segmentation (research in progress by Sebastien Derivaux)

Step 2: Matching and results

- Quickbird image
- Segmented image
- Recognized objects: In white = unknown object
Experiments on VHR images

Step 3: Results assessment

Values of Precision, Recall and F-measure (on/in overall, all classes) for several minScore values

<table>
<thead>
<tr>
<th>minScore</th>
<th>Precision</th>
<th>Recall</th>
<th>F-Measure</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.85</td>
<td>0.878</td>
<td>0.861</td>
<td>0.870</td>
</tr>
<tr>
<td>0.9</td>
<td>0.893</td>
<td>0.854</td>
<td>0.873</td>
</tr>
<tr>
<td>0.98</td>
<td>0.954</td>
<td>0.823</td>
<td>0.884</td>
</tr>
<tr>
<td>1</td>
<td>0.967</td>
<td>0.771</td>
<td>0.858</td>
</tr>
</tbody>
</table>

Compared results between minScore = 1 and minScore = 0.98.

<table>
<thead>
<tr>
<th>classes</th>
<th>Precision</th>
<th>Recall</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.98</td>
<td>1</td>
</tr>
<tr>
<td>Orange_House</td>
<td>0.895</td>
<td>0.875</td>
</tr>
<tr>
<td>Vegetation</td>
<td>0.995</td>
<td>0.994</td>
</tr>
<tr>
<td>Road</td>
<td>0.980</td>
<td>0.947</td>
</tr>
<tr>
<td>Water</td>
<td>0.999</td>
<td>0.999</td>
</tr>
</tbody>
</table>
Experiments on VHR images

Step 3: Results assessment

Percentage of recognized objects according to the minScore value, and the percentage of the corresponding image (pixels of the recognized objects) according to the minScore value.
Conclusion and perspectives

- Experiment results have shown effectiveness of the method, despite the fact that the results could be improved with more attention on the segmentation algorithms.
- Automatic extraction of knowledge could be done by machine learning system to enrich the ontology.
- Topological relations based on the RCC-8 (Region Connection Calculus) theory will also be integrated.
- Incorporation in a multi-strategy classification approach in order to guide the process, to label the clusters, and to improve the final classification results.
ACI MD 'FoDoMusT' (2004-2007)

“FOuille de DOnnées MUlti-STRatégie pour extraire et qualifier la végétation urbaine à partir d'une banque de données images”

http://lsiit.u-strasbg.fr/afd/sites/fodomust/fr-accueil.php
Thanks for your attention!