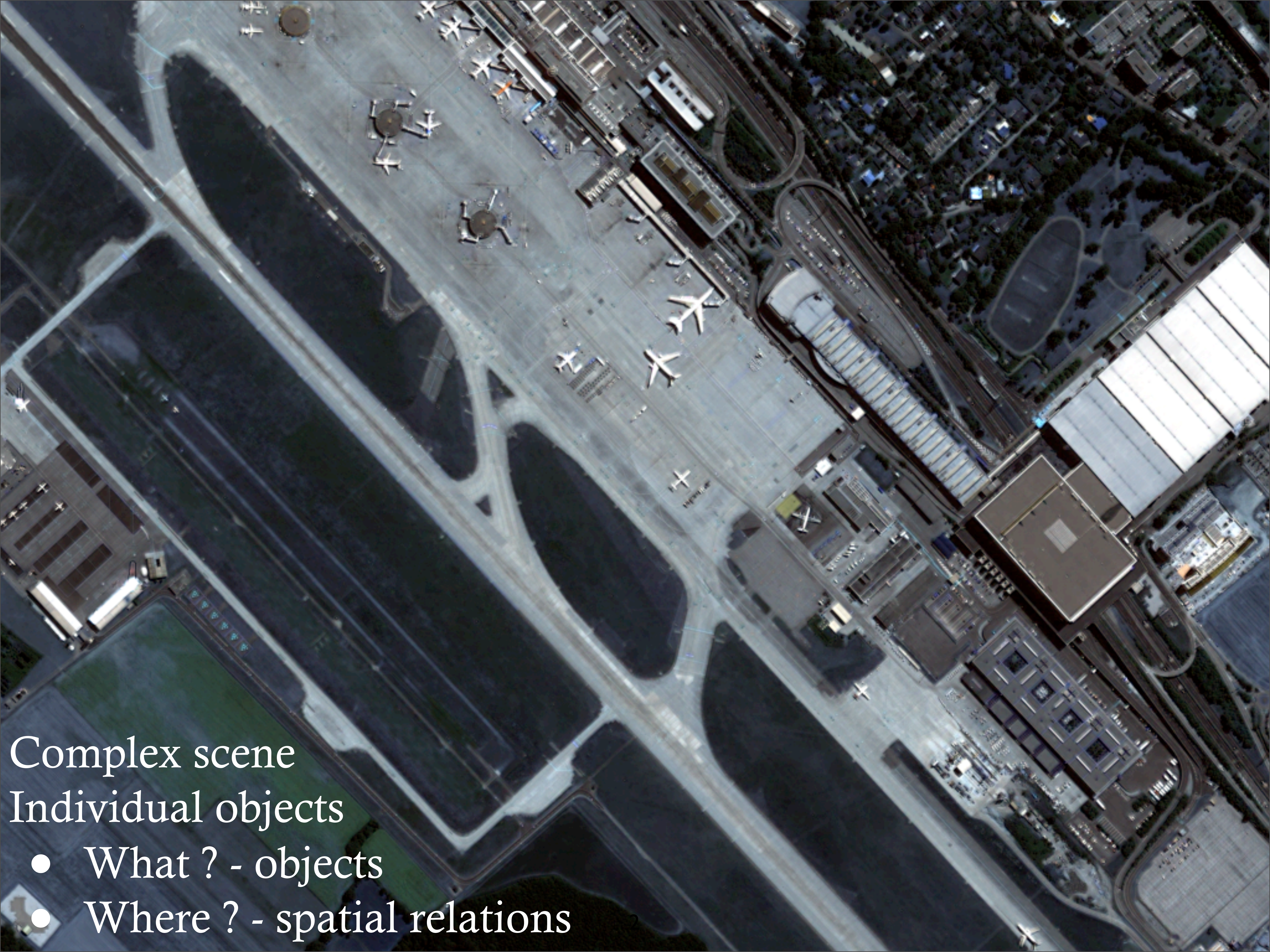
Télécom ParisTech, LTCI, CNRS
TSI Departement
13 January 2011

PhD Defense

Spatial Relations and Spatial Reasoning for the Interpretation of Earth Observation Images Using a Structural Model.

Maria Carolina Vanegas Orozco

Advisors: Isabelle Bloch
Jordi Inglada


Complex scene
Individual objects
• What ? - objects
• Where ? - spatial relations

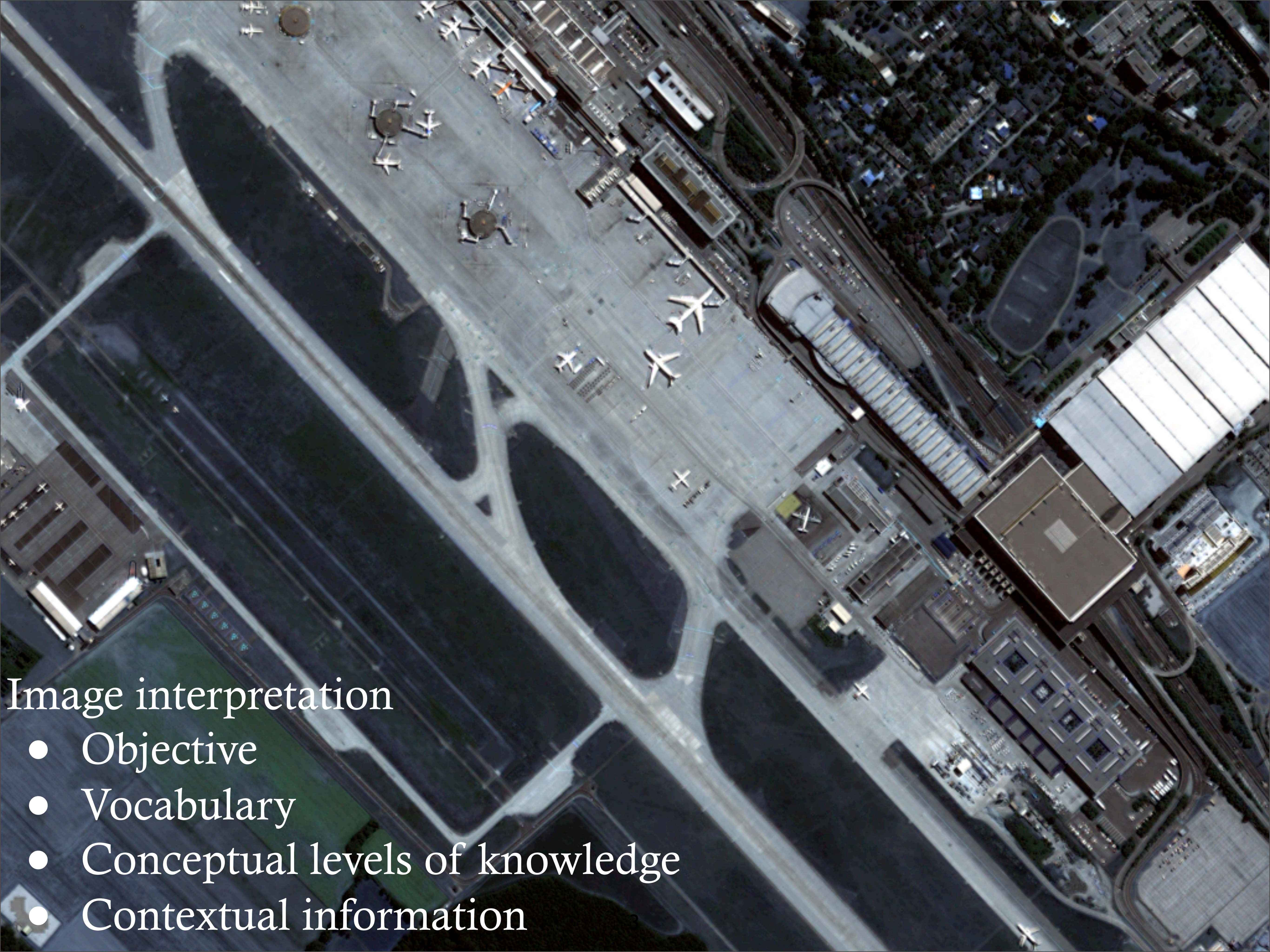
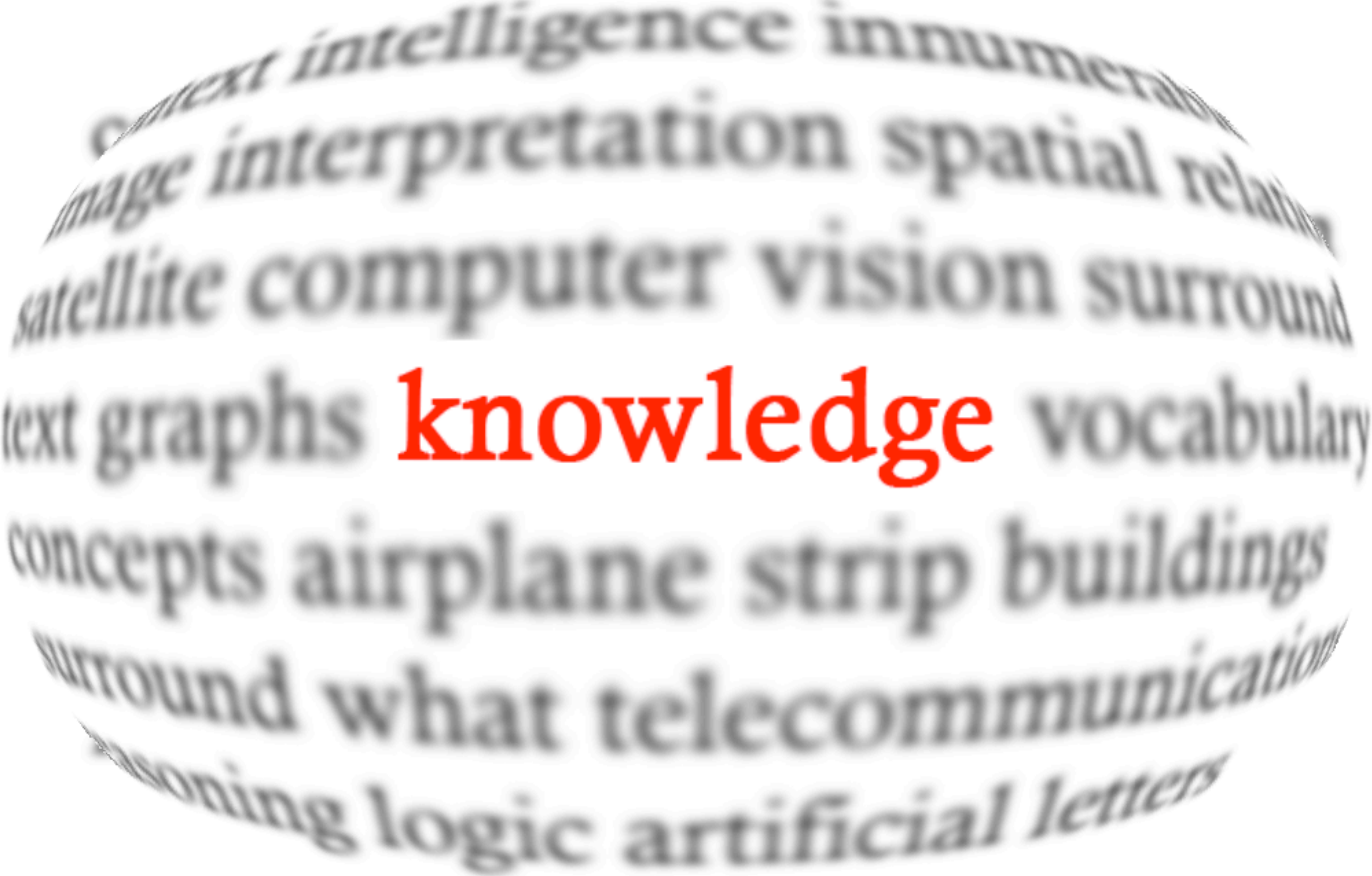


Image interpretation

- Objective
- Vocabulary
- Conceptual levels of knowledge
- Contextual information


intelligence
interpretation spatial
satellite computer vision surround
text graphs knowledge vocabulary
concepts airplane strip buildings
what telecommunication
logic artificial

Using knowledge

- Model describing the spatial organization of the scene
    - Spatial relations
    - Objects
- Knowledge for the extraction of objects
    - Image processing methods
- Mapping between low level features and high level concepts

Representing knowledge

Uncertainty with
respect to the model

Representing knowledge

Uncertainty with
respect to the model

Uncertainty with
labeling the objects in the
image

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Uncertainty with
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image

Imprecision of spatial
relations

Representing knowledge

Uncertainty with respect to the model

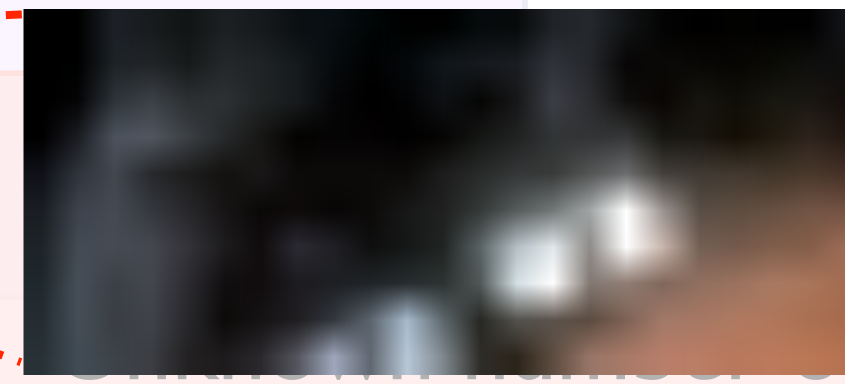
Uncertainty with labeling the objects in the image

Unknown number of instantiations

Im ial

Representing knowledge

Uncertainty with
respect to the model



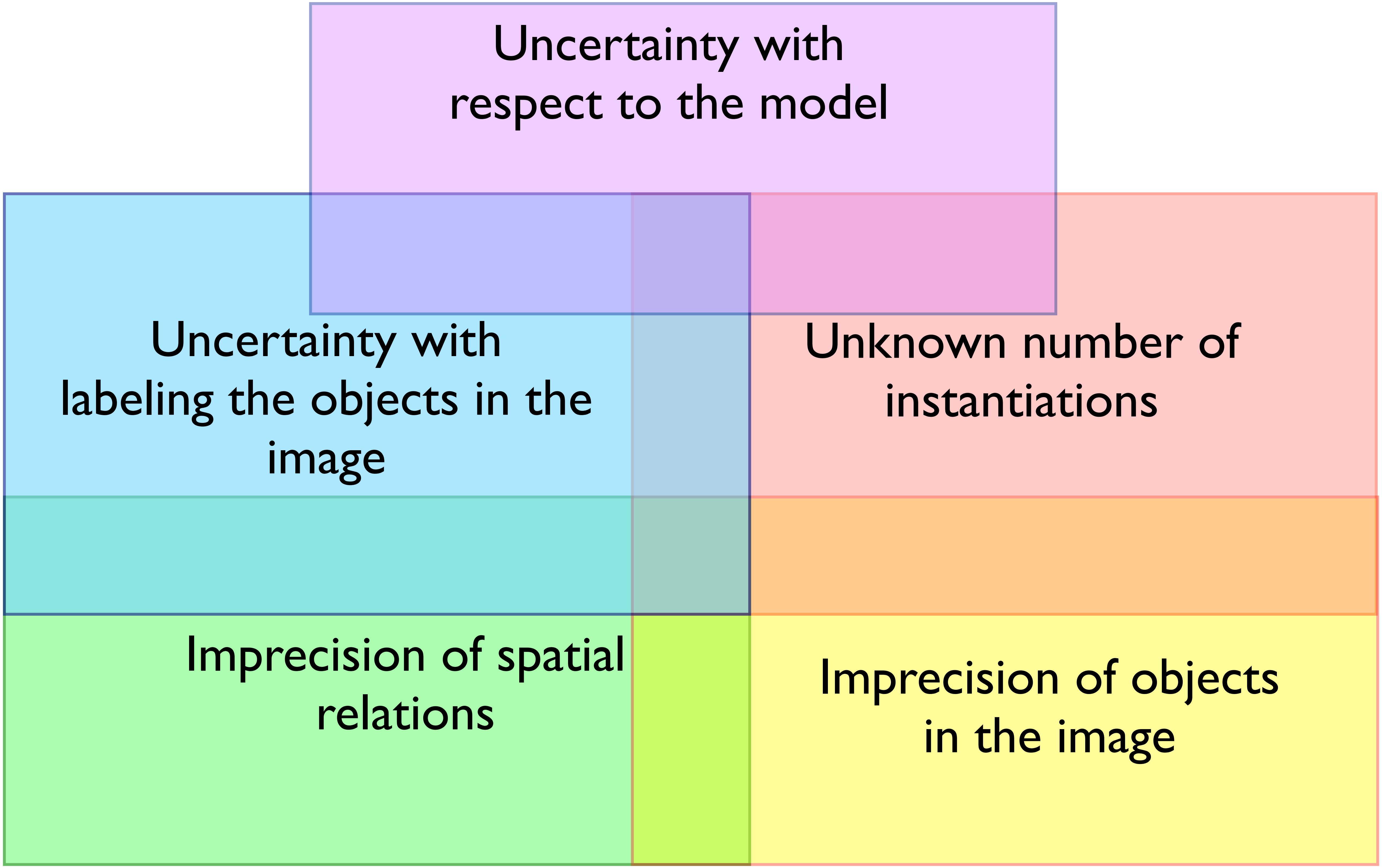
U
labeli
image

instantiations

Imprecision of spatial
relations

Imprecision of objects
in the image

Representing knowledge



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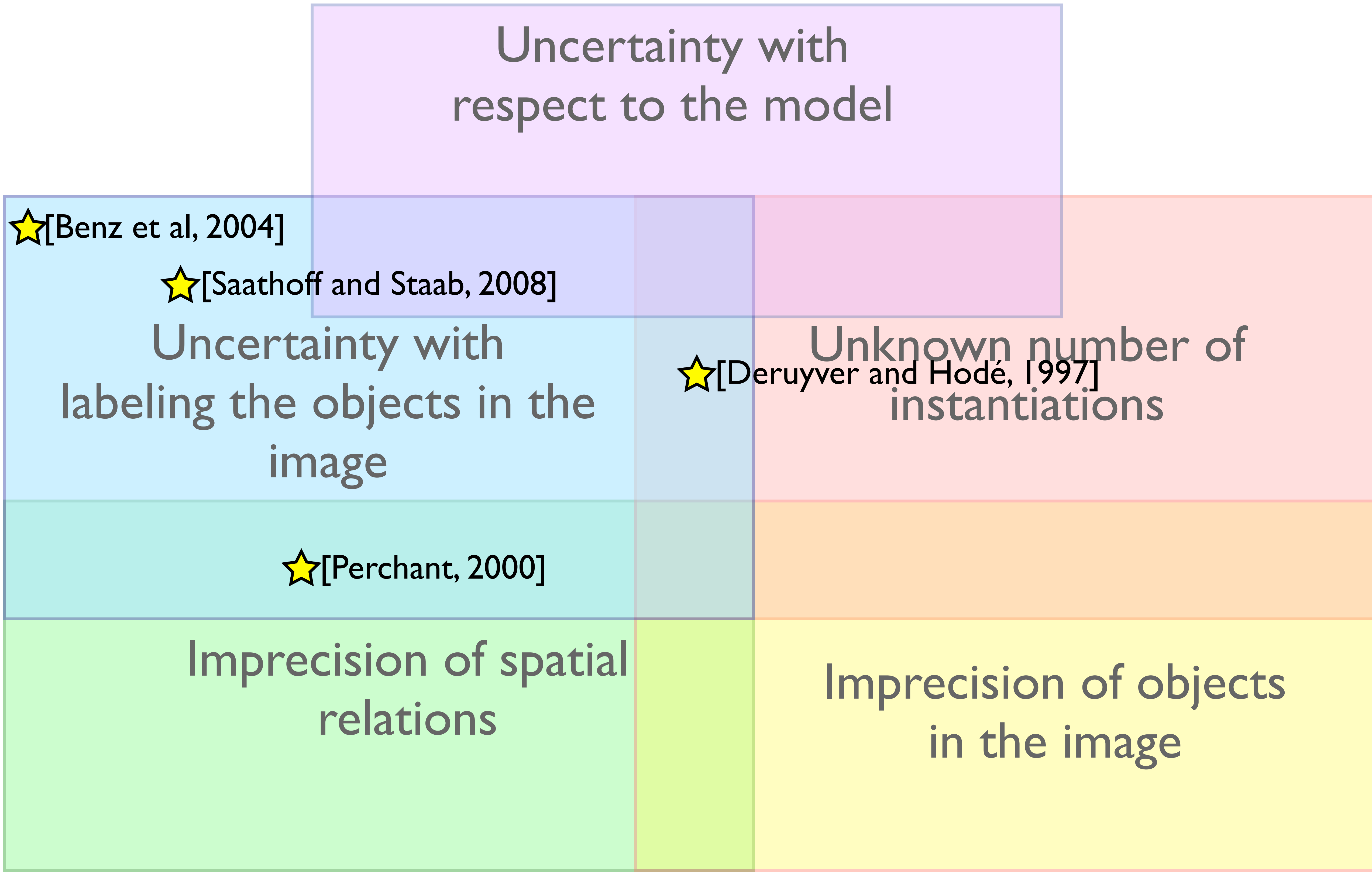

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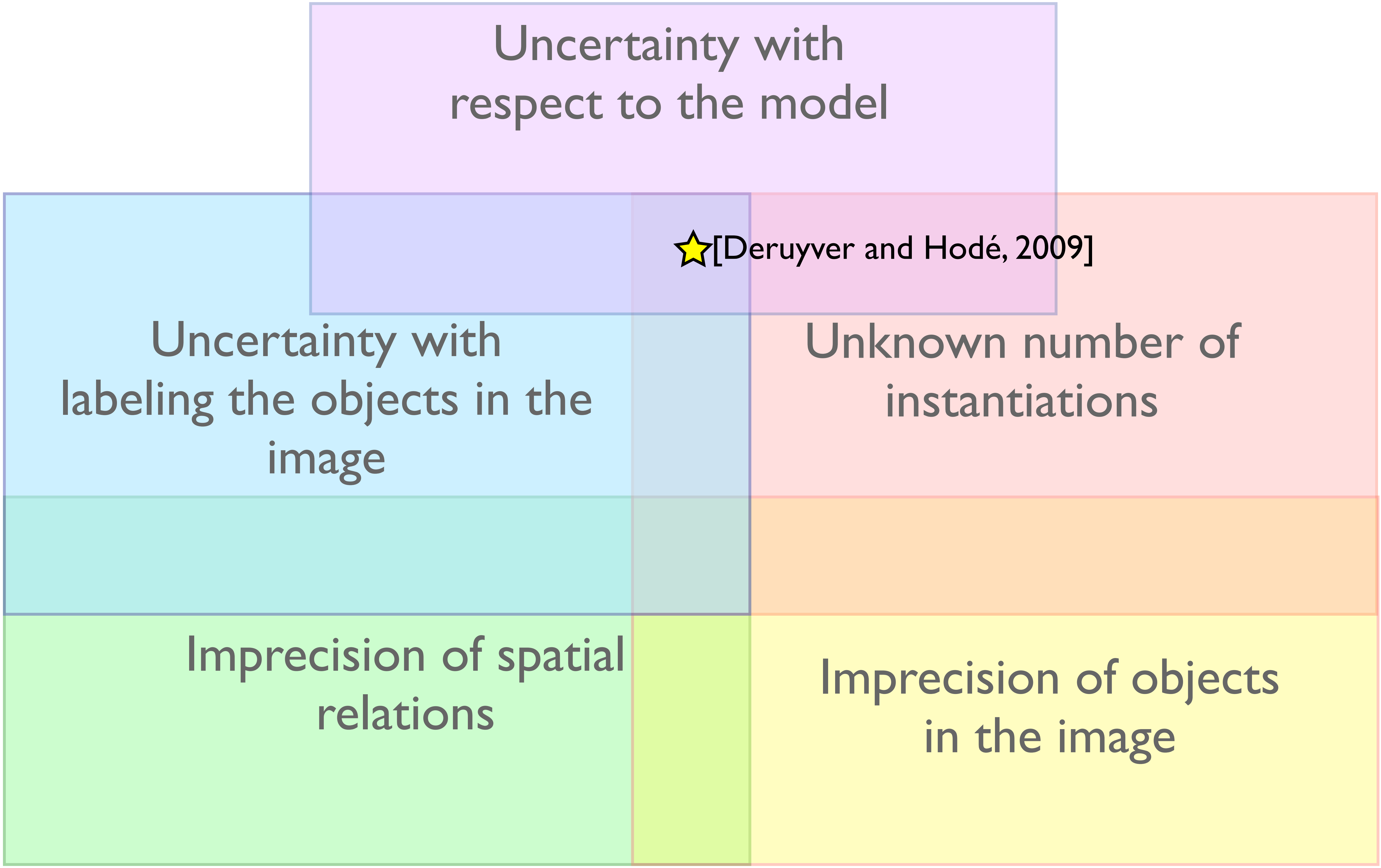

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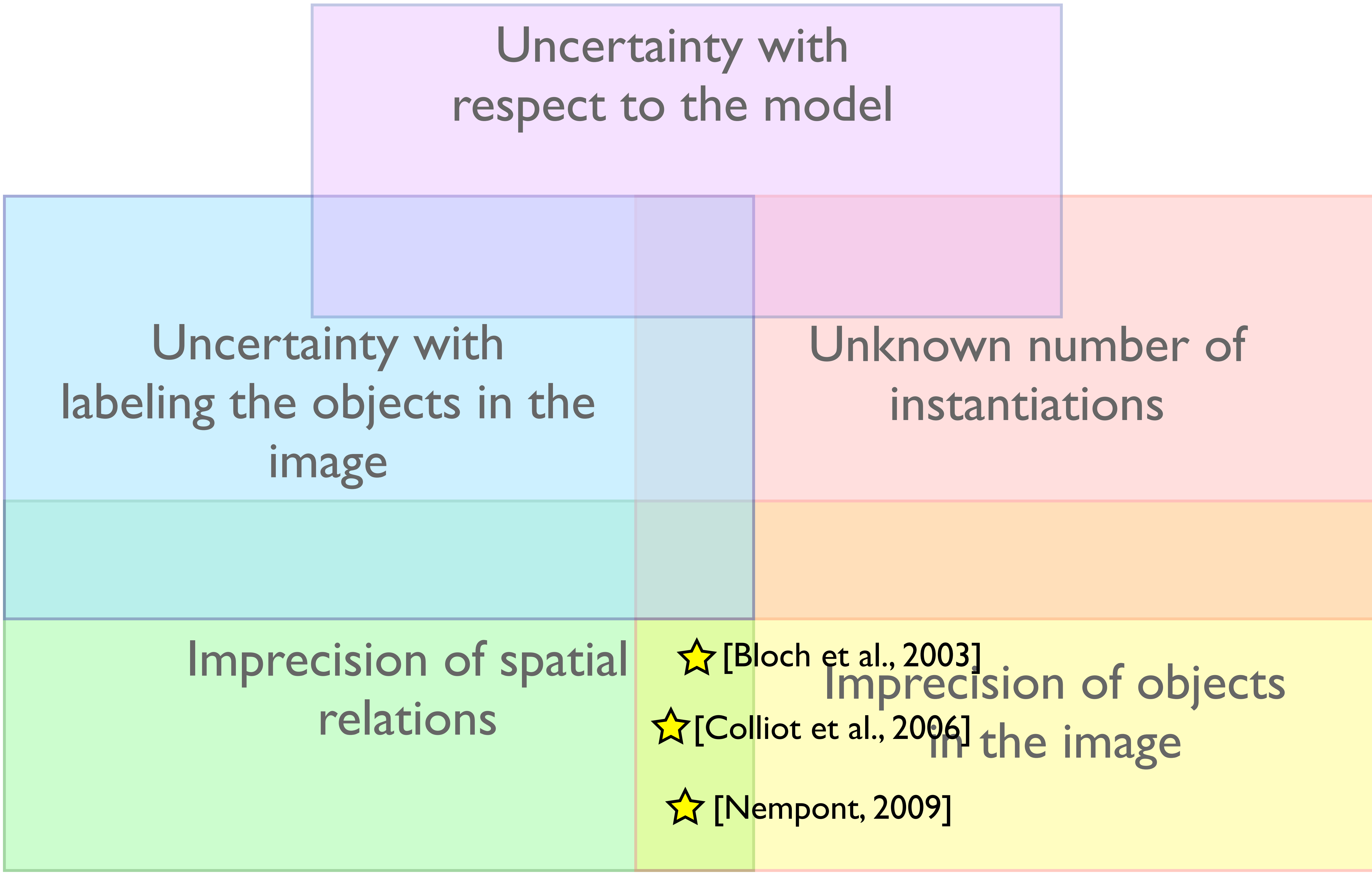

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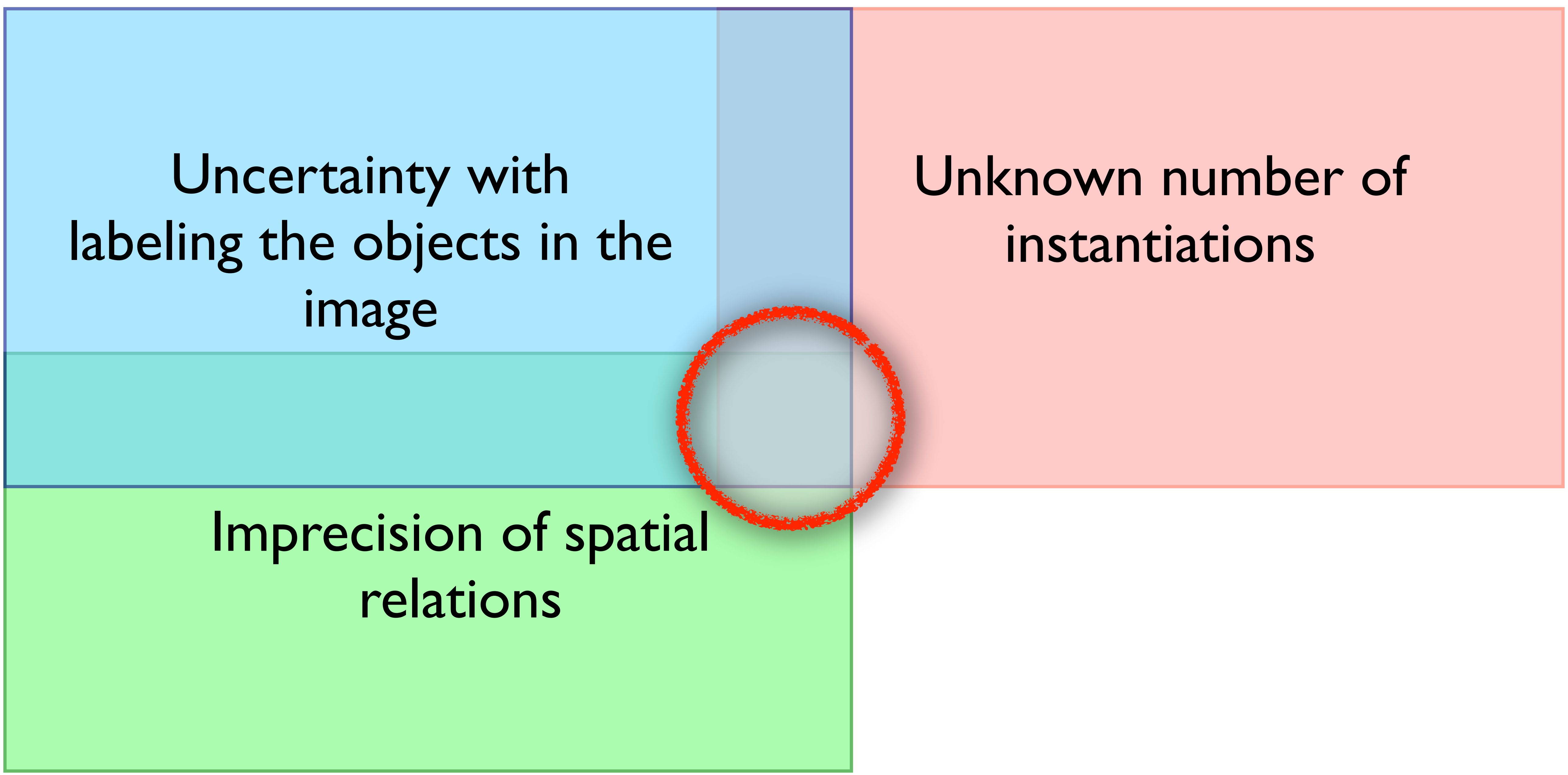
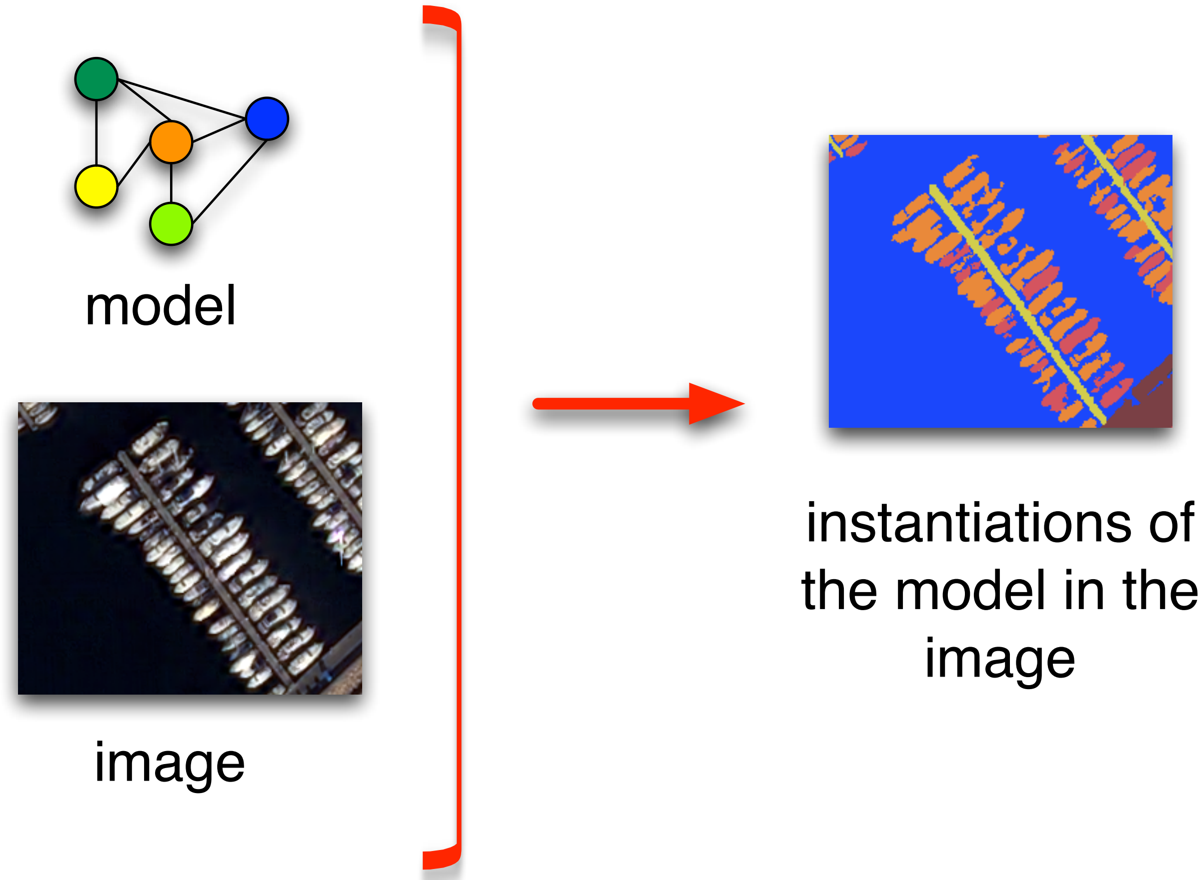


Our Objective



1. What are the spatial relations that we can find in Earth observation images ?
2. How can we represent them ? (model + image)
3. How can we reason with them to find the instantiations of the model in the image ?

Outline

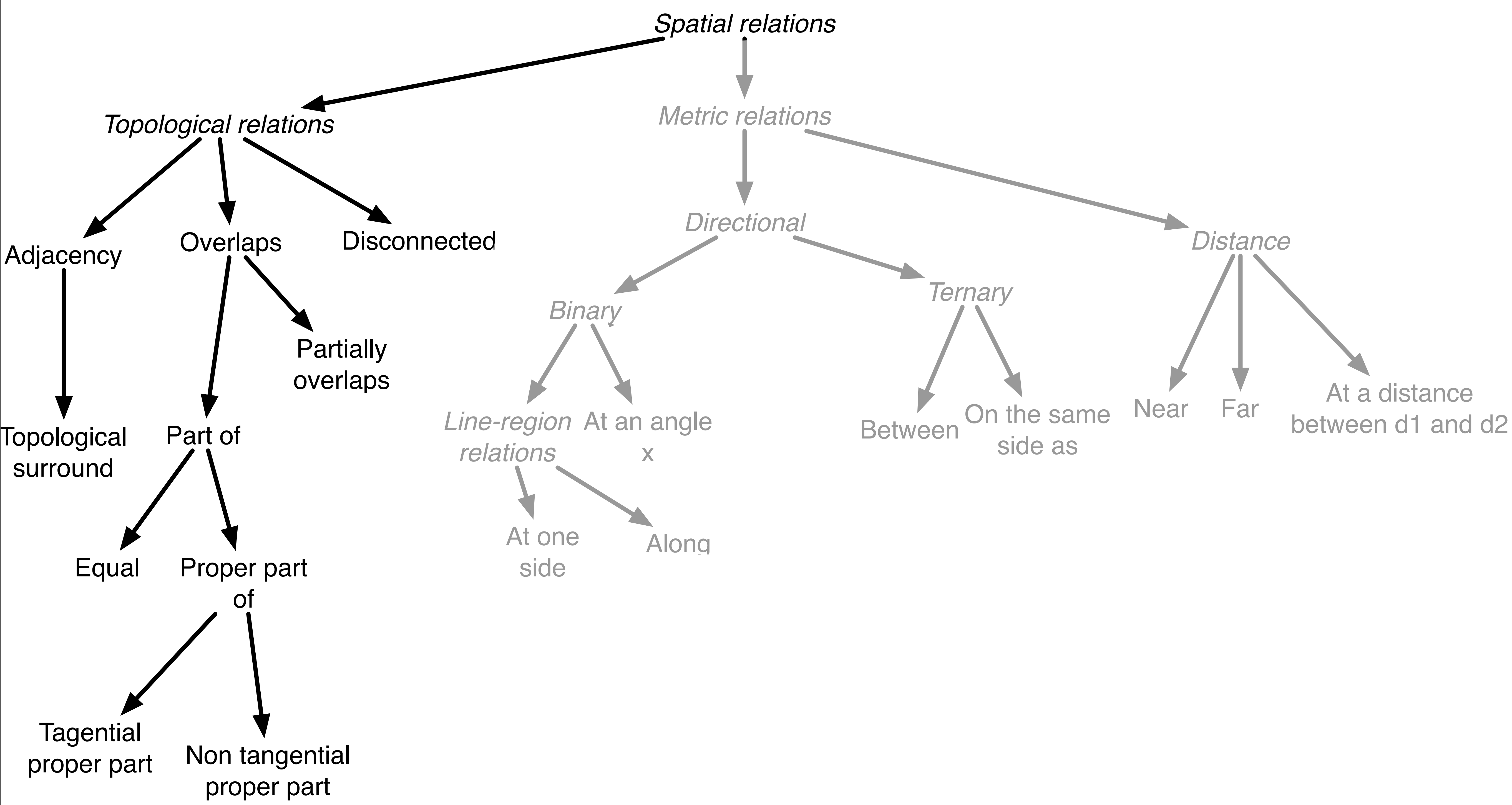
- Spatial relations
  - State of the art
  - Contribution
    - Example
- Interpretation of satellite images using a structural model (concepts + spatial relations)
- Conclusions and perspectives

Modeling of Spatial Relations

- Some spatial relations are by nature imprecise (ex: surround)
- Fuzzy logic is an appropriate tool
- Two ways of modeling spatial relations [Bloch, 2006]

1. Given two objects, assess the degree to which the relation is satisfied
2. Given one reference object, define the area of space in which the relation is satisfied to some degree (fuzzy landscape)

Spatial Relations (state of the art)



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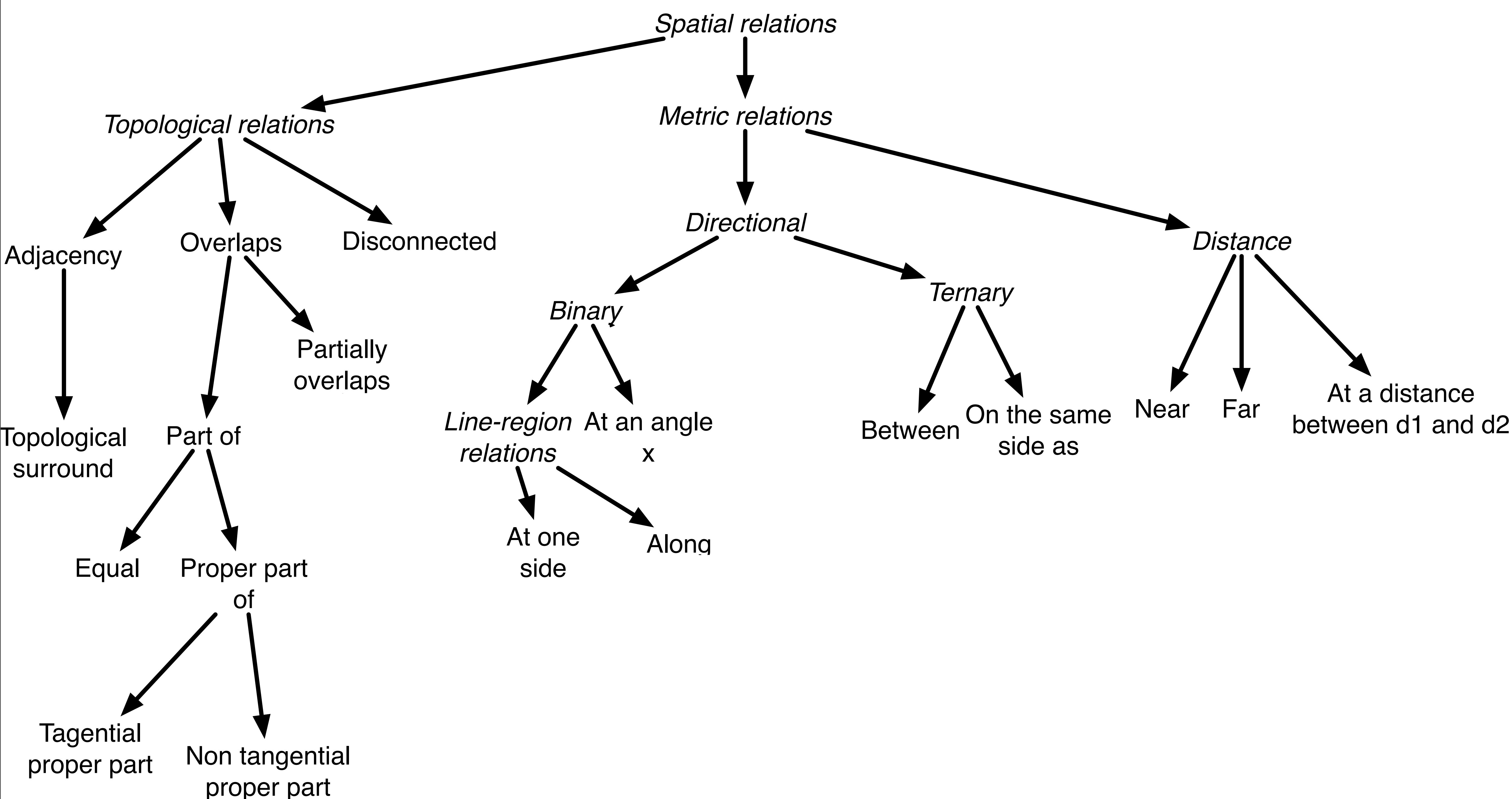

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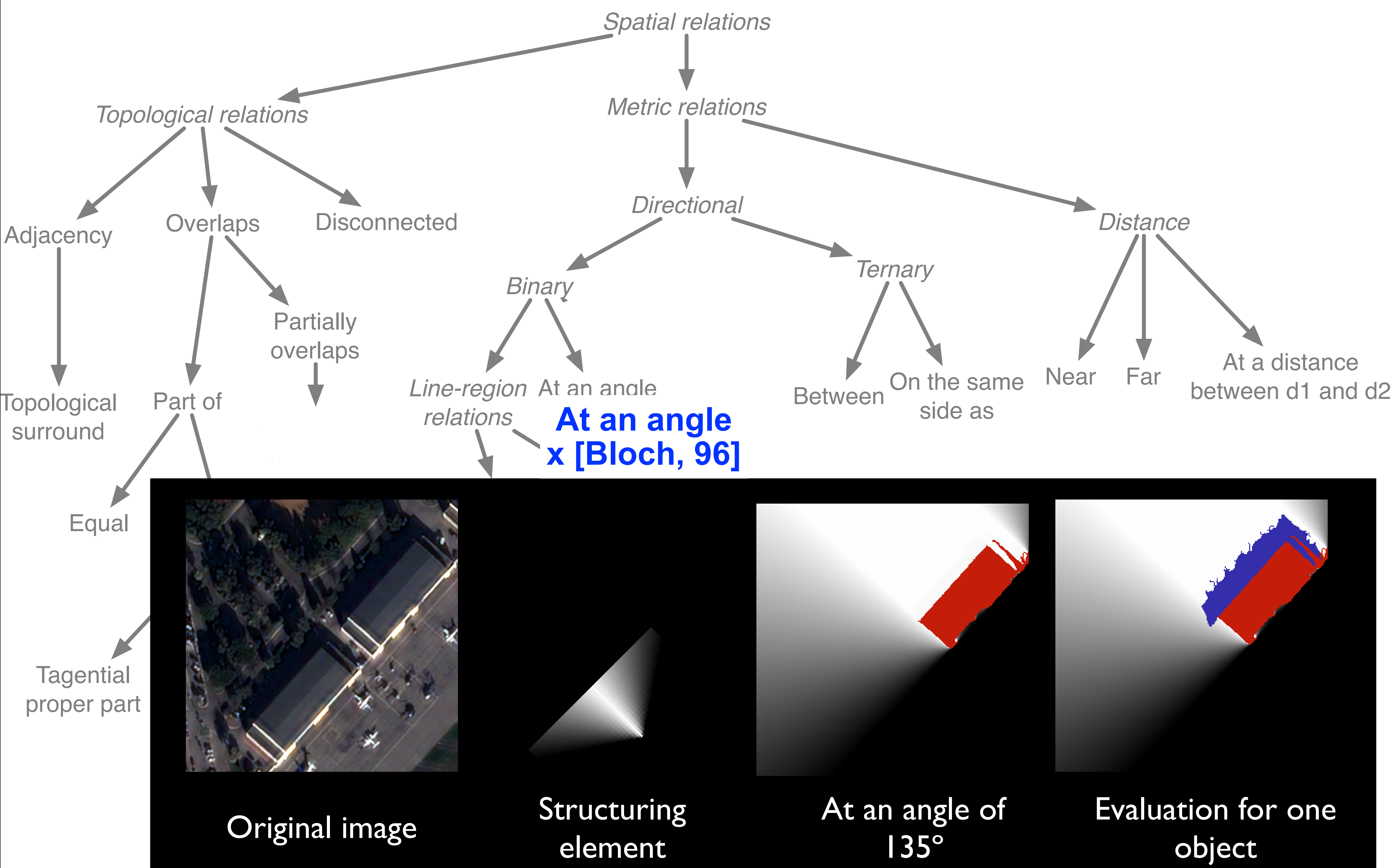

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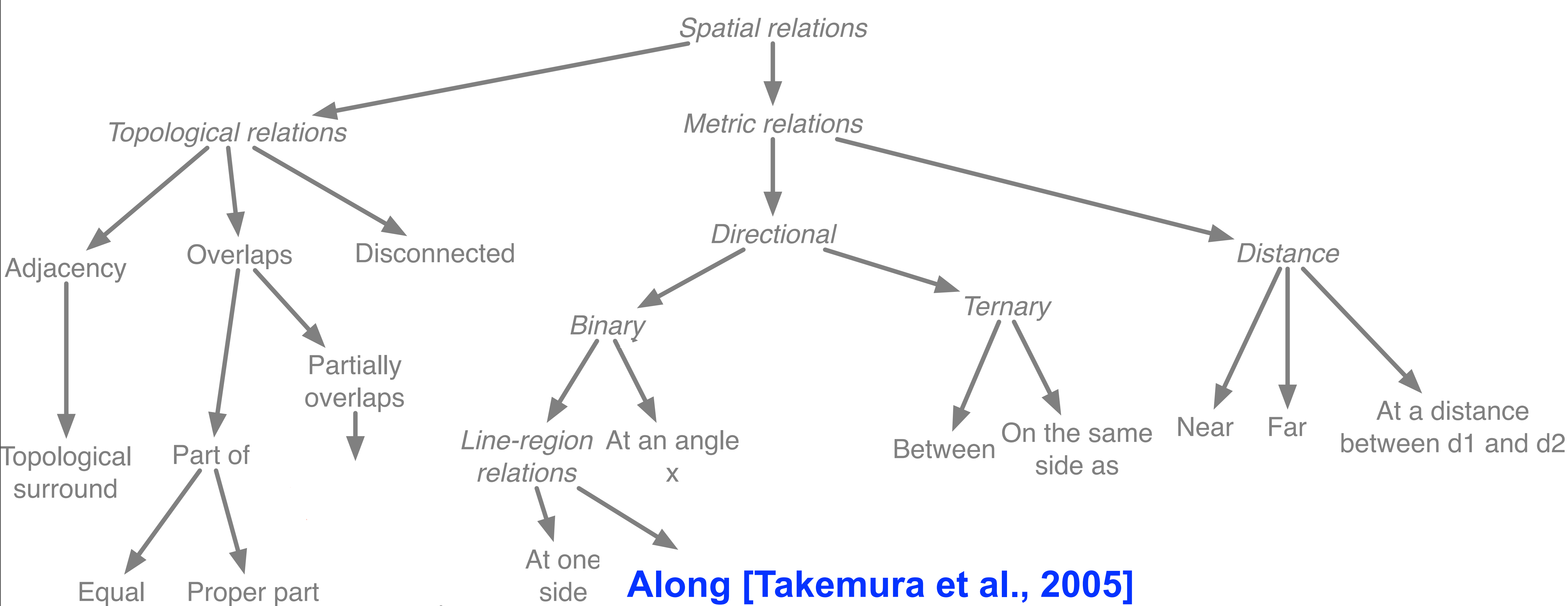
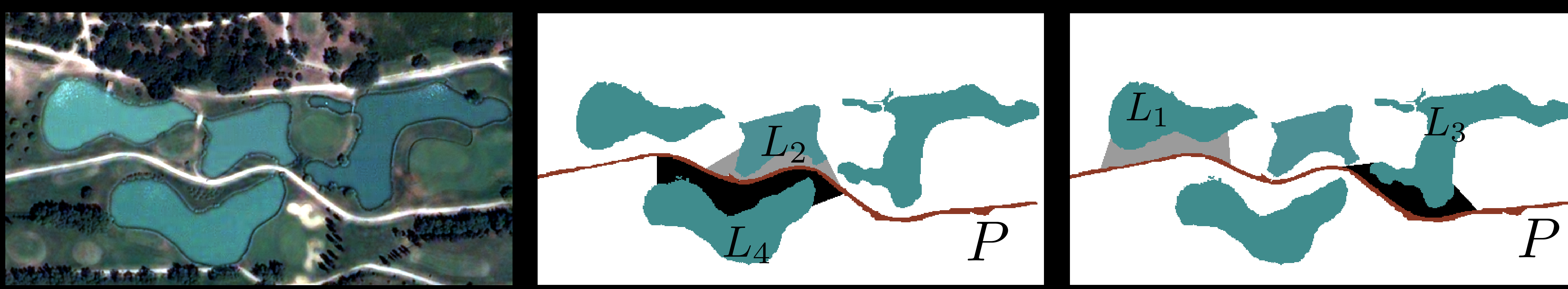




Original image

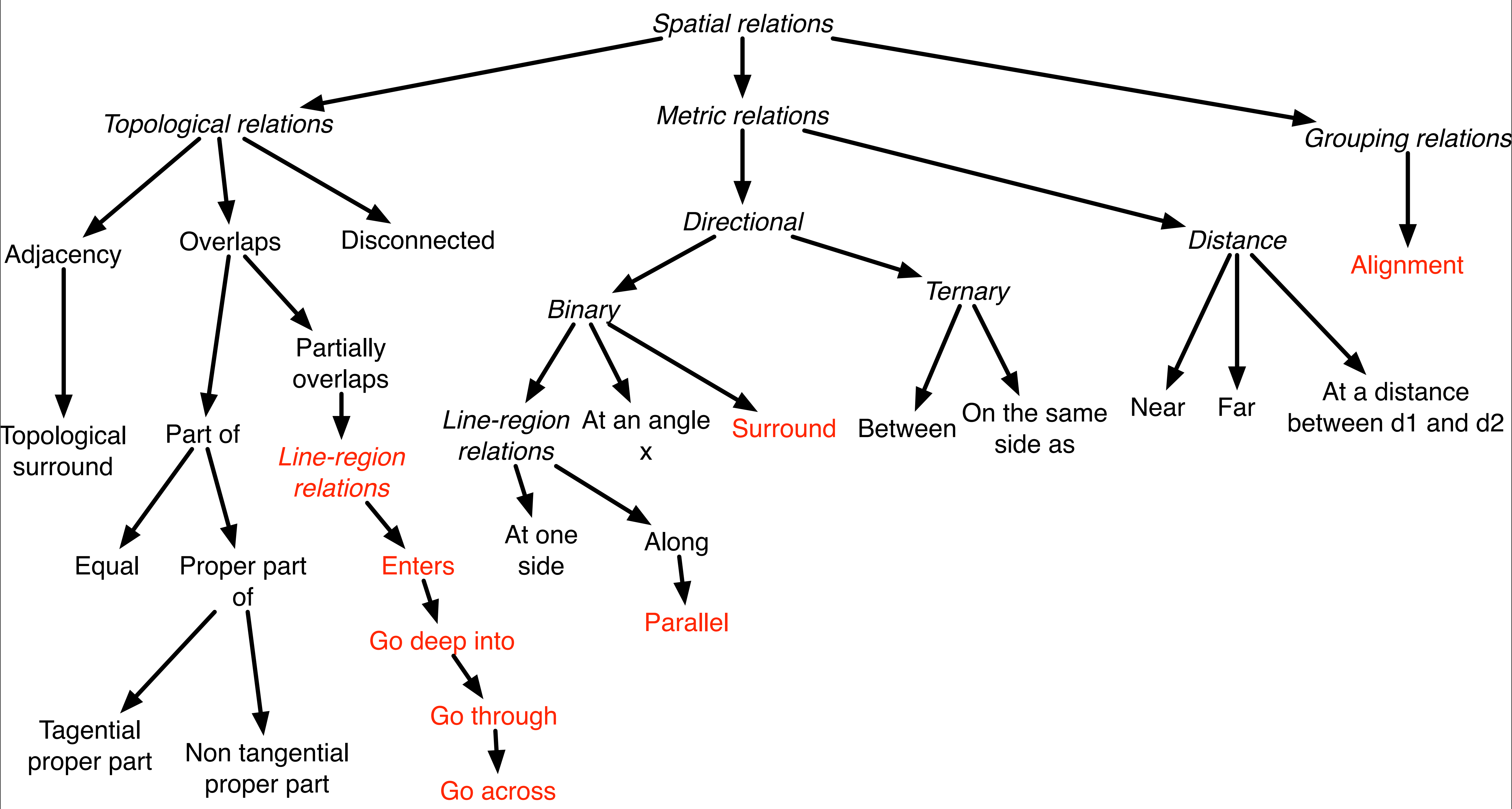
$\mu_{along}(P, L_2) = 0.98$

$\mu_{along}(P, L_4) = 0.97$

$\mu_{along}(P, L_1) = 0.86$

$\mu_{along}(P, L_3) = 0.84$

Spatial Relations (contribution)



[IGARSS, 2009] [WILF, 2009] [IPMU, 2010] [IGARSS, 2010] [CVIU(submitted), 2010]

Alignment

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- Alignment of points
- Determine if a group of objects is aligned by observing its barycenters [Christophe and Ruas, 2002]

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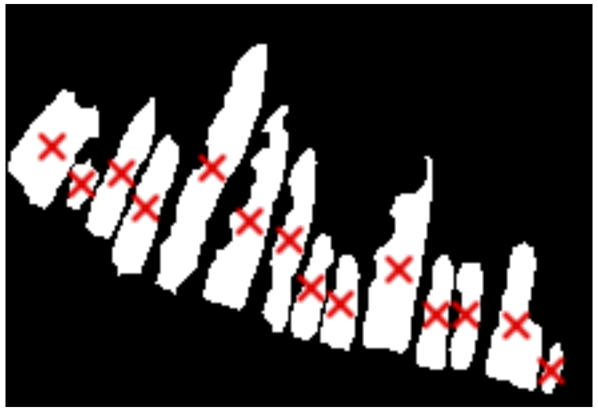
Original image

Segmented boats



Barycenters

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- Determine if a group of objects is aligned by observing its barycenters [Christophe and Ruas, 2002]

Original image

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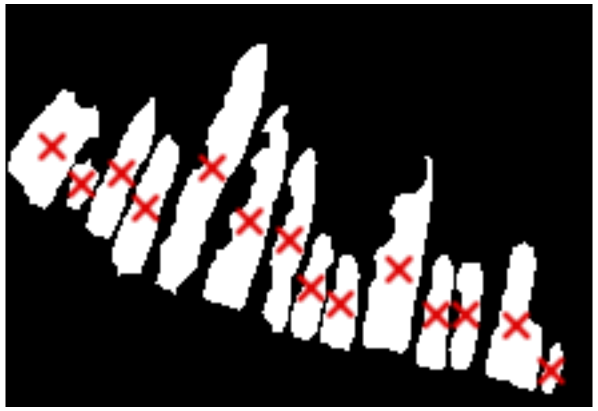


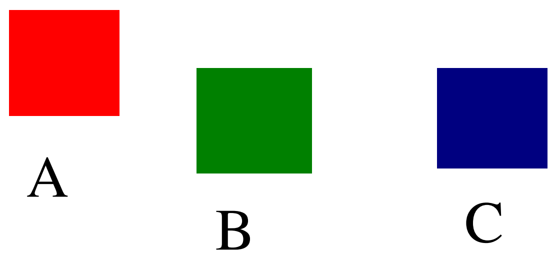
Barycenters

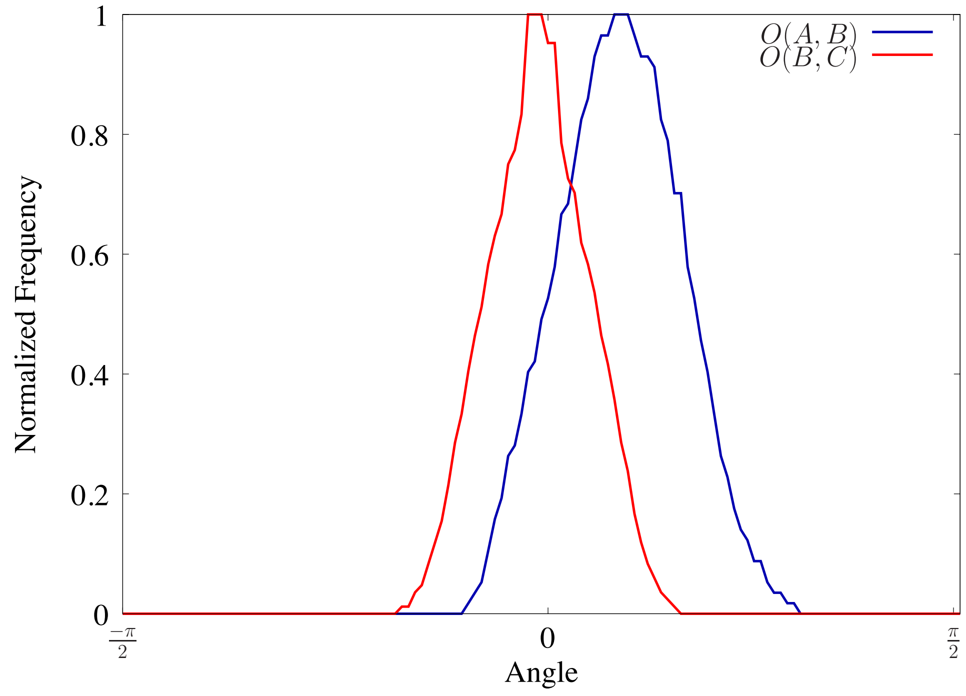
- Consider the whole object to determine if a group of objects is aligned
  - Use relative position measures

Alignment (preliminary concepts)

- Measure the relative position between two objects
- Orientation histogram (based on [Miyajima and Ralescu, 1994])

$$O(A,B)(\theta) = \frac{|\{(p,q) \in A \times B | mod(\angle(\vec{pq}, \vec{u}_x), \pi) = \theta\}|}{\max_{\phi \in [0,\pi)} |\{(p,q) \in A \times B | mod(\angle(\vec{pq}, \vec{u}_x), \pi) = \phi\}|}$$





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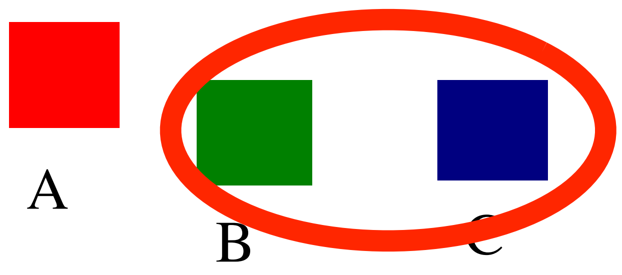

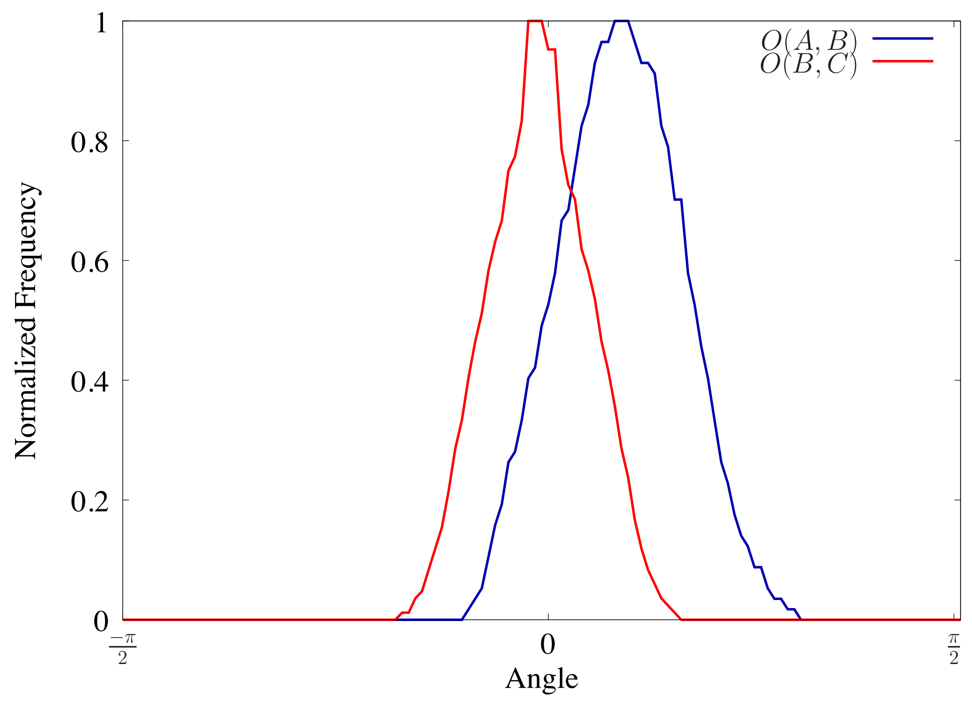

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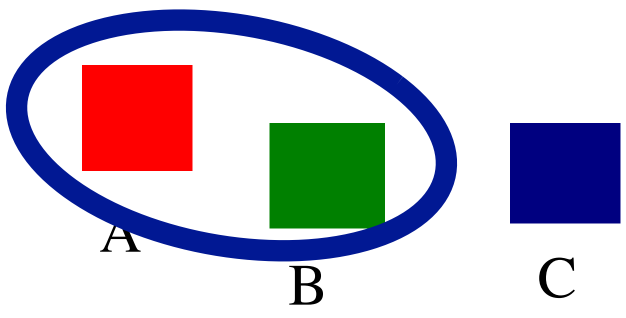
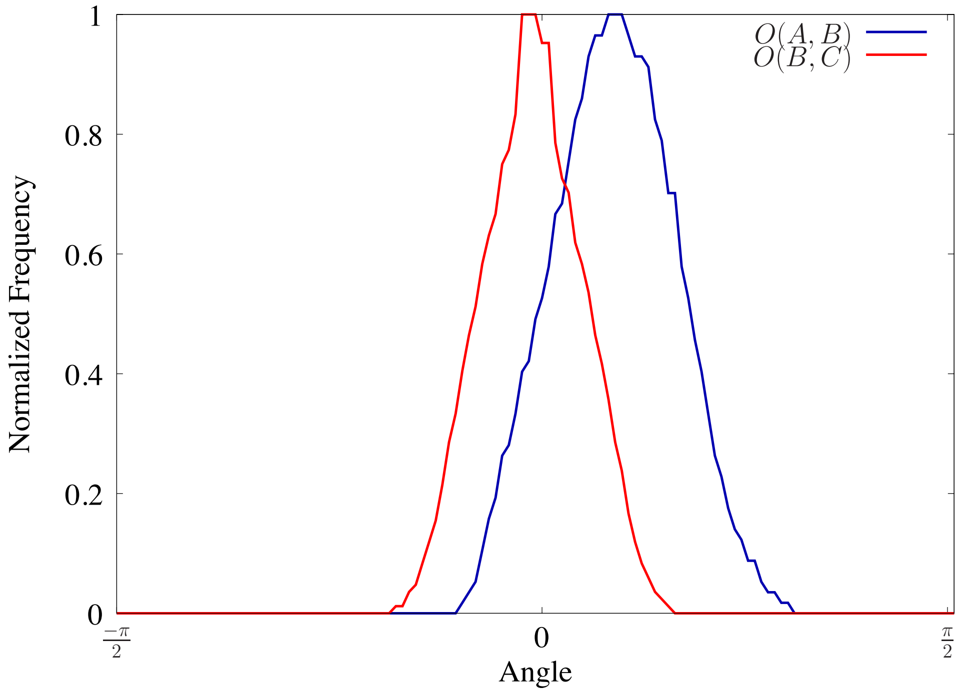
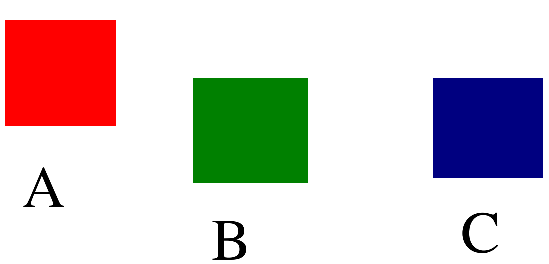


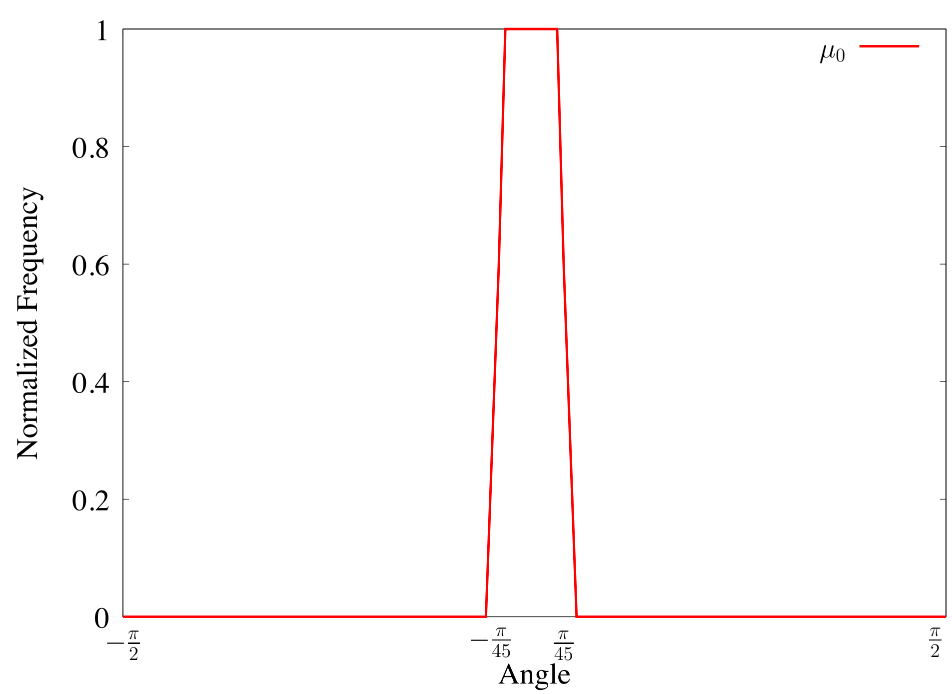


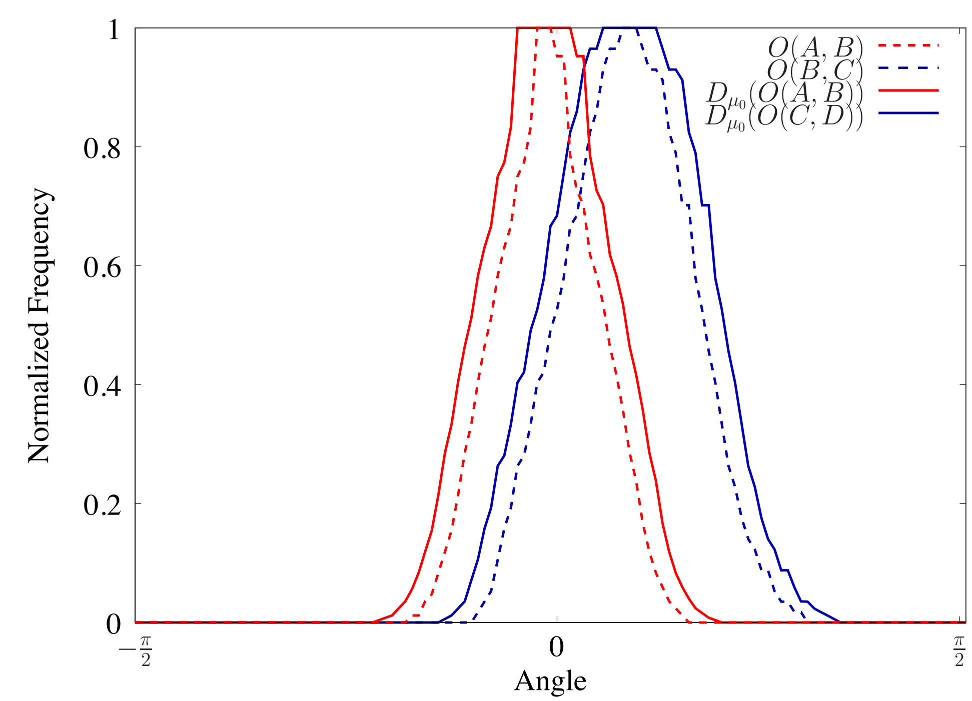
Alignment (preliminary concepts)

- Similarity measure between two orientation histograms
  - the imprecision of comparing two angles is modeled through ν_0

$$sim(O(A,B),O(C,D)) = \max_{\theta \in [0,\pi)} \left[D_{\nu_0}(O(A,B))(\theta) \wedge D_{\nu_0}(O(C,D))(\theta) \right]$$







Global Alignment

A group S is *globally aligned* if the following conditions are satisfied:

(i) The consecutive members of S are neighbors,

(ii) $|S| \geq 3$, and

(iii) there exists $\theta \in [0, \pi[$ such that $A_i, A_j \in \mathcal{S}$, A_i is able to see A_j in direction θ or $\theta + \pi$ with the horizontal axis.

$$\mu_{ALIG}(S) = sim(O(A_0, \mathcal{S} \setminus \{A_0\}), \ldots, O(A_n, \mathcal{S} \setminus \{A_n\}))$$

Local Alignment

A group S is *locally aligned* if the following conditions are satisfied:

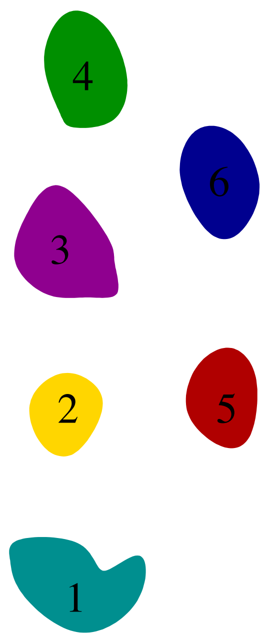
(i) The consecutive members of S are neighbors,

(ii) $|S| \geq 3$, and

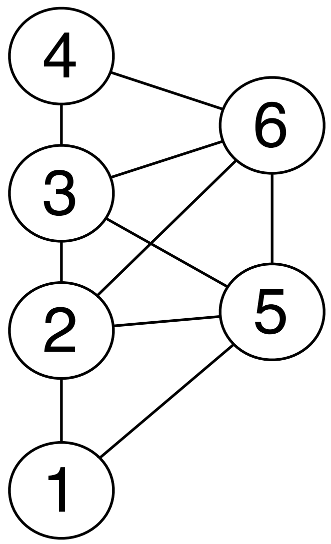
(iii) for every $A_i, A_j, A_k \in \mathcal{S}$ such that A_j and A_k are neighbors of A_i , the orientations $O(A_i, A_k)$ and $O(A_i, A_j)$ are similar.

$$\mu_{LA}(S) = \min_{A_i, A_j, A_k : Neigh(A_i, A_j) \wedge Neigh(A_i, A_k)} sim(O(A_i, A_j), O(A_i, A_k))$$

Local Alignment (underlying idea)



Objects

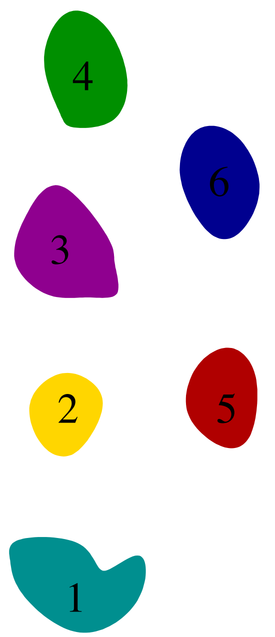


Neighborhood graph

R1 $\forall X, Y, Z(Neigh(X,Y) \wedge Neigh(Y,Z))$
$$\Rightarrow sim(O(X,Y),(Y,Z) \geq \beta)$$

R2 $\forall A, B \; \exists X_0, \ldots X_m$ for $m > 1$ such that $X_0 = A$,
$$X_m = B \text{ and } \wedge_{i=0}^{m-1} Neigh(X_i, X_{i+1})$$

Local Alignment (underlying idea)



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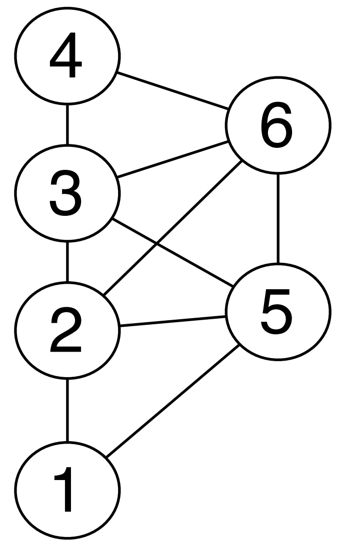

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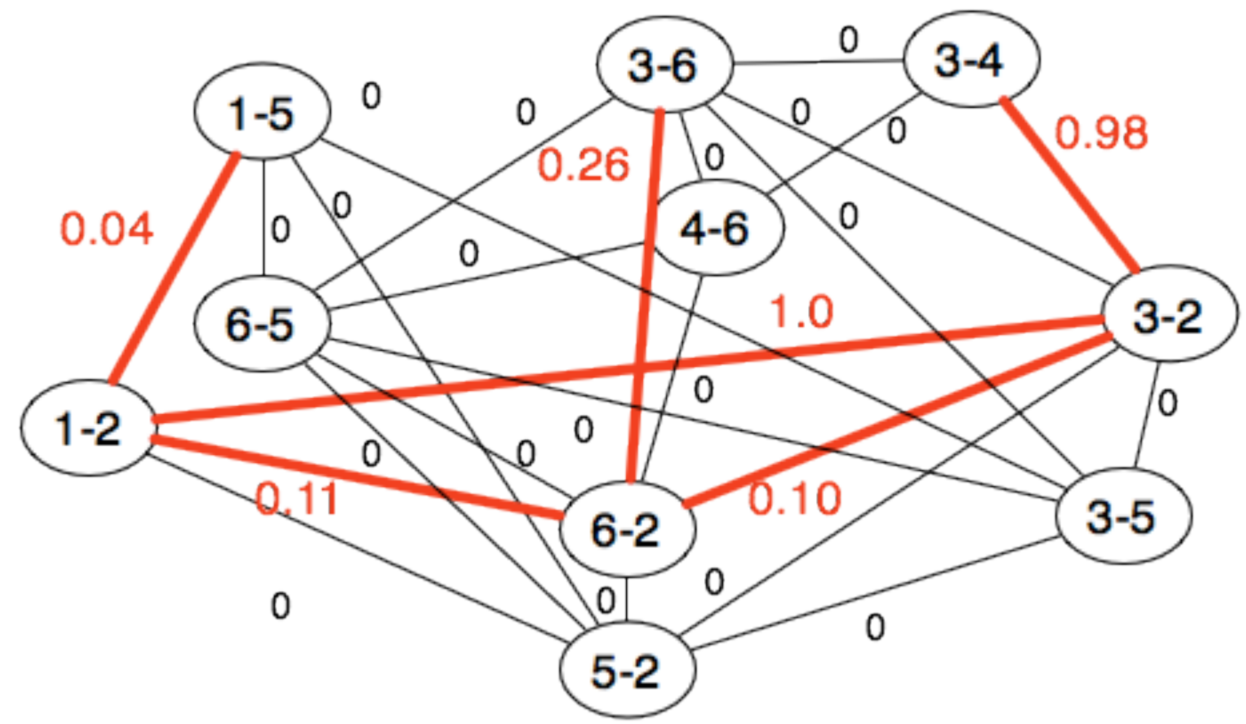

Dual graph

R1 $\forall \tilde{V}_i, \tilde{V}_j \; Conn(\tilde{V}_i, \tilde{V}_j) \Rightarrow (\tilde{s}_{ij} \geq \beta)$

R2 $\forall \tilde{V}_i, \tilde{V}_j \; \exists \tilde{U}_0, \ldots, \tilde{U}_K \text{ for } K > 1 \text{ such that } \tilde{U}_0 = \tilde{V}_i,$

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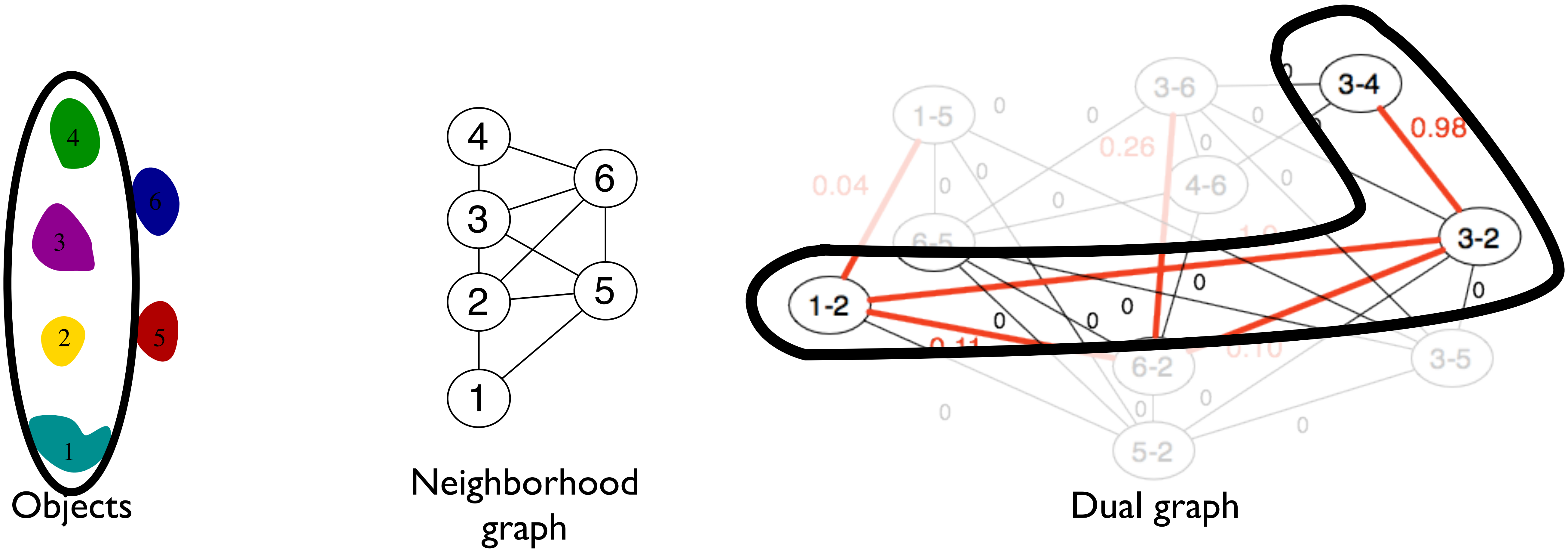

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Local Alignment (underlying idea)

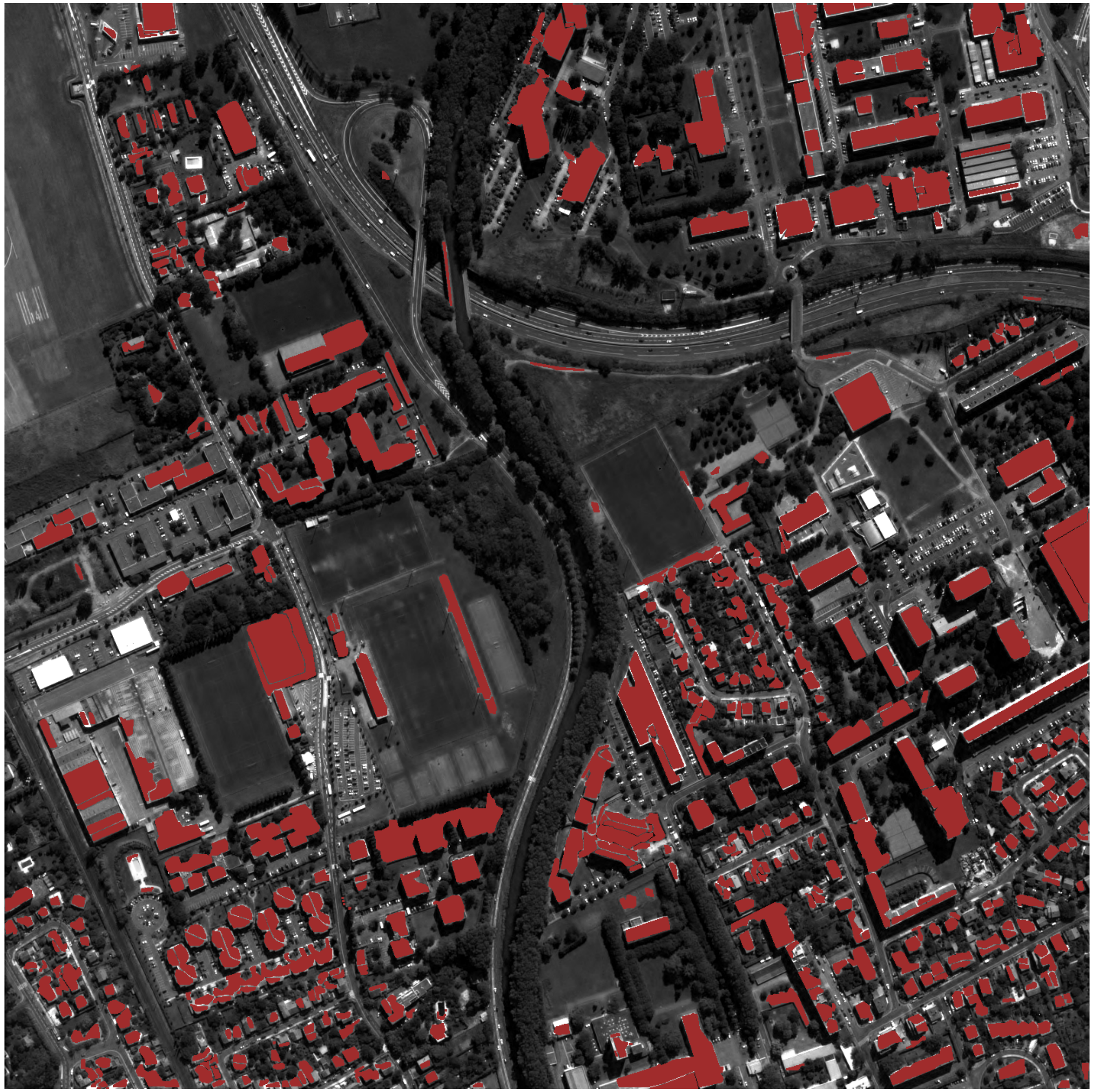
The locally aligned groups to a degree β correspond to the clusters in the dual graph which have a degree greater or equal to β.

From local to global alignment

- The locally aligned groups are candidates to global aligned groups.
- If $\mu_{ALIG}(\mathcal{S}) < \beta$ then the vertices of the dual graph with the minimum degree are eliminated.

Example: Urban morphologies

Quickbird image: Toulouse



Extracted buildings [Poulain et al. 2008]

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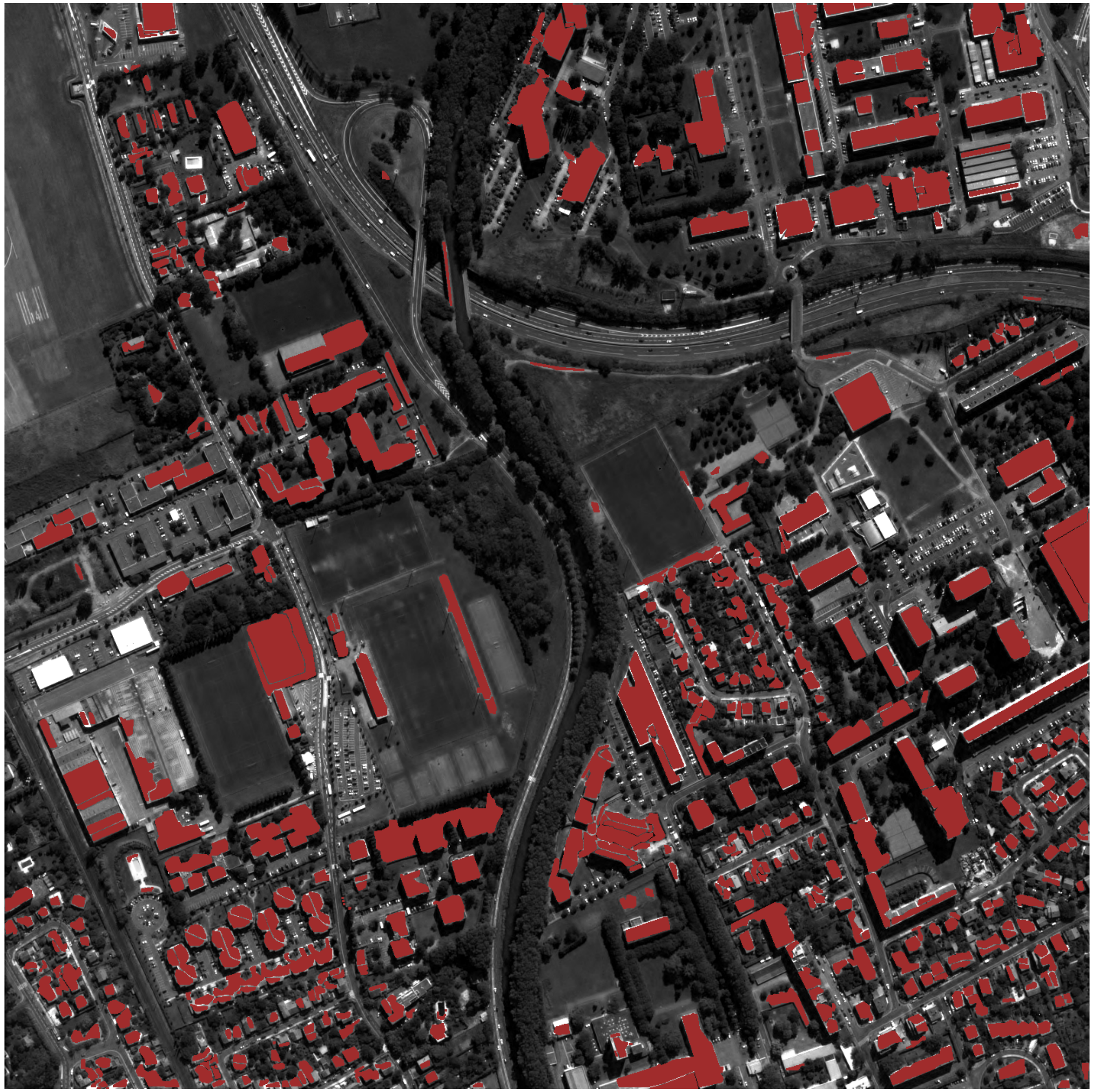

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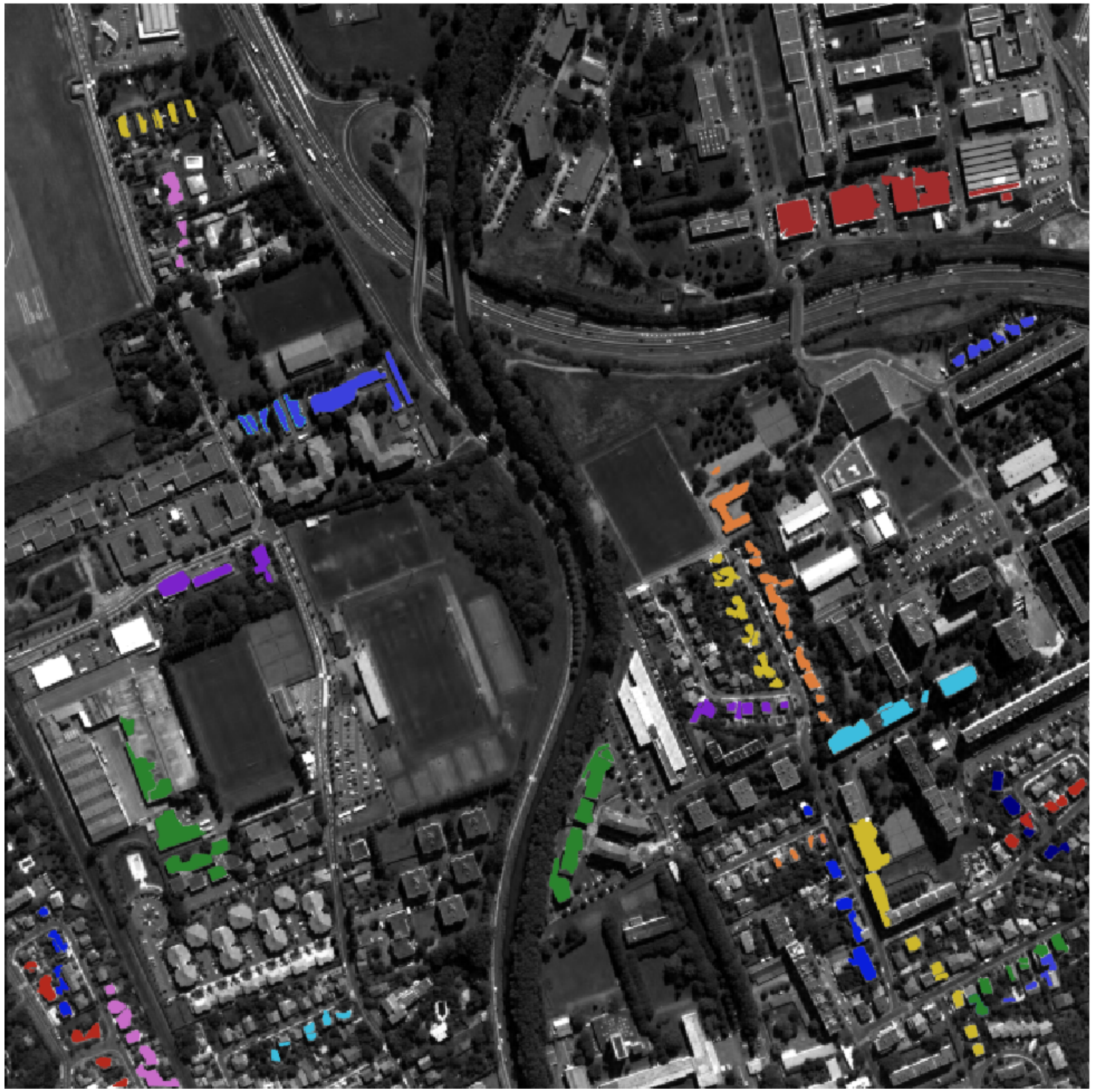

Some globally aligned buildings
to a degree greater than β=0.85

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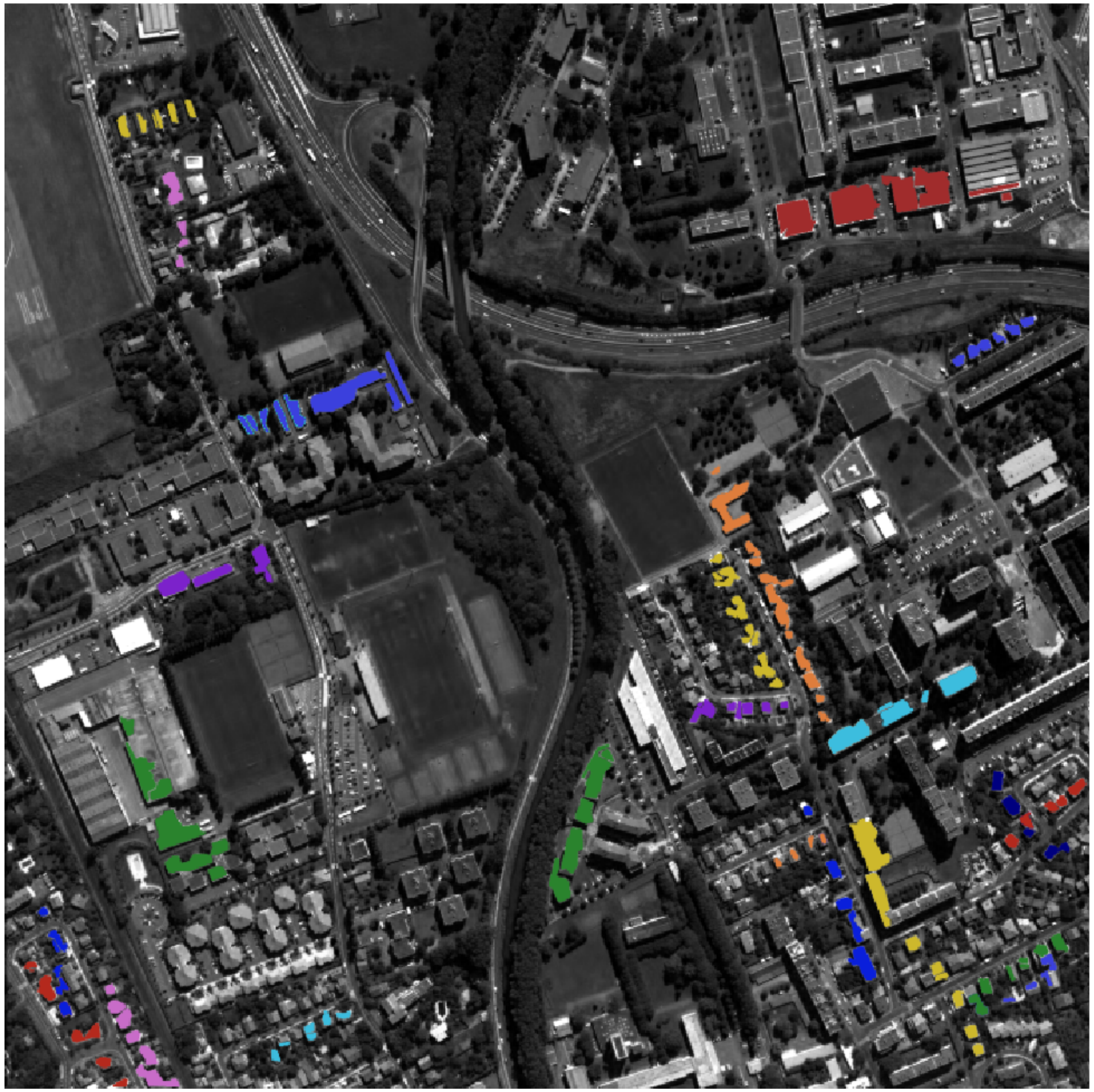

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Groups of globally aligned buildings which are
close and aligned to another group

Outline

- Spatial relations
  - State of the art
  - Contribution
    - Example
- Interpretation of satellite images using a structural model (concepts + spatial relations)
- Conclusions and perspectives

Structural model

The structural model is represented as a nested conceptual graph:

- allows to represent groups of objects
- graphical representation
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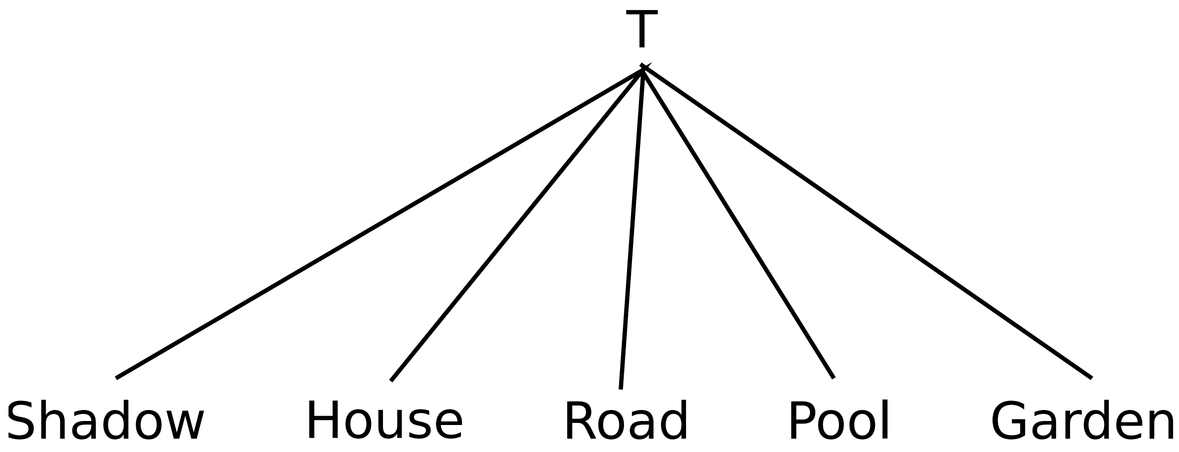

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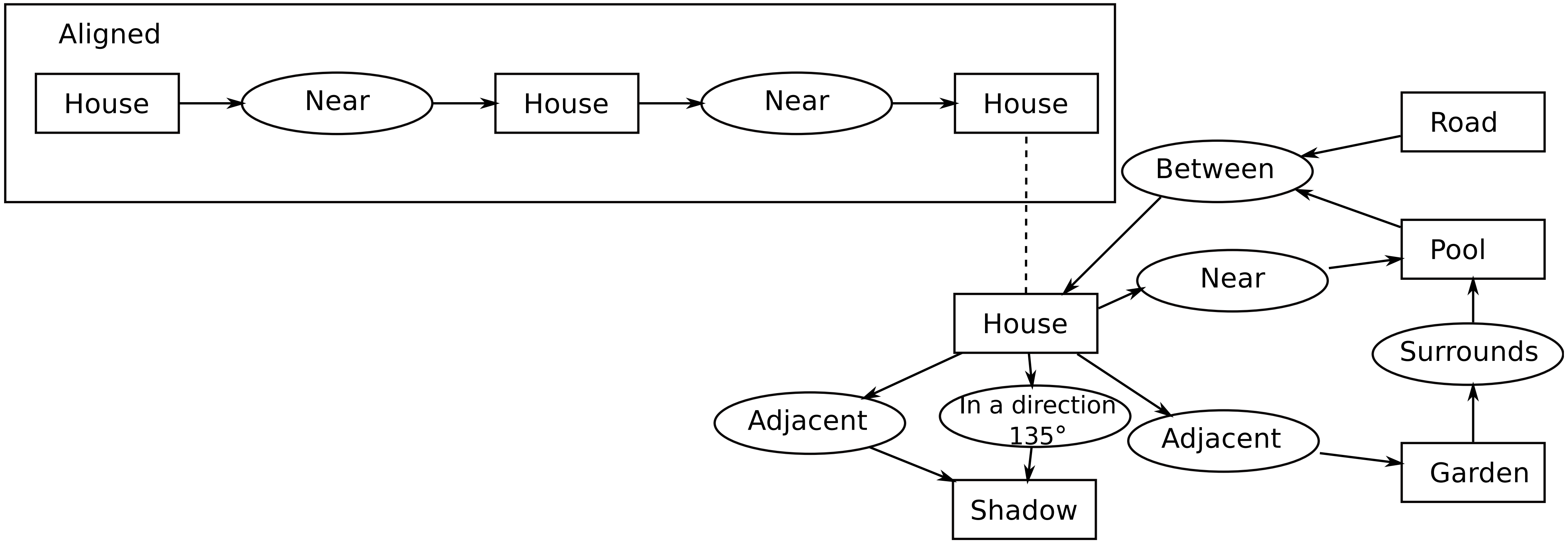

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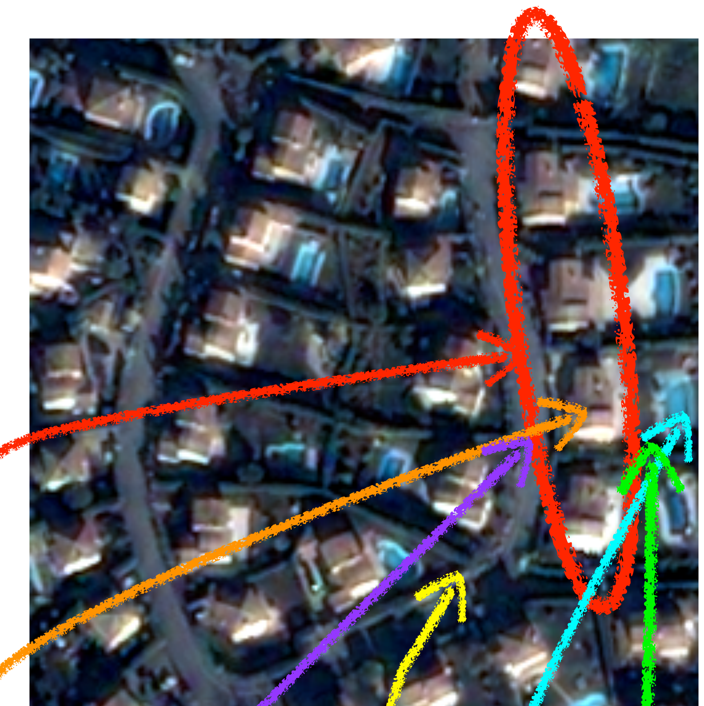
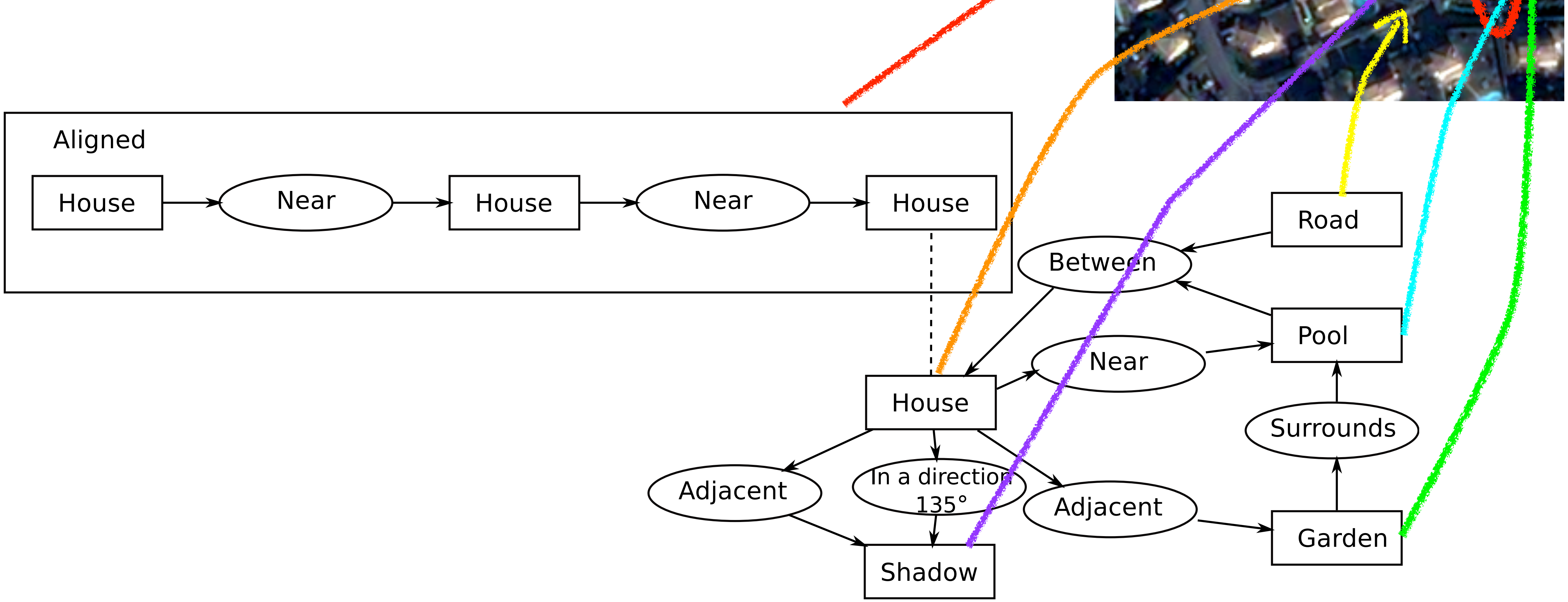
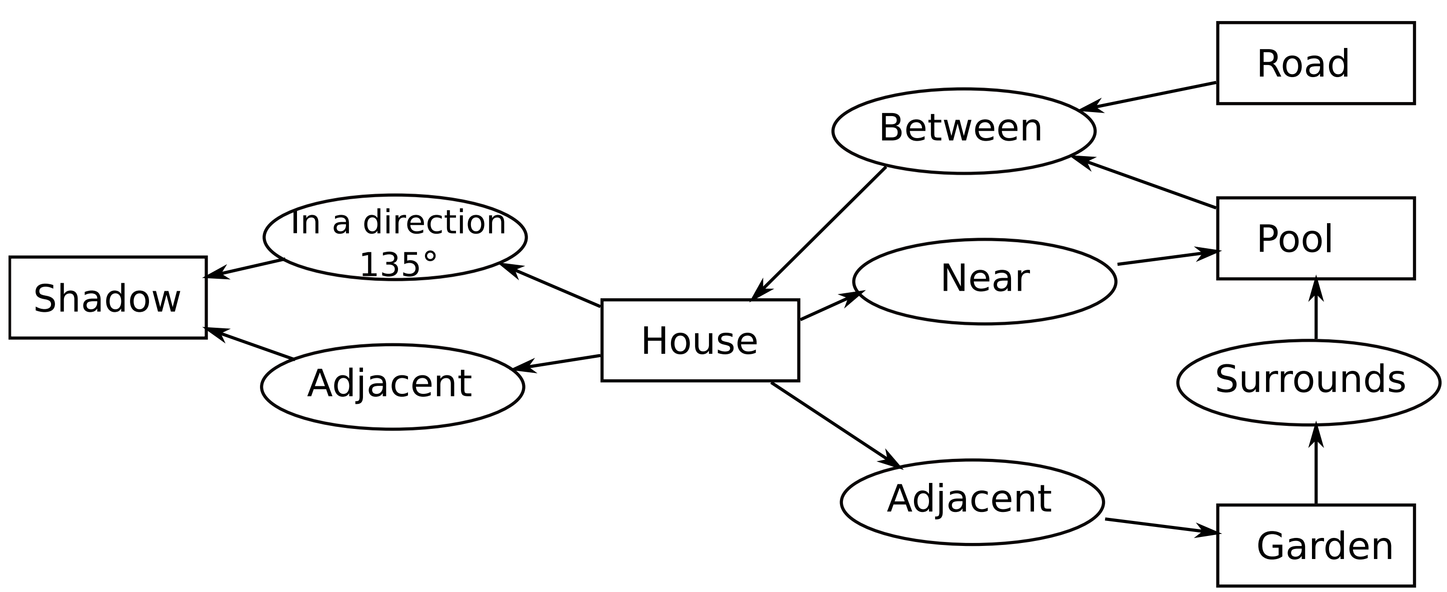




Interpretation using a model

- To find the instantiations of the model in the image, we find the homorphisms from the conceptual graph onto the image's regions.
    - multiple and unknown number of instantiations



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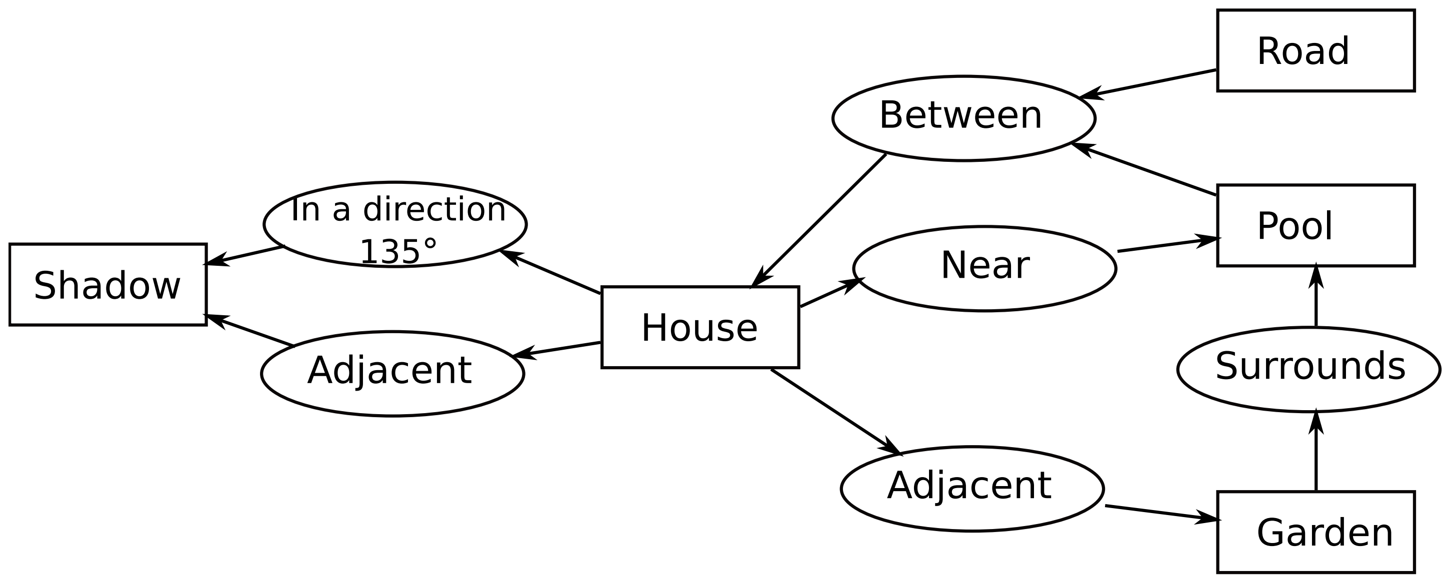

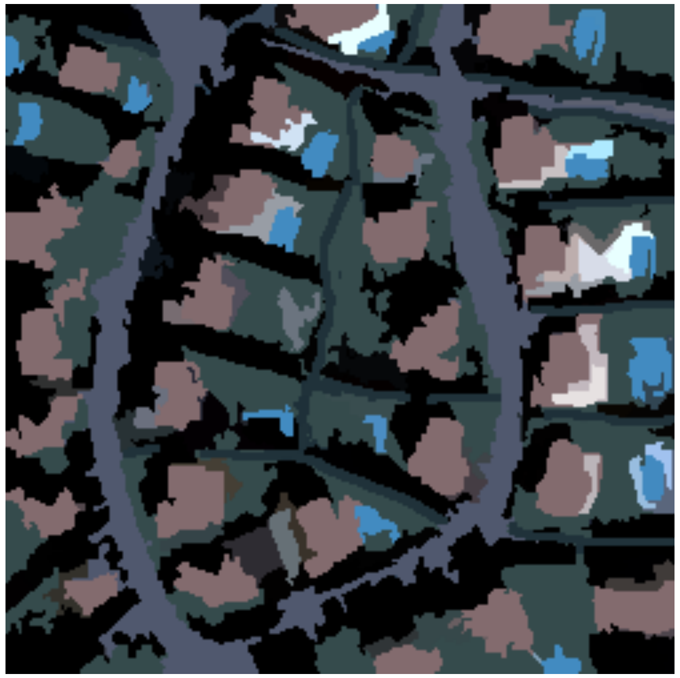

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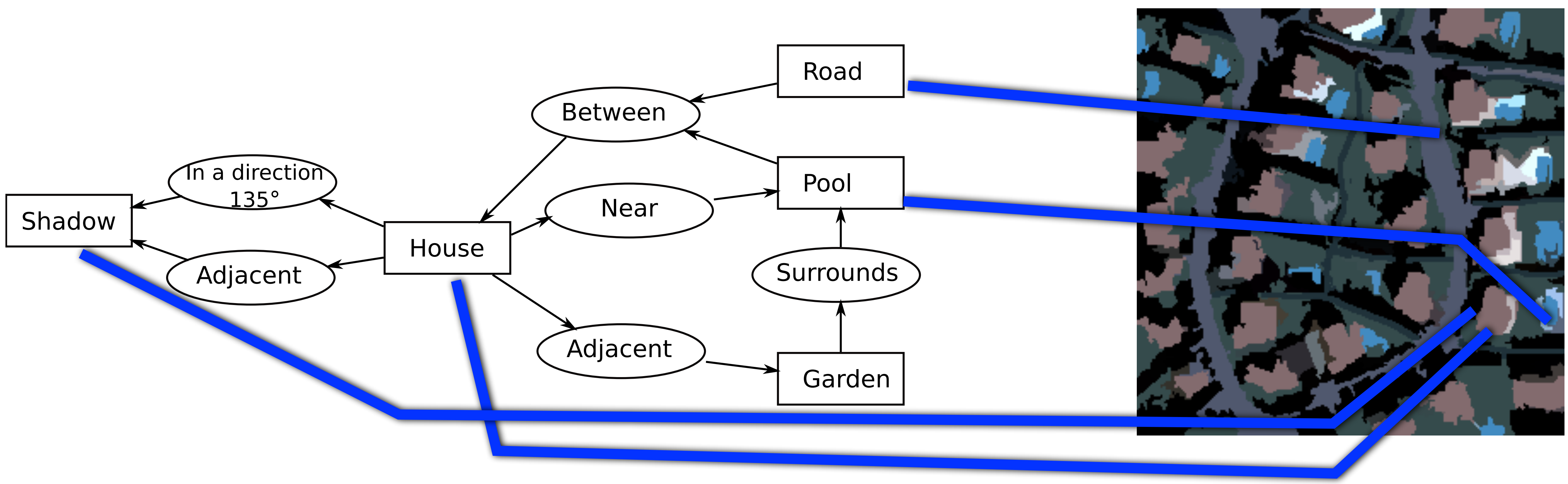

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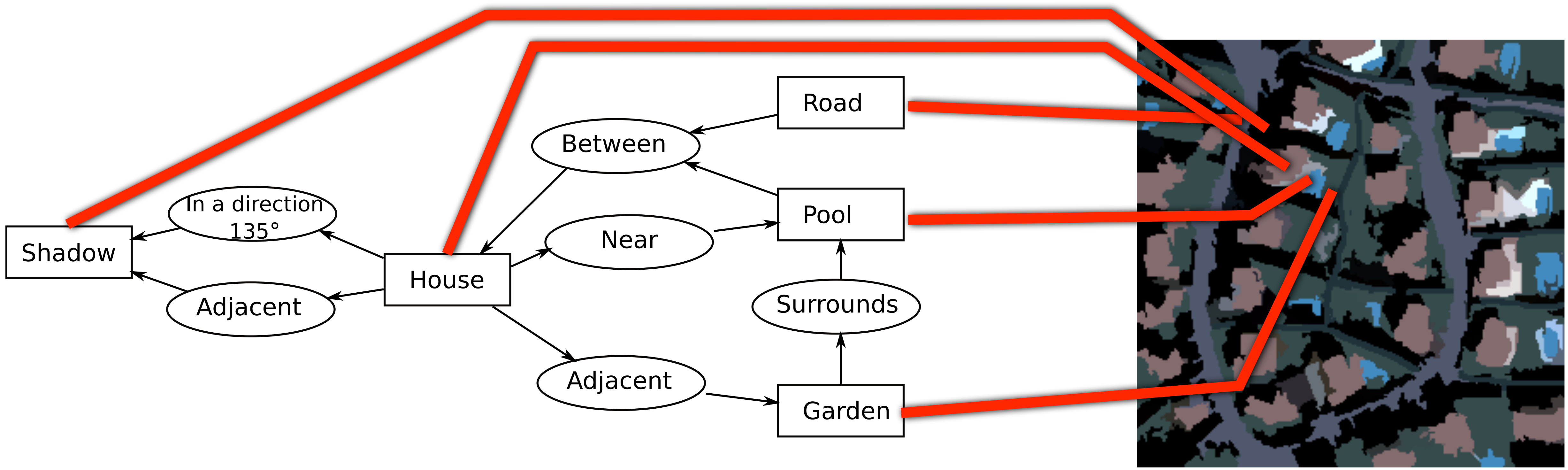
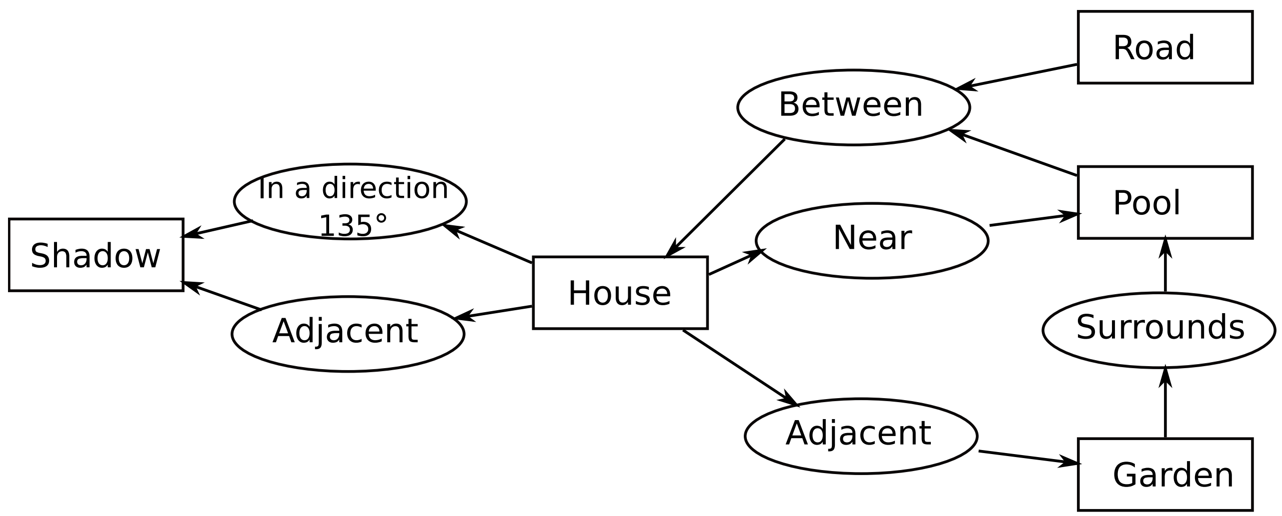


FCSP [Dubois et al., 1996]

- Fuzzy Constraint Satisfaction Problem $\mathcal{P} = \langle \mathcal{X}, \mathcal{D}, \mathcal{C} \rangle$
  - $\mathcal{X} = \{x_1, x_2, \ldots, x_n\}$ a set of n variables, representing a concept node of the graph.
  - $\mathcal{D} = \{D_1, D_2, \ldots, D_n\}$ a set of n domains. Each domain D_i is associated with a variable x_i. Represents the regions on the image (membership functions)
  - $\mathcal{C} = \{C_1, C_2, \ldots, C_t\}$ a set of t fuzzy constraints, representing the relations on the conceptual graph.



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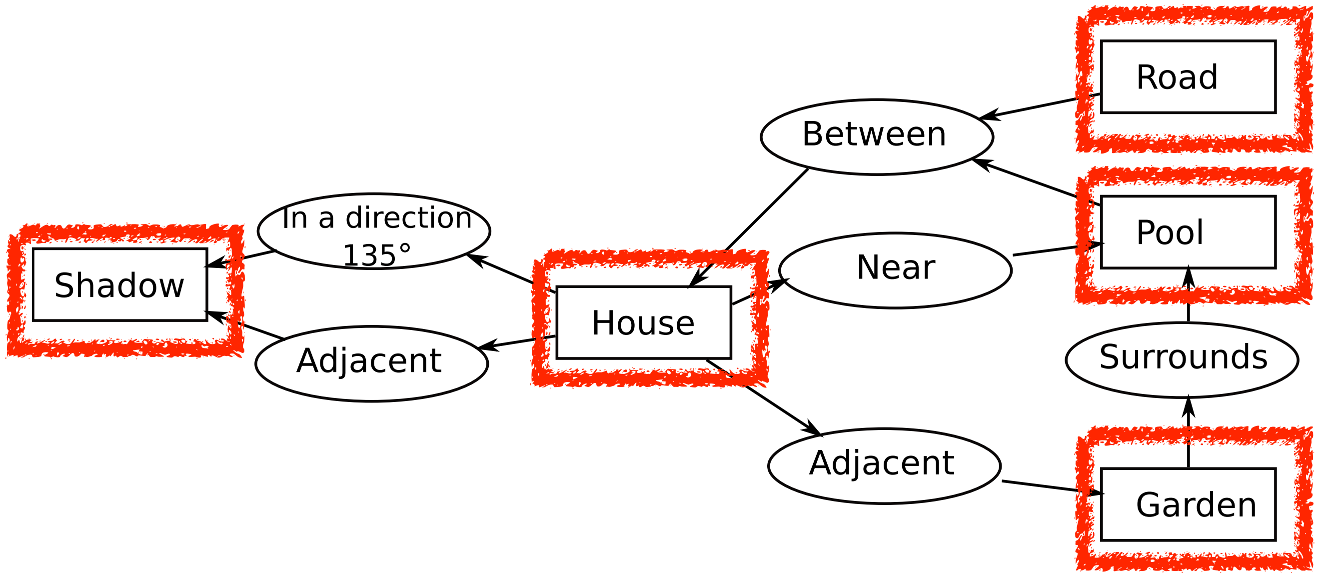

FCSP [Dubois et al., 1996]

- Fuzzy Constraint Satisfaction Problem $\mathcal{P} = \langle \mathcal{X}, \mathcal{D}, \mathcal{C} \rangle$
  - $\mathcal{X} = \{x_1, x_2, \ldots, x_n\}$ a set of n variables, representing a concept node of the graph.
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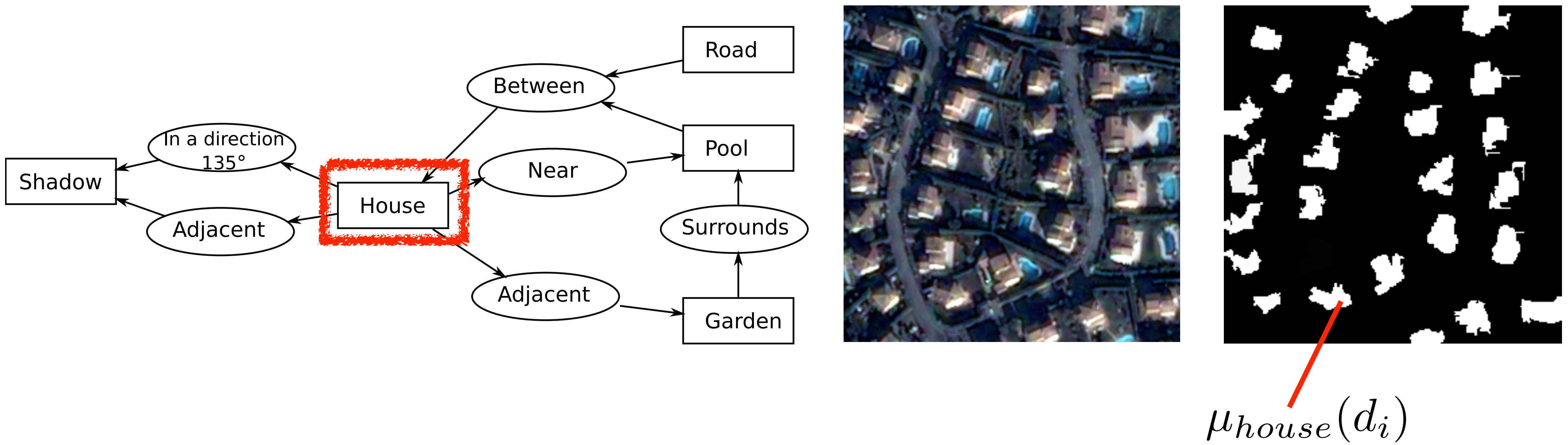

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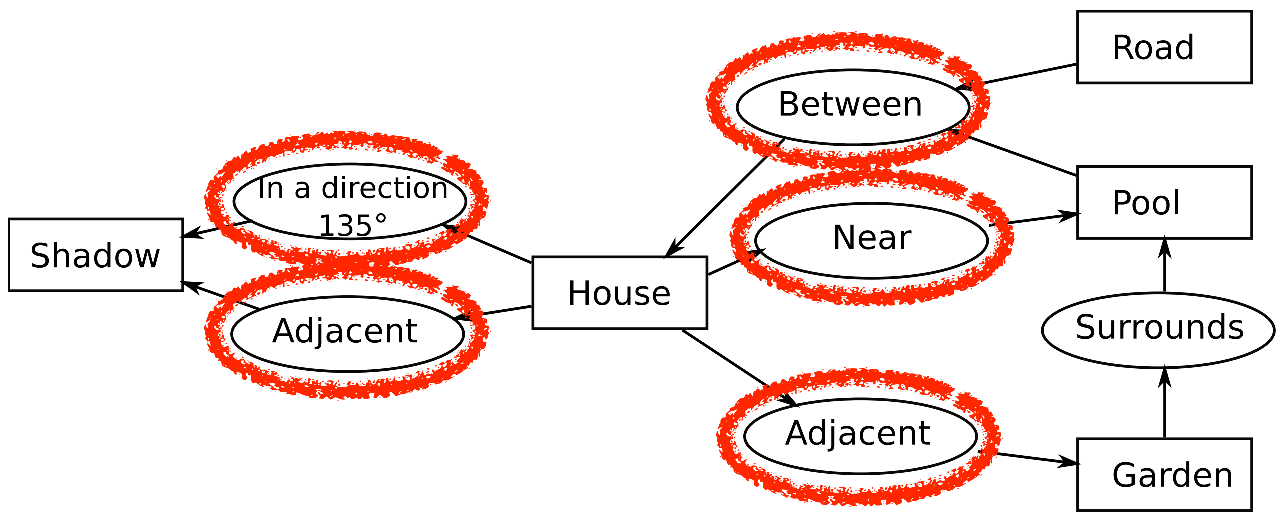
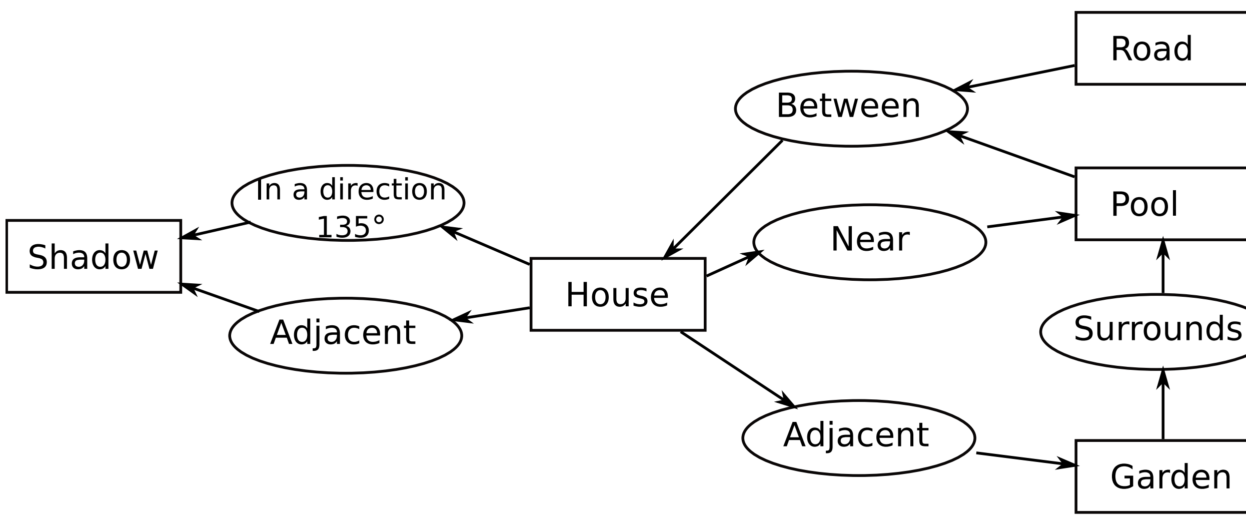


Arc-consistency

- A FCSP is arc-consistent if for every constraint involving x_i and x_j, if for every $a_i \in D_i$ we have that

$$\mu_{x_i}(a_i) \leq \sup_{(a_i, b_j) \in D_i \times D_j} \min[\mu_{R_k}(a_i, b_j), \mu_{x_j}(b_j)]$$



D_{house} D_{garden} D_{pool}

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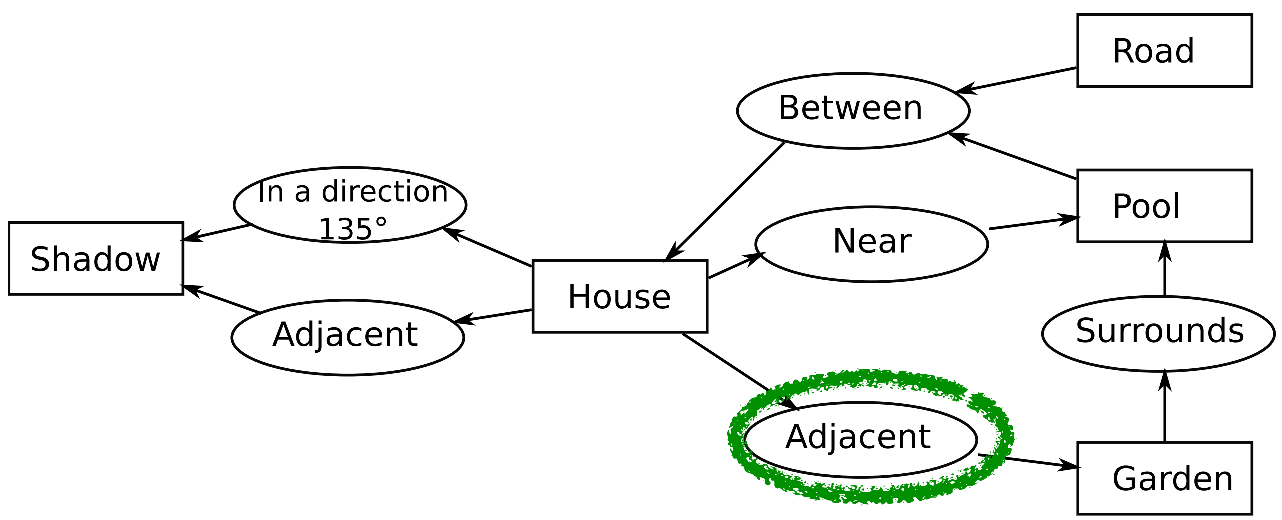

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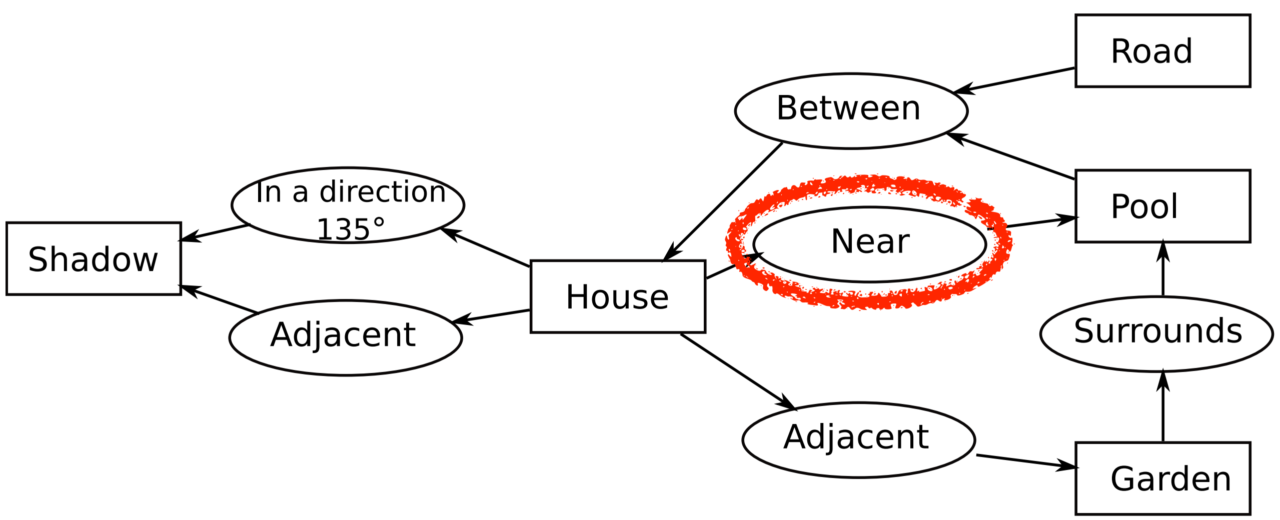

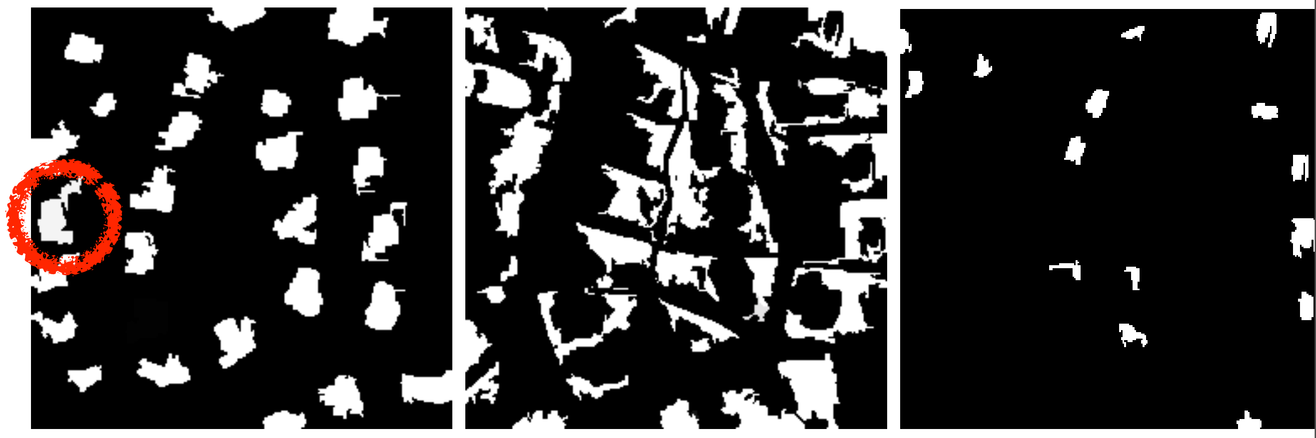

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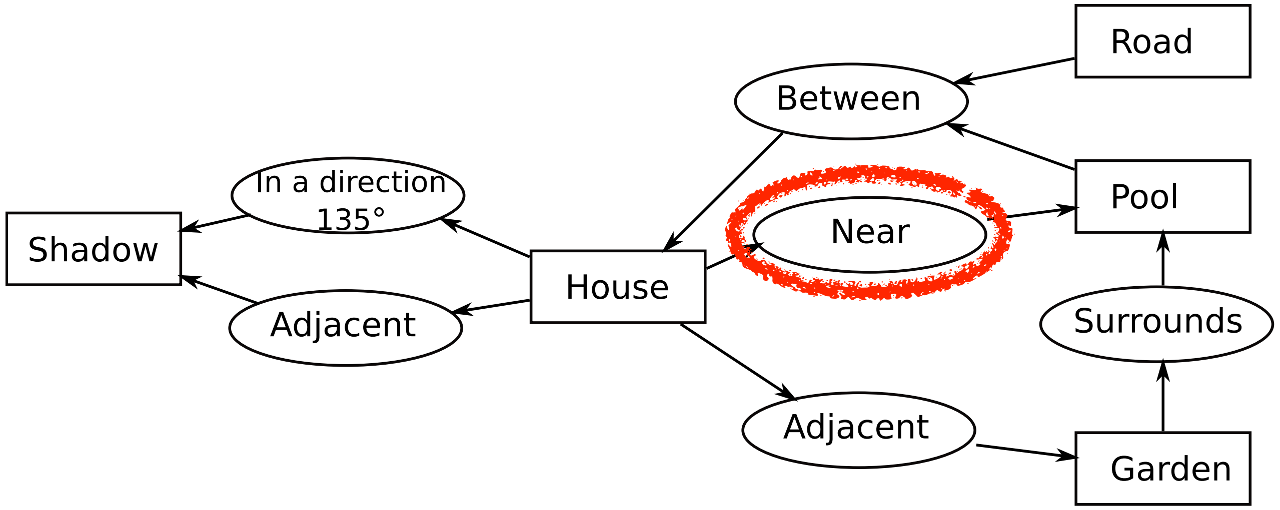


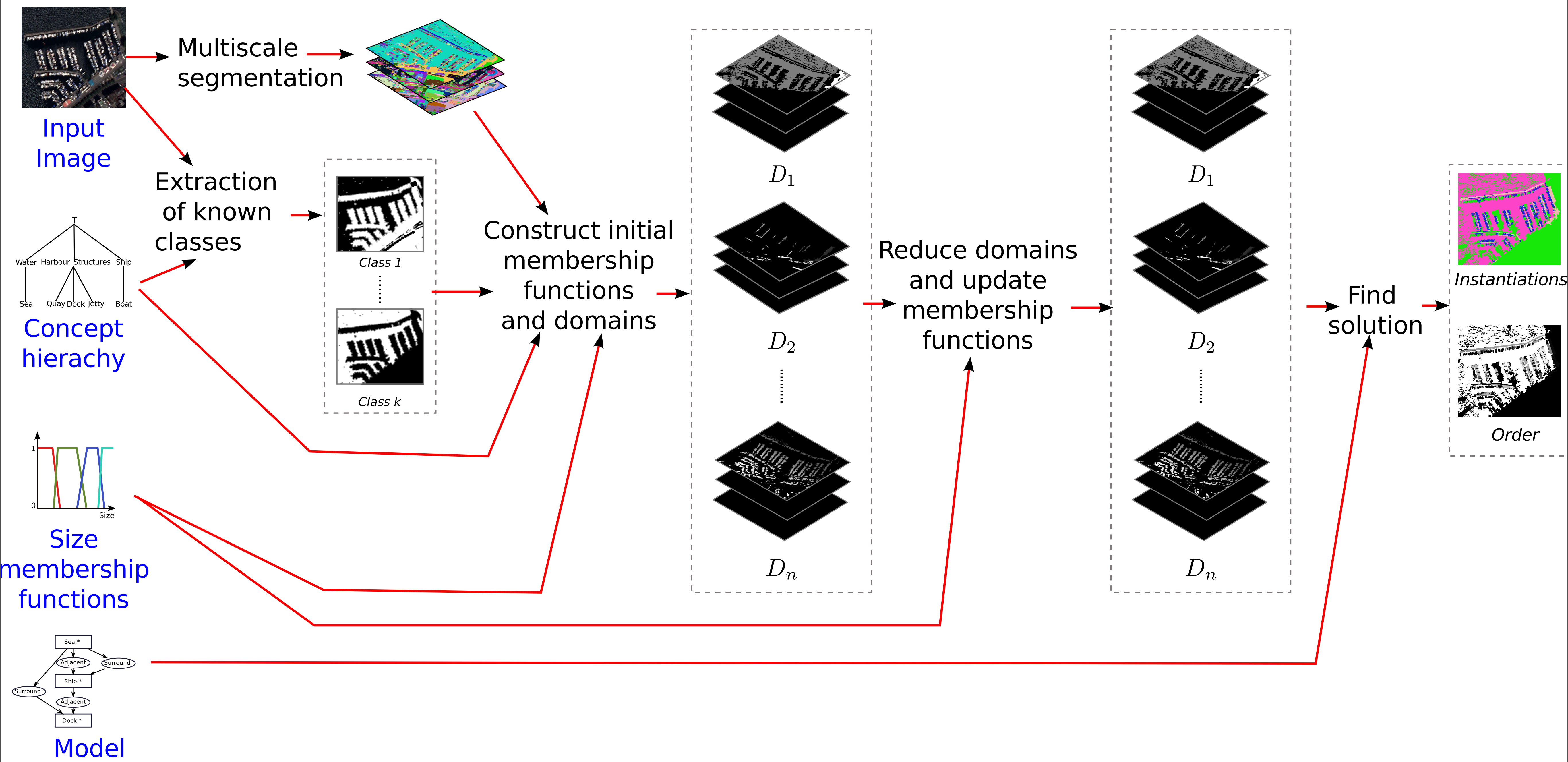
FAC-3

Recursively check each constraint and reduce the membership in order to make it arc-consistent

does not work for groups!

D_{house} D_{garden} D_{pool}

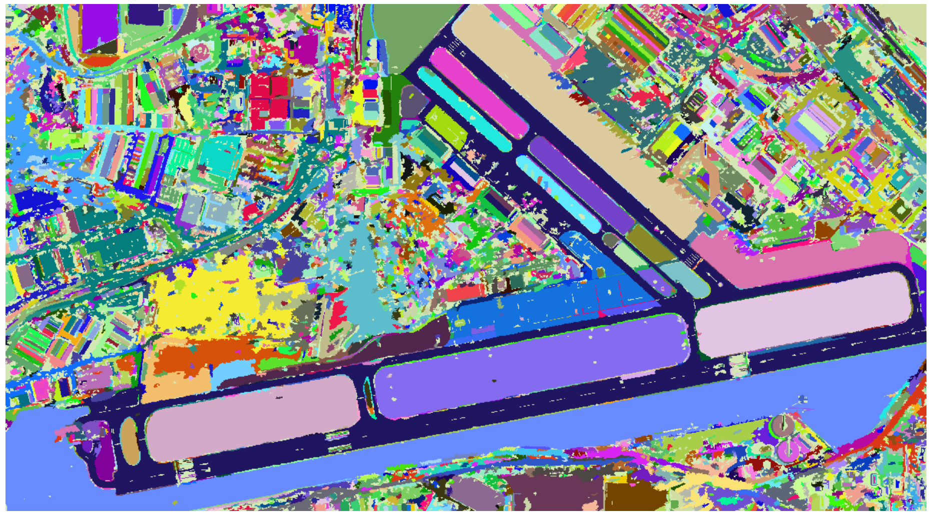
Interpretation using a model (outline)



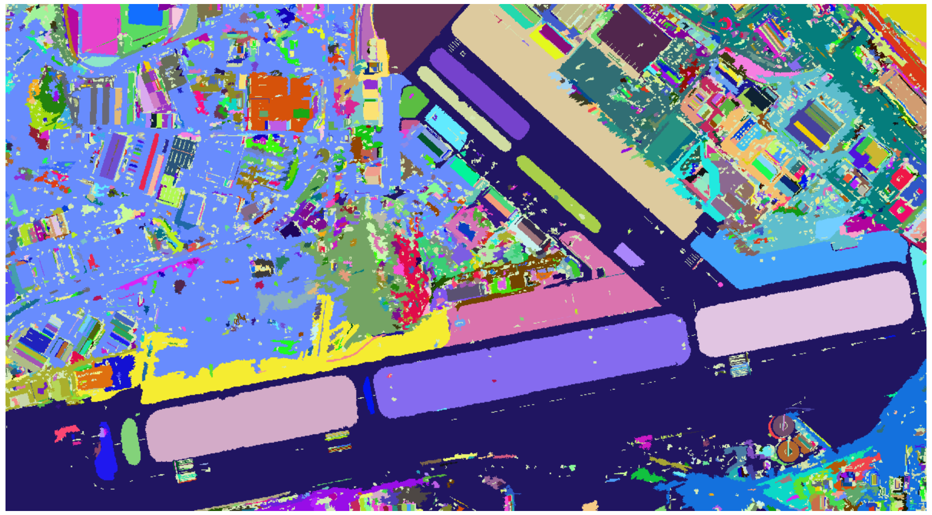
Construction of initial membership functions

Original image

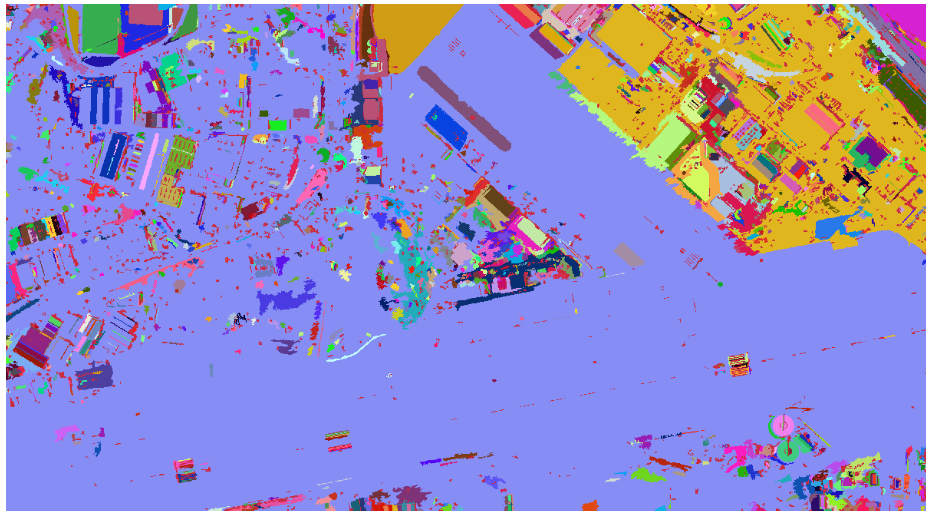
Multi-scale segmentation (hierarchical Mean Shift)



scale 0

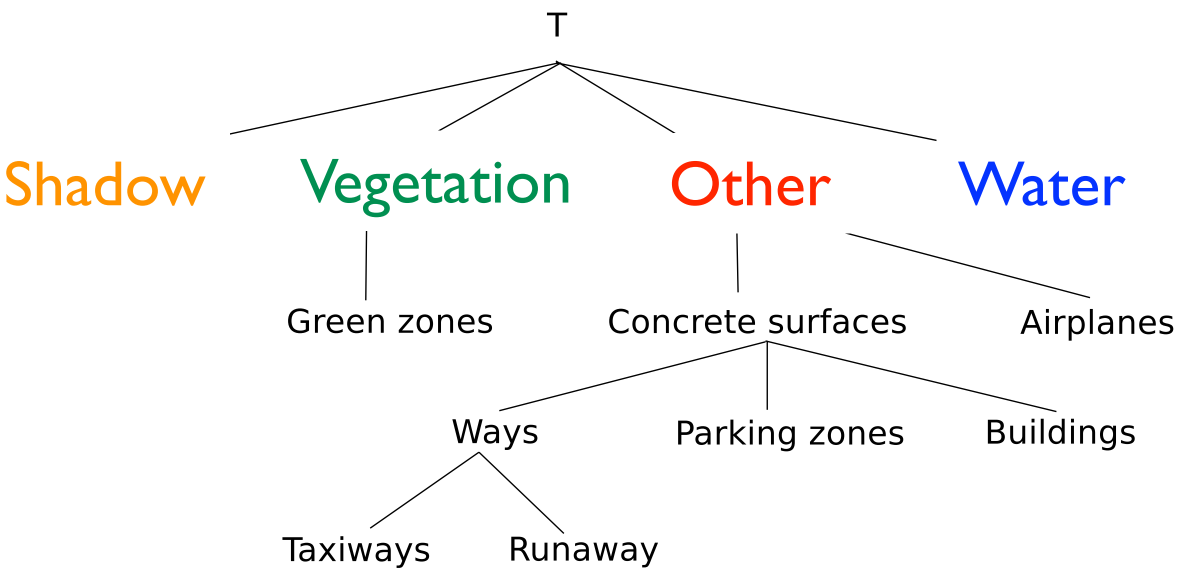


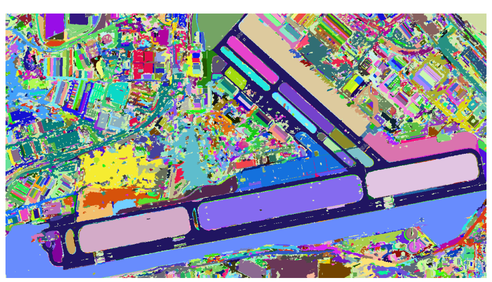
scale 1

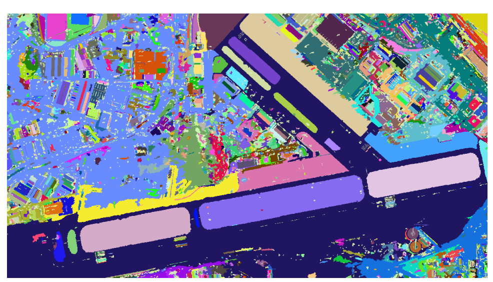


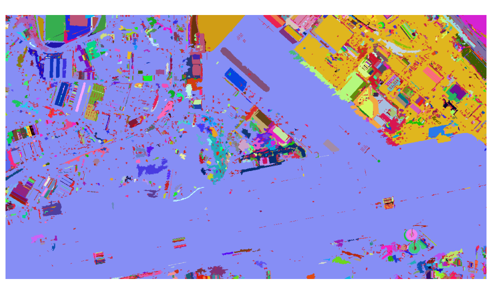
scale 2

Construction of initial membership functions

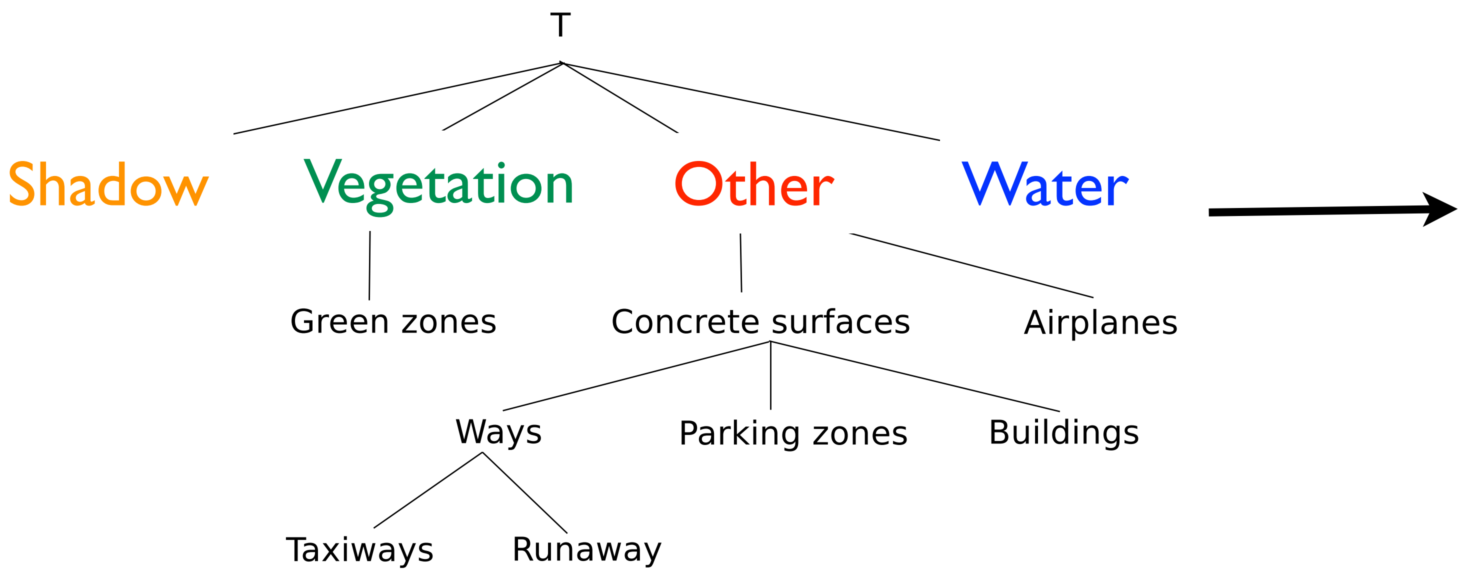


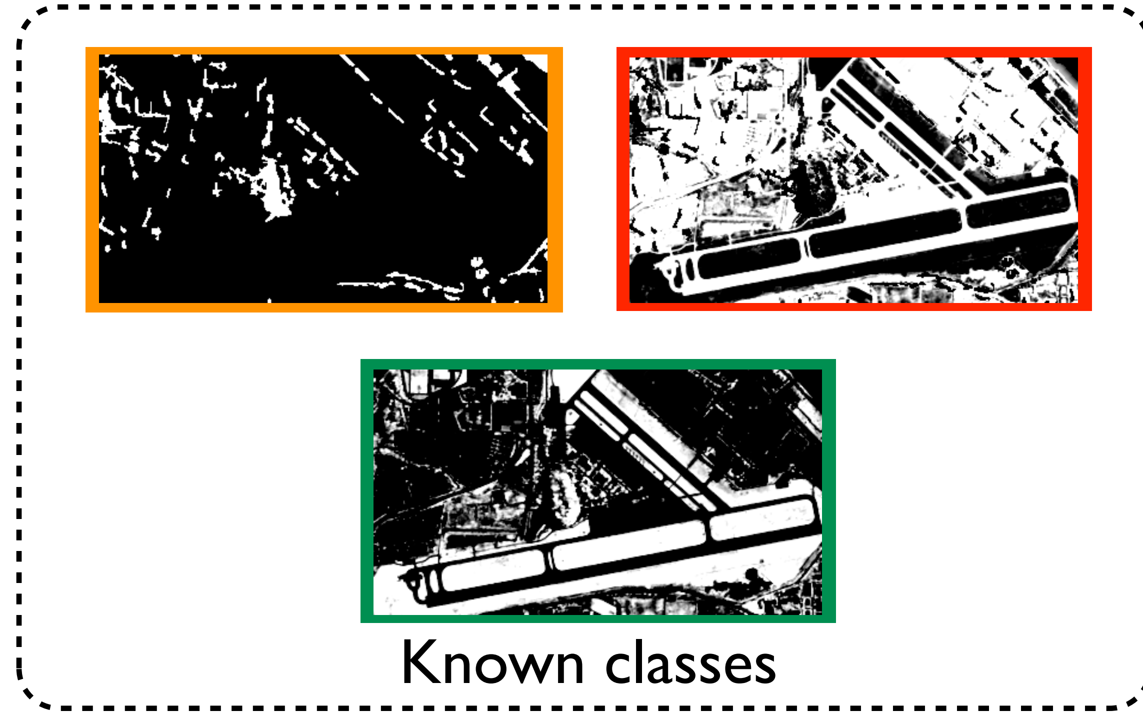


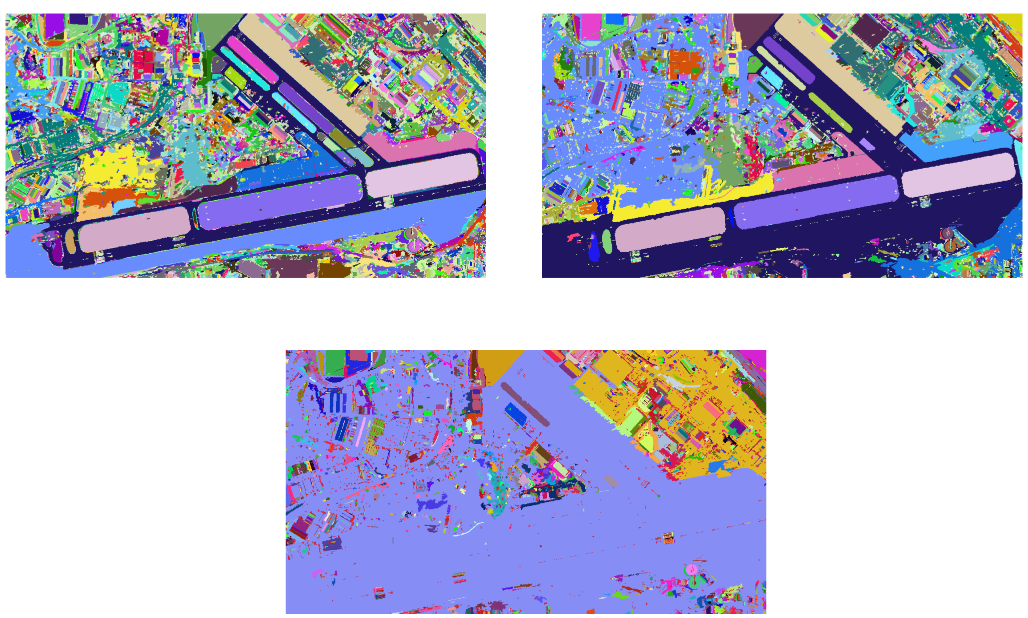




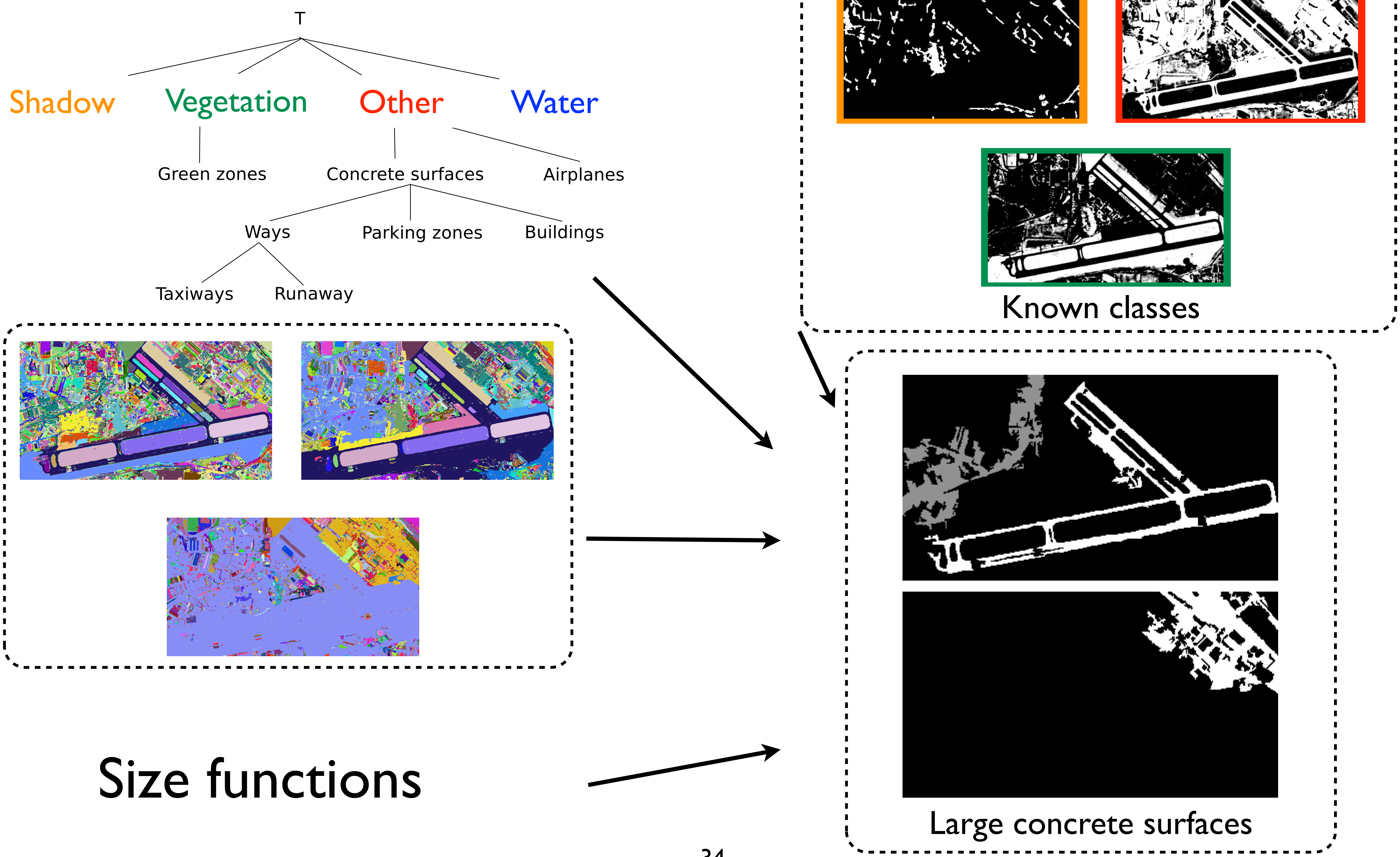
Construction of initial membership functions







Construction of initial membership functions



Reduction of domains (modified FAC-3 algorithm)

- The FAC-3 algorithm is not adapted to deal with groups of objects

Reduction of domains (modified FAC-3 algorithm)

- The FAC-3 algorithm is not adapted to deal with groups of objects

groups of objects

- constraint
  - relations inside
  - alignment
- variable
  - group seen as an object

Reduction of domains (modified FAC-3 algorithm)

- The FAC-3 algorithm is not adapted to deal with groups of objects

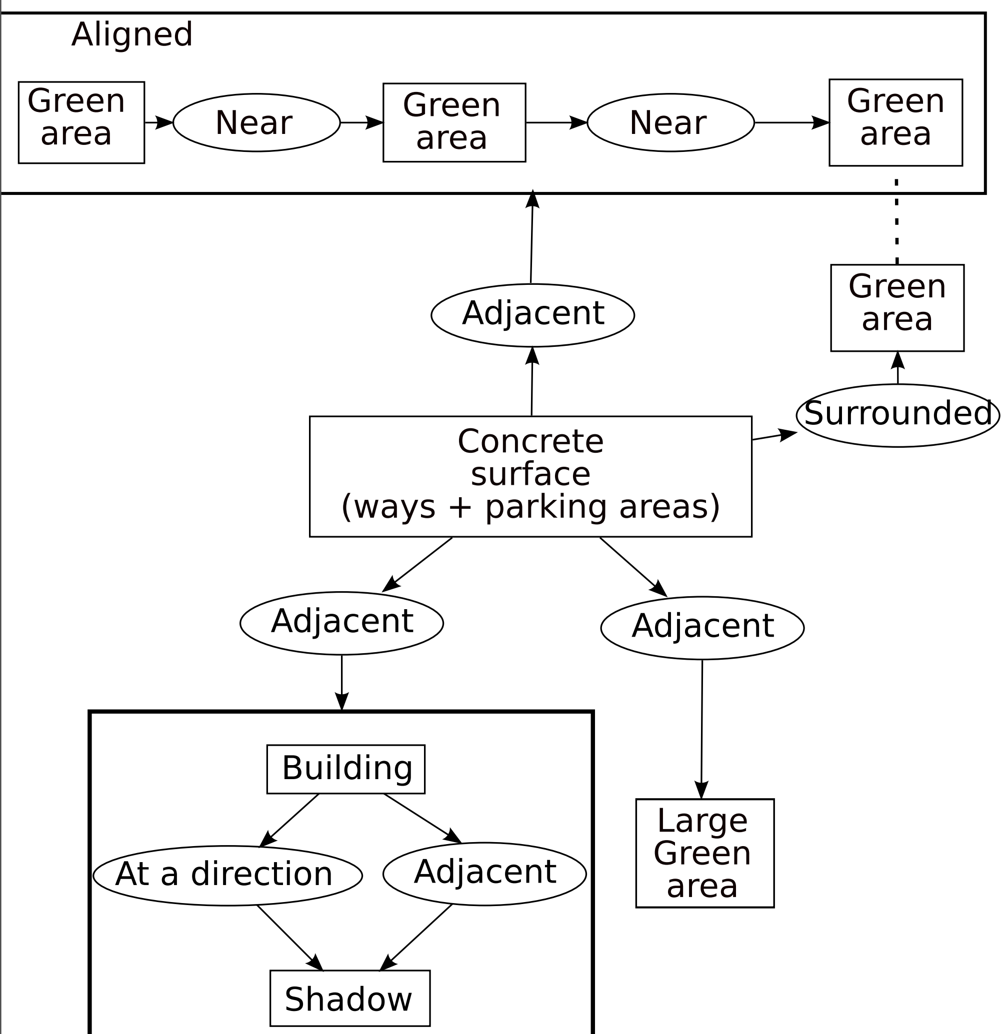
groups of objects

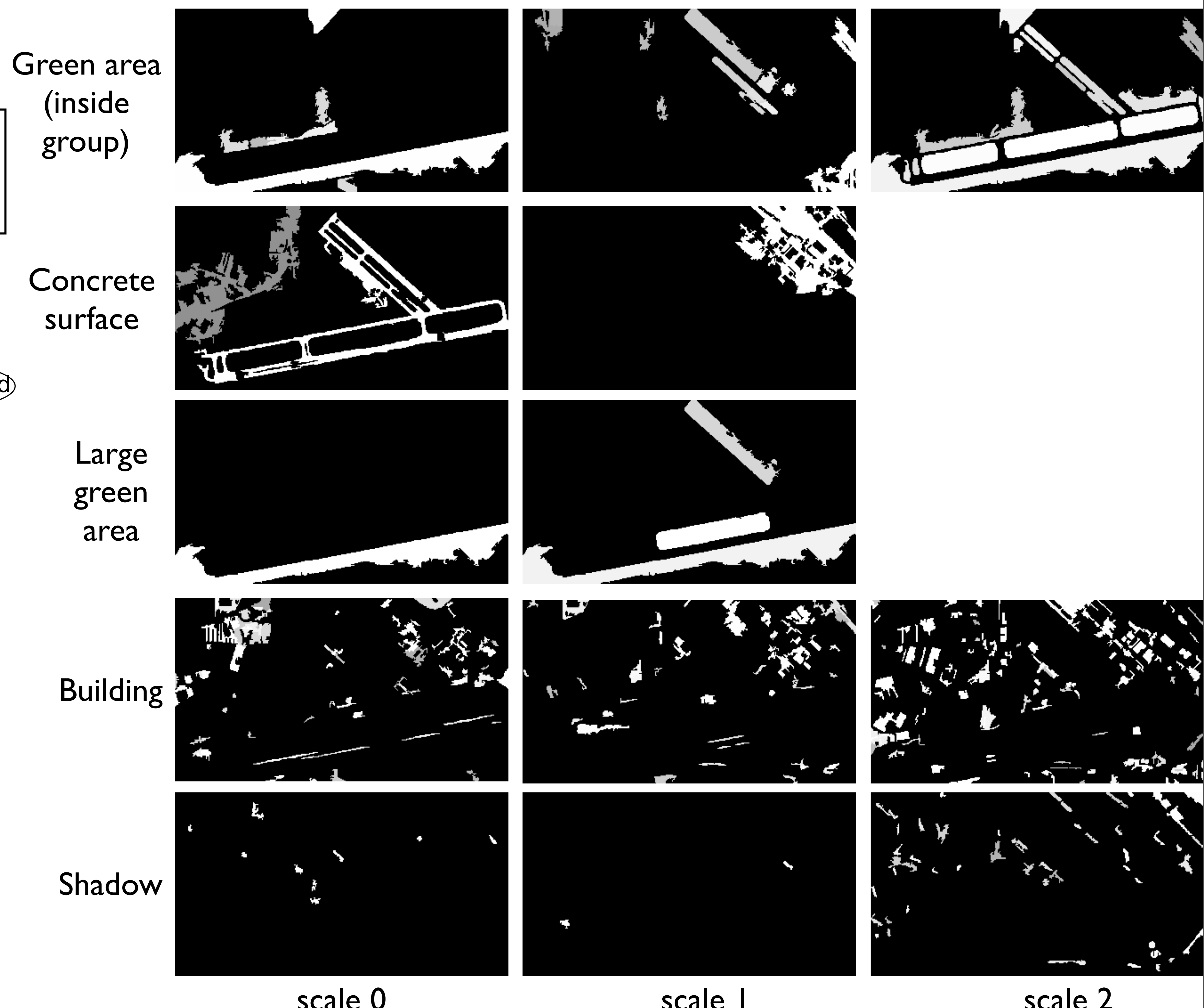
constraint
– relations inside
– alignment

variable
– group seen as an object

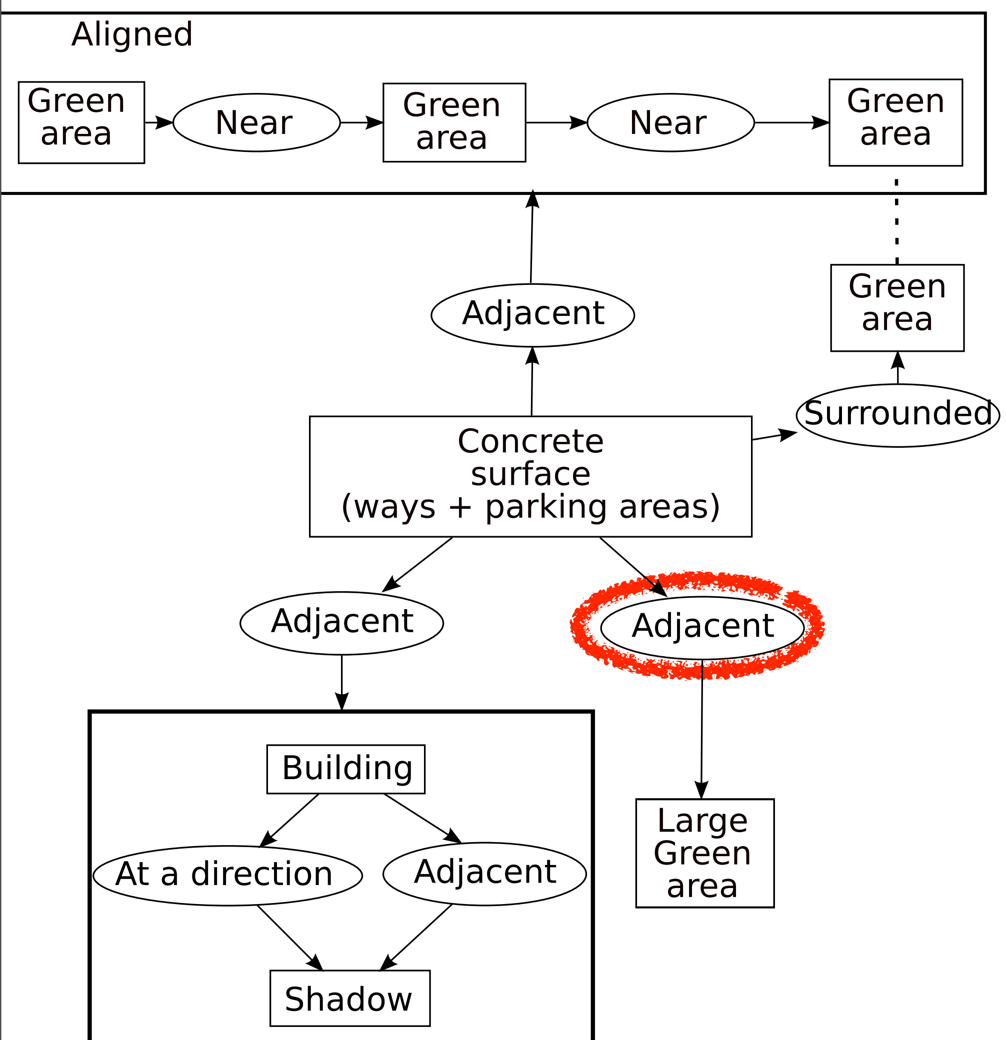
- When evaluating the arc-consistency condition in a group the domains of the group and the objects inside the group can be modified.

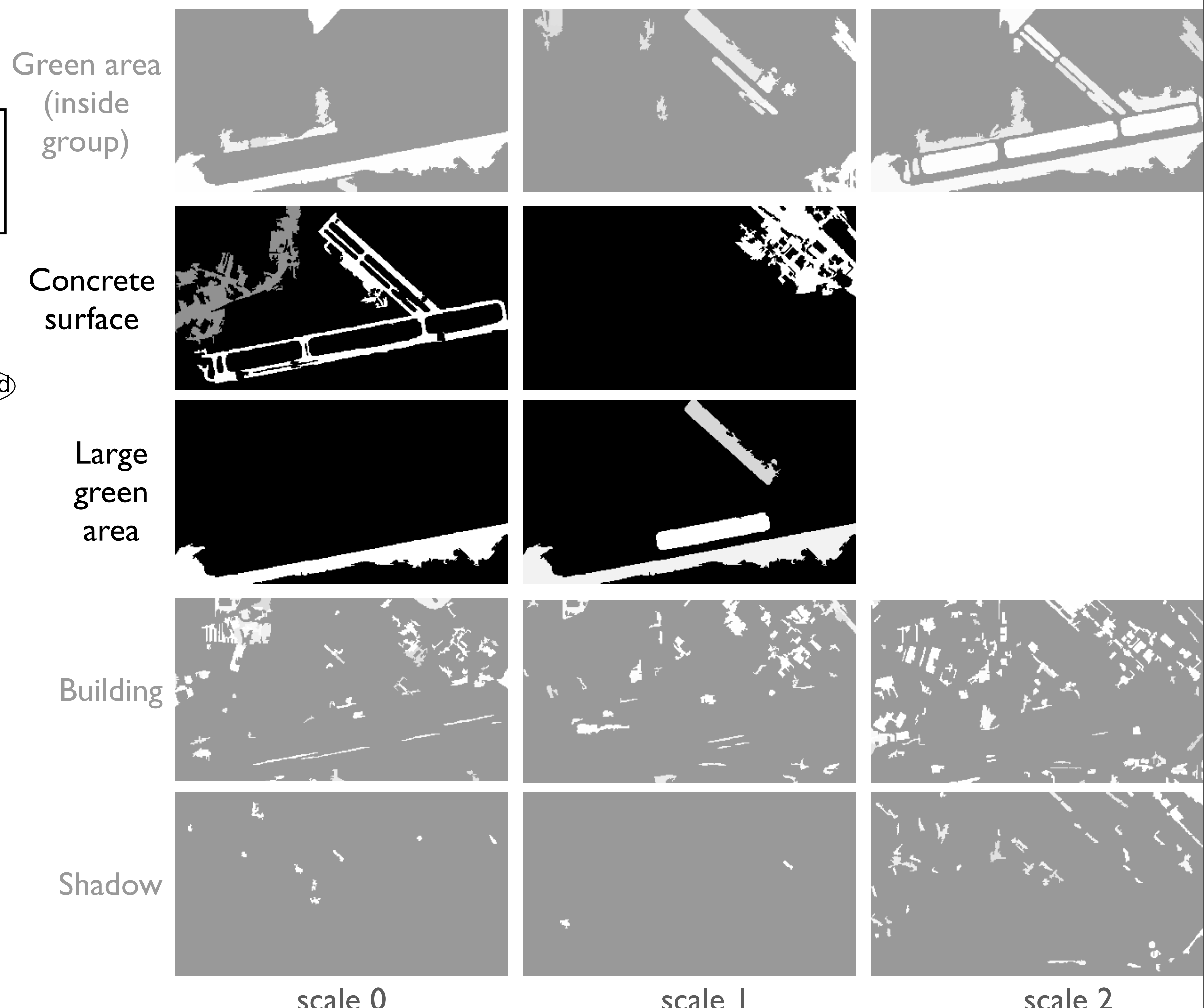
Reduction of domains





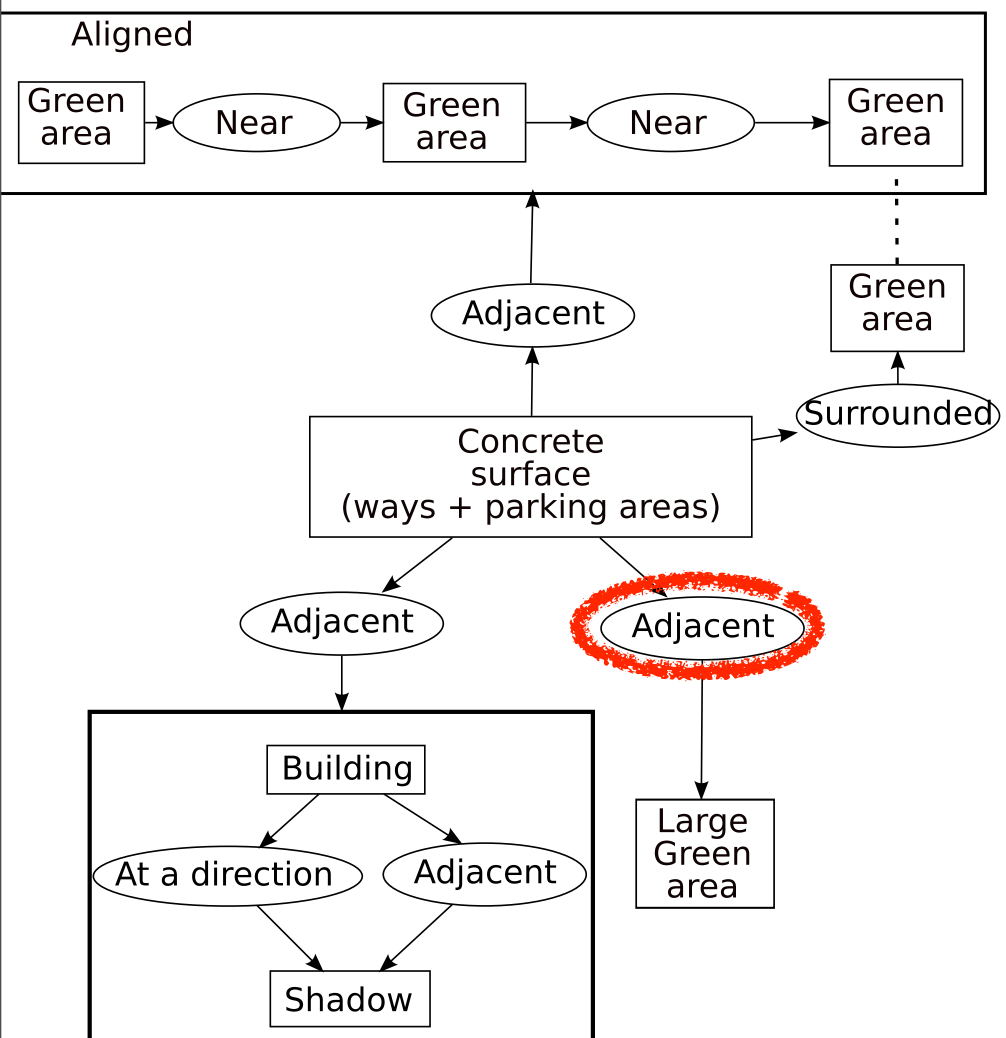
Reduction of domains

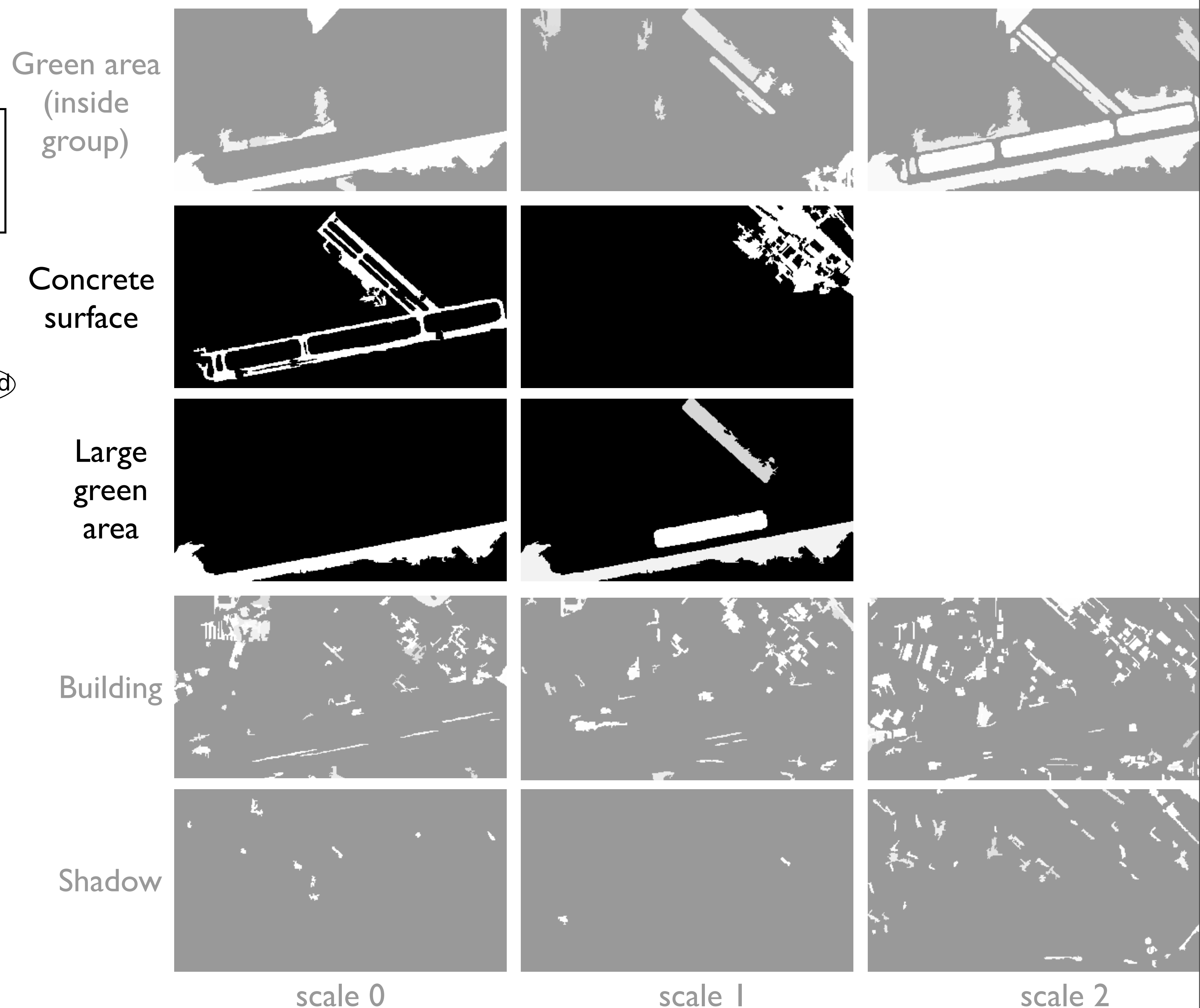




Before evaluating arc-consistency

Reduction of domains





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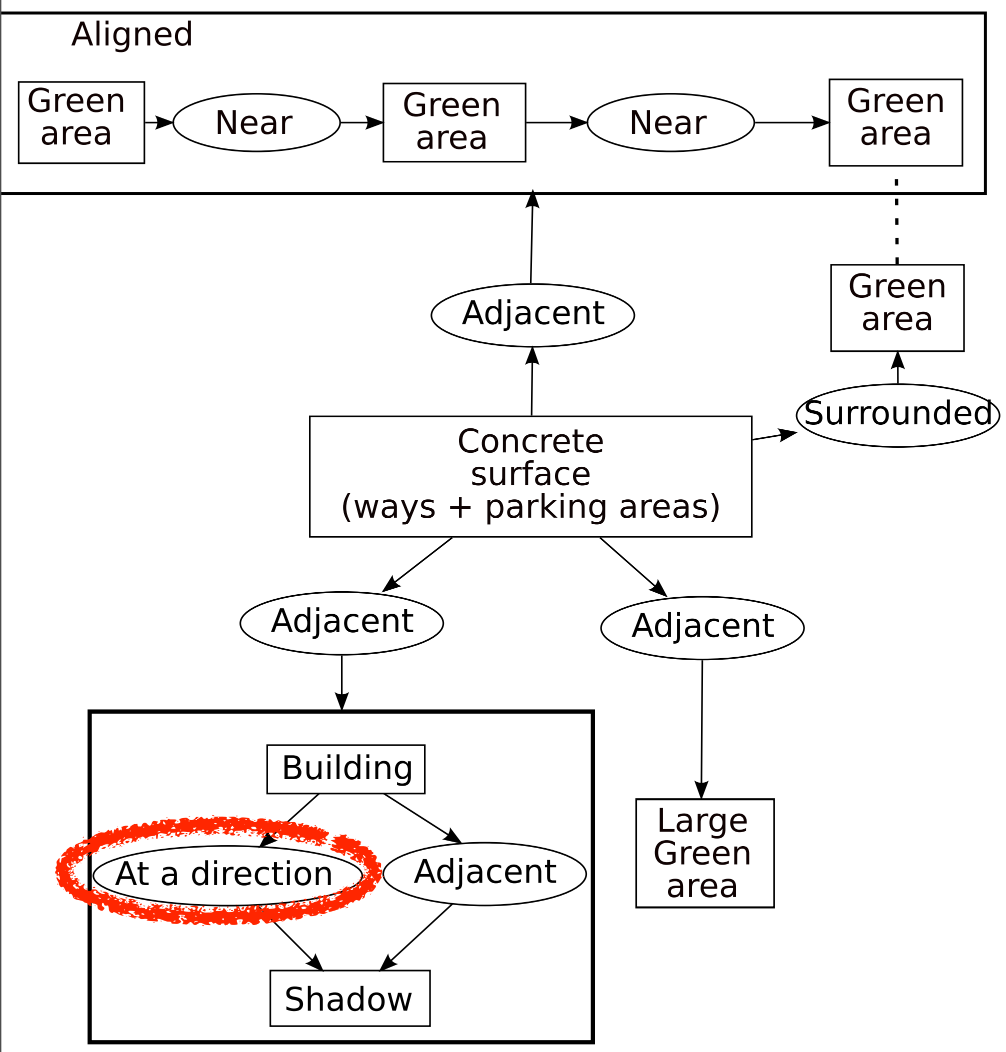

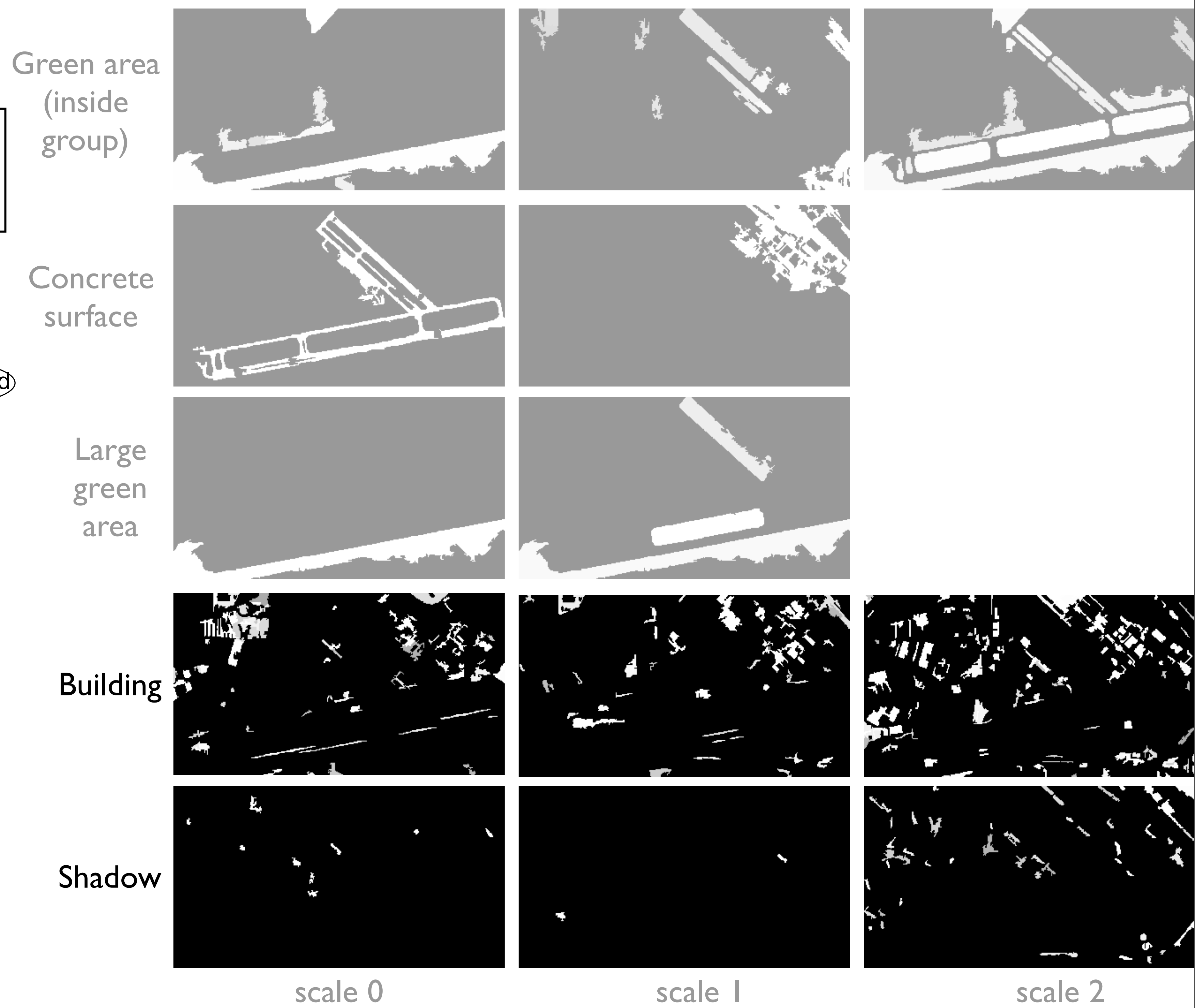

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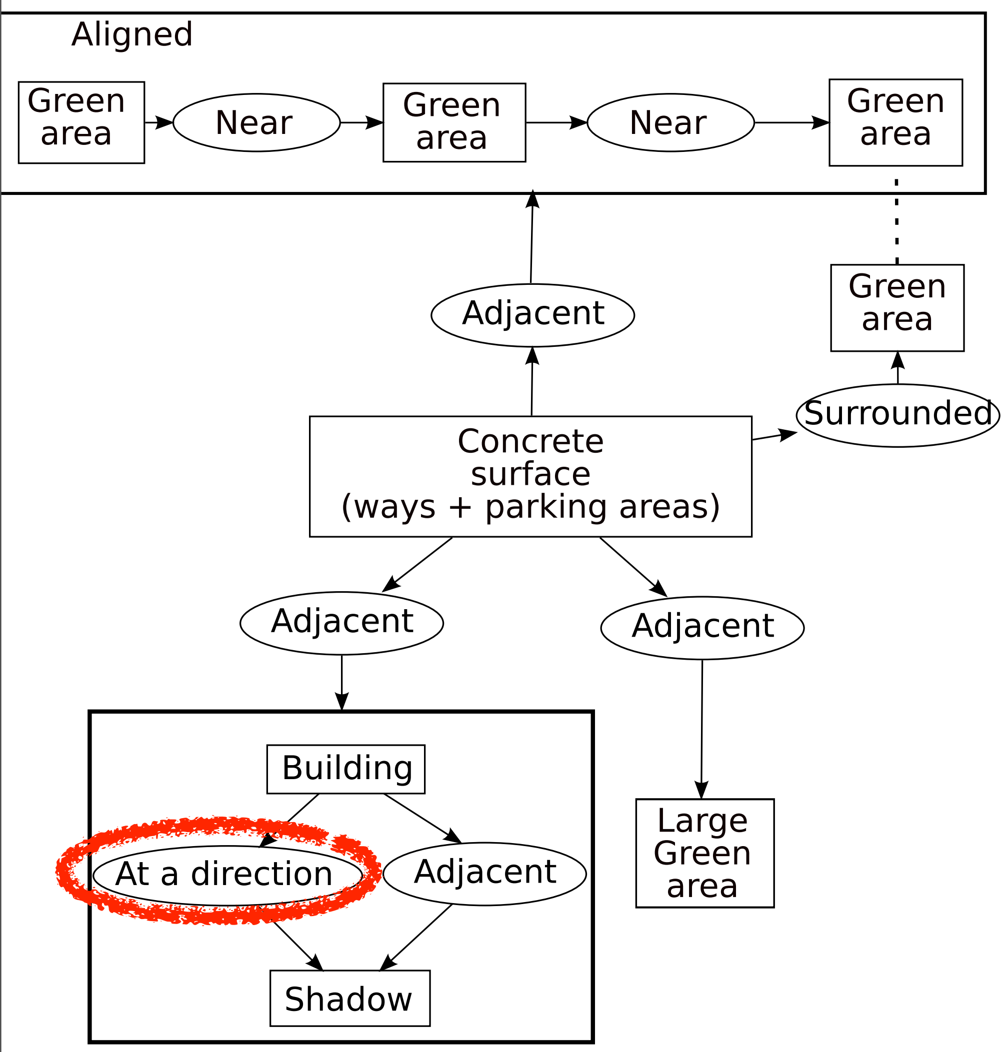

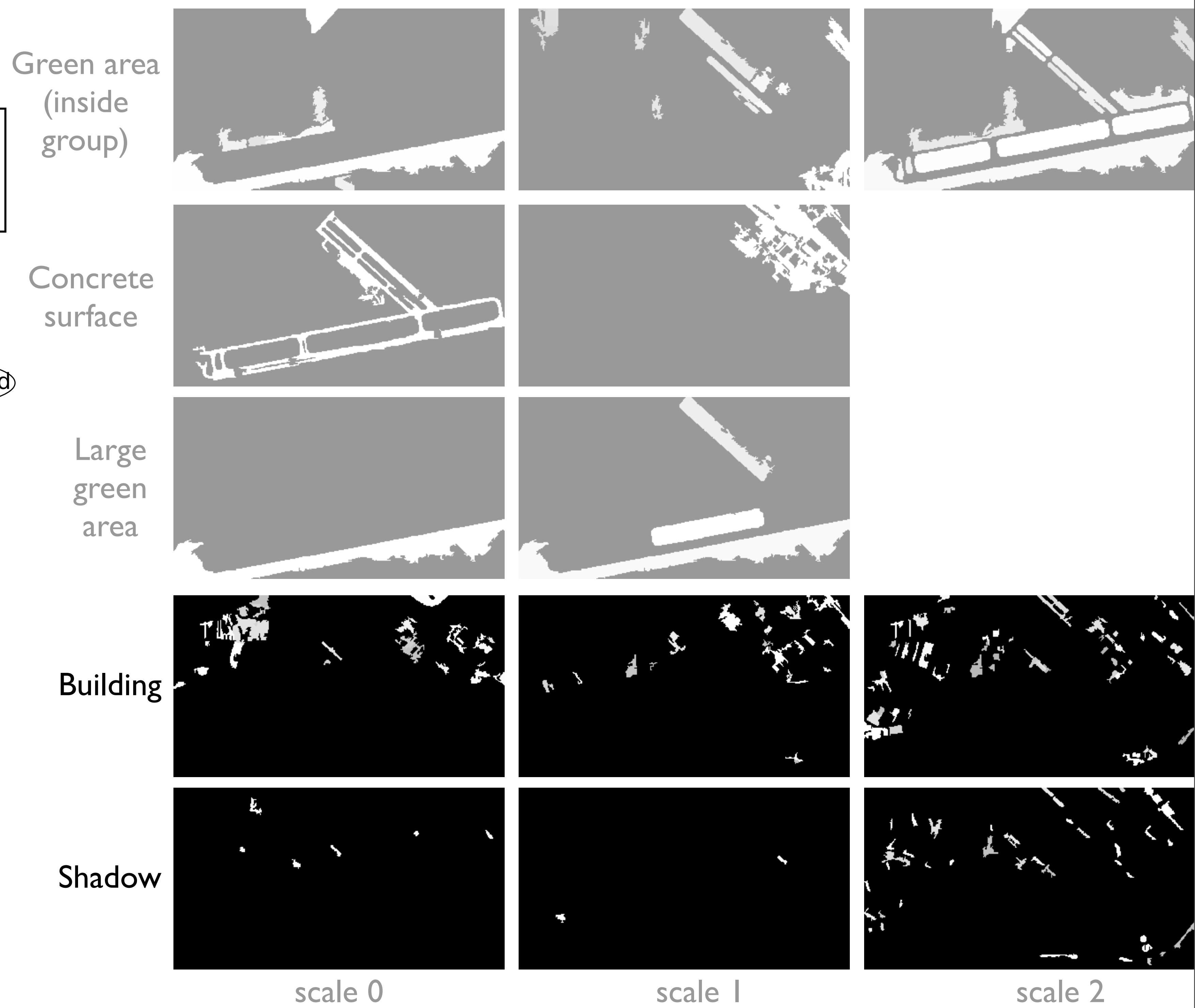

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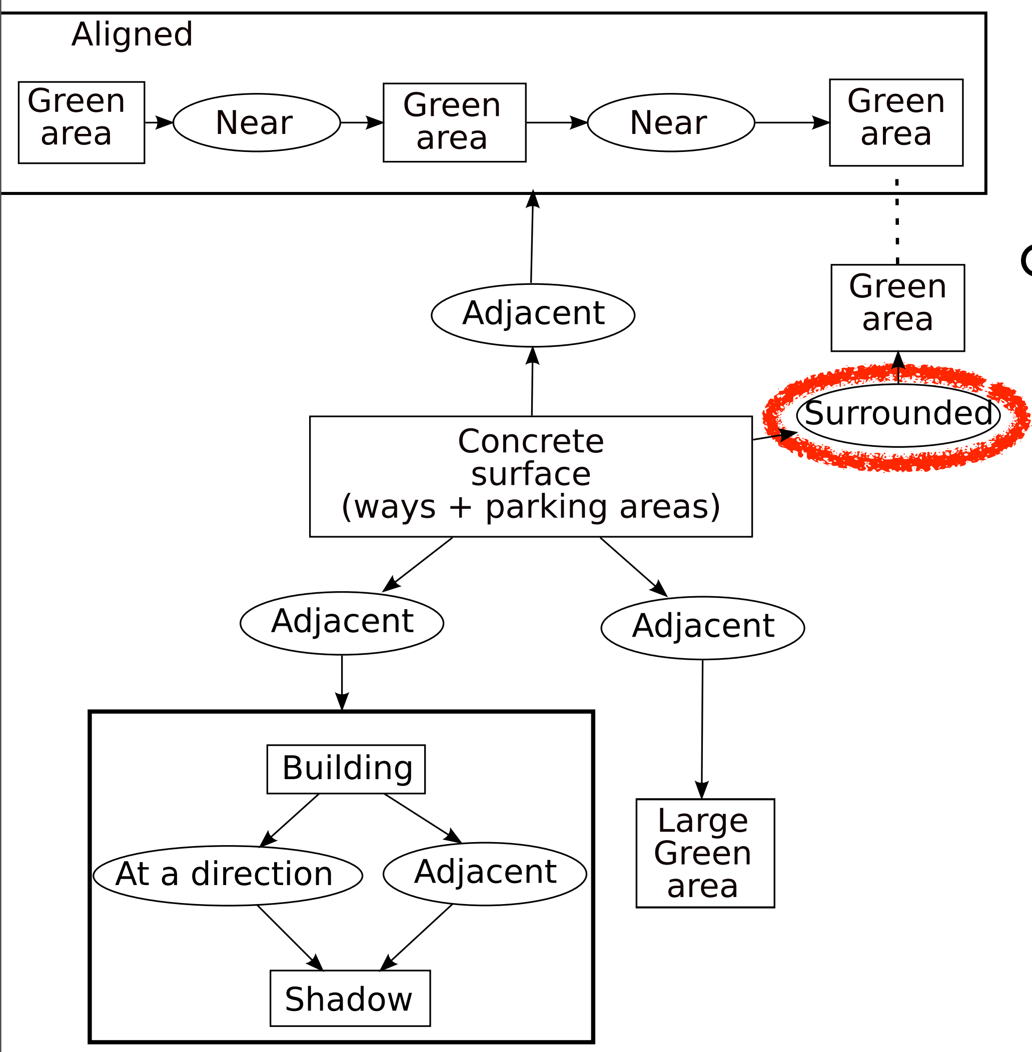

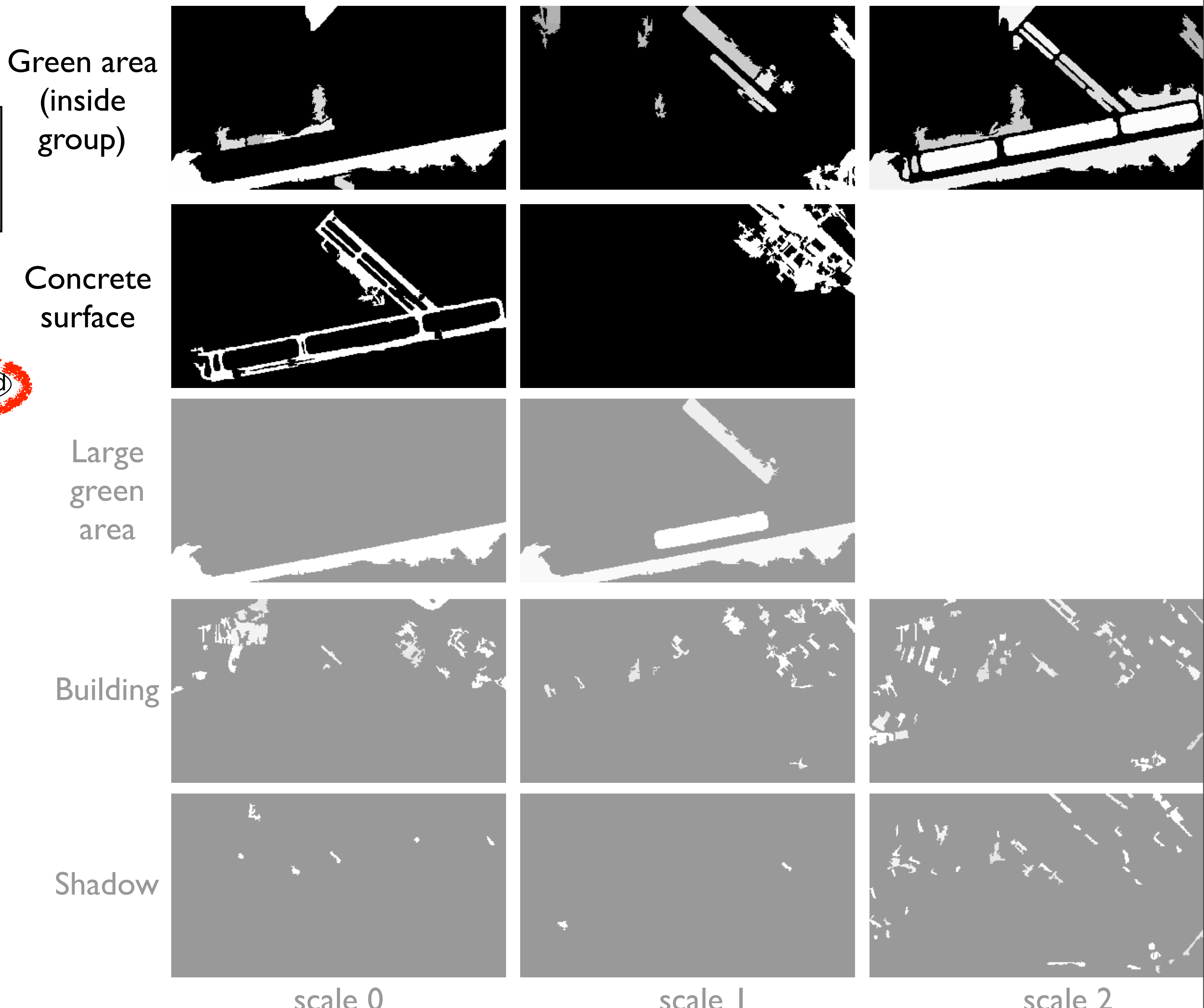

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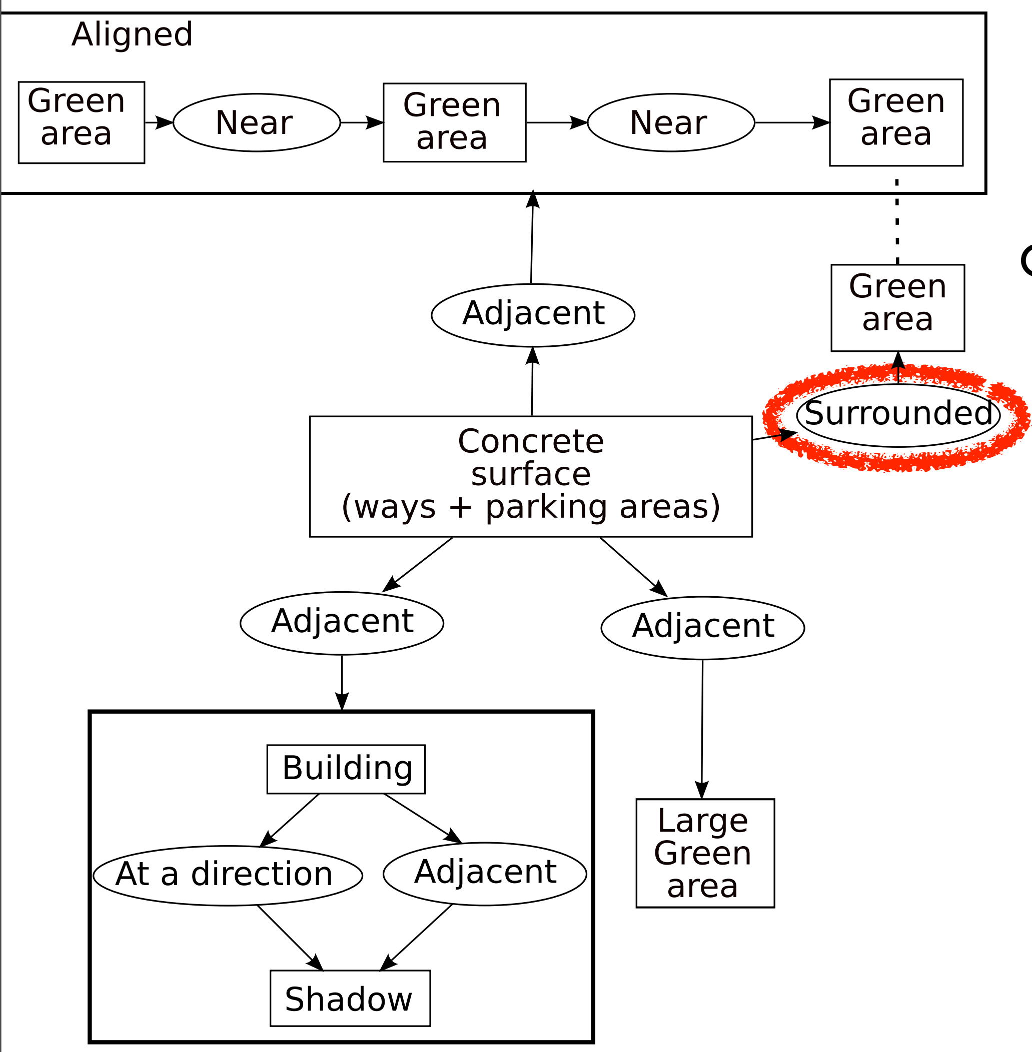

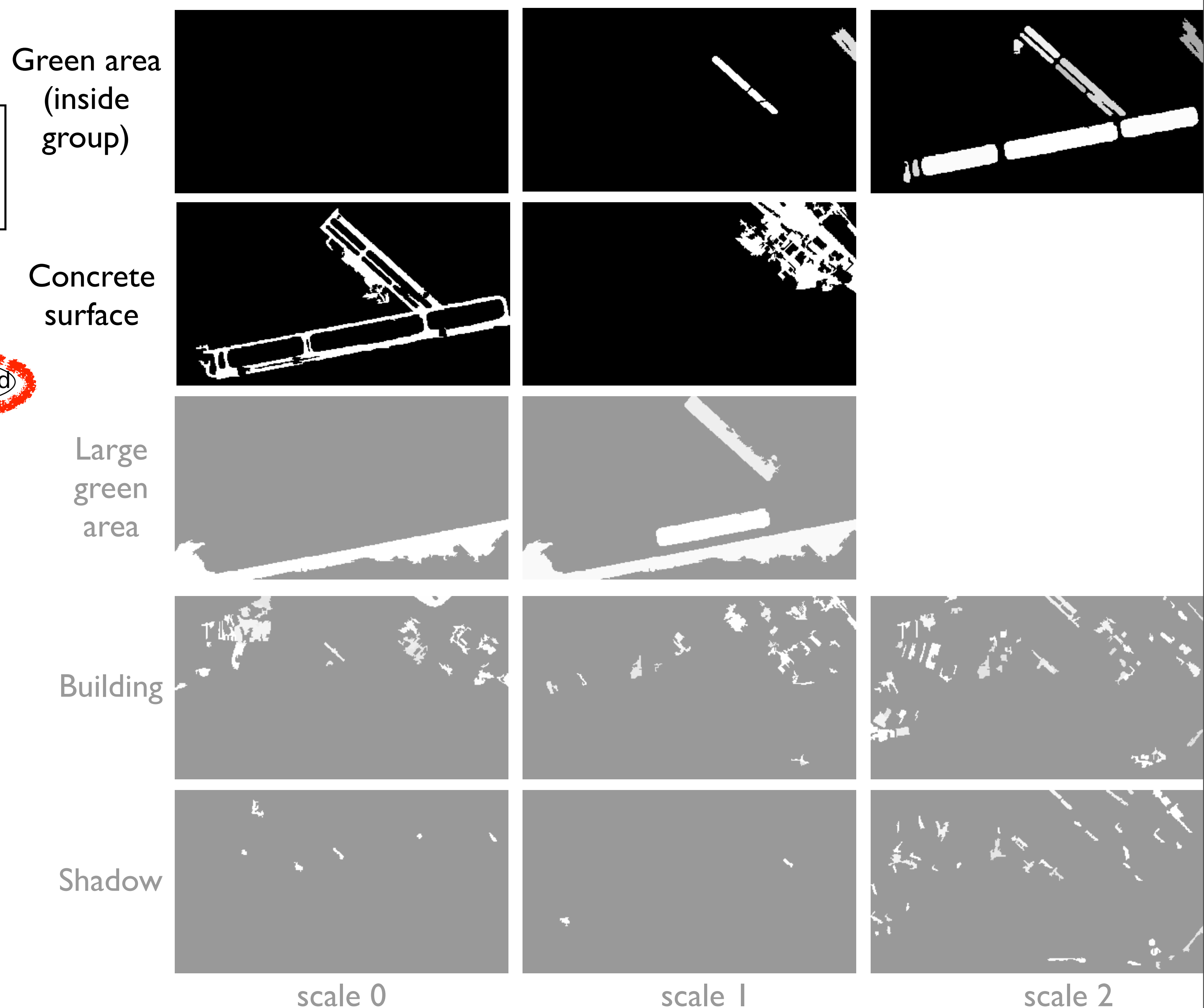

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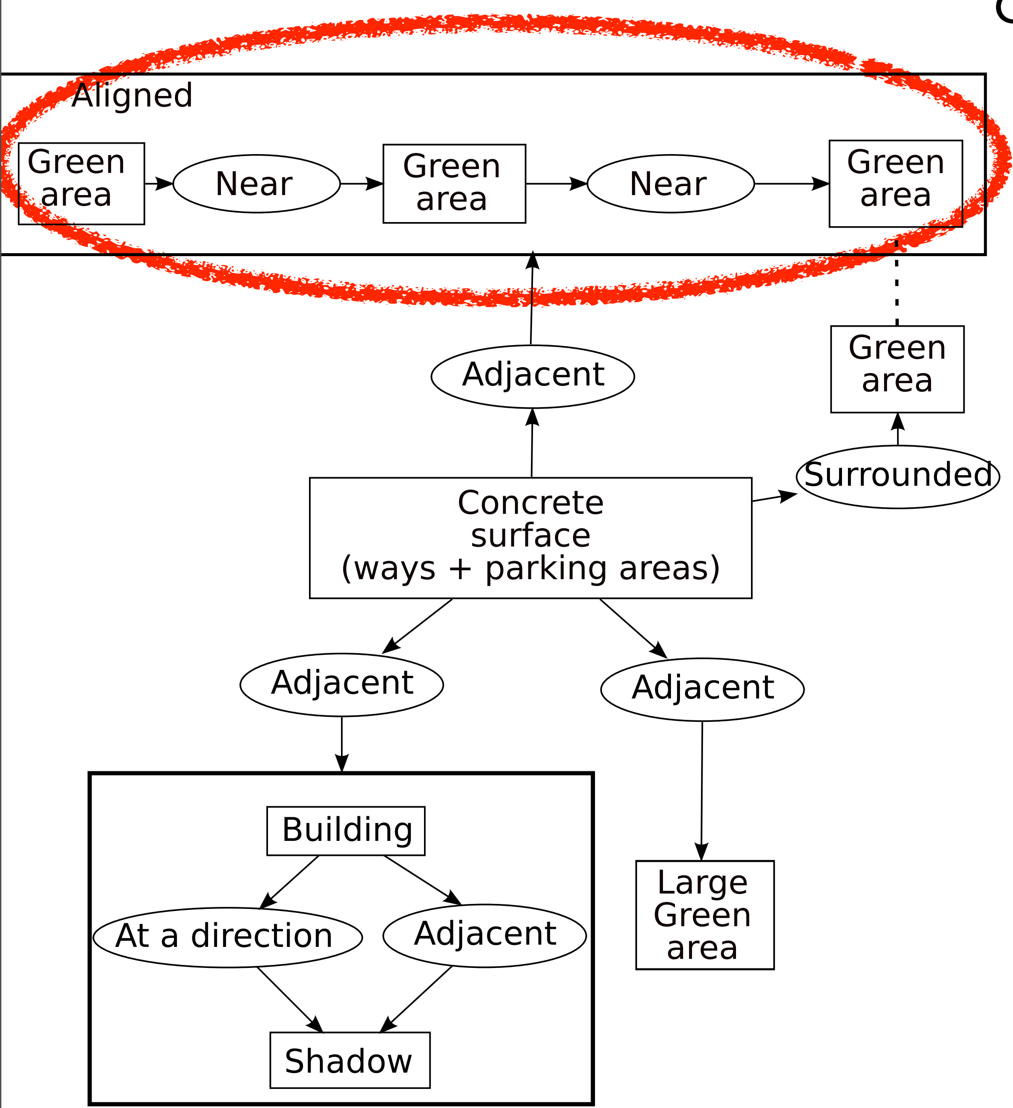

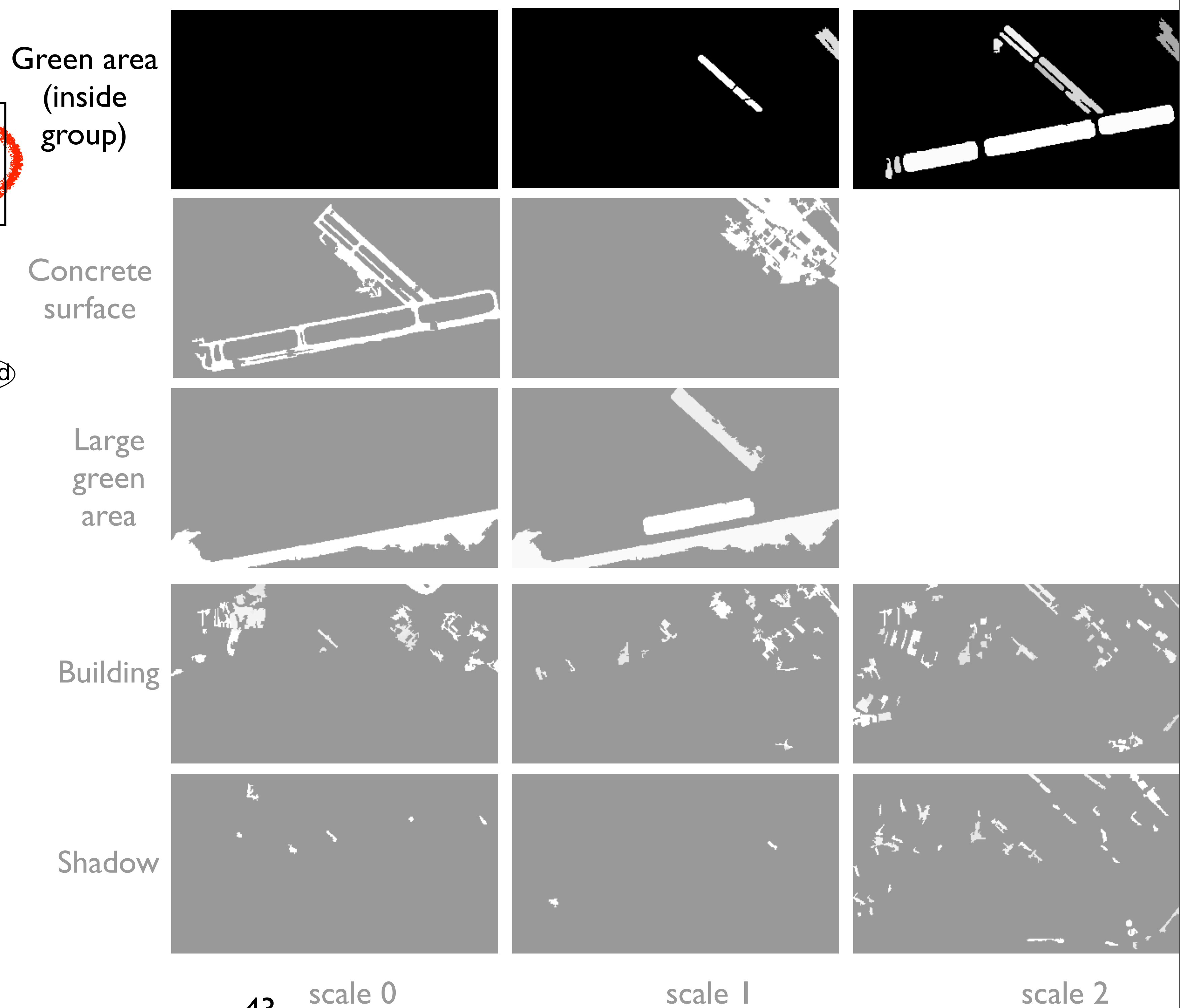

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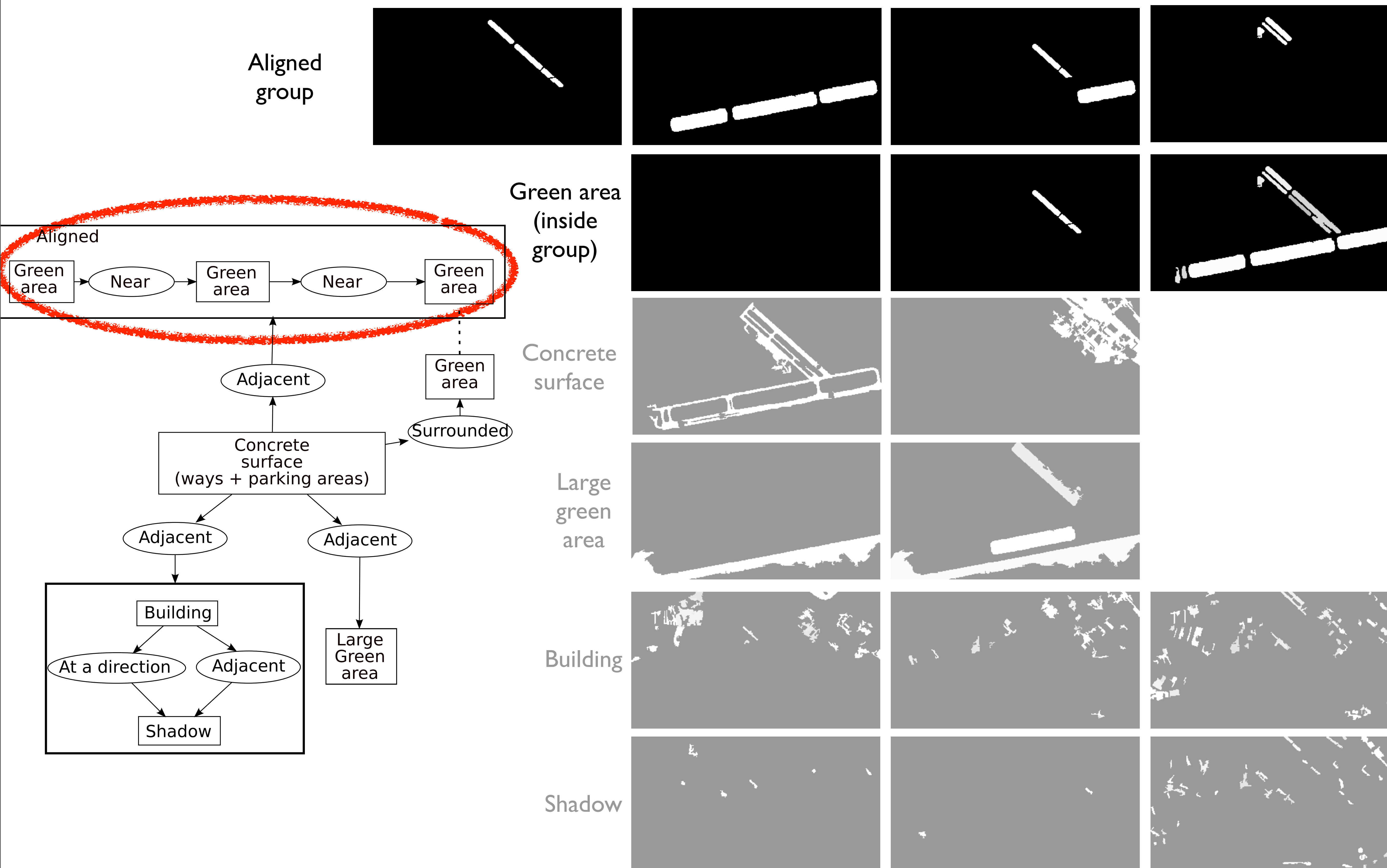

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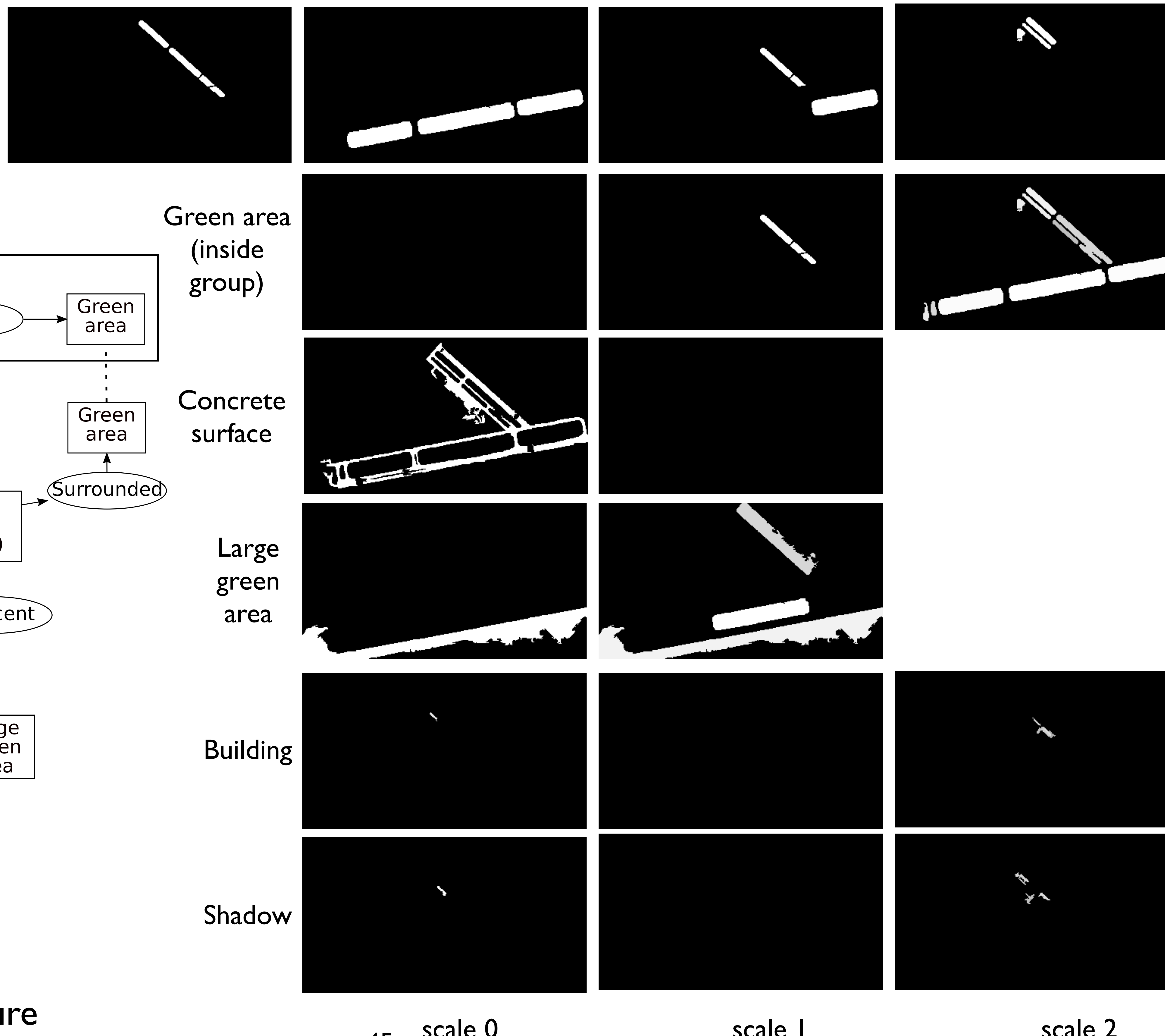

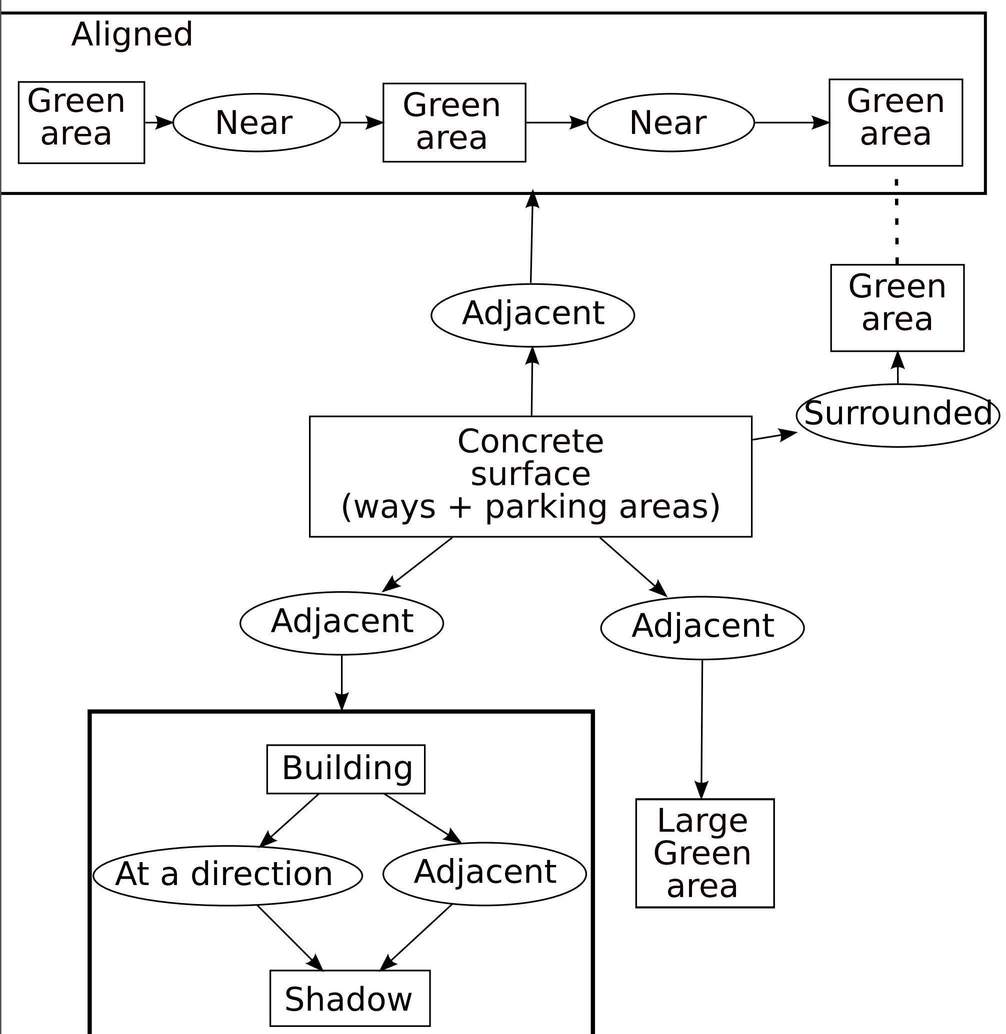

Arc-consistency closure

Finding a solution

- Which is (are) the best instantiation(s) ?
- Use the consistency value of each instantiation (all relations are satisfied)

$$Cons(V) = \min_{\tilde{C}_k \in \mathcal{C}} \mu_{R_k}(V \downarrow_{S_k})$$

  - Very strict:

Sol 1	0.40	0.55	0.42	0.62
Sol 2	0.40	0.89	0.92	0.87
	μ_{R_1}	μ_{R_2}	...	

Finding a solution

- Organize according to leximin order:

Sol 1	0.40	0.55	0.42	0.62
Sol 2	0.40	0.89	0.92	0.87

Finding a solution

- Organize according to leximin order:

Sol 1	0.40	0.42	0.52	0.62
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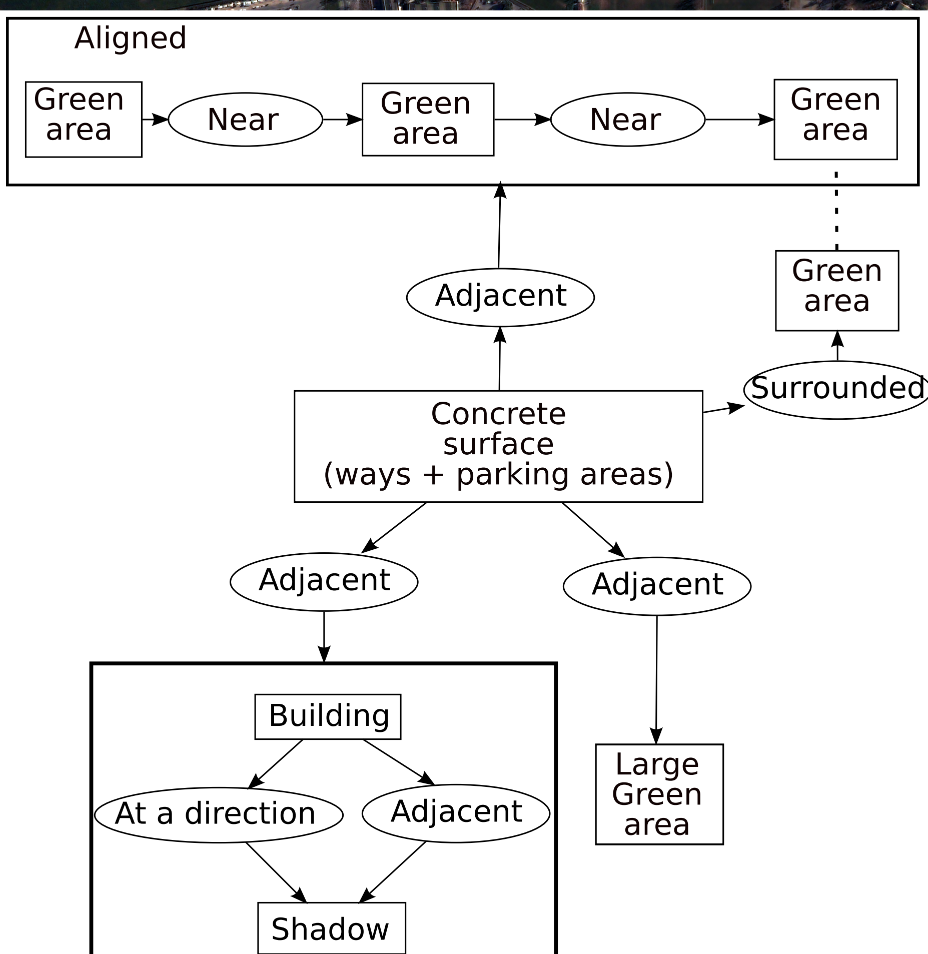
Finding a solution

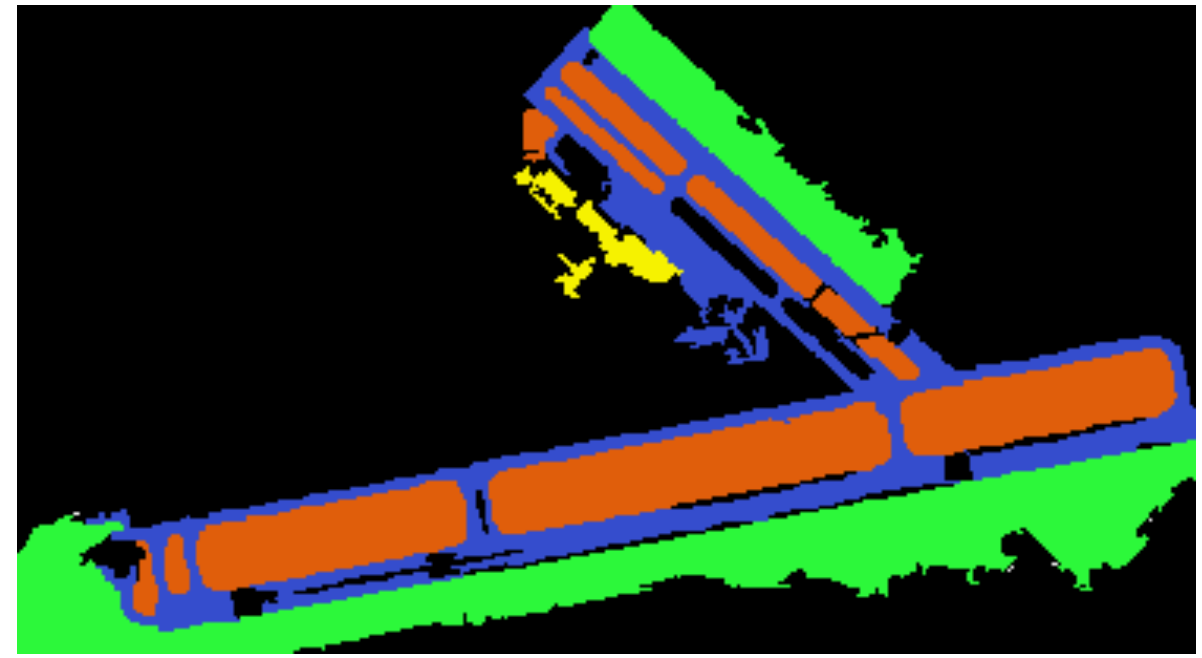
- Organize according to leximin order:

Sol 2	0.40	0.87	0.89	0.92
Sol 1	0.40	0.42	0.52	0.62

order
lexicographic

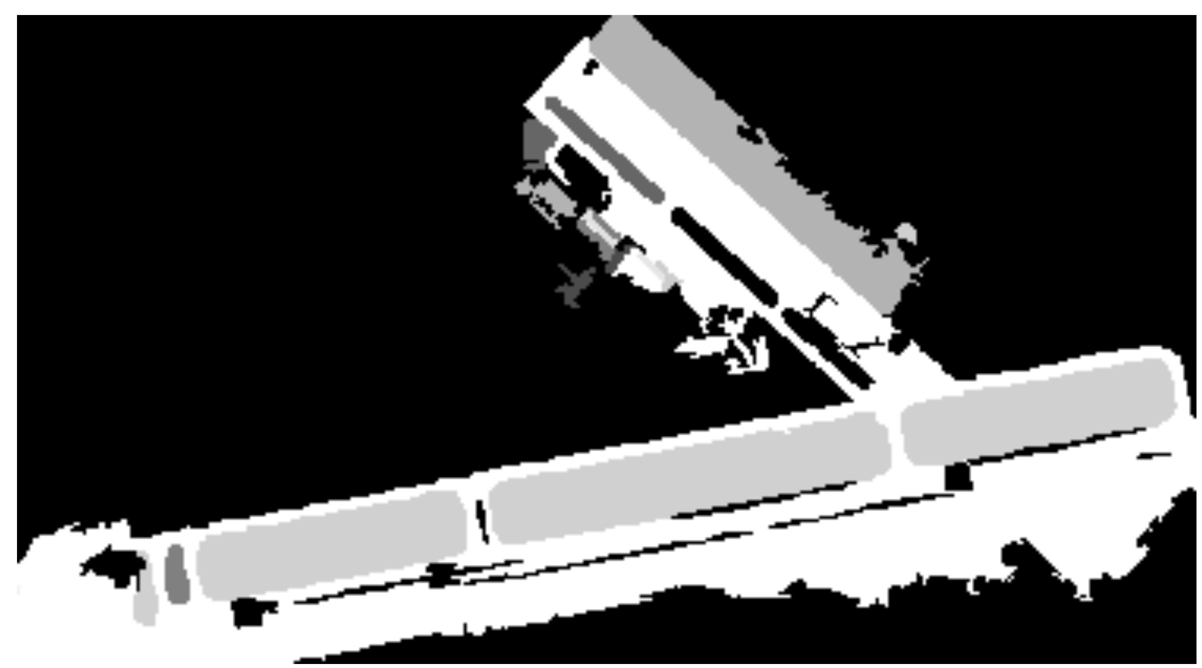
Finding a solution





Instantiations

- Concrete surface
- Aligned green areas
- Large green area
- Building + shadow
- Other

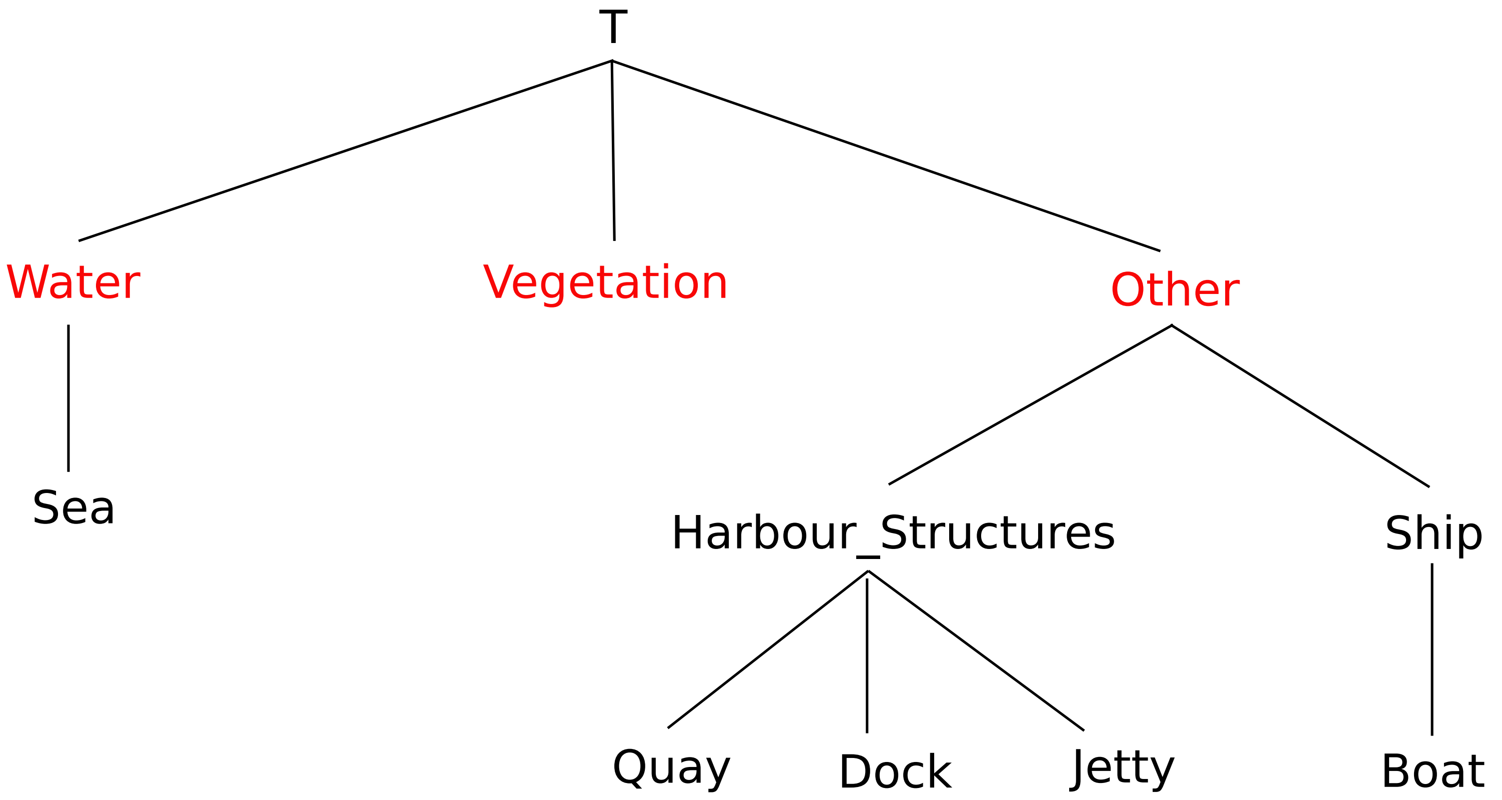


Order

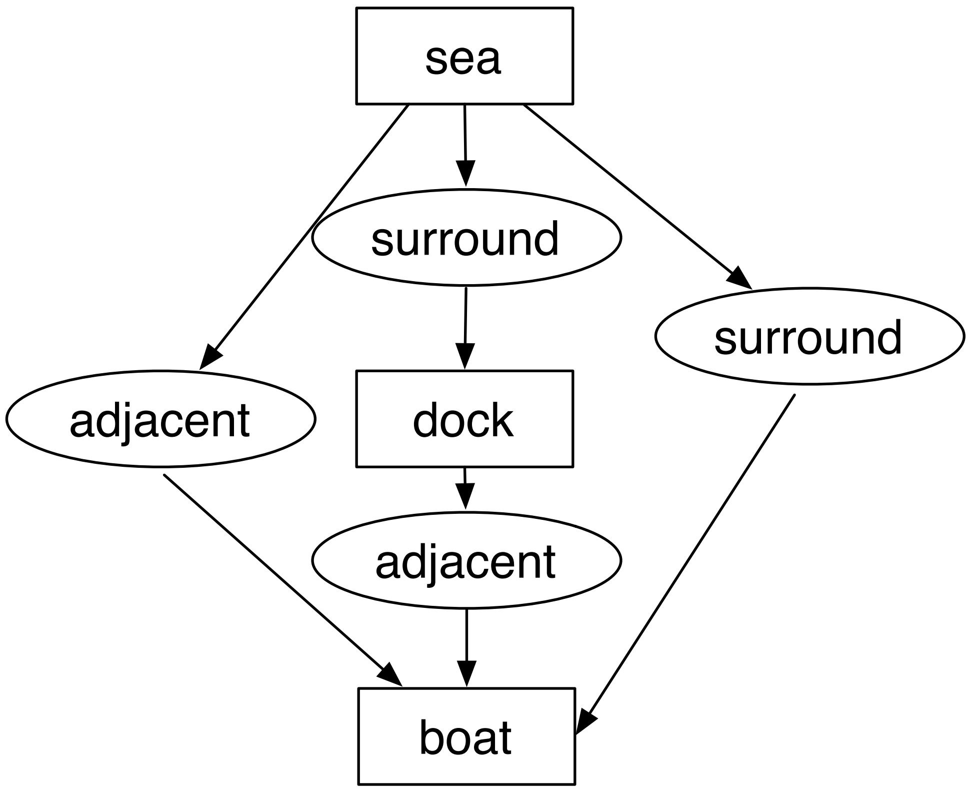
Example harbor

Original image

Example harbor



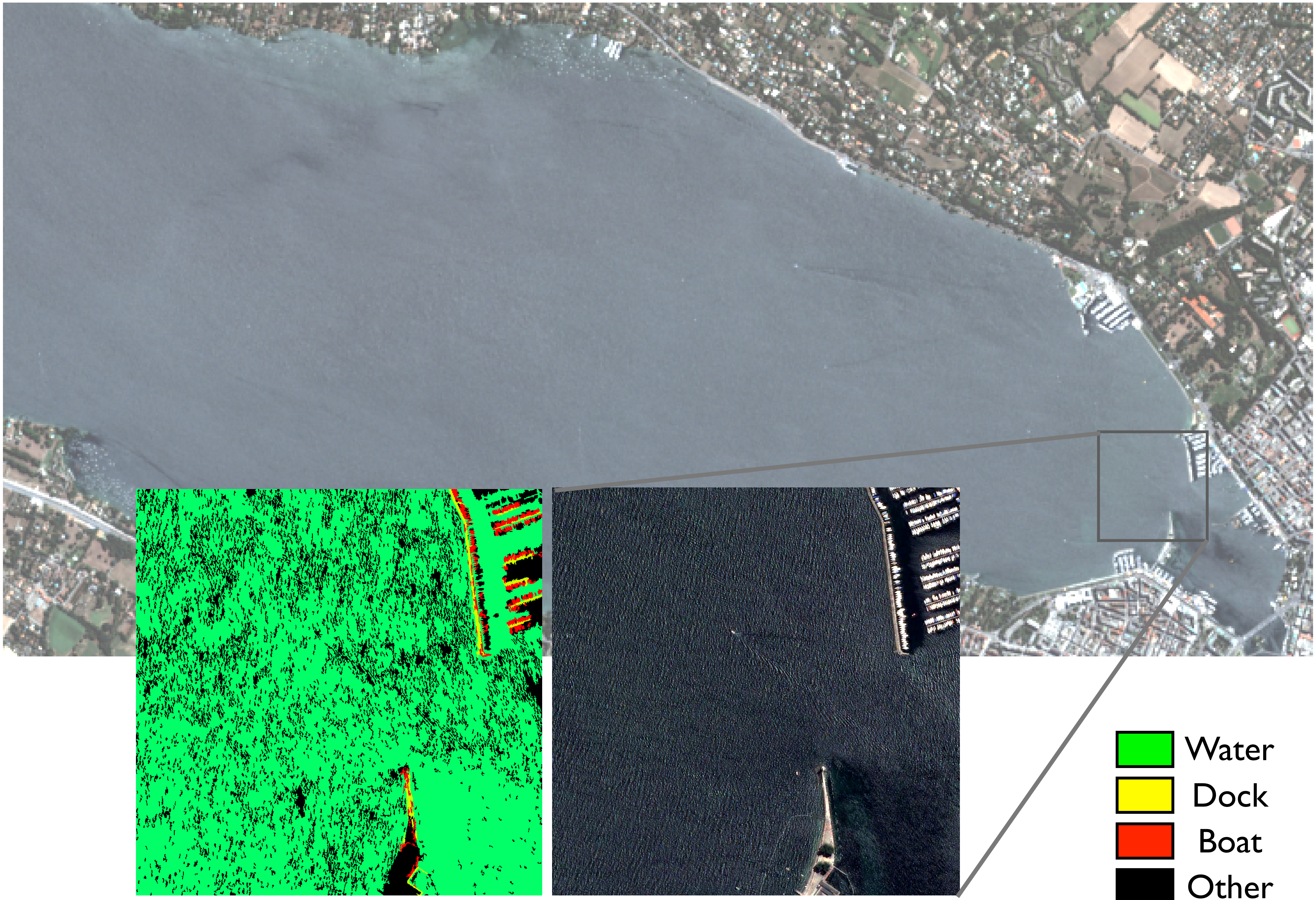
Concept hierarchy



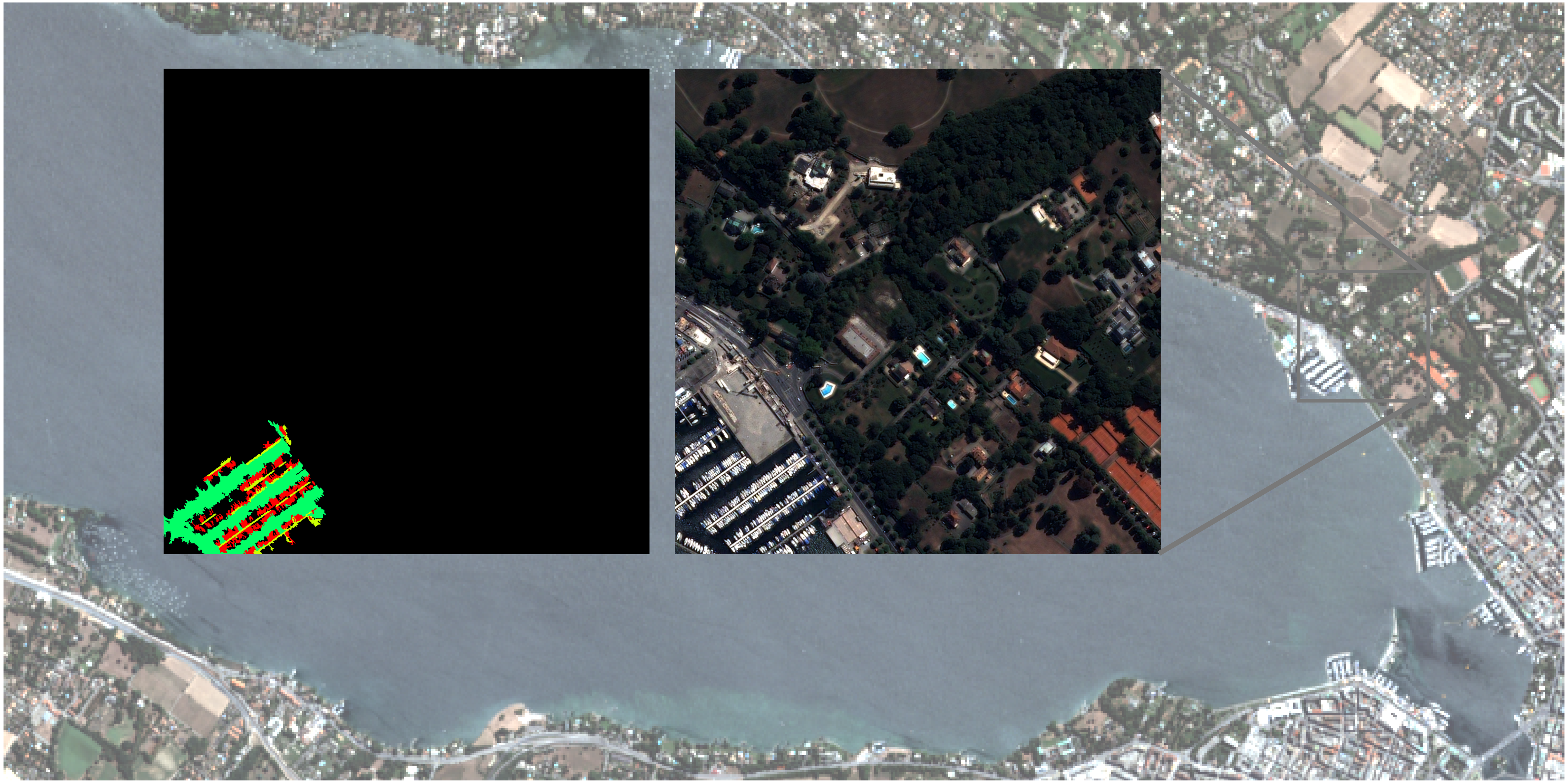
Conceptual graph

Example harbor

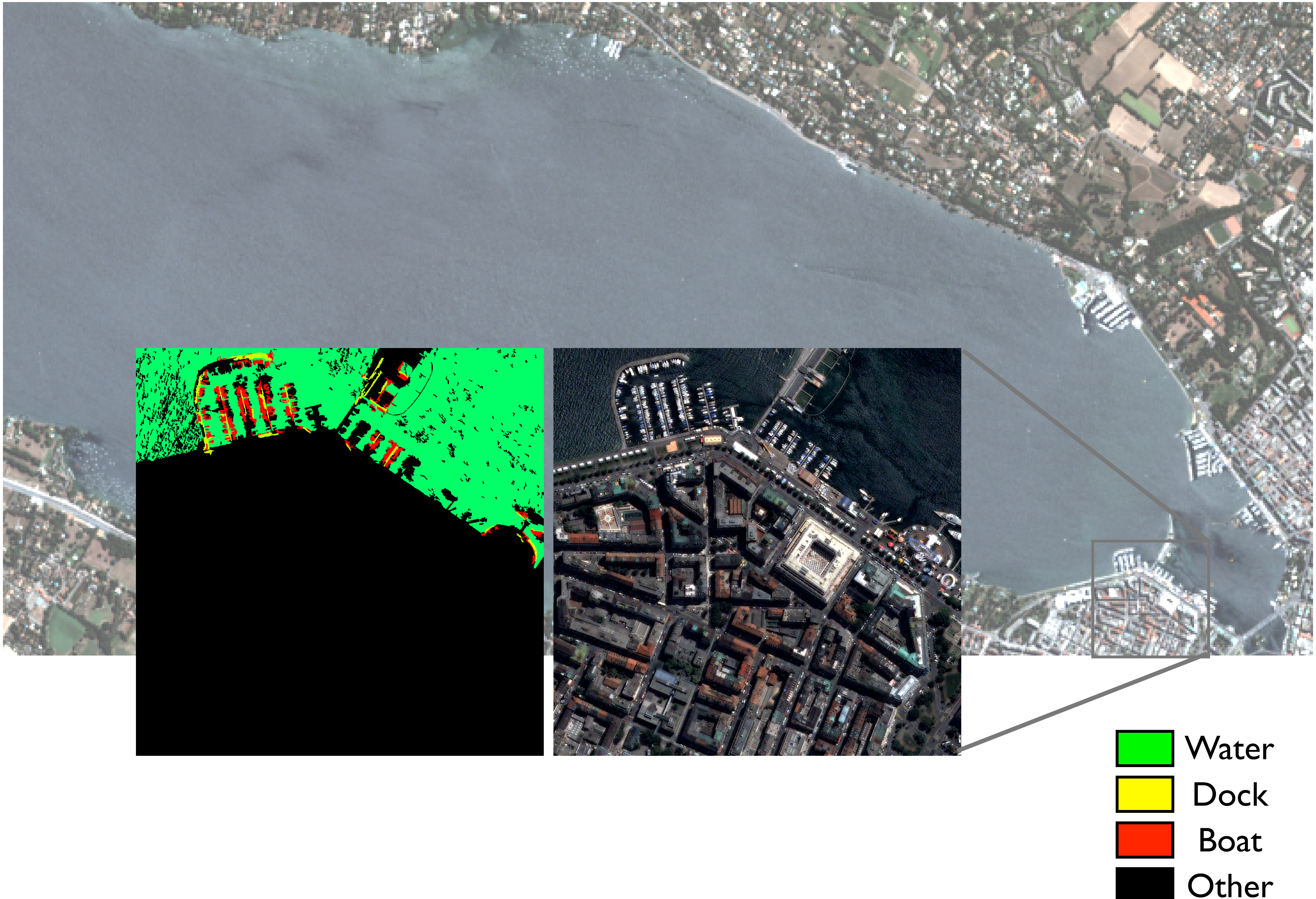
Example harbor



Example harbor



Example harbor



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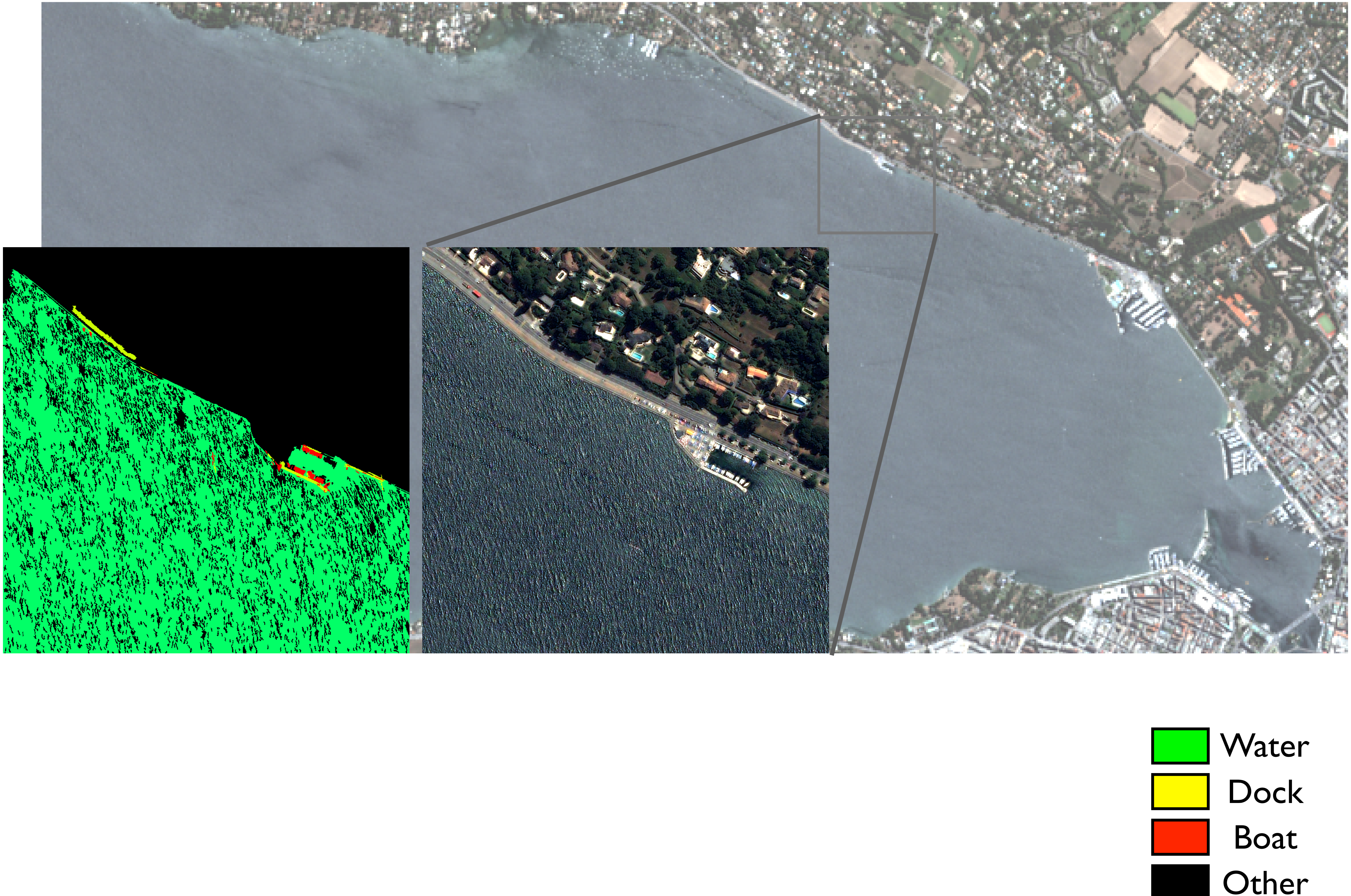

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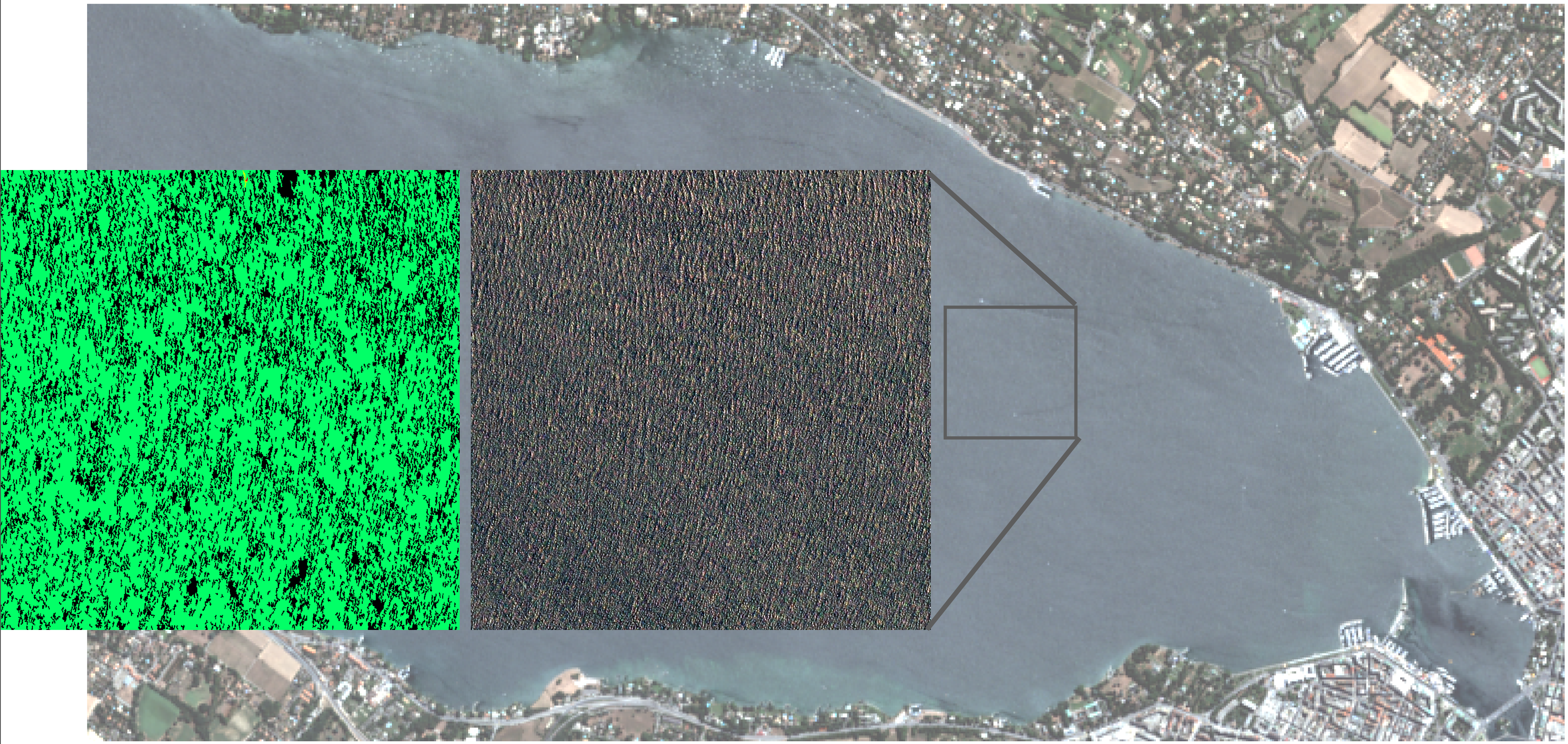

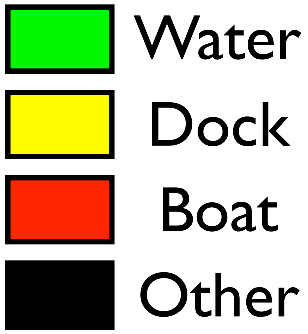

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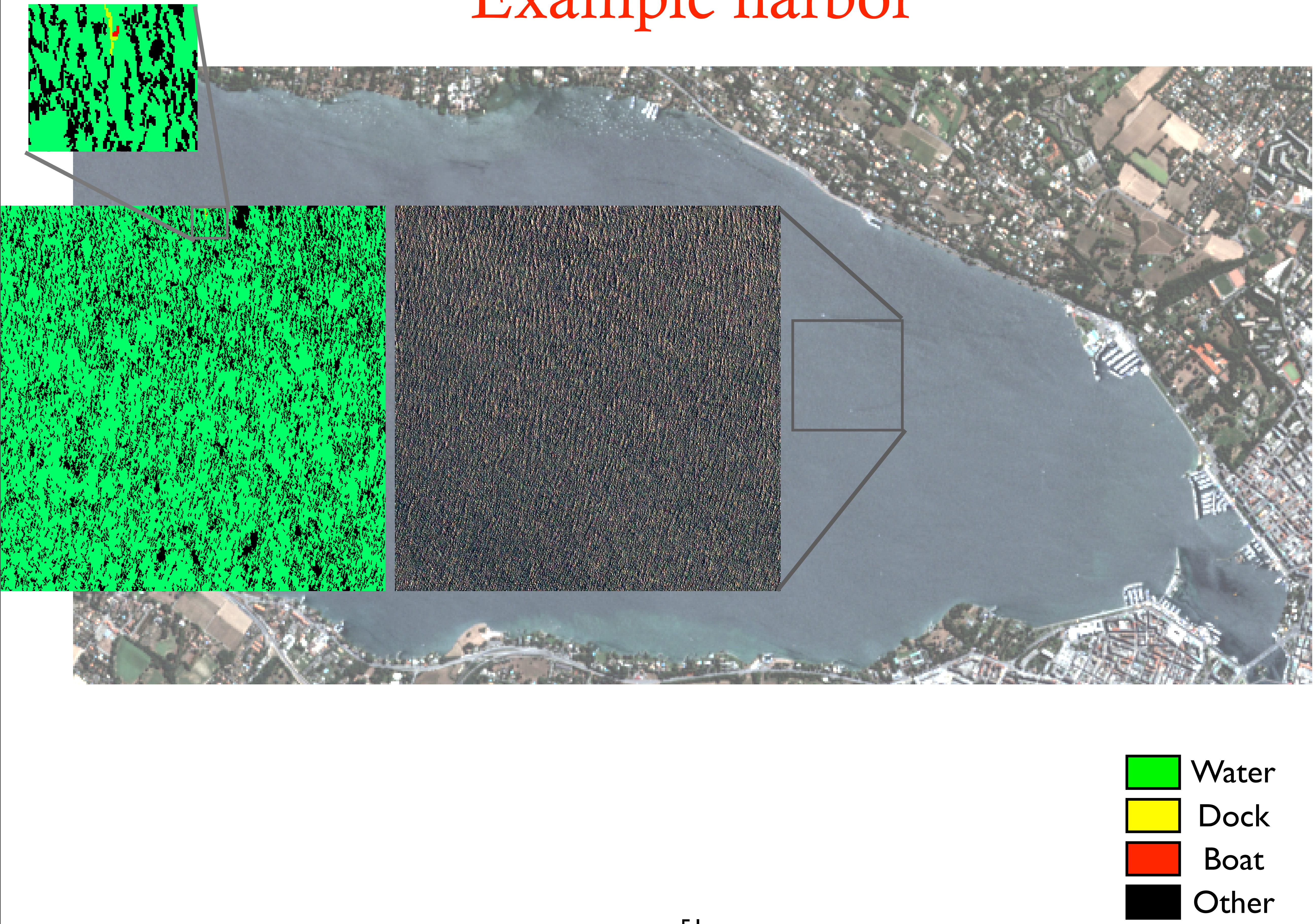


Outline

- Spatial relations
  - State of the art
  - Contribution
    - Example
- Interpretation of satellite images using a structural model (concepts + spatial relations)
- Conclusions and perspectives

Conclusions

- We proposed novel definitions for spatial relations
  - Take into account imprecision
  - Are in accordance with perception
- Proposed an extension of nested conceptual graphs to allow the representation of aligned groups of objects (complex concept nodes).

Conclusions

- Extension of fuzzy CSP
  - Extension of arc-consistency algorithm for constraints with arity greater than 2.
  - Determine the arc-consistency closure of a network containing complex concept nodes.
- Proposed a methodology for image interpretation using a structural model.
- Spatial relations and interpretation system implemented in OTB (Orfeo Toolbox)

Perspectives (short term)

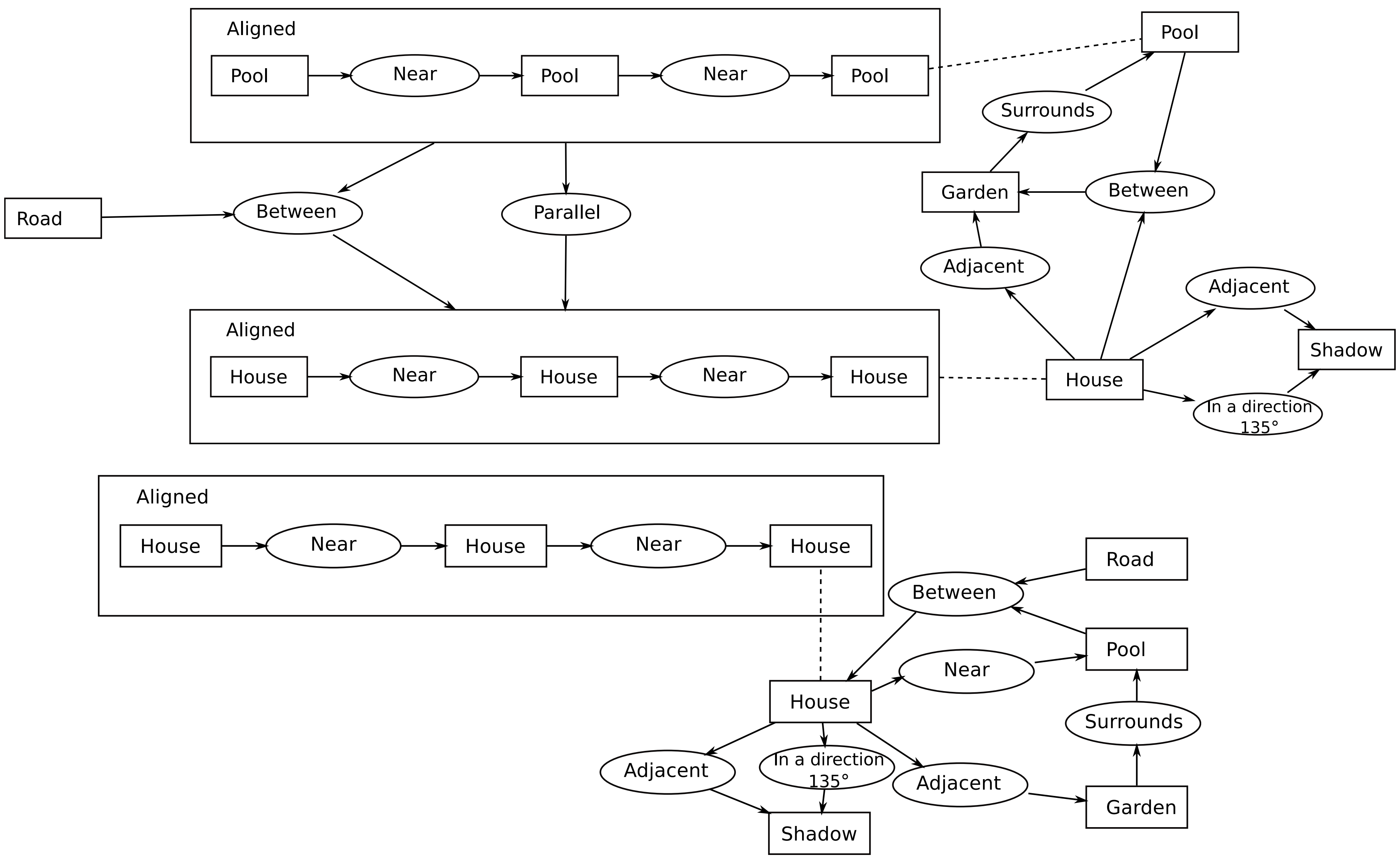
- Introduction of uncertainty of the model into the interpretation method
- Optimization of the algorithm for determining the arc-consistency closure of nested constraint networks with complex concept nodes
  - Ordering of constraints
- Extraction of initial regions and labeling
  - More appropriate segmentation algorithms [Bin, 2007], [Guigues et al. , 2003]
  - Corine landcover

Perspectives (long term)

- Integration of the interpretation system into a query based architecture with relevance feedback

Perspectives (long term)

- Integration of the interpretation system into a query based architecture with relevance feedback
- Several models can describe the same scene



Perspectives (long term)

- Integration of the interpretation system into a query based architecture with relevance feedback
- Several models can describe the same scene
- Study of the relevance of spatial relations for describing a scene
  - relevance in language description [Dessalles, 2008]

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- Integration of the interpretation system into a query based architecture with relevance feedback
- Several models can describe the same scene
- Study of the relevance of spatial relations for describing a scene
  - relevance in language description [Dessalles, 2008]
- Automatic creation of the structural models