Modeling and representation of spatial uncertainty in image processing and understanding

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Uncertainty in images

Due to:

- observed phenomenon,
- sensor characteristics and limitations,
- reconstruction algorithms,
- noise,
- limited reliability,
- representations,
- processing algorithms...

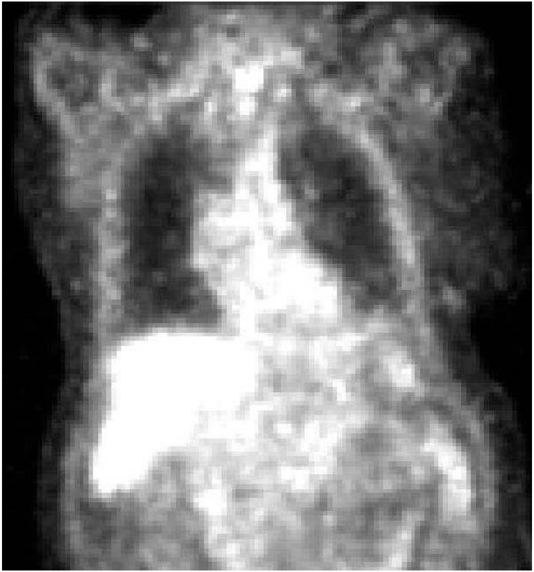
and also:

- associated knowlegde,
- dynamic world...

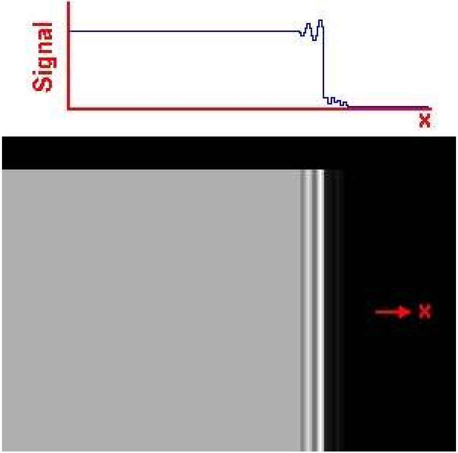
$\Rightarrow$ uncertain, imprecise, partial, ambiguous, biased, conflictual information.

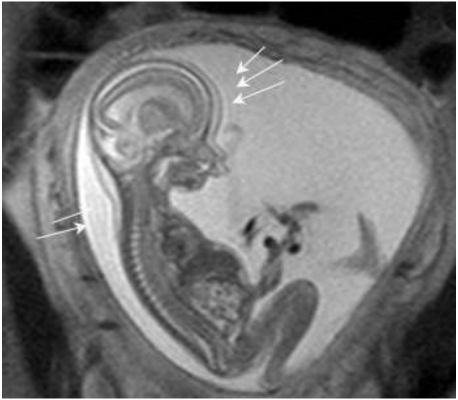
Uncertainty and imprecision: a few examples

Uncertainty and imprecision: a few examples

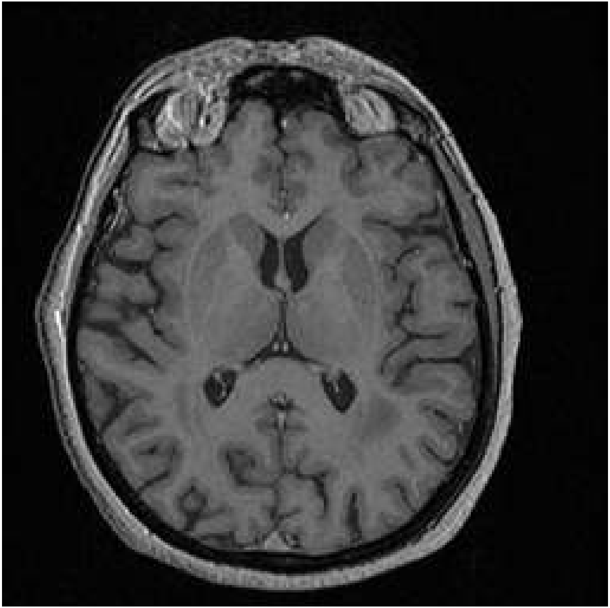


Uncertainty and imprecision: a few examples

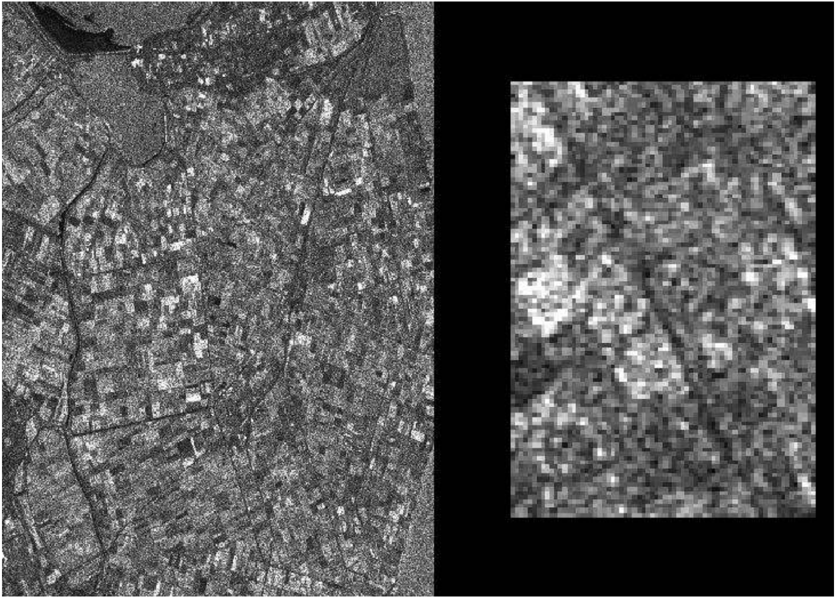




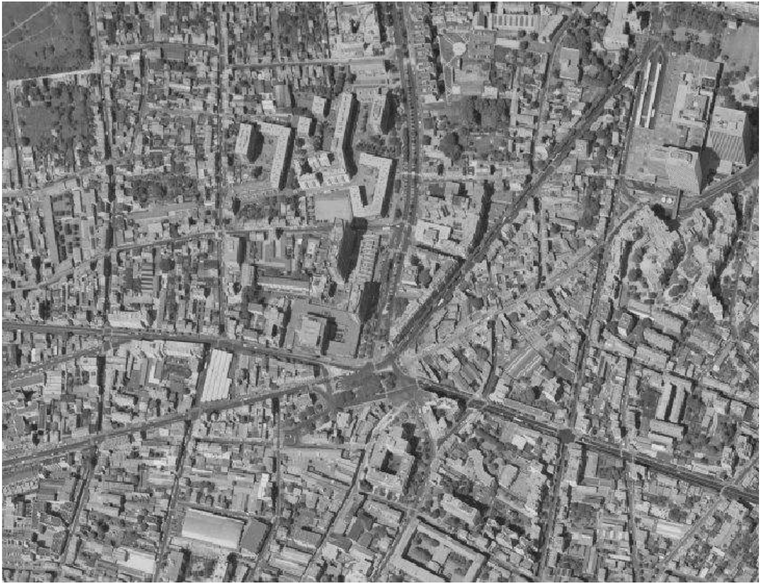
Uncertainty and imprecision: a few examples



Uncertainty and imprecision: a few examples



Uncertainty and imprecision: a few examples



Uncertainty and imprecision: a few examples

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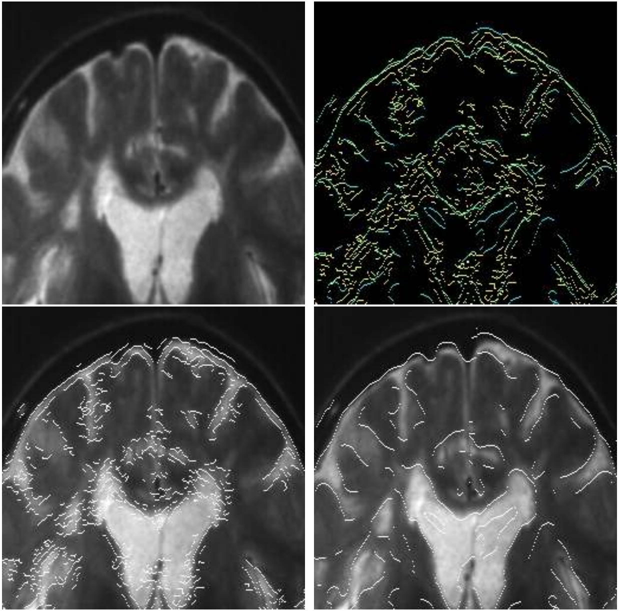


Uncertainty and imprecision: a few examples

[morphologie]

morphologie fonctionnel atlas animations vidéo reconstruction 3D liens

Noyau caudé

- embryologie
  - histologie
    - crâne
      - méninges
- moelle épinière
  - tronc cérébral
- nerfs crâniens
  - cervelet
    - cortex cérébral
- noyaux gris
  - substance blanche
- v3
  - v4
    - ventricules latéraux

auteur : D Hasboun

illustrations : H Fournié

Le noyau caudé est un noyaux gris central, en forme de **fer à cheval** ouvert en avant.
Il s'enroule **autour du thalamus**, repose sur sa face supérieure, puis descend en arrière du thalamus.

Il se continue en avant dans le lobe temporal. Il présente d'avant en arrière :

−une **tête** volumineuse située en dehors de la corne frontale du ventricule latéral

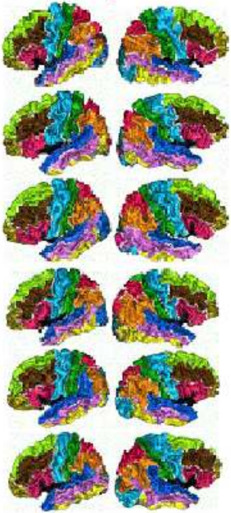
−un **corps** dont le volume diminue d'avant en arrière. Il repose sur le thalamus puis descend en arrière du pulvinar.

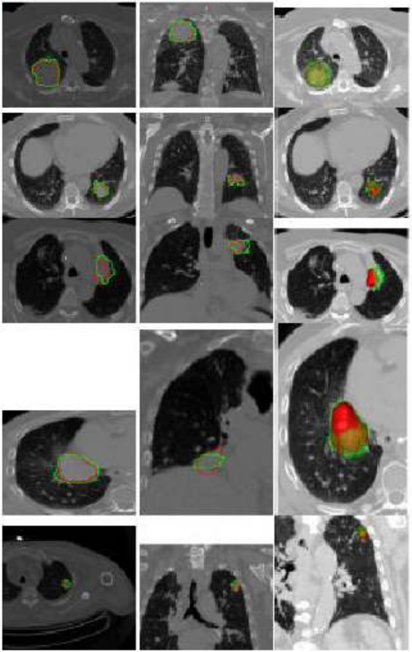
−la **queue** du noyau cadé chemine dans le lobe temporal, au−dessus de la corne temporale du ventricule latéral, dans la région sous lenticulaire.

Le noyau caudé constitue le **néostriatum** avec le putamen.

accueil - morphologie - fonctionnel - animations - vidéo - atlas - 3D - liens - préface - bibliographie - aide

Variability



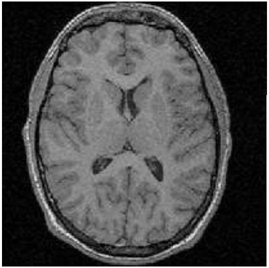


Fuzzy sets in a nutshell (Zadeh, 1965)

- Space $\mathcal{S}$ (image space, space of characteristics, etc.).
- Fuzzy set: $\mu : \mathcal{S} \rightarrow [0, 1]$ – $\mu(x)$ = membership degree of x to μ.
- Set theoretical operations: complementations, conjunctions (t-norms), disjunctions (t-conorms).
- Logic operators, aggregation and fusion operators...

Example: spatial fuzzy set

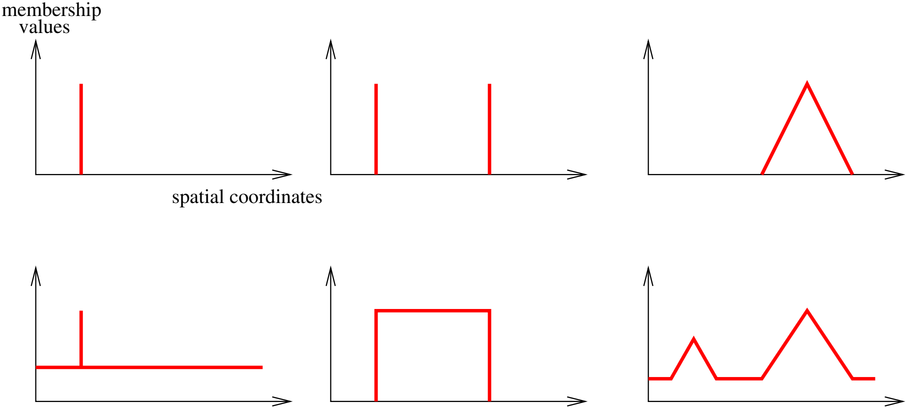
- $\mathcal{S}$: $\mathbb{R}^n$ or $\mathbb{Z}^n$ in the digital case.
- $\mu : \mathcal{S} \rightarrow [0, 1]$ - $\mu(x)$ = degree to which x belongs to the fuzzy object.



Fuzzy sets and spatial information

- knowledge and (visual) data,
- local, structural,
- different types of uncertainty (mostly deterministic),
- large toolbox:
  - representations,
  - features and measurements,
  - transformations (geometrical, morphological...),
  - extension of image processing methods (filtering, classification...)
  - information fusion,
  - spatial reasoning,
  - ...

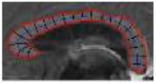
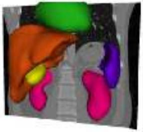
Possible positions for an object = fuzzy set



Importance of models

Models to guide segmentation, recognition, interpretation:

- properties of data (geometry, statistics...),
- shape and appearance,
- iconic models (atlases, maps),
- spatial organization (spatial relations),
- symbolic models,
- imprecision and uncertainty,
- fusion with observations and data.

From images to models:

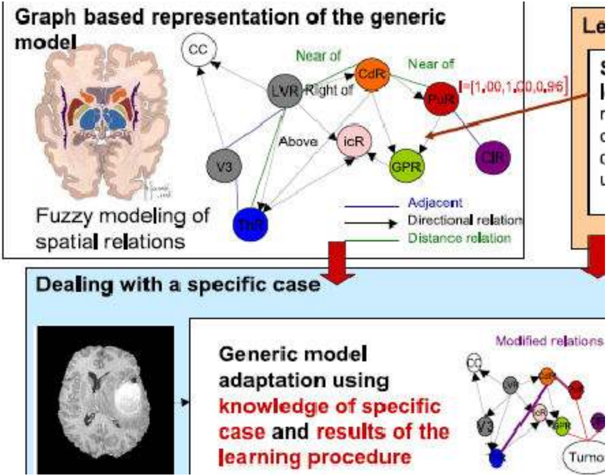
- example: building anatomical models.

Models for image understanding

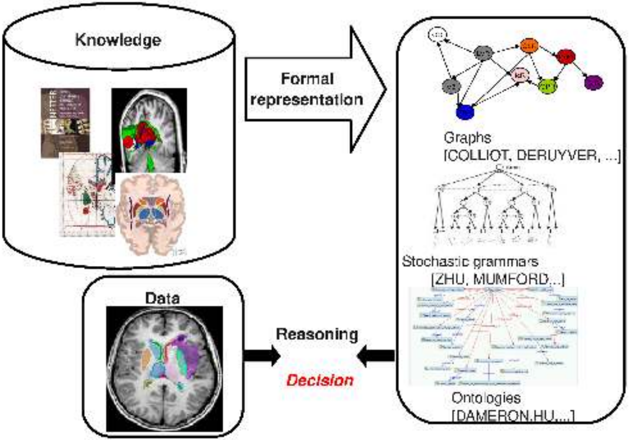
- Developing mathematical models for representing
  - knowledge,
  - information in images,

  leading to operational and efficient algorithms for image interpretation.
- Filling the semantic gap between symbolic knowledge and visual percepts.
- Developing methods dealing with pathological cases.
- Developing associated computer tools.
- Answering the needs expressed by users.

Structural models



Representation and reasoning



(Inexact) graph matching, model matching and instanciation (ontologies, conceptual graphs...), constraint satisfaction problems, spatial reasoning...

Spatial reasoning

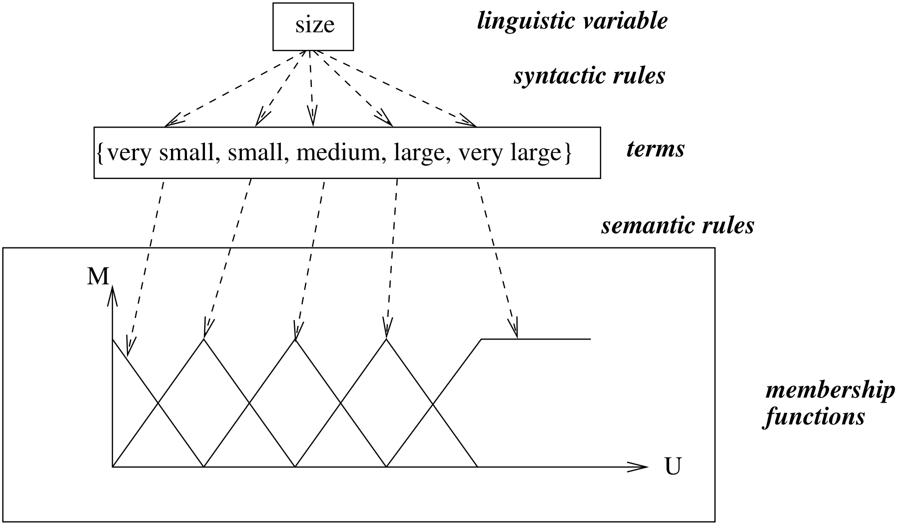
Knowledge representation and reasoning on spatial entities and spatial relations

- Spatial logics.
- Semi-quantitative framework: fuzzy sets and fuzzy logics.
- Two types of relations:
  - crisp defintion in the case objects are crisp (adjacency, distance),
  - intrinsically vague notion (directional relation, complex relations such as “between” or “along”).
- Ingredients: knowledge representation, imprecision representation, fusion of heterogeneous information, reasoning and decision.

Semantic gap

- Symbol grounding = "How is symbol meaning to be grounded in something other than just more meaningless symbols?" (Harnad)
- Anchoring = "creating and maintaining the correspondence between symbols and sensor data that refer to the same physical object" (Saffiotti & Coradeschi)
- Semantic gap = "lack of coincidence between the information that one can extract from the visual data and the interpretation of these data by a user in a given situation" (Smeulders)

Linguistic variable (Zadeh, 1975) and semantic gap



Mathematical morphology

Dilation: operation in complete lattices that commutes with the supremum.
Erosion: operation in complete lattices that commutes with the infimum.

⇒ applications on sets, fuzzy sets, functions, logical formulas, graphs, etc.

Using a structuring element:

- dilation as a degree of conjunction: $\delta_B(X) = \{x \in \mathcal{S} \mid B_x \cap X \neq \emptyset\}$,
- erosion as a degree of implication: $\varepsilon_B(X) = \{x \in \mathcal{S} \mid B_x \subseteq X\}$.

A lot of other operations...

Fuzzy spatial relations

Fuzzy sets $\Rightarrow$ relations become a matter of degree

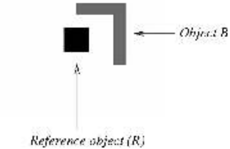
- Set theoretical relations.
- Topology: connectivity, connected components, neighborhood, boundaries, adjacency.
- Distances.
- Relative direction.
- More complex relations: between, along, parallel, around...

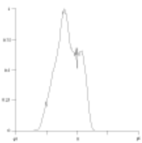
Most of them can be defined from mathematical morphology.

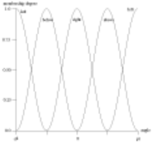
Filling the semantic gap using fuzzy representations in concrete domains

Example: directional relation

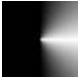
- Degree to which a spatial relation between two objects in satisfied.

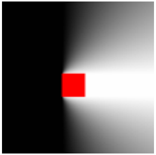


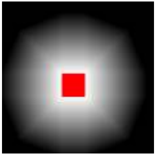




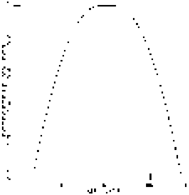
- Region of space in which a spatial relation to a reference object is satisfied (up to some degree).

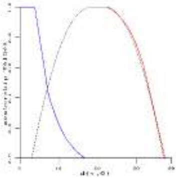


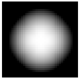


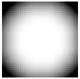


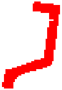
Example: spatial representation of knowledge about distance

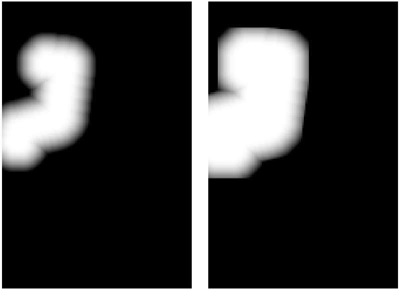


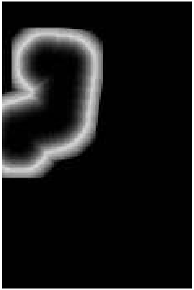




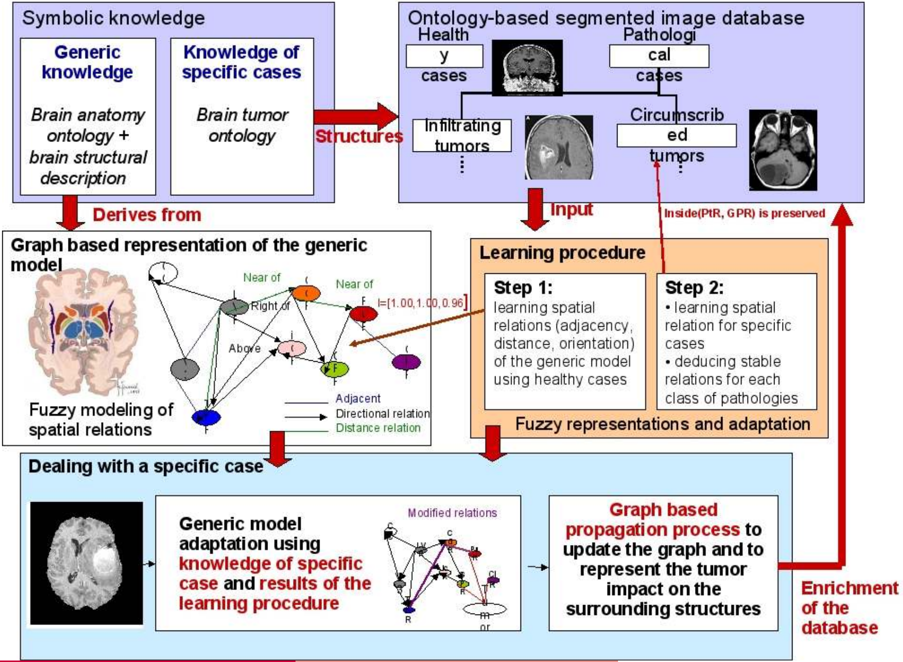




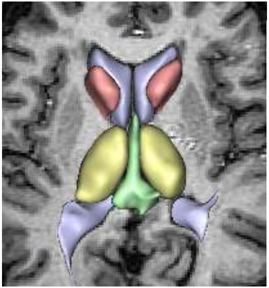


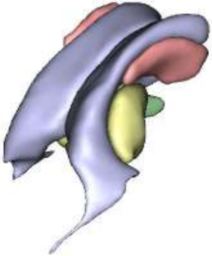


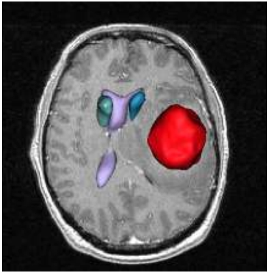
Example: the heart is between the lungs

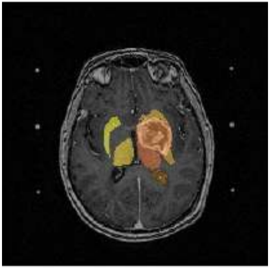

Symbolic knowledge
Generic knowledge
Brain anatomy ontology + brain structural description
Knowledge of specific cases
Brain tumor ontology
Structures
Ontology-based segmented image database
Health
y
cases
Pathologi
cal
cases
Infiltrating tumors
Circumscrib
ed
tumors
Derives from
Input
Inside(PtR, GPR) is preserved
Graph based representation of the generic model
Near of
Near of
Right of
Above
I=[1.00,1.00,0.96]
Fuzzy modeling of spatial relations
Adjacent
Directional relation
Distance relation
Learning procedure
Step 1:
learning spatial relations (adjacency, distance, orientation) of the generic model using healthy cases
Step 2:
• learning spatial relation for specific cases
• deducing stable relations for each class of pathologies
Fuzzy representations and adaptation
Dealing with a specific case
Generic model adaptation using knowledge of specific case and results of the learning procedure
Modified relations
Graph based propagation process to update the graph and to represent the tumor impact on the surrounding structures
Enrichment of the database

Some segmentation and recognition results (Olivier Colliot, Hassan Khotanlou)

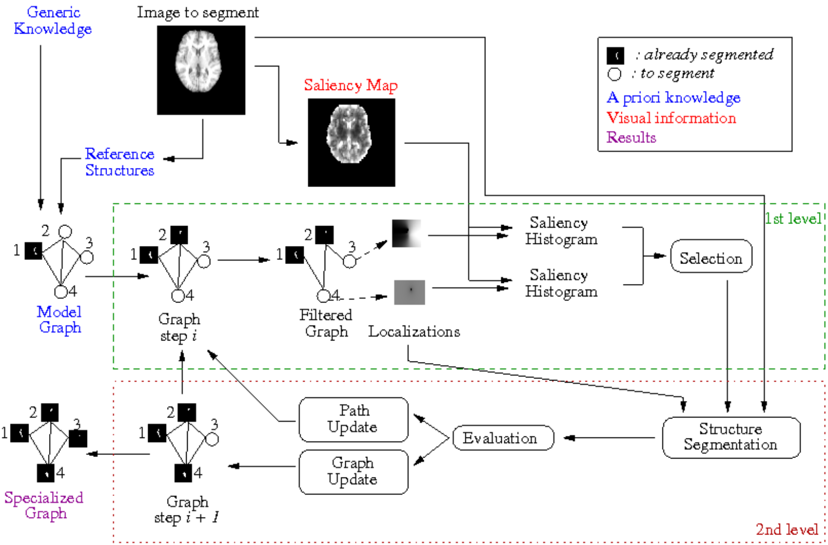




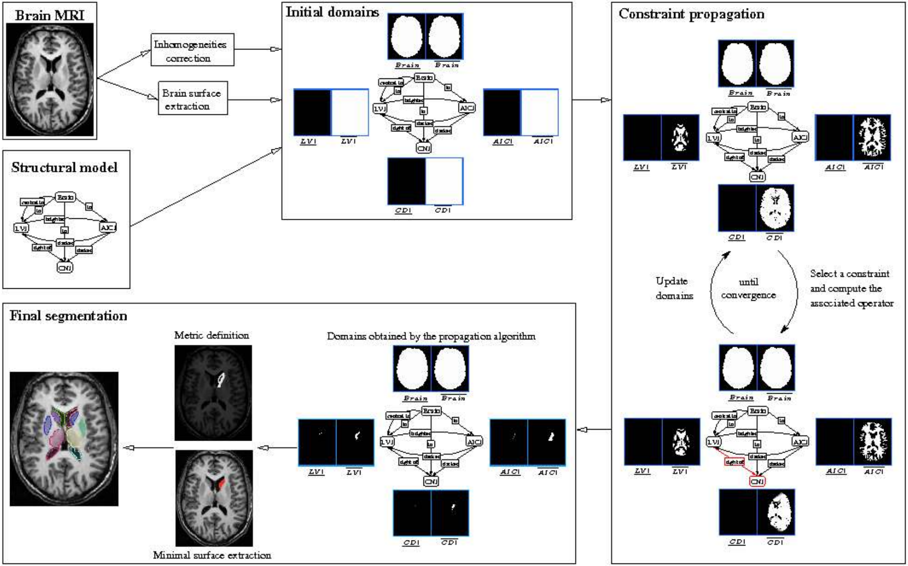


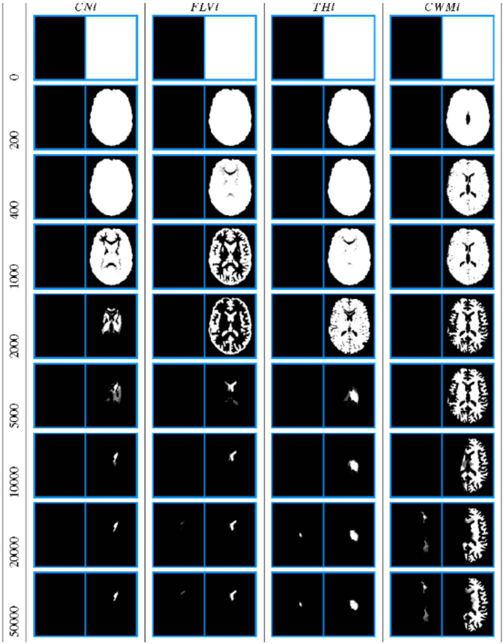


Best segmentation path (Geoffroy Fouquier)



Global approach using CSP (Olivier Nempont)




CNI
FLVI
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CWMI
0
200
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20000
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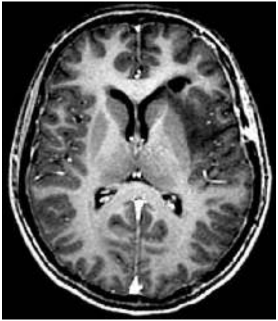
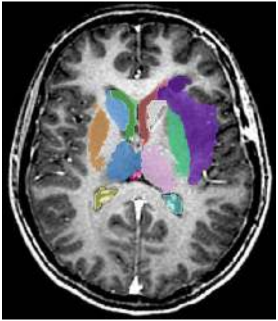
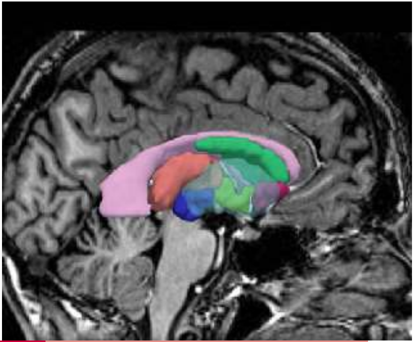
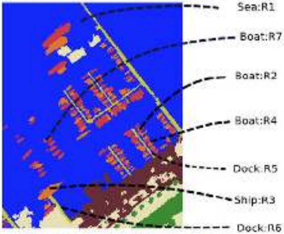




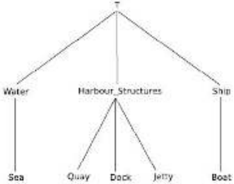


Satellite image understanding using conceptual graphs and fuzzy CSP (Carolina Vanegas, with CNES)

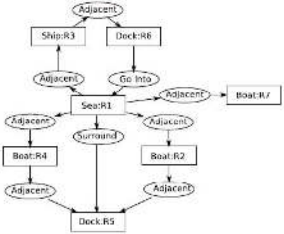
(a) Example image.



(b) Labeled image: The blue regions represent the sea, the red and orange represent ships or boats and the yellow regions represent the docks.

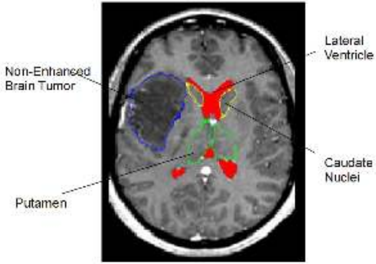


(c) Concept hierarchy T_C in the context of harbors.



(d) Conceptual graph representing the spatial organization of some elements of Figure 5.8(b).

Image understanding as an abduction problem (Yifan Yang, Jamal Atif)



Pathological brain with a peripheral tumor

$\mathcal{K} \models (\gamma \rightarrow \varphi)$: Compute the "best" explanation γ to observations φ based on expert knowledge $\mathcal{K}$:

- ontology and description logics,
- spatial relations,
- tableau method.

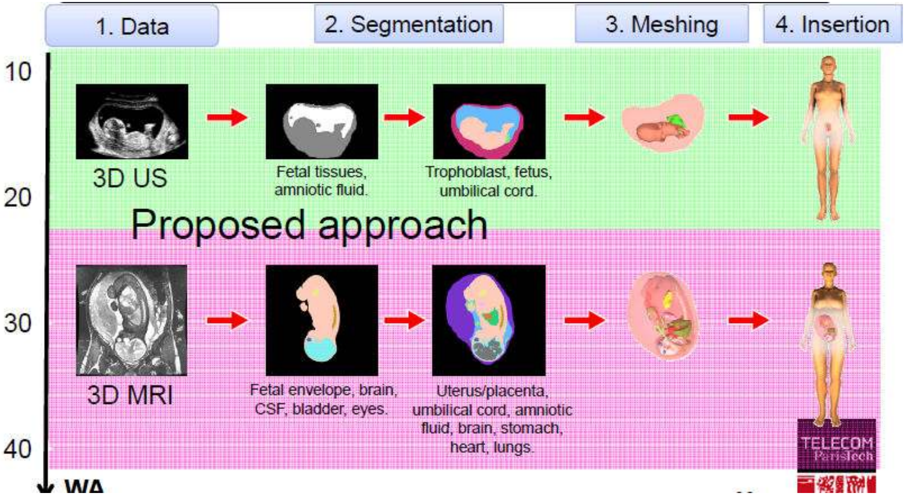
Models from images

Example: realistic modeling of the human body (WHIST Lab / C2M, CHU Bicêtre...)

Typical approach:

1. Models (signal, image, knowledge, domain...).
2. Segmentation and recognition of anatomical structures.
3. Construction of realistic digital models (labeled voxels or meshes).
4. Deformations (position, age, size...).
5. Simulations (ex: numerical dosimetry).

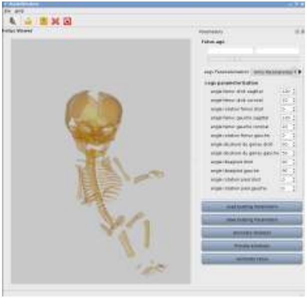
Fetus and pregnant woman (Jérémie Anquez, Lazar Bibin, Sonia Dahdouh, Juan Pablo de la Plata)

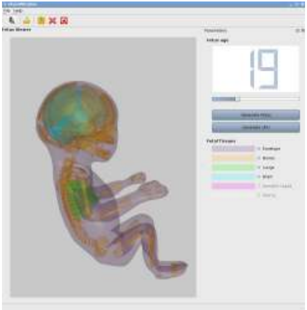


13 SA (US3D) 23 SA (IRM) 31 SA (IRM)

Models available for research purpose on http://femonum.telecom-paristech.fr/

Fetus growth model (Sonia Dahdouh, Antoine Serrurier)



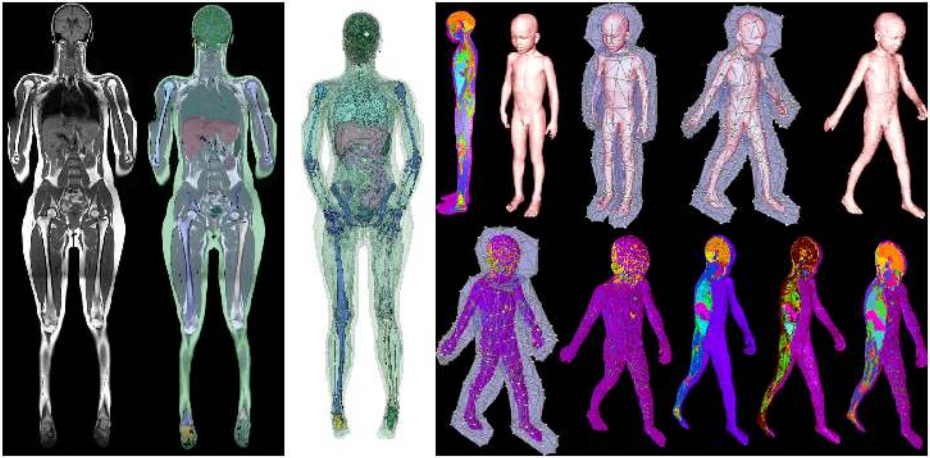


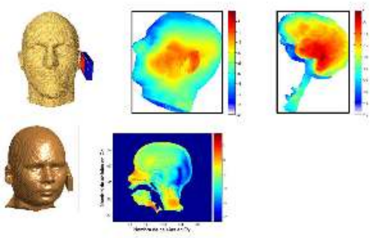
18 WA

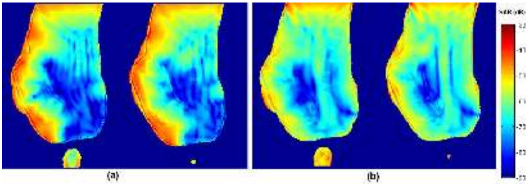
26 WA

32 WA

Whole body child models (Geoffroy Fouquier, Sonia Dahdouh, Noura Faraj)






(a)
(b)


SAR (dB)
-25
-30
-35
-40
-45
-50
-55
-60

Some other models and open problems

- Modeling bipolar information:
  - positive: observations, preferences,
  - negative: constraints.
- Combining different types of uncertainty.
- Structural spatio-temporal modeling.
- Logics (description, fuzzy, morphologic...) $\Rightarrow$ more on symbolic reasoning, abduction, revision...
- Learning: data and expert knowledge?
- Semantic gap and symbol grounding.
- Semantic annotation, verbal description of image content (and its evolution in time).
- ...

And visualization...