Researches on Spatio-temporal modelling at the Geomatics Unit

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April 19, 2013

TOC

- Who are we?
- Definitions
- A Well-known topological relationships model
- Projective relationships
- Spatio-temporal modeling

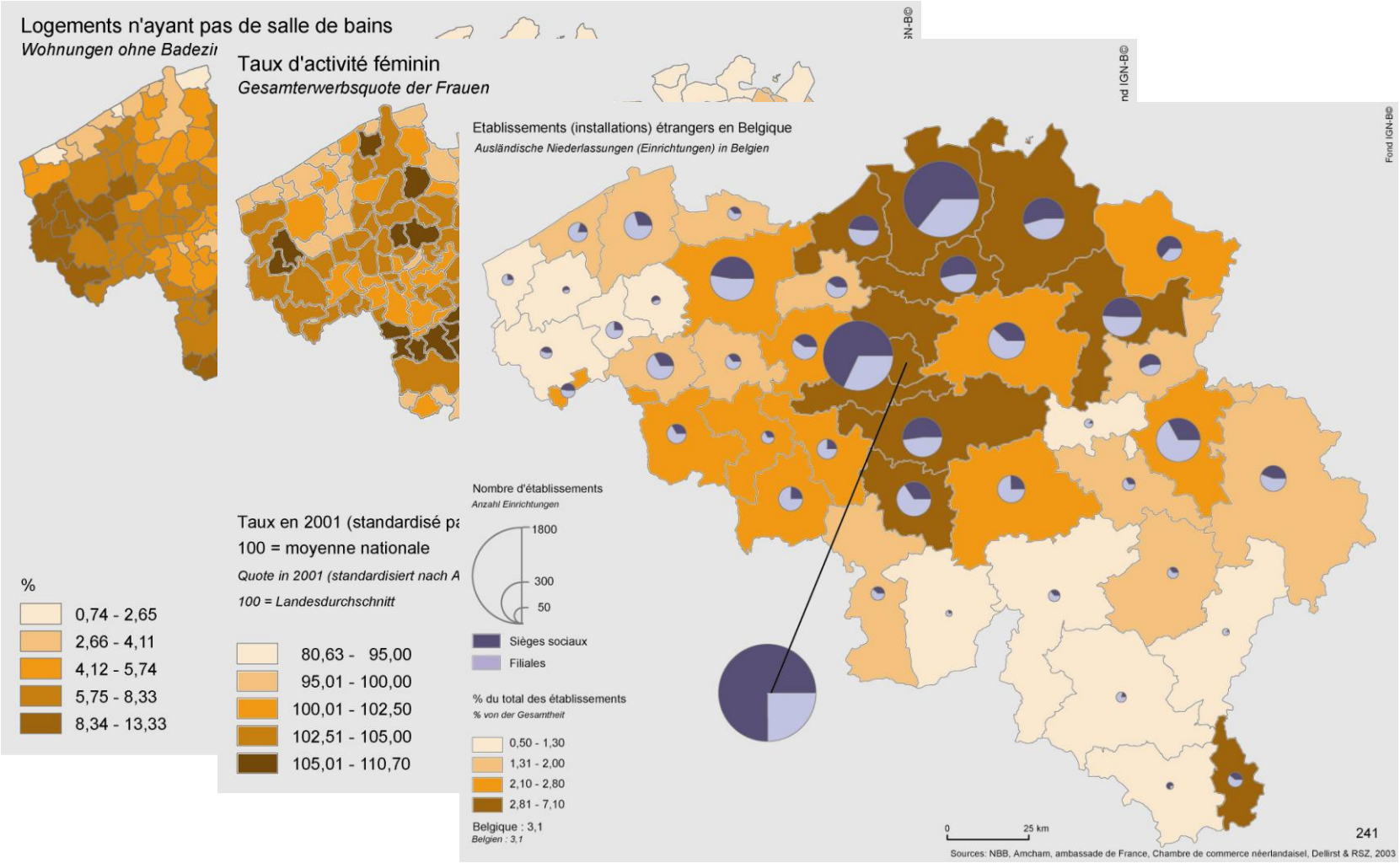
l'Unité de Géomatique de l'Université de Liège

Unité de Géomatique

Geomatics Unit

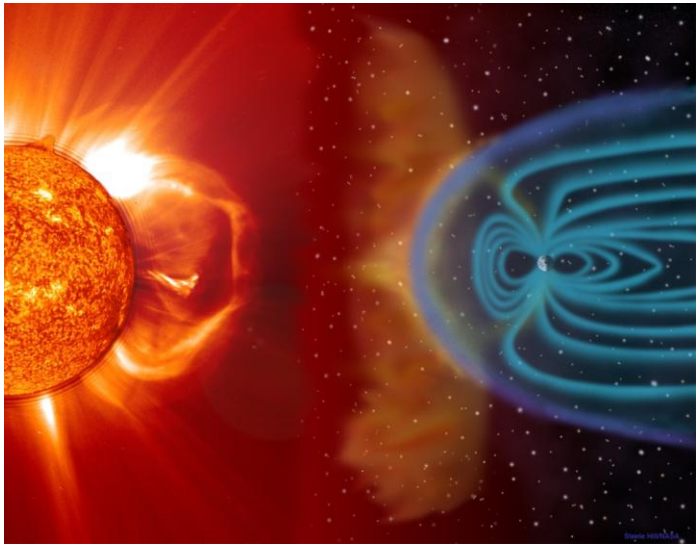
Université de Liège

Cartographie

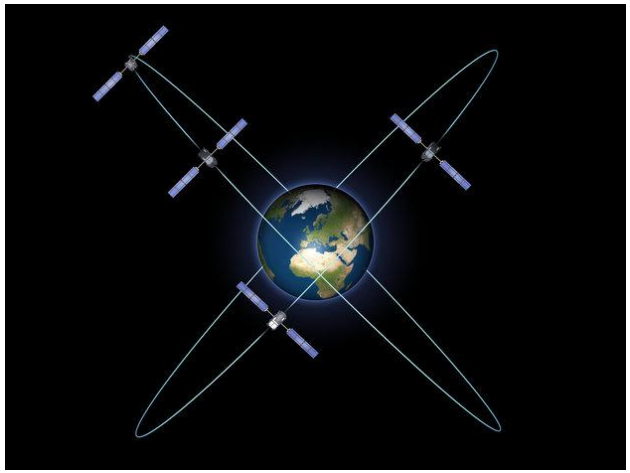


L'Atlas numérique - http://www.atlas-belgique.be/cadre

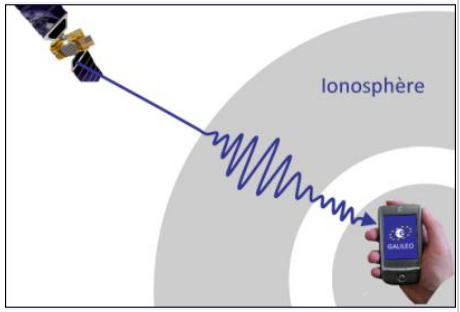
Géodésie et GNSS

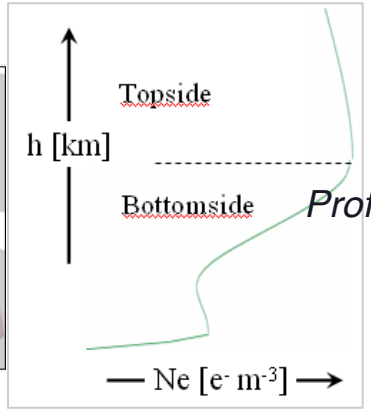


Météorologie spatiale influençant la propagation des ondes électromagnétique



Nouvelle constellation GALILEO

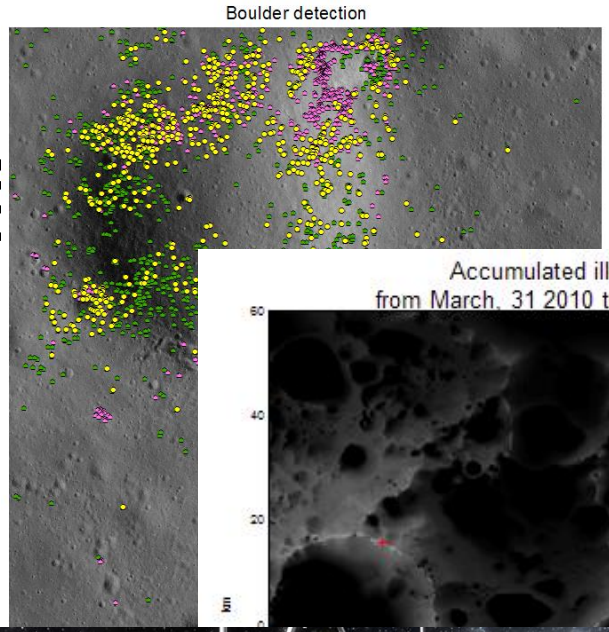


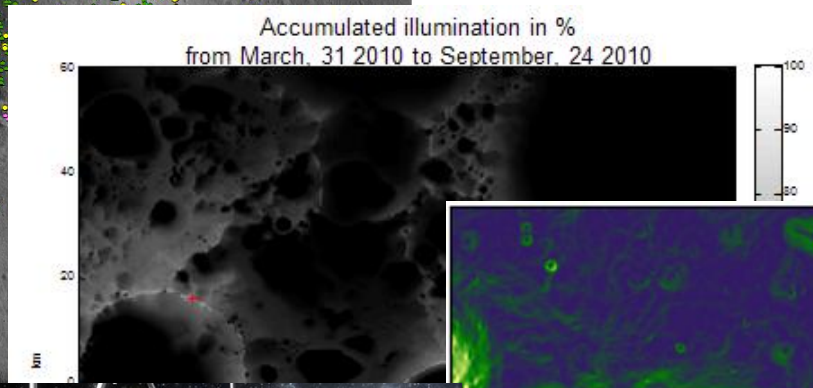


Profil de densité électronique affectant la propagation des signaux GNSS

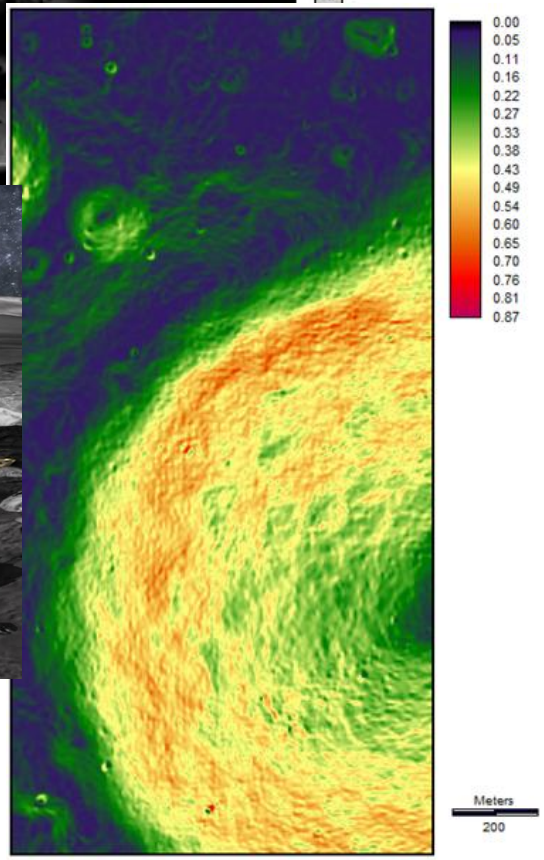
Télédé

Classification des bâtiments extraits d'images satellitaires stéréo à très haute résolution



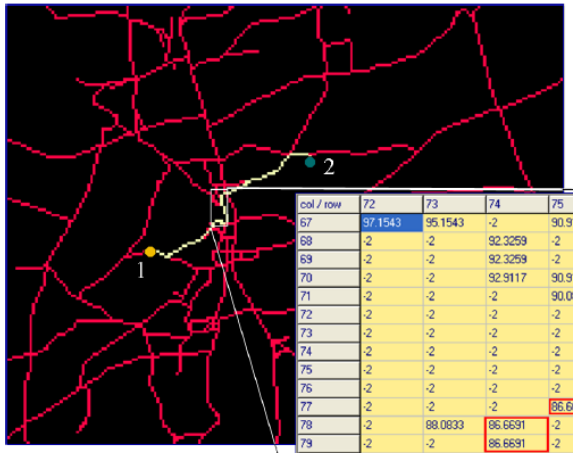


Projet LandSafe – ESA. Représentation du relief lunaire

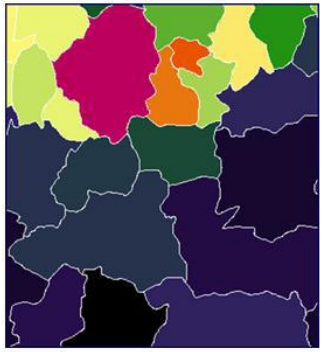


slope

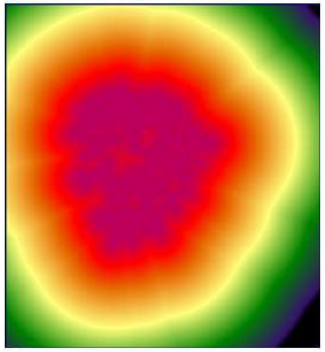
SIG et analyse spatiale



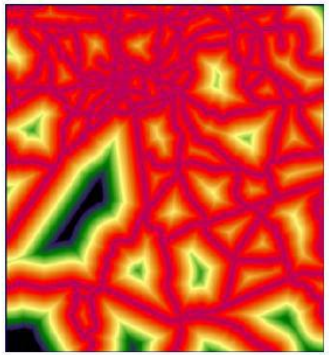
col / row	72	73	74	75	76	77	78	79
67	97.1543	95.1543	-2	90.9117	-2	-2	86.6691	86.6691
68	-2	-2	92.3259	-2	88.0833	86.6691	-2	87.4975
69	-2	-2	92.3259	-2	-2	86.6691	-2	-2
70	-2	-2	92.9117	90.9117	-2	86.6691	-2	-2
71	-2	-2	-2	90.0833	88.0833	86.6691	-2	-2
72	-2	-2	-2	-2	-2	-2	86.6691	-2
73	-2	-2	-2	-2	-2	-2	86.6691	-2
74	-2	-2	-2	-2	-2	-2	86.6691	-2
75	-2	-2	-2	-2	-2	-2	-2	86.6691
76	-2	-2	-2	-2	-2	-2	-2	86.6691
77	-2	-2	-2	86.6691	86.6691	86.6691	-2	86.6691
78	-2	88.0833	86.6691	-2	-2	86.6691	86.6691	87.2548
79	-2	-2	86.6691	-2	-2	-2	87.2548	-2
80	87.2548	86.6691	87.2548	87.2548	87.2548	-2	87.2548	-2
81	86.6691	-2	-2	-2	87.2548	87.2548	87.8406	-2
82	87.2548	-2	-2	-2	-2	88.6691	-2	-2



Factor 1: rural character

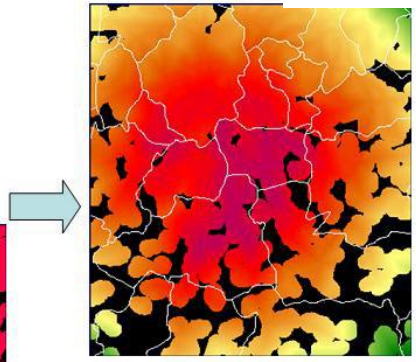


Factor 3 : integration of the scenario



Factor 2: main road proximity

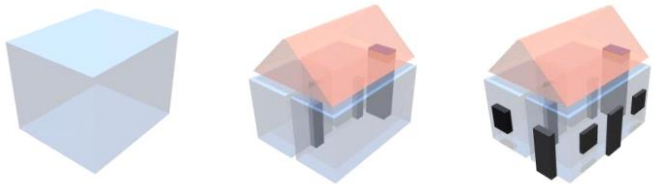
Constraint: developed site



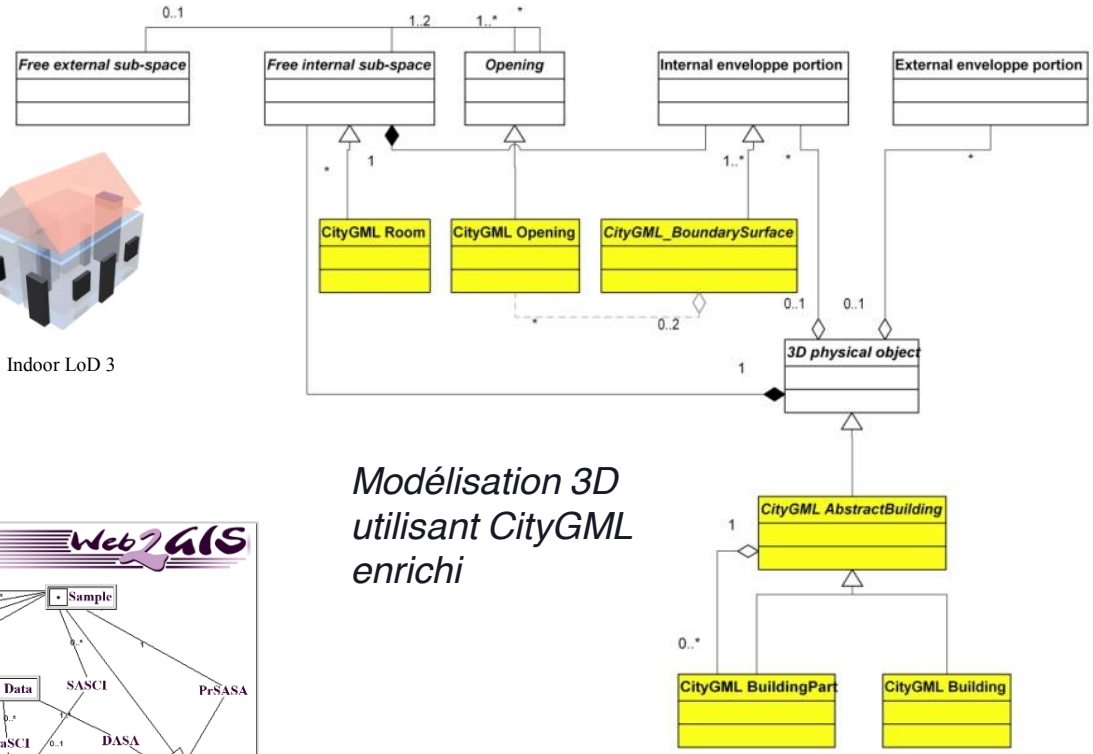
Result : performance index

Crime mapping – analyse spatiale dans le cadre d'enquêtes criminelles telles que les « tueurs du Brabant »

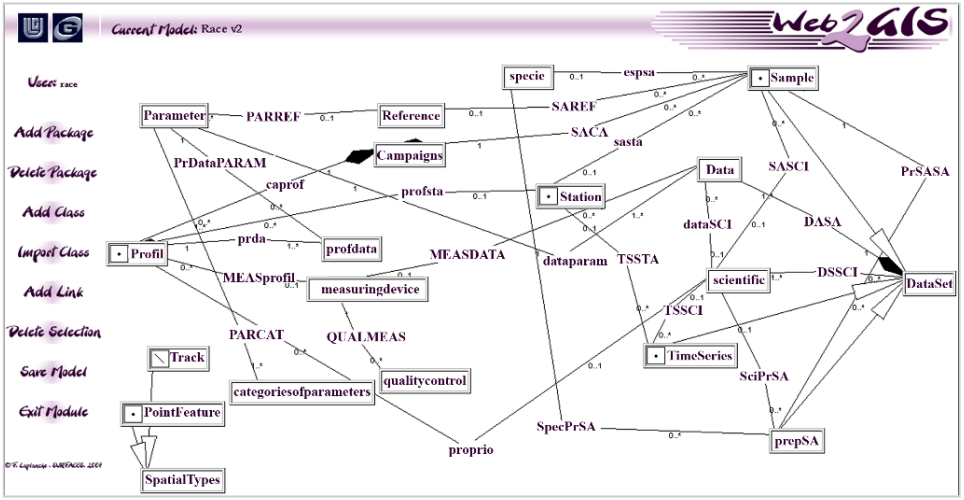
Base de données spatiales et SIG



Indoor LoD 1 Indoor LoD 2 Indoor LoD 3



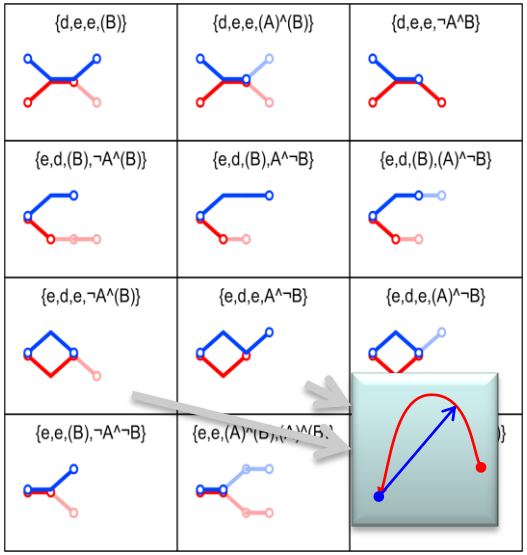
Modélisation 3D utilisant CityGML enrichi



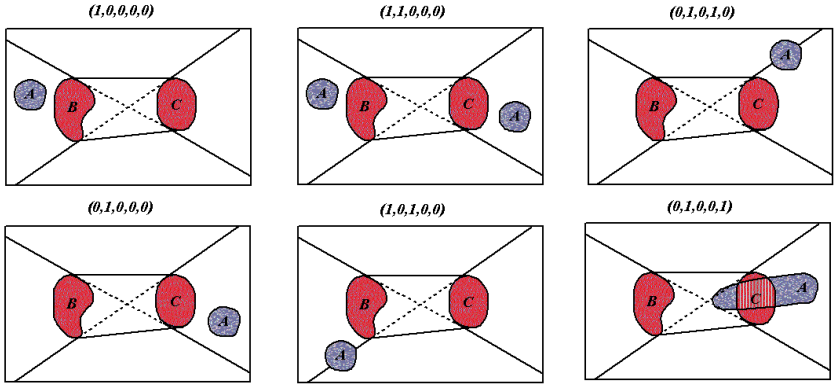
Logiciel Web2GIS (ULg) de conception et gestion de SIG

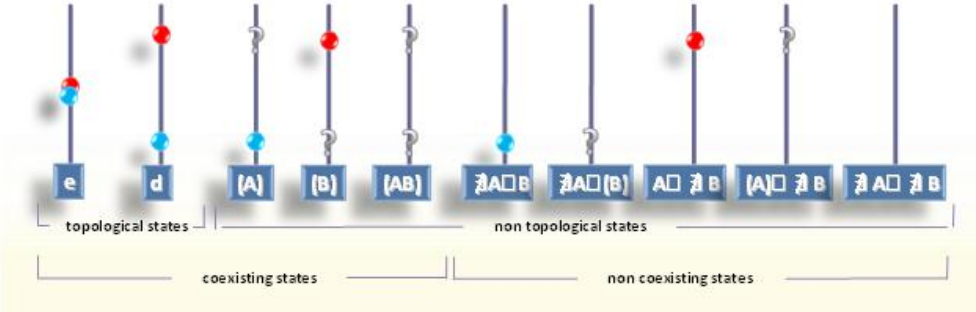
Sciences de l'information géographique

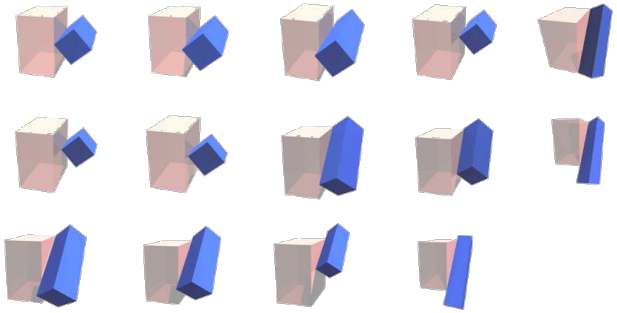
Modèle basé sur la notion d'état spatio-temporel



Modèle de relations projectives ternaires



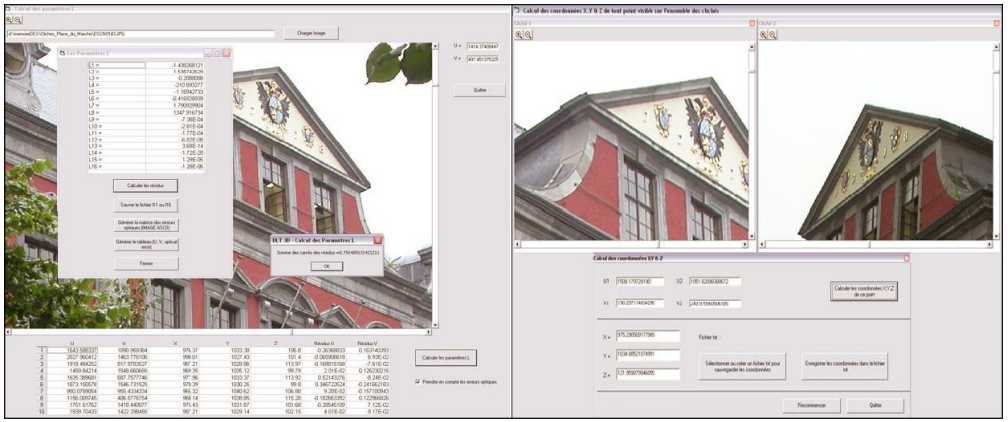


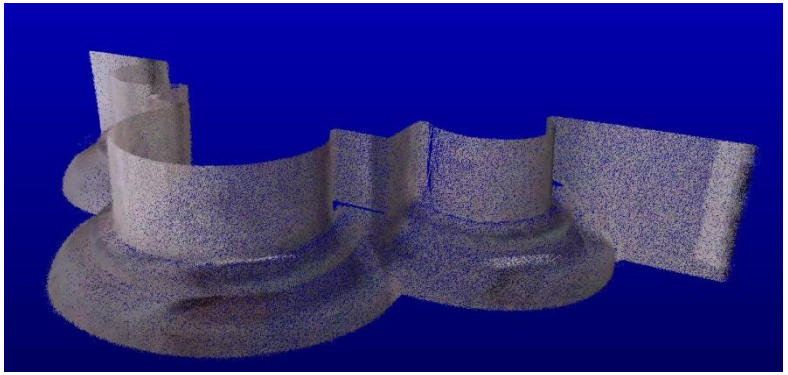


Modèle de relations topologiques 3D

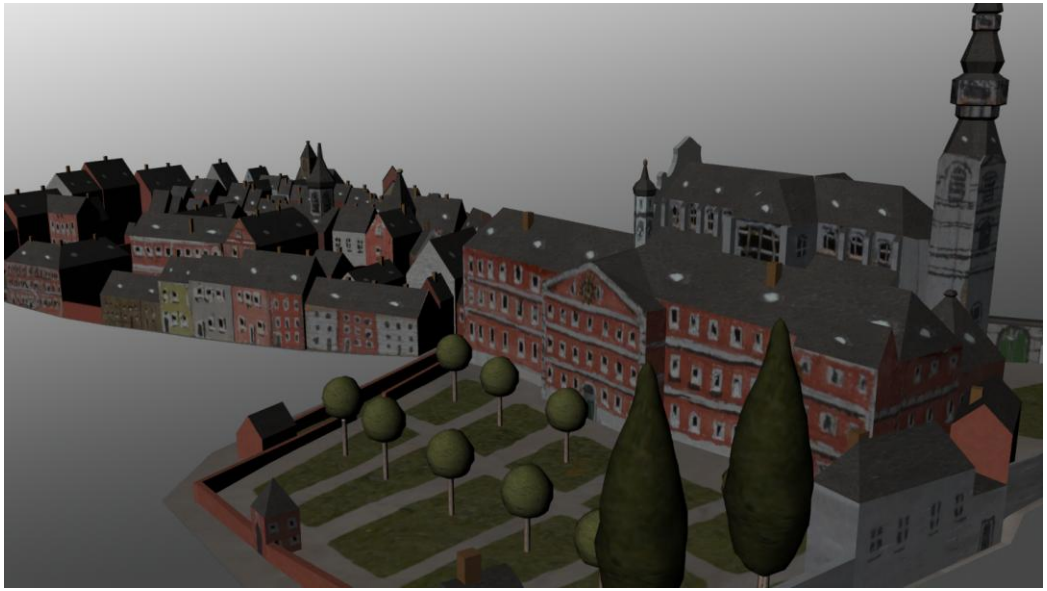
Topométrie / lasergrammétrie

Logiciel (ULg) de levé rapide topo-photographique





Reconstitution 3D par Lasergrammétrie terrestre – Cathédrale St-Paul



Modèle 3D historique – projet Virtual Leodium

Qualitative Spatial Reasoning

Definitions

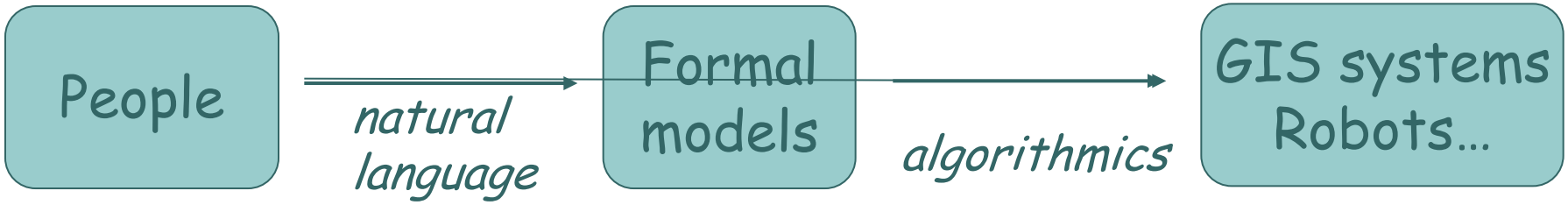
- *Saying that Alaska is 1 518 800 km² is sufficiently exact quantitative information about size and distances in Alaska but very likely it is not meaningful in relation to the spatial knowledge of the average listener. On the other hand saying that Alaska alone is bigger than all the states of the East coast from Maine to Florida is cognitively more immediate*

Definitions

- QSR is a branch of Artificial Intelligence (AI), linked to Spatial Cognition, highly related to Geographical Information Science (GISc) and by extension to most aspects of geography. It is a particular (through its spatial component) sub-field of Qualitative Reasoning (QR) and is often associated with Spatio-Temporal (Qualitative) Reasoning when time is considered.

Definitions

- Qualitative Reasoning is an approach for dealing with commonsense knowledge of the physical world without numerical computation.
- Its main goal is to make this knowledge explicit, so that given appropriate reasoning techniques, a computer could make predictions, diagnose and explain the behaviour of physical systems in a qualitative manner



Definitions

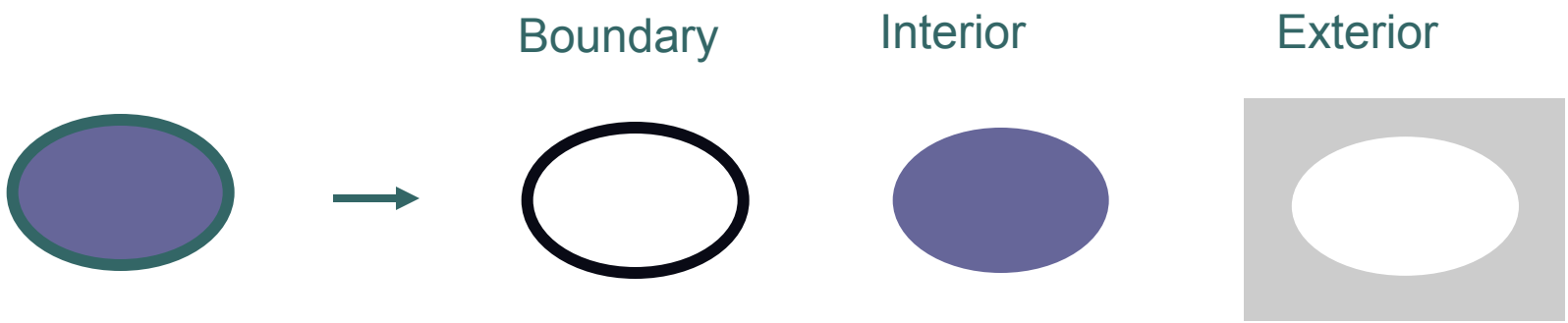
- the biggest challenge remains the development of calculi, allowing reasoning about objects in multidimensional space.
- The two main prevalent forms of qualitative reasoning are Composition Table (based on transitivity between relationships) and Conceptual Neighbourhood diagram (based on a continuity concept between relationships).

Background and Motivations

Definition of many qualitative relations

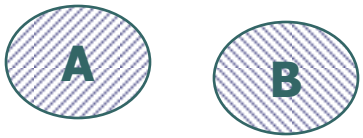
- Topological:
  - Lakes inside Scotland
- Projective:
  - Cities between Glasgow and Edinburgh
  - Lakes surrounded by mountains
  - Shops on the right of the road
  - Flags above the tree
- Metric:
  - Edinburgh is east of Glasgow
  - Edinburgh is not far from Glasgow

The 9-i model



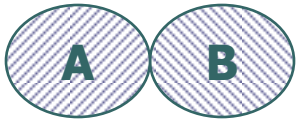
$$\begin{bmatrix} \partial A \cap \partial B & \partial A \cap \mathring{B} & \partial A \cap \overline{B} \\ \mathring{A} \cap \partial B & \mathring{A} \cap \mathring{B} & \mathring{A} \cap \overline{B} \\ \overline{A} \cap \partial B & \overline{A} \cap \mathring{B} & \overline{A} \cap \overline{B} \end{bmatrix}$$

The 9-i model



$$\begin{array}{c|ccc} & \partial B & B^\circ & B^- \\ \hline \partial A & \varnothing & \varnothing & \neg\varnothing \\ A^\circ & \varnothing & \varnothing & \neg\varnothing \\ A^- & \neg\varnothing & \neg\varnothing & \neg\varnothing \end{array}$$

disjoint



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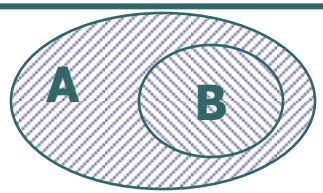
meet



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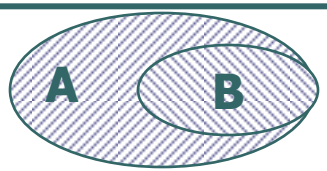
contains



$$\begin{array}{c|ccc} & \partial B & B^\circ & B^- \\ \hline \partial A & \neg\varnothing & \varnothing & \neg\varnothing \\ A^\circ & \neg\varnothing & \neg\varnothing & \neg\varnothing \\ A^- & \varnothing & \varnothing & \neg\varnothing \end{array}$$

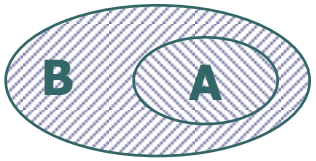
covers

$$\begin{array}{c|ccc} & \partial B & B^\circ & B^- \\ \hline \partial A & \neg\varnothing & \varnothing & \varnothing \\ A^\circ & \varnothing & \neg\varnothing & \varnothing \\ A^- & \varnothing & \varnothing & \neg\varnothing \end{array}$$

equal

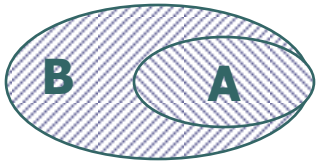
$$\begin{array}{c|ccc} & \partial B & B^\circ & B^- \\ \hline \partial A & \neg\varnothing & \neg\varnothing & \neg\varnothing \\ A^\circ & \neg\varnothing & \neg\varnothing & \neg\varnothing \\ A^- & \neg\varnothing & \neg\varnothing & \neg\varnothing \end{array}$$

overlap



$$\begin{array}{c|ccc} & \partial B & B^\circ & B^- \\ \hline \partial A & \varnothing & \neg\varnothing & \varnothing \\ A^\circ & \varnothing & \neg\varnothing & \varnothing \\ A^- & \neg\varnothing & \neg\varnothing & \neg\varnothing \end{array}$$

inside

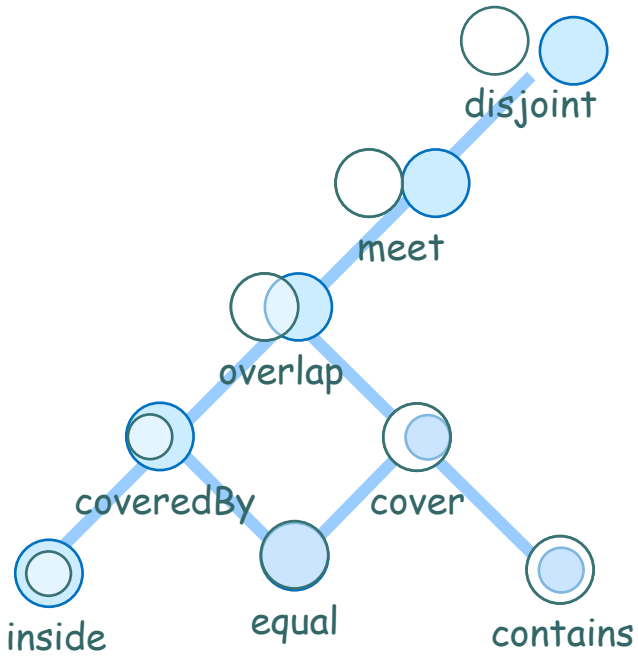


$$\begin{array}{c|ccc} & \partial B & B^\circ & B^- \\ \hline \partial A & \neg\varnothing & \neg\varnothing & \varnothing \\ A^\circ & \varnothing & \neg\varnothing & \varnothing \\ A^- & \neg\varnothing & \neg\varnothing & \neg\varnothing \end{array}$$

covered by

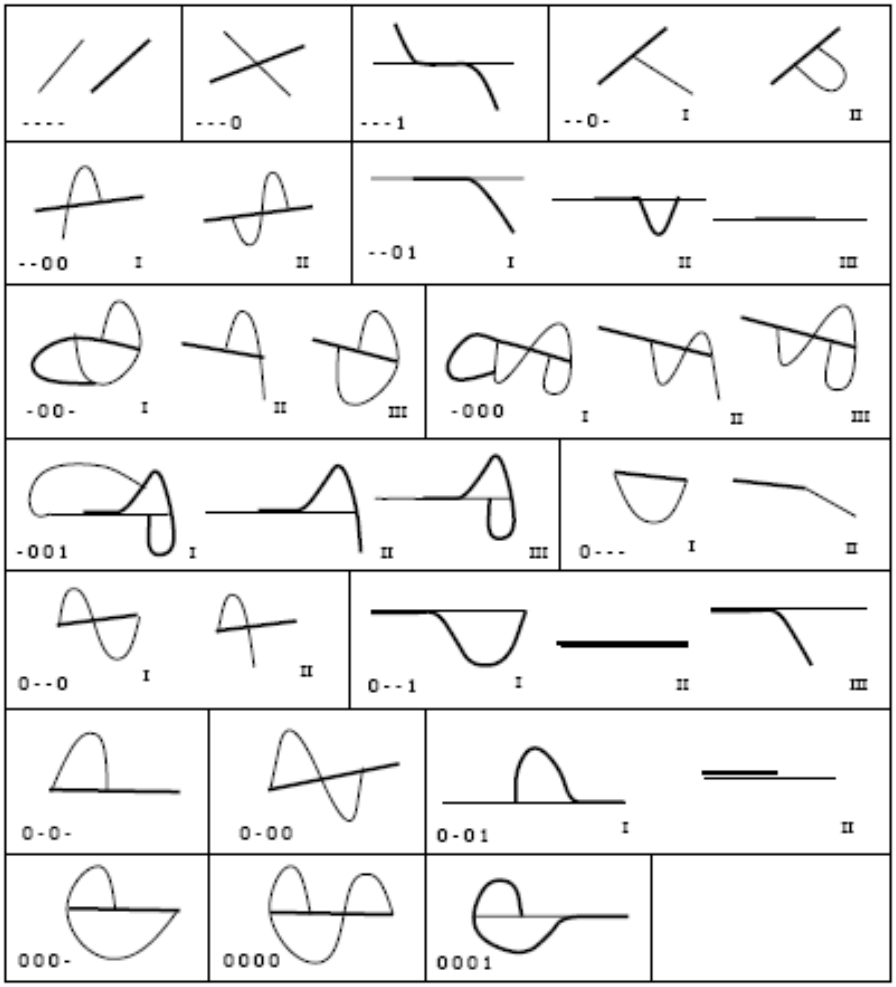
The 9-i model

- Conceptual neighbourhood diagram



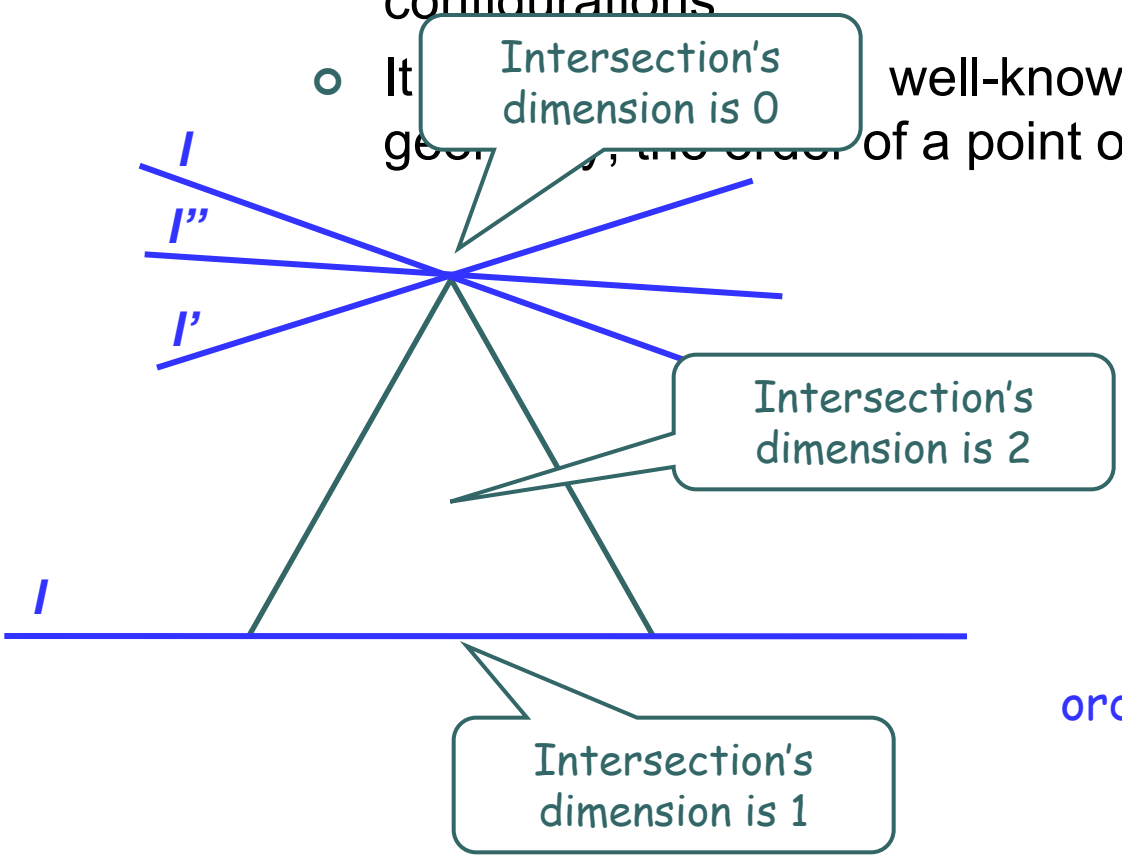
The 9-i model

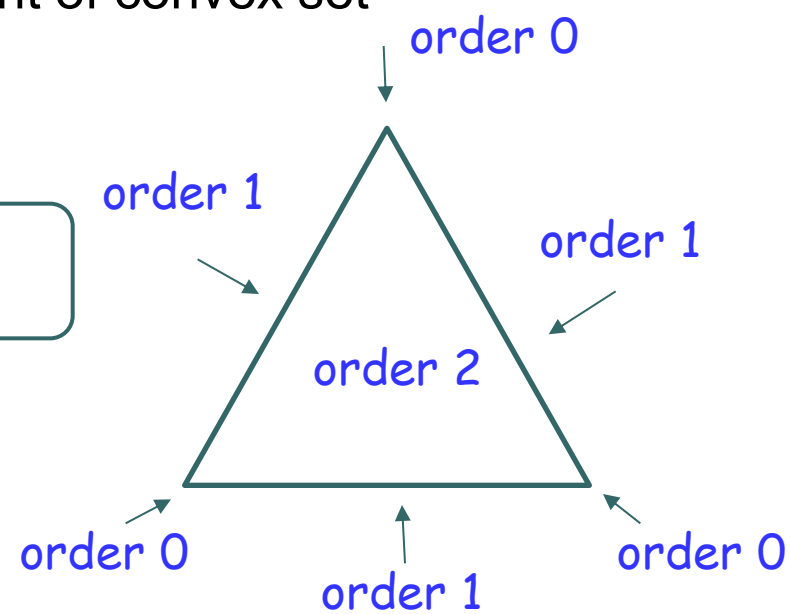
33 line-line topological relationships



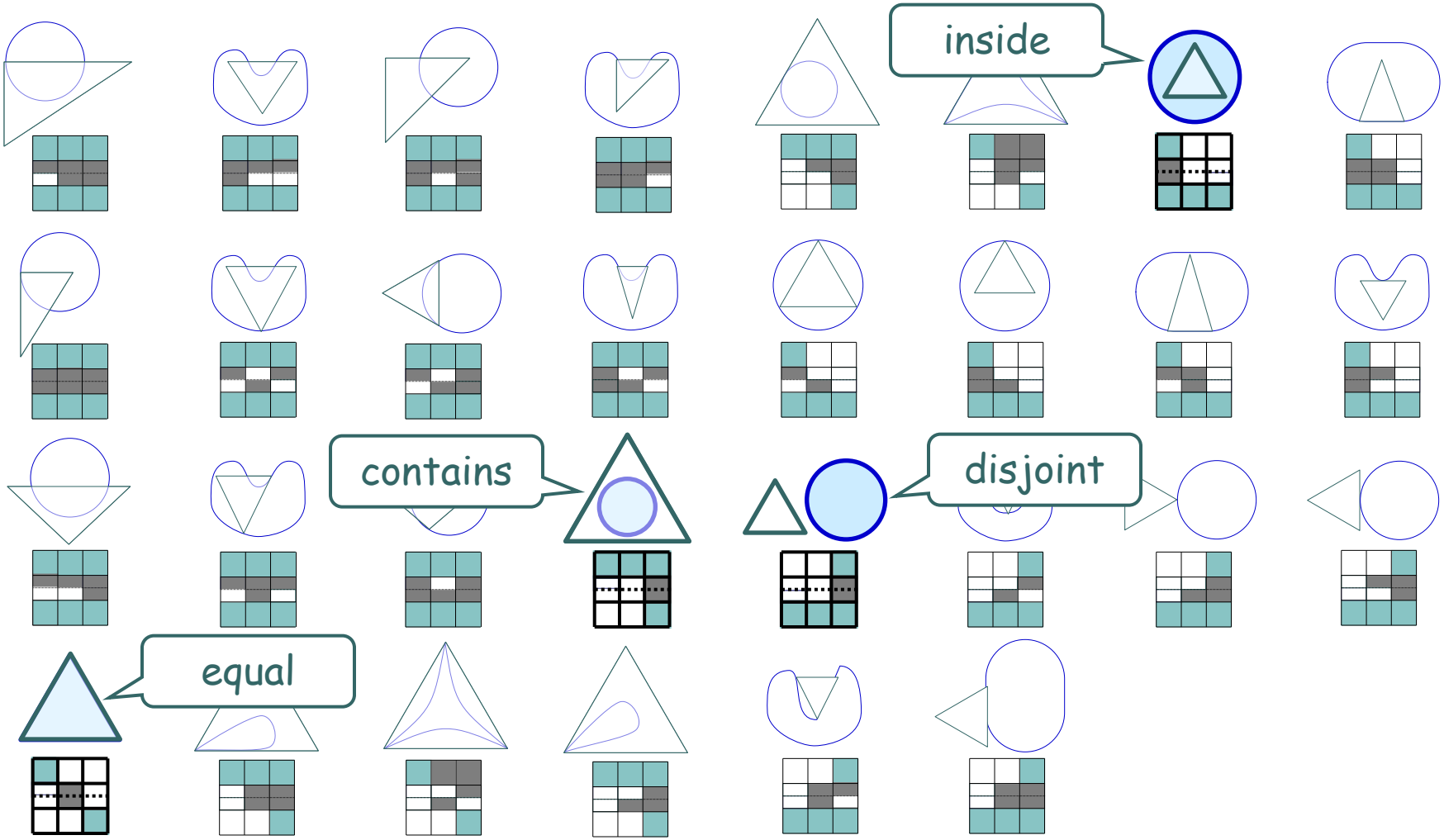
Dimensional Model

- In 2002, we proposed a refinement of binary topological relations which could handle these types of configurations
- It [illegible] well-known concept of projective ge[illegible] of a point of convex set

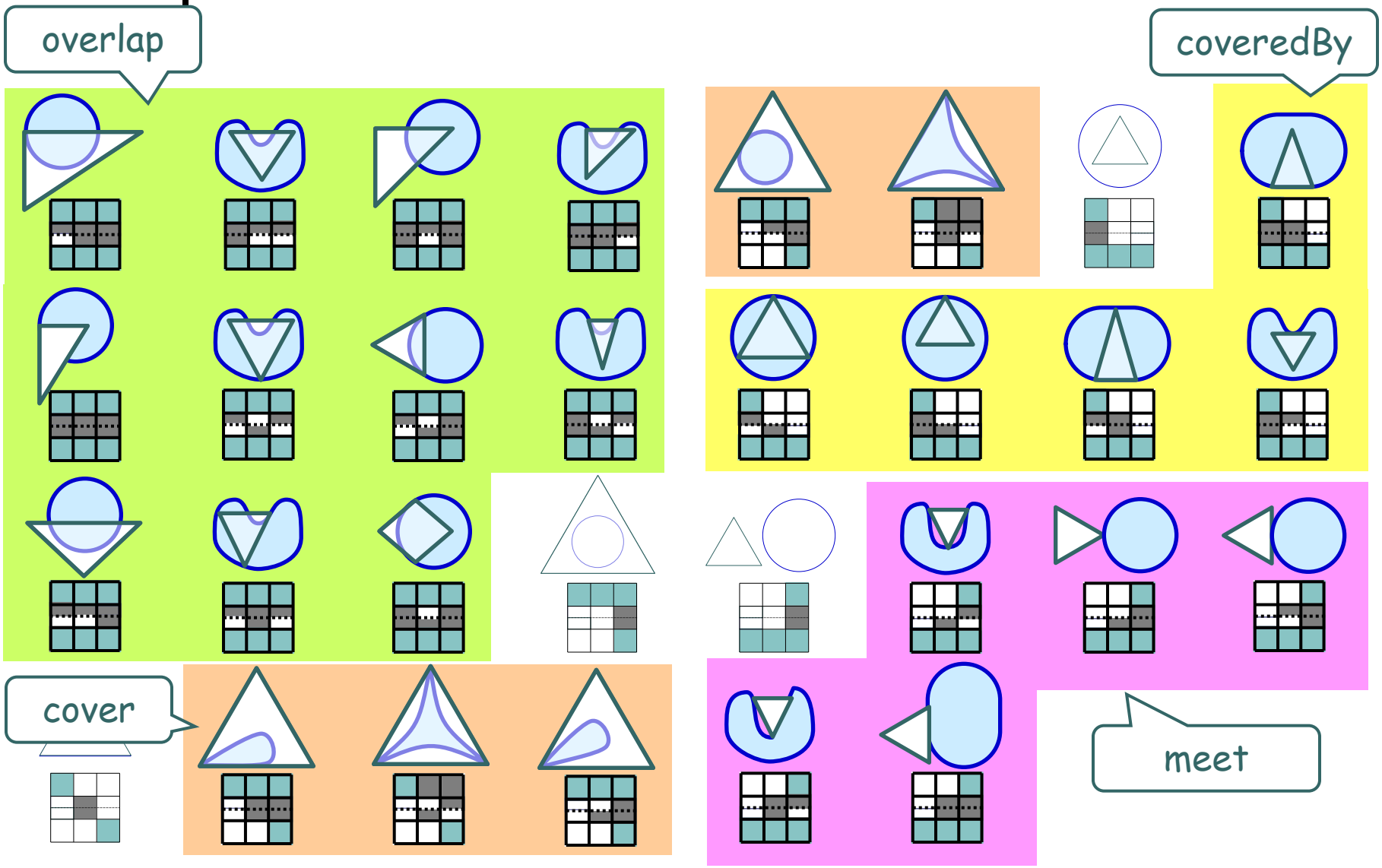




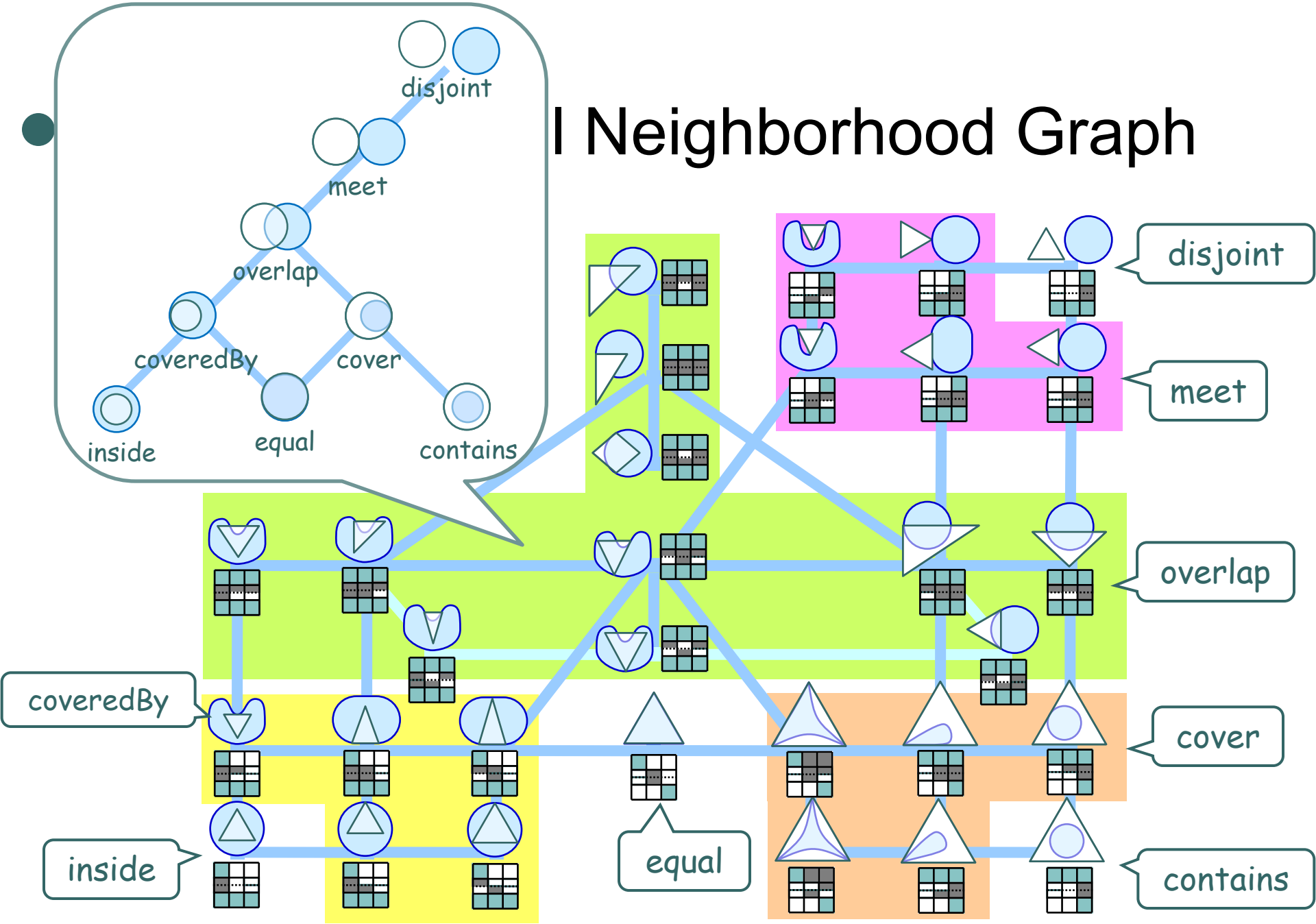
Identified Relations



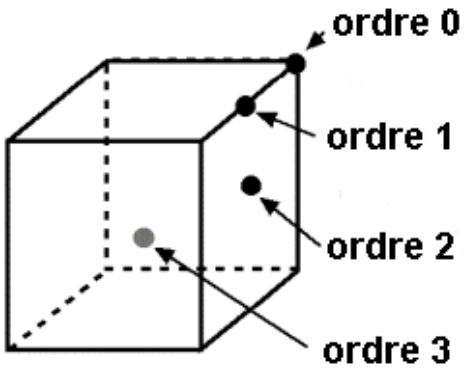
Identified Relations

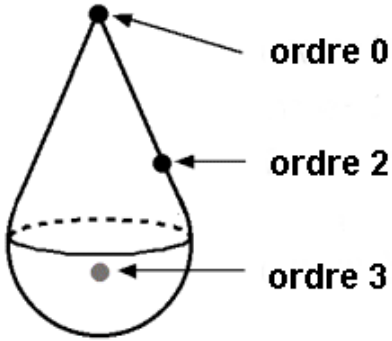


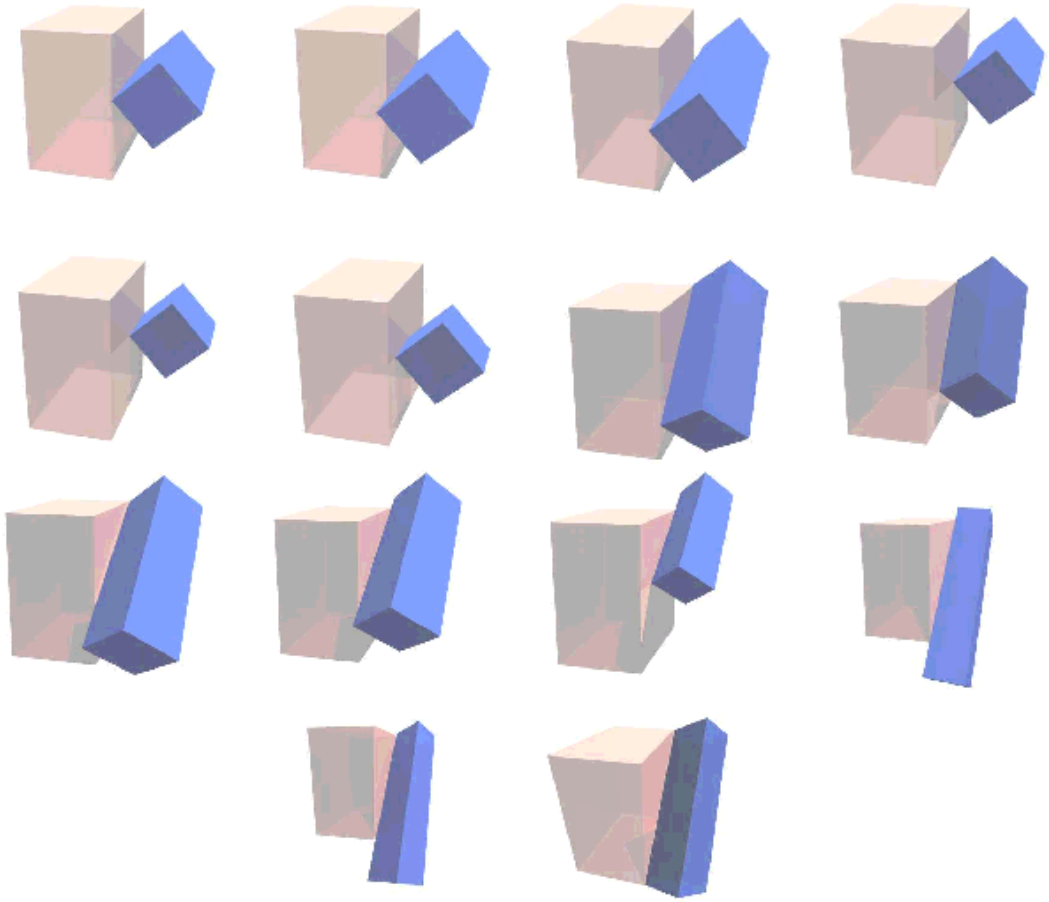
l Neighborhood Graph



Binary projective relations

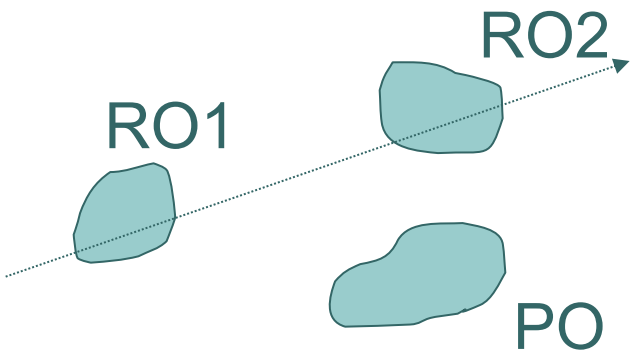






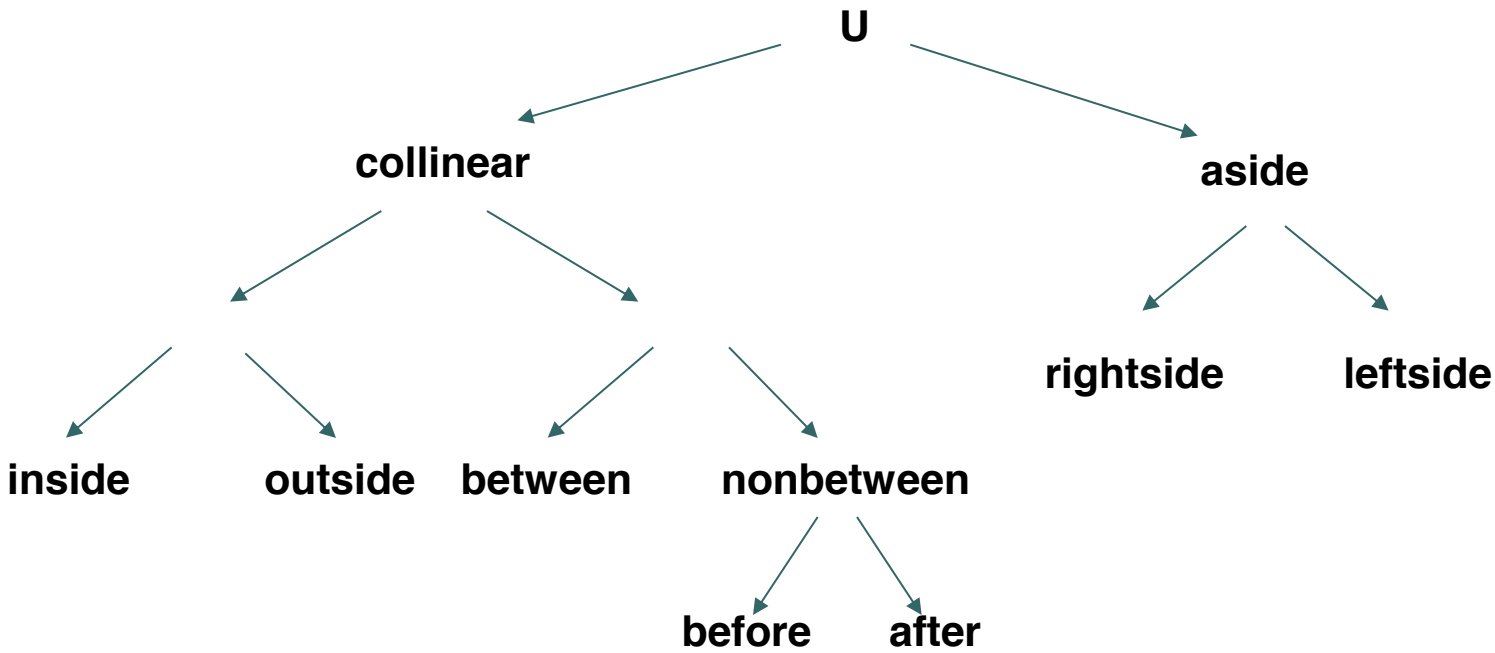
Ternary projective relationships among points in R^2

- Projective invariants
  - Collinearity properties
    - e.g., three points belong to the same line



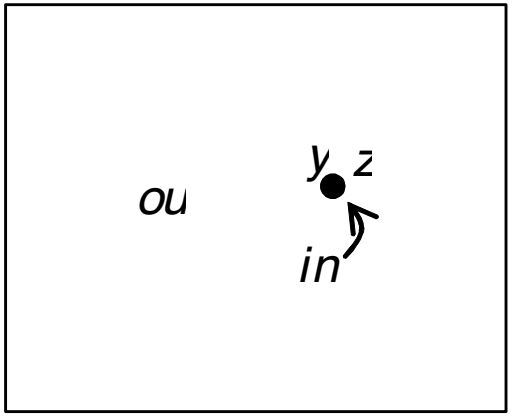
Ternary projective relationships among points in R^2

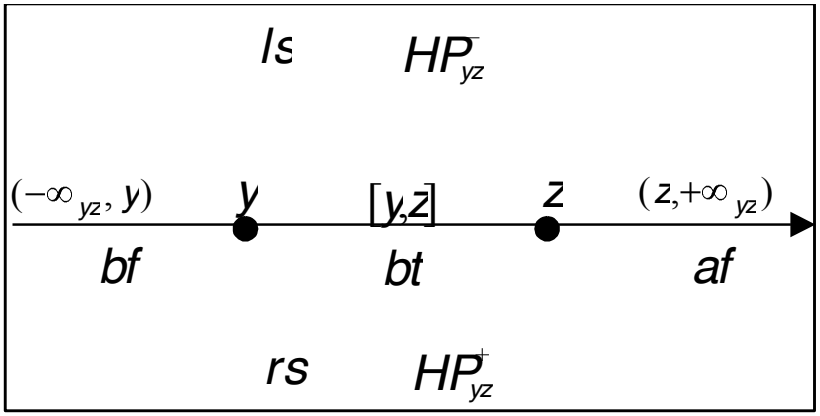
- Deriving other projective properties from collinearity



Ternary projective relationships among points in R²

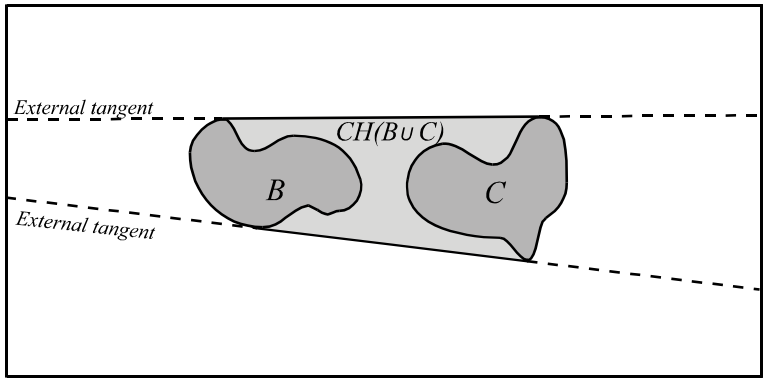
- Partition of R² based on the two reference points
- Set of JEPD relationships (7)

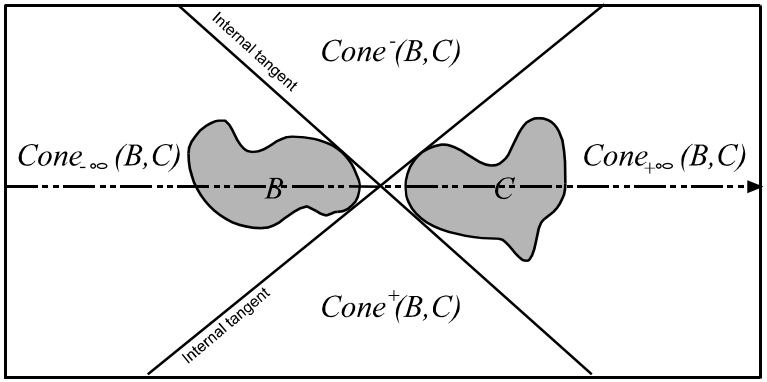




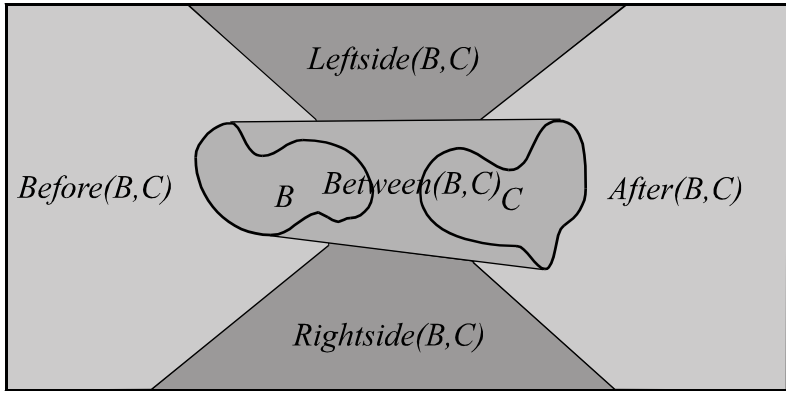
Ternary projective relationships among regions in R²

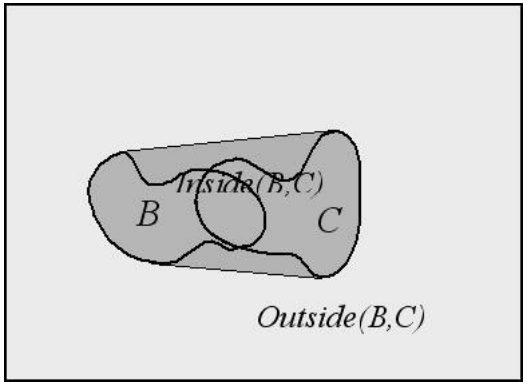
- Still based on collinearity and reference objects shapes
- Set of JEPD relationships (34)





Ternary projective relationships among regions in R^2



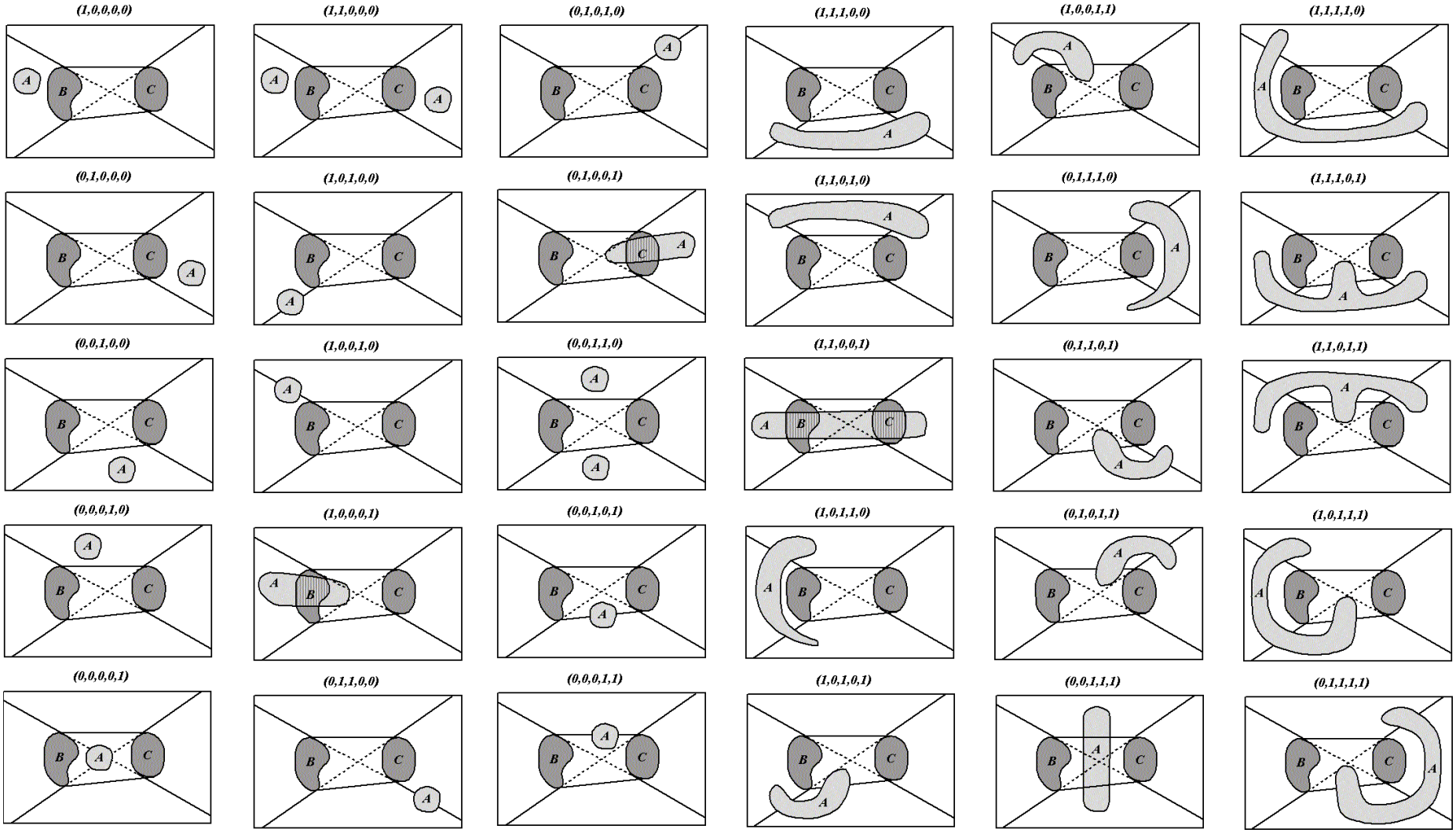


	$A \cap Leftside(B,C)$	
$A \cap Before(B,C)$	$A \cap Between(B,C)$	$A \cap After(B,C)$
	$A \cap Rightside(B,C)$	

$A \cap Inside(B,C)$	$A \cap Outside(B,C)$

ls(A,B,C) = (1 0 0 0 0 | 0 0), *bf(A,B,C)* = (0 1 0 0 0 | 0 0)

Ternary projective relationships among regions in R²



Reference

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Université de Liège

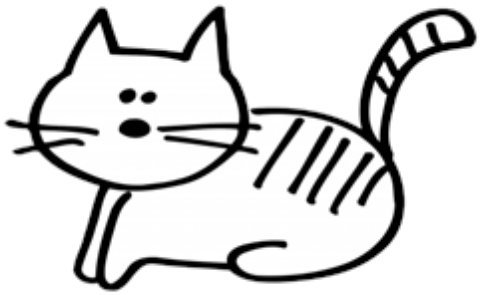
Unité de Géomatique
Geomatics Unit

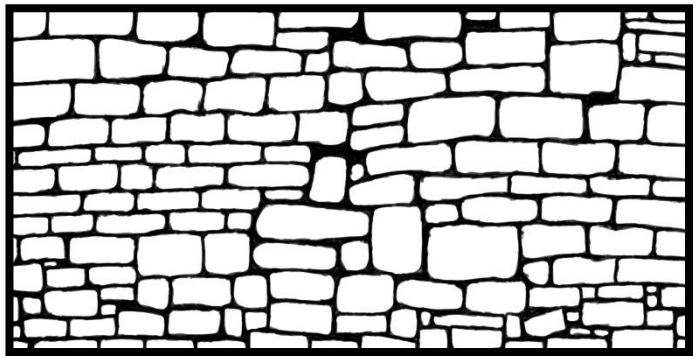
Spatiotemporal reasoning

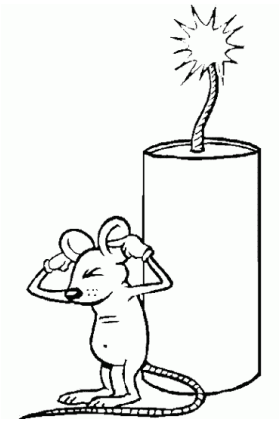
Example of identity
across space and time.

Pierre Hallot - 19th of April 2013

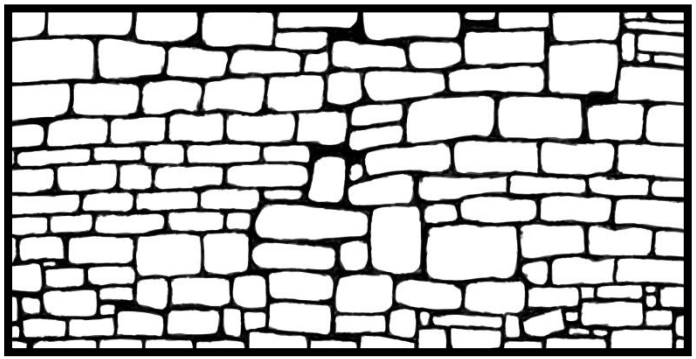
Let’s take a cat, a wall and a firecracker…



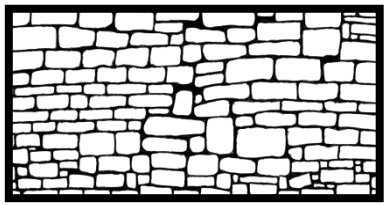




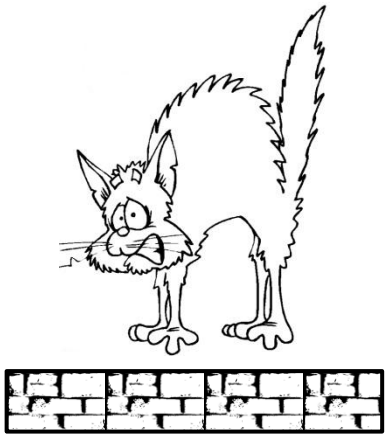
What happens if…



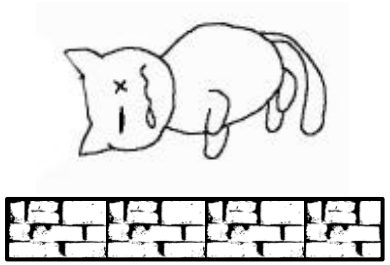
What is the cat's state?



For our point of view,
the cat is hidden…



The cat exits

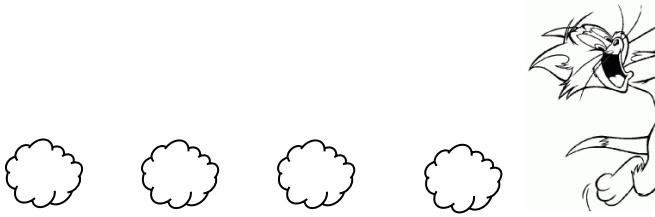


The cat does not exist anymore

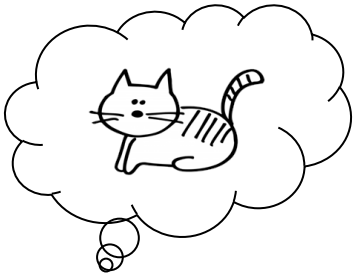
More about the cat

- Till when will the cat exist ?

- Does the cat's non-presence destroy its identity ?

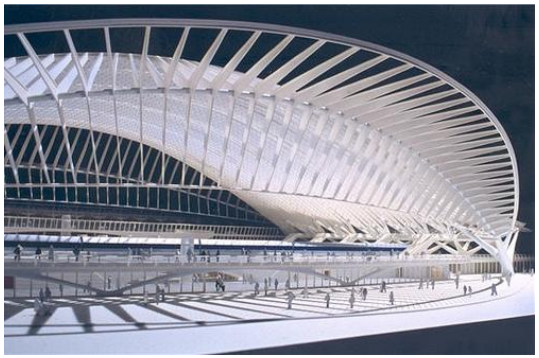


- If we remember the cat, is this relation sufficient to maintain its identity over time ?



What about a geographical object ?

- Does an object exist before its physical realisation ?



- Does an objet exist after its physical destruction?

- What about the identity of an object which only appears once a while ?

Does a geographical object may exist
before | after
its physical
realisation | destruction?

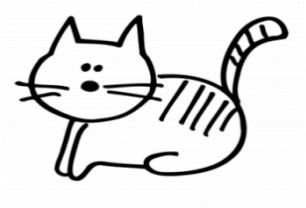
Study of identity across space and time

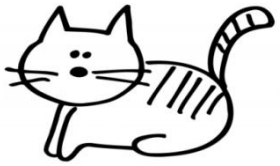
Outlines

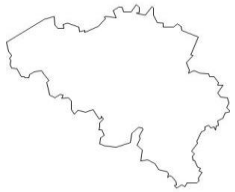
1. State-of-the-art review
2. Objectives
3. Object spatio-temporal state
4. Relationships between spatio-temporal states
5. Life and Motion Configuration
6. LMC generalization
7. Natural language interpretation

Identity

( )







Objectives

One object description

Object	Identity	Spatiality
Static	Object identity modelling ***Objective 1***	Data models| Topology | Projective | Metric
Dynamic	Identity base change ***Objective 1***	Shape evolution| Spatial transformation | Projections

Objectives

Two objects relationships descriptions

Relationship Object/Object	Identity	Space
Static	***Objective 2***	RCC | 9-i | CBM
Dynamic	***Objective 3***	QTC | relative trajectories | REMO |
	Objective 4	

1 State of the art

2 Objectives

3 Object spatio-temporal states

Relationships between spatio-temporal states

Life and Motion Configuration

LMC generalisation

Natural language interpretation

Workspace

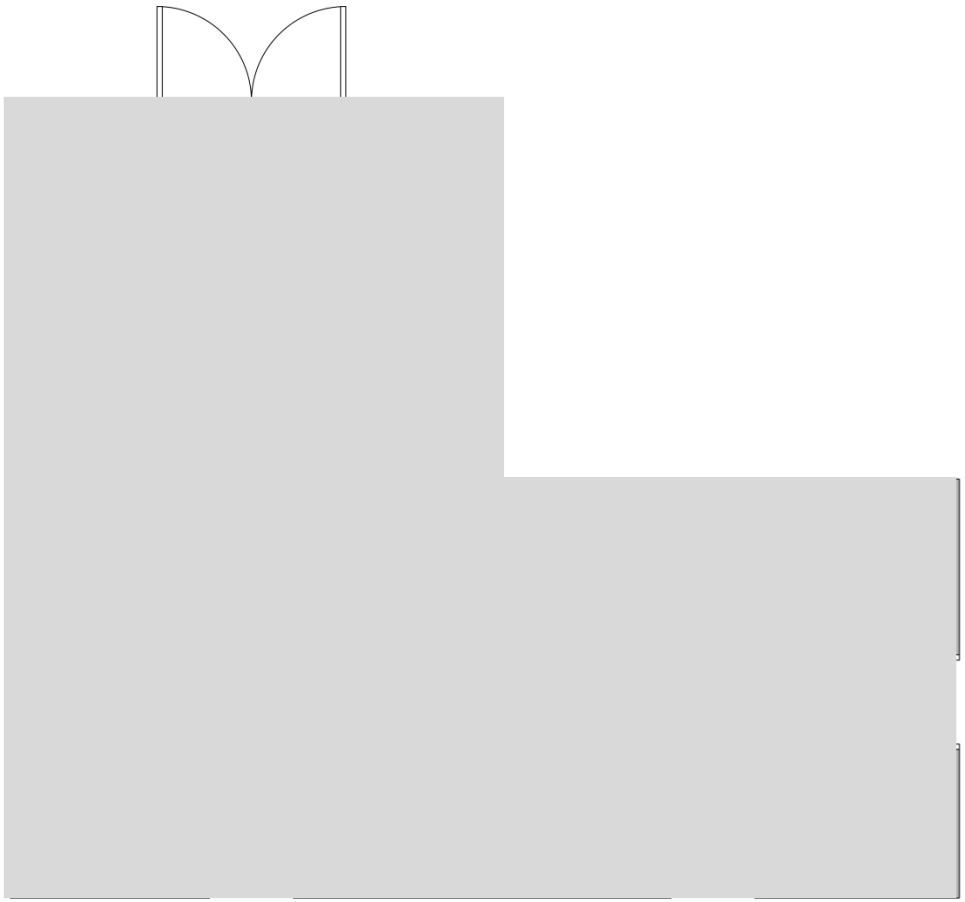
- Defined as

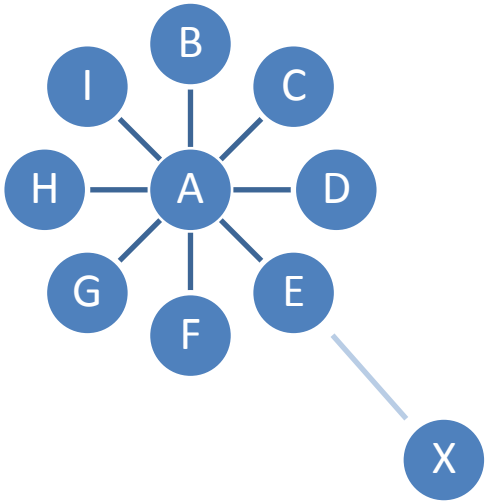
{ }

:

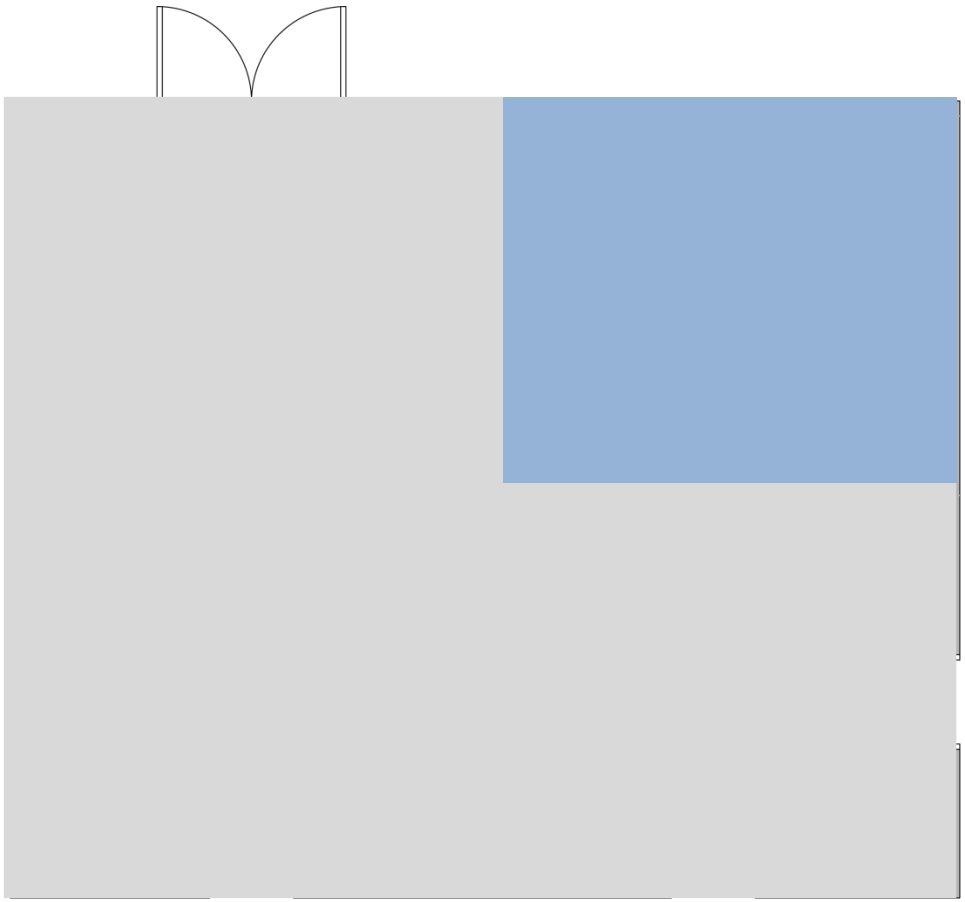
Visibility space | Geographical space |
Conceptual space | Mathematical space |
…

Workspace



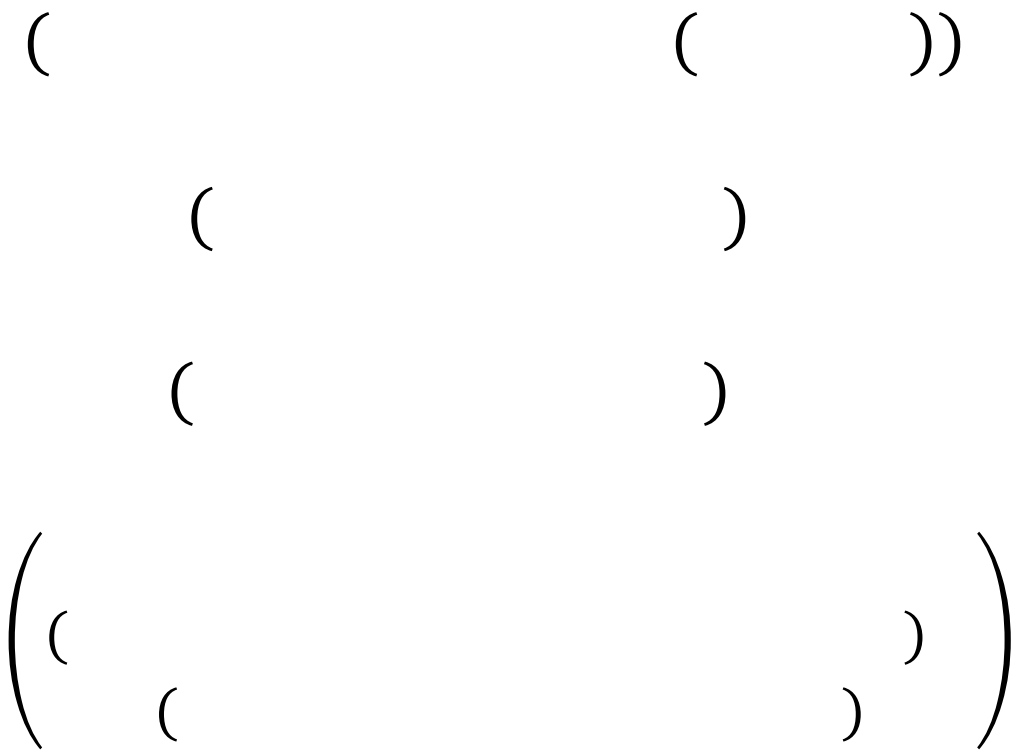


Workspace

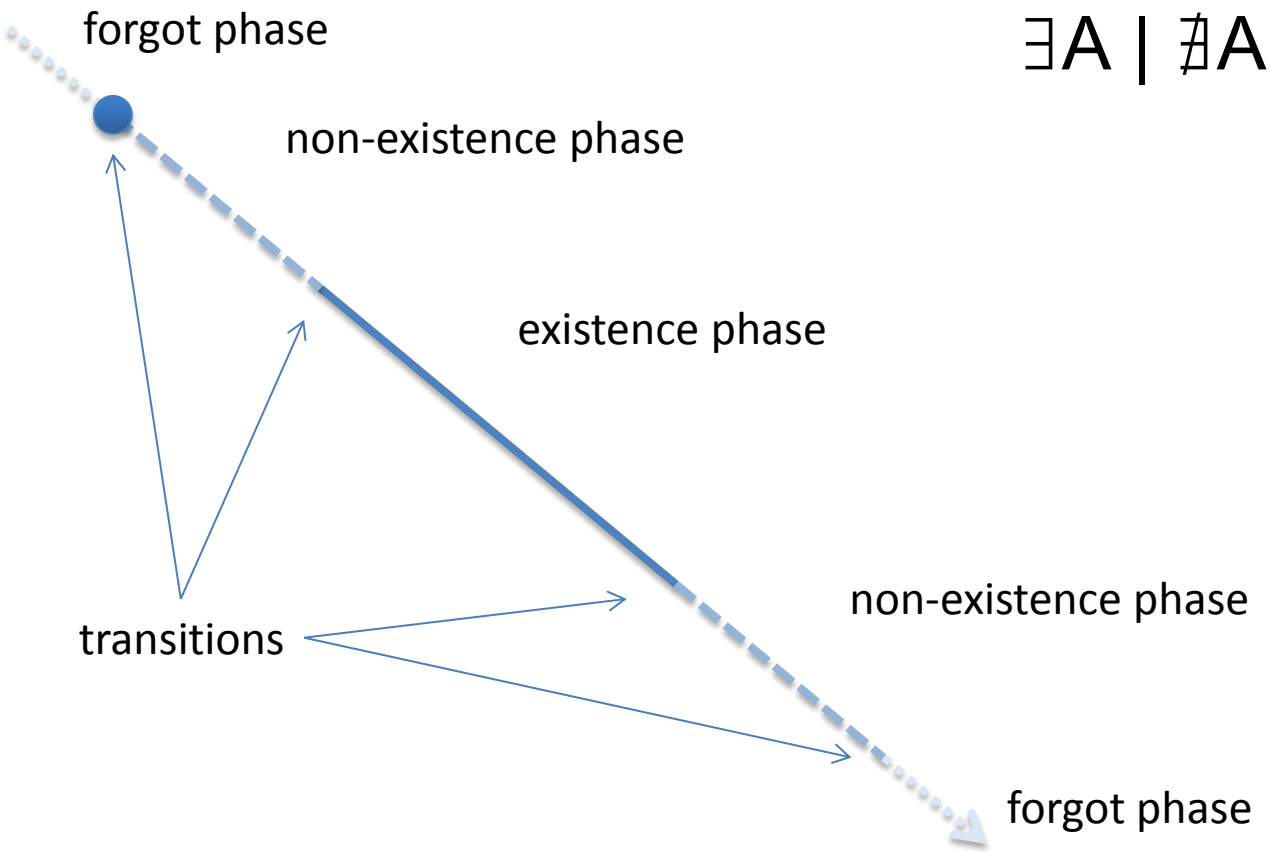


Object spatio-temporal state

Non-existent | Non-present | Present | Transition

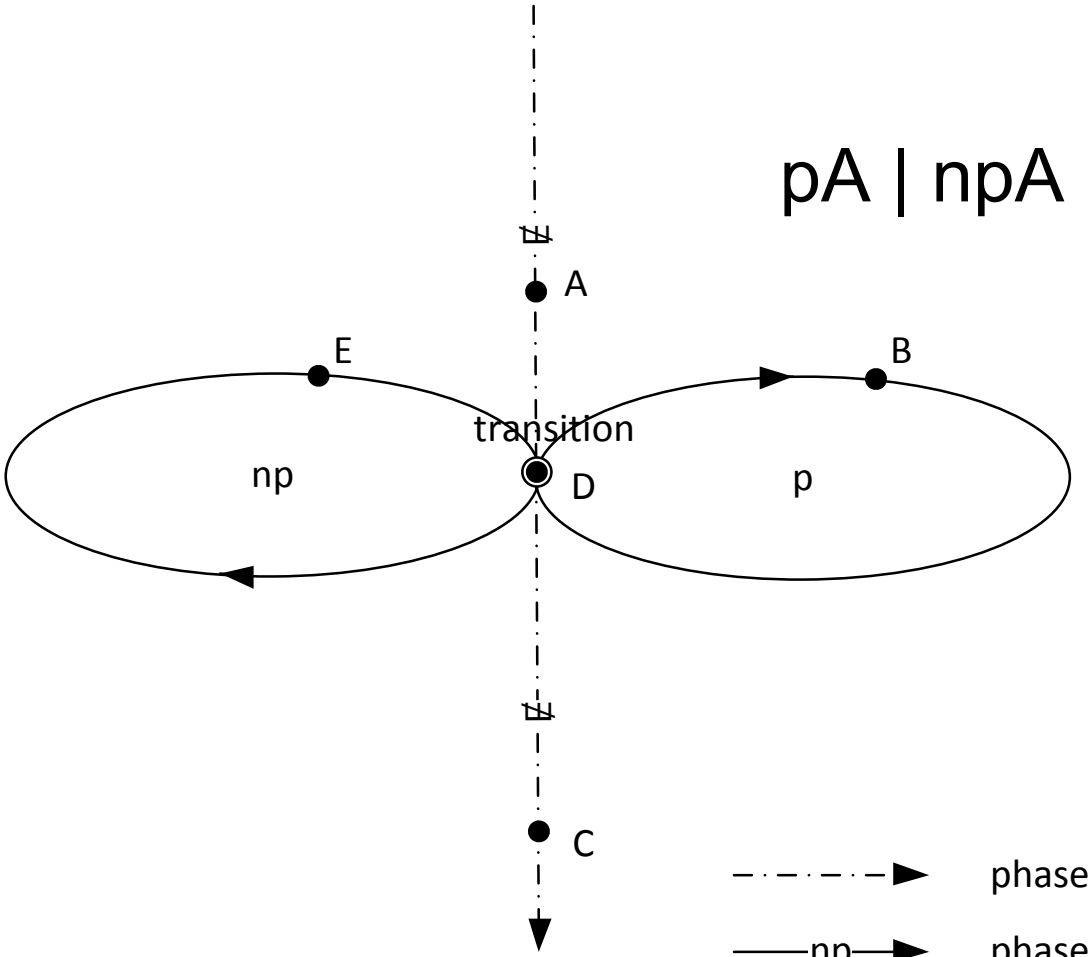


Conceptual representation



$\exists A \mid \nexists A \mid tA \mid \emptyset$

Conceptual representation



pA | npA | ∄A | tA

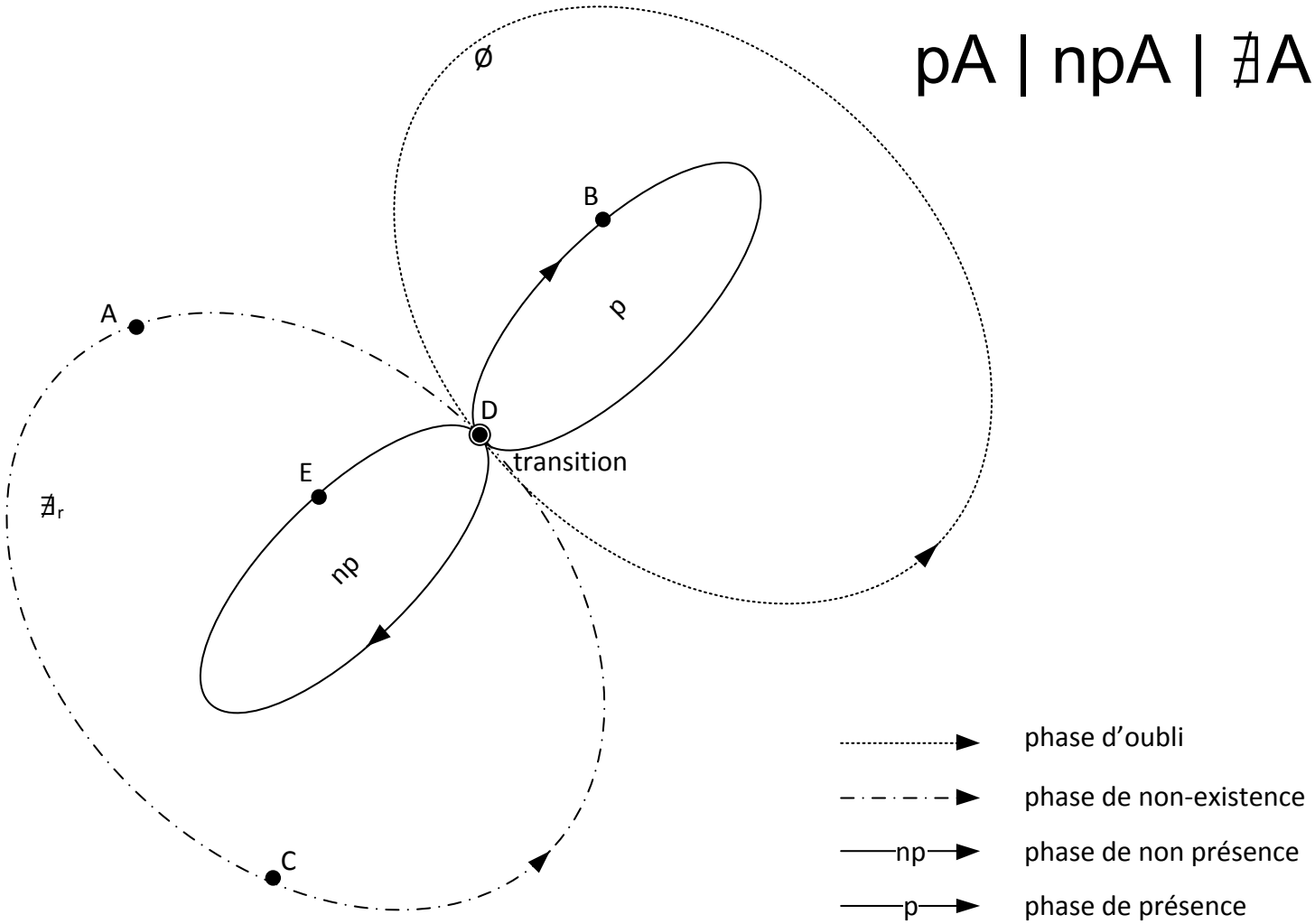
phase de non-existence

np phase de non présence

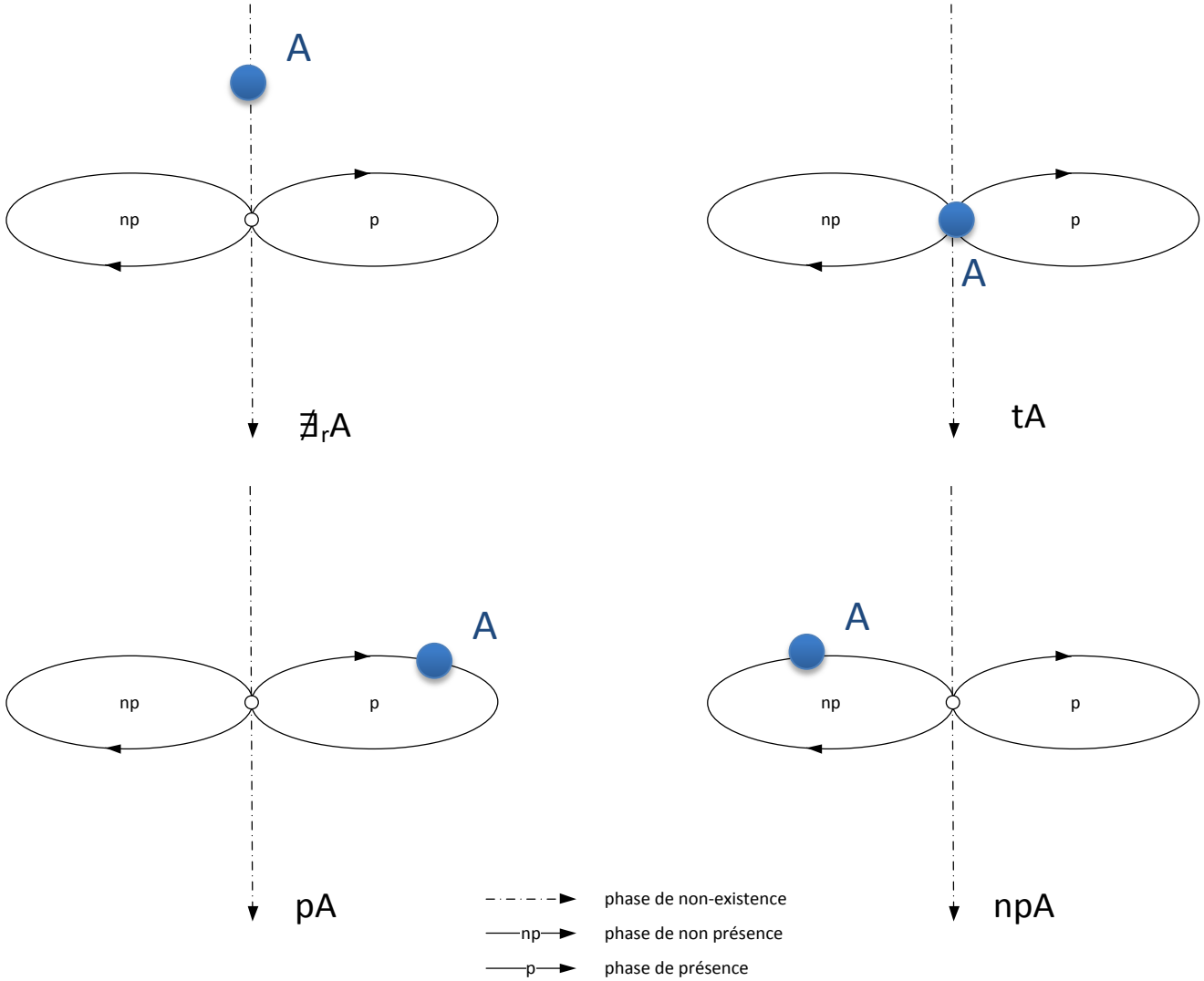
p phase de présence

Conceptual representation

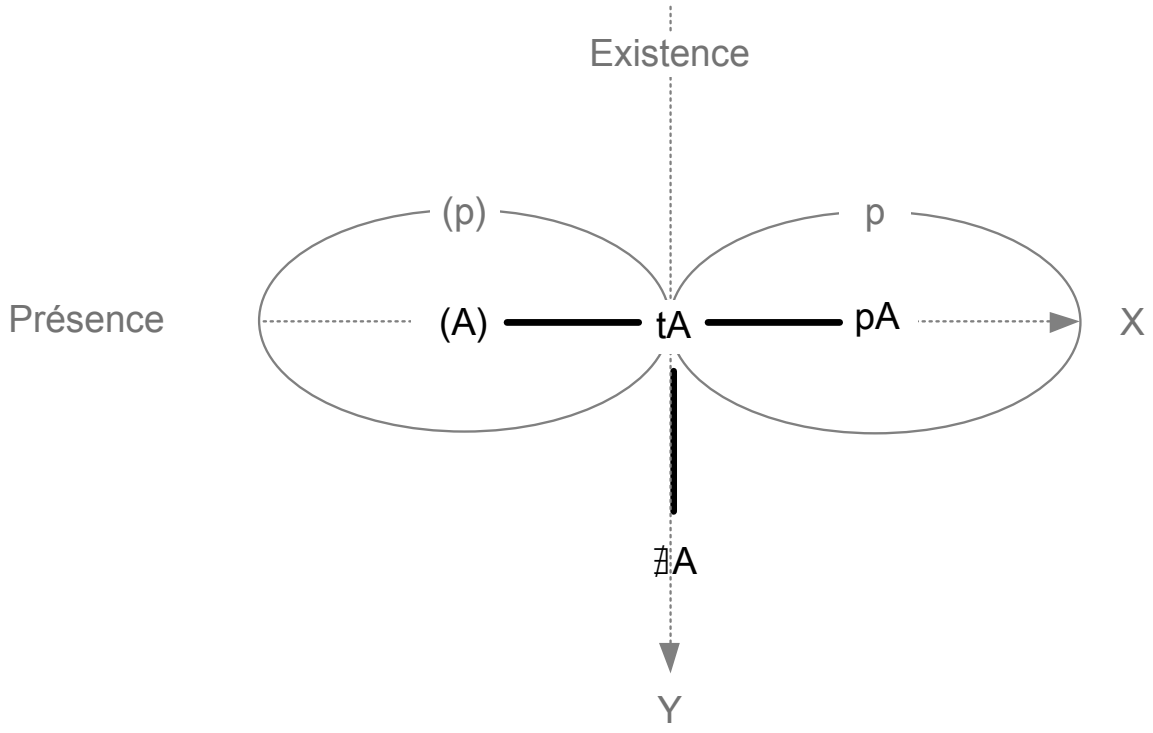
pA | npA | ∄A | tA | Ø



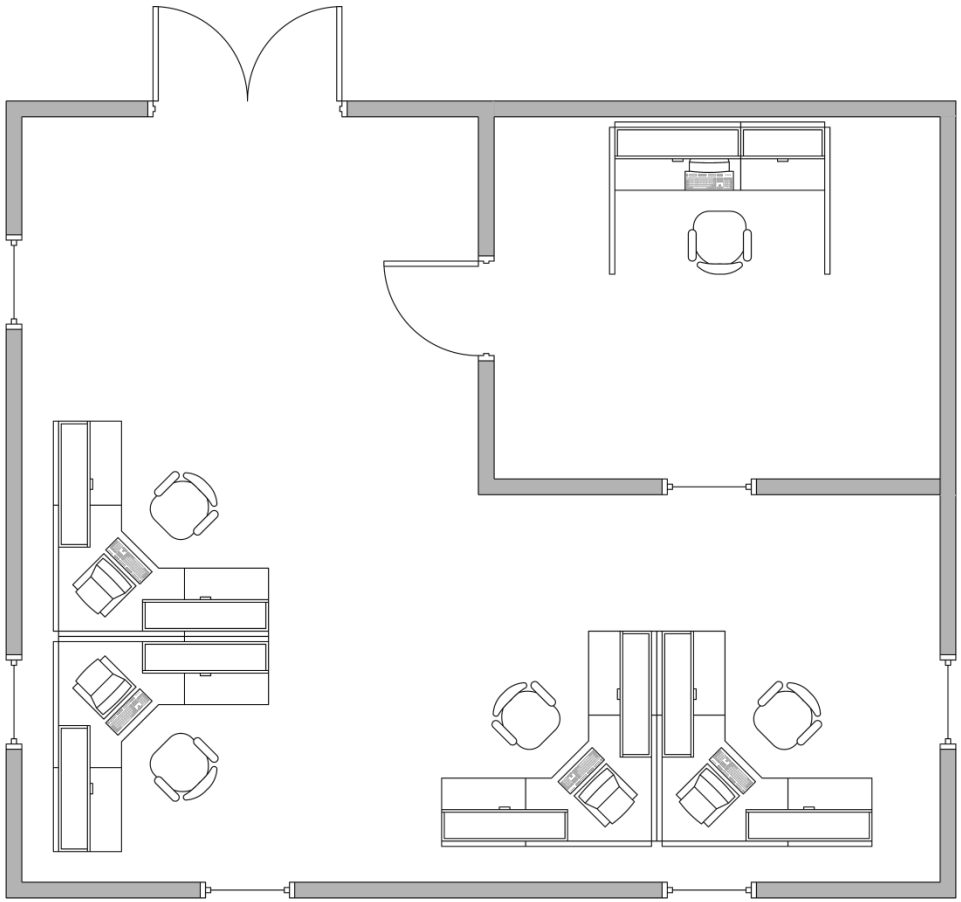
Conceptual representation

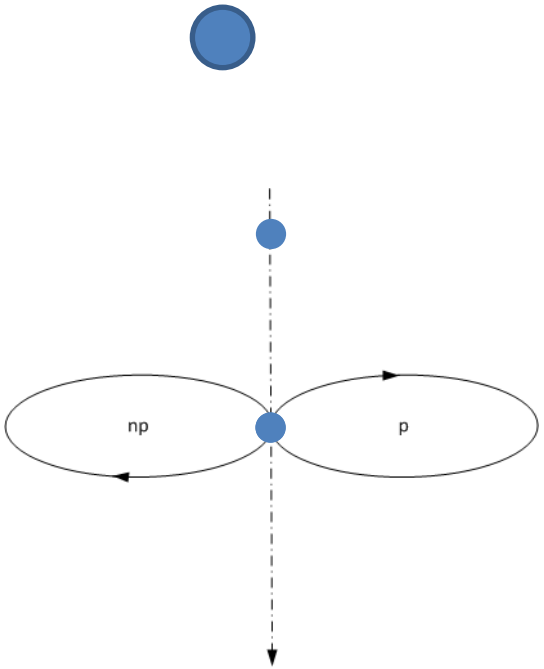


Conceptual neighbourhood graph



Object spatio-temporal state





A tA npA tA pA

1 State of the art

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4 Relationships between spatio-temporal states

Life and Motion Configuration

LMC generalisation

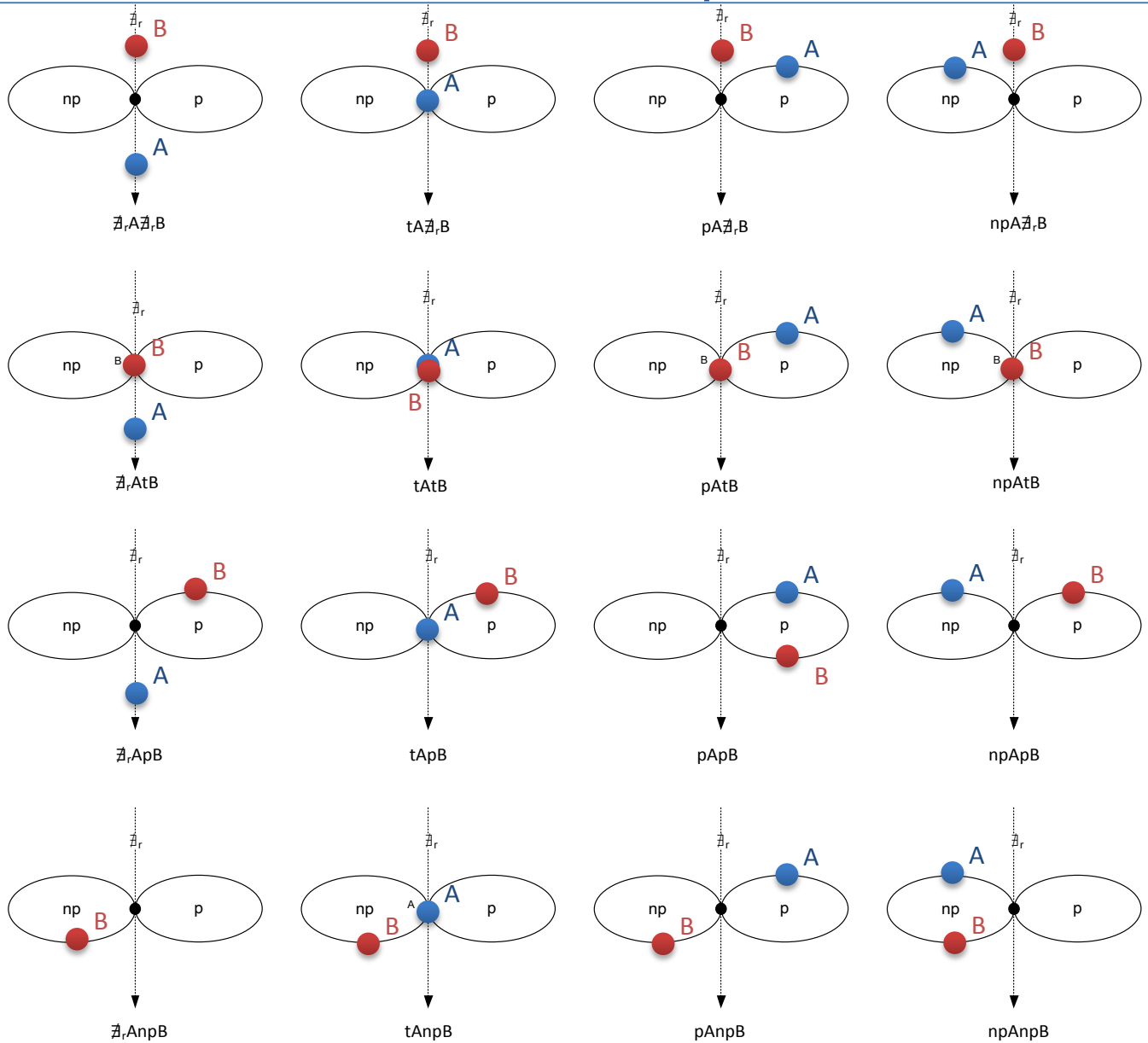
Natural language interpretation

STS-i relationships

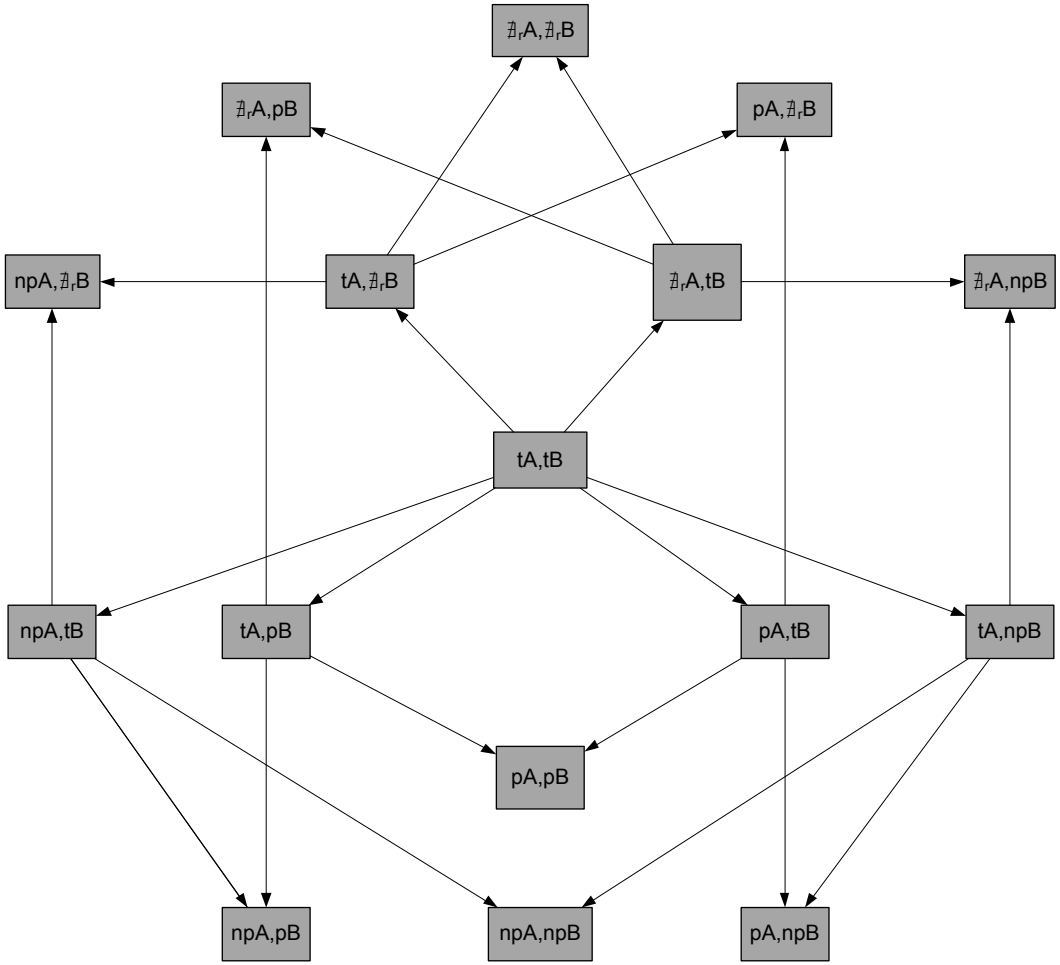
- 16 relationships between two objects
  - Relationships between identity state of objects
  - Possibility to take a spatial logic into account when objects are both present

$$R_{A-B} = \left\{ \begin{array}{l} \acute{o}_r A - \acute{o}_r B,\ pA - \acute{o}_r B,\ npA - \acute{o}_r B, \\ tA - \acute{o}_r B, \acute{o}_r A - pB,\ pA - pB, \\ npA - pB, tA - pB, \acute{o}_r A - npB, \\ pA - npB, npA - npB, tA - npB, \\ \acute{o}_r A - tB,\ pA - tB, npA - tB, tA - tB \end{array} \right\}$$

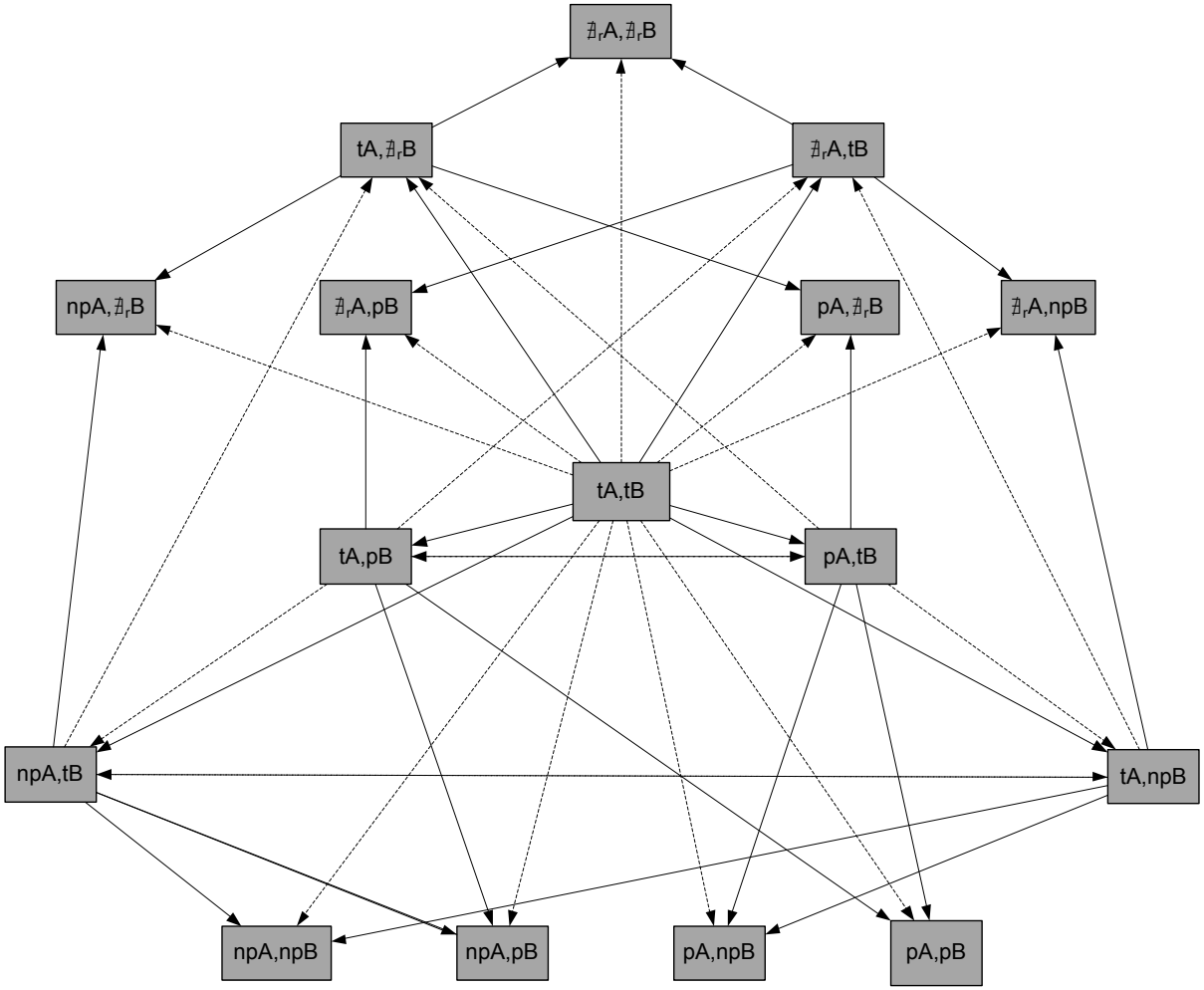
STS-i relationships



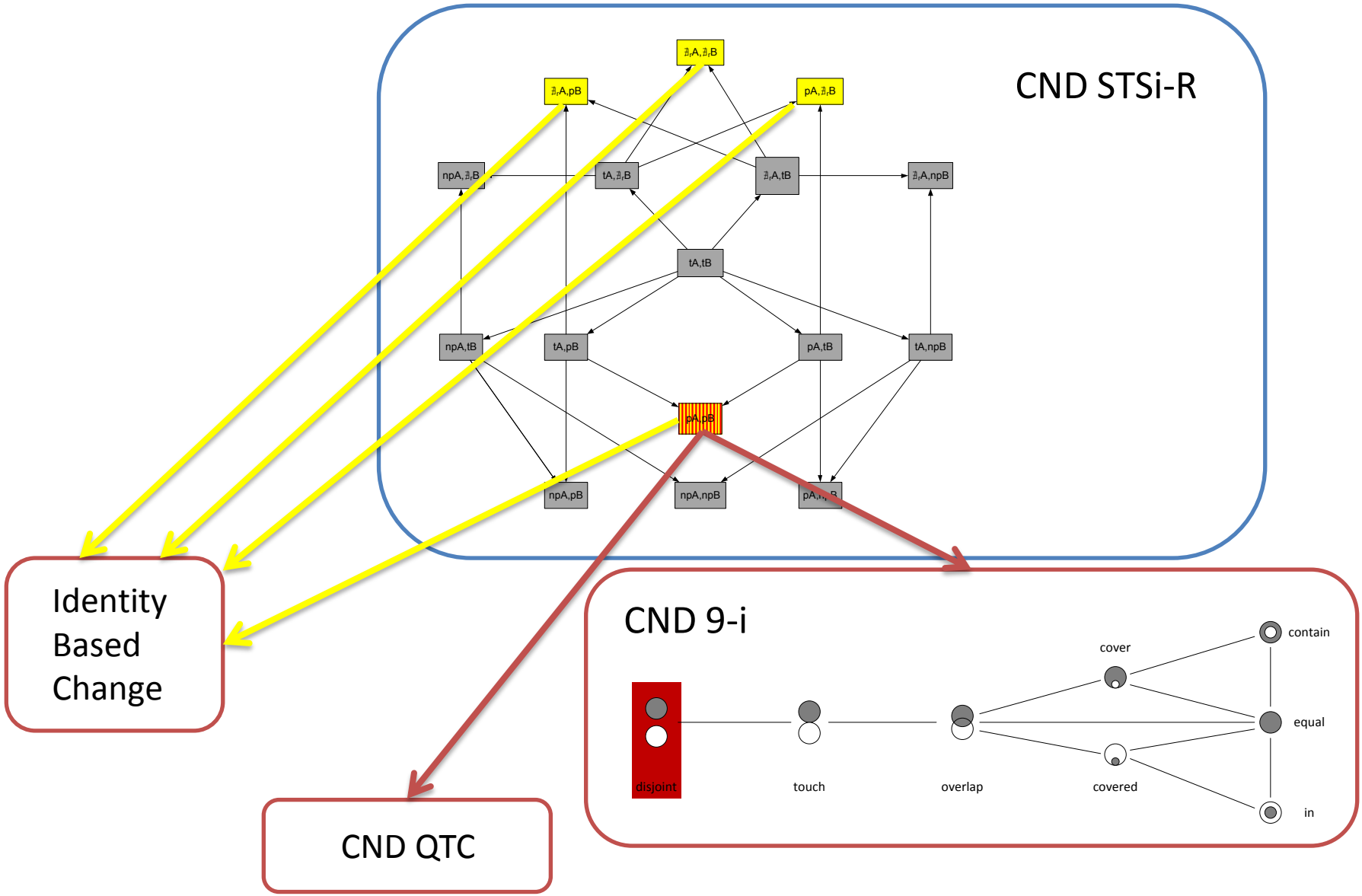
CND | 1 change


∄rA,∄rB
∄rA,pB
pA,∄rB
npA,∄rB
tA,∄rB
∄rA,tB
∄rA,npB
tA,tB
npA,tB
tA,pB
pA,tB
tA,npB
pA,pB
npA,pB
npA,npB
pA,npB

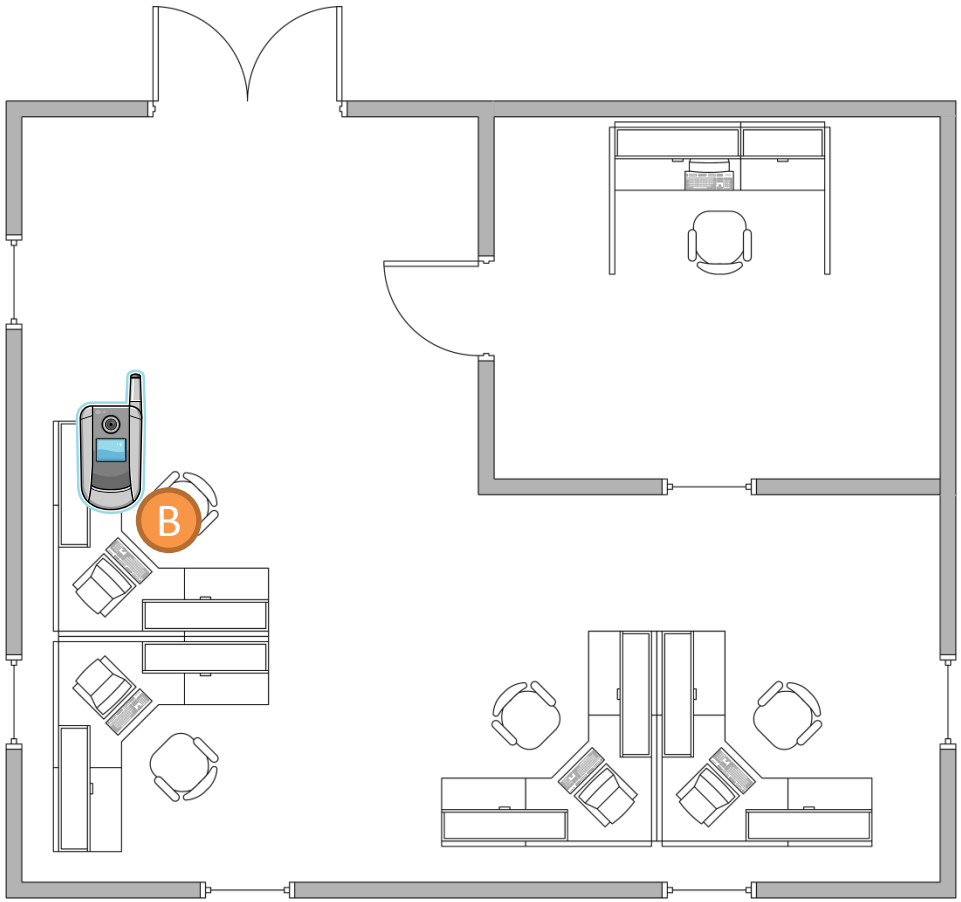
CND | 2 change

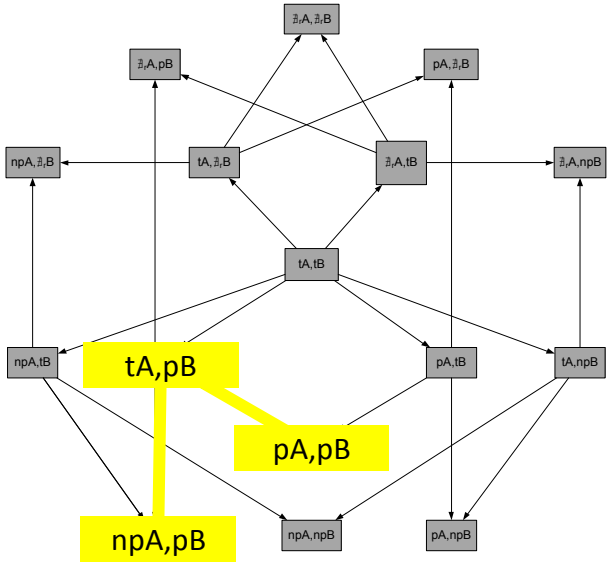

$\not{a}_r$A,$\not{a}_r$B
tA,$\not{a}_r$B
$\not{a}_r$A,tB
npA,$\not{a}_r$B
$\not{a}_r$A,pB
pA,$\not{a}_r$B
$\not{a}_r$A,npB
tA,tB
tA,pB
pA,tB
npA,tB
tA,npB
npA,npB
npA,pB
pA,npB
pA,pB

CNDs combination



STS-i relationships





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4 Relationships between spatio-temporal states

5 Life and Motion Configuration

LMC generalisation

Natural language interpretation

Life and motion configuration

- Formalization of identity relationships evolution between two objects

- Formal language | Visual language

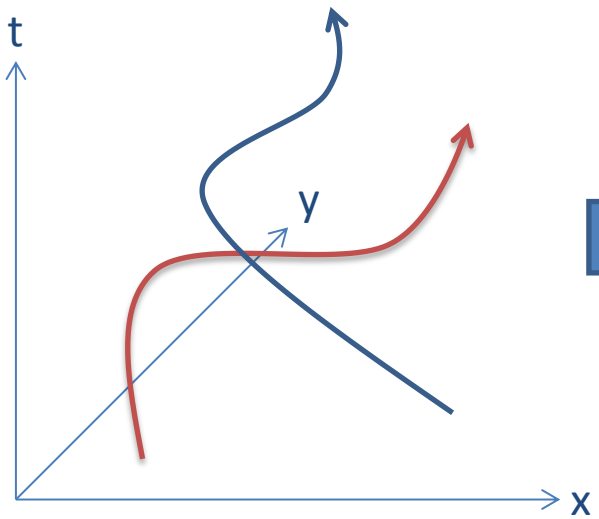
- Exhaustive computation of possible change

$$LMC(AB)_n @ \; n(R_{AB}(STS-i))$$

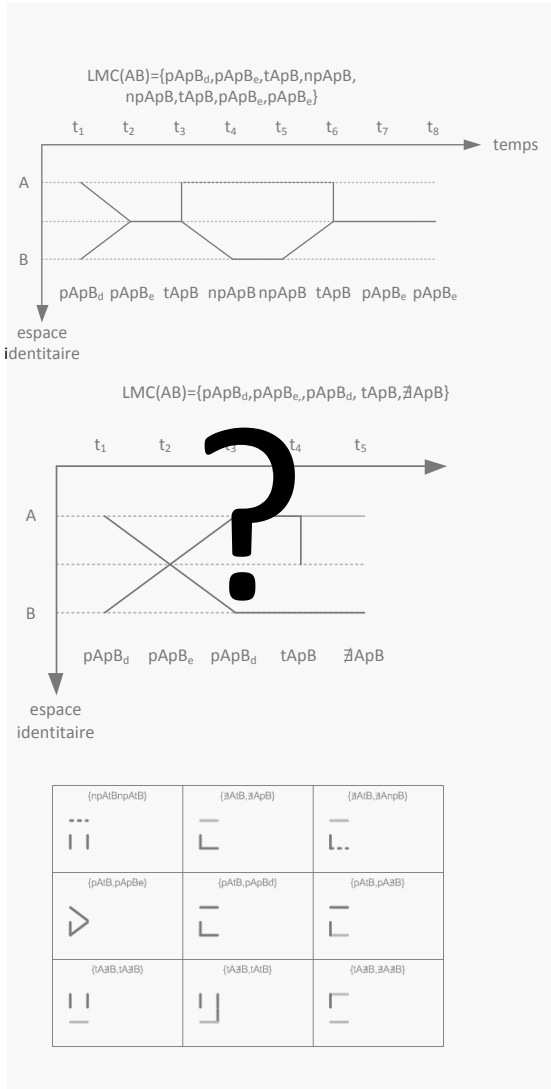
$$avec \quad n \in \mathrm{N}$$

LMC

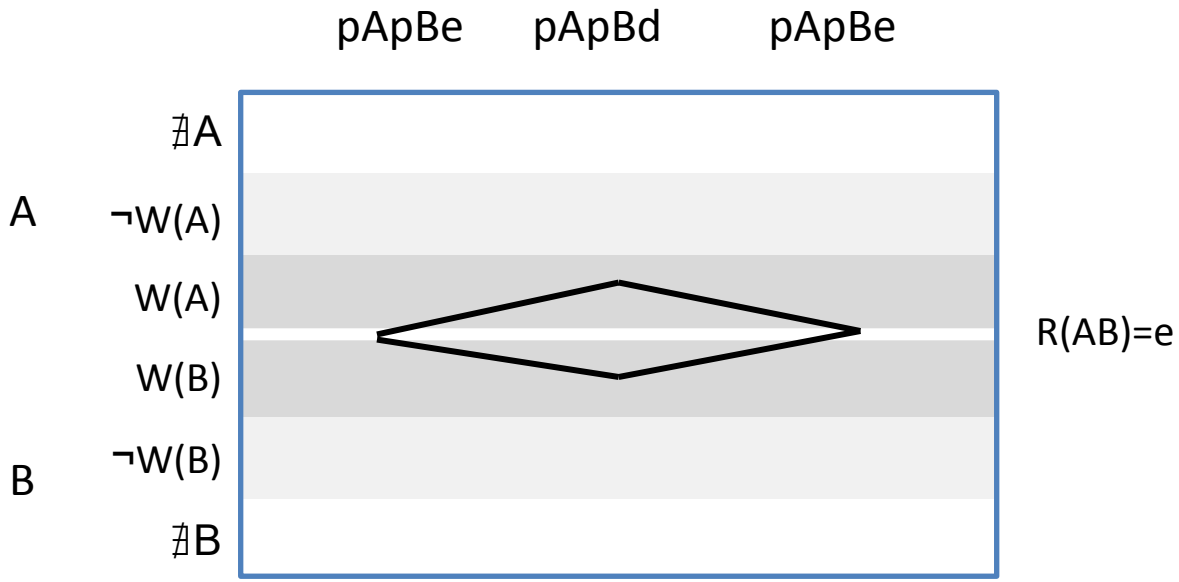
3D temporal space



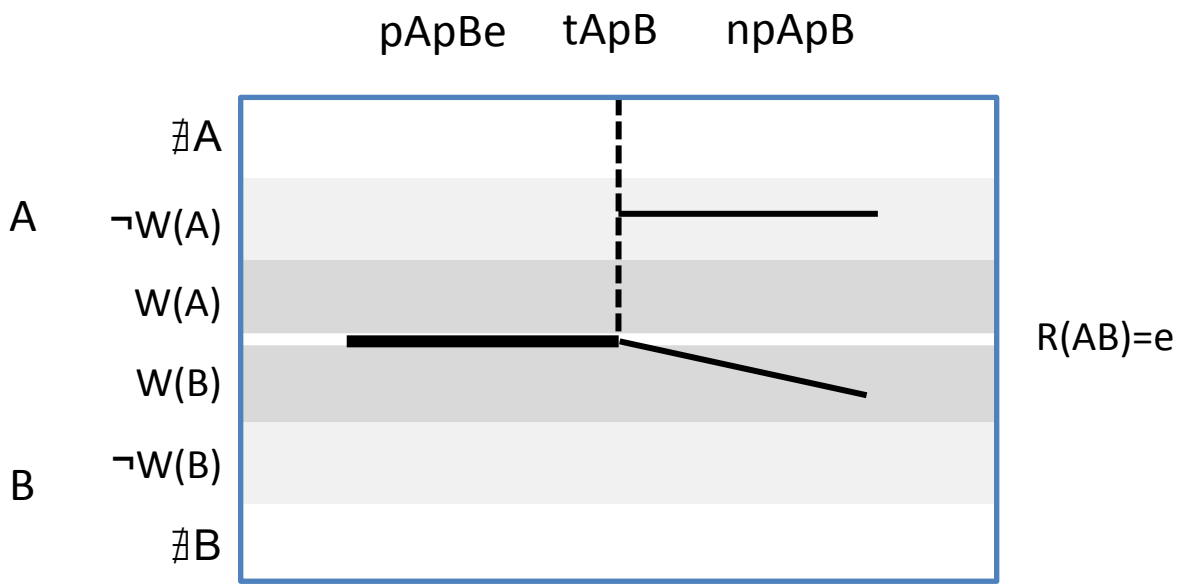
Formalization

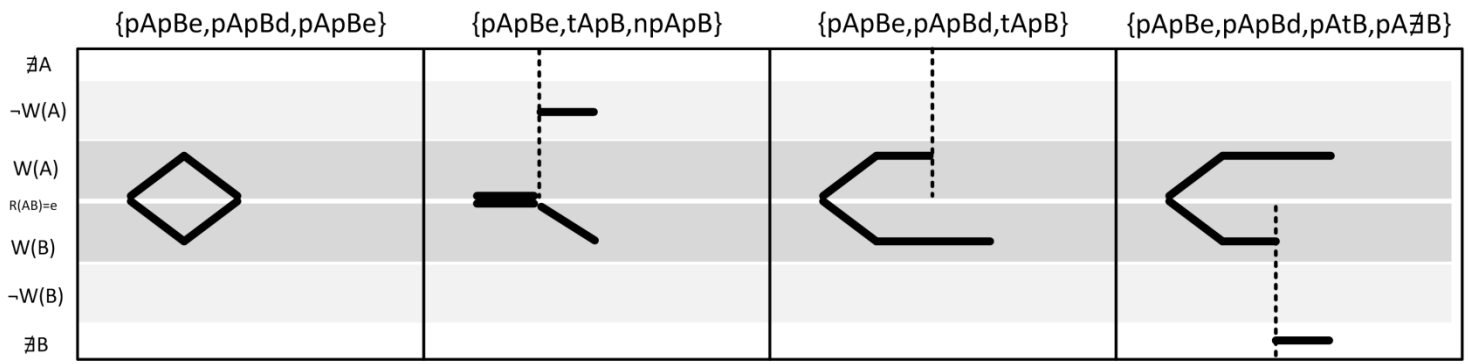


LMC | Visual language

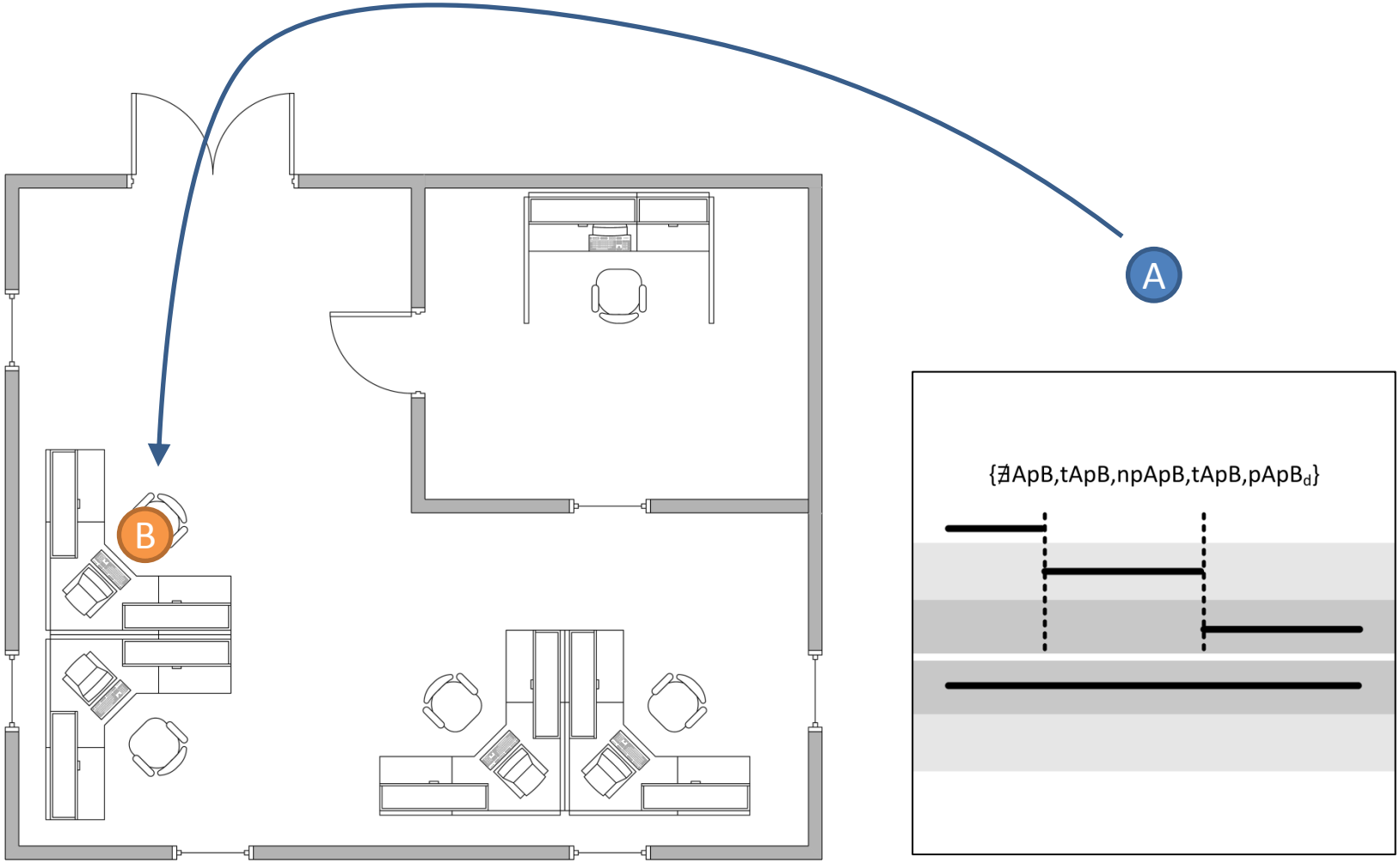


LMC | Visual language

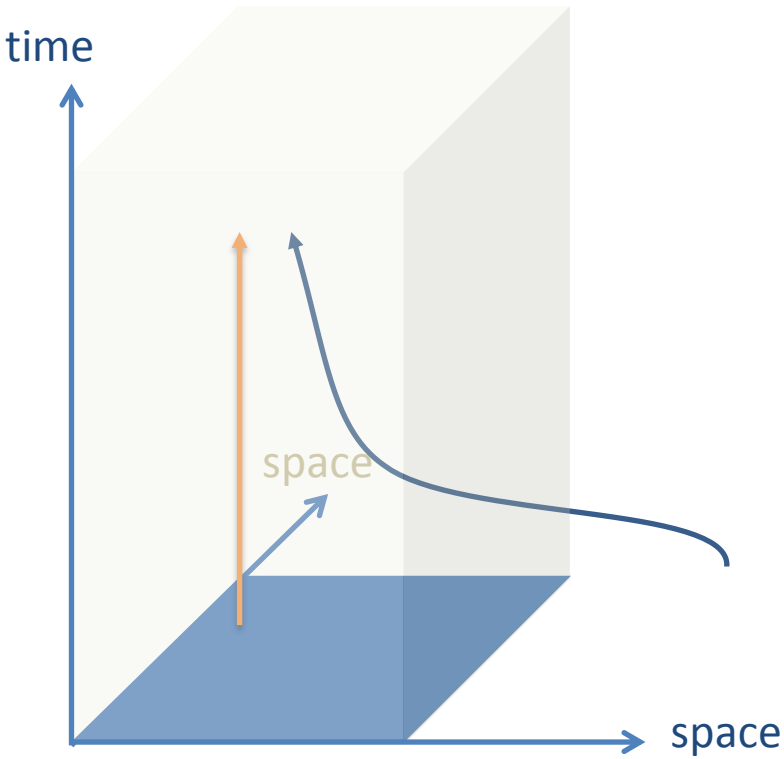


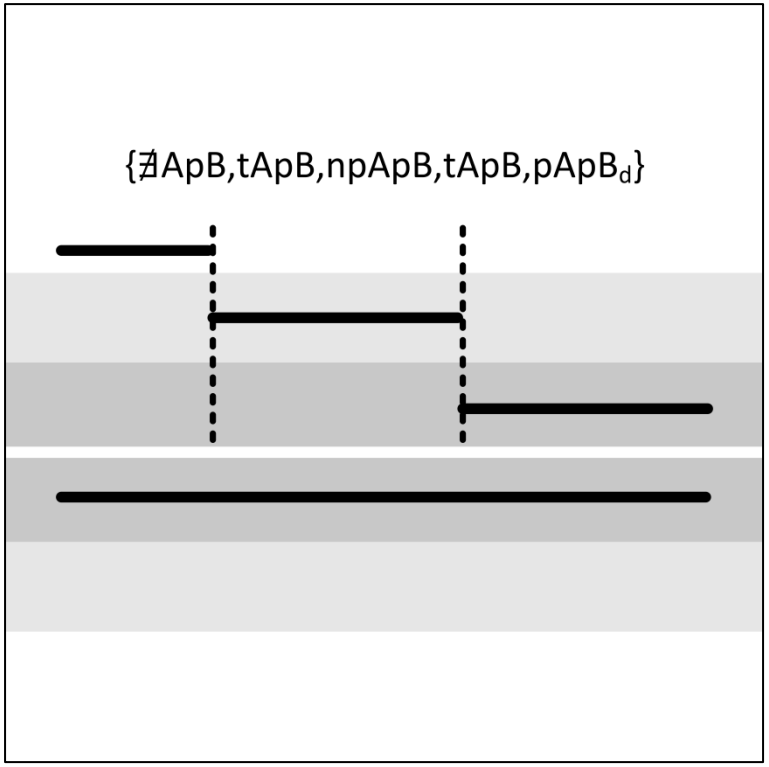


Life and motion configuration



Life and motion configuration





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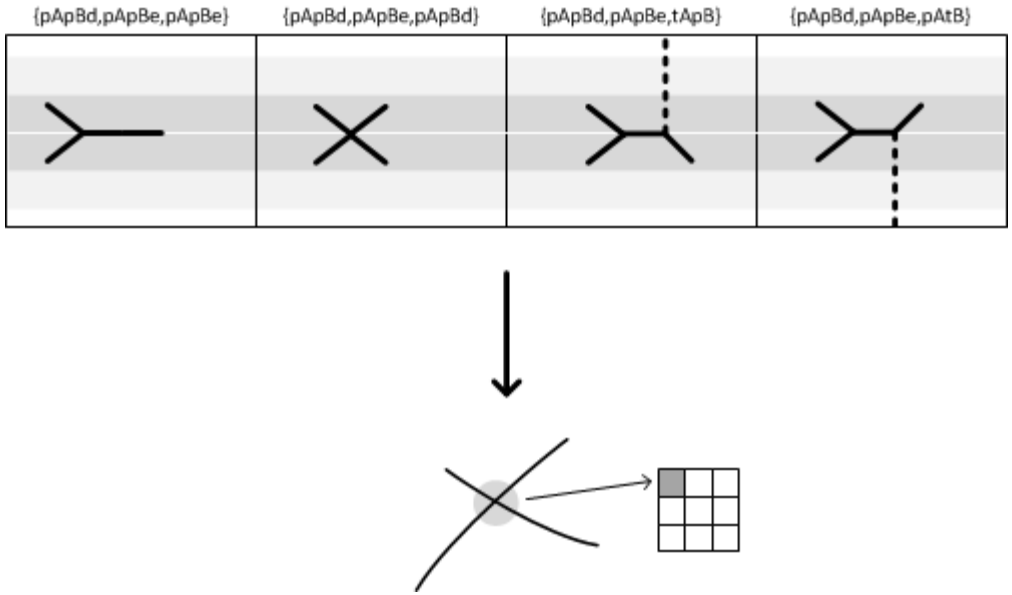
Natural language interpretation

LMC Generalization

9-i | CBM | 9-i+

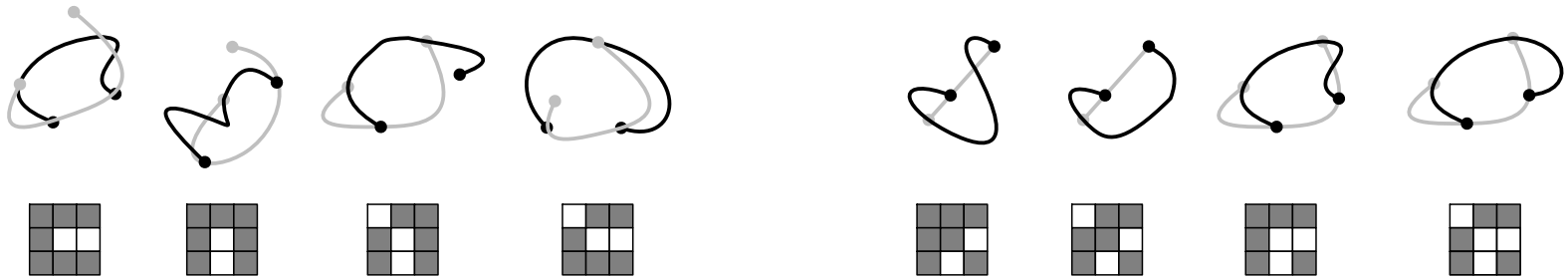


Generalization condition

$$\forall LMC_{A-B}, \exists pApBe \subset LCM(2,\ldots,n-1) \rightarrow R\ \ A^0 B^0\ \ = \neg\varnothing$$

Impossible relationships

- 8 topological relationships do not generalize life and motion configurations
- Impossible relationships in a spatio-temporal context



- Negative spatio-temporal condition:

$R_{\{\varnothing,\neg\varnothing\}}(A,B) \neq$

A/B	A^0	∂A	A^-
B^0			
∂B	$\neg\varnothing$		
B^-		$\varnothing$	

V

A/B	A^0	∂A	A^-
B^0		$\neg\varnothing$	
∂B			$\varnothing$
B^-			

1 State of the art

2 Objectives

3 Object spatio-temporal states

4 Relationships between spatio-temporal states

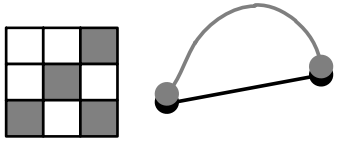
5 Life and Motion Configuration

6 LMC generalisation

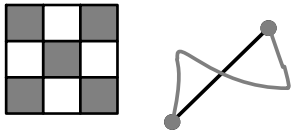
7 Natural language interpretation

Relationships | Matrix configuration

- Natural language interpretation of 25 generalized relationships
  - Repetitions | Non-univocal definitions | Lot of remaining information | Complex description



L'objet A et B débutent et terminent leur phase de présence ensemble.

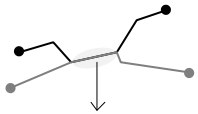


Les objets A et B apparaissent, se rencontrent et disparaissent ensemble.

Relationships | **Matrix configuration**

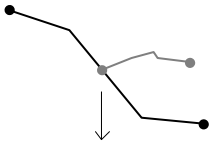
- More efficient interpretation
- Natural French language prepositions

Rencontre | Croisement | Génération | Capture | Égalité | Ignorance



$R_{\{\varnothing,\neg\varnothing\}}(A,B)=$

A/B	A^0	∂A	A^-
B^0	$\varnothing$		
∂B			
B^-			

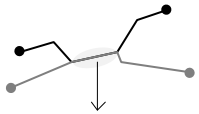


$R_{\{\varnothing,\neg\varnothing\}}(A,B)=$

A/B	A^0	∂A	A^-
B^0			
∂B	$\neg\varnothing$		
B^-			

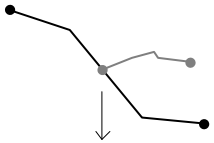
Relationships | **Matrix configuration**

Spatial reasoning | LMC interpretation



$\mathbf{R_{\{\varnothing,\neg\varnothing\}}(A,B)=}$

A/B	A^0	∂A	A^-
B^0	$\varnothing$		
∂B			
B^-			

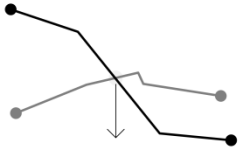


$\mathbf{R_{\{\varnothing,\neg\varnothing\}}(A,B)=}$

A/B	A^0	∂A	A^-
B^0			
∂B	$\neg\varnothing$		
B^-			

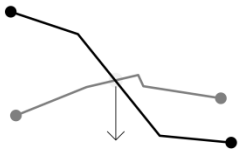
Natural language interpretation

- Spatio-temporal « meeting »
  - 9-i
  - CBM
  - Projective



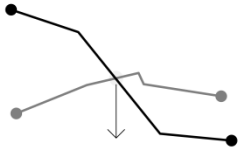
$\mathbf{R}_{\{\varnothing,\neg\varnothing\}}(\mathbf{A,B})=$

A/B	A^0	∂A	A^-
B^0	$\varnothing$		
∂B			
B^-			



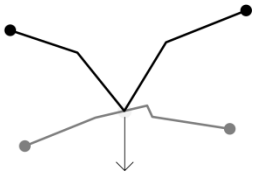
$\mathbf{R}_{\{\varnothing,0,1\}}(\mathbf{A,B})=$

A/B	A^0	∂A	A^-
B^0	0D		
∂B			
B^-			



$\mathbf{R}_{\{\varnothing,P0,P1\}}(\mathbf{A,B})=$

A/B	A^0	∂A	A^-
B^0	P1		
∂B			
B^-			

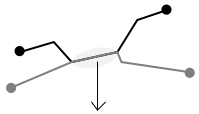


$\mathbf{R}_{\{\varnothing,P0,P1\}}(\mathbf{A,B})=$

A/B	A^0	∂A	A^-
B^0	P0		
∂B			
B^-			

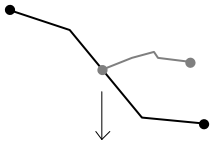
Relationships | **Matrix configuration**

Spatial reasoning | **LMC interpretation**



$R_{\{\varnothing,\neg\varnothing\}}(A,B)=$

A/B	A^0	∂A	A^-
B^0	$\varnothing$		
∂B			
B^-			



$R_{\{\varnothing,\neg\varnothing\}}(A,B)=$

A/B	A^0	∂A	A^-
B^0			
∂B	$\neg\varnothing$		
B^-			

( ) ( )

( ) ( )

Conclusions

- 4 research objectives completed

  - Definition of identity across space and time
    - Modelling identity spatio-temporal state of one object
    - Definition of possible cases of existence and presence

  - Study of spatio-temporal identity relationships between two objects
    - Spatio-temporal identity states relationships model
    - CNDs | Decision trees

Conclusions

- 4 research objectives completed
  - Study the temporal evolution of spatio-temporal identity relationship
    - Life and motion configuration model
    - Formal and iconic representation
    - Framework for spatio-temporal reasoning
  - LMC applications
    - Generalization of spatio-temporal relationships
    - Natural language interpretation
      - Useful for ontological spatio-temporal information definition

Outlook

Formal | Semantic | Practical

- Composition table
  - Completion of reasoning model
  - Knowledge inference
- Take into account a complex objects spatiality
  - Integration of spatial reasoning models to LMC 9-i | CBM | D-Line | …
- Workspace | Perceived space
  - Egocentric workspace definition
  - Psychological perception of space
- Presence history
  - Spatio-temporal footprints
  - Study of spatio-temporal footprints relationships

Outlook

Formal | **Semantic** | Practical

- Spatial cognition | LMC interpretation
  - Model cognitive value
  - User panel perception of spatio-temporal information
  - Interpretation of panel predicates
- FNRS research project

Formal | Semantic | **Practical**

- Practical implementation
  - Prototype of LMC automatic computation
  - Management of existence and presence
- CND collaboration
  - Use of CND as spatio-temporal reasoning model selection

Thanks for the time interval shared together

Thanks for the "$pApB_d$" relation between you and me.

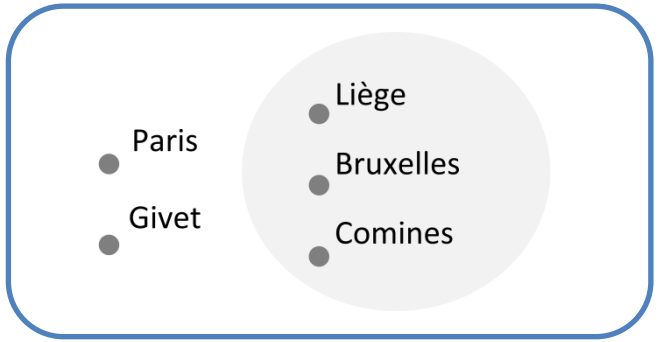
Maybe more "pAnpB" for some…

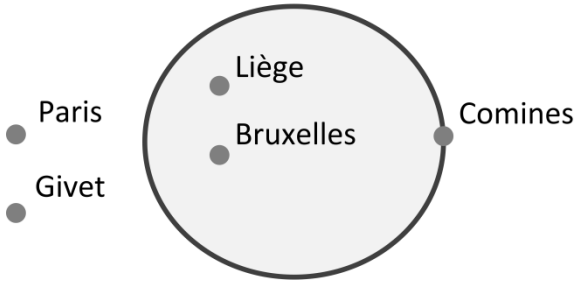
Even if for now,
there will be a "$pA\not\exists B$" relationship
between you and my presentation,
I hope it will be for a long time.

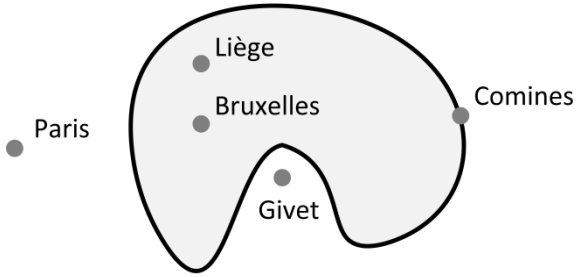
I hope too that we will never share a "pAnpB" relationship
for a 'too long' time.

No cats was injured during this research.

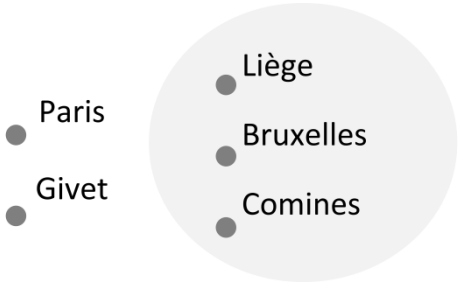
Set theory | Topology | Projective | Metric

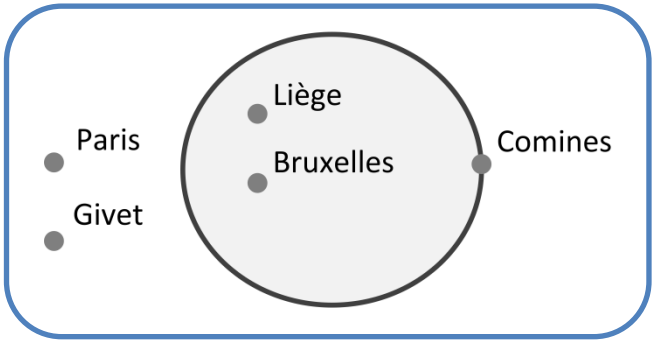


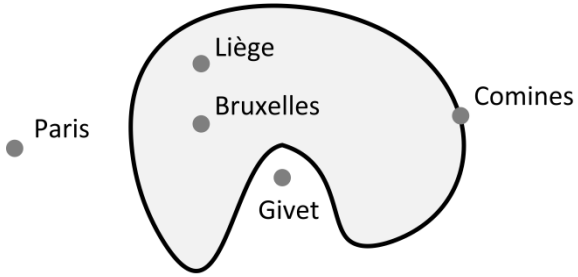




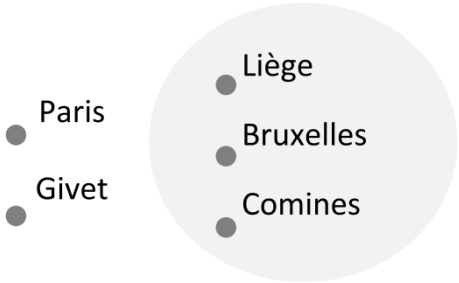
Set theory | **Topology** | Projective | Metric

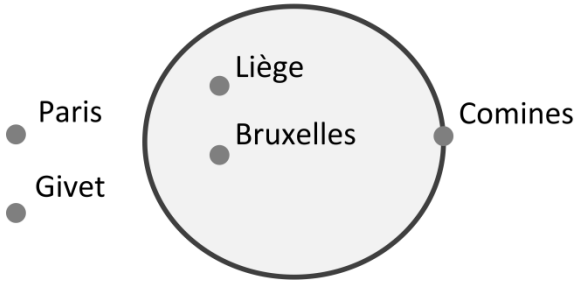


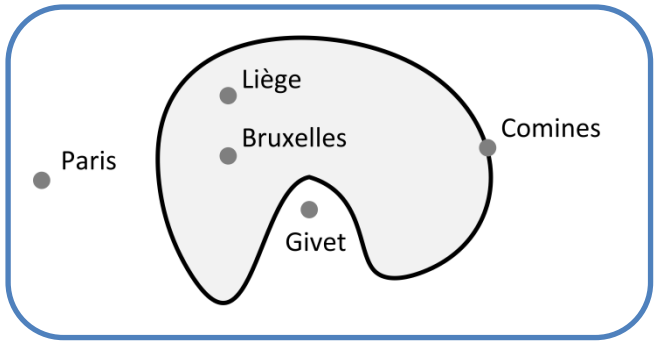




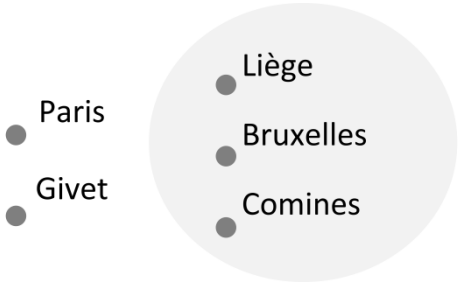
Set theory | Topology | **Projective** | Metric

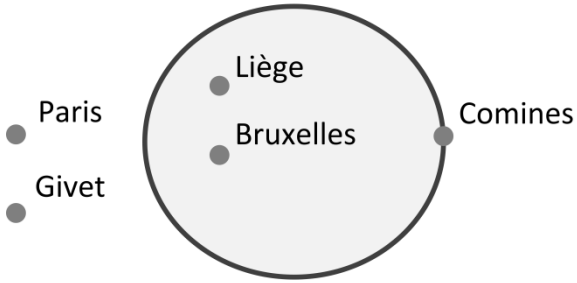


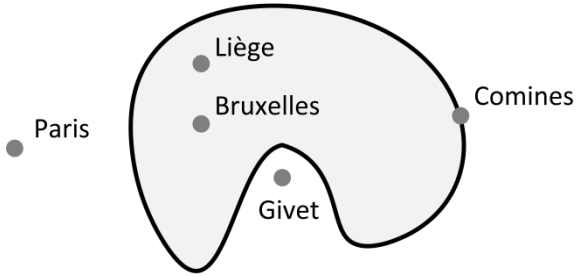


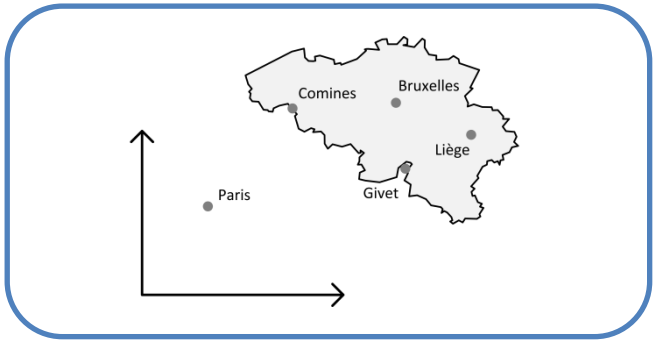


Set theory | Topology | Projective | **Metric**









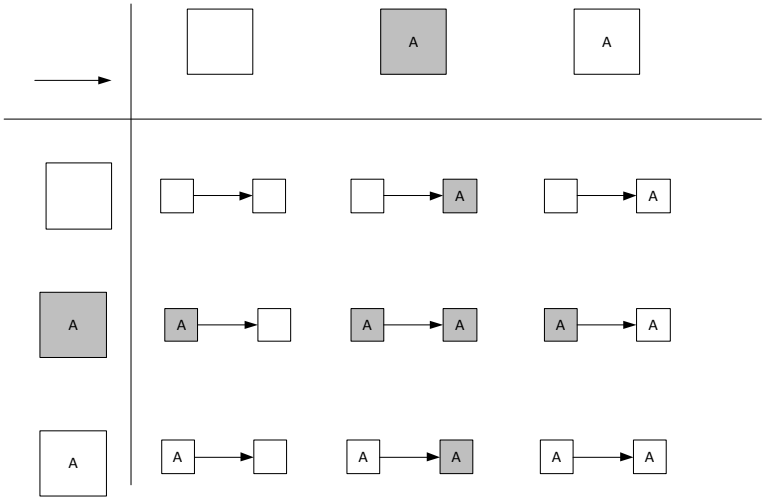
Instant | Interval

- Axiomatization
  - Galton | Ligozat | McDermott
  - ⟨ ⟩

Instant | **Interval**

- Axiomatization
  - Allen
- Actions | Events
  - Situation Calculus

Identity | Combination | Mereology

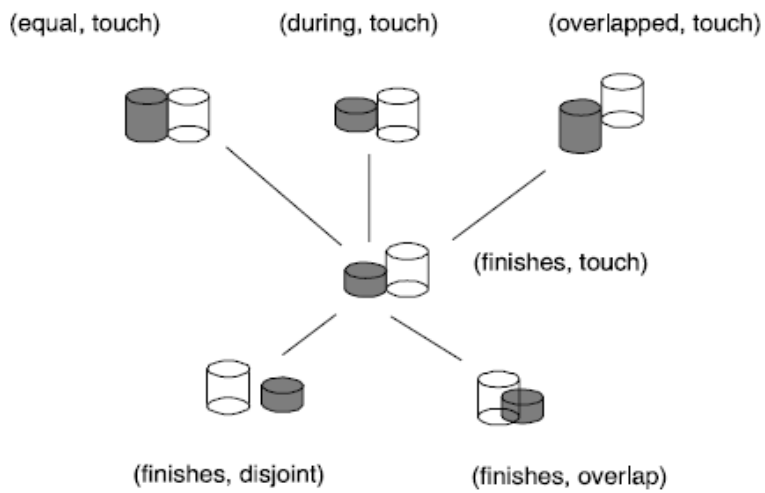


Hornsby, K. and Egenhofer M. (2000)

		Visible	Invisible
Existent	Active	*actor*	*spy*
	Inactive	*scenery*	*camouflage*
Non-existent	Active	*ghost*	*fable*
	Inactive	*mirage*	*myth*

Campos, J. et al. (2003)

Identity | **Combination** | Mereology



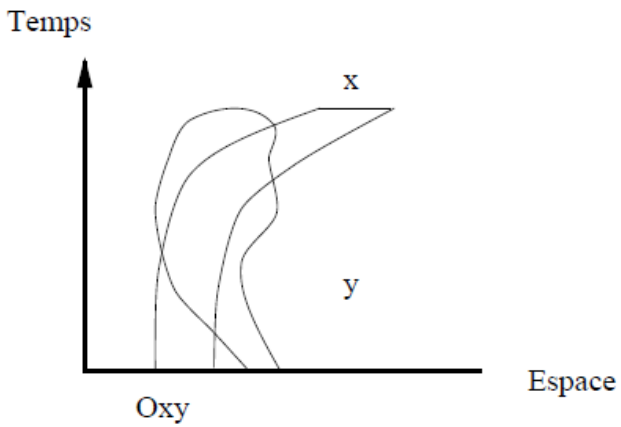
$I: \quad X \;\; DC, EC \;\; Y \;, \quad I: \quad Y \;\; TPP \;\; Z \;,$

$J: \quad X \;\; PO \;\; Y \;, \quad J: \; Y \;\; DC \;\; Z$

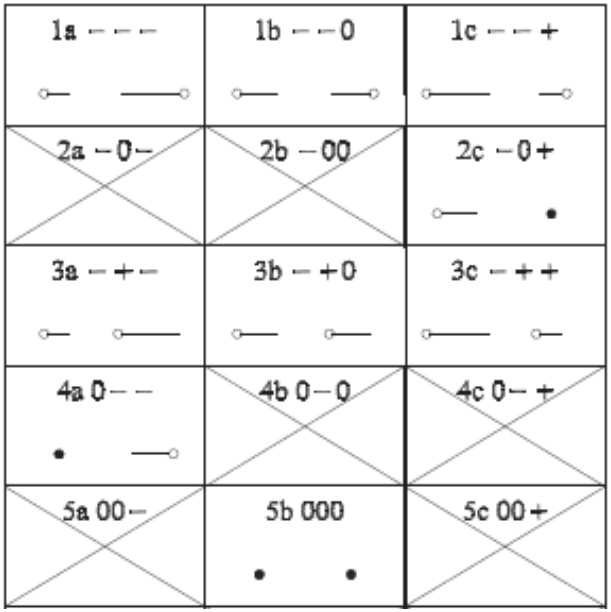
Claramunt, C. and Jiang, B (2001)

Gerevini, A. and Nebel, B. (2002)

Identity | Combination | **Mereology**



Muller, P. (1999)



Van de Weghe et al. (2006)

Research objectives

1. **Formalization** of identity spatio-temporal states

2. Spatio-temporal reasoning model based on **identity state evolution** across space-time.

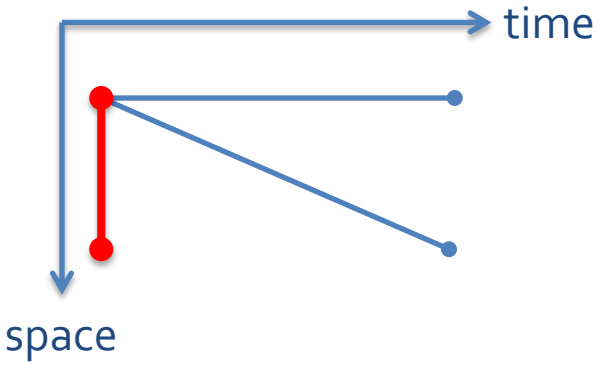
3. Study of identity spatio-temporal states **relationships**.

4. Definition of a **visual language** describing spatio-temporal information evolution.

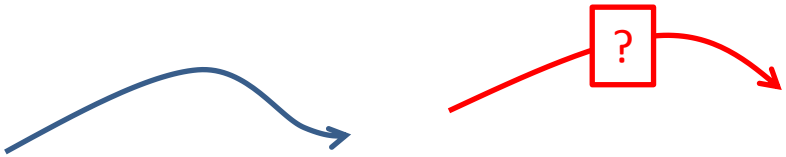
Research assumptions

- No backward in time

- No instantaneous movement

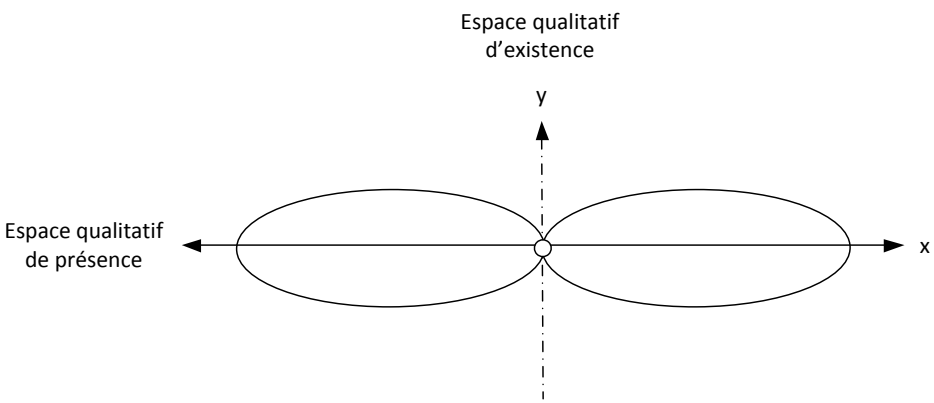


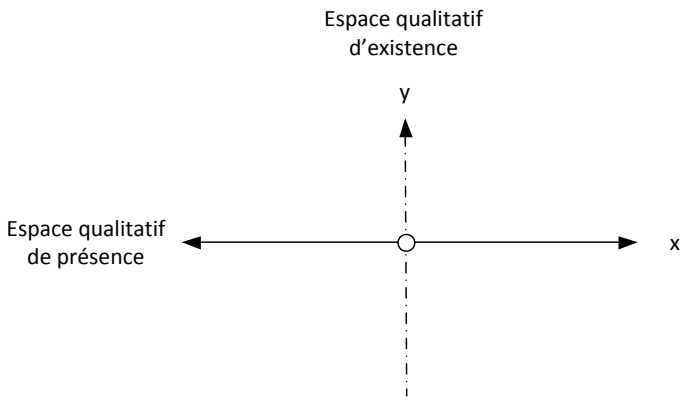
- No resurrection



Dominance theory

Conceptual representation





Dominance theory

$$Holds >,i \wedge Lim\ t,i \wedge Holds-at\ 0,t \rightarrow 0 \succ >> \wedge$$

$$Holds <,i \wedge Lim\ t,i \wedge Holds-at\ 0,t \rightarrow 0 \succ <<$$

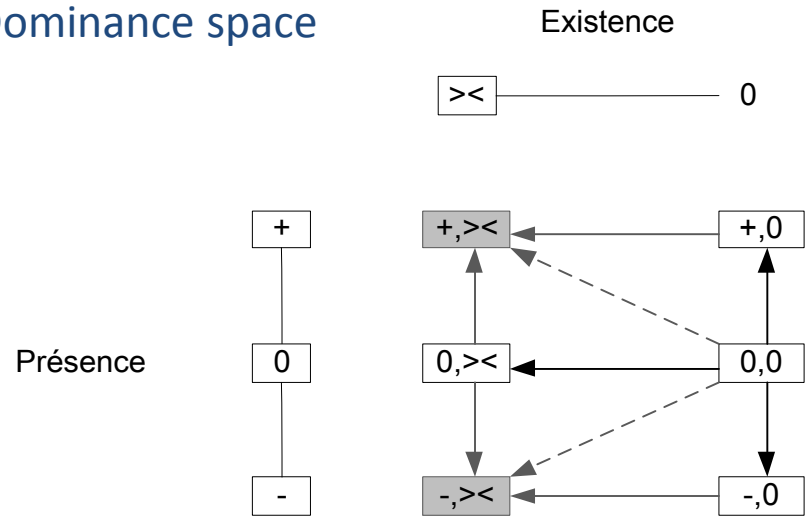
donc

$$Holds >\!<,i \wedge Lim\ t,i \wedge Holds-at\ 0,t \rightarrow 0 \succ >\!<$$

et

$$S_Y = <\ \prec 0 \succ >>\ \ ou\ \ >\!< \prec 0$$

Dominance space



Dominance theory (once again)

$$S_{AB} = \left\{ \begin{array}{l} -><-><,+><-><,0><-><, \\ -0-><,+0-><,00-><,-><+><, \\ +><+><,0><+><,-0+><, \\ +0+><,00+><,-><0><, \\ +><0><,0><0><,-00><, \\ +00><,000><,-><-0, \\ +><-0,0><-0,-0-0, \\ +0-0,00-0,-><+0, \\ +><+0,0><+0,-0+0,+0+0, \\ 00+0,-><00,+><00,0><00, \\ -000,+000,0000 \end{array} \right\}$$