Ministério da
Ciência e Tecnologia

GOVERNO FEDERAL

Spatio-Temporal Database

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Topics

(1) Dynamic Geospatial Data and Applications

(2) Ontology for Spatio-Temporal Data

(3) Representation of Spatio-Temporal Data

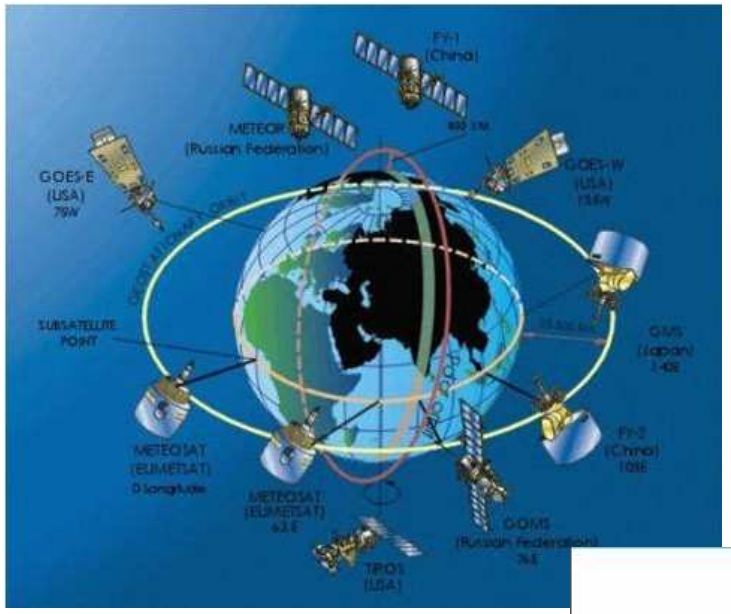
- (a) Existing Spatio-Temporal Database Models

(4) Spatio-Temporal Database Systems

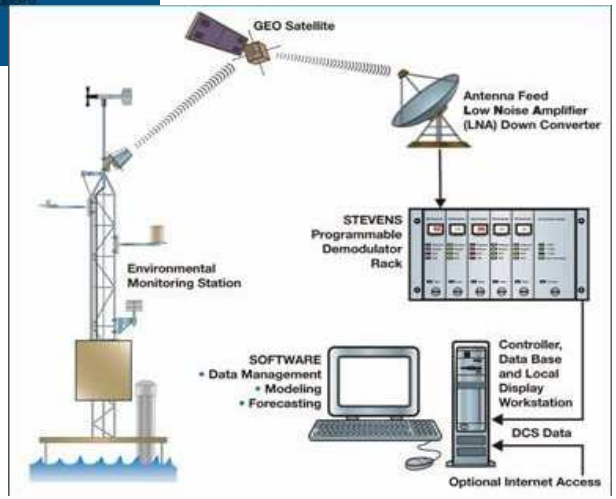
Dynamic Geospatial Data and Applications

Dynamic Geospatial Data

Technological advances in geospatial data collection.



Earth observation and GPS satellites

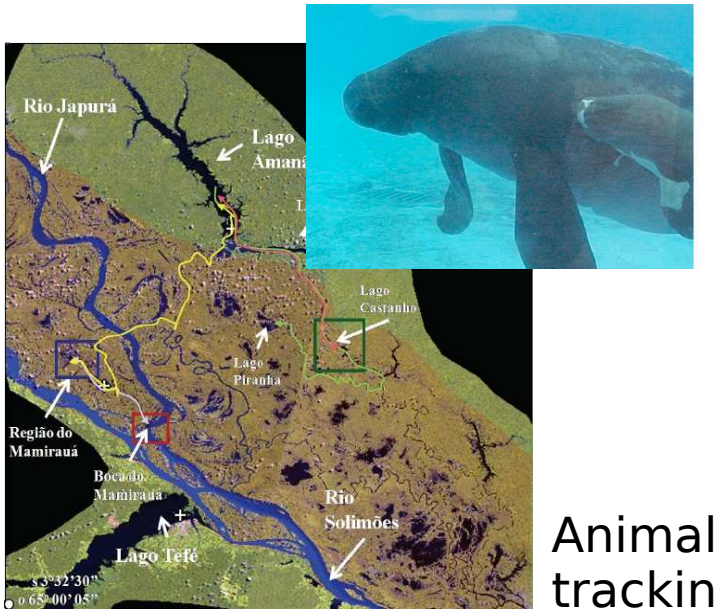


wireless and mobile computing, radio-frequency identification (RFIDs) and sensor networks

Dynamic Geospatial Data

Technological advances in geospatial data collection.

Applications which handle dynamic geospatial information



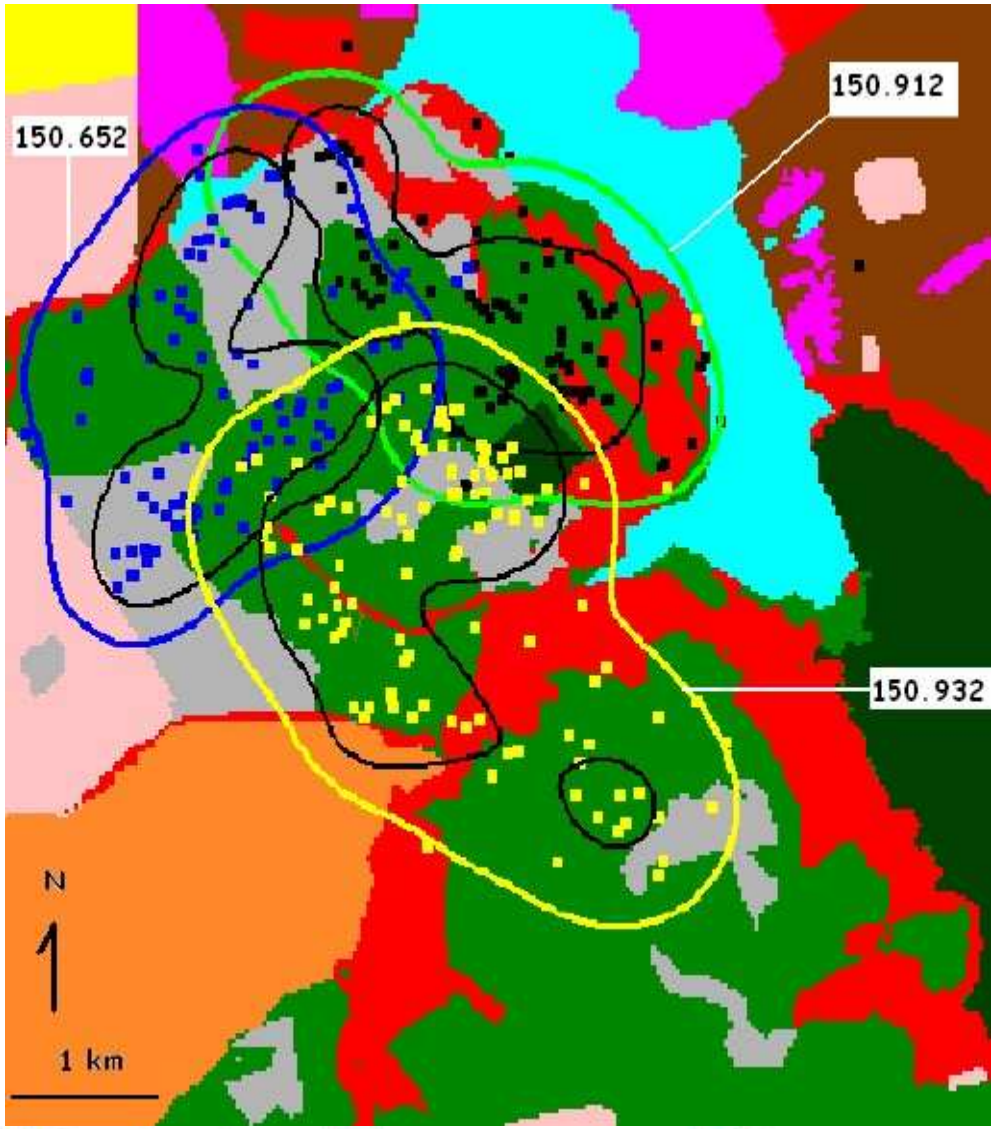
[Arraut, E. M. 2008]

Animal tracking monitoring

oil spill on the ocean

hurricane and volcanic eruption monitoring

Dynamic Geospatial Data: Applications



Levantamento, área de vida, uso e seleção de habitat de **Aves de Rapina** na região central do estado de São Paulo.

Julho de 2005 a junho de 2007 - monitorando 6 aves de rapina por rádio-telemetria.

Mapa de Uso e Ocupação do Solo

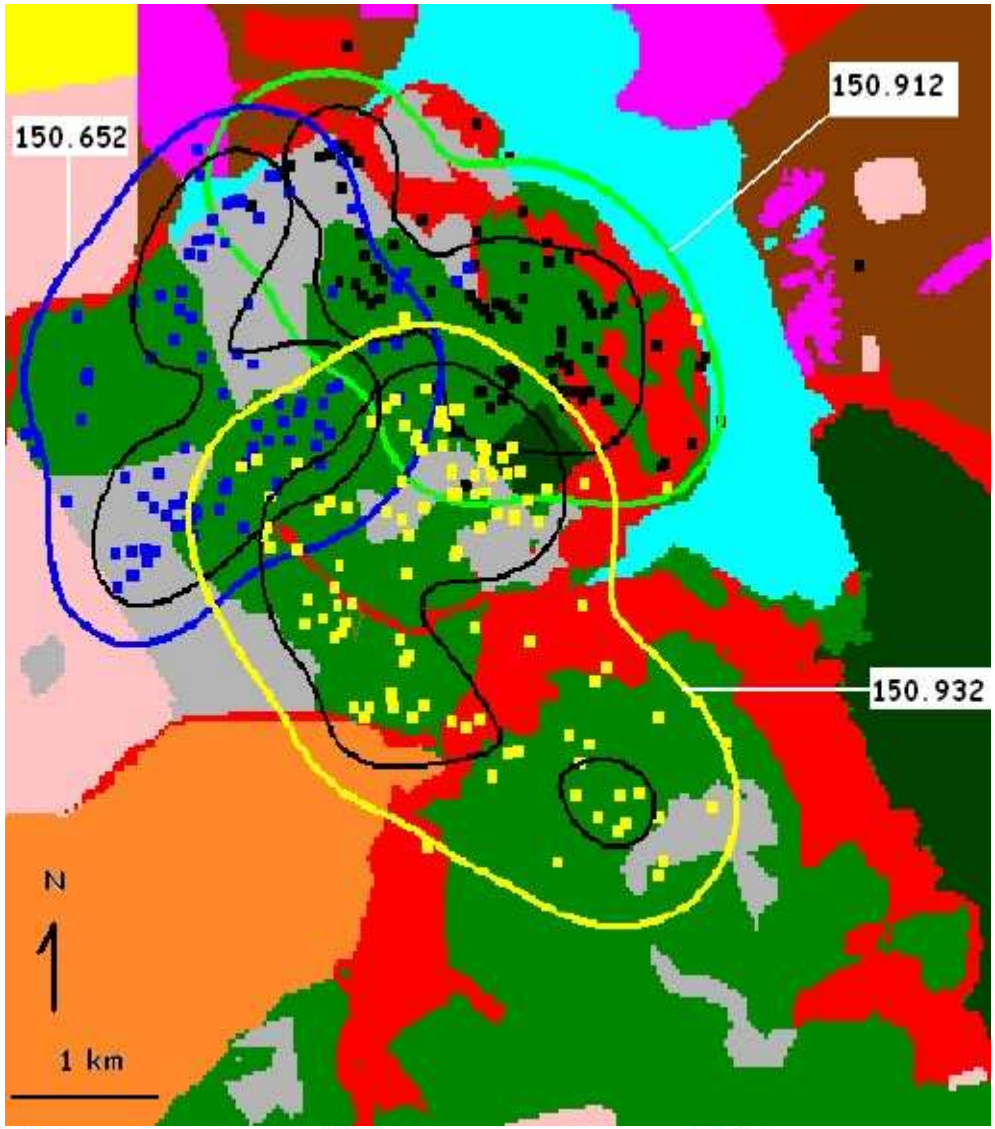
X

Trajetórias Dos Animais

Cana-de-açúcar
Formação florestal
Pastagem
Laranja
Urbanização
Campo cerrado
Outros cultivos
Cerrado aberto
Eucalipto
Água
Pinus

[Marco Granzinolli, 2009]

Dynamic Geospatial Data: Applications



Todos os dados geo-espaciais estão variando ao longo do tempo: Uso e Ocupação do Solo (***geo-field***) e Localizações dos animais (***geo-object***).

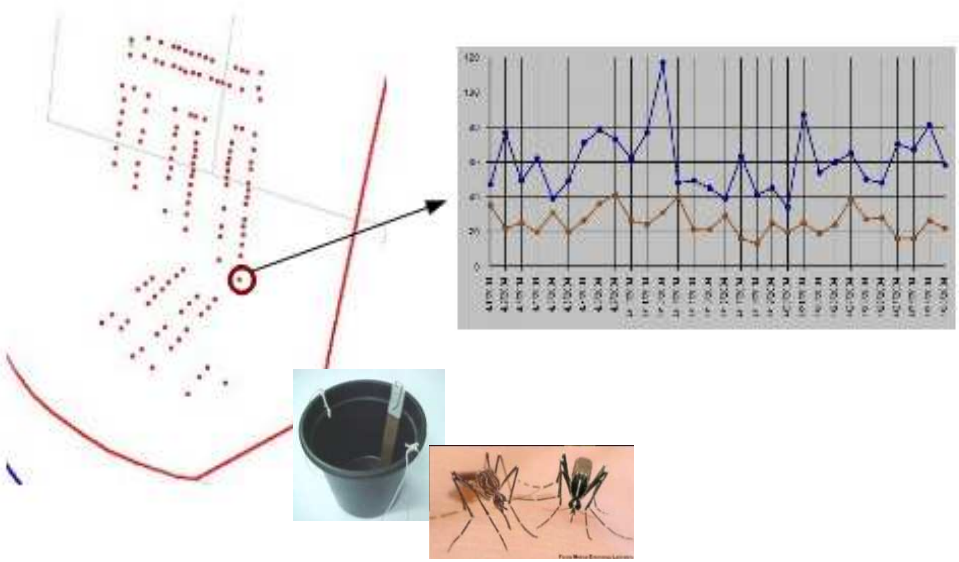
"Quanto tempo o animal 150.652 permaneceu em cada uso e ocupação do solo?"

"Em quais momentos o animal 150.652 sai do cerrado aberto e entra no campo cerrado"

[Marco Granzinolli, 2009]

Dynamic Geospatial Data: Applications

SAUDAVEL



“Which month had the biggest number of infected eggs?”

“When and where were more than 80 infected eggs collected by each trap? ”

[Monteiro et. al., 2009]

[INPE’s Antarctica Program, 2010]

“When and where did objects o1 and o2 meet each other (considering a meeting when the distance between two objects is less than 2 meters)?”

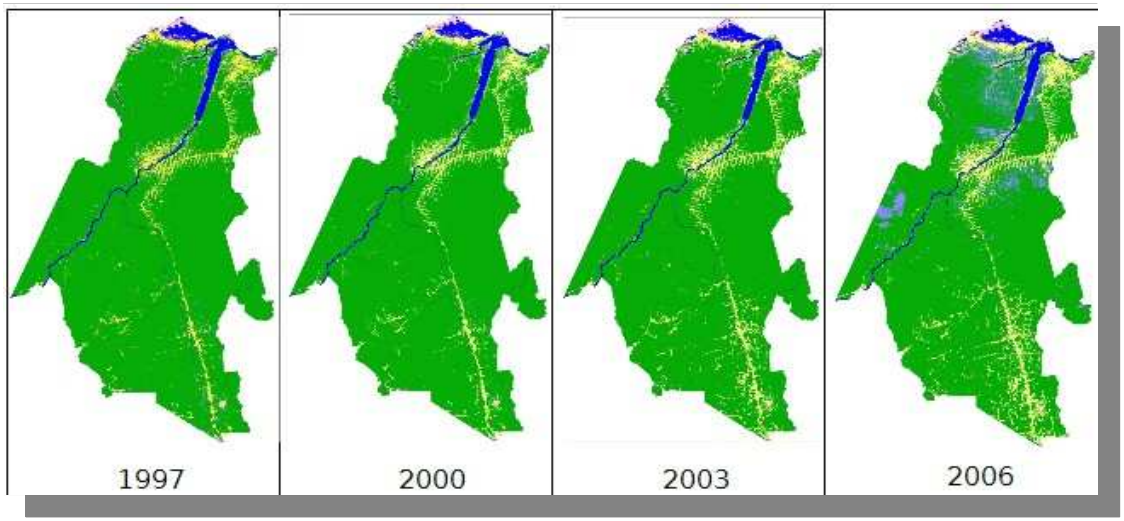
“Where and when was there a spatio-temporal cluster of objects?”

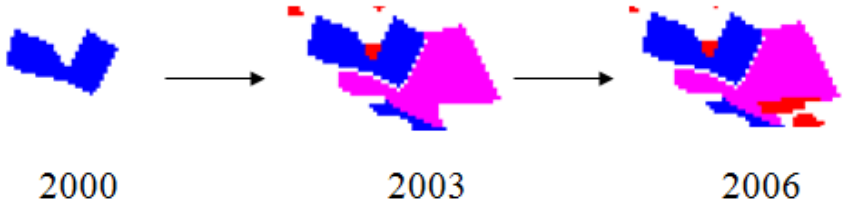
Movement Monitoring

Dynamic Geospatial Data: Applications

PRODES

Imagens Classificadas





Polígonos de Desmantamento

"*How was the state of a specific deforested region in 2002? (considering that this specific deforested region was not observed in 2002)?*"

"*how did a specific deforested region evolve over time between 2000 and 2008?*"

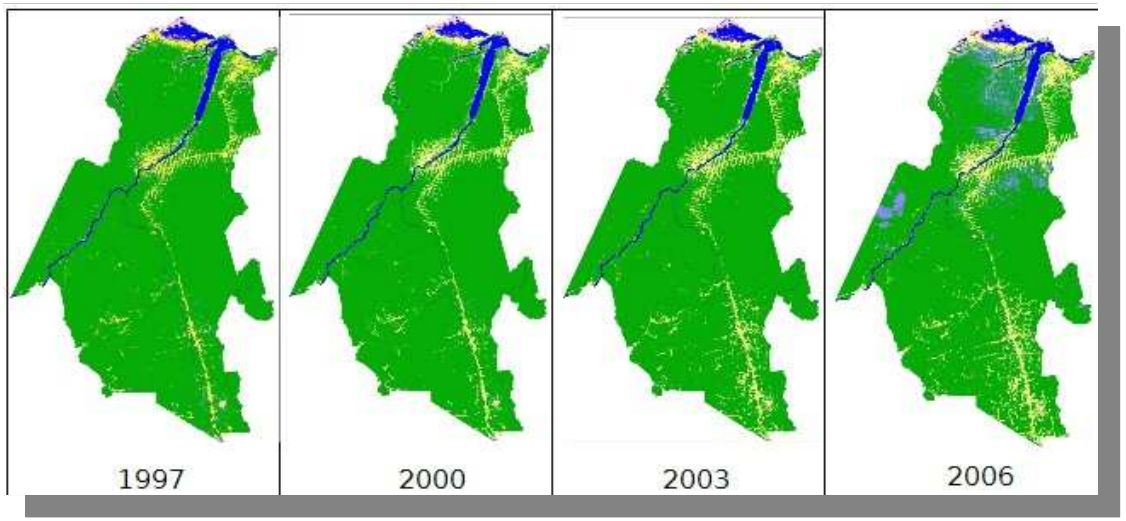
"*how did the deforested regions that started less than 2 kilometer far from the river r1 evolve over time?*"

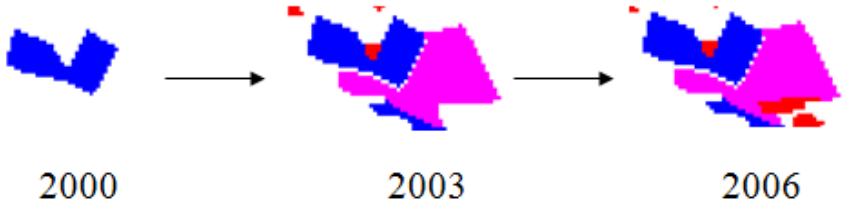
"*when did a specific deforested region reach the municipality x?*"

Dynamic Geospatial Data: Applications

PRODES

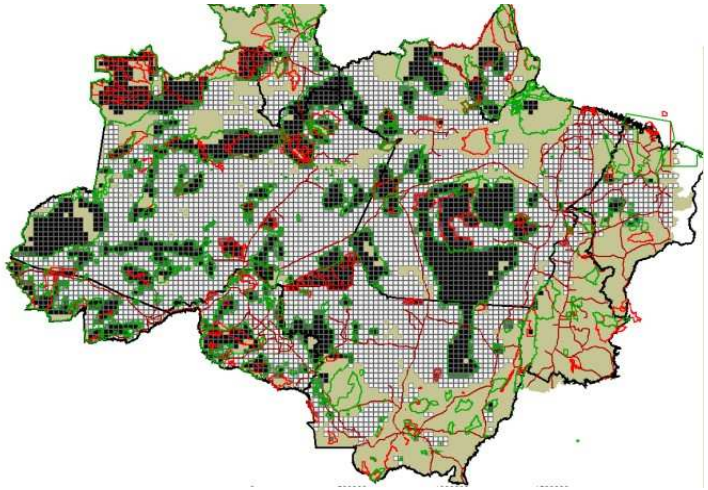
Imagens Classificadas





Polígonos de Desmantamento

Land Use and Land Cover Modeling

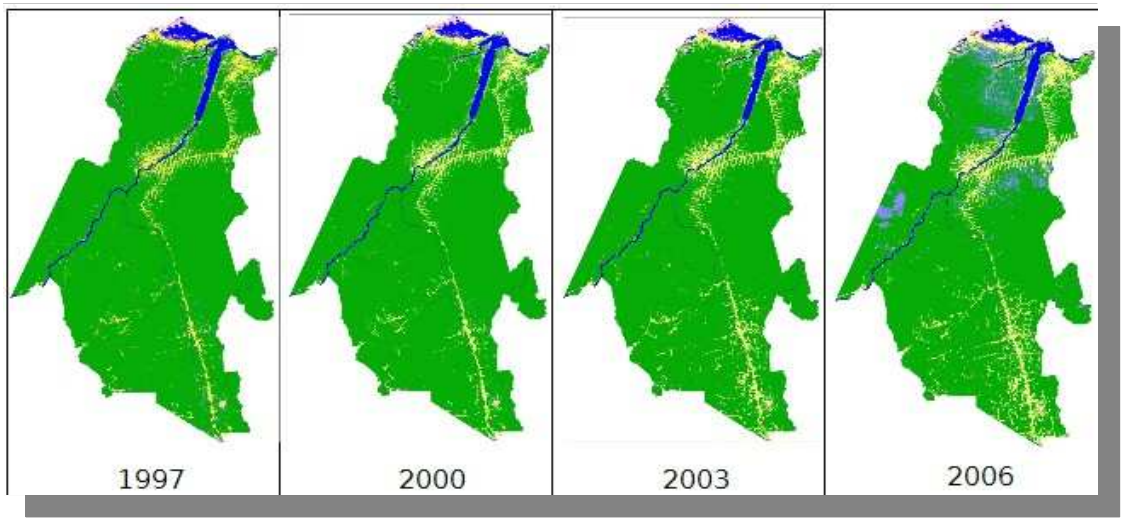


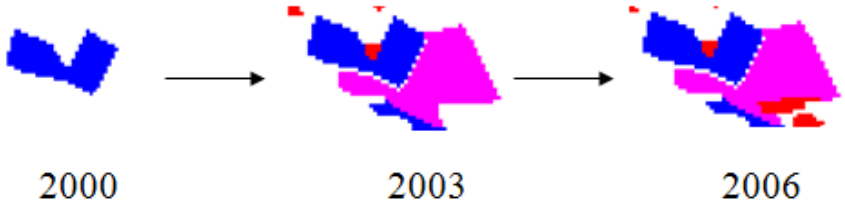
"given a cell, how has the forest status been varying in this cell over time?"

Dynamic Geospatial Data: Applications

PRODES

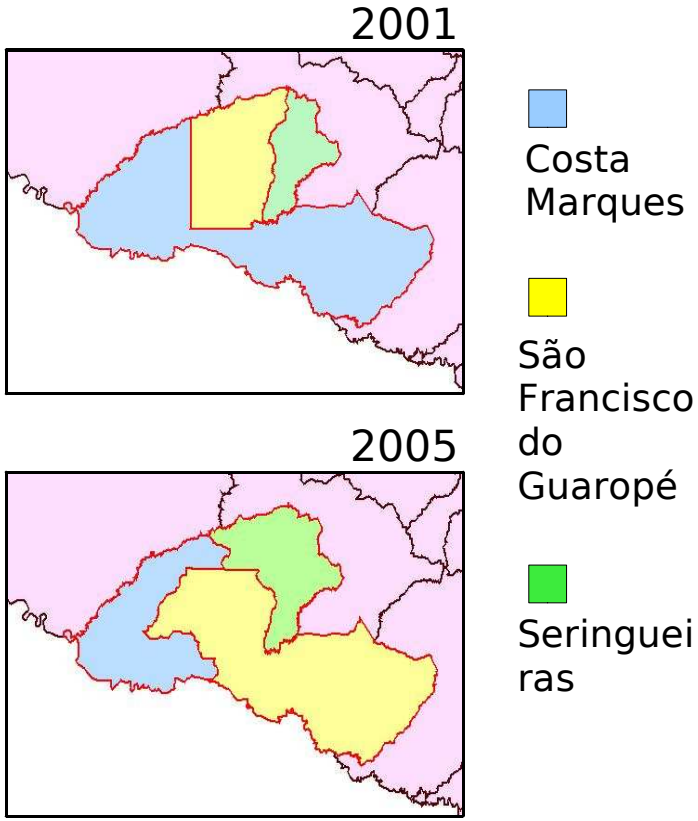
Imagens Classificadas





Polígonos de Desmantamento

Municipal Management

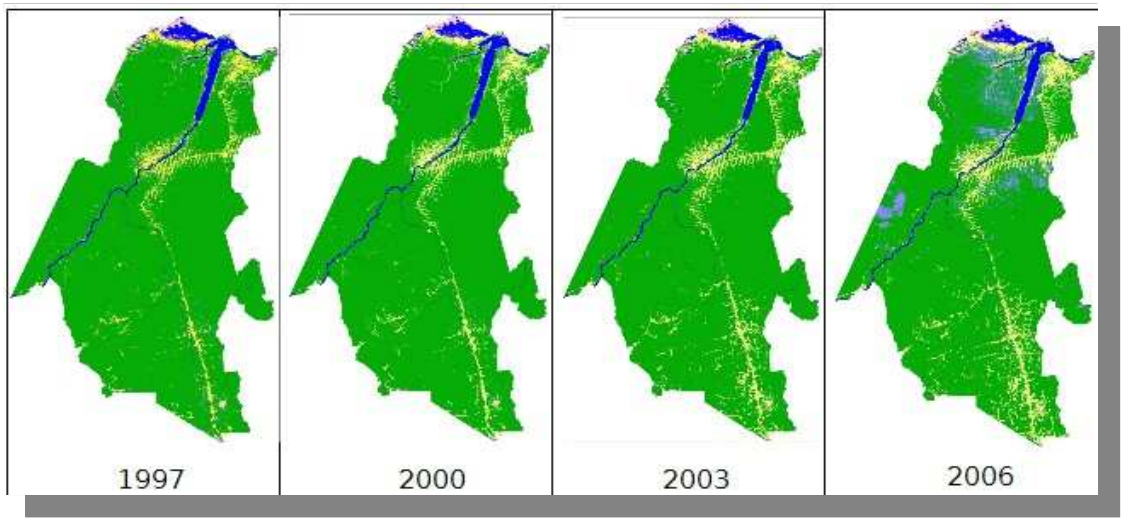


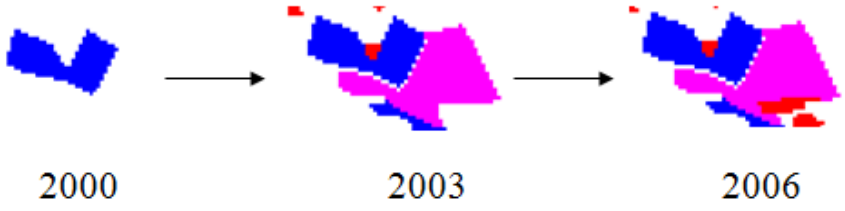
"How many hectares were deforested in each municipality? "

Dynamic Geospatial Data: Applications

PRODES

Imagens Classificadas





Polígonos de Desmantamento

Descobrir **padrões** de áreas desmatadas e como esses padrões evoluem no tempo:

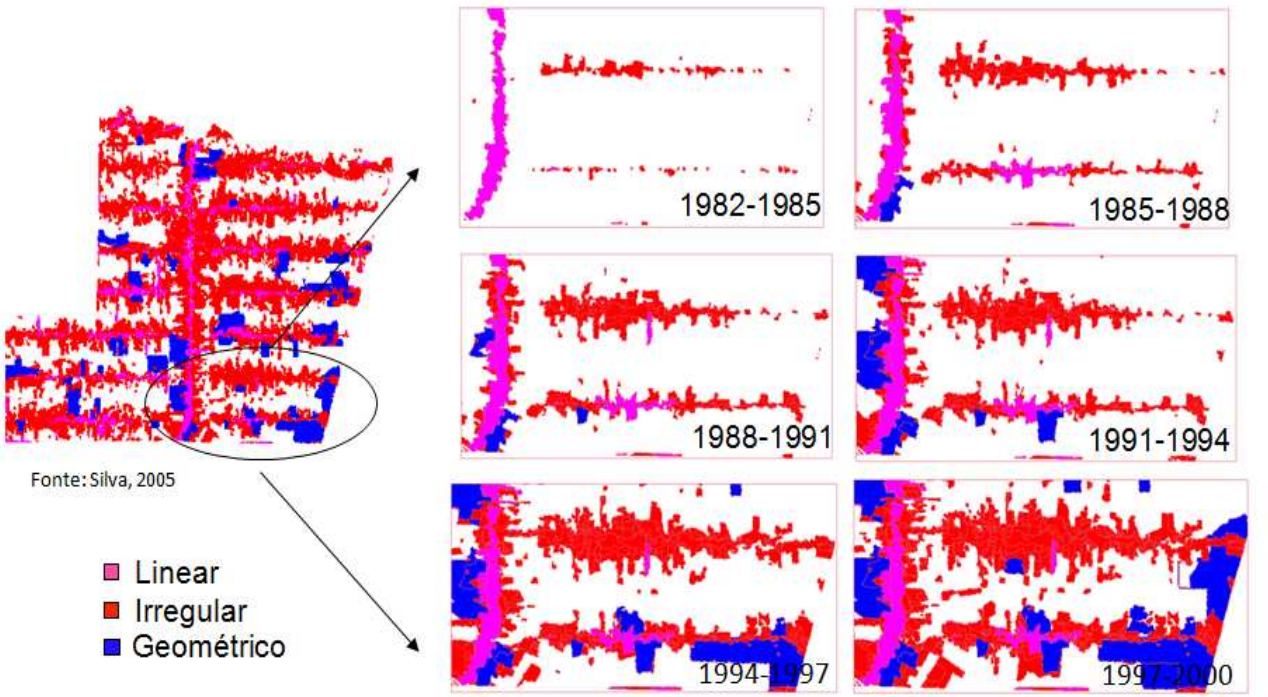
*é importante ter o conceito de **objeto** (área desmatada) e de **evolução desse objeto** ao longo do tempo.*

[Silva et al., 2005]

[Motta et al., 2009]

[Bittencourt et al., 2008]

Dynamic Geospatial Data: Applications



Descobrir **padrões** de áreas desmatadas e como esses padrões evoluem no tempo:

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Dynamic Geospatial Data

Regarding spatio-temporal data, there are many distinct research areas in geographical information system (GIS) science:

Ontology for Spatio-Temporal Data

Indexing of Spatio-Temporal Data

Spatio-Temporal Data Mining and Pattern Recognition

Representation and Query of Spatio-Temporal Data

Spatio-Temporal Visualization

Dynamic Geospatial Data

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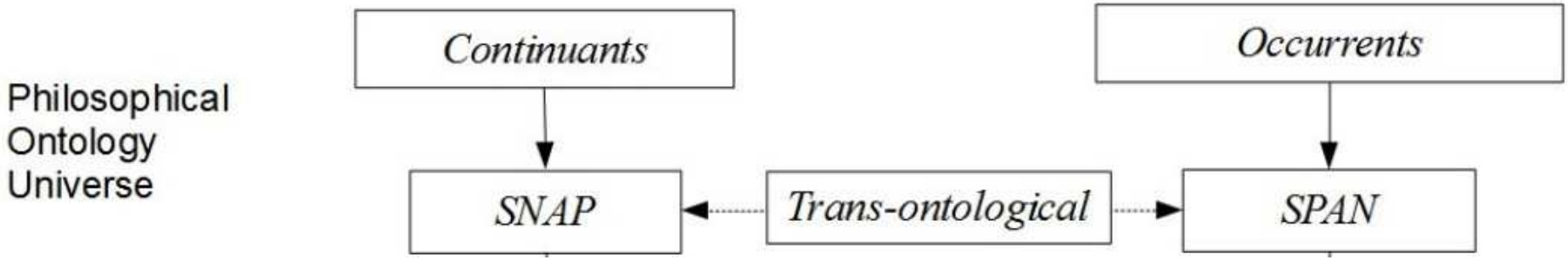
Ontology for Spatio-Temporal Data

Ontology for Spatio-Temporal Data

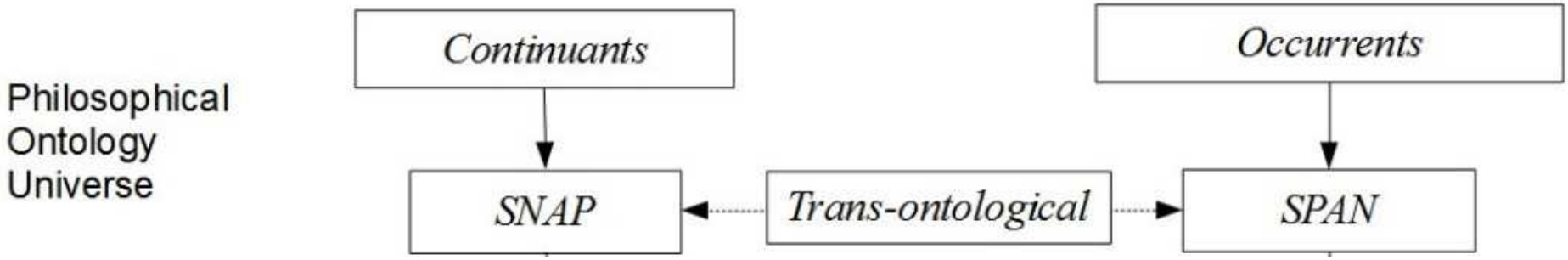


well-established classification of real world phenomena into: ***continuants*** and ***occurrents*** [Galton, 2008].

Continuants (entities that endure in the world through time):
(a) can undergo changes, (b) has spatial parts but not temporal part, (c) is wholly present at each moment of its existence.

Ex.: a person, an aircraft, and a volcano

Ontology for Spatio-Temporal Data

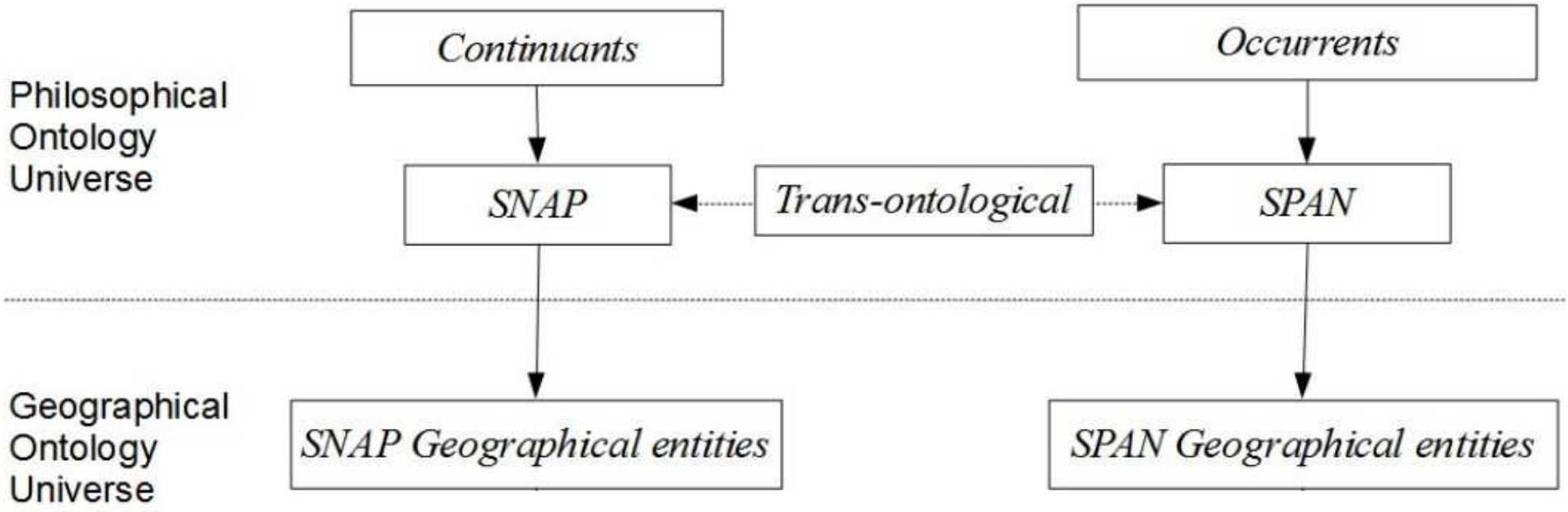


well-established classification of real world phenomena into: ***continuants*** and ***occurrents*** [Galton, 2008].

Occurrents (entities that happen or go on in time - processes/events):
(a) can not undergo change, (b) has temporal parts, and
(c) is not wholly present at any time short of its entire durations.

Ex.: a persons' life, a flight and an eruption

Ontology for Spatio-Temporal Data



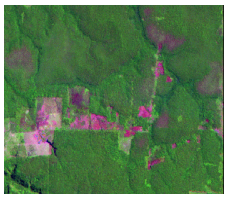
SNAP and SPAN ontologies [Grenon and Smith, 2004]

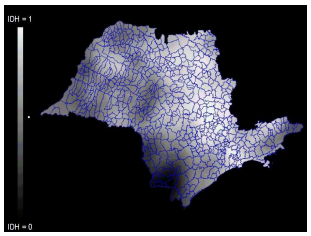
SNAP and SPAN ontologies have been applied to the geography domain, resulting in a geographical ontology. [Grenon and Smith, 2004]

Representation of Spatio-Temporal Data

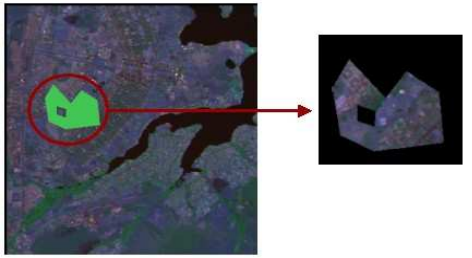
Representation of Spatio-Temporal Data

Static geospatial information is represented in GIS following well-established ideas.

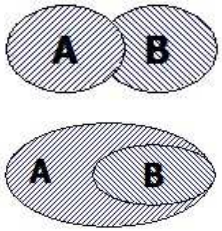


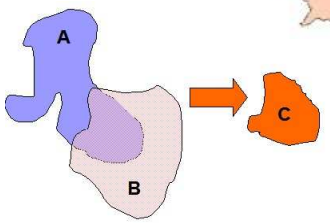


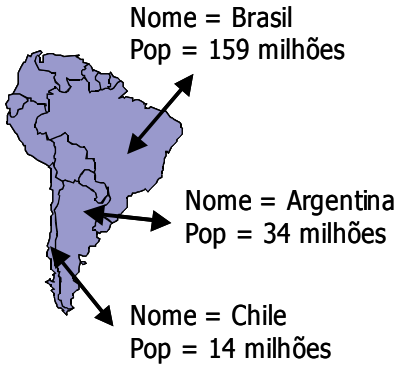
Geo-Fields and Geo-Objects



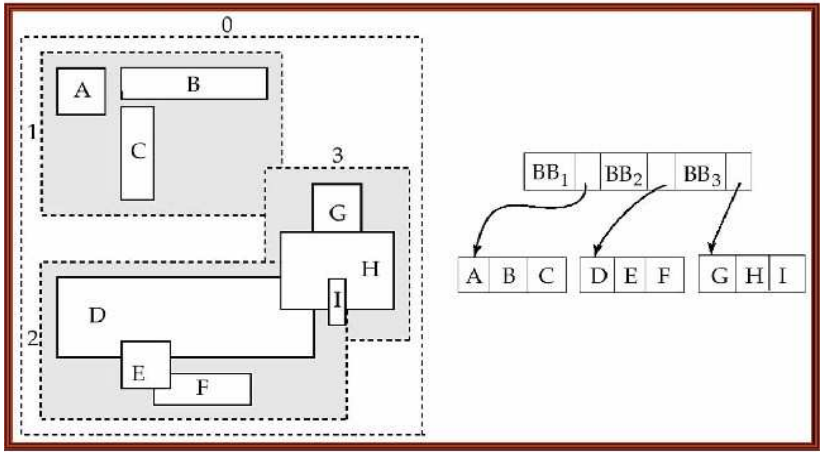
Spatial Operations







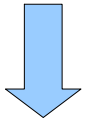
Spatial Index



The majority of GIS and spatial DBMS is based on these ideas and concepts!

Representation of Spatio-Temporal Data

Static geospatial information is represented in GIS following well-established ideas.



There is no consensus on how to represent dynamic geospatial information in computational systems.

Spatial information: every **spatial DBMS** (ex.: Oracle Spatial and PostGIS) follows a pattern to represent and query spatial information (**SFS-OGC**).

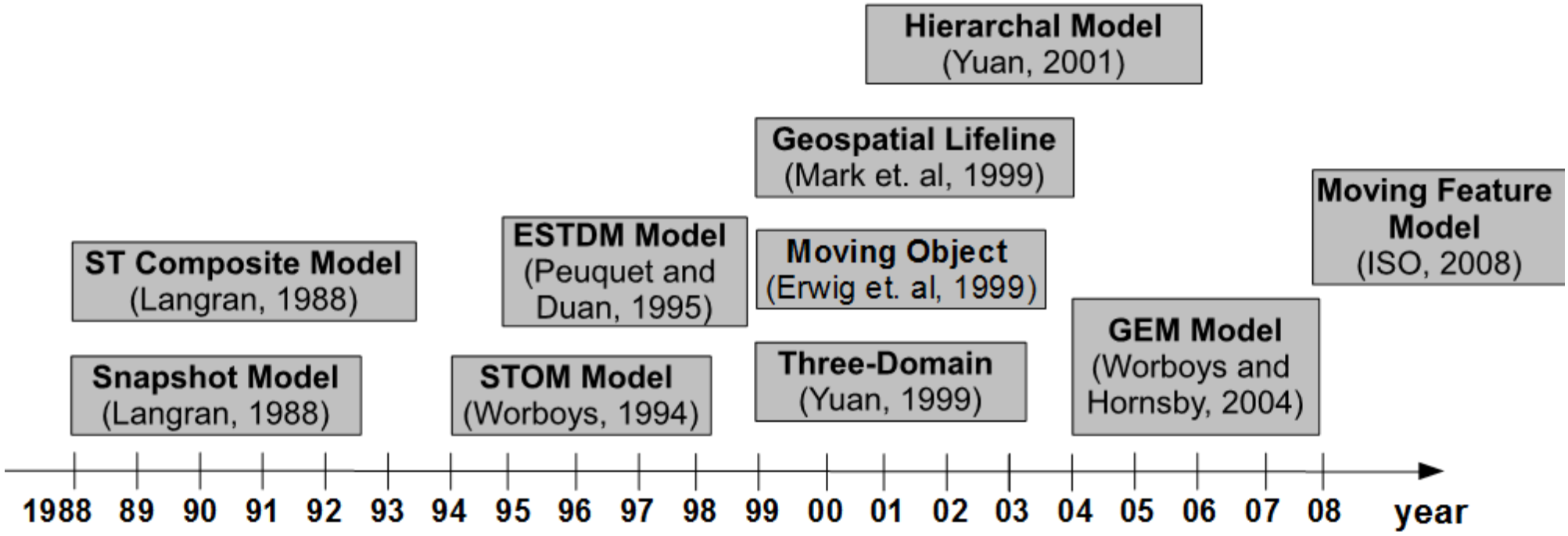
And spatio-temporal information?

"There are four stages in introducing temporal capacity into GIS: (0) static GIS, (1) temporal snapshots, (2) object change, and (3) events, actions and processes. Most current proprietary technologies are in stage zero..." [Worboys, 2005]

Existing Spatio-Temporal Database Models

There are many proposals of spatio-temporal database models.

ontology of space and time and its representation through data types, relationships and operations among them.

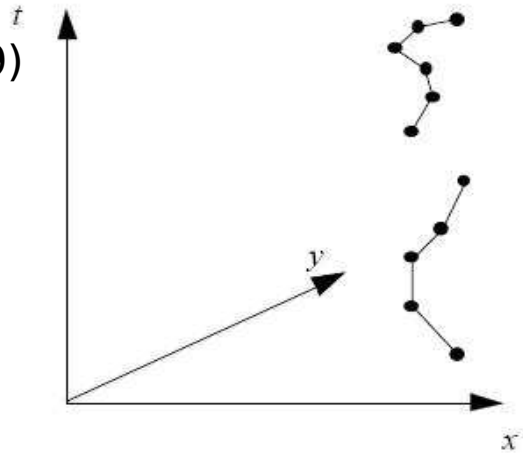


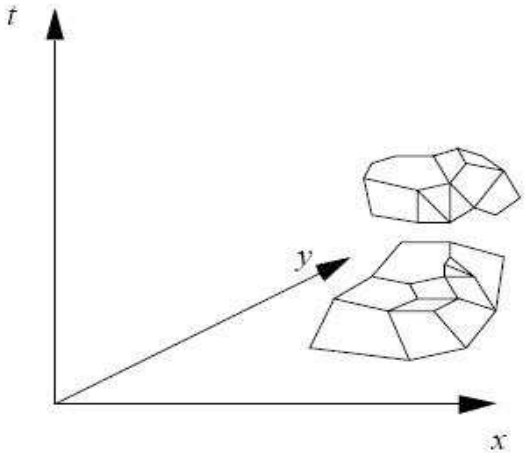
Existing Spatio-Temporal Database Models

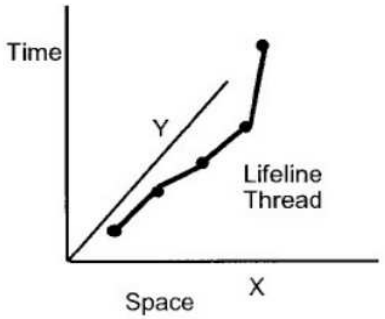
There are many proposals of spatio-temporal database models.

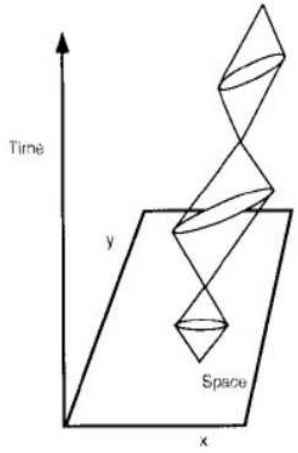
Moving Object (Erwig et. al, 1999)

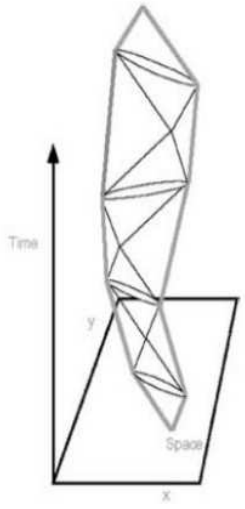
- Algebra: data types and operations for objects in moviment.
- Levels of abstraction: Abstract and Disc
- SECONDO
- Not consider fields varying over time.
- Only consider linear trajectory.







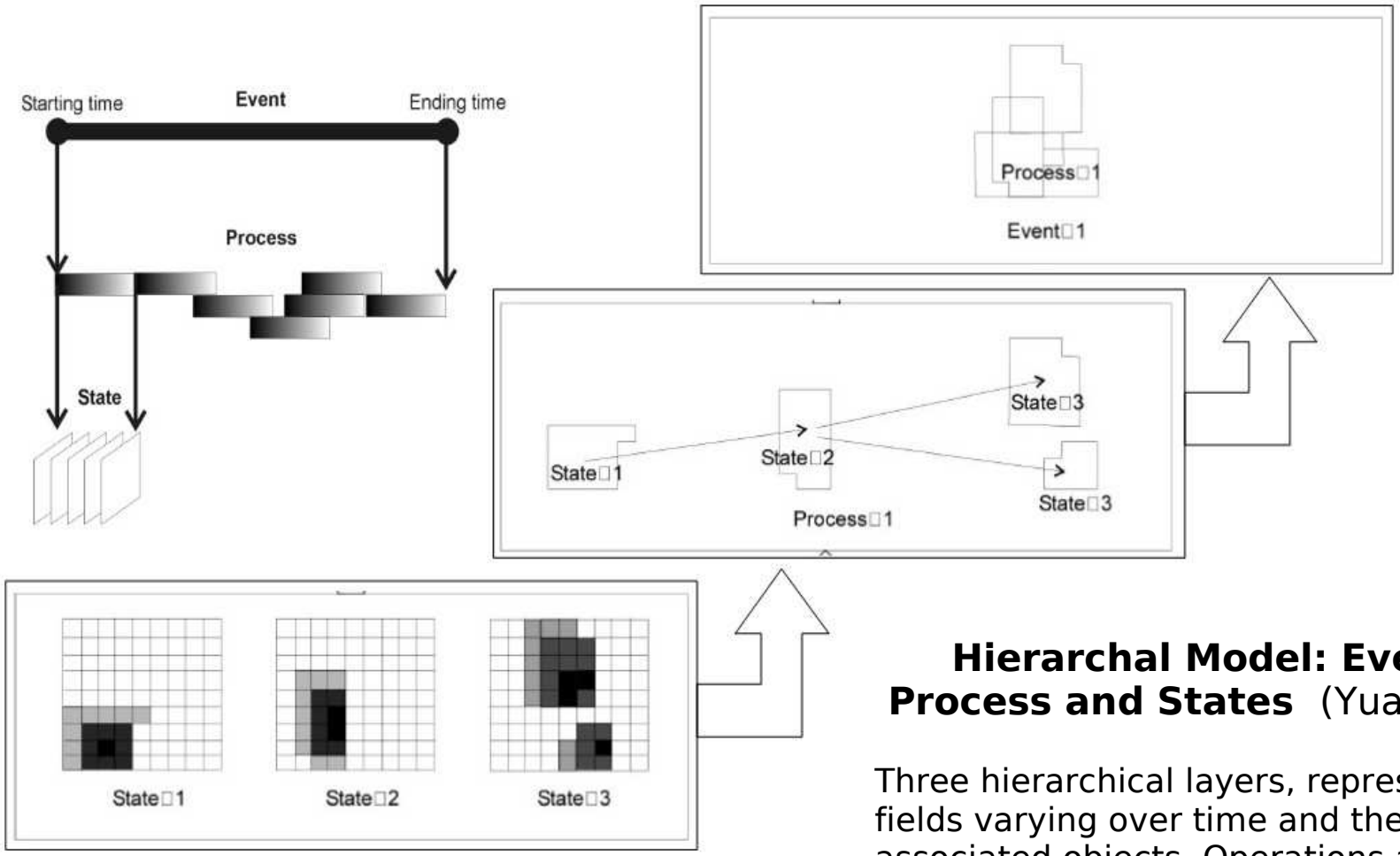




Geospatial Lifeline
(Mark et. al, 1999)
Different types of trajectories.

Existing Spatio-Temporal Database Models

There are many proposals of spatio-temporal database models.

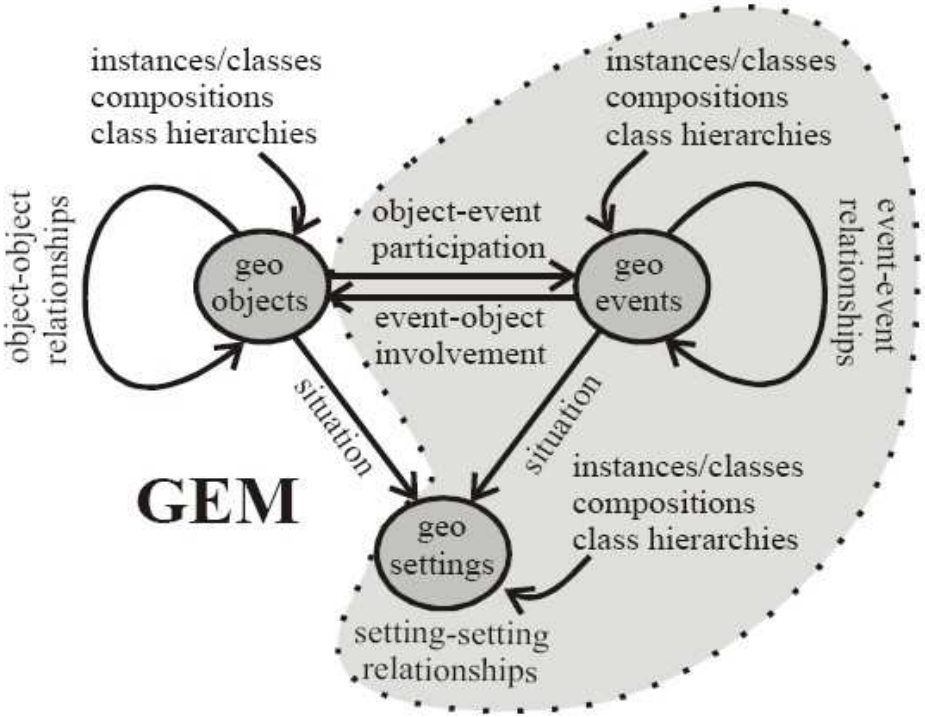


Hierarchal Model: Events, Process and States (Yuan, 2001)

Three hierarchical layers, representing fields varying over time and theirs associated objects. Operations are done over filds and objects.

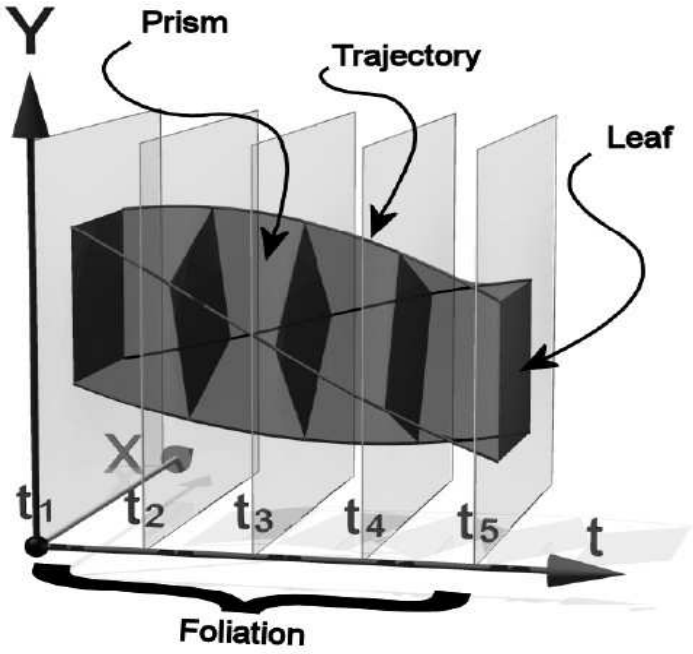
Existing Spatio-Temporal Database Models

There are many proposals of spatio-temporal database models.



Geospatial Event Model
(Worboys and Hornsby, 2004)

Relationships between objects and events and between events and events.

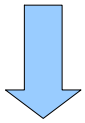


Moving Feature Model (ISO, 2008)

Do not consider feature geometry deformation and changes in non-spatial attributes.

Existing Spatio-Temporal Database Models

There are many proposals of spatio-temporal database models.



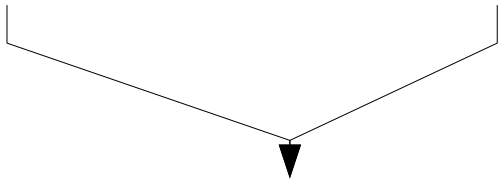
BUT ...

"*A serious weakness of existing spatio-temporal models is that each of them deals with few common features found across a number of specific applications*." [Pelekis at al. 2004]

Geo-Fields which change over time	Geo-Objects which change over time	
	Discrete geometry change	Continuous geometry change
Snapshot Model, ESTDM Model, and Hierarchal Model	STC Model, STOM Model Three-domain Model, and GEM Model	Moving Object Model, Geospatial lifeline, and Moving Feature Model

Representation of Dynamic Geospatial Data

Geo-Object which change over time			**Geo-Field which vary over time**
geometry is fixed and non-spatial attributes change over time	**geometry changes discretely over time** and non-spatial attributes also can change.	**geometry changes continuously over time** and non-spatial attributes also can change.	
(a)	(b)	(c)	(d)



Difference between (b) and (c) is pointed out by Galton [2004] and Guting and Schneider [2005]

fiat objects → sudden changes

bona fide objects → gradual changes

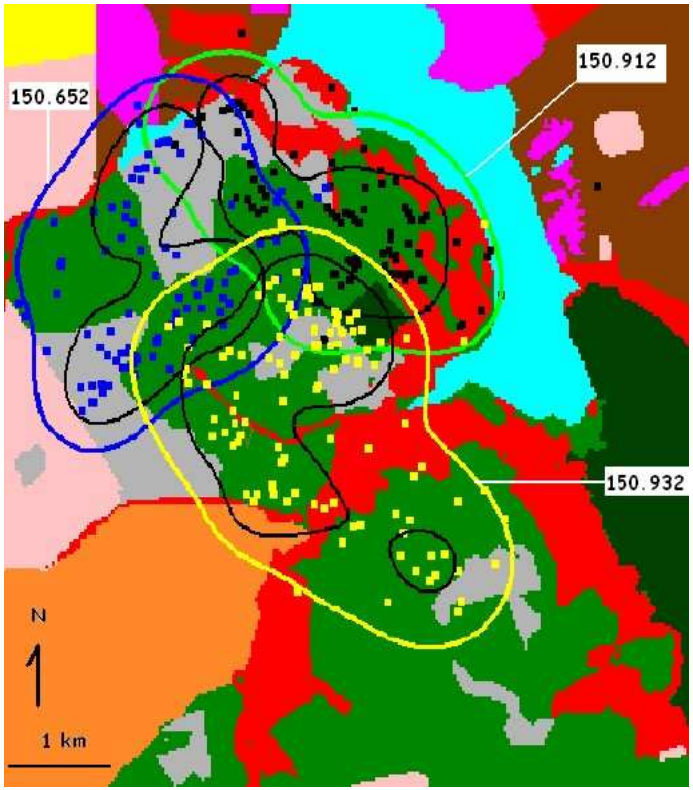
moving object model → continuous geometry changes

other models → discrete geometry changes

Representation of Dynamic Geospatial Data

Geo-Object which change over time			**Geo-Field which vary over time**
geometry is fixed and non-spatial attributes change over time	**geometry changes discretely over time** and non-spatial attributes also can change.	**geometry changes continuously over time** and non-spatial attributes also can change.	
- SAUDAVEL: egg traps - LUCC Modeling: cell space	- Municipal limit changes	- Movement monitoring (ex.: Aves de rapina e elefante marinho) - PRODES: Evolution of deforested areas	- PRODES: classified images - Land Use and Land Cover Maps

Representation of Dynamic Geospatial Data



What model can we use to support (represent and query) this application? What model is able to represent and query geo-fields as well as geo-objects which change over time?

Hierarchal Model (Yuan, 2001)

Geospatial Lifeline (Mark et. al, 1999)

Moving Feature Model (ISO, 2008)

ESTDM Model (Peuquet and Duan, 1995)

Moving Object (Erwig et. al, 1999)

ST Composite Model (Langran, 1988)

GEM Model (Worboys and Hornsby, 2004)

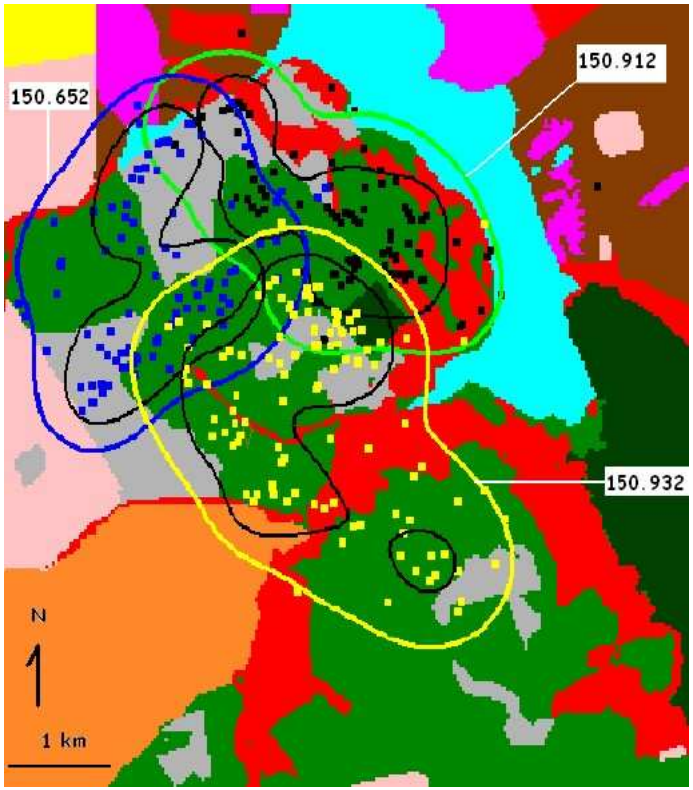
Three-Domain (Yuan, 1999)

Snapshot Model (Langran, 1988)

STOM Model (Worboys, 1994)

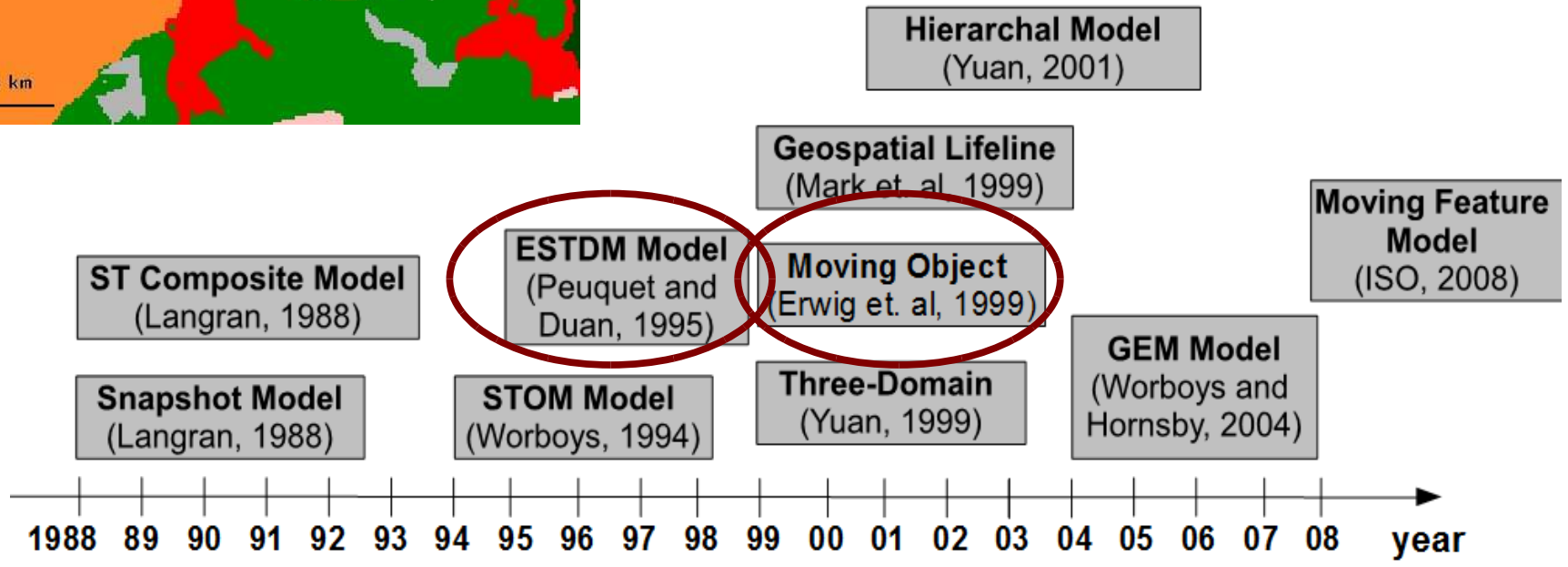
1988 89 90 91 92 93 94 95 96 97 98 99 00 01 02 03 04 05 06 07 08 year

Representation of Dynamic Geospatial Data



(1) ESTDM [Peuquet and Duan, 1995] → Variação do uso e cobertura do solo.

(2) Moving Object [Erwing et, al, 1999] → Trajetórias dos animais



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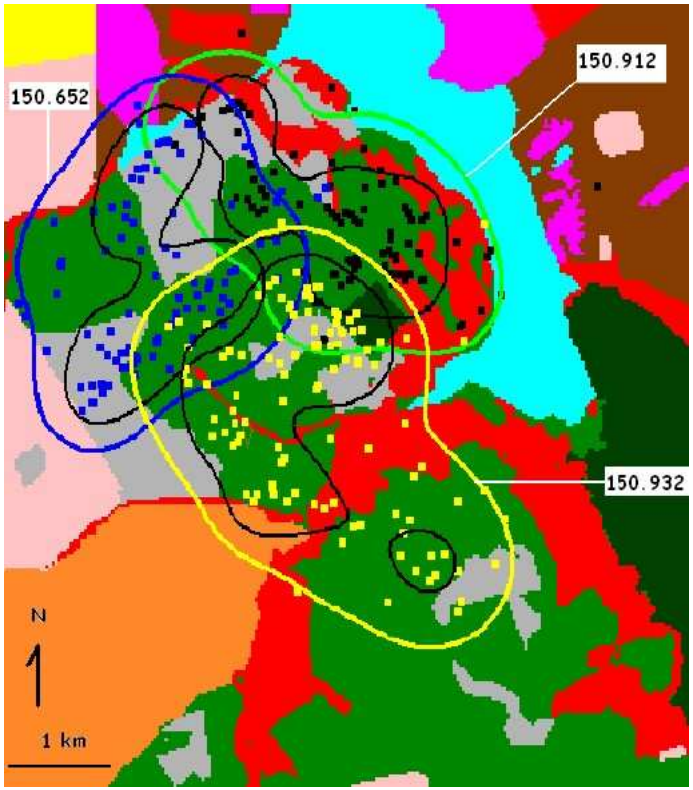

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How to answer these questions?

"Quanto tempo o animal 150.652 permaneceu em cada uso e ocupação do solo?"

"Em quais momentos o animal 150.652 sai do cerrado aberto e entra no campo cerrado"

Spatio-Temporal Database Systems

SECONDO: Moving Object Database

- SECONDO: A Database System for Moving Objects

(http://dna.fernuni-hagen.de/Secondo.html/index.html)

- A prototype developed by University of Hagen, Germany

- Able to represent, store and query objects which move over time.

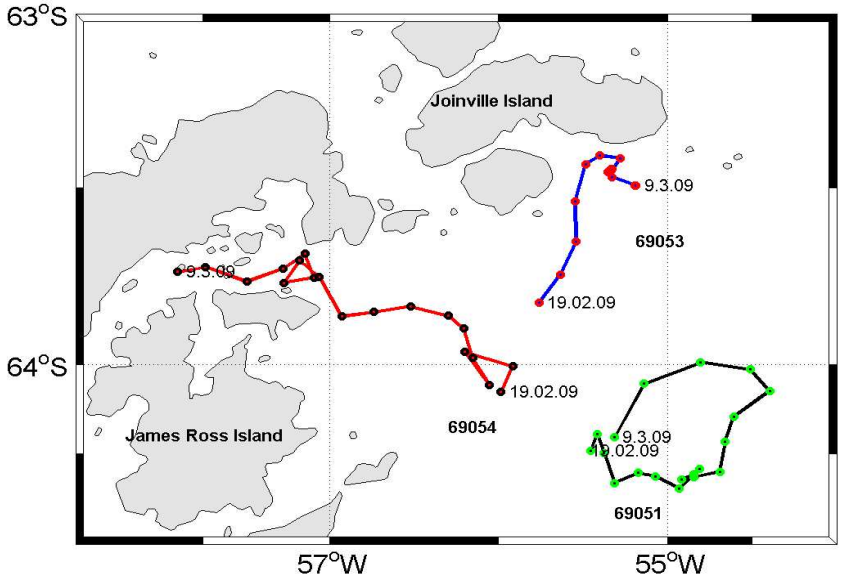
SECONDO: Moving Object Database

Moving Points (ex.: animais, veiculos e pessoas)

Moving Regions (ex.: mancha de oleo)

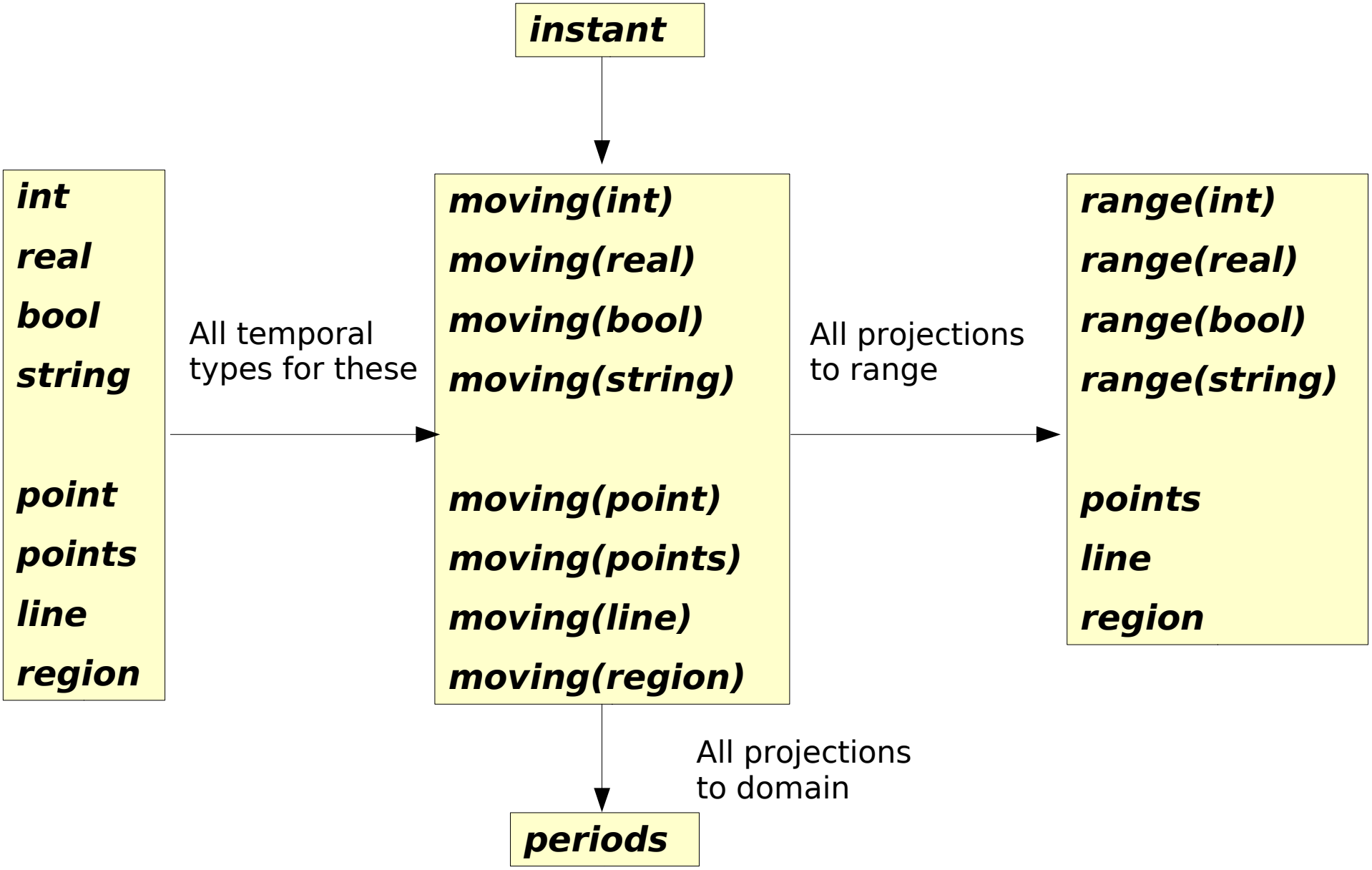
oil spill on the ocean

Animal tracking monitoring

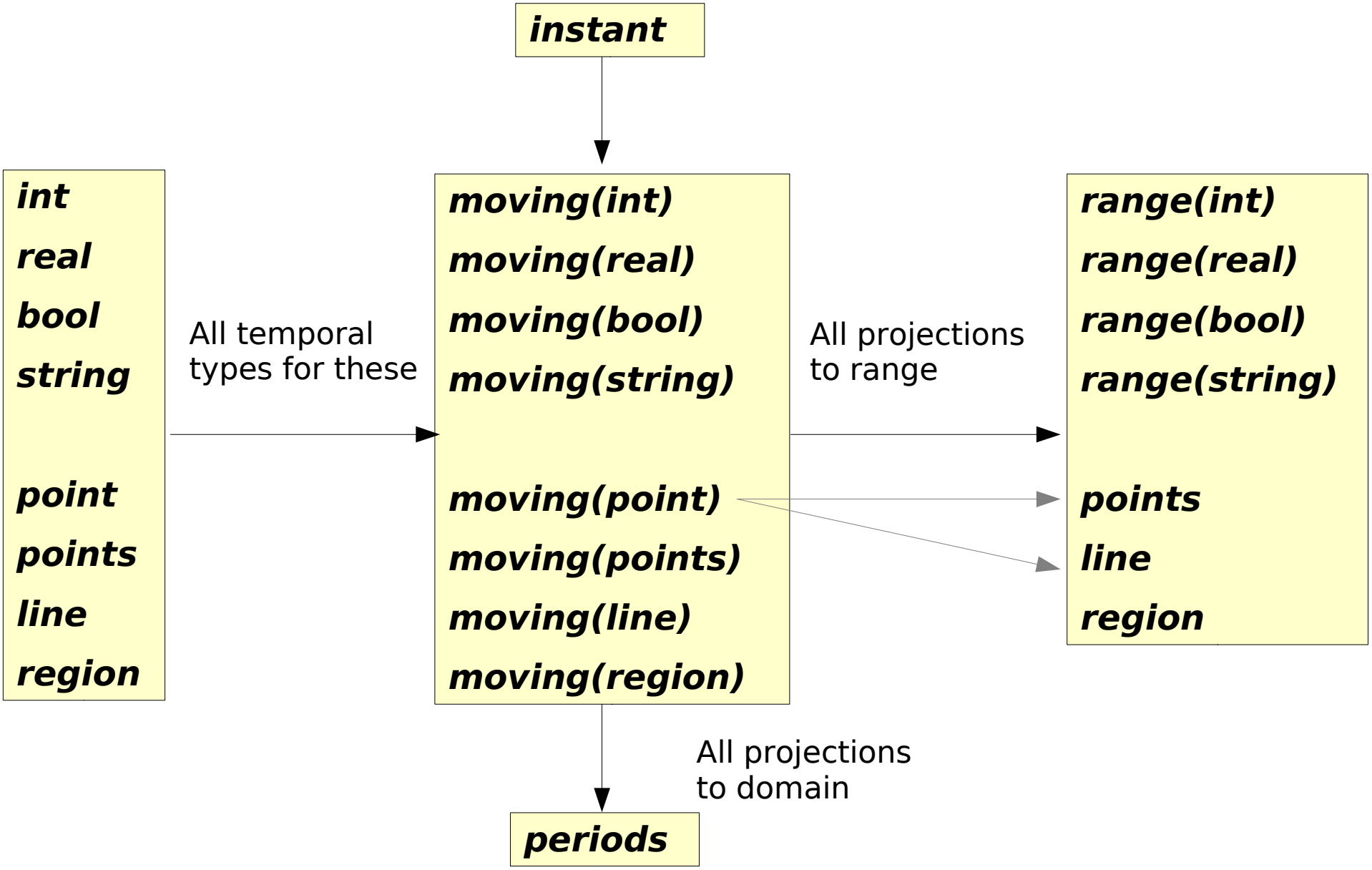


Iceberg tracking monitoring in Antarctica - SOS-Climate

SECONDO: Moving Object Algebra



SECONDO: Moving Object Algebra



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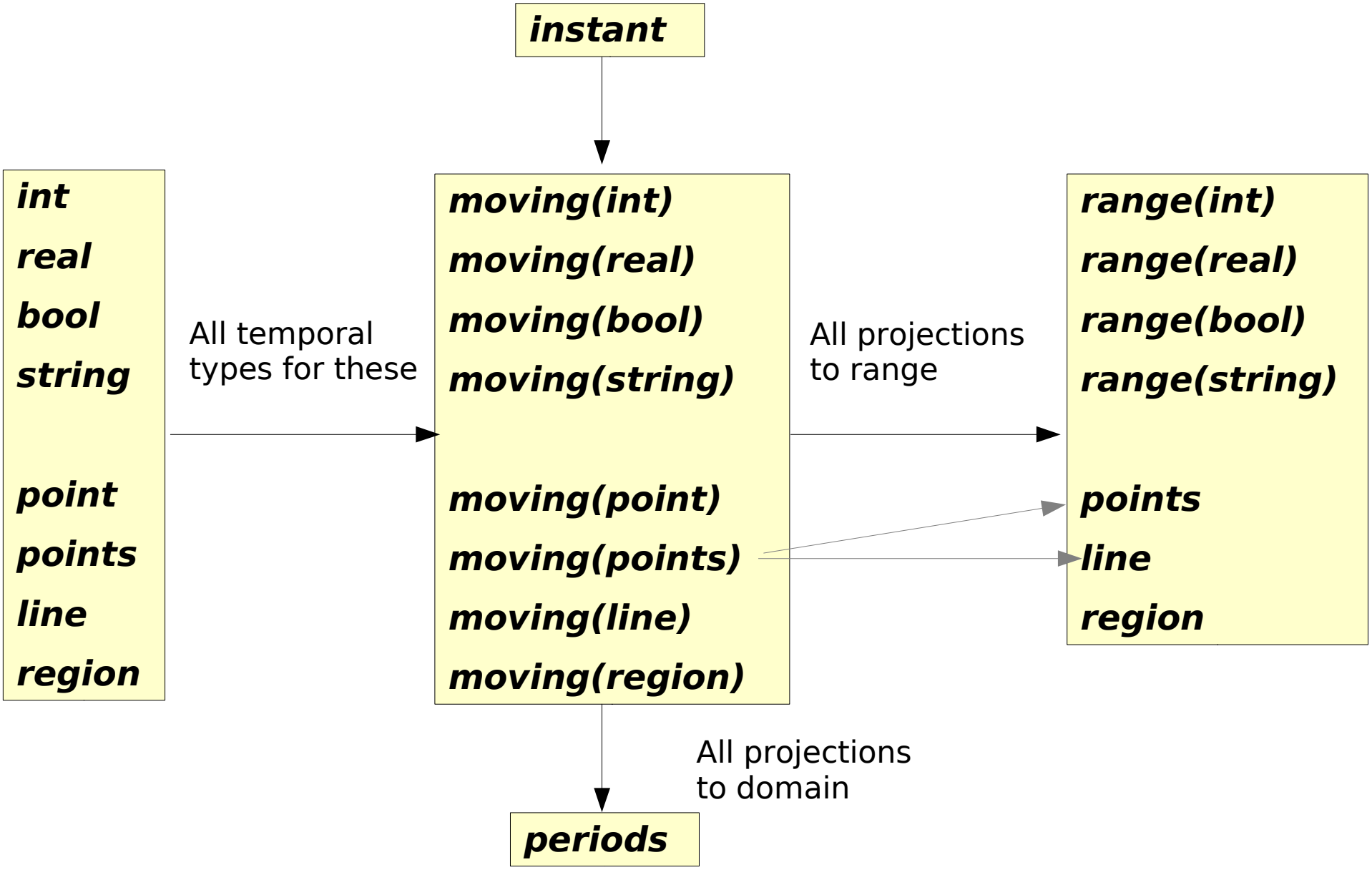

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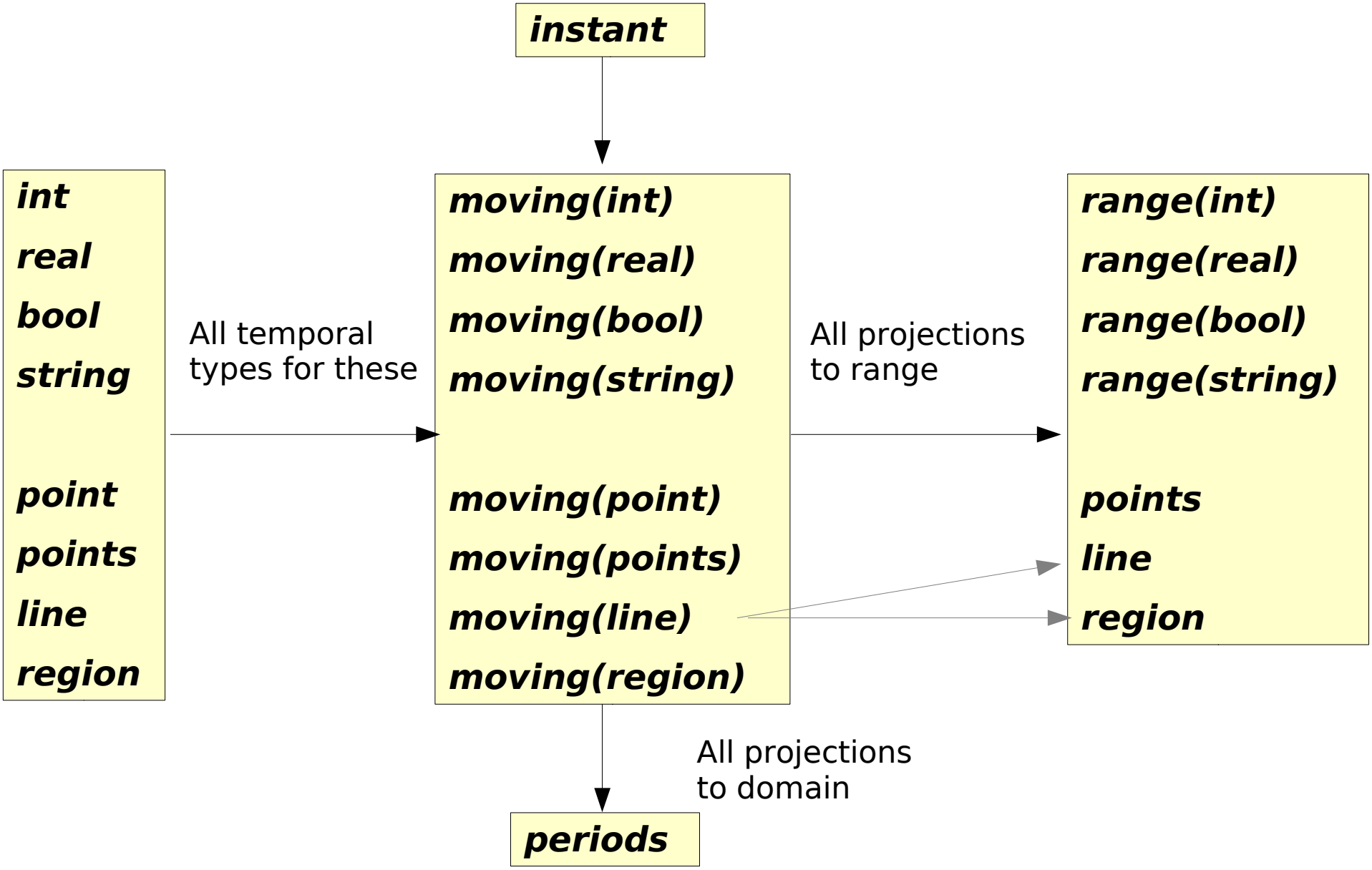
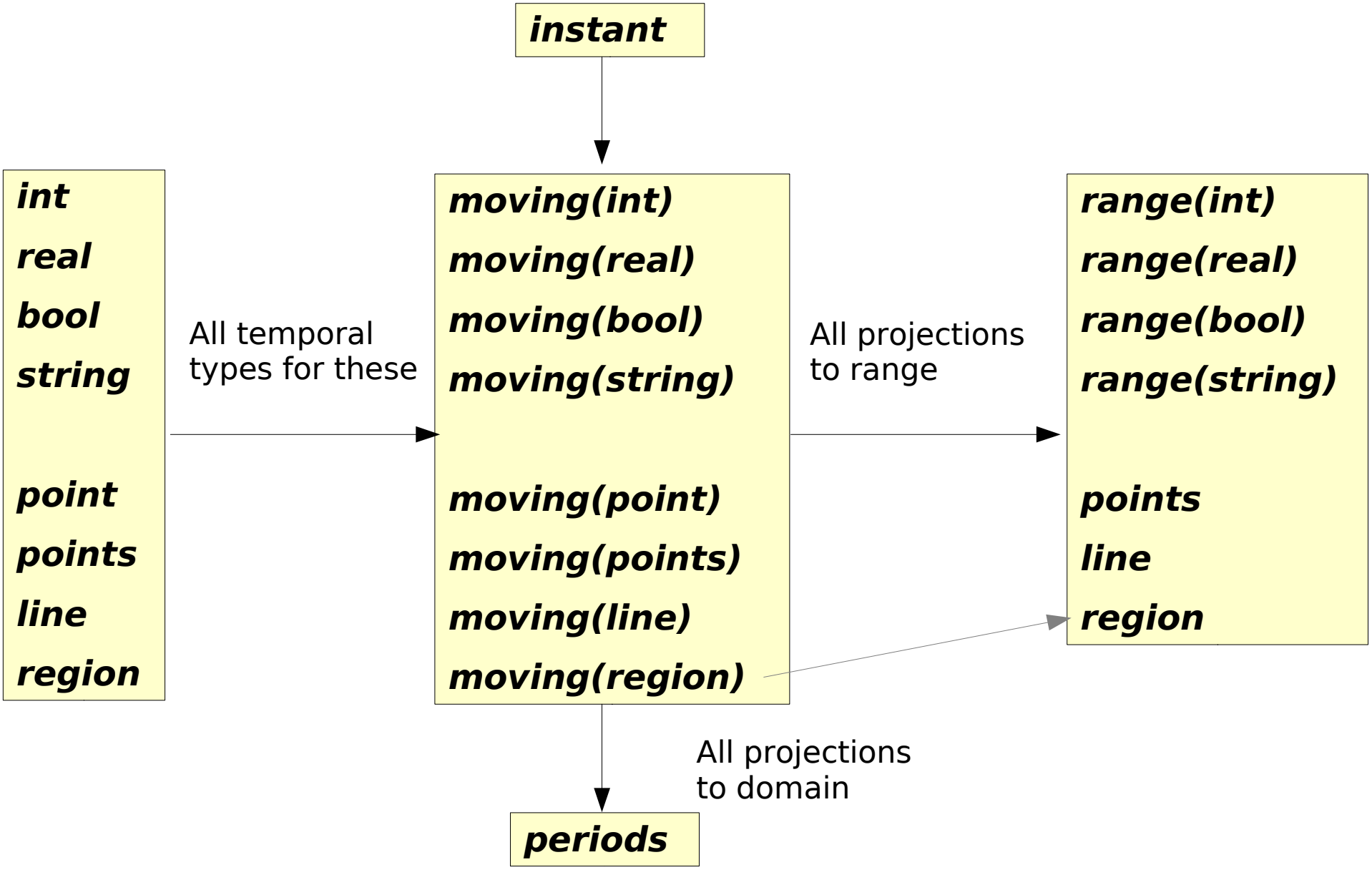


SECONDO: Moving Object Algebra



SECONDO: Moving Object Algebra

For each data type α, the set of possible values and its carrier set A_α are:

$$A_{moving(\alpha)} := \{ f \mid f: \overline{A}_{instant} \rightarrow \overline{A}_\alpha \text{ is a partial function}$$
$$\wedge\, \Gamma(f) \text{ is finite} \}$$

$\overline{A}$: carrier set without undefined value.

$\Gamma(f)$: f consists only of a finite number of continuous components.

Each value f is a function describing the development over time of a value from the carrier set A_α.

SECONDO: Moving Object Algebra

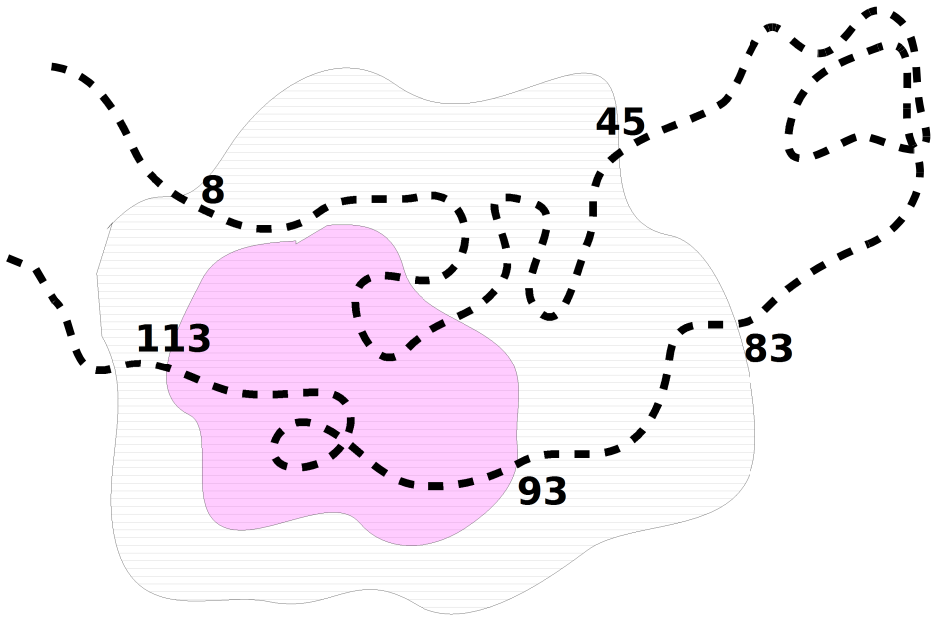
Some Operations

Operation	Signature
trajectory	*moving*(*point*) → *line* *moving*(*points*) → *line*
traversed	*moving*(*line*) → *region* *moving*(*region*) → *region*
intersection	*moving(point)* x *moving(region)* → *moving(point)*
distance	*moving(point) x moving(point)* → *moving(real)*
deftime	*moving(point)* → *periods*
length	*line* → *real*
min	*moving(real)* → *real*

SECONDO: Example of Use

1) Animals a_1 → their locations change continuously over time.

2) Habitat fragmentation area hF_1 → its limit changes continuously over time.




```
habitat_frag (id: string,
    habitat: mregion)

animal_tracking (id: string,
    description: string,
    tracking: mpoint)
```

a_1 from time 1 to 120

hF_1 at time 1

hF_1 at time 50

SECONDO: Example of Use

1) Find all animals that are longer than 5000 km?

```
SELECT *
FROM animal_tracking
WHERE length(trajectory(tracking)) > 5000
```

SECONDO: Example of Use

2) Retrieve any pairs of animals, which, during their tracking, came closer to each other than 500 meters.

```
SELECT *
FROM animal_tracking AS t1, animal_tracking AS t2
WHERE t1.id <> t2.id AND
min(distance(t1.tracking, t2.tracking)) < 0.5
```

SECONDO: Example of Use

3) At what times was animal a1 within the habitat fragmentation area hF1 ?

```
SELECT deftime(intersection(a.tracking, h.habitat))
FROM animal_tracking AS a, habitat_frag AS h
WHERE a.id = 'a1' AND h.id = 'hF1'
```