



Ministério da
Ciência e Tecnologia



Spatio-Temporal Database

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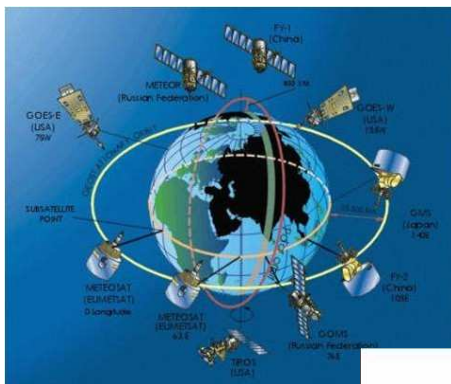
Topics

- (1) Spatio-temporal Data and Applications
- (2) Representation of Spatio-Temporal Data
 - (a) Existing Spatio-Temporal Database Models
- (3) Spatio-Temporal Database Systems

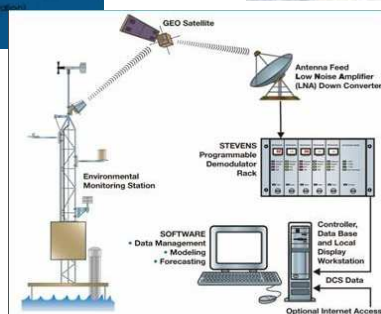
Spatio-temporal Data and Applications

Spatio-temporal Data

Technological advances in geospatial data collection.



Earth observation and GPS satellites



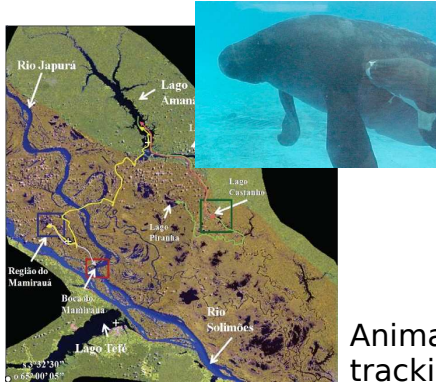
wireless and mobile computing, radio-frequency identification (RFIDs) and sensor networks

Spatio-temporal Data

Technological advances in geospatial data collection.



Applications which handle dynamic geospatial information



[Arraut, E. M. 2008]

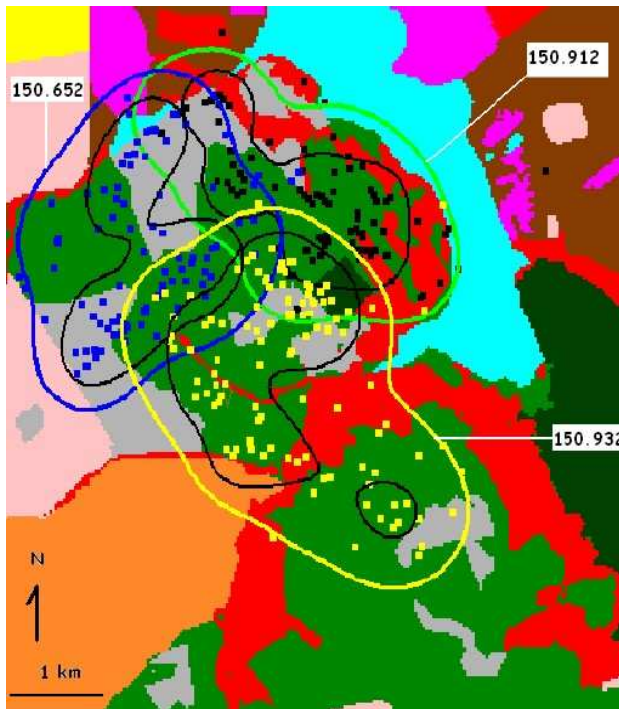
Animal tracking monitoring

oil spill on the ocean



hurricane and volcanic eruption monitoring

Spatio-temporal Data and Applications



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

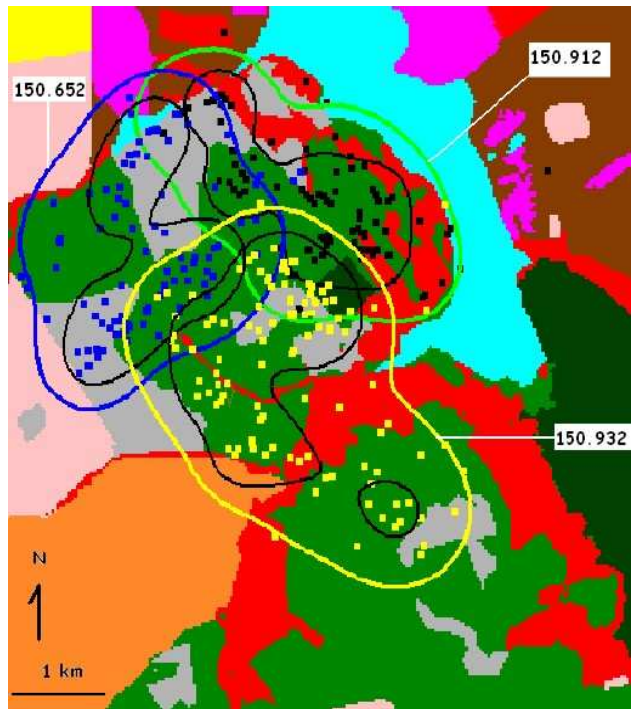
Julho de 2005 a junho de 2007 - monitorando 6 aves de rapina por rádio-telemetria.

Mapa de Uso e Ocupação do Solo
X
Trajetórias Dos Animais

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

[Marco Granzinoli, 2009]

Spatio-temporal Data and Applications



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

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

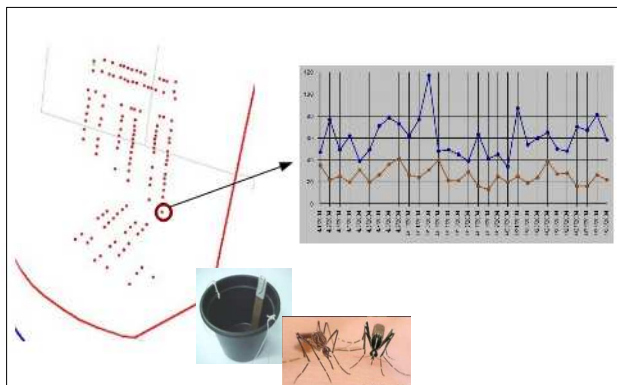
“Quanto tempo o animal 150.652 permaneceu em cada uso e ocupação do solo?”

“Em quais momentos o animal 150.652 sai do cerrado aberto e entra no campo cerrado?”

[Marco Granzinoli, 2009]

Spatio-temporal Data and 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]

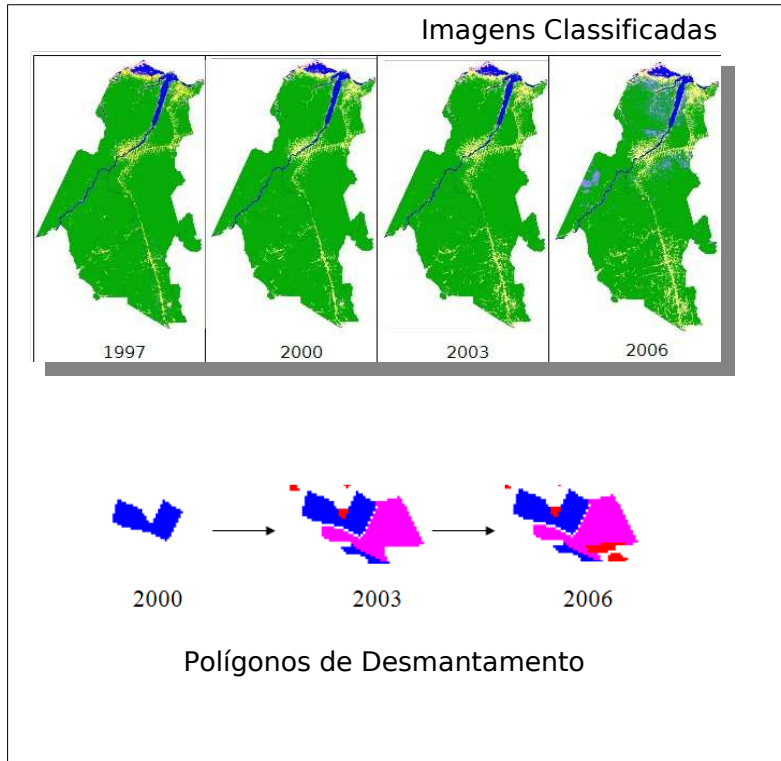
“When and where did objects o1 and o2 meet each other (considering a meeting when the distance between two objects is less than 2 meters)?”

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

Movement Monitoring

Spatio-temporal Data and Applications

PRODES



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

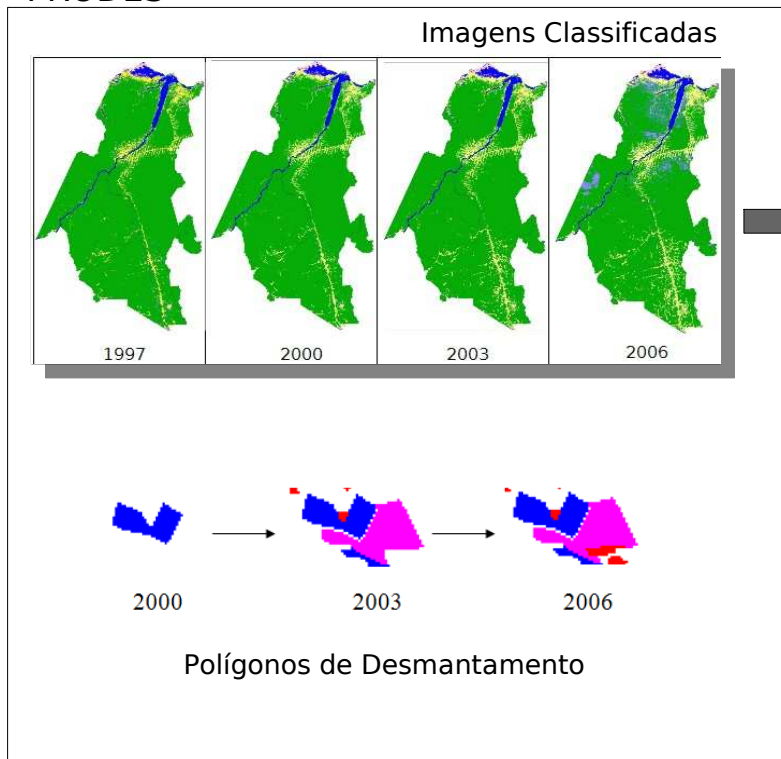
"how did a specific deforested region evolve over time between 2000 and 2008?"

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

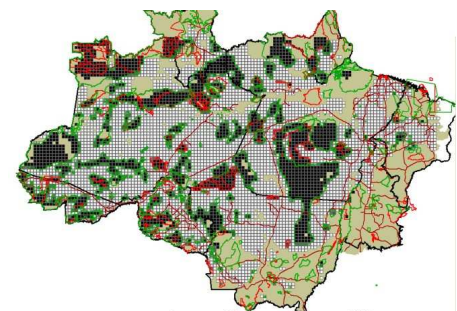
"when did a specific deforested region reach the municipality x?"

Spatio-temporal Data and Applications

PRODES



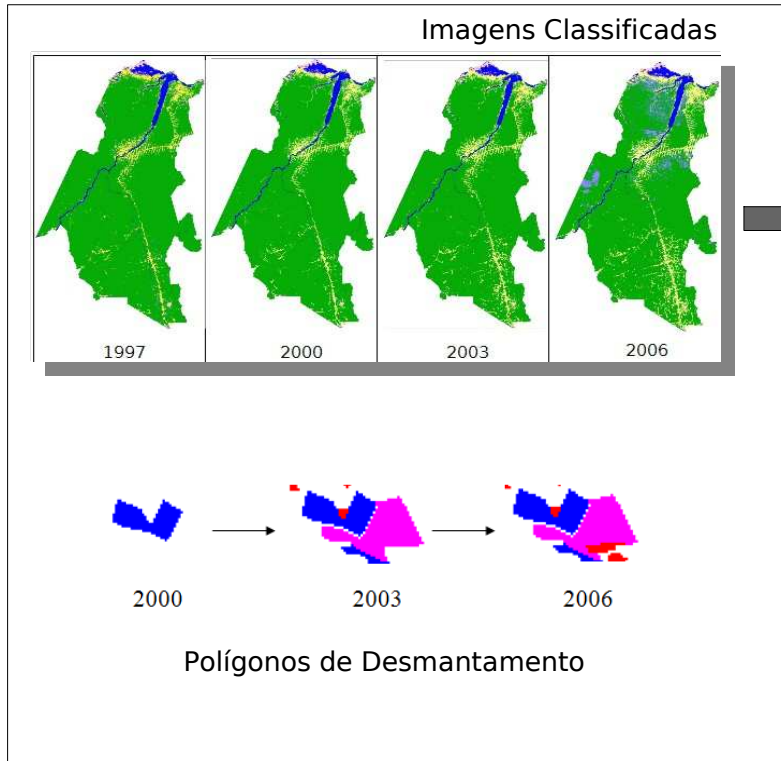
Land Use and Land Cover Modeling



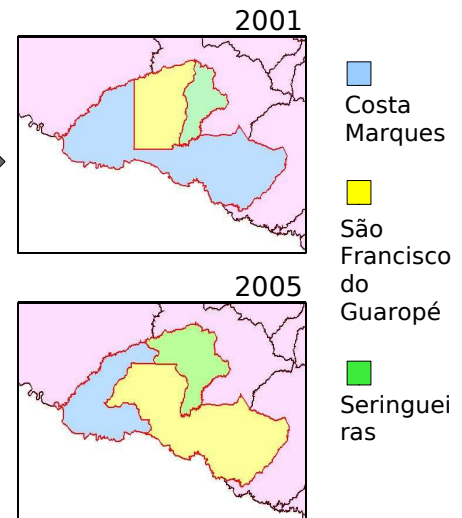
"given a cell, how has the forest status been varying in this cell over time?"

Spatio-temporal Data and Applications

PRODES



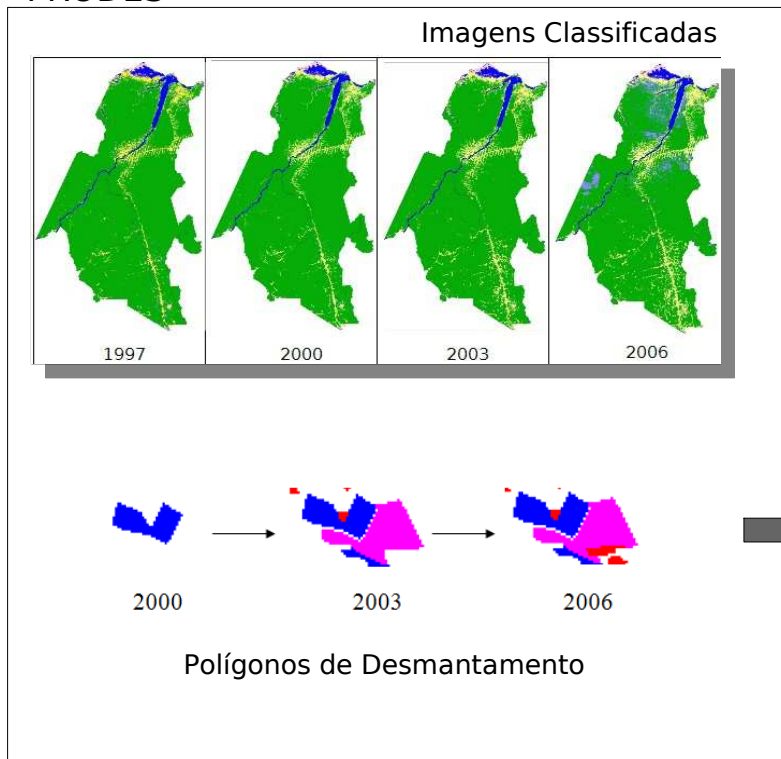
Municipal Management



"How many hectares were deforested in each municipality?"

Spatio-temporal Data and Applications

PRODES



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

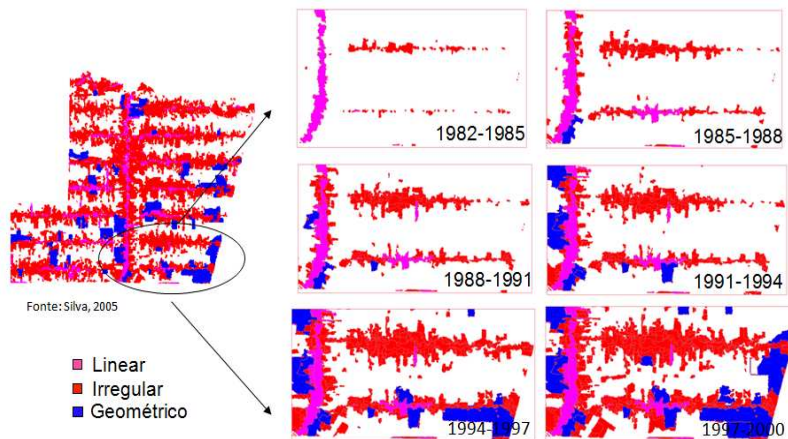
*é importante ter o conceito de **objeto** (área desmatada) e de **evolução desse objeto** ao longo do tempo.*

[Silva et al., 2005]

[Motta et al., 2009]

[Bittencourt et al., 2008]

Spatio-temporal Data and Applications



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

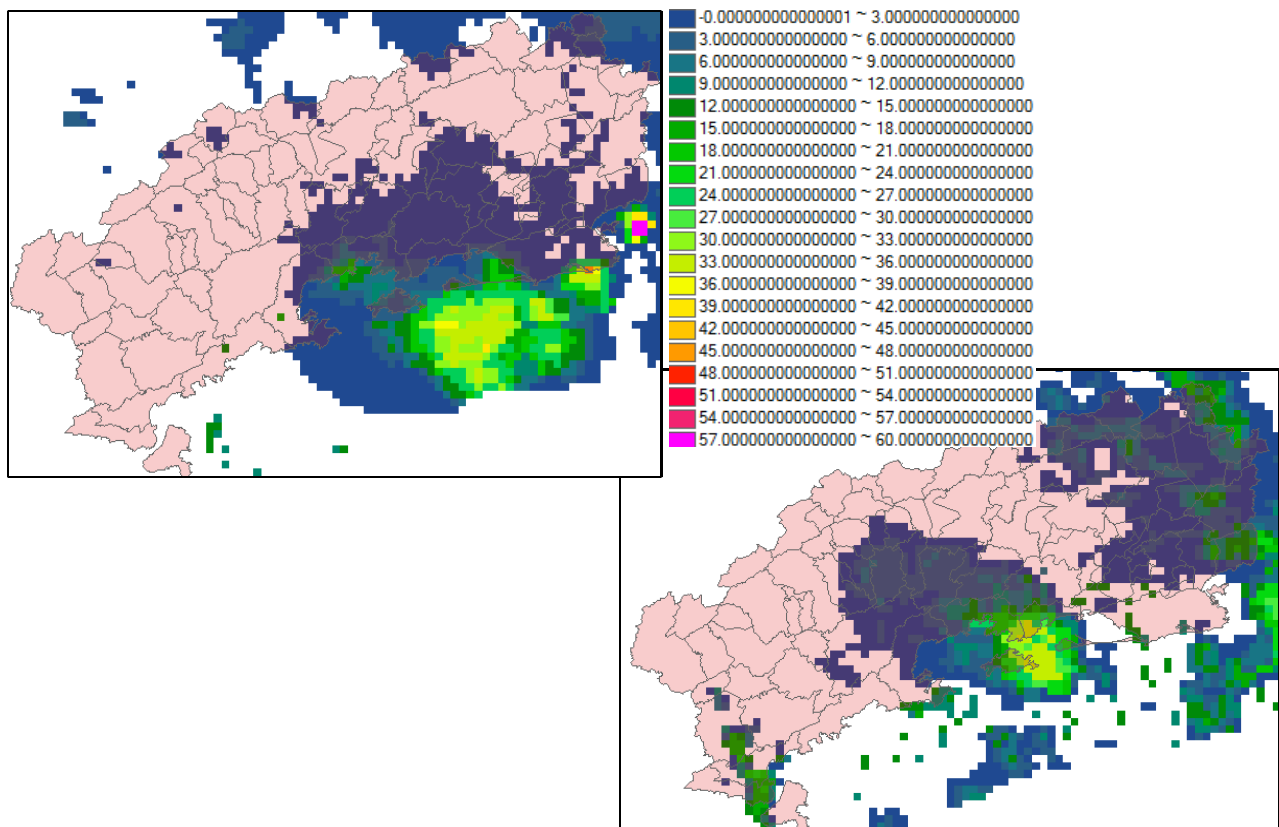
é importante ter o conceito de **objeto** (área desmatada) e de **evolução desse objeto** ao longo do tempo.

[Silva et al., 2005]

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Spatio-temporal Data and Applications



Spatio-temporal Data

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

Representation and Query of Spatio-Temporal Data

Indexing of Spatio-Temporal Data

Analysis of Spatio-Temporal Data

Spatio-Temporal Data Mining and Pattern Recognition

Spatio-Temporal Visualization

Spatio-temporal Data

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Representation and Query of Spatio-Temporal Data

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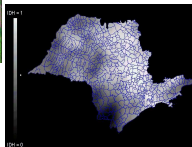
Spatio-Temporal Data Mining and Pattern Recognition

Spatio-Temporal Visualization

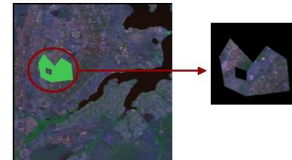
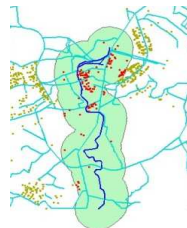
Representation of Spatio-Temporal Data in Computational Systems

Representation of Spatial Data

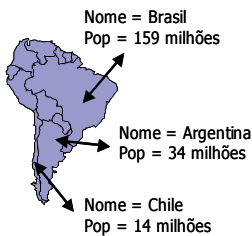
Static geospatial information is represented in GIS following well-established ideas.



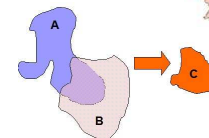
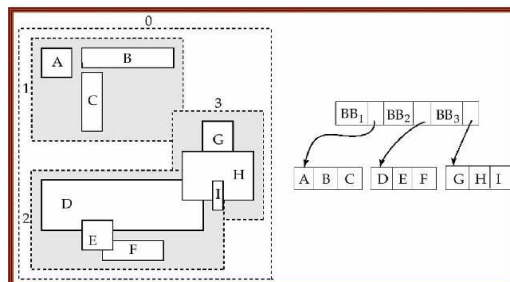
Geo-Fields and Geo-Objects



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.

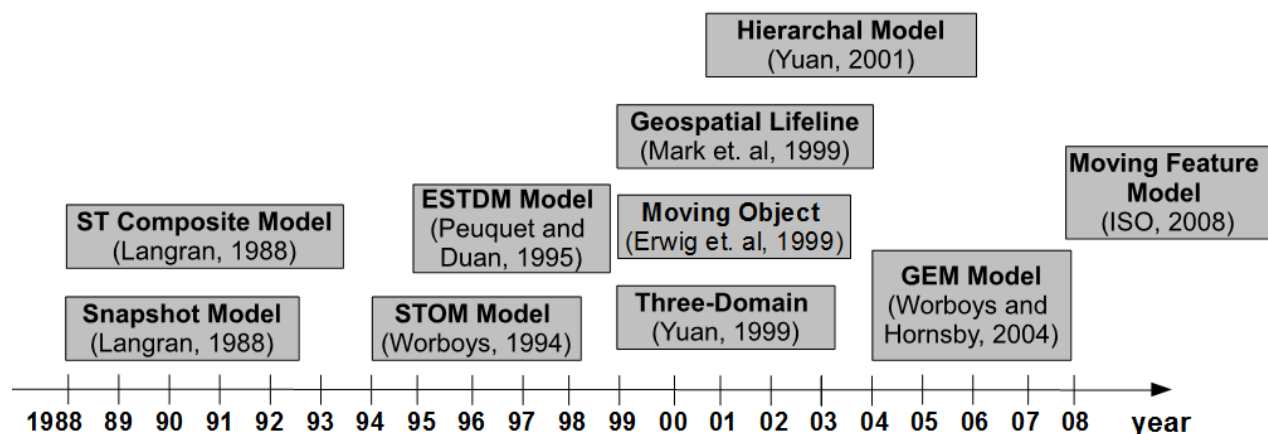
Spatial information: every **spatial DBMS** (ex.: Oracle Spatial and PostGIS) follows a pattern to represent and query spatial information (**SFS-OGC**).

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.

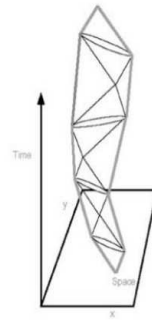
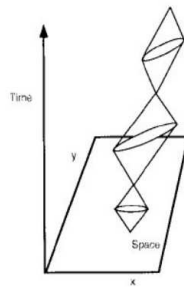
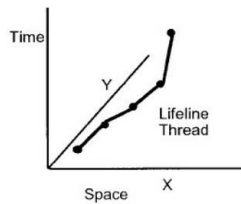
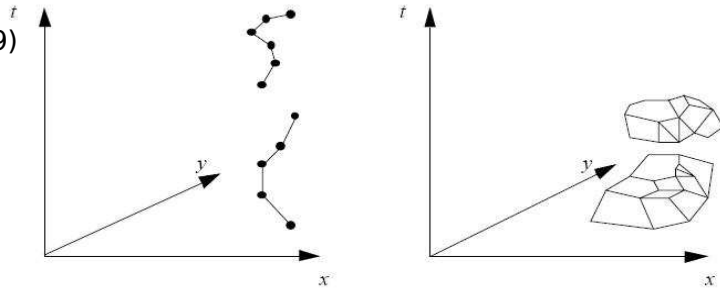


Existing Spatio-Temporal Database Models

There are many proposals of spatio-temporal database models.

Moving Object (Erwig et. al, 1999)

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

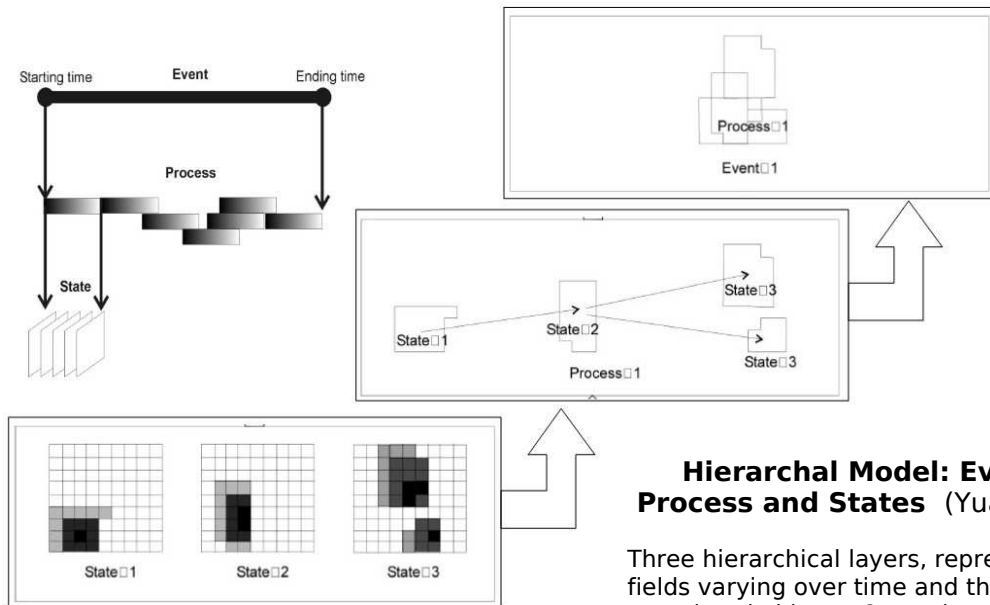


Geospatial Lifeline (Mark et. al, 1999)

Different types of trajectories.

Existing Spatio-Temporal Database Models

There are many proposals of spatio-temporal database models.

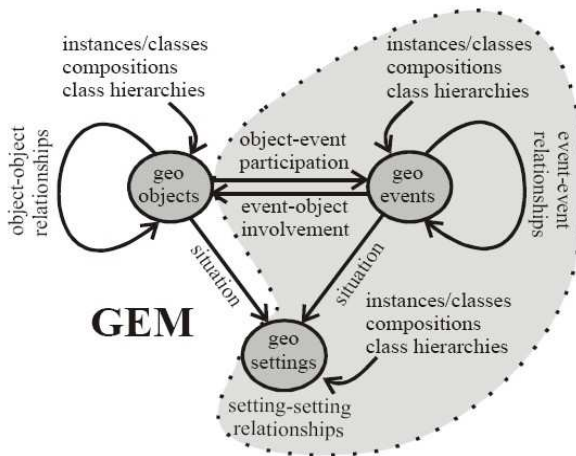


Hierarchal Model: Events, Process and States (Yuan, 2001)

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

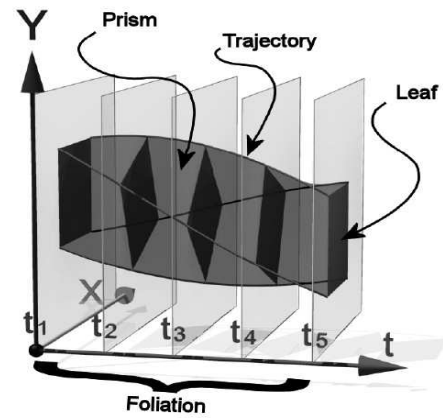
Existing Spatio-Temporal Database Models

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 et al. 2004]

Representation of Spatio-Temporal 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. | |
| Examples: - SAUDAVEL: egg traps - LUCC Modeling: cell space | Examples: - Municipal limit changes | Examples: - Movement monitoring (ex.: Aves de rapina e elefante marinho) - PRODES: Evolution of deforested areas | Examples: - PRODES: classified images - Land Use and Land Cover Maps |

Representation of Spatio-Temporal Data

| Geo-Object which change over time | | | Geo-Field which vary over time |
|--|--|--|--------------------------------|
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| (a) | (b) | (c) | (d) |

(a)

(b)

(c)

(d)

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

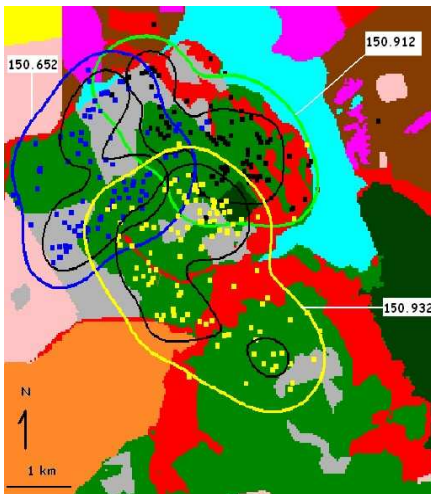
fiat objects → sudden changes
bona fide objects → gradual changes

moving object model → continuous geometry changes
 other models → discrete geometry changes

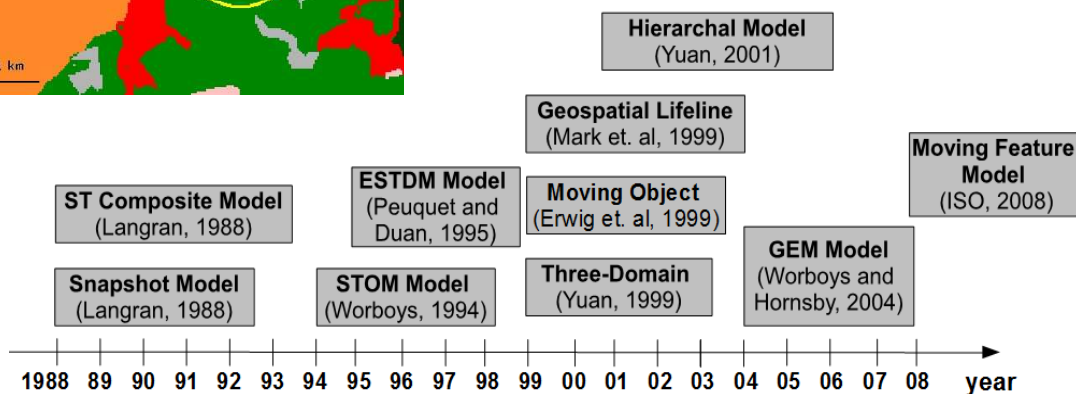
Representation of Spatio-Temporal Data

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| | <ol style="list-style-type: none"> 1. ST Composite Model [Langran, 1988] 2. STOM Model [Worboys, 1994] 3. Three-Domain Model [Yuan, 1999] 4. GEM Model [Worboys and Hornsby, 2004] | <ol style="list-style-type: none"> 1. Geospatial Lifeline [Mark et. al, 1999] 2. Moving Object [Erwing et. al, 1999] 3. Moving Feature Model [ISO, 2008] | <ol style="list-style-type: none"> 1. Snapshot Model [Langran, 1988] 2. ESTDM Model [Peuquet and Duan, 1995] 7. Hierarchal Model [Yuan, 2001] |

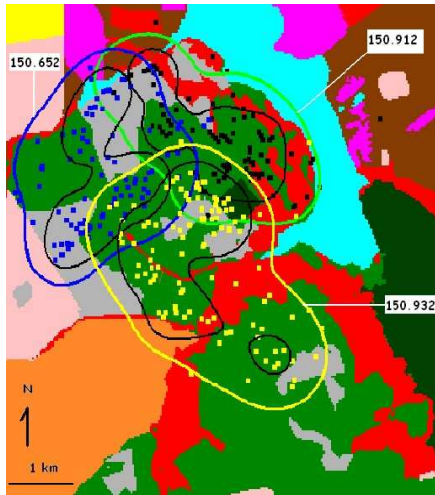
Representation of Spatio-Temporal Data



*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?*

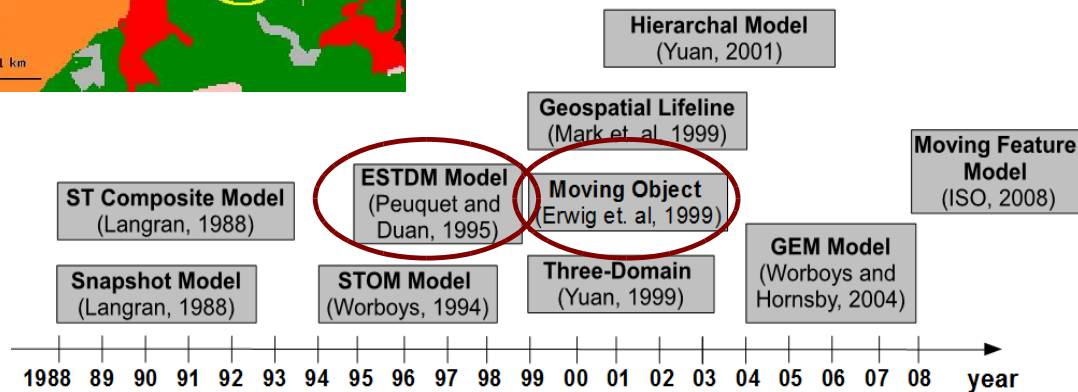


Representation of Spatio-Temporal Data

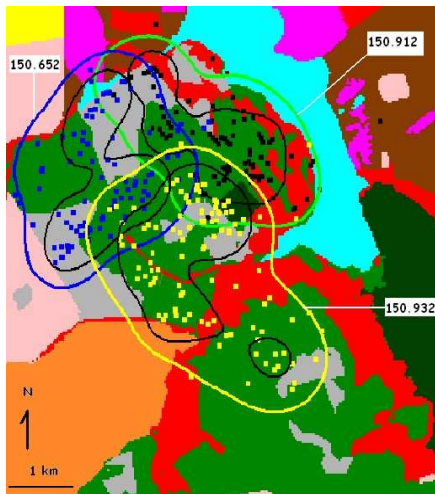


(1) ESTDM [Peuquet and Duan, 1995] → *Variação do uso e cobertura do solo.*

(2) Moving Object [Erwing et al, 1999] → *Trajeto rias dos animais*



Representation of Spatio-Temporal Data



(1) ESTDM [Peuquet and Duan, 1995] → *Vari a o do uso e cobertura do solo.*

(2) Moving Object [Erwing et al, 1999] → *Trajeto rias dos animais*

How to answer these questions?

“Quanto tempo o animal 150.652 permaneceu em cada uso e ocupa a o do solo?”

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

Spatio-Temporal Database Systems

Spatio-Temporal Database Systems

(1) SECONDO

(2) HERMES - Oracle Spatial

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.

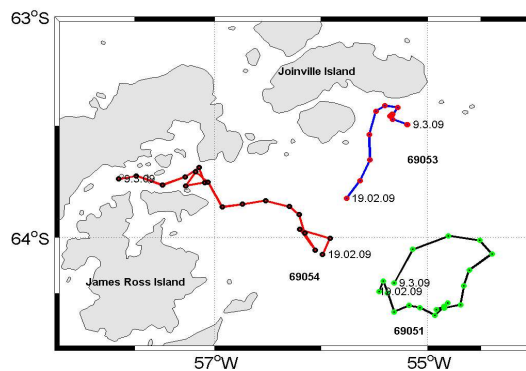
SECONDO: Moving Object Database

Moving Points (ex.: animais, veiculos e pessoas) oil spill on the ocean

Moving Regions (ex.: mancha de oleo)

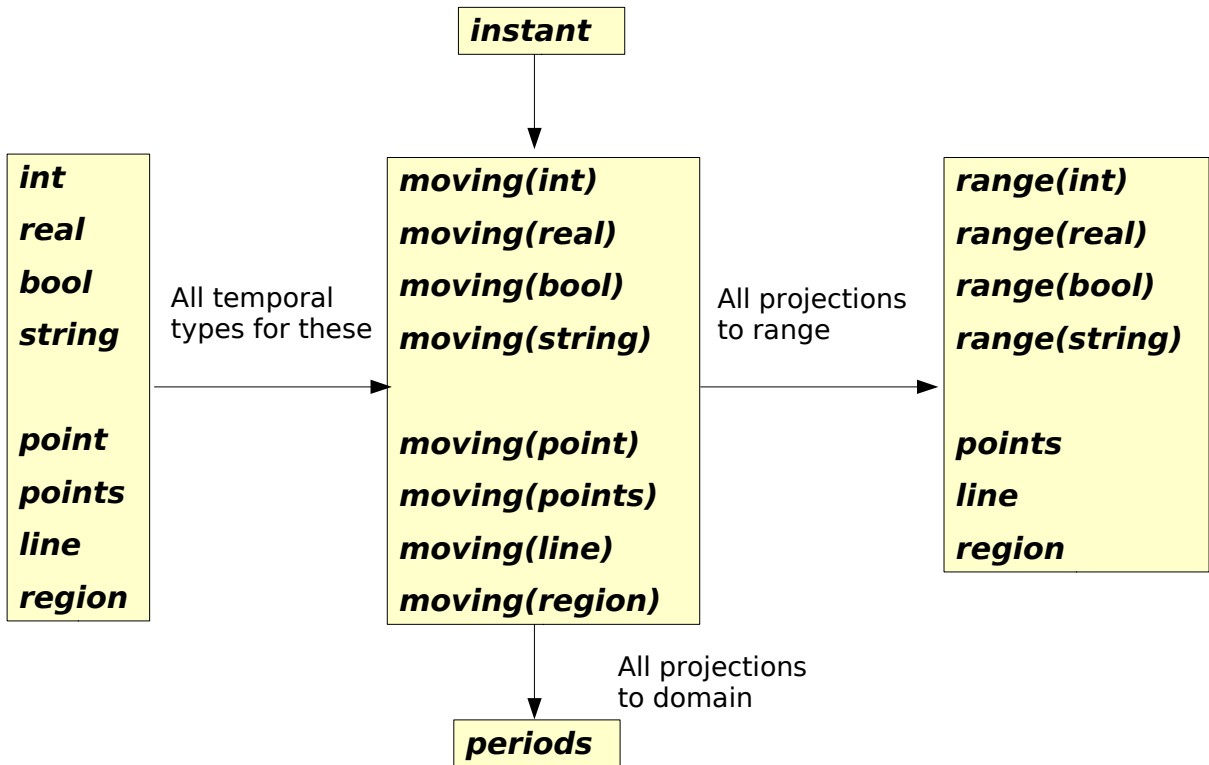


Animal tracking monitoring

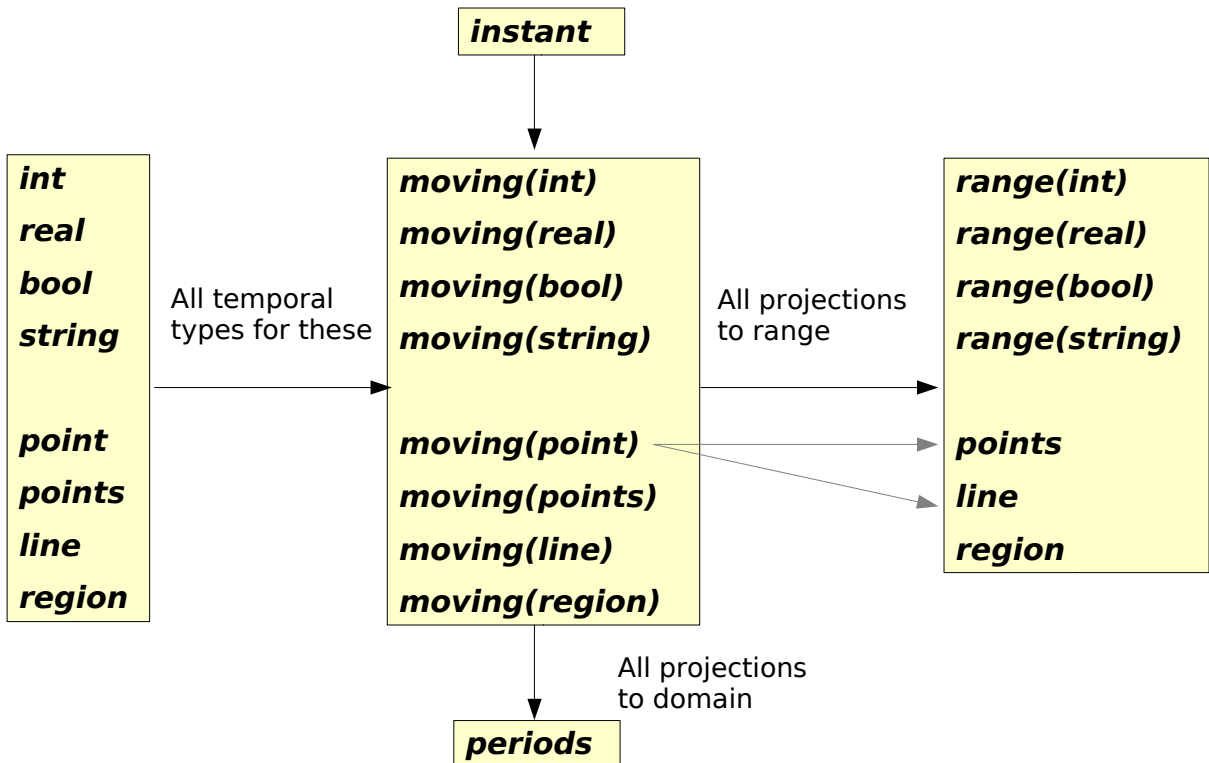


Iceberg tracking monitoring in Antarctica - SOS-Climat

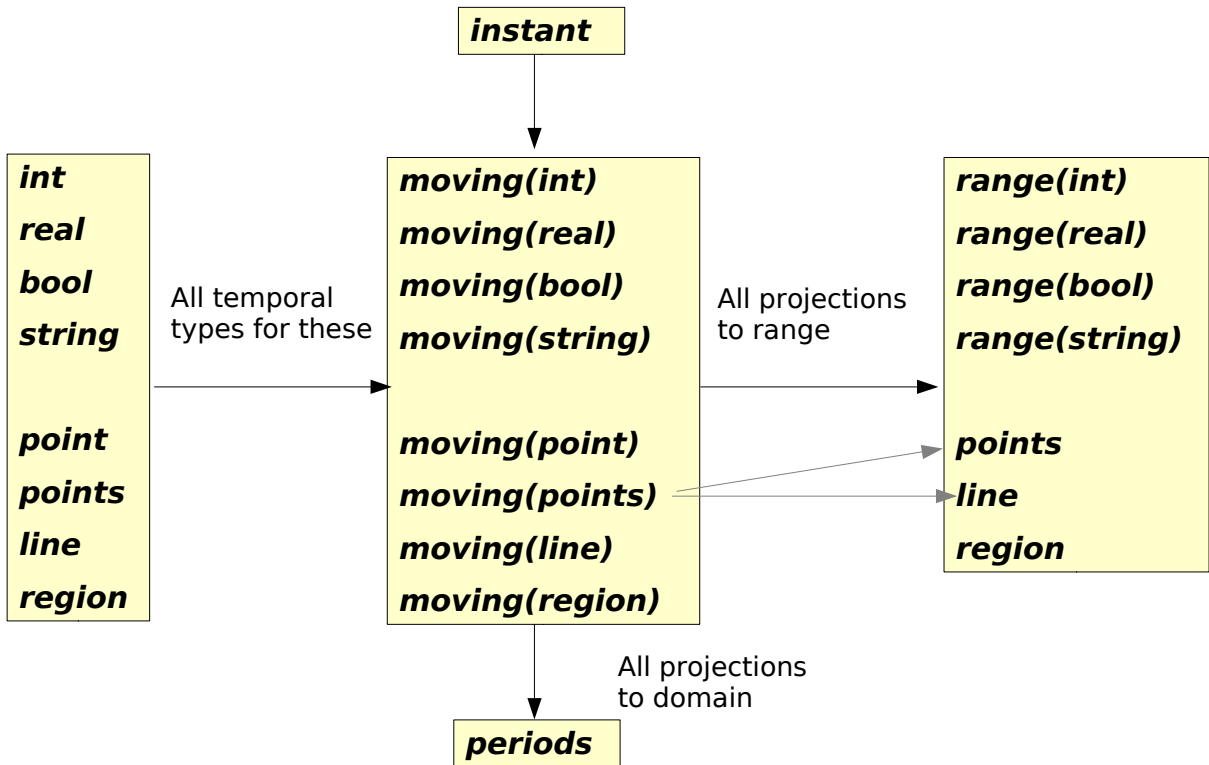
SECONDO: Moving Object Algebra



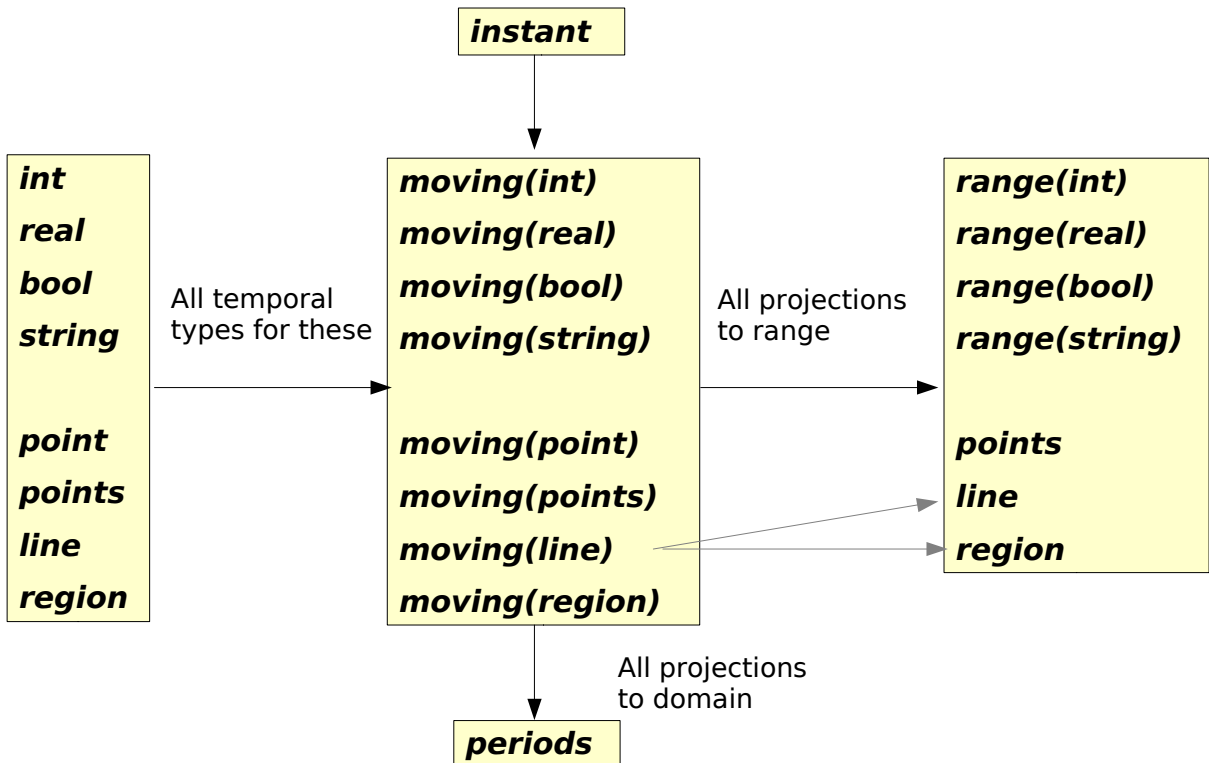
SECONDO: Moving Object Algebra



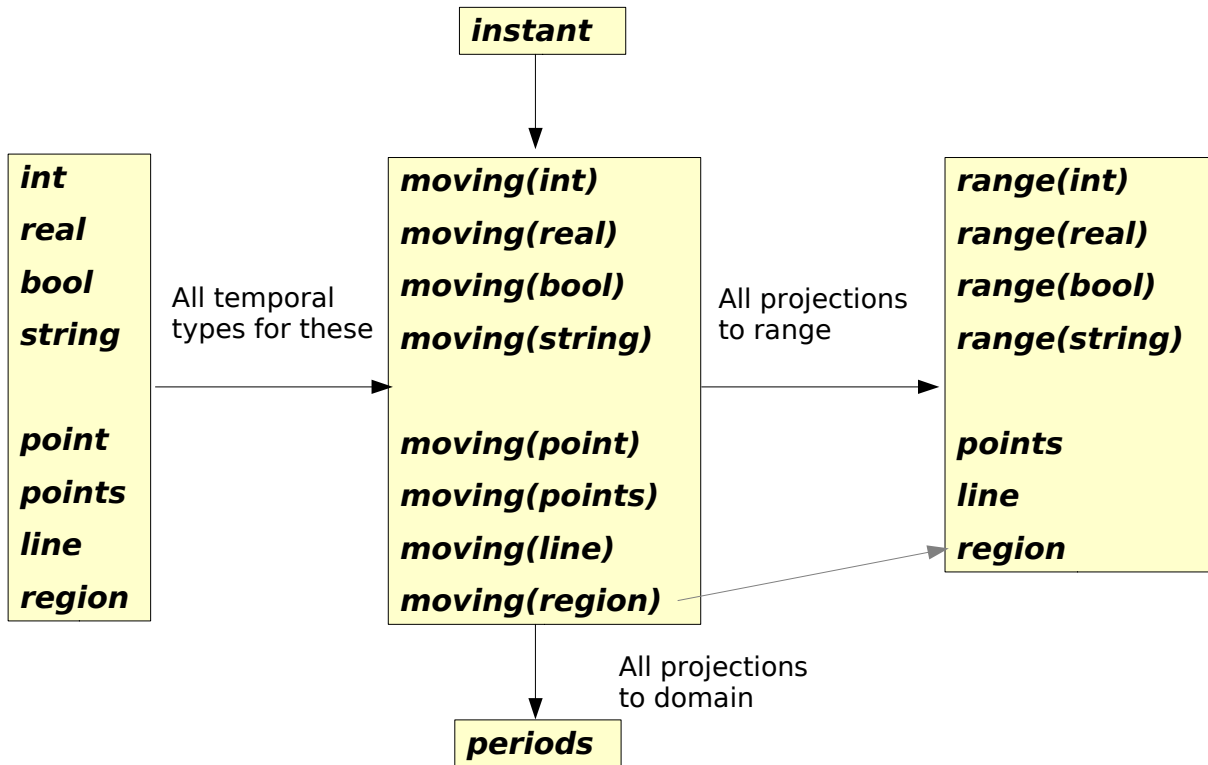
SECONDO: Moving Object Algebra



SECONDO: Moving Object Algebra



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:

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

\bar{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

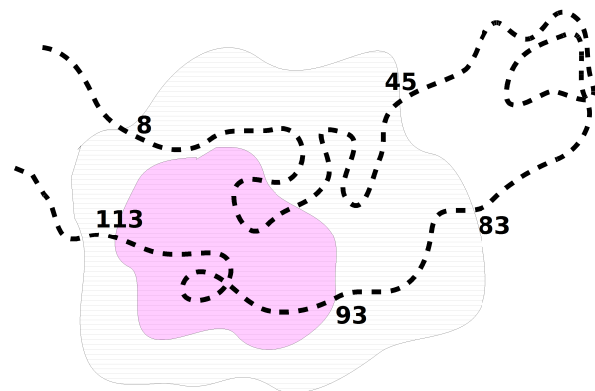
Some Operations

| Operation | Signature |
|---------------------|--|
| trajectory | $moving(point) \rightarrow line$ $moving(points) \rightarrow line$ |
| traversed | $moving(line) \rightarrow region$ $moving(region) \rightarrow region$ |
| intersection | $moving(point) \times moving(region) \rightarrow moving(point)$ |
| distance | $moving(point) \times moving(point) \rightarrow moving(real)$ |
| deftime | $moving(point) \rightarrow periods$ |
| length | $line \rightarrow real$ |
| min | $moving(real) \rightarrow real$ |

SECONDO: Example of Use

1) Animals $a_1 \rightarrow$ their locations change continuously over time.

2) Habitat fragmentation area $hF_1 \rightarrow$ 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

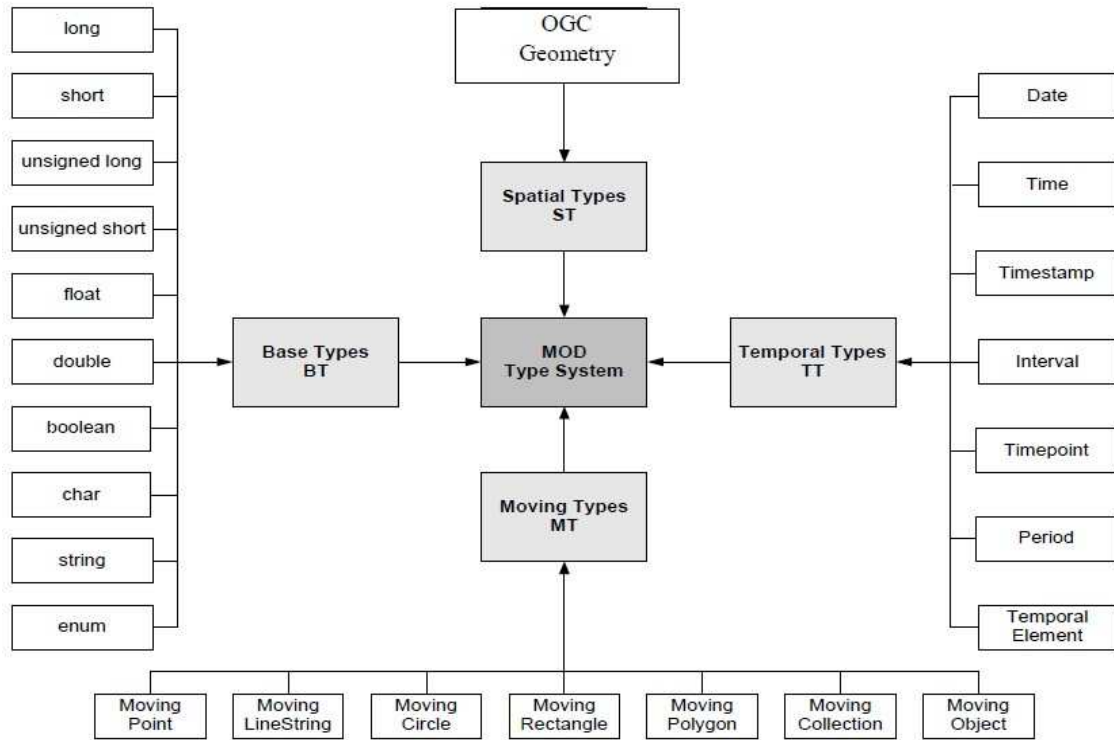
3) At what times was animal a1 within the habitat fragmentation area hF1 ?

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

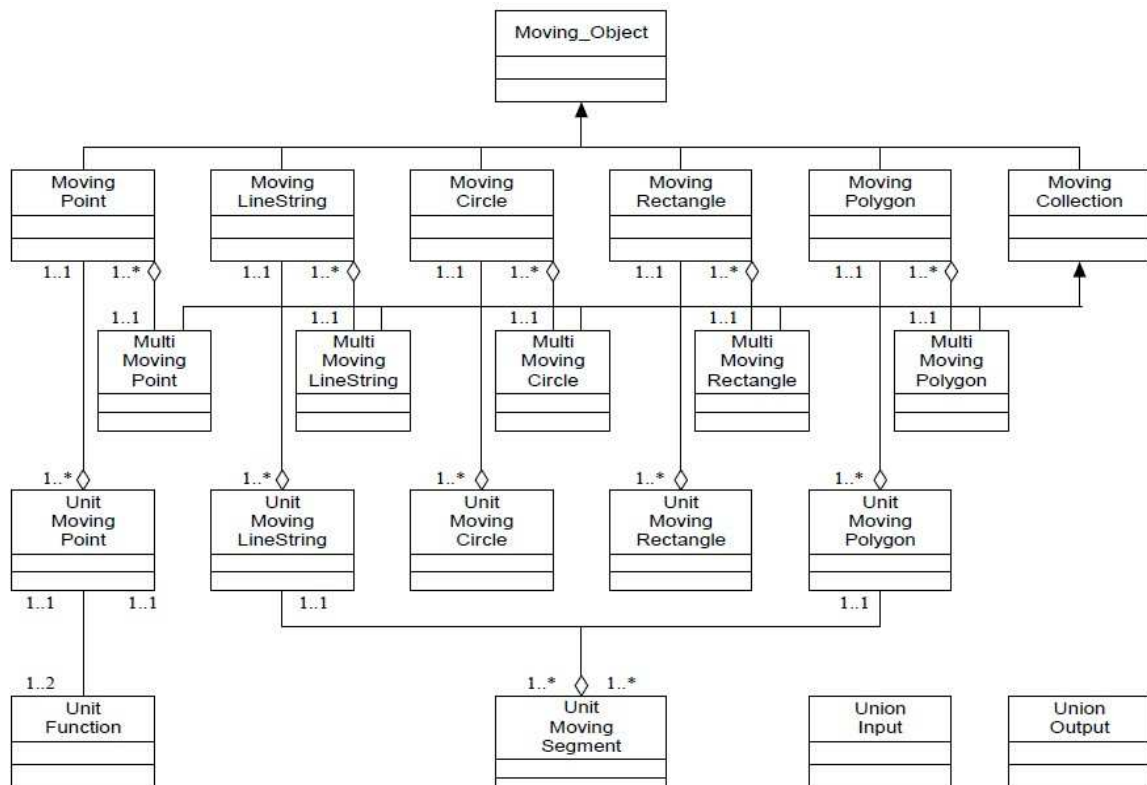
HERMES

- A framework that extends a OGC-compliant ORDBMS by supporting moving object data. [Pelekis, N. et. al, 2010]
- Moving Object Data: time-varying geometries that change their position and/or extent in space and time dimensions, either discretely or continuously.
- **HERMES MOD** (Moving Object Database) **Engine**: datatype-oriented model and an extension of SQL-like query language for supporting the modeling and querying of moving object database (MOD) on top of OGC-compliant ORDBMS.

HERMES - Data Type Model

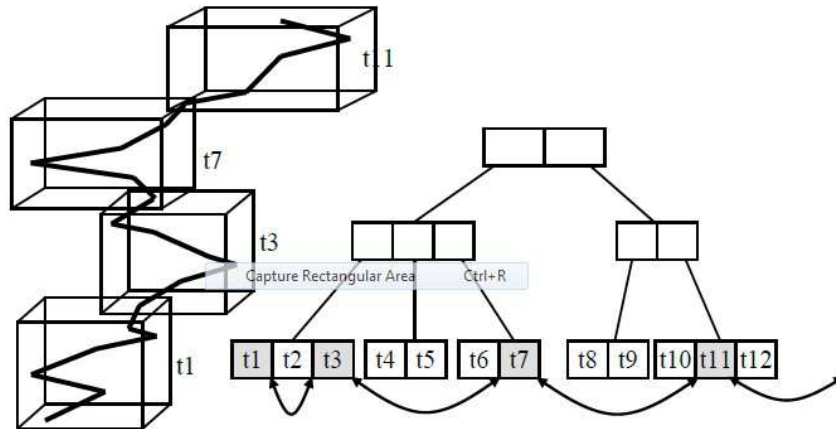


HERMES - Moving Types



HERMES

- It provides:
 - Trajectory Bundle tree (TB-tree)
 - trajectory-based operations
 - k nearest neighbor (k-NN) search
 - different techniques for trajectory similarity search



HERMES

- Proof of concept: it was implemented on top of a commercial ORDBMS, namely **Oracle**, while our design has also been successfully applied and repeated in the open-source **PostgreSQL / PostGIS** spatial extension.