MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Spatiotemporal Data, Temporal GIS and Applications

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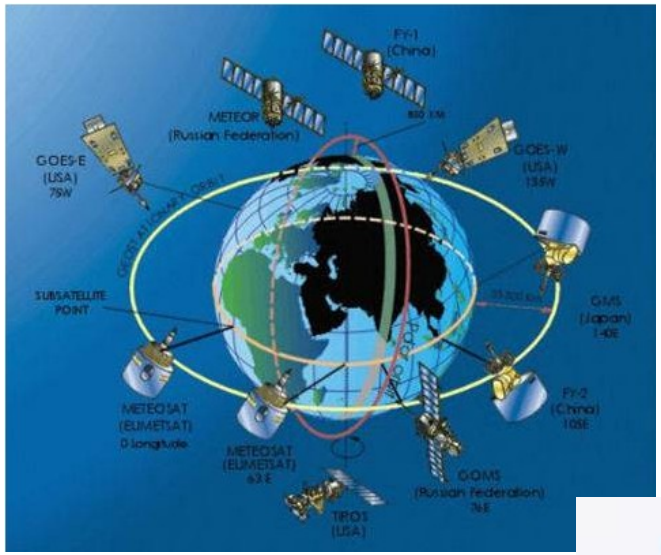
Junho de 2017

Geographic Information System (GIS)
and
Spatiotemporal Data

Spatiotemporal Data

Technological advances in geospatial data collection.

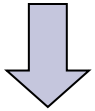


Earth observation
and GPS satellites

Mobile phones, GPS devices,
social networks,
geosensors networks...

Spatiotemporal Data

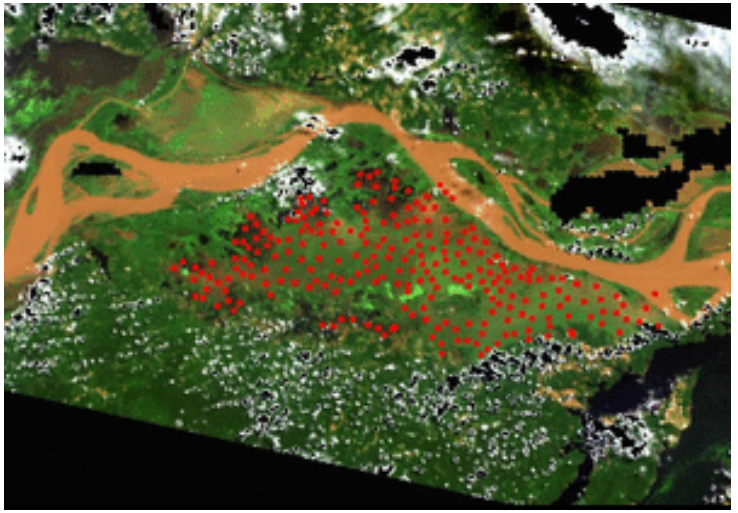
Technological advances in geospatial data collection.



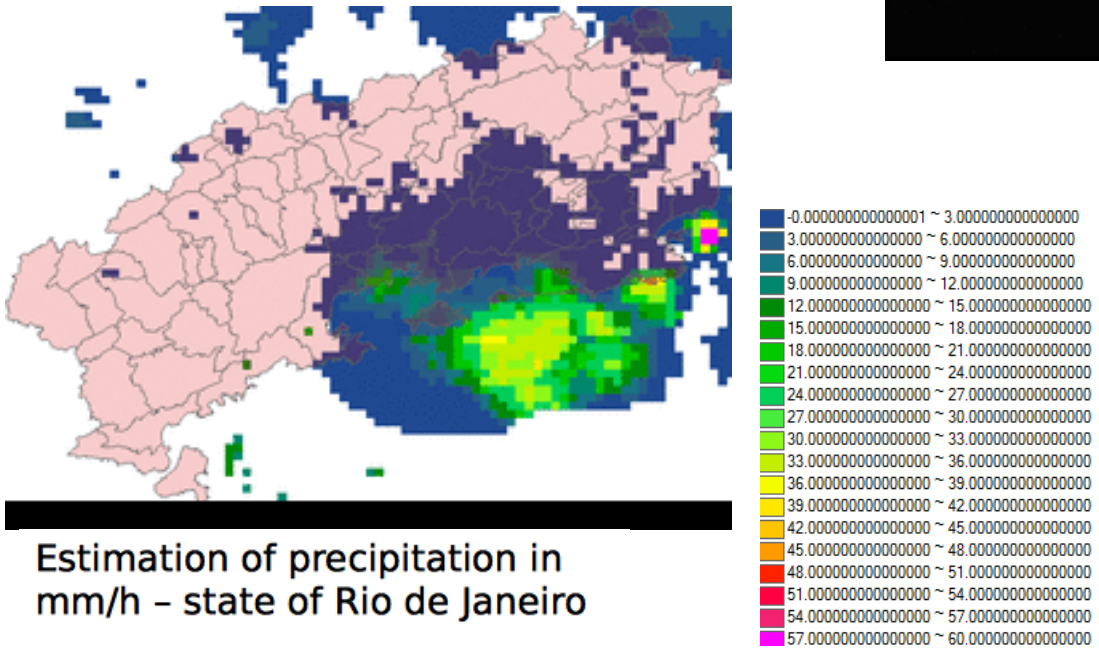
Diversity of spatiotemporal data from different application domains.

Spatiotemporal Data and Applications

Environmental and
Natural Disaster Monitoring



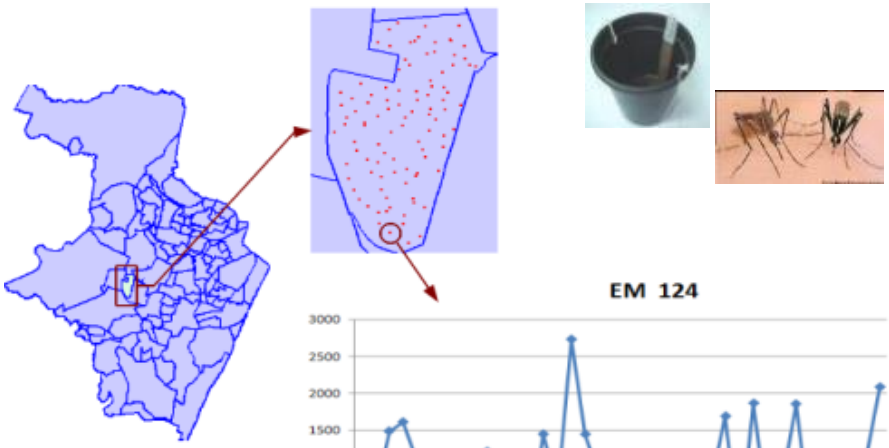
Variation of chlorophyll in an Amazon rainforest lake.



Estimation of precipitation in mm/h – state of Rio de Janeiro

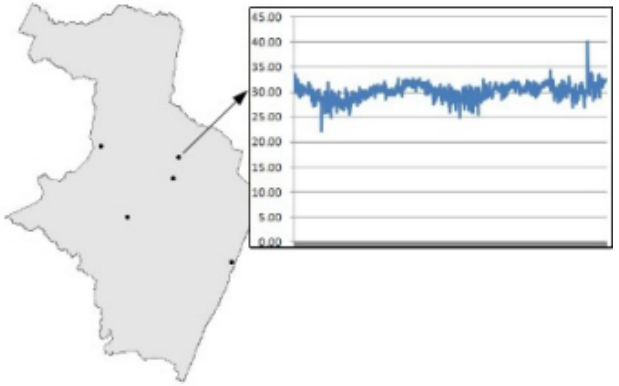
Spatiotemporal Data and Applications

Public Health



Number of mosquito eggs gathered from one egg trap - Recife

Temperature variation collected by meteorological stations - Recife.



(a)

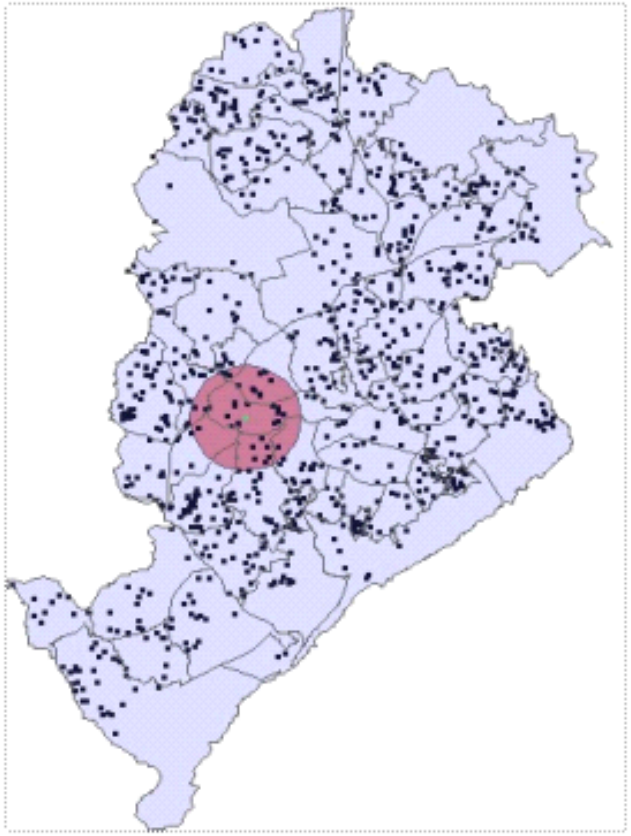
"Which month had the biggest number of infected eggs?"

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

SAUDAVEL **[Monteiro et. al., 2009]**

Spatiotemporal Data and Applications

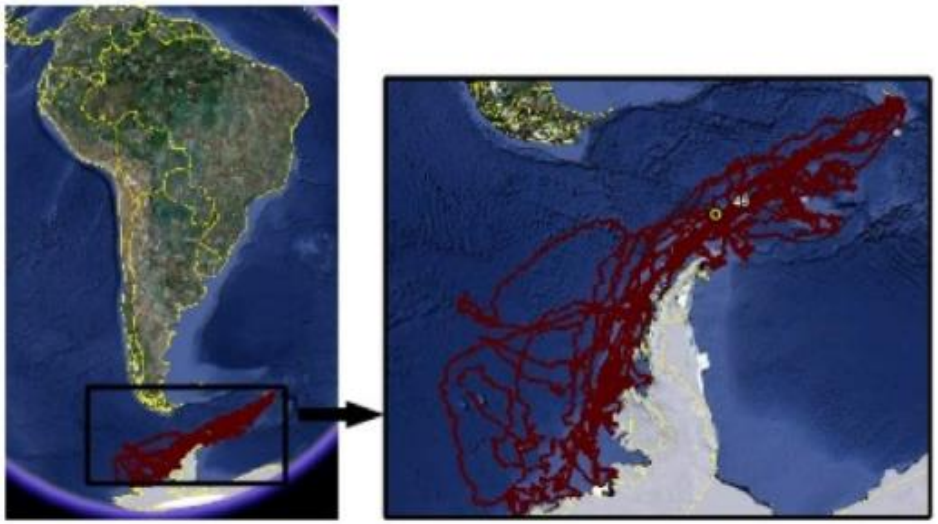
Public Health



occurrences of meningitis in
Belo Horizonte city

Spatiotemporal Data and Applications

[INPE's Antarctica Program, 2010]

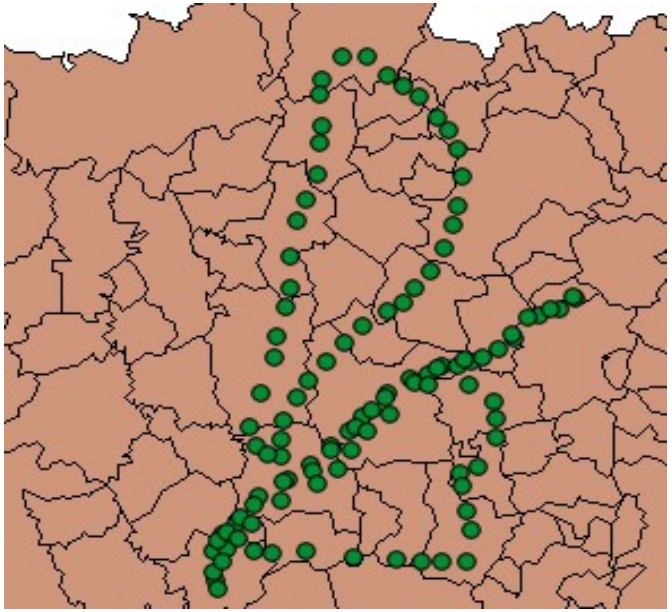


Trajectories of ten sea elephants in Antarctica

"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 spatiotemporal cluster of objects?"

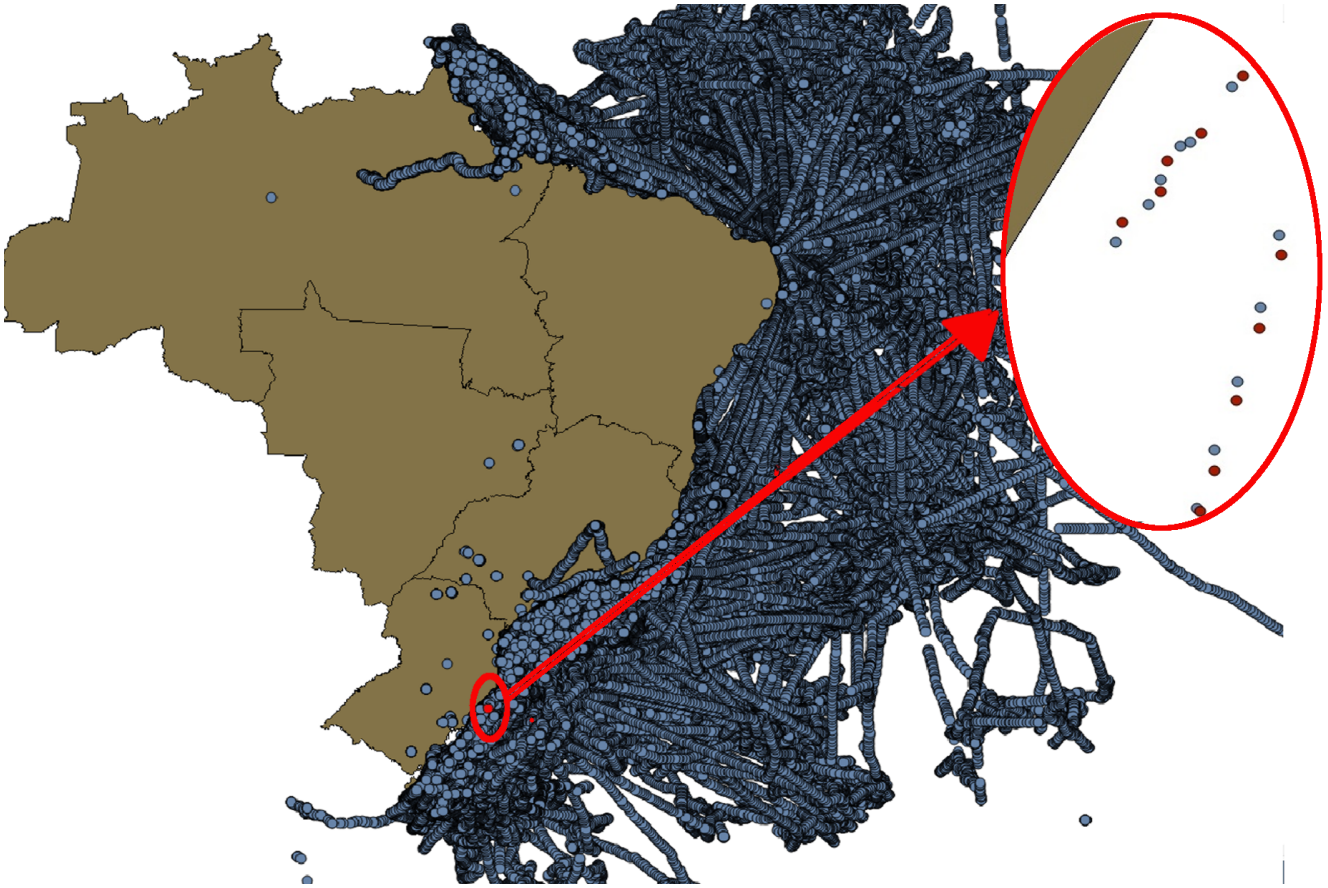
Location-based Systems



Set of cars equipped with GPS and air pollution sensors.

Spatiotemporal Data and Applications

Location-based Systems

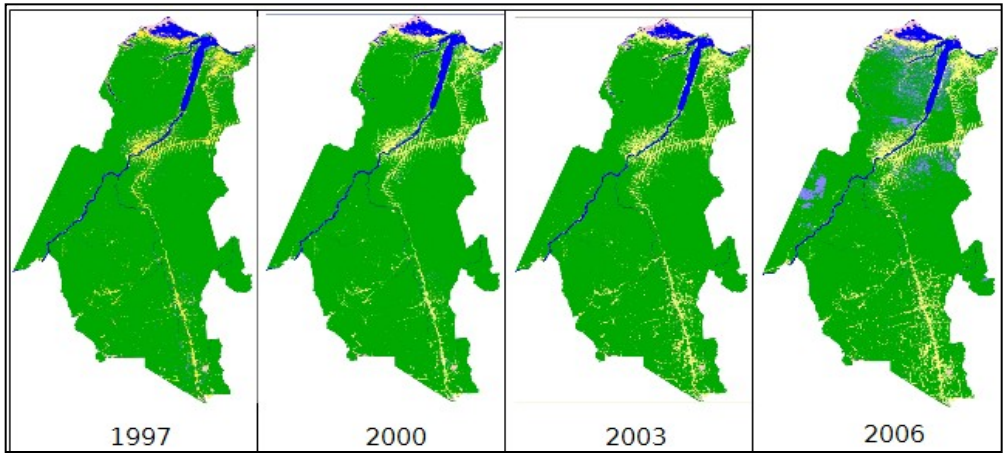


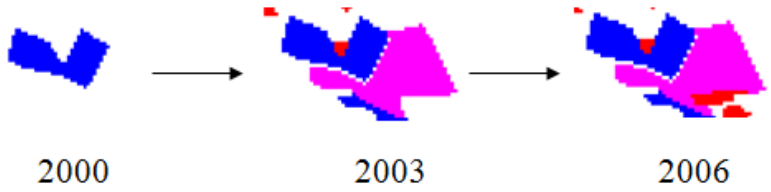
Trajetórias de embarcações de pesca na costa brasileira.

Spatiotemporal Data and 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?"

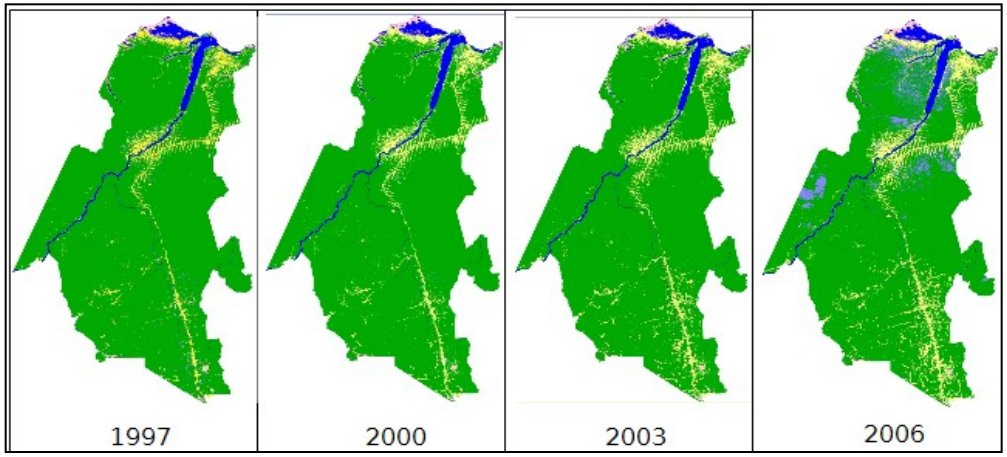
"how did the deforested regions that started less than 2 kilometer far from the river r1 evolve over time?"

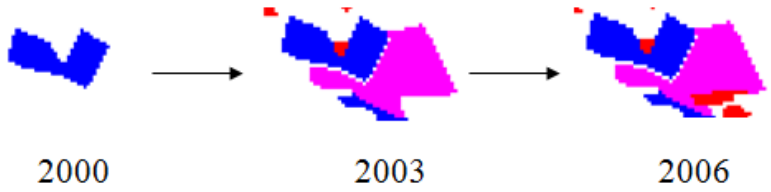
"when did a specific deforested region reach the municipality x?"

Spatiotemporal Data and Applications

PRODES

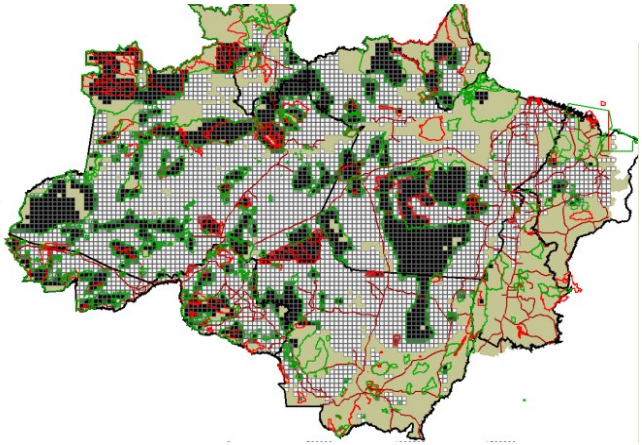
Imagens Classificadas





Polígonos de Desmantamento

Land Use and Land Cover Modeling

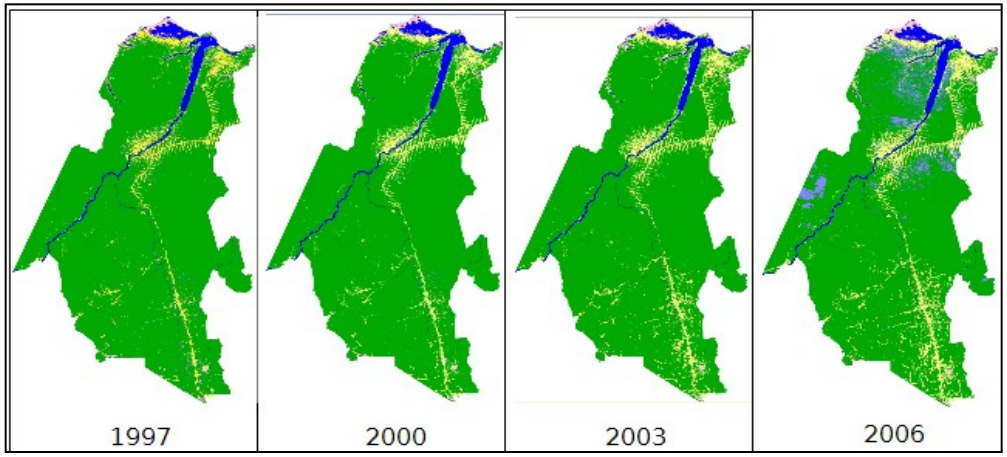


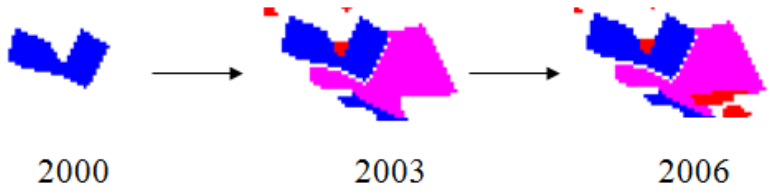
"given a cell, how has the forest status been varying in this cell over time?"

Spatiotemporal Data and Applications

PRODES

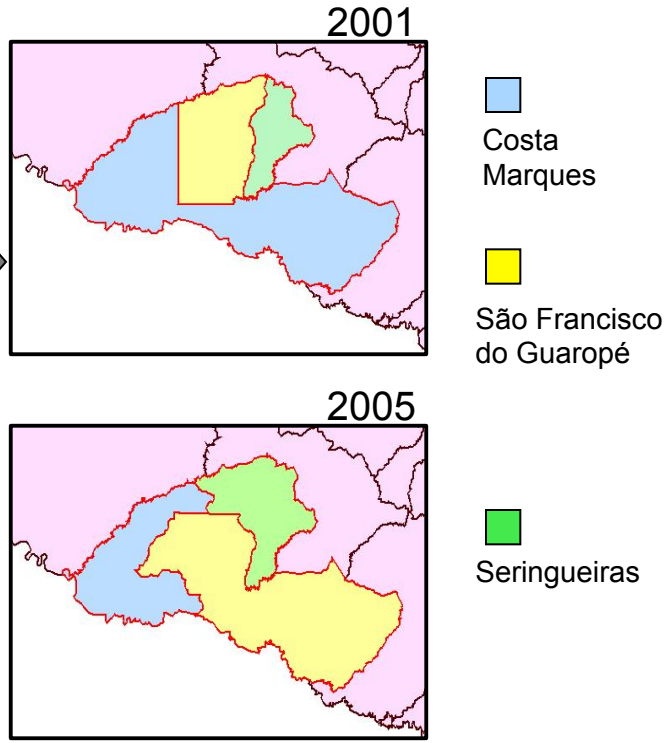
Imagens Classificadas





Polígonos de Desmantamento

Municipal Management

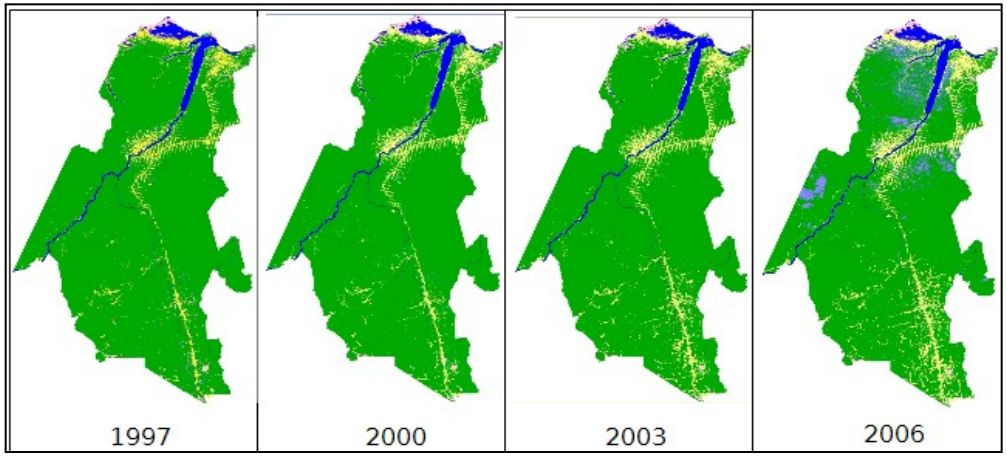


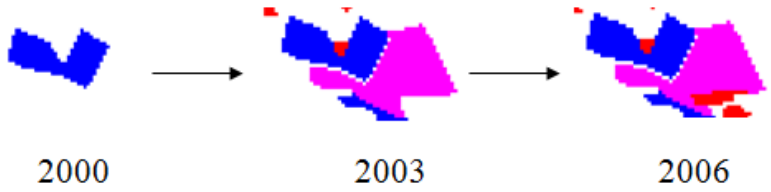
"How many hectares were deforested in each municipality? "

Spatiotemporal Data and Applications

PRODES

Imagens Classificadas





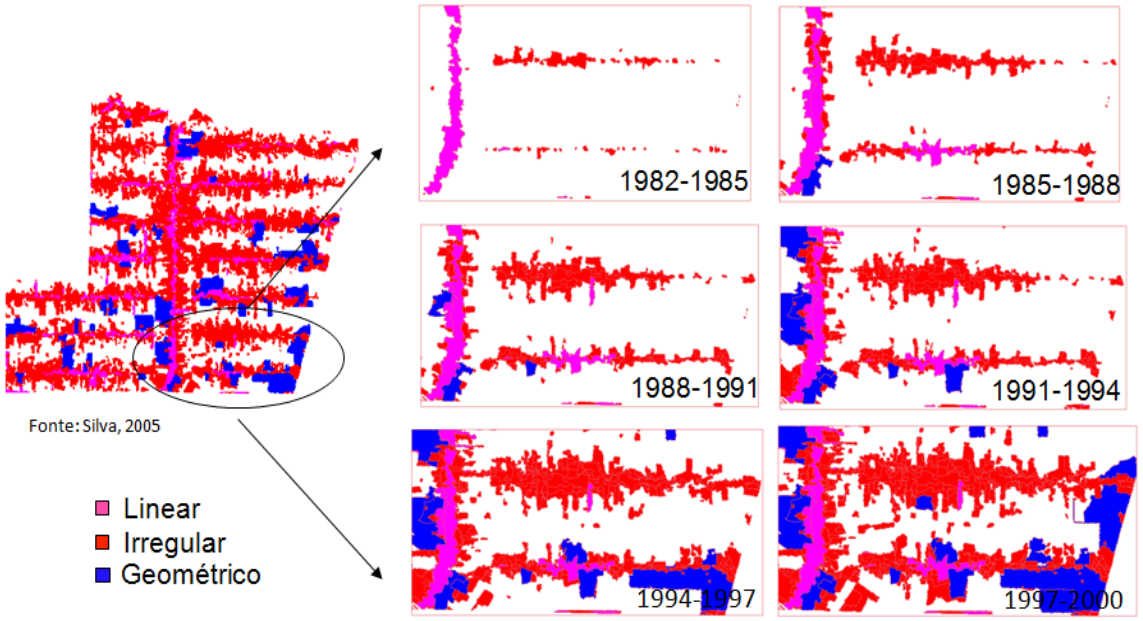
Polígonos de Desmantamento

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]

Spatiotemporal Data and Applications



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[Silva et al., 2005]
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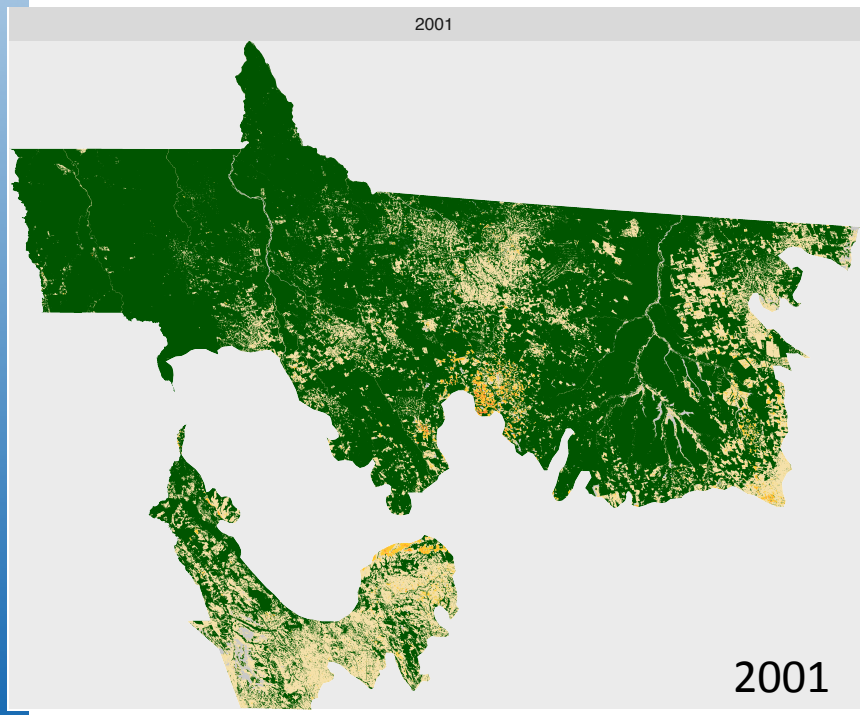
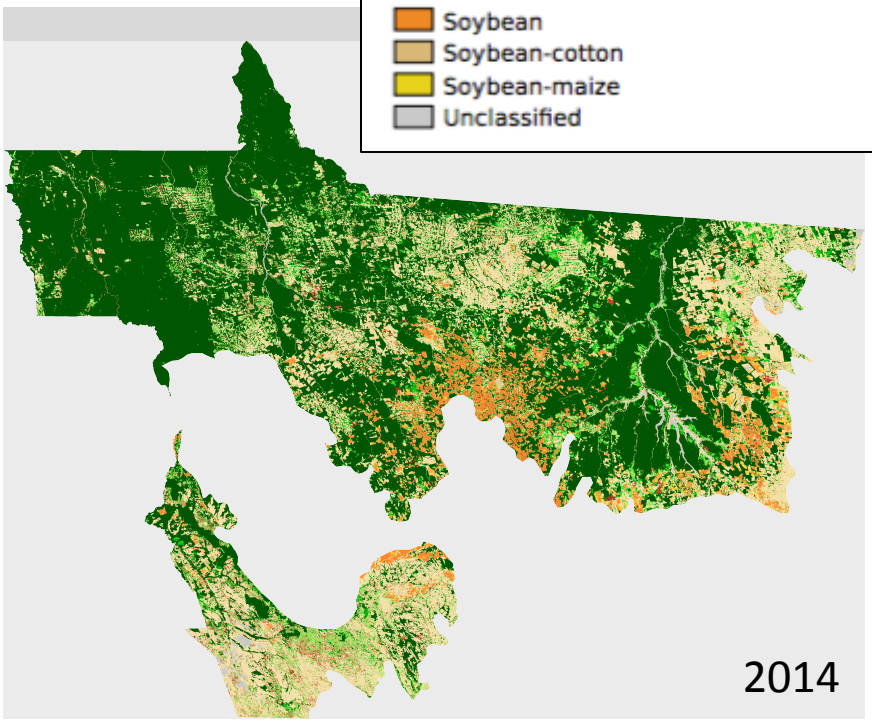
Spatiotemporal Data and Applications

Land use and land cover change (LUCC) analysis

Land use change trajectories in the Amazonian biome of Mato Grosso state - Brazil (2001-2014)



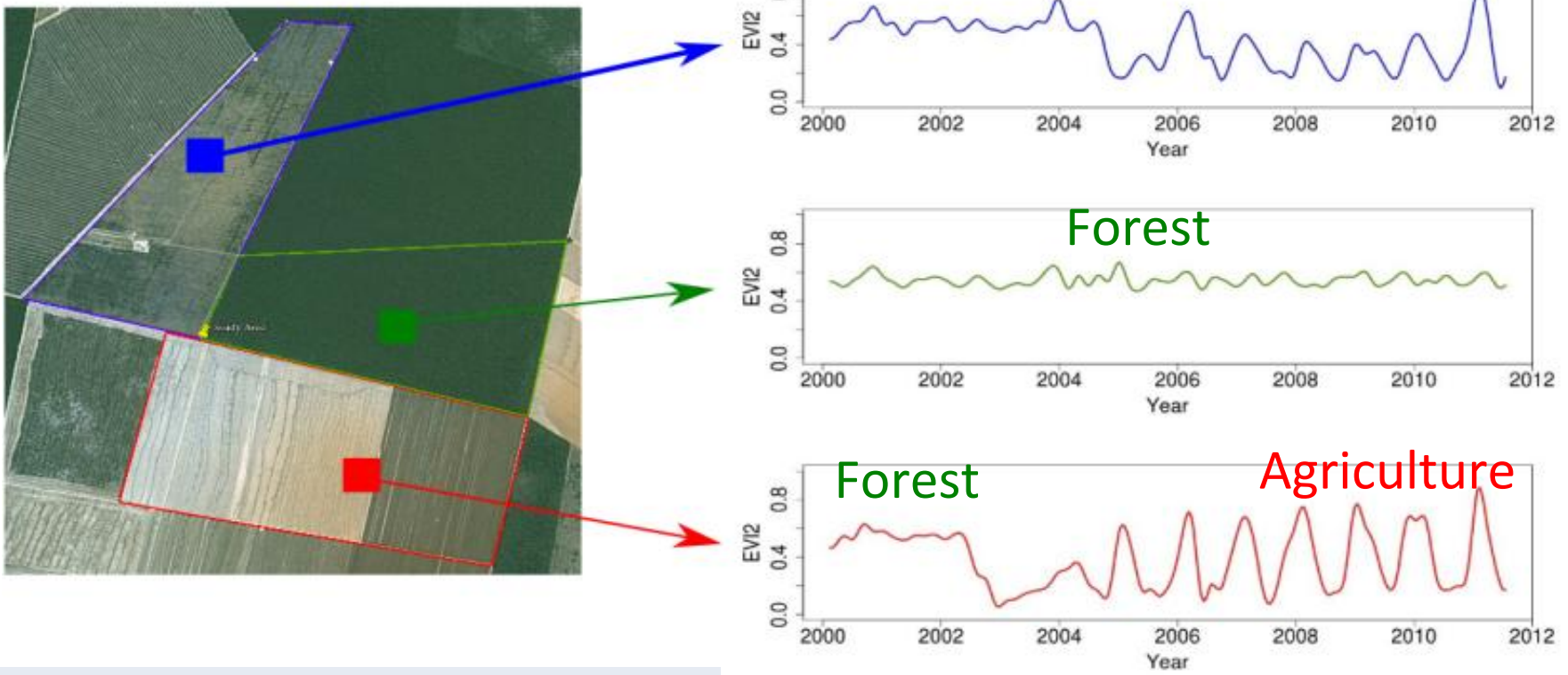


graphics: Victor Maus (INPE, IFGI)

Spatiotemporal Data and Applications

Land use change trajectories – analysis of vegetation index (e.g. EVI and NDVI) time series extracted from EO satellite images.

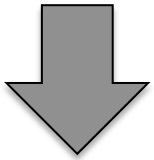
LUCC Analysis



graphics: Victor Maus (INPE, IFGI)

Spatiotemporal Data and Applications

Diversity of spatiotemporal data from different application domains.



We need **temporal GIS** able to deal with distinct types of spatiotemporal data in an integrated way.

Temporal GIS

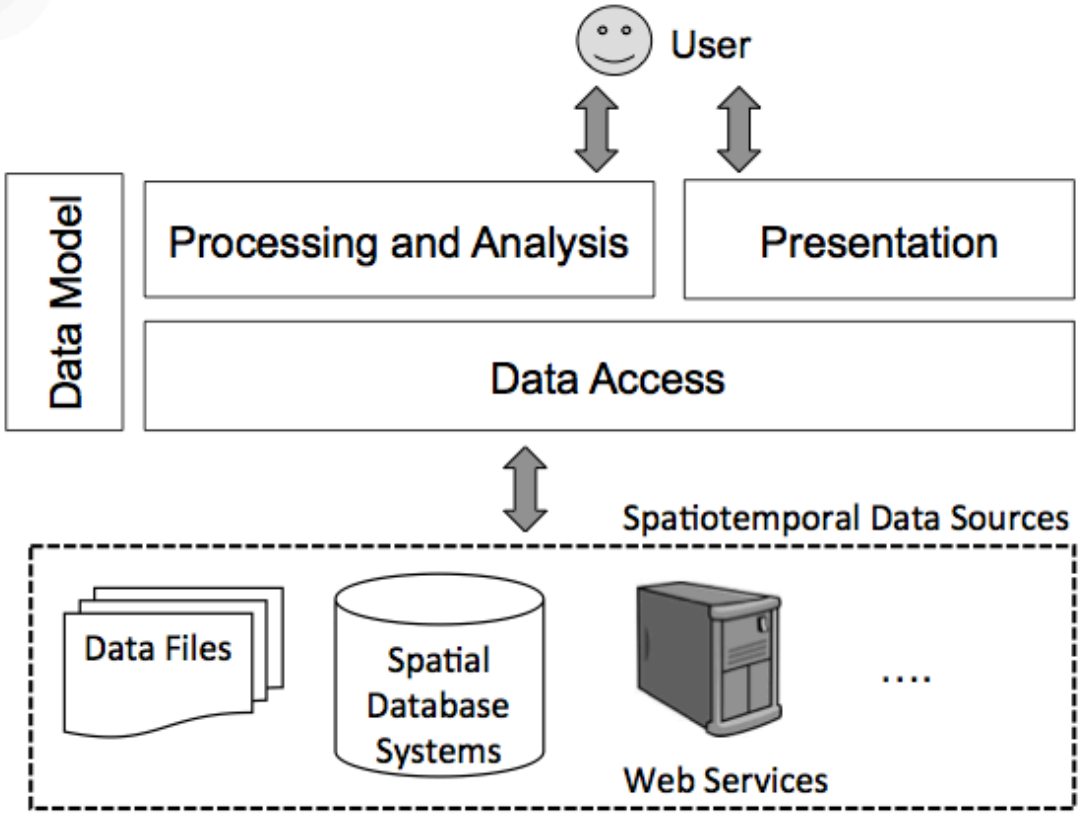
Temporal GIS refers to GIS that can model, access, combine, process, analyze and visualize spatiotemporal information.

In the literature, there are many proposals of conceptual models to represent and handle spatiotemporal data in GIS and database systems. However, there is not yet a full-scale and comprehensive temporal GIS available (Yuan, 2009).

Most existing temporal GIS technologies either are still in the research phase or are specific for certain application domain.

Temporal GIS - Challenges

How to model spatiotemporal data in a GIS?

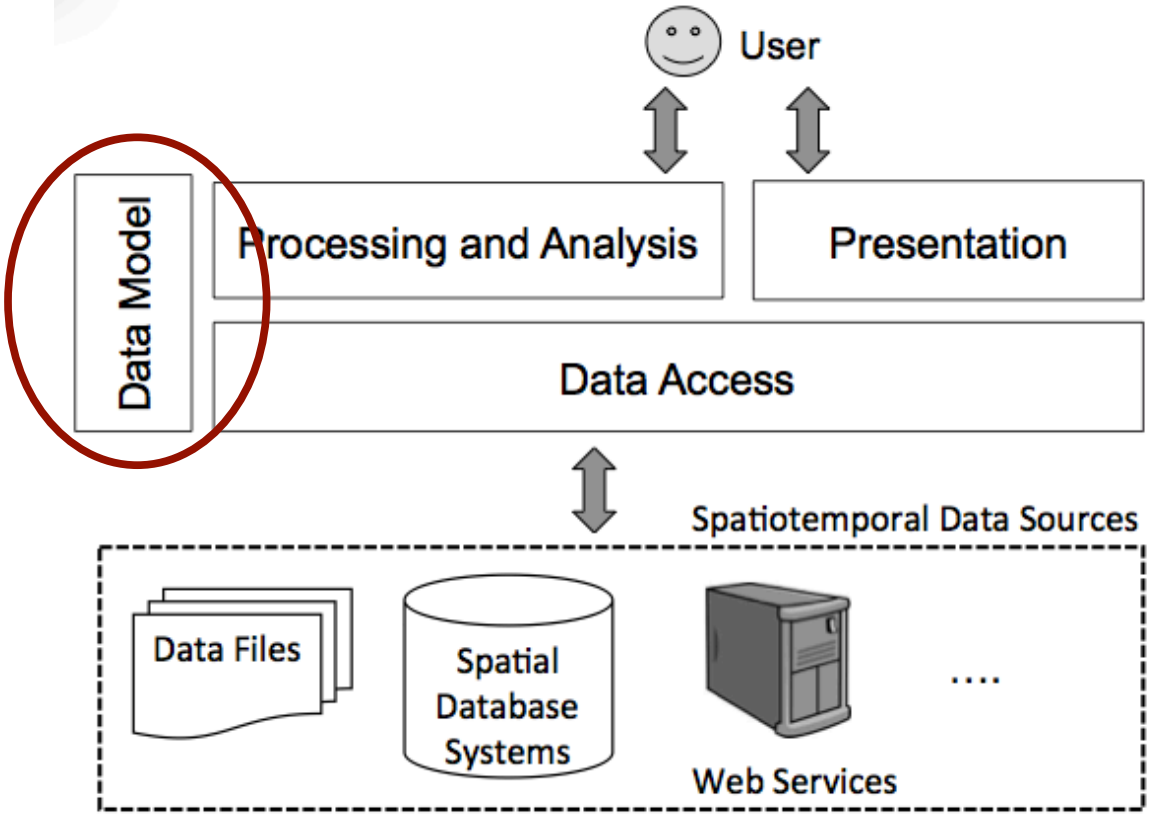


GIS general architecture

Temporal GIS - Challenges

How to model spatiotemporal data in a GIS?

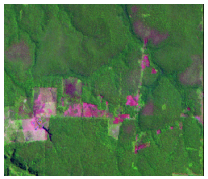
We need a data model that defines a minimal set of data types able to represent different kinds of spatiotemporal information from distinct application domains.

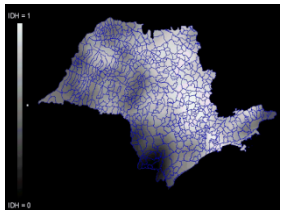


GIS general architecture

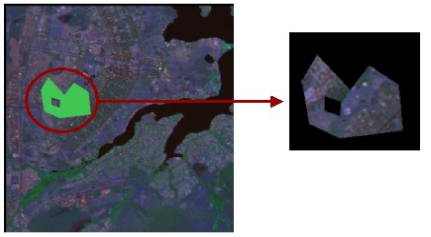
Representation of Spatial Data

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

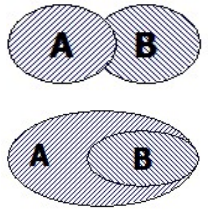


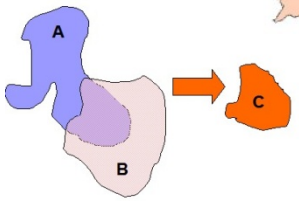


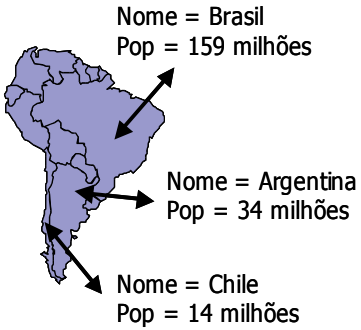
Geo-Fields and Geo-Objects



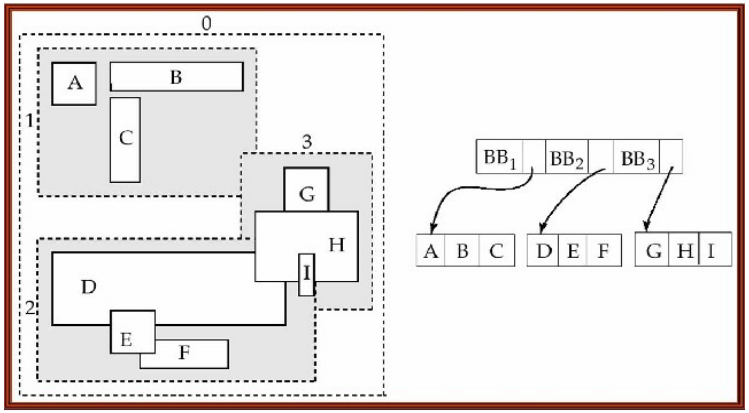
Spatial Operations







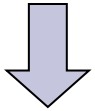
Spatial Index



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

Representation of Spatiotemporal 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]

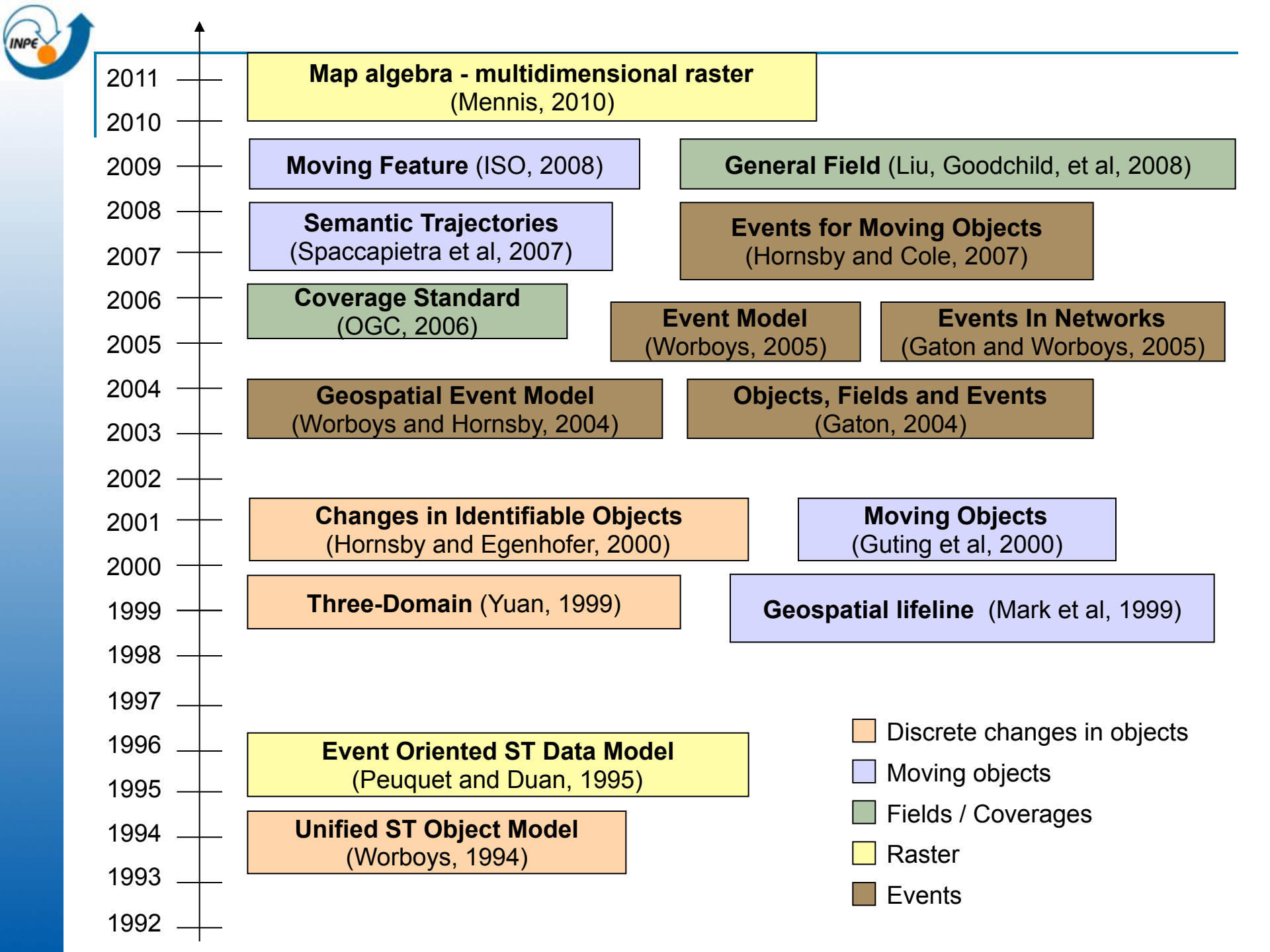
Existing Spatiotemporal Data Models

"A serious weakness of existing spatiotemporal models is that each of them deals with few common features found across a number of specific applications."

[Pelekis at al., 2004]

"happenings (events) should be upgraded to an equal status with things in dynamic geographic representations"

[Worboys, 2005]


2011
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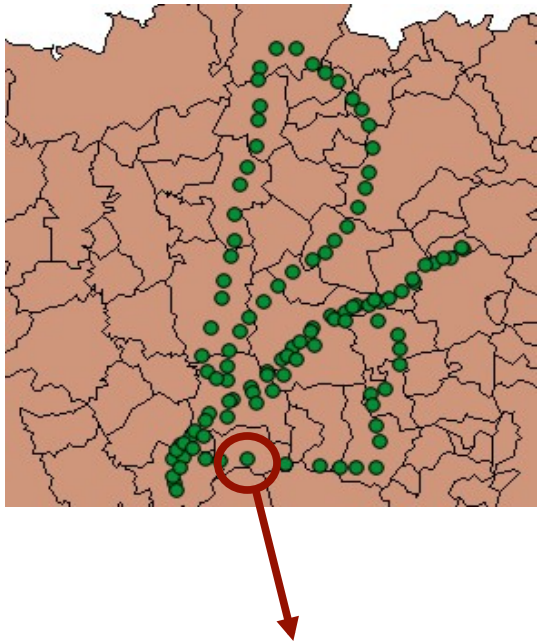
Map algebra - multidimensional raster (Mennis, 2010)
Moving Feature (ISO, 2008)
General Field (Liu, Goodchild, et al, 2008)
Semantic Trajectories (Spaccapietra et al, 2007)
Events for Moving Objects (Hornsby and Cole, 2007)
Coverage Standard (OGC, 2006)
Event Model (Worboys, 2005)
Events In Networks (Gaton and Worboys, 2005)
Geospatial Event Model (Worboys and Hornsby, 2004)
Objects, Fields and Events (Gaton, 2004)
Changes in Identifiable Objects (Hornsby and Egenhofer, 2000)
Moving Objects (Guting et al, 2000)
Three-Domain (Yuan, 1999)
Geospatial lifeline (Mark et al, 1999)
Event Oriented ST Data Model (Peuquet and Duan, 1995)
Unified ST Object Model (Worboys, 1994)
Discrete changes in objects
Moving objects
Fields / Coverages
Raster
Events

An Observation-Based Spatiotemporal Data Model

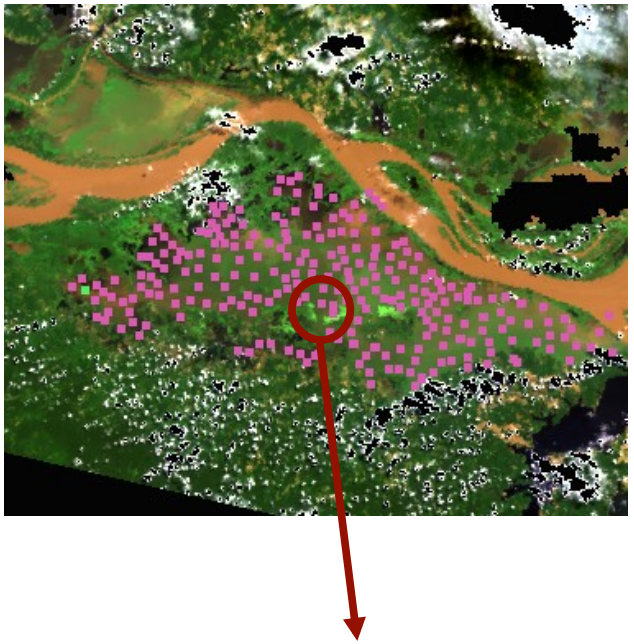
Why “Observation-Based”

Although most spatiotemporal phenomena are continuous over time and space, they are often measured through discrete observations....



Observation of a trajectory.

(Instant, Point, Real)



Observation collected in a river in Amazon.

(Instant, Point, Real)

Spatiotemporal Data Types

Observations are our means to assess spatiotemporal phenomena in the real world [Kuhn 2009].

Observations

An observation has three attributes: *space*, *time* and *theme [Sinton, 1978].*

Raw Data

Spatiotemporal Data Types

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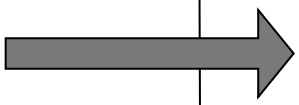
Raw Data



Time Series

Trajectory

Coverage

Spatiotemporal Data Types

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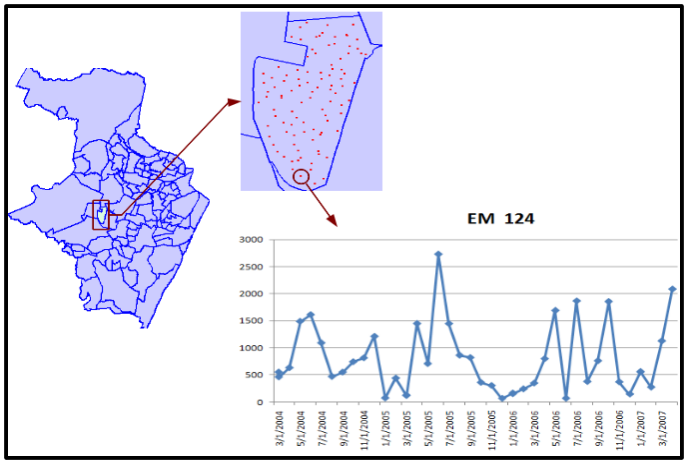
Raw Data

Time Series

Fix space, vary time and measure theme



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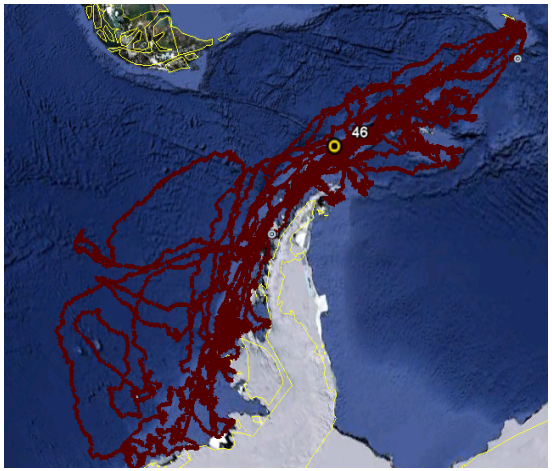
Raw Data

Trajectory

Fix theme, vary time and measure space



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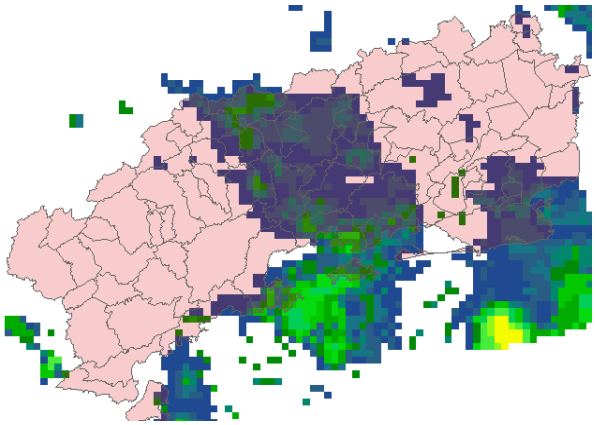
Coverage

Fix time, vary space and measure theme



Spatiotemporal Data Types

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Raw Data

Time Series

how the number of mosquito eggs varies over time

Trajectory

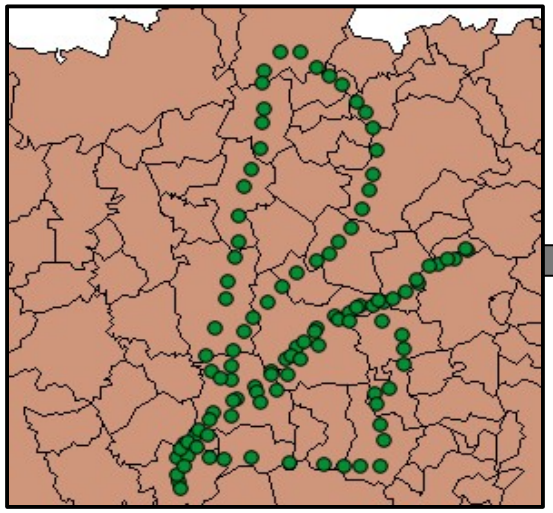
how animals move over time

Coverage

how precipitation varies within the limits of Rio de Janeiro state

Spatiotemporal Data Types

Different Views on the Same Observation Set



a set of cars equipped with GPS and air pollution sensors

Observations

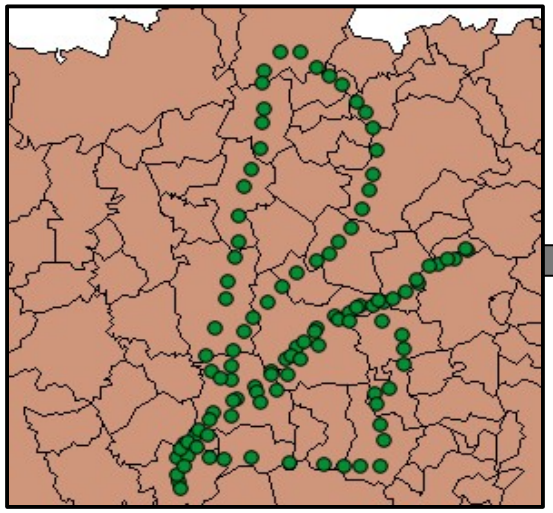
each observation contains a car identity, a time instant, a location and an air pollution value

(1) "*When the average pollution in the city was greater than x for more than five hours*?"

(2) "*How long did car c01 stay in the south region of the city?*"

(3) "*What city district had the worst pollution index in this day?*"

Different Views on the Same Observation Set



a set of cars equipped with GPS and air pollution sensors

Observations

each observation contains a car identity, a time instant, a location and an air pollution value

Time Series

air pollution variation over time

Trajectory

car location variation over time

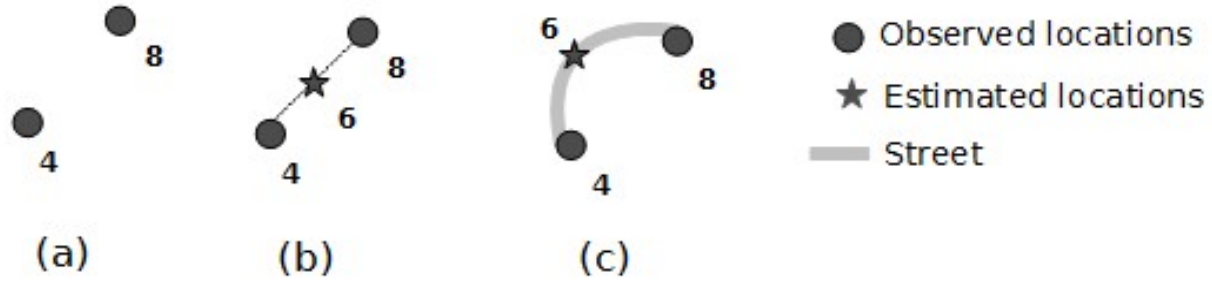
Coverage

air pollution variation within the city limits

Interpolators

Spatiotemporal Data Types:
Observations + Interpolators

allows a user to choose the most suitable interpolation function for each type instance.



Consider two observations of a moving car, one at instant 4 and the other at 8. There are different methods to estimate car location at the non-observed time 6. Choices include a linear interpolator (b) or a method that uses a street map as a spatial constraint (c).

Events

Time Series

how the number of mosquito eggs varies over time

Trajectory

how animals move over time

Coverage

how precipitation varies within the limits of Rio de Janeiro state

Spatiotemporal Data Types

If we know what conditions lead to an event, we can express them using operations over the proposed data types.

Examples:

(1) “rain in Angra is more than 10 mm/hour for more than 5 hours” → ‘flood’ event

(2) “the average temperature is above 30o C for more than a week and more than 50 eggs on average were found in the same week” → ‘dengue epidemic’ event in Recife

(3) “the minimal distance between two sea elephants is shorter than 2 meters” → ‘meeting of two animals’ event

Events

Time Series

how the number of mosquito eggs varies over time

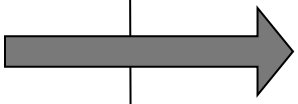
Trajectory

how animals move over time

Coverage

how precipitation varies within the limits of Rio de Janeiro state

Spatiotemporal Data Types



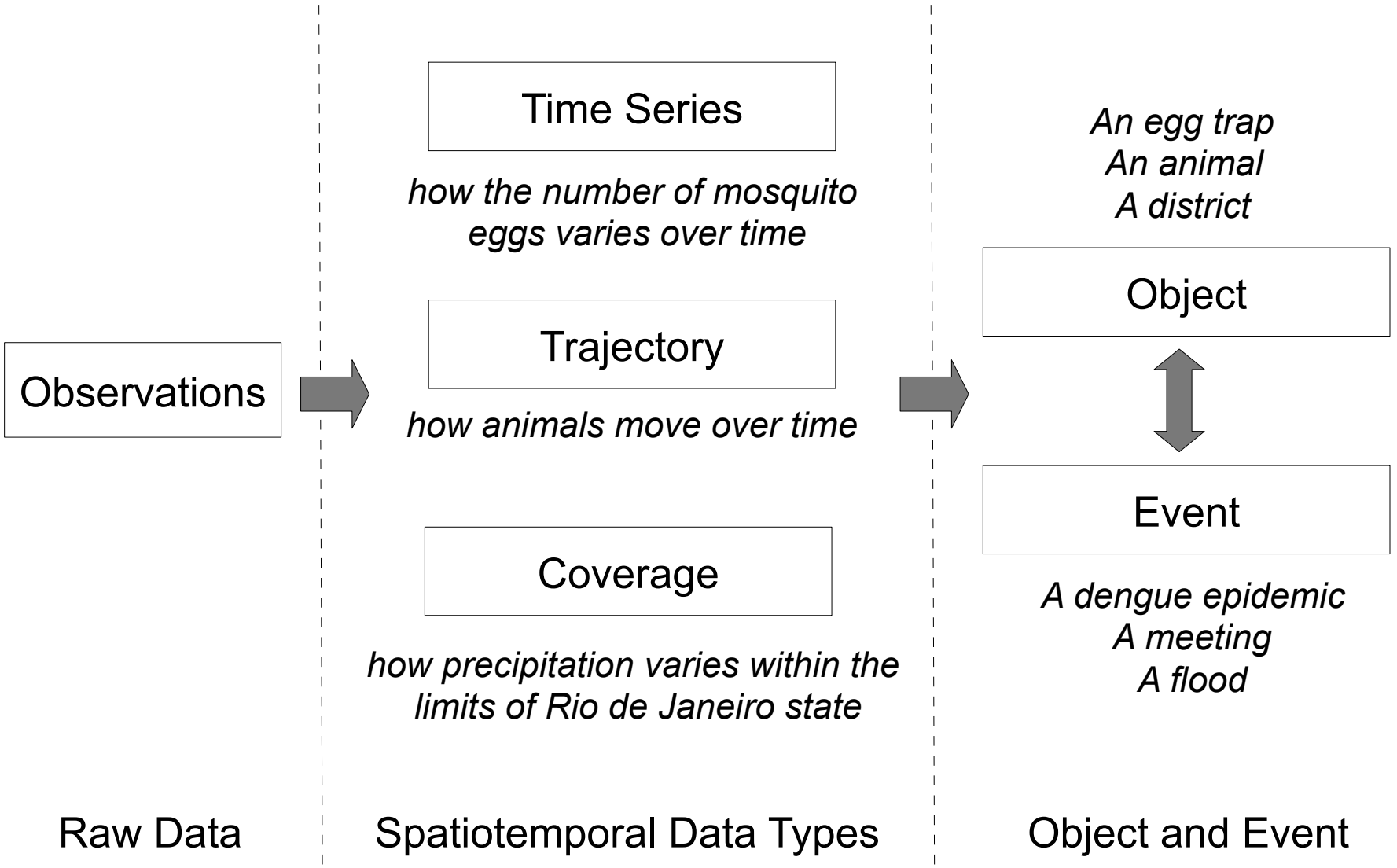
Event

an individual episode with a definite beginning and end.

Examples: a flood, a dengue epidemic and a meeting of two animals

Spatiotemporal Data Model

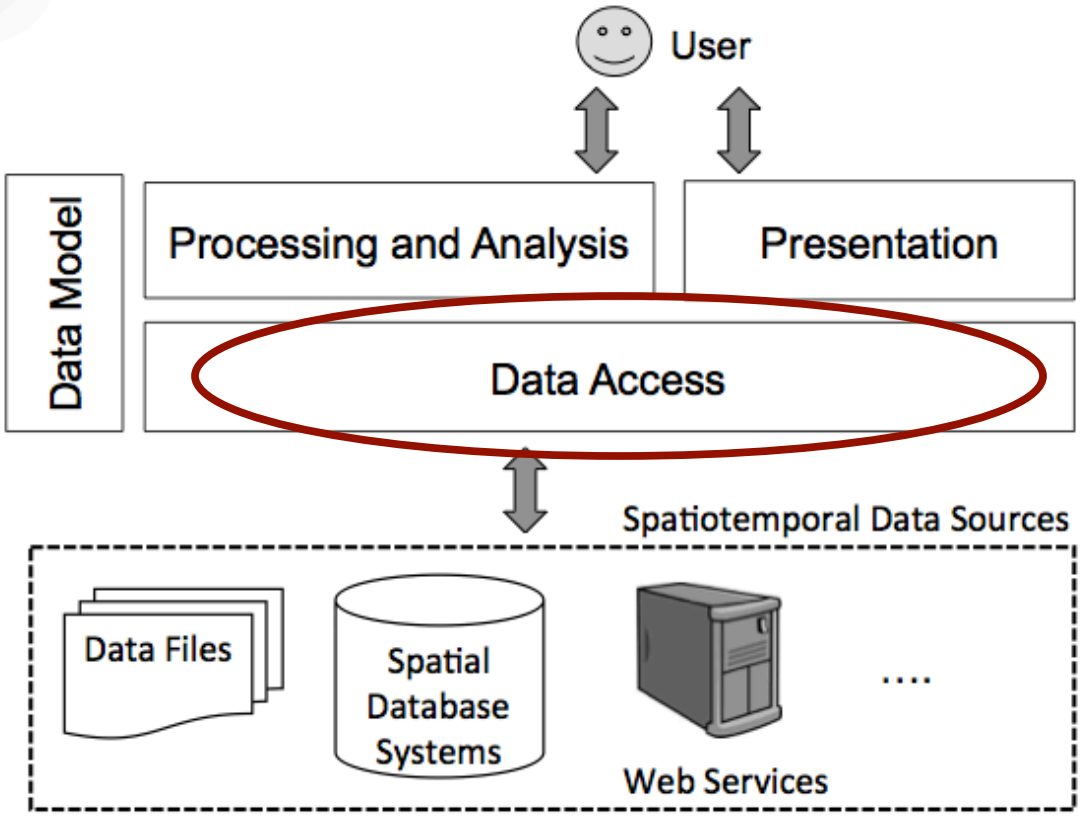
(Ferreira et al, 2014)



Temporal GIS - Challenges

How to access spatiotemporal data sets from distinct kinds of data sources?

There are not standards on how to store spatiotemporal data in spatial database systems or files as well as on how to serve such data through web services.

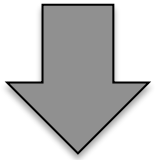


GIS general architecture

Temporal GIS - Challenges

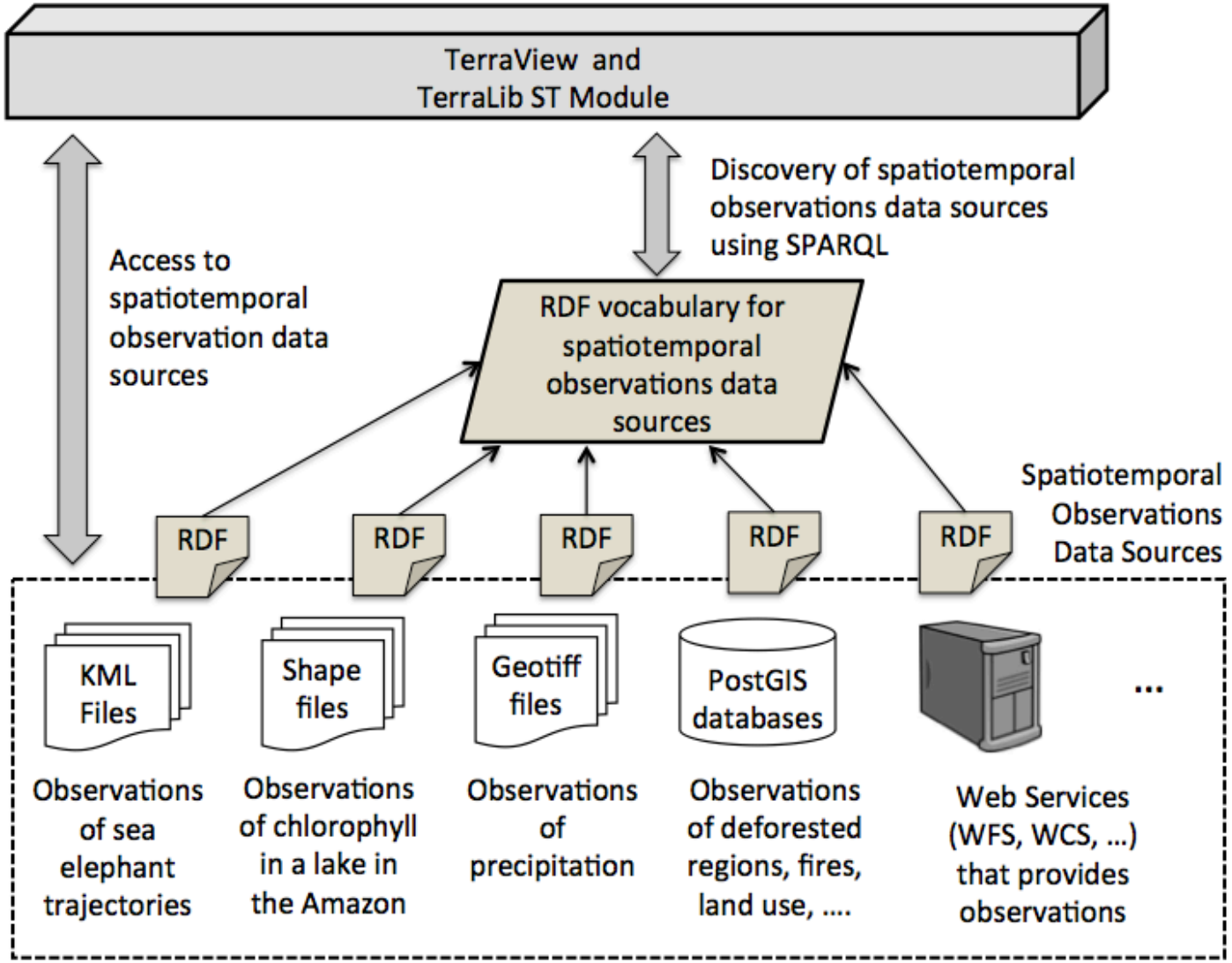
We consider that data sources store and provide **spatiotemporal observations**, which are basic units for spatiotemporal data representation.

A temporal GIS must access these observations from data sources and allow users to create different views on them, according to application needs.



We define a RDF vocabulary to describe how spatiotemporal observations are stored and provided by data sources.

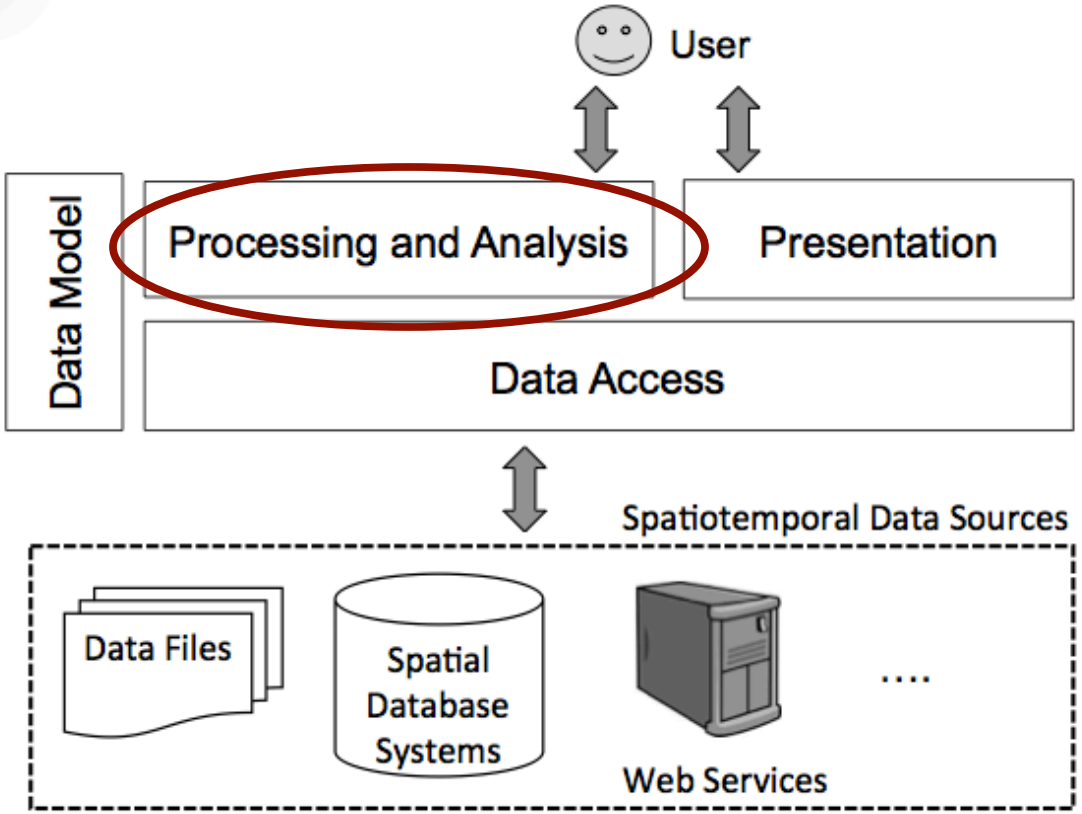
Temporal GIS – RDF Vocabulary



Temporal GIS - Challenges

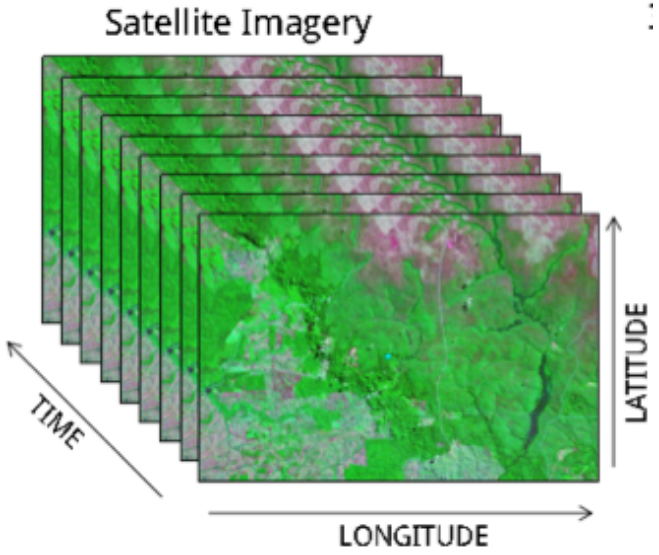
How to process and analyze spatiotemporal data sets?

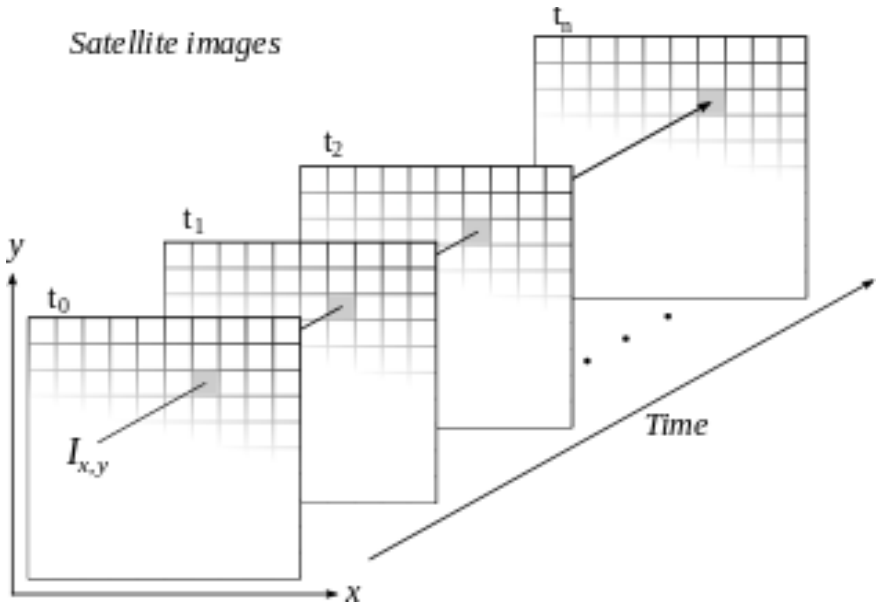
Temporal GIS need to provide methods for spatiotemporal analysis.



GIS general architecture

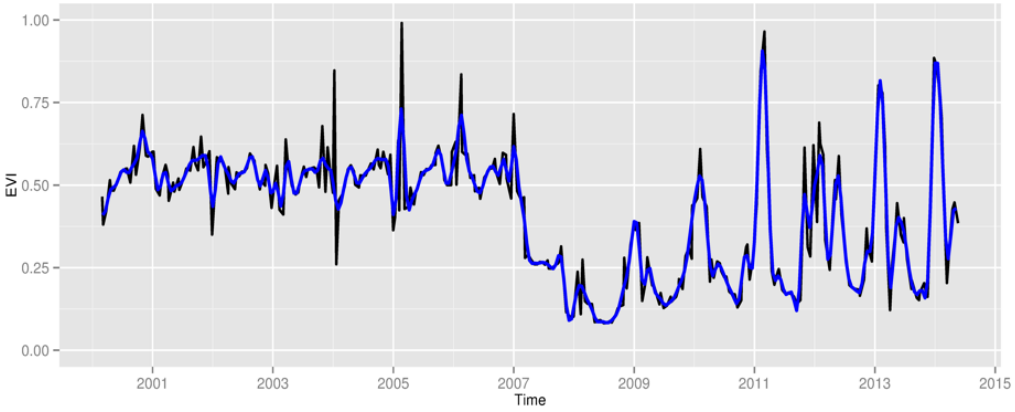
Time Series Analysis – Land Use Change





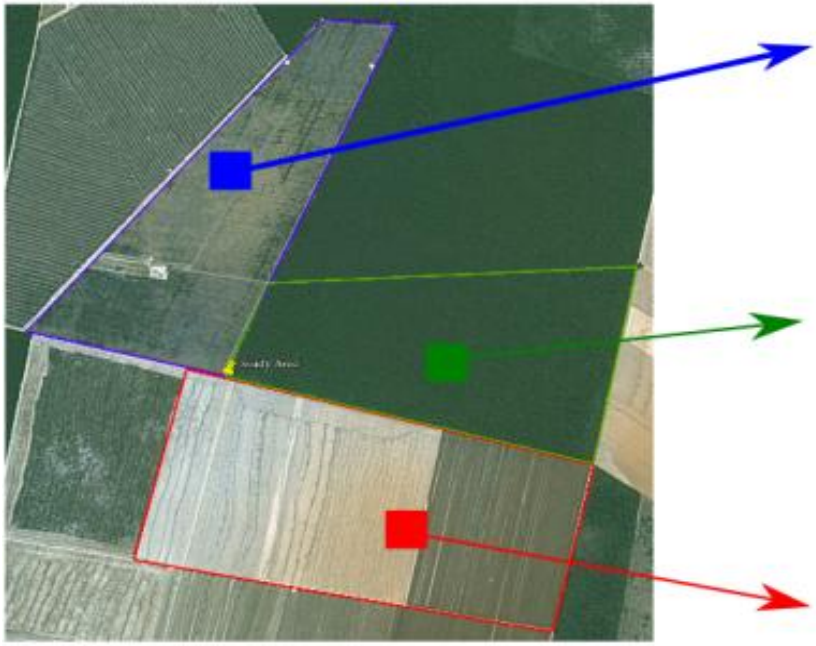
Space-first: classify images separately. Compare results in time

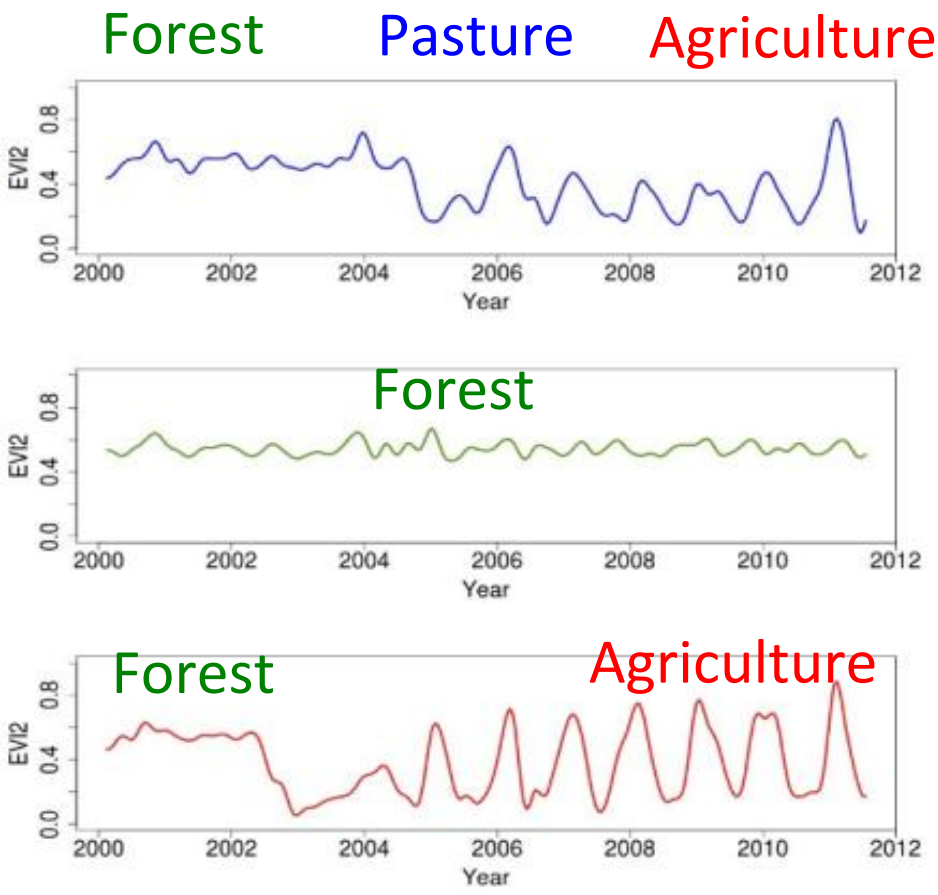
Time-first: classify time series separately. Join results to get maps



Time Series Analysis – Land Use Change

Land use change trajectories – analysis of vegetation index (e.g. EVI and NDVI) time series extracted from EO satellite images.

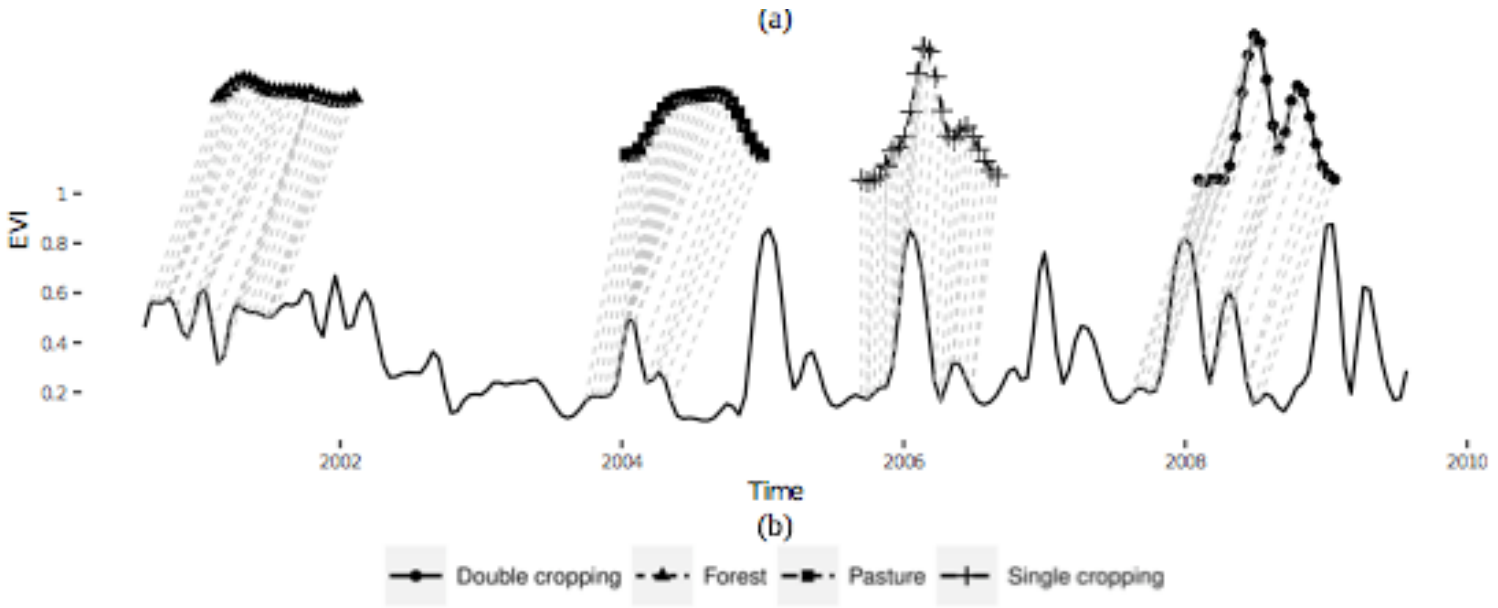




graphics: Victor Maus (INPE, IFGI)

Time Series Analysis – Land Use Change

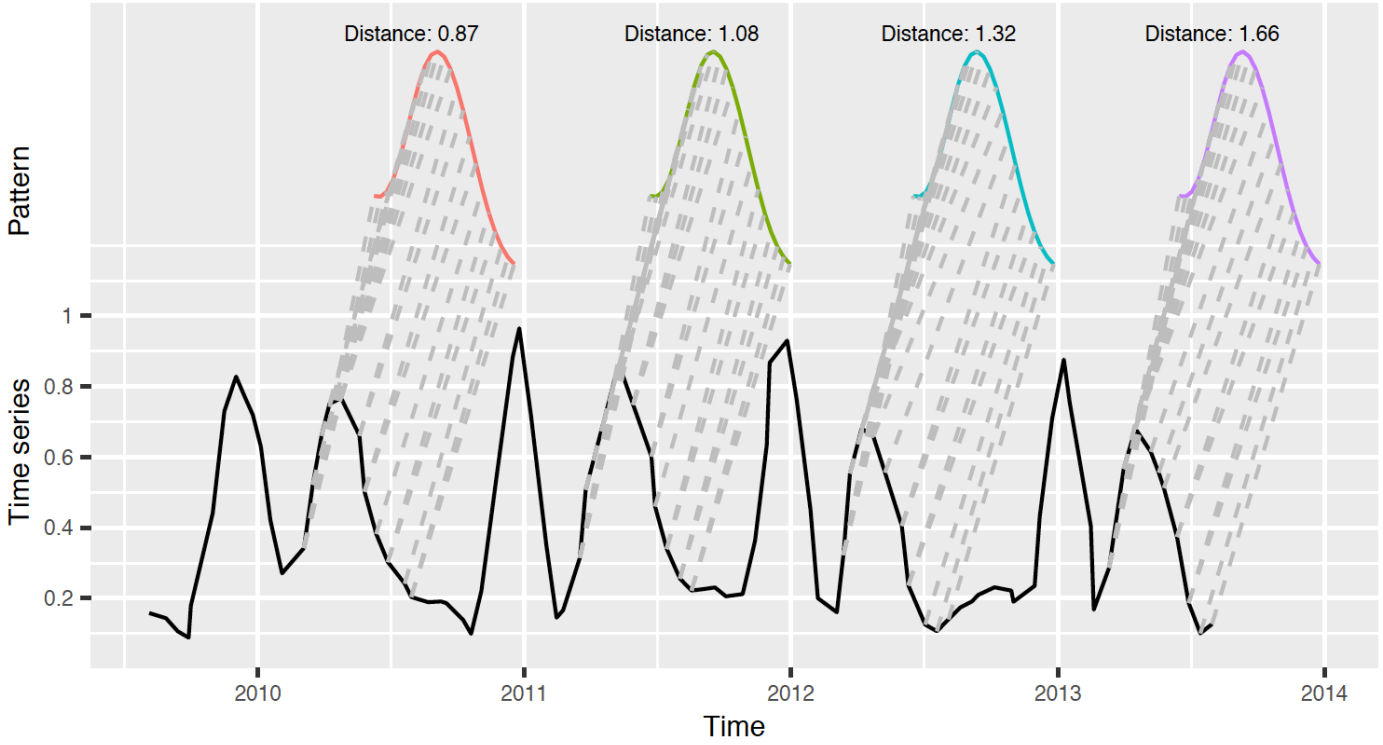
How to match land use patterns in a remote sensing time series?



Finding subsequences in a time series
High computational complexity
Patterns are idealized, data is noisy

Time Series Analysis – TWDTW

Time-Weighted Dynamic Time Warping (TWDTW) for remote sensing time series



TWDTW finds alignments of short templates in a long time series considering the agricultural calendar

Time Series Analysis – TWDTW

Time-Weighted Dynamic Time Warping (TWDTW) for remote sensing time series

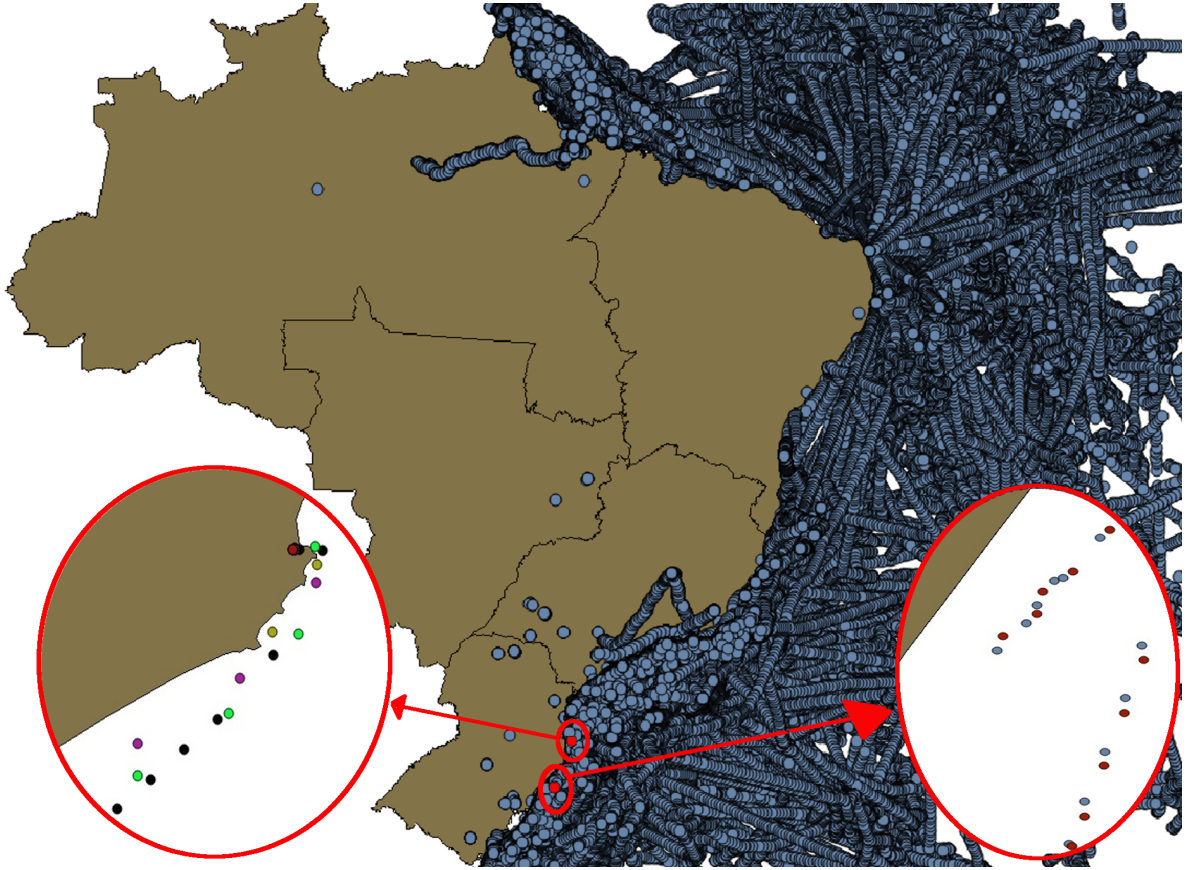
Journal of Statistical Software

MMMMMM YYYY, Volume VV, Issue II. *doi: 10.18637/jss.v000.i00*

dtwSat: Time-Weighted Dynamic Time Warping for satellite image time series analysis in R

Victor Maus INPE
Gilberto Câmara INPE
Marius Appel University of Münster
Edzer Pebesma University of Münster

Trajectory Analysis

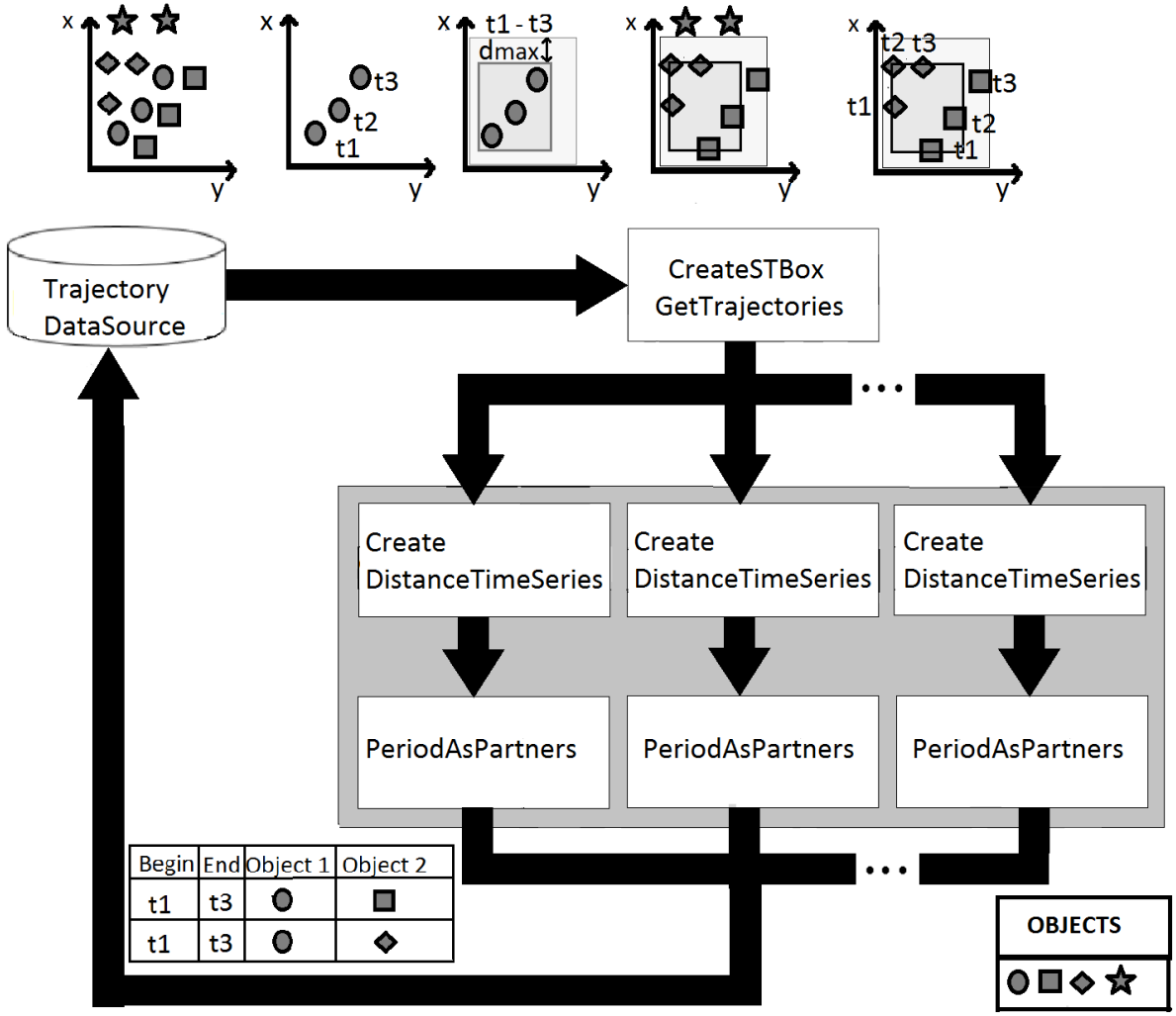


Identify patterns in trajectory data sets.

Partner: pairs of trajectories whose objects stay together during a certain period.

graphics: Diego Monteiro (INPE, 2017)

Trajectory Analysis



graphics: Diego Monteiro (INPE, 2017)

Spatiotemporal Database Systems for Trajectories

Spatiotemporal Database - Trajectories

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.

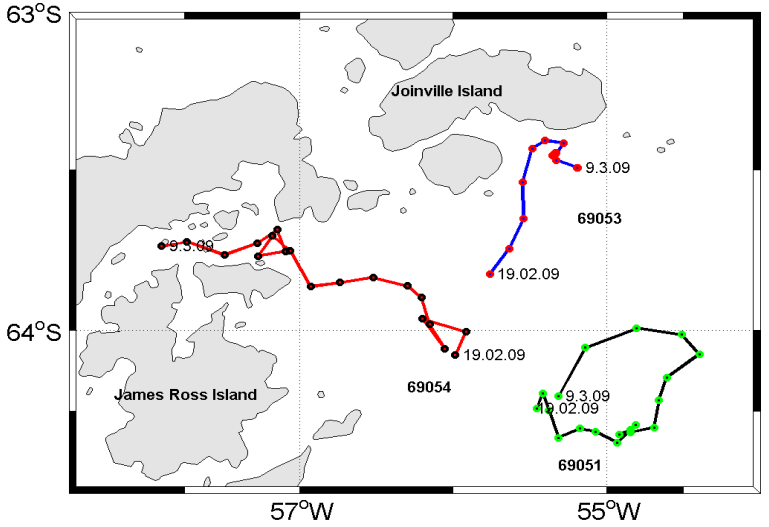
SECONDO: Moving Object Database

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

Moving Regions (ex.: mancha de oleo)

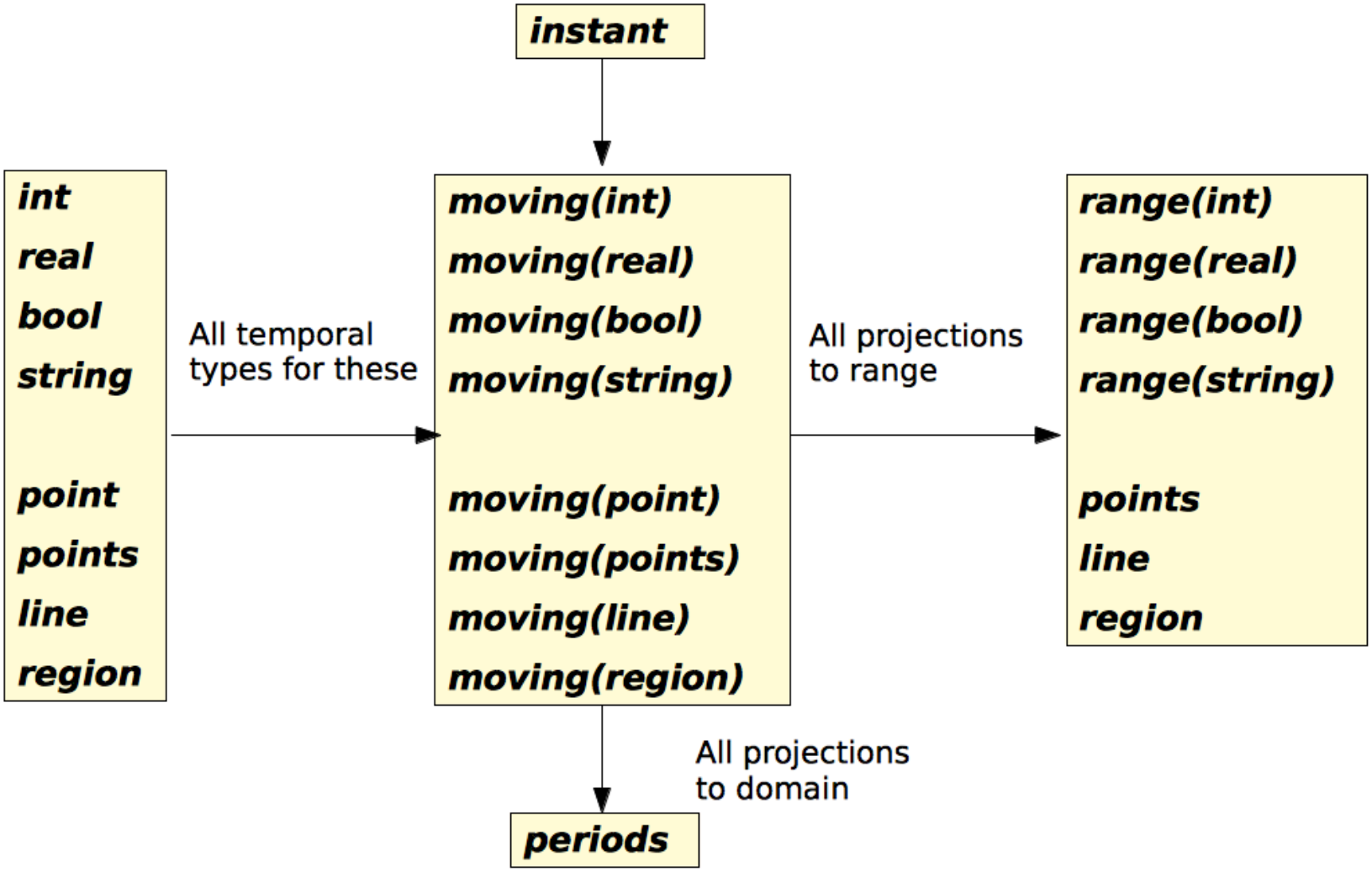
oil spill on the ocean

Animal tracking monitoring



Iceberg tracking monitoring in Antarctica - SOS-Climate

SECONDO: Moving Object Algebra



SECONDO: Moving Object Algebra

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 Operations

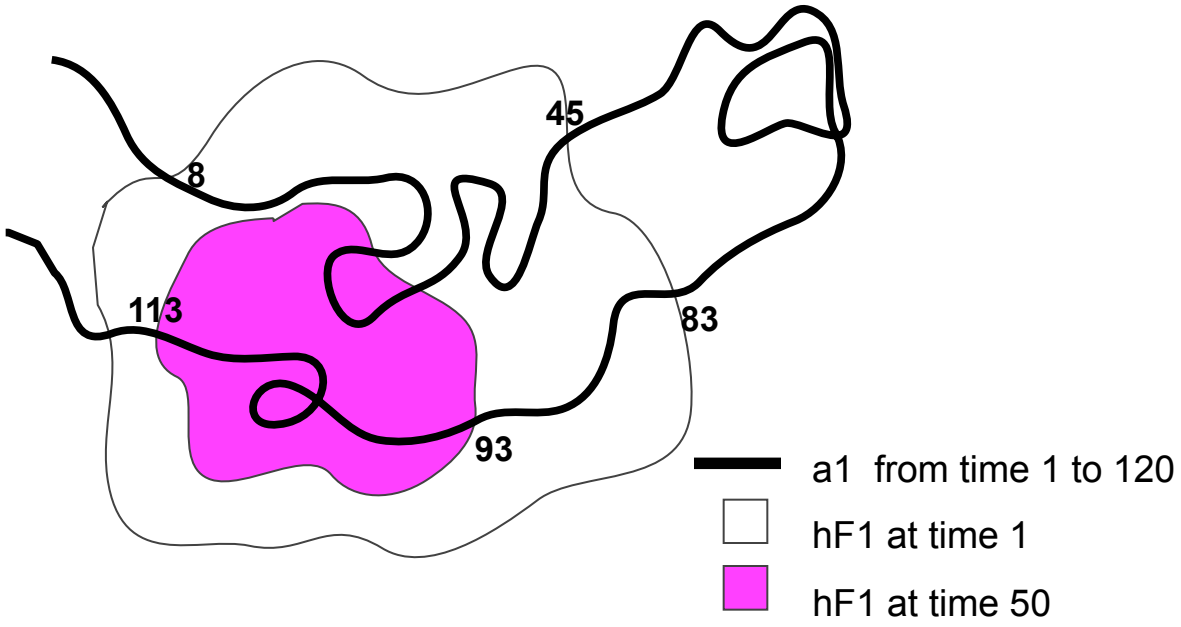
Some Operations

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: Examples

1) Animals a1 → their locations change continuously over time.

2) Habitat fragmentation area hF1 → its limit changes continuously over time.



habitat_frag (id: string, habitat: mregion)

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

SECONDO: Examples

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

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

SECONDO: Examples

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: Examples

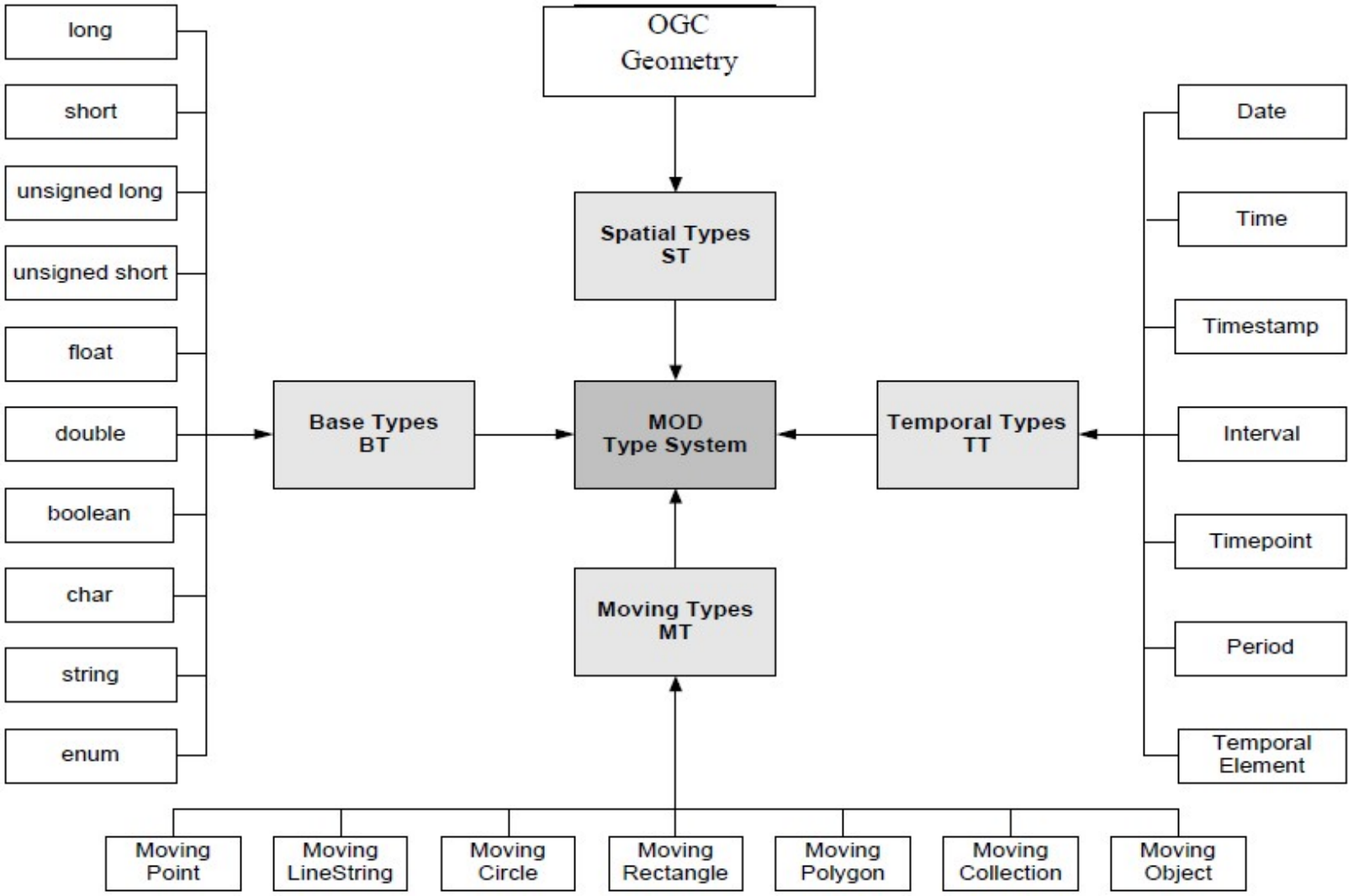
3) At what times was animal a1 within the habitat fragmentation area hF1 ?

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

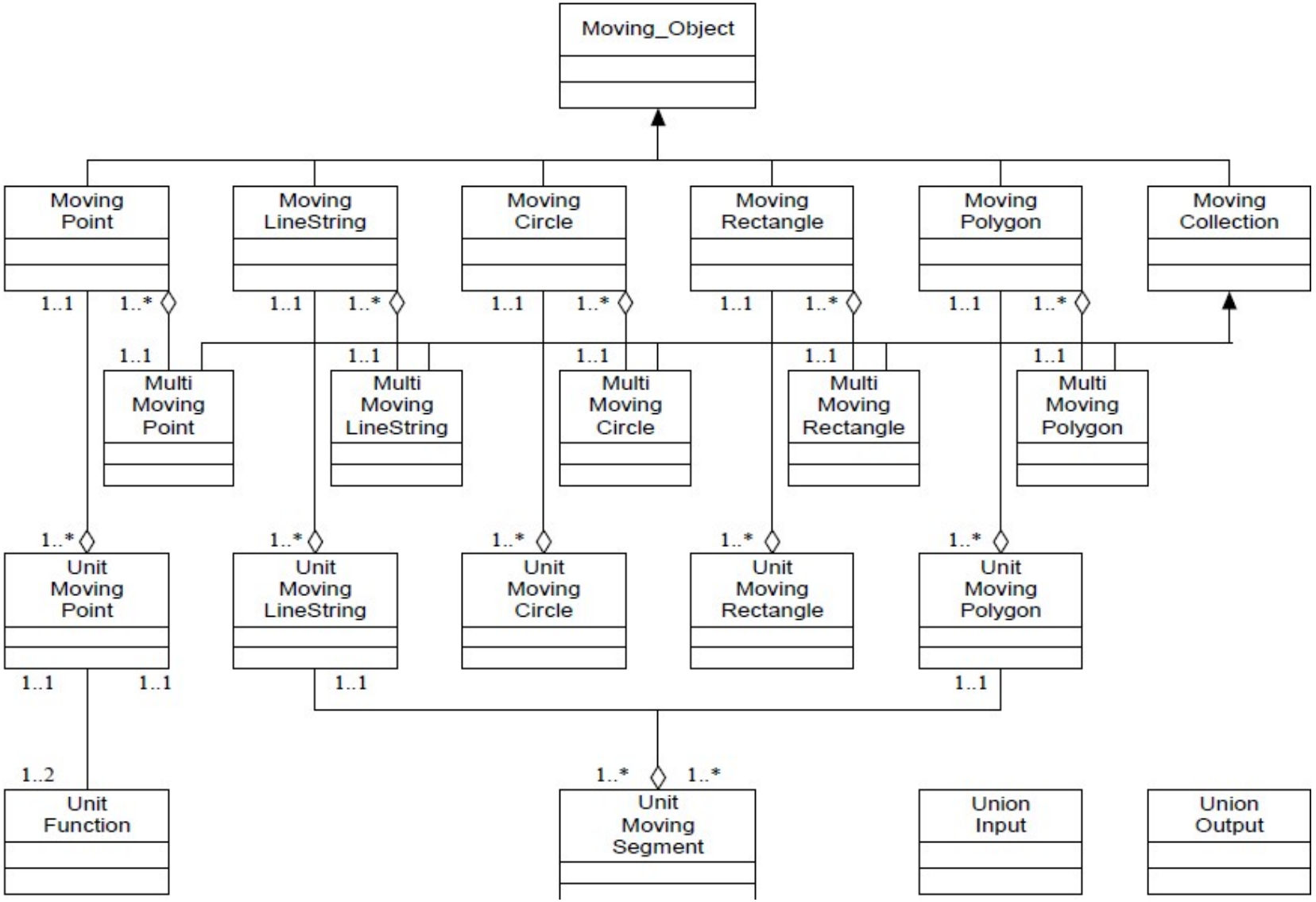
HERMES

- 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

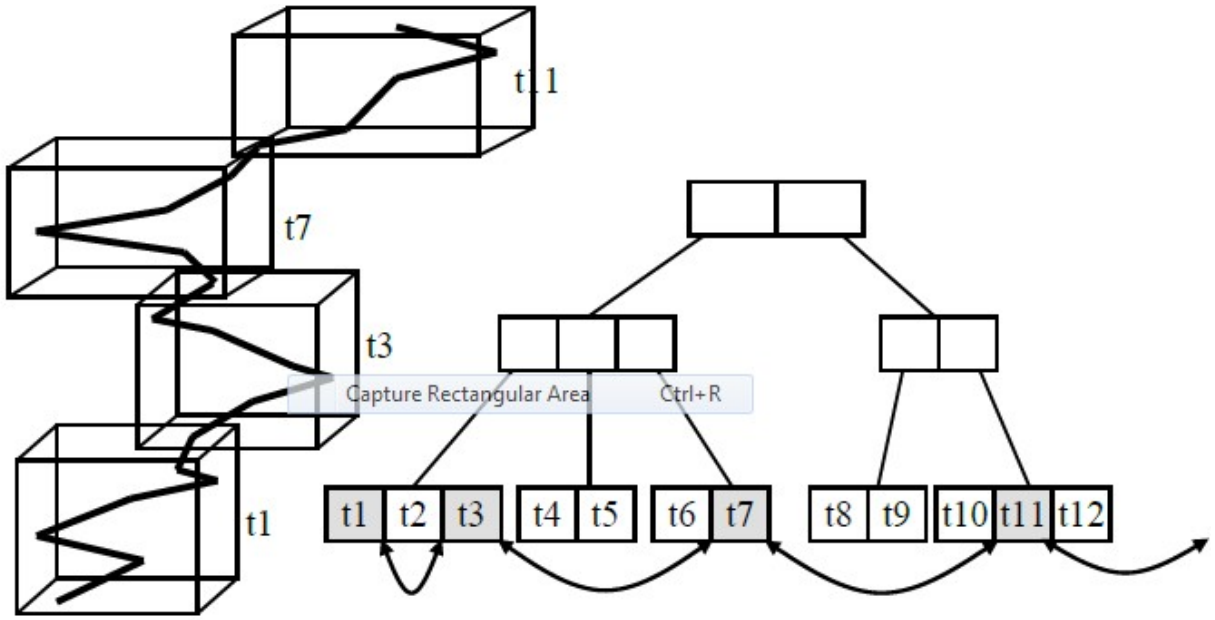


HERMES – Moving Types



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.