MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

– Spatiotemporal Data – Applications, Representations and Database Systems

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CAP 349 – Bancos de Dados Geográficos (07/08/2013)

Disponível em: http://wiki.dpi.inpe.br/doku.php?id=cap349

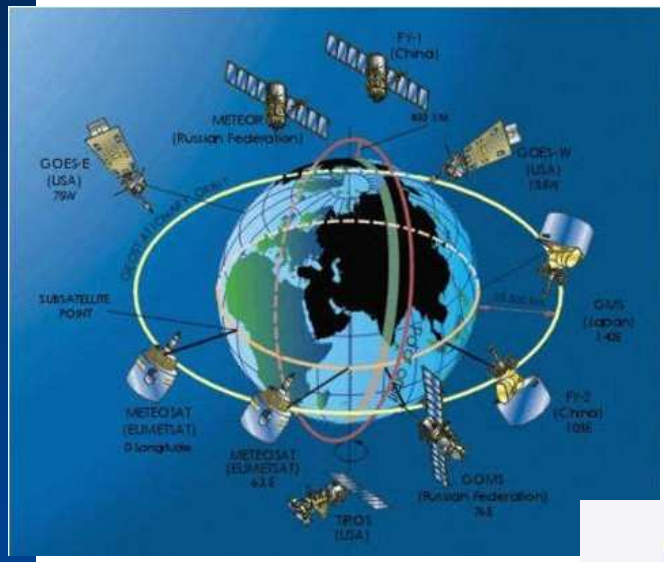
Summary

- Spatiotemporal Data and Applications
- Representation of Spatiotemporal Data
  - Current scenario – Existing models and Challenges
  - An Observation-Based Spatiotemporal Data Model: Observation, Time Series, Trajectory, Coverage, Coverage Series and Event
- SpatioTemporal Database Systems
- TerraLib and TerraView

Spatiotemporal Data and Applications

Spatiotemporal Data

Technological advances in geospatial data collection.

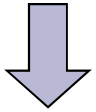


Earth observation
and GPS satellites

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

Spatiotemporal Data

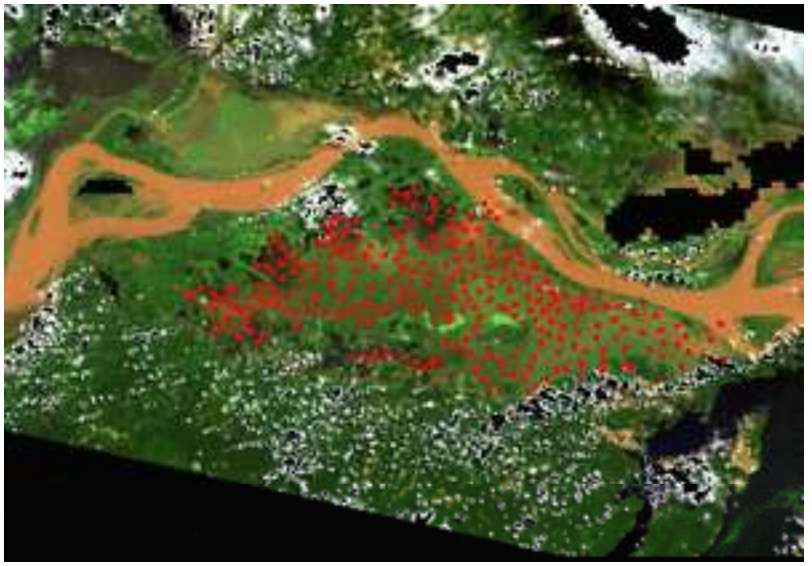
Technological advances in geospatial data collection.



Large spatiotemporal data sets in many application domains.

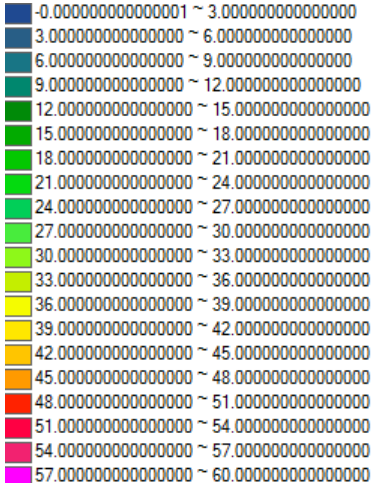
Spatiotemporal Data and Applications

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

Environmental and Natural Disaster Monitoring

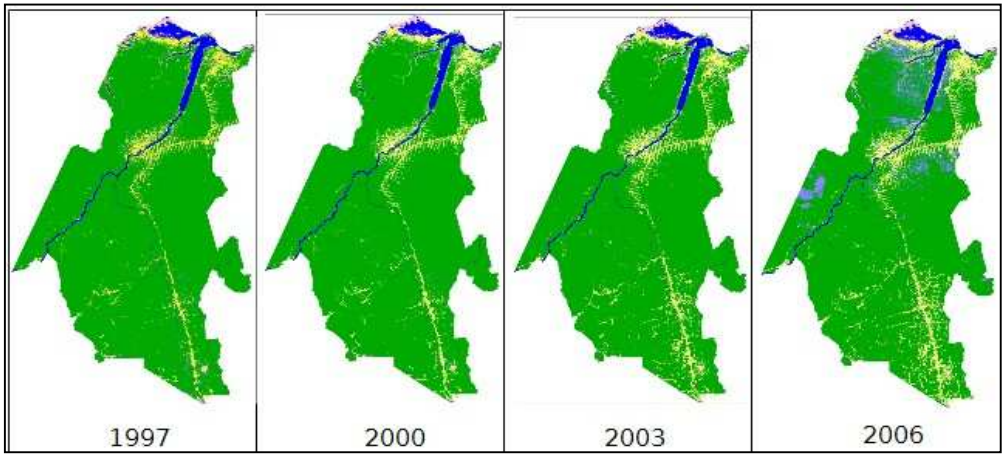
oil spill on the ocean

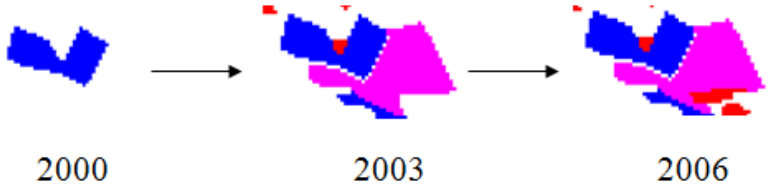
hurricane and volcanic eruption monitoring

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?"

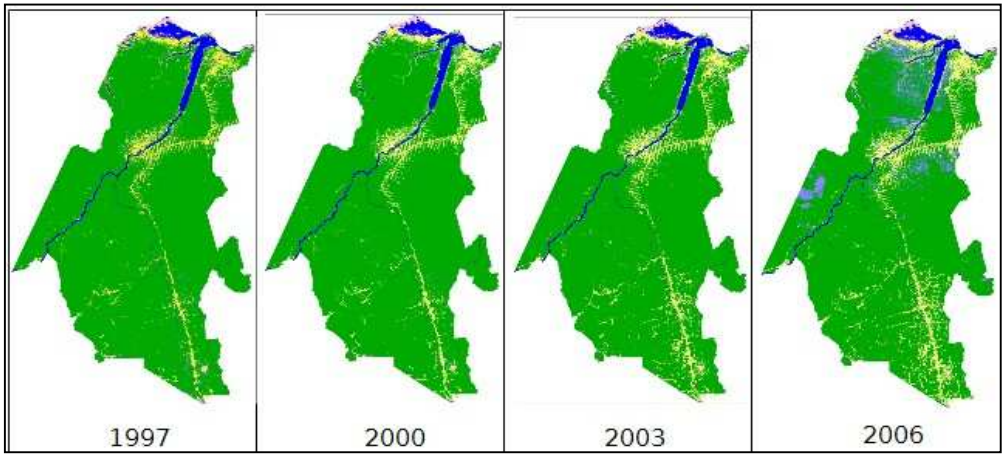
"how did the deforested regions that started less than 2 kilometer far from the river r1 evolve over time?"

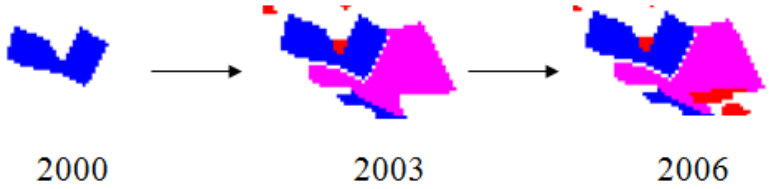
"when did a specific deforested region reach the municipality x?"

Spatiotemporal Data and Applications

PRODES

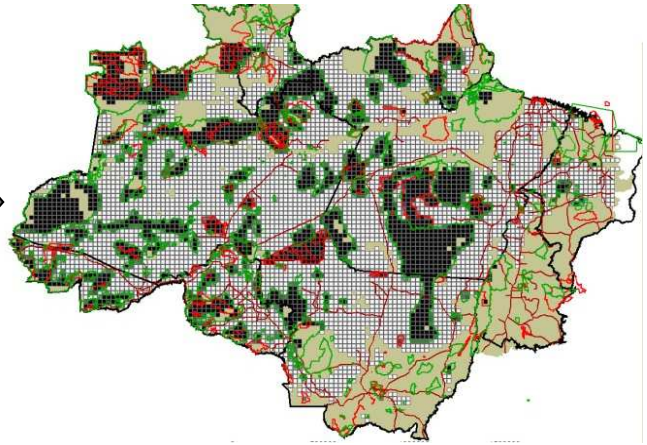
Imagens Classificadas





Polígonos de Desmantamento

Land Use and Land Cover Modeling

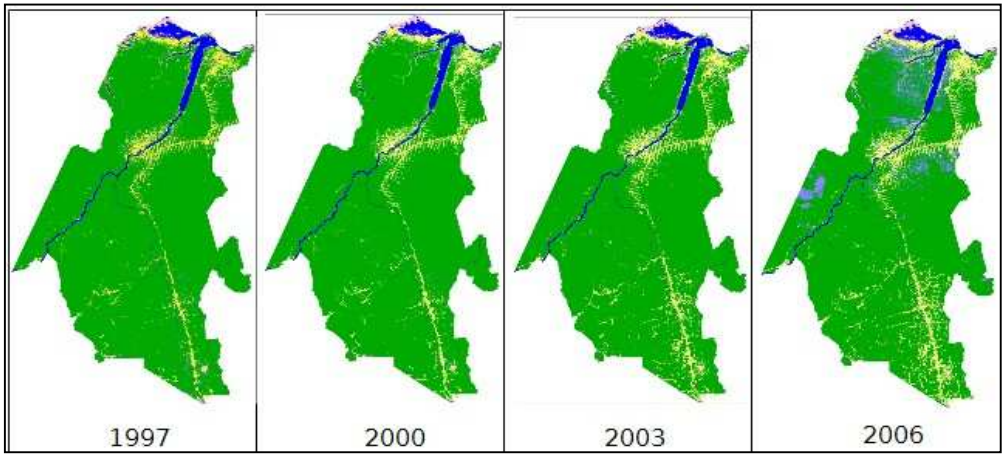


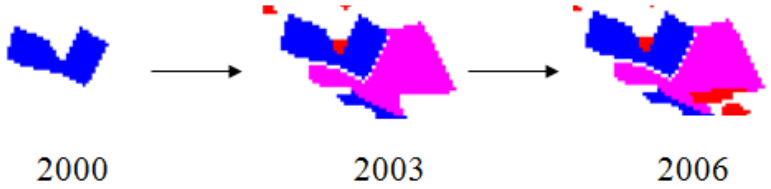
"given a cell, how has the forest status been varying in this cell over time?"

Spatiotemporal Data and Applications

PRODES

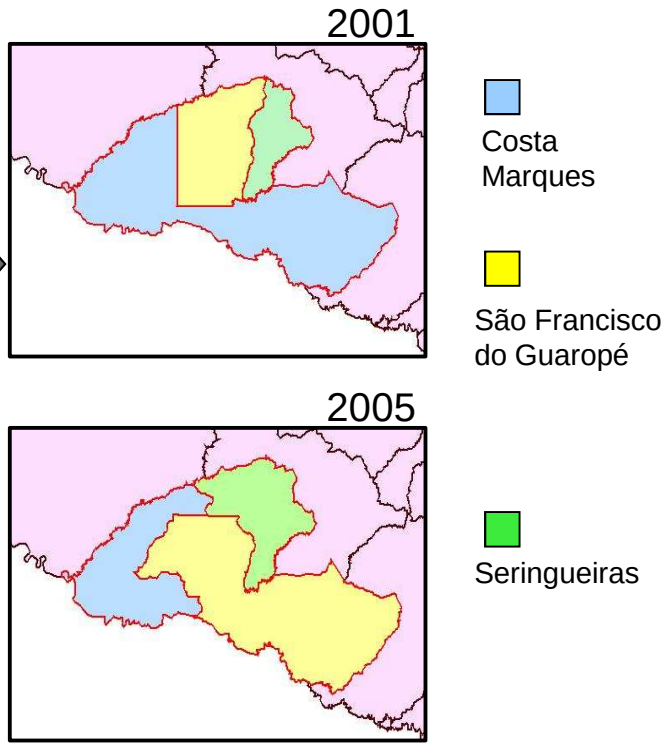
Imagens Classificadas





Polígonos de Desmantamento

Municipal Management

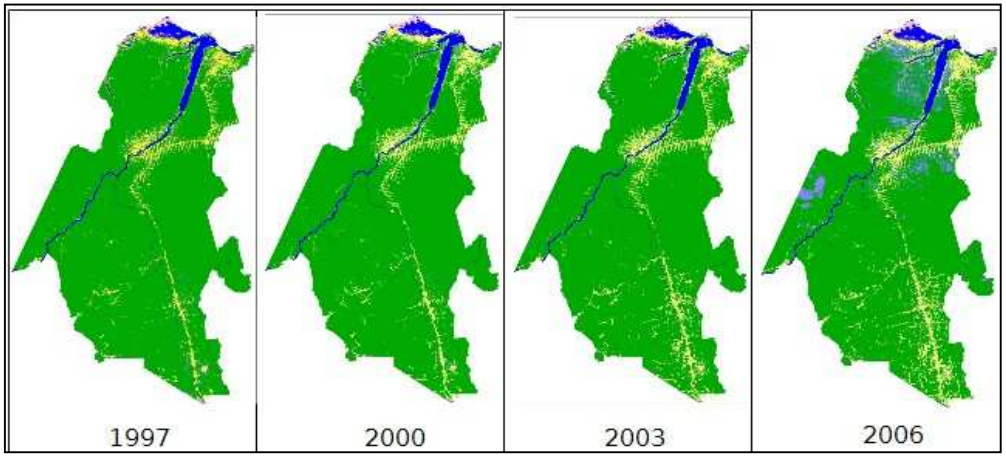


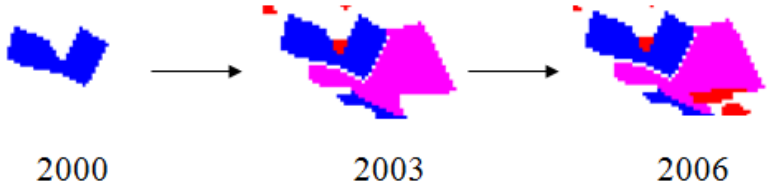
"How many hectares were deforested in each municipality? "

Spatiotemporal Data and Applications

PRODES

Imagens Classificadas





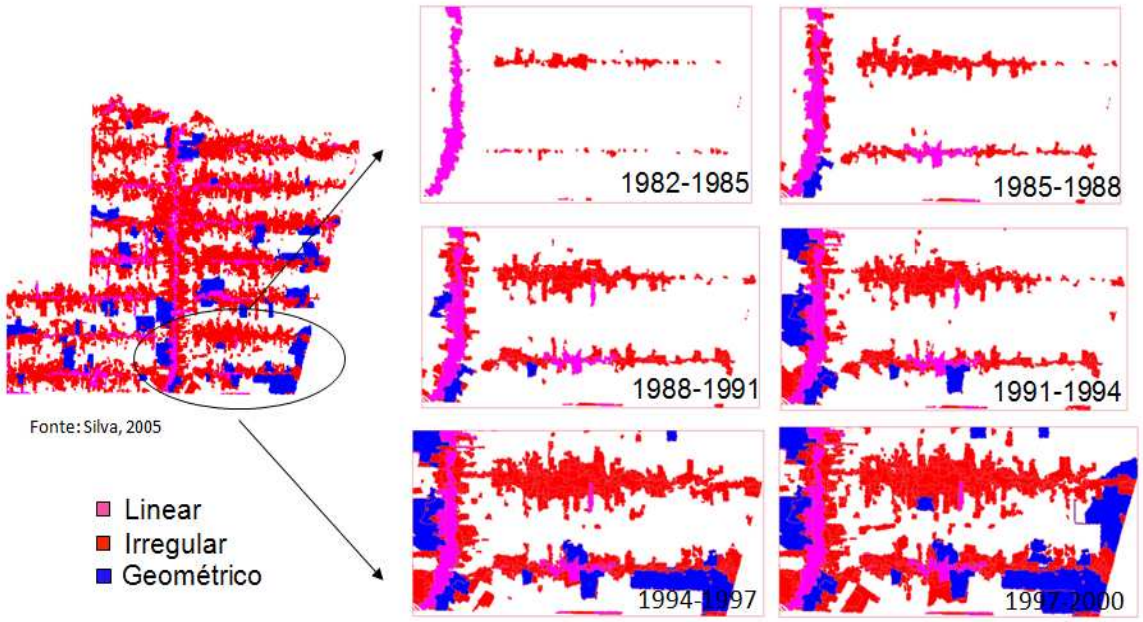
Polígonos de Desmantamento

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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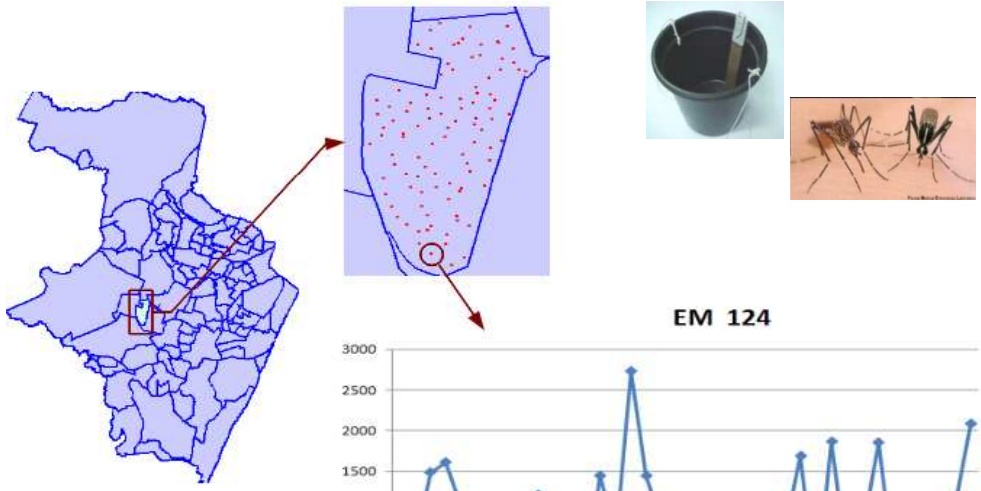
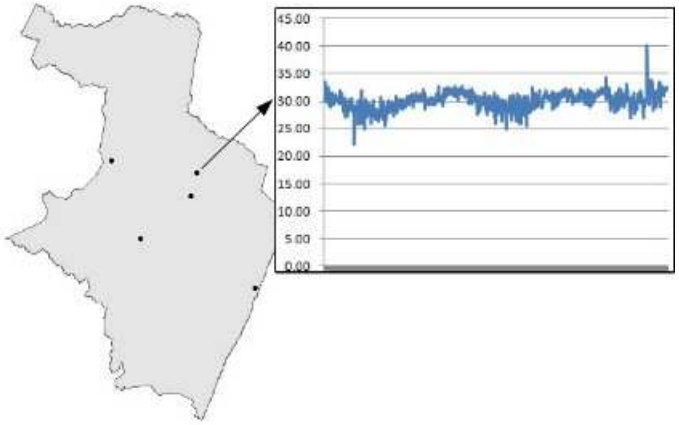
Spatiotemporal Data and Applications

Public Health



Number of mosquito eggs gathered from one egg trap - Recife

Temperature variation collected by meteorological stations - Recife.



(a)

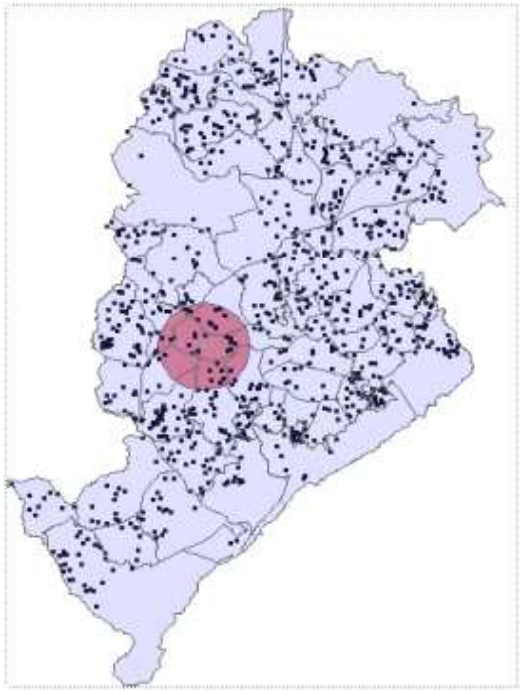
"Which month had the biggest number of infected eggs?"

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

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

Spatiotemporal Data and Applications

Public Health

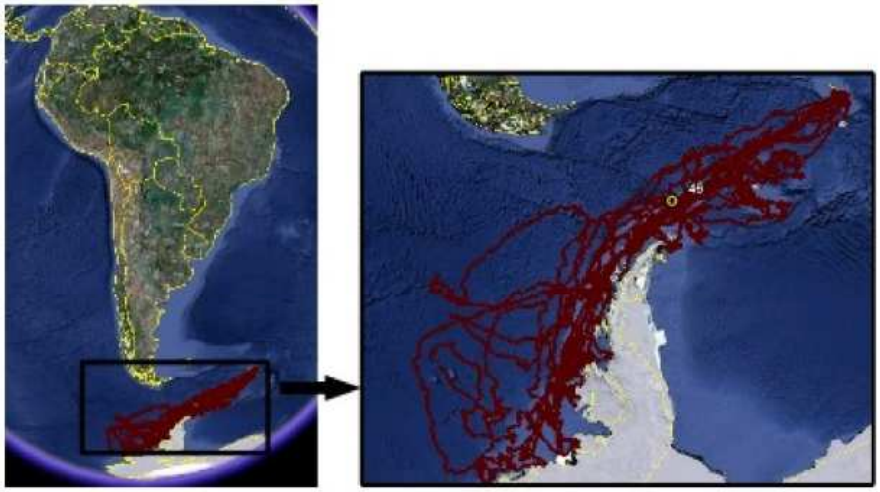


occurrences of meningitis in
Belo Horizonte city

Spatiotemporal Data and Applications

Location-based Systems

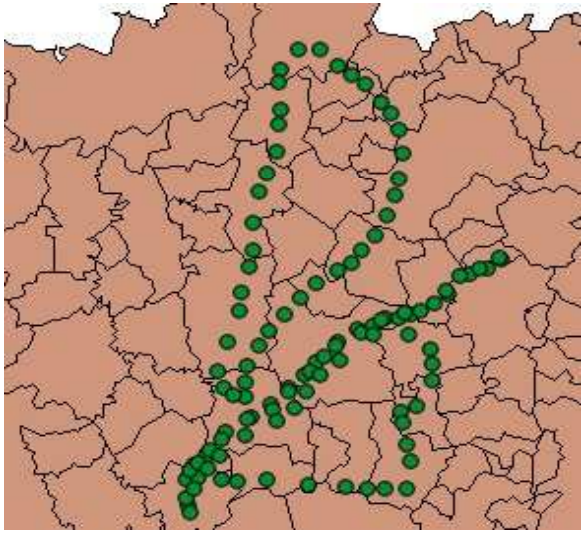
[INPE's Antarctica Program, 2010]



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)?"

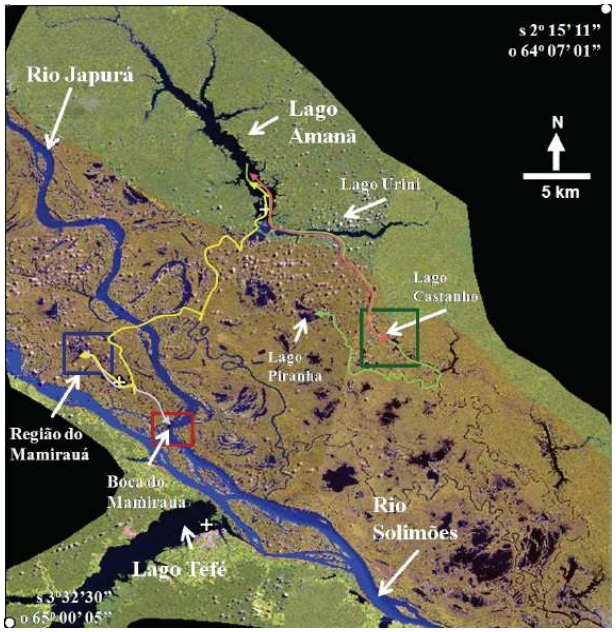
"Where and when was there a spatiotemporal cluster of objects?"



Set of cars equipped with GPS and air pollution sensors.

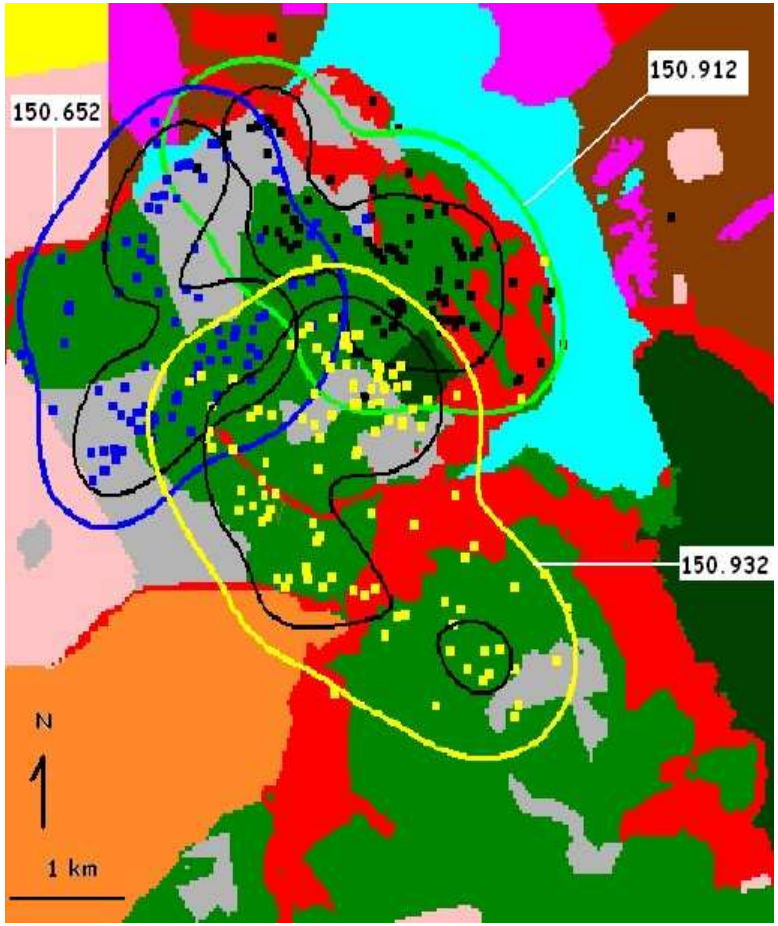
Spatiotemporal Data and Applications

Location-based Systems



[Arraut, E. M. 2008]

Spatiotemporal Data and Applications



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

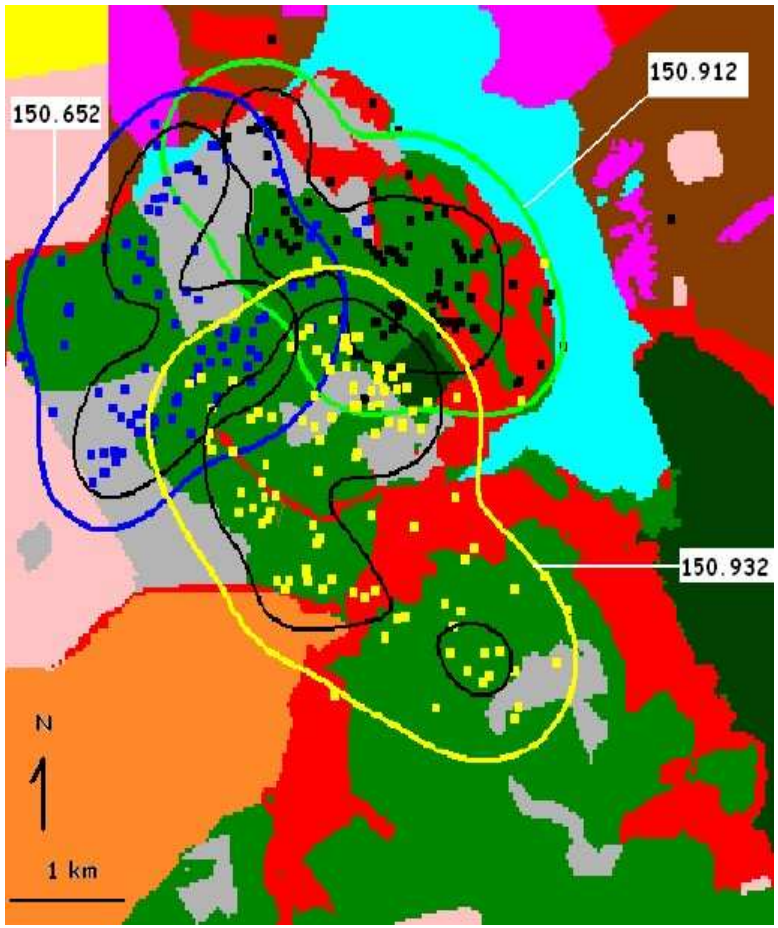
Julho de 2005 a junho de 2007 - monitorando 6 aves de rapina por rádio-telemetria.

Mapa de Uso e Ocupação do Solo
X
Trajetórias Dos Animais

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

[Marco Granzinolli, 2009]

Spatiotemporal Data and Applications



"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]

Spatiotemporal Data Representation

Spatiotemporal Data

Regarding spatiotemporal data, there are many distinct research areas in geographical information systems (GIS) science:

Representation and Query of Spatiotemporal Data

Indexing of Spatiotemporal Data

Analysis of Spatiotemporal Data

Spatiotemporal Data Mining and Pattern Recognition

Spatiotemporal Visualization

Spatiotemporal Data

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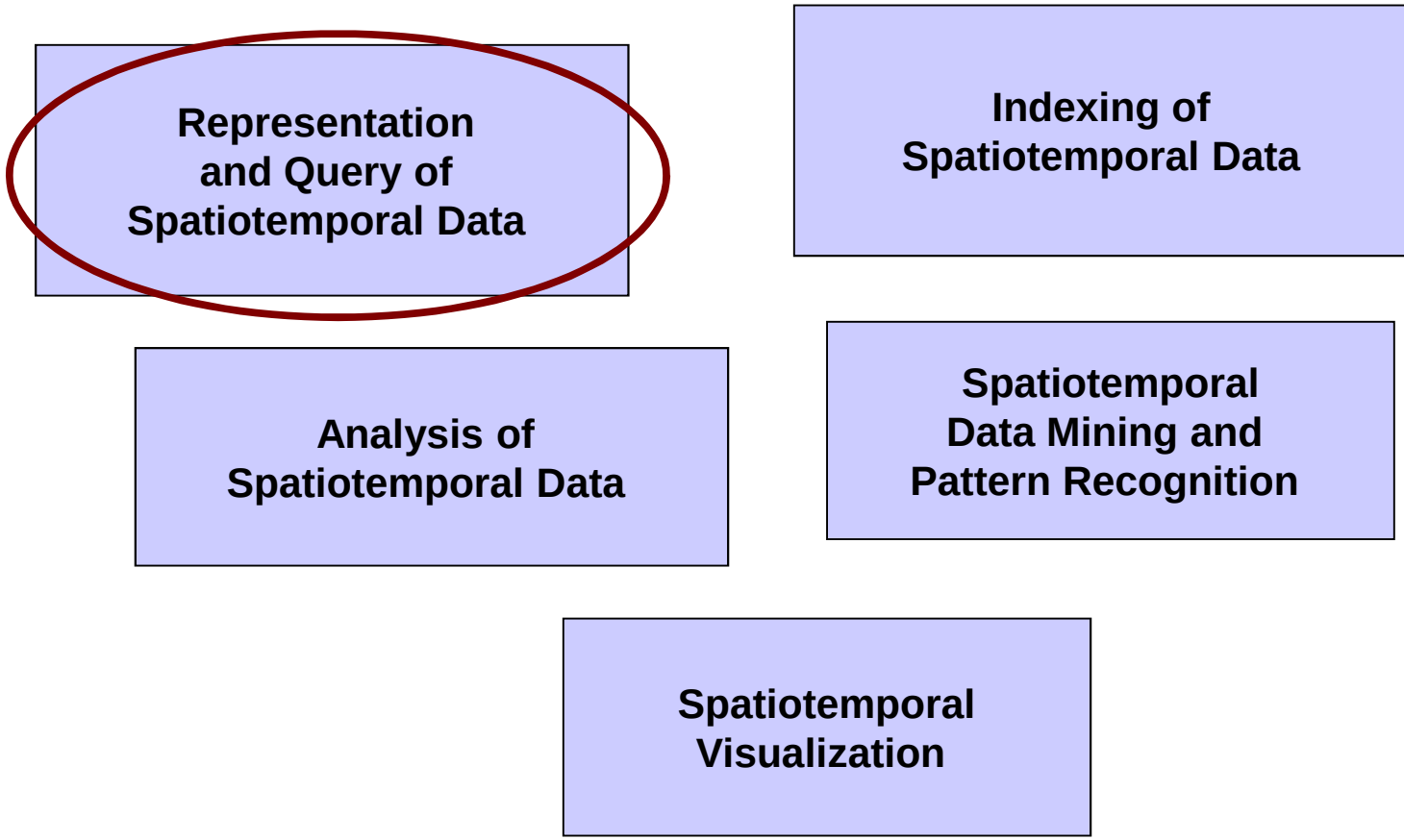
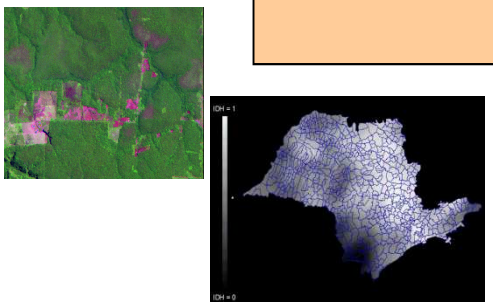
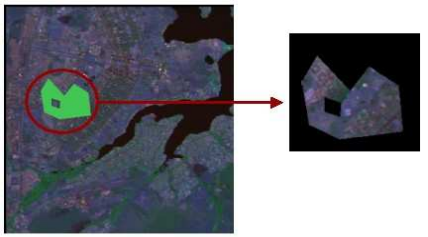


Representation of Spatial Data

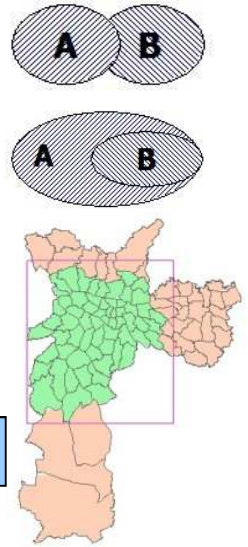
Static geospatial information is represented in GIS following well-established ideas.

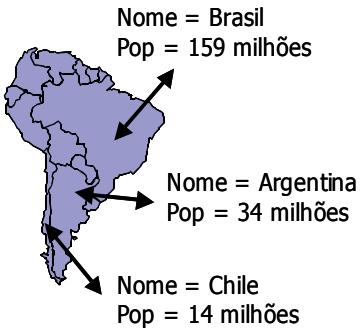


Geo-Fields and Geo-Objects

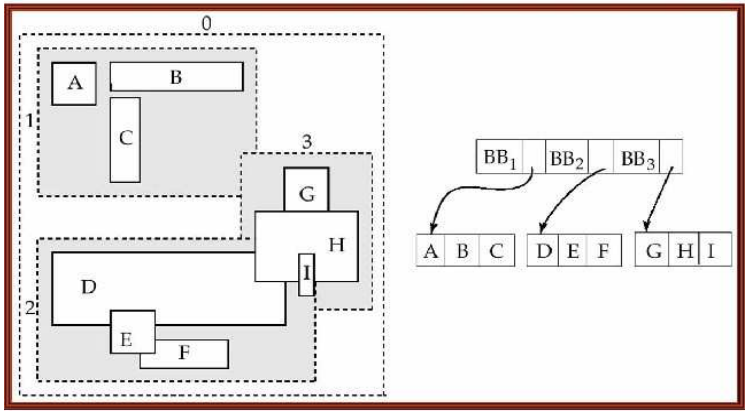


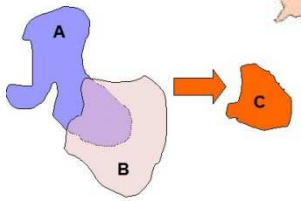
Spatial Operations





Spatial Index

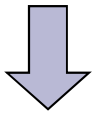




The majority of GIS and spatial DBMS is based on these ideas and concepts!

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]

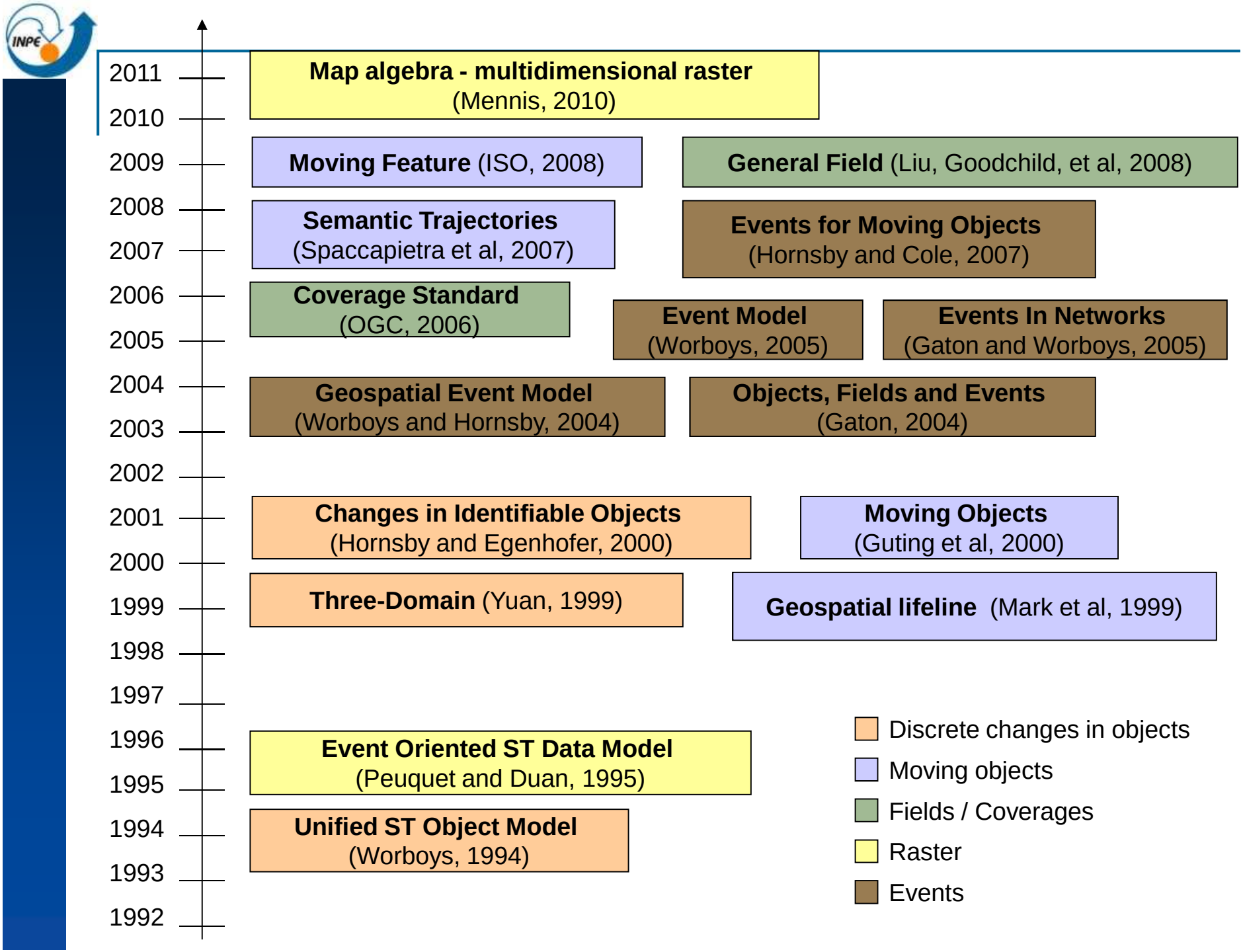
Existing Spatiotemporal Data Models

"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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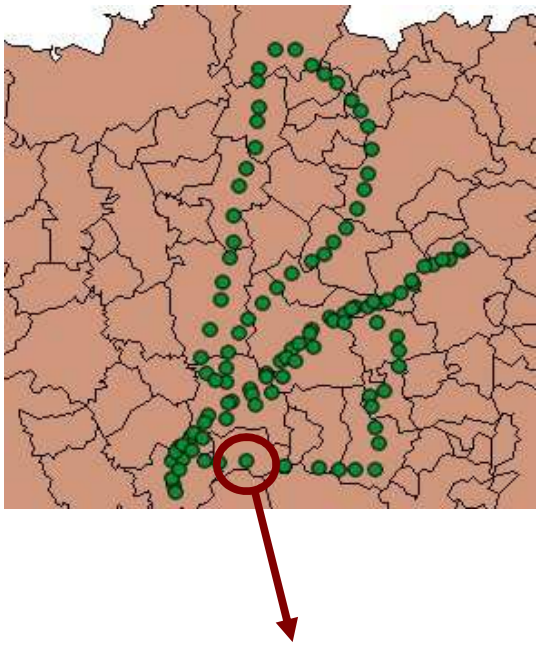
1992
Map algebra - multidimensional raster (Mennis, 2010)
Moving Feature (ISO, 2008)
General Field (Liu, Goodchild, et al, 2008)
Semantic Trajectories (Spaccapietra et al, 2007)
Events for Moving Objects (Hornsby and Cole, 2007)
Coverage Standard (OGC, 2006)
Event Model (Worboys, 2005)
Events In Networks (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

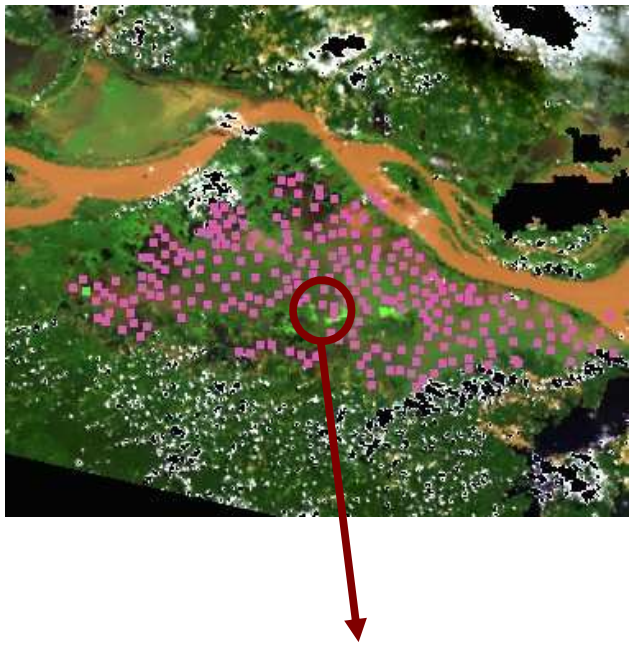
Why “Observation-Based”

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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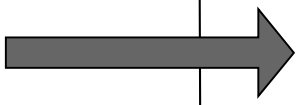
Raw Data



Time Series

Trajectory

Coverage

Spatiotemporal Data Types

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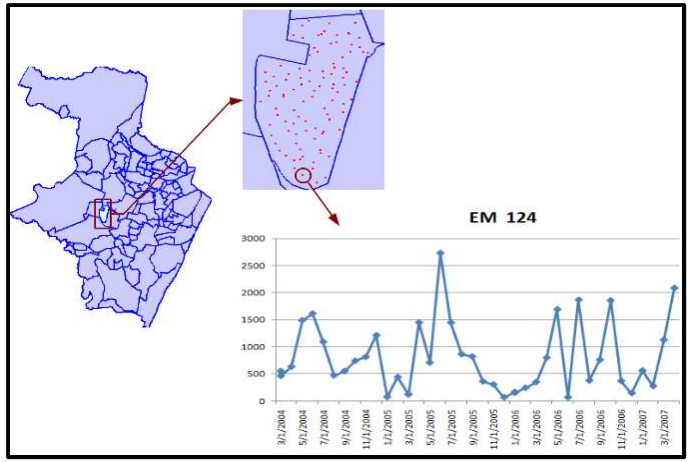
Raw Data

Time Series

Fix space, vary time and measure theme



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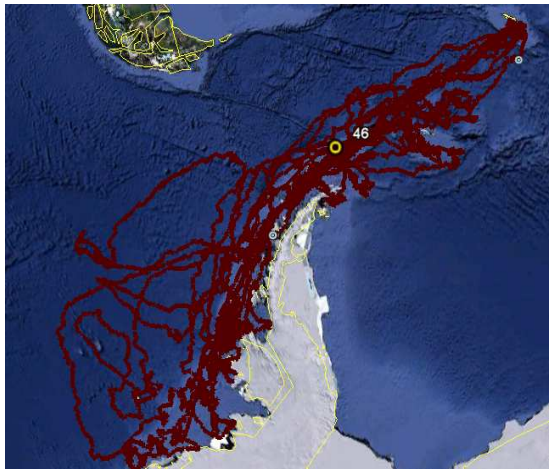
Raw Data

Trajectory

Fix theme, vary time and measure space



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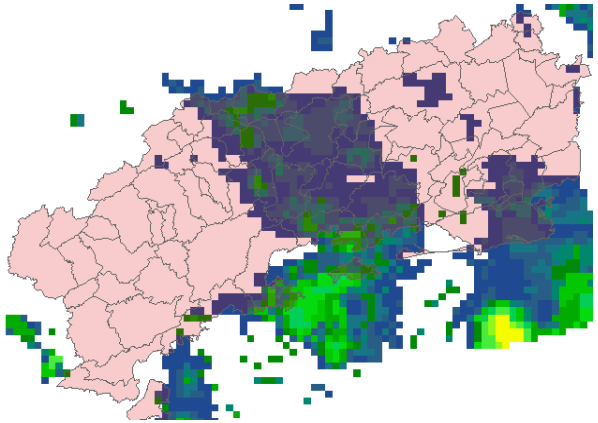
Coverage

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

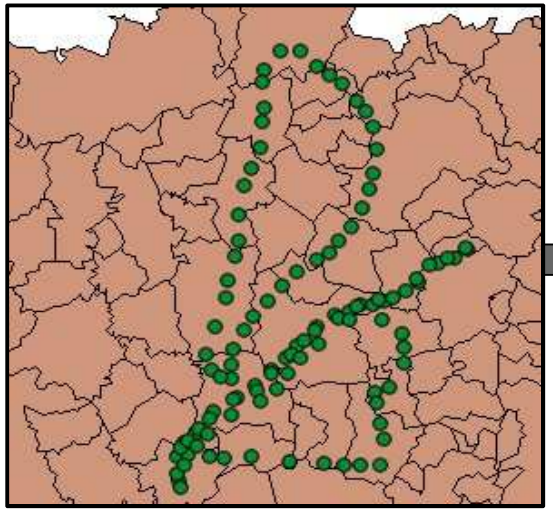
how animals move over time

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

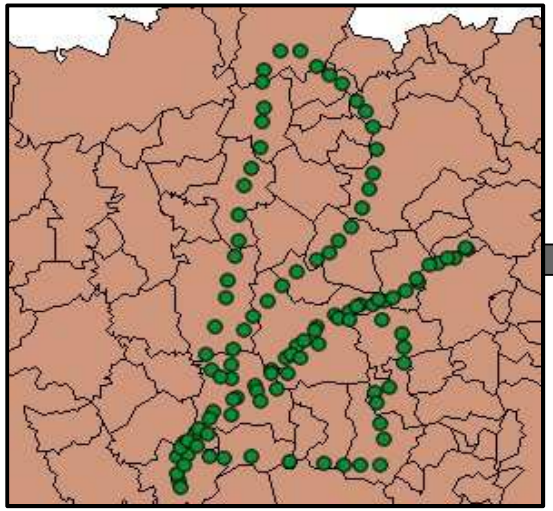
each observation contains a car identity, a time instant, a location and an air pollution value

(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

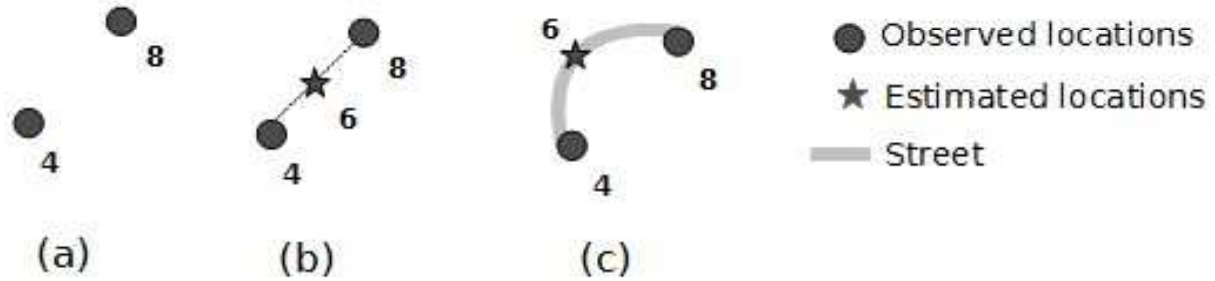
Coverage

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

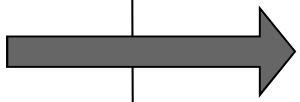
Trajectory

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 Database Systems

Spatiotemporal Database Systems

1) SECONDO

1) 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.

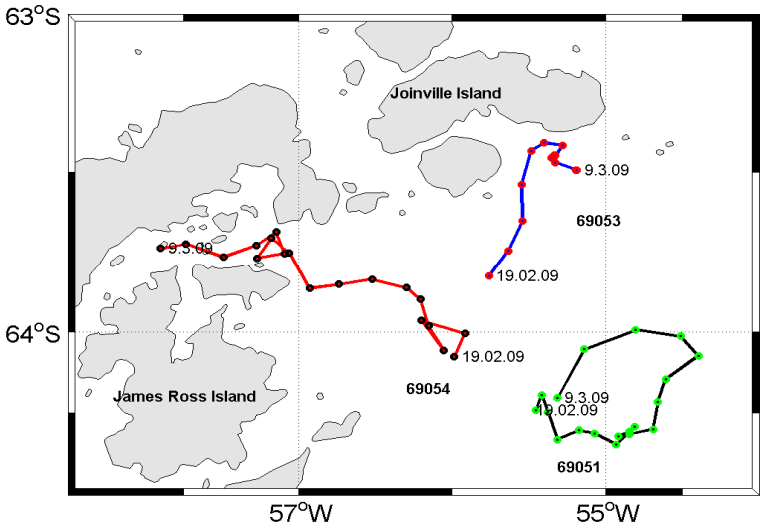
SECONDO: Moving Object Database

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

Moving Regions (ex.: mancha de oleo)

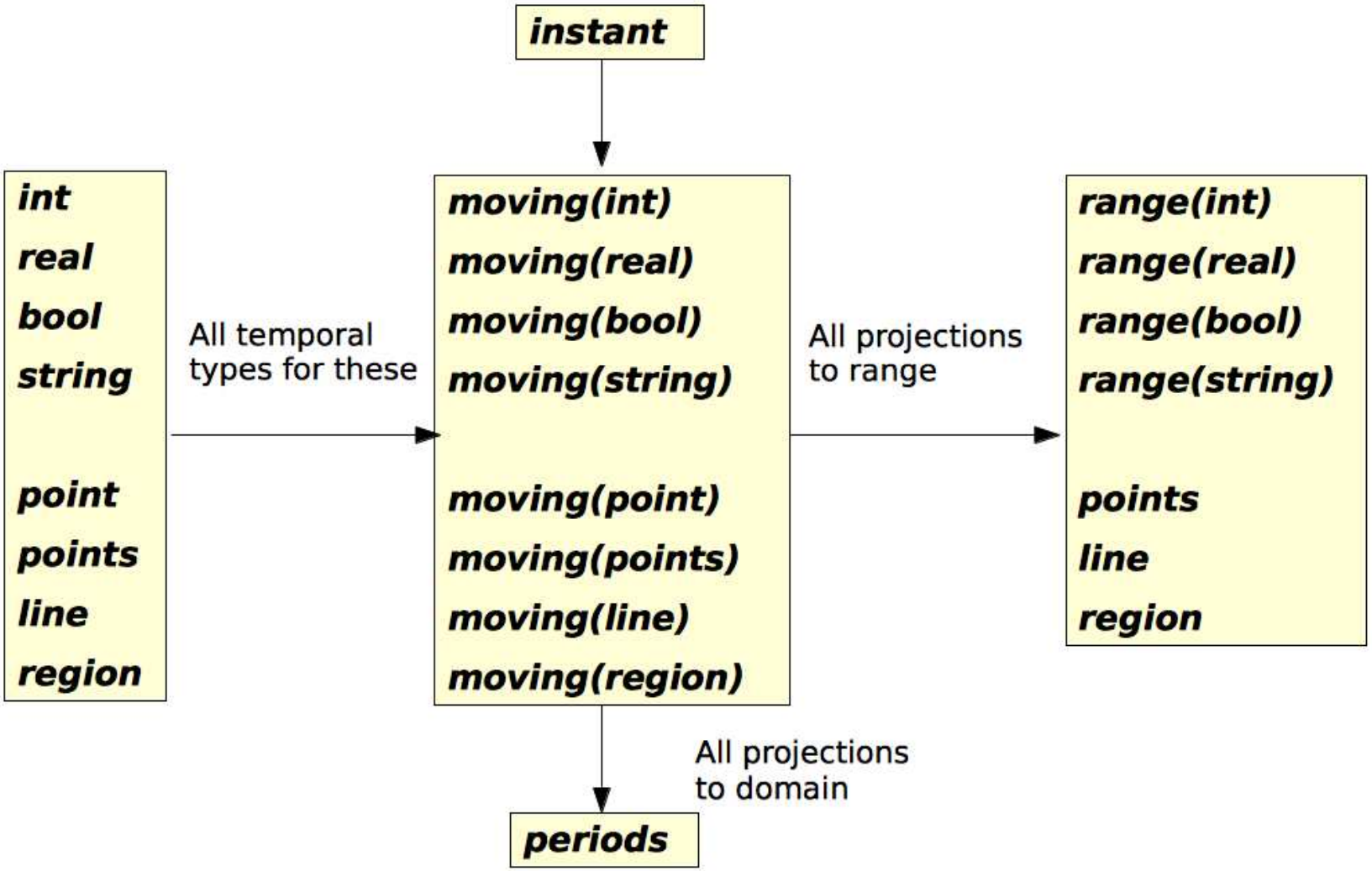
oil spill on the ocean

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

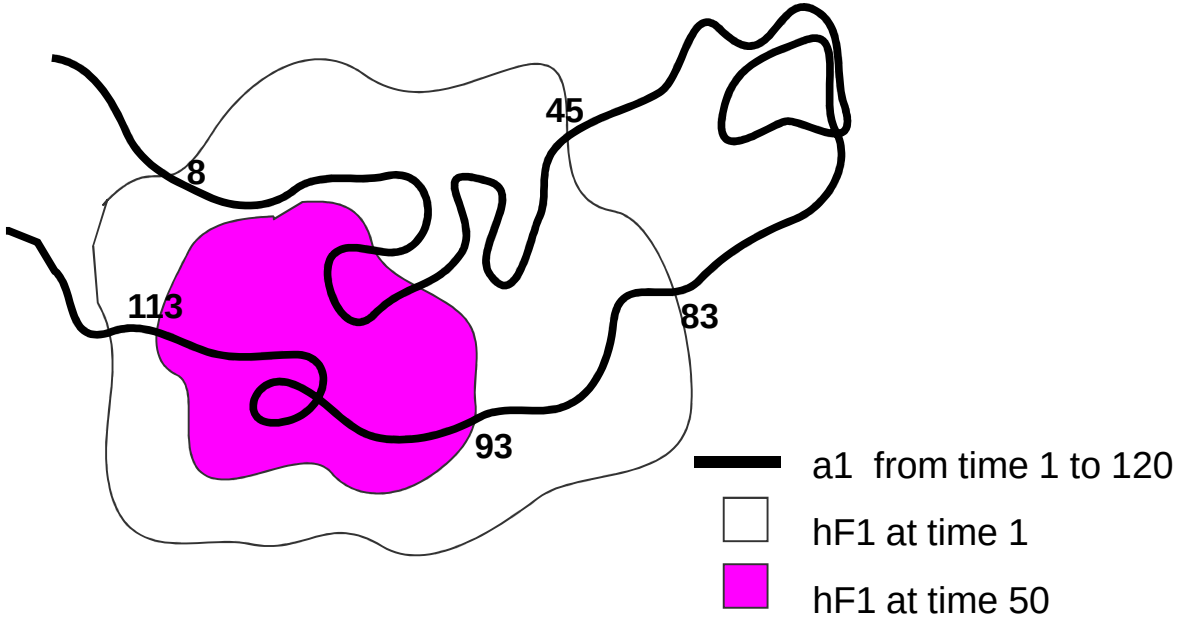
Some Operations

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'
```

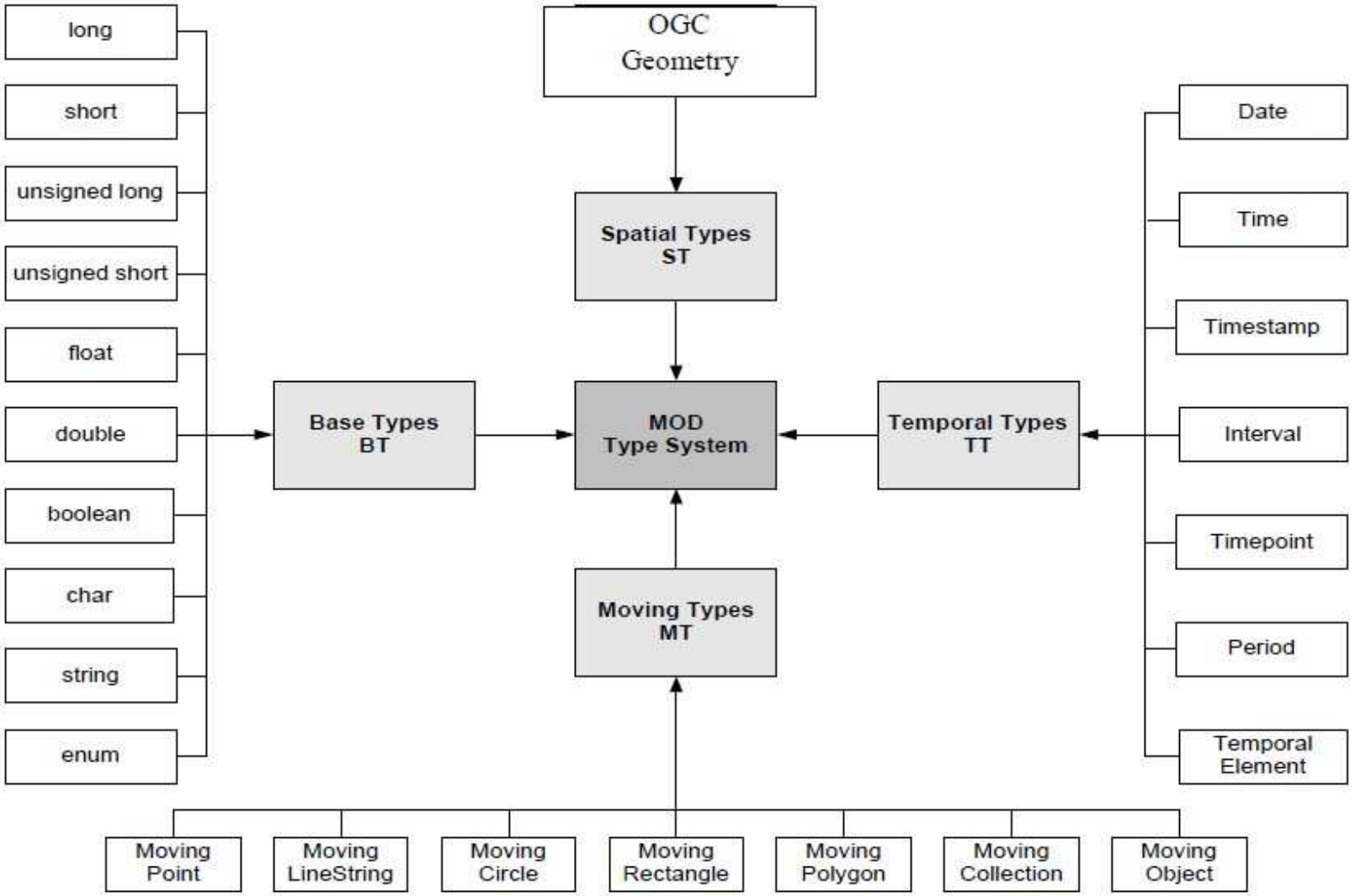
HERMES

- A framework that extends a OGC-compliant ORDBMS by supporting moving object data. [Pelekis, N. et. al, 2010]

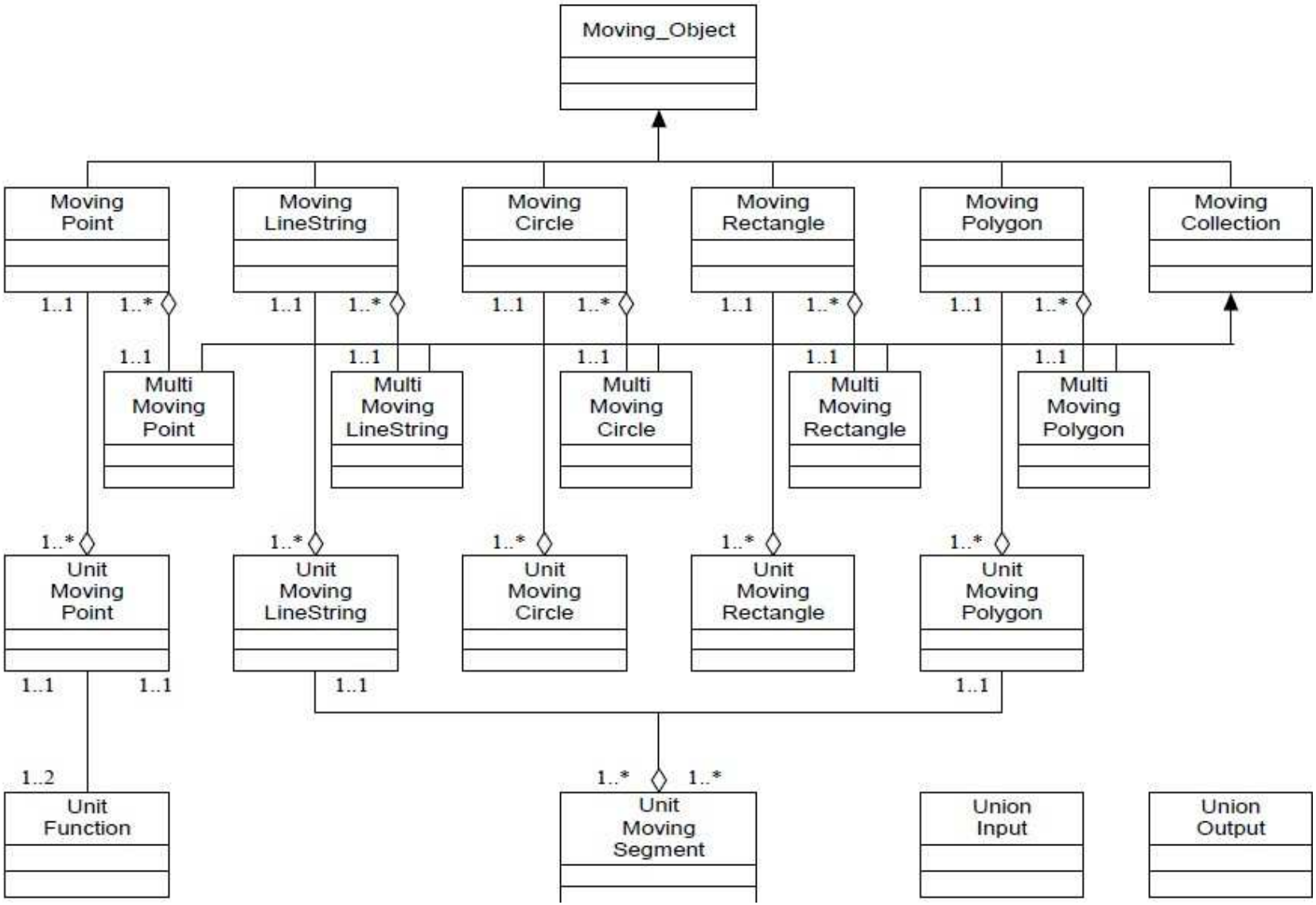
- Moving Object Data: time-varying geometries that change their position and/or extent in space and time dimensions, either discretely or continuously.

- 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

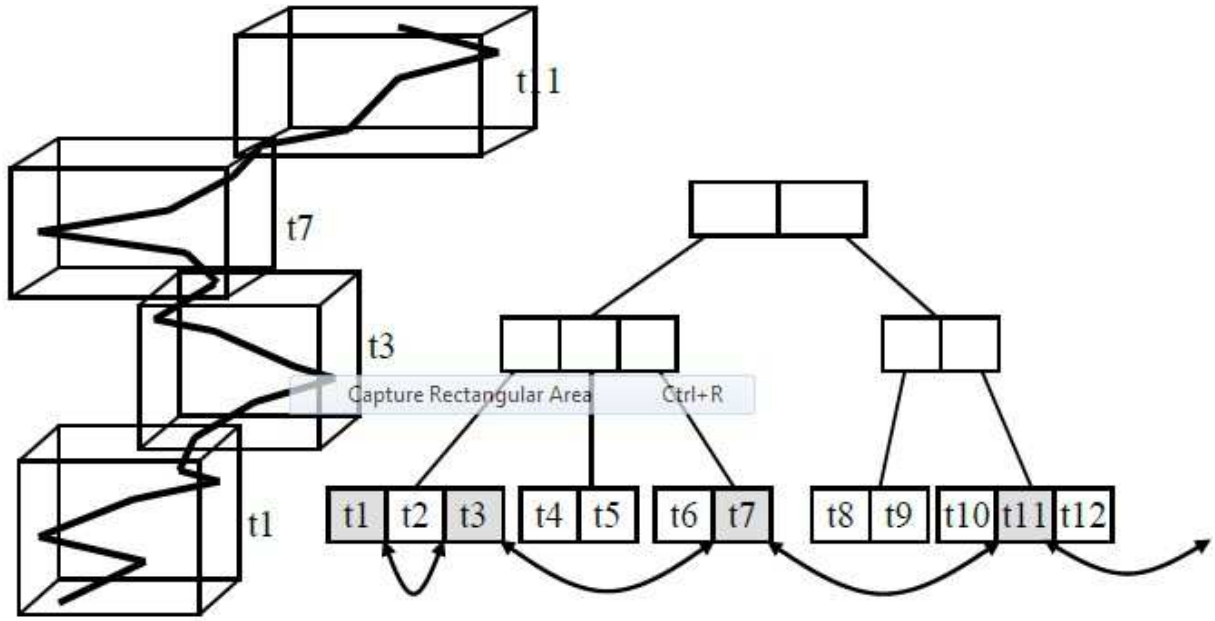


HERMES – Moving Types



HERMES

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

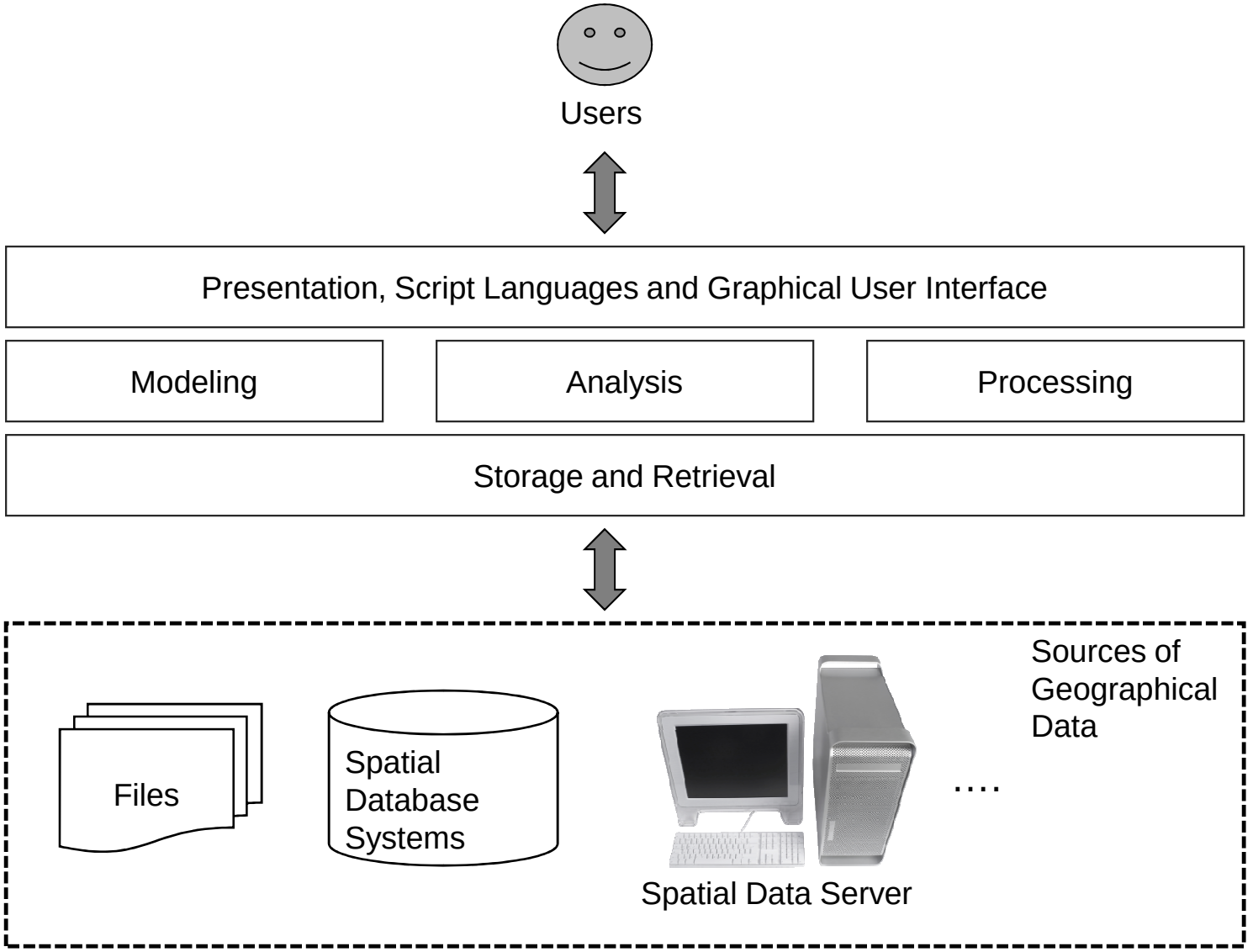


HERMES

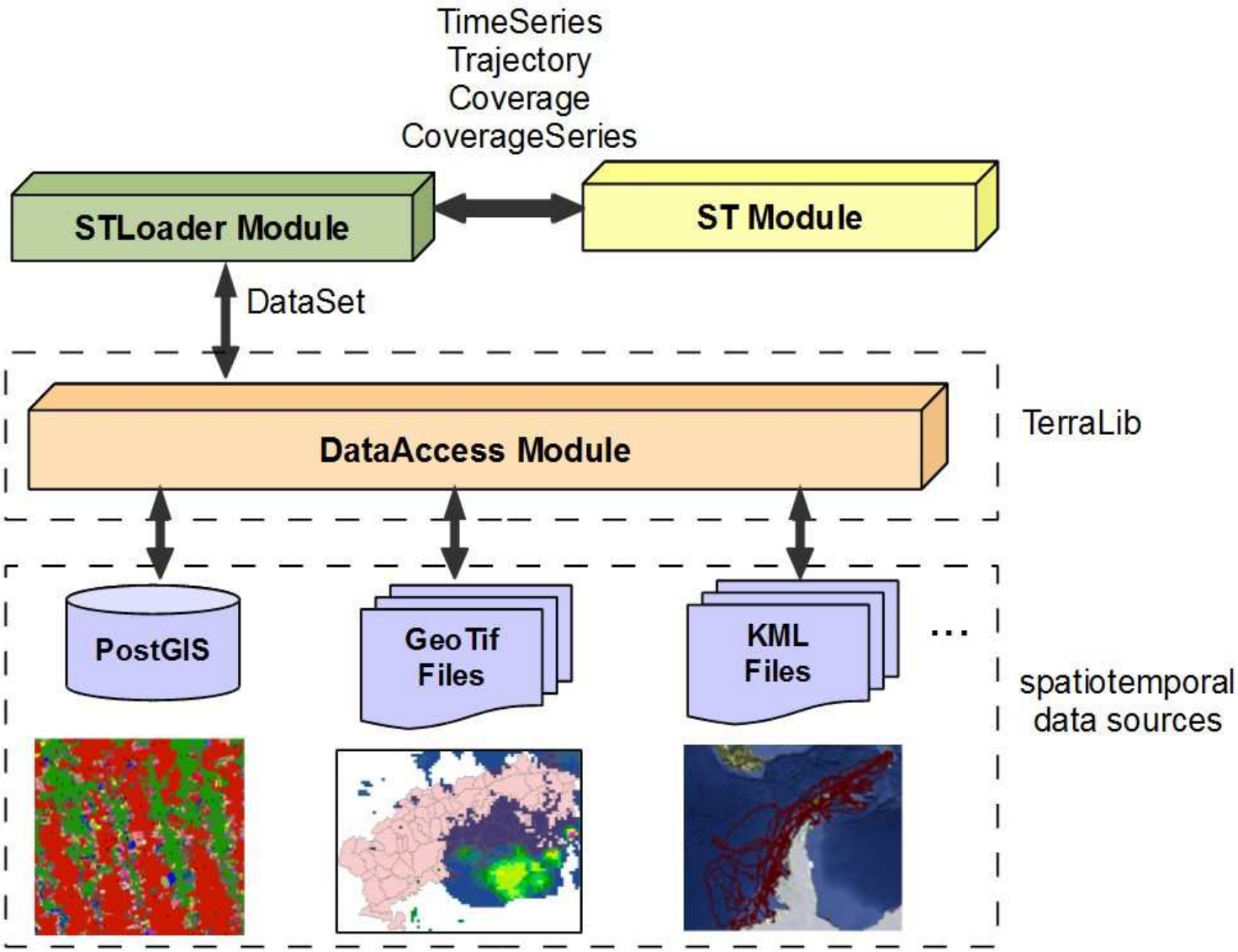
- Proof of concept: it was implemented on top of a commercial ORDBMS, namely Oracle, while our design has also been successfully applied and repeated in the open-source PostgreSQL / PostGIS spatial extension.

Challenges of a Temporal GIS and Terralib/TerraView 5.0

Challenges of a Temporal GIS



TerraLib / TerraView 5.0



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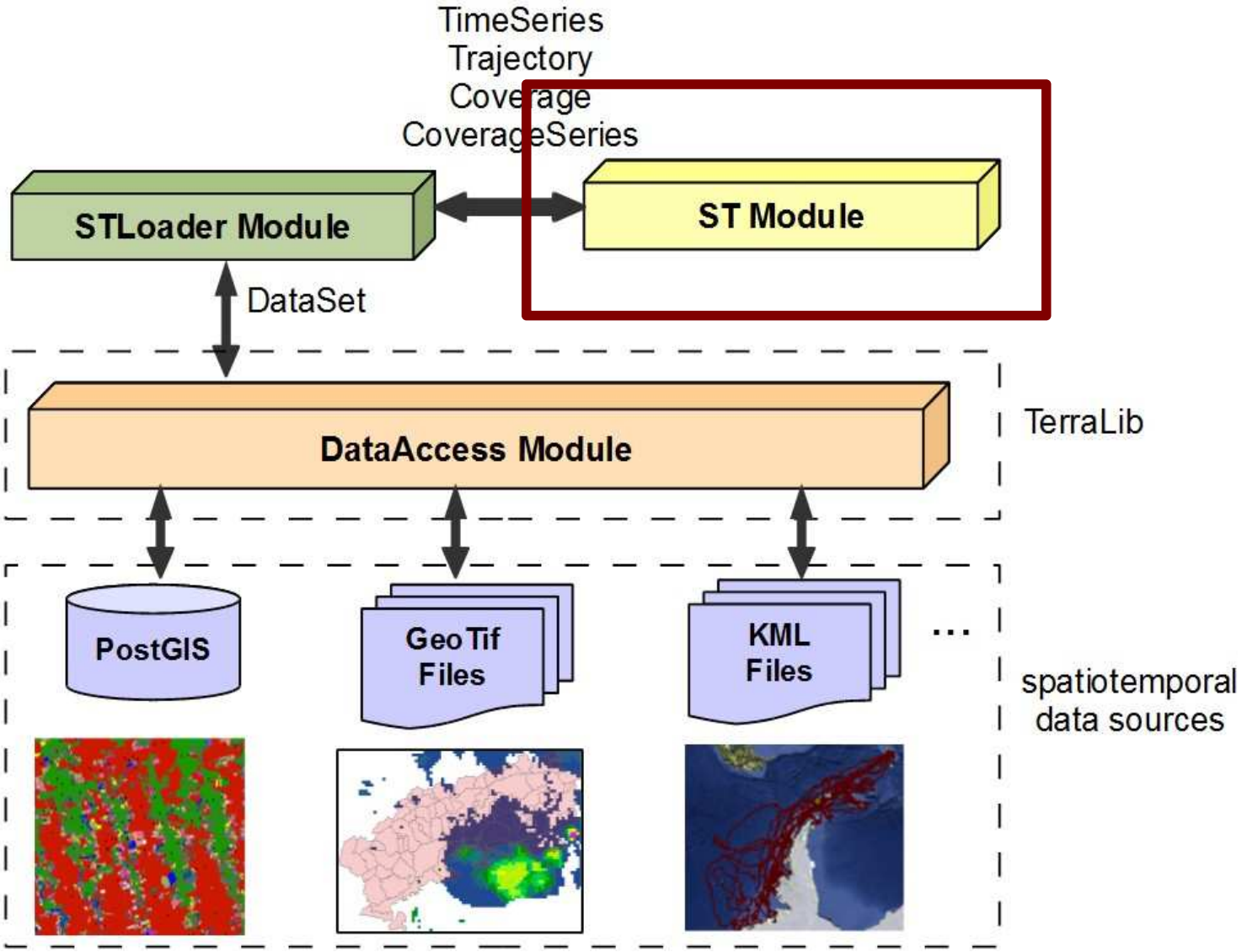
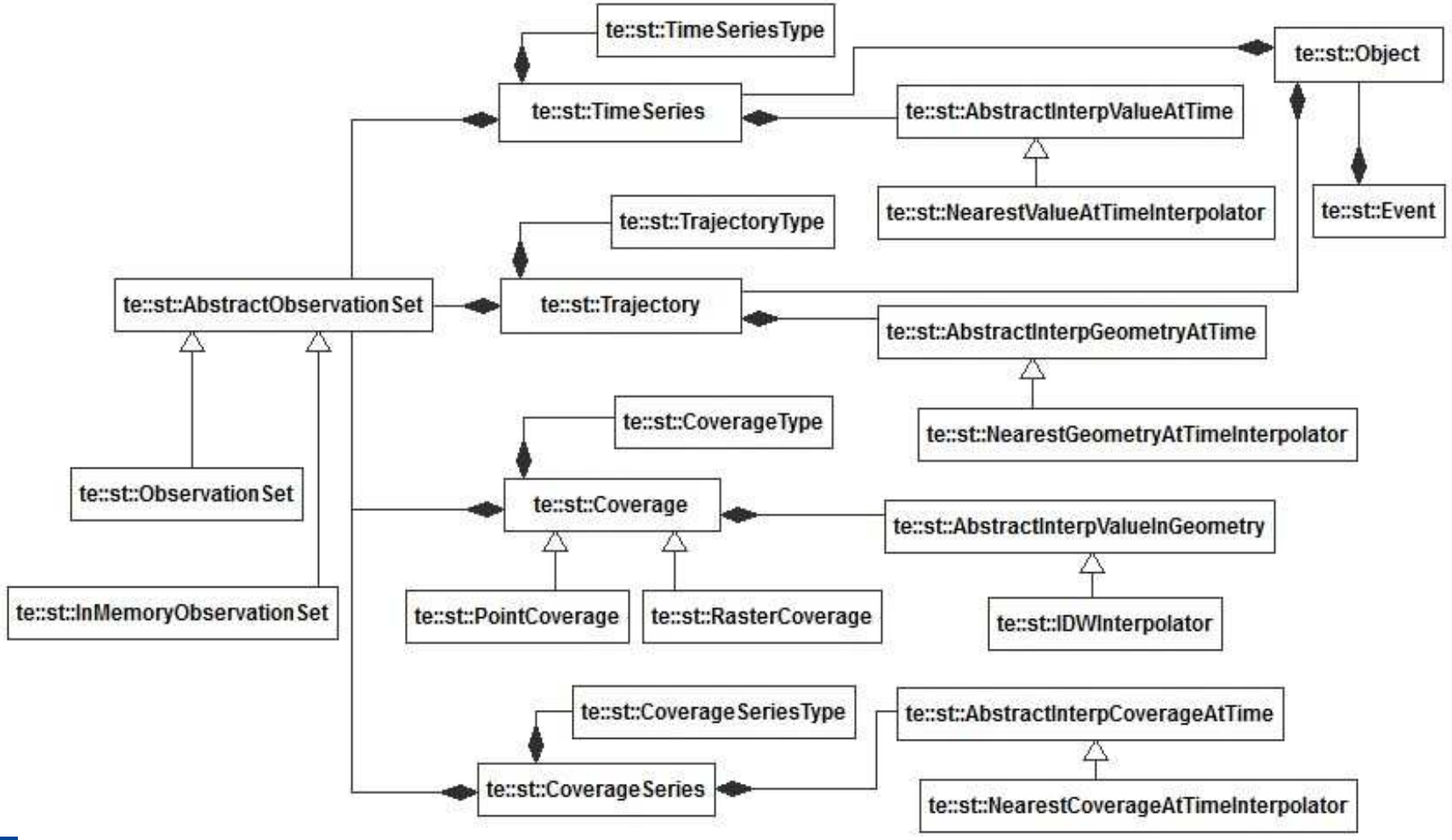


ST Module

It contains all *data types* and *functions* of the algebra.
Each type and its operations were implemented as C++ *classes* and their *methods*.

ST Module


te::st::TimeSeriesType
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te::st::TimeSeries
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te::st::NearestValueAtTimeInterpolator
te::st::Event
te::st::TrajectoryType
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te::st::Coverage
te::st::AbstractInterpValueInGeometry
te::st::InMemoryObservationSet
te::st::PointCoverage
te::st::RasterCoverage
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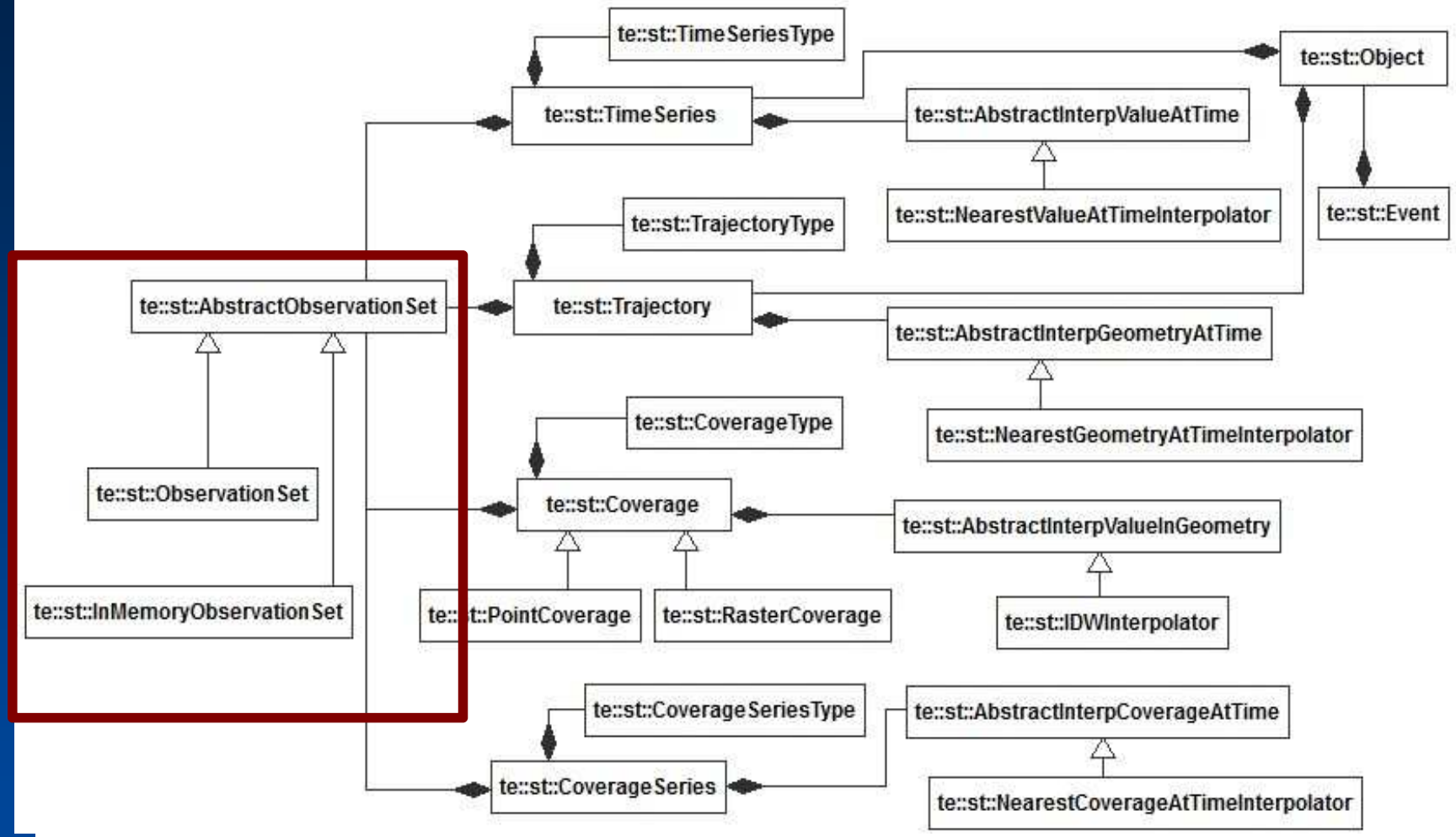
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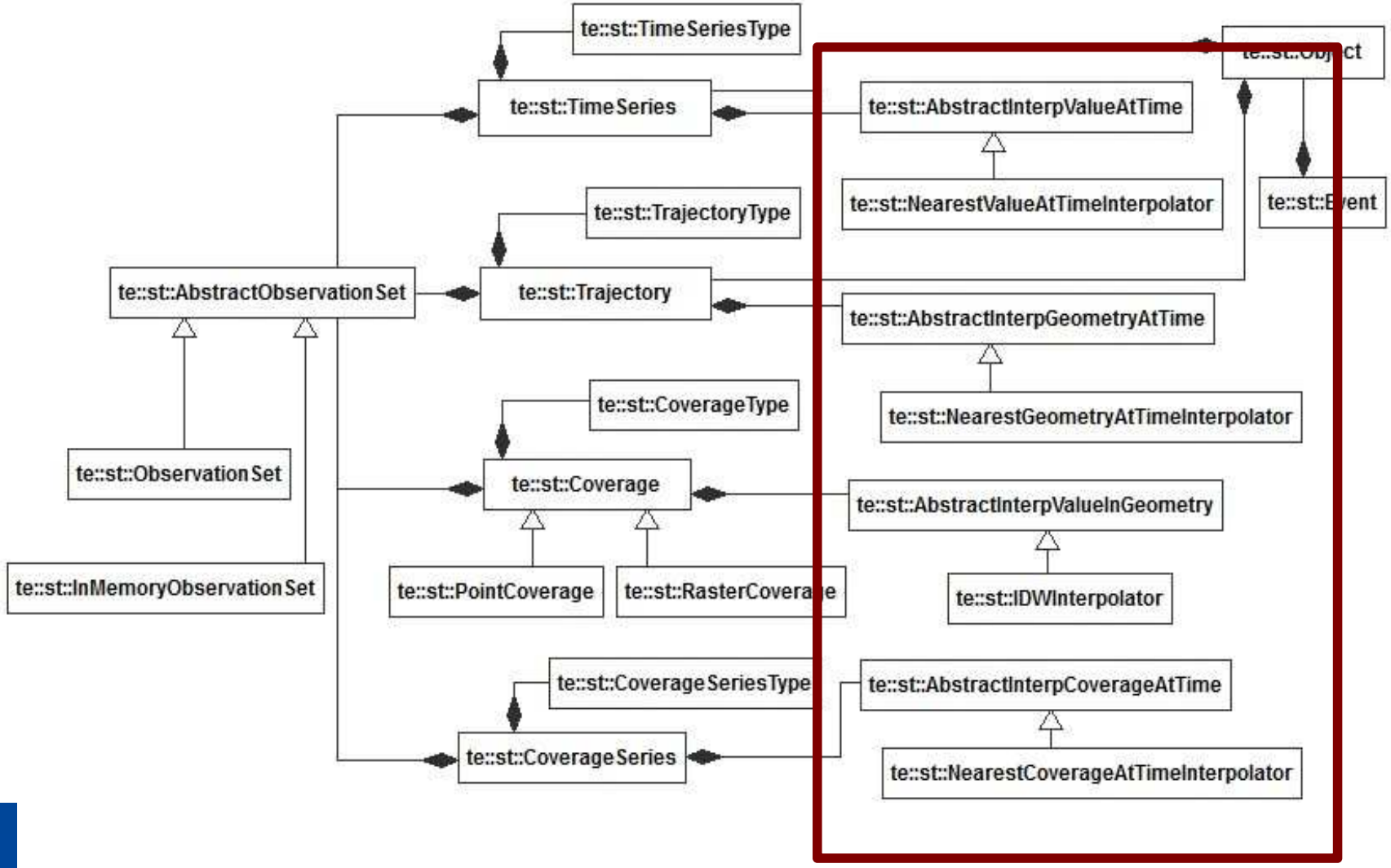
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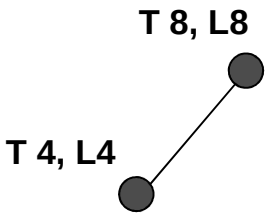
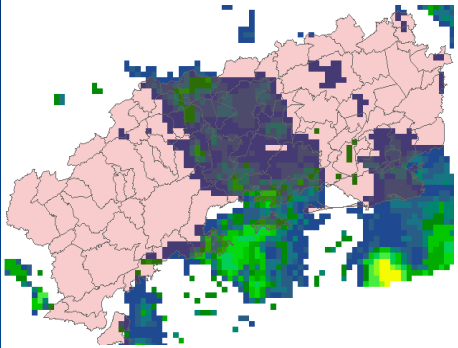


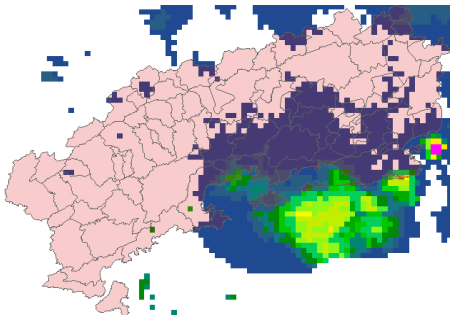
NearestGeometryAtTimeInterpolator:

estimate at time T5 → L4

estimate at time T7 → L8



T 4, CV4



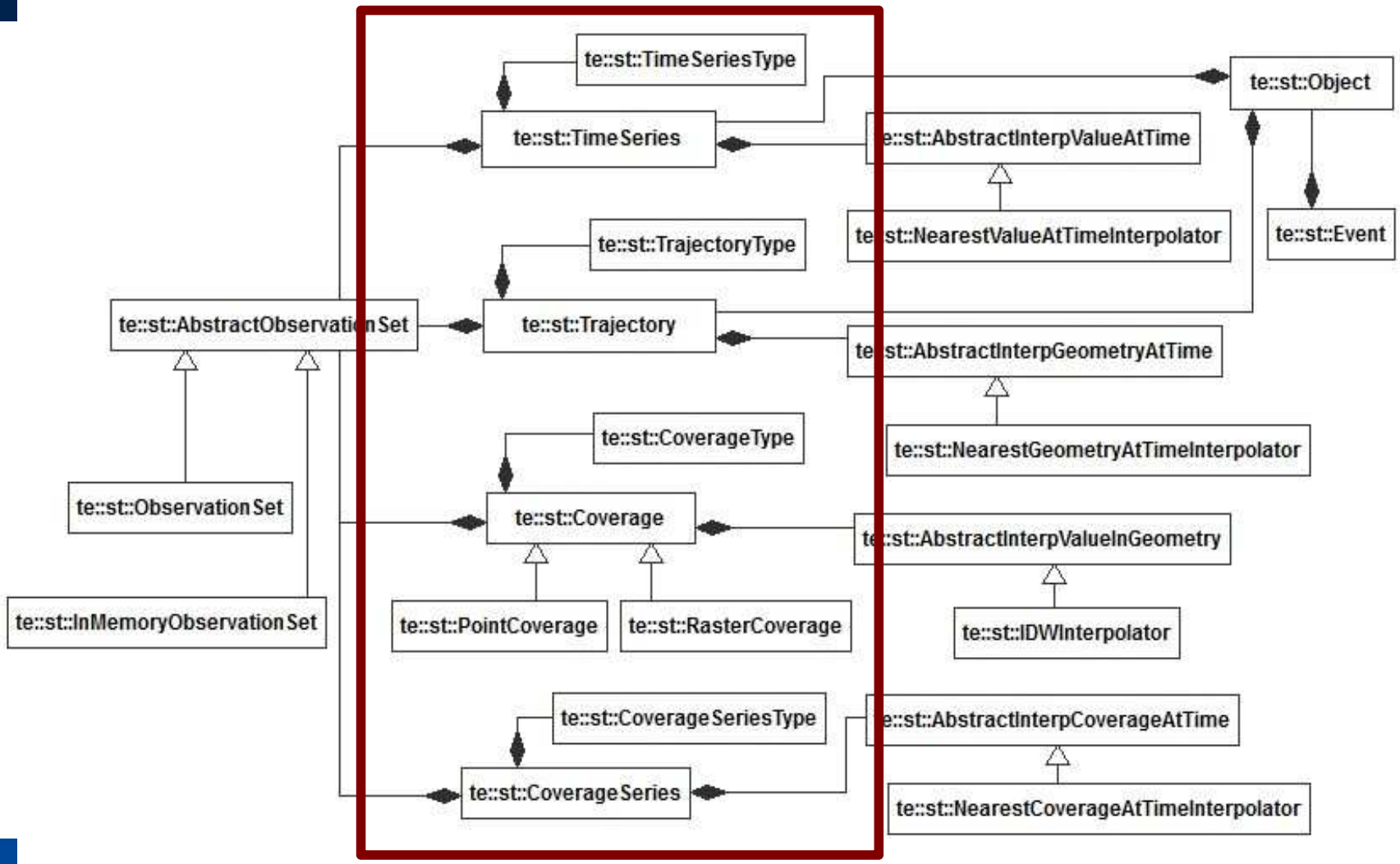
T 8, CV8

NearestCoverageAtTimeInterpolator:

estimate at time T5 → CV4

estimate at time T7 → CV8

ST Module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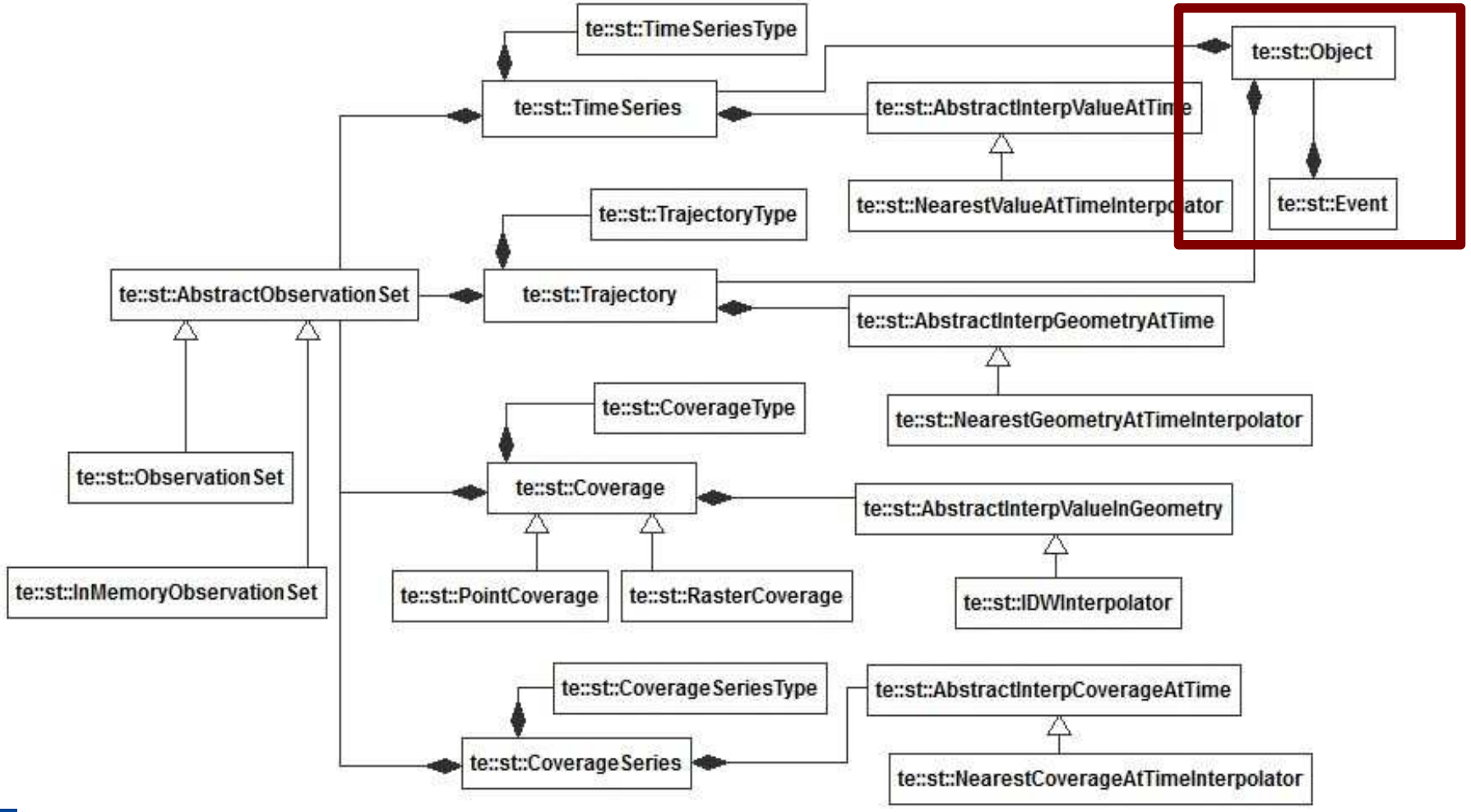
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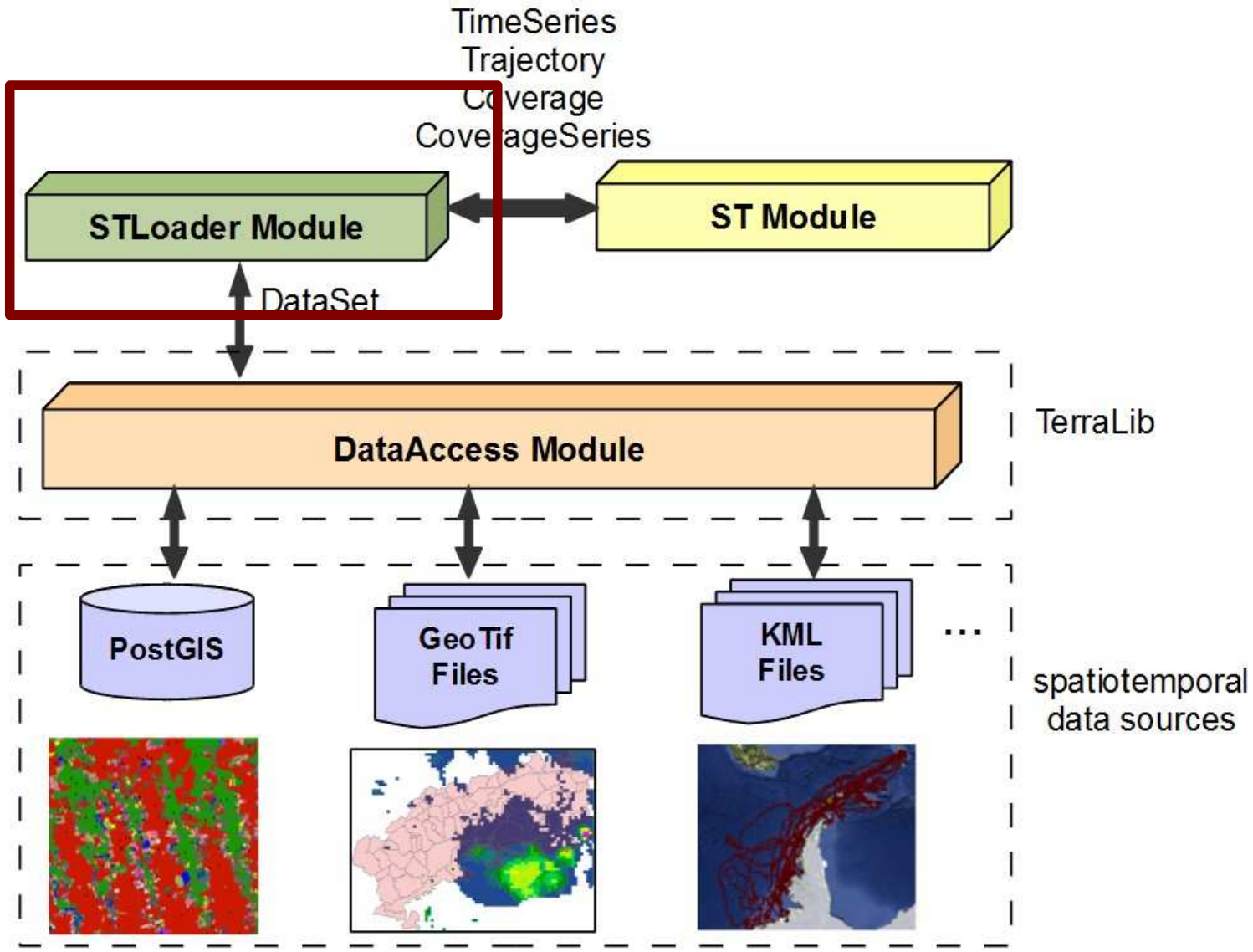
TerraLib

STLoader: transforms the data sets into instances of the spatiotemporal types of ST Module.

DataAccess: loads data sets with spatial and temporal information from different kinds of data sources.



Why ST Loader module?

- ISO and OGC: effort towards spatial data interoperability.
  - Data Files → ex.: KML and GML
  - Database → SF Access Specification → ex.: PostGIS, …
- However, few results have been achieved regarding spatiotemporal data interoperability
- A Challenge: how to translate spatial and temporal information stored in different data sources into the spatiotemporal data types for further analyzes?
- The Proposal: a strategy to perform this transformation based on metadata files → Validation using trajectories.

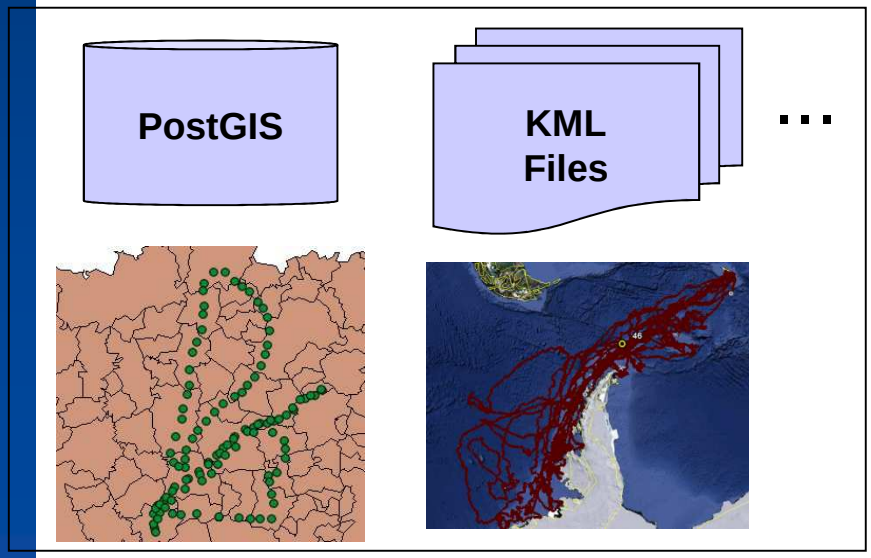
ST Loader Module: Trajectory

PostGIS:

- **spatial data**: OGC *Simple Feature* Specification (tables `geometry_columns` and `spatial_ref_sys`)

- **temporal data**: SQL date and time types - `timestamp`, `interval`, `date` and `time`.

- **example**: *feature* table called `car_trajectories` that has three columns: (1) `car_id`, (2) `location` and (3) `date_time`.



ST Loader Module: Trajectory

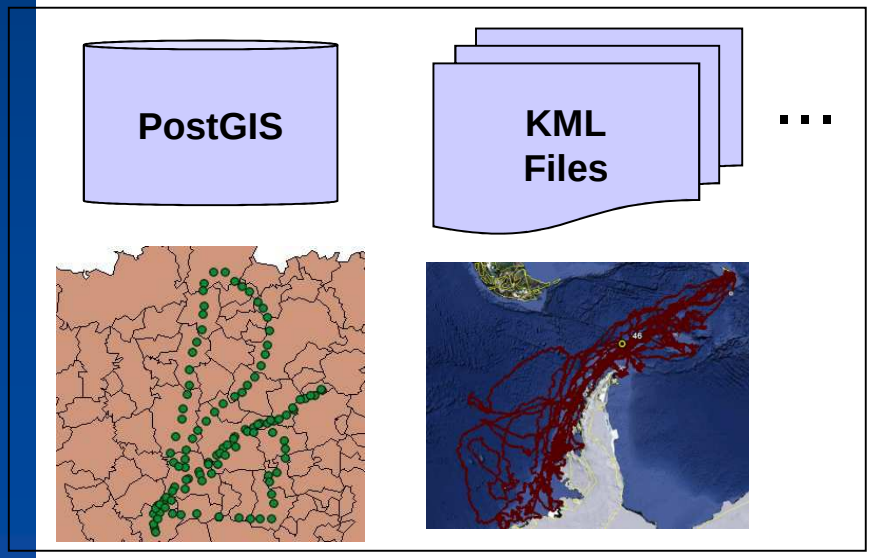
KML:

- `kml::PlacemarkType` to represent spatial objects and time stamps associated to them.

- **spatial data**: `kml:MultiGeometryType`, `kml:PointType`, `kml:LineStringType`, `kml:LinearRingType` and `kml:PolygonType`.

- **temporal data**: `kml:TimeStampType` and `kml:TimeSpanType`.

- **example**: `kml:FolderType` for each animal.



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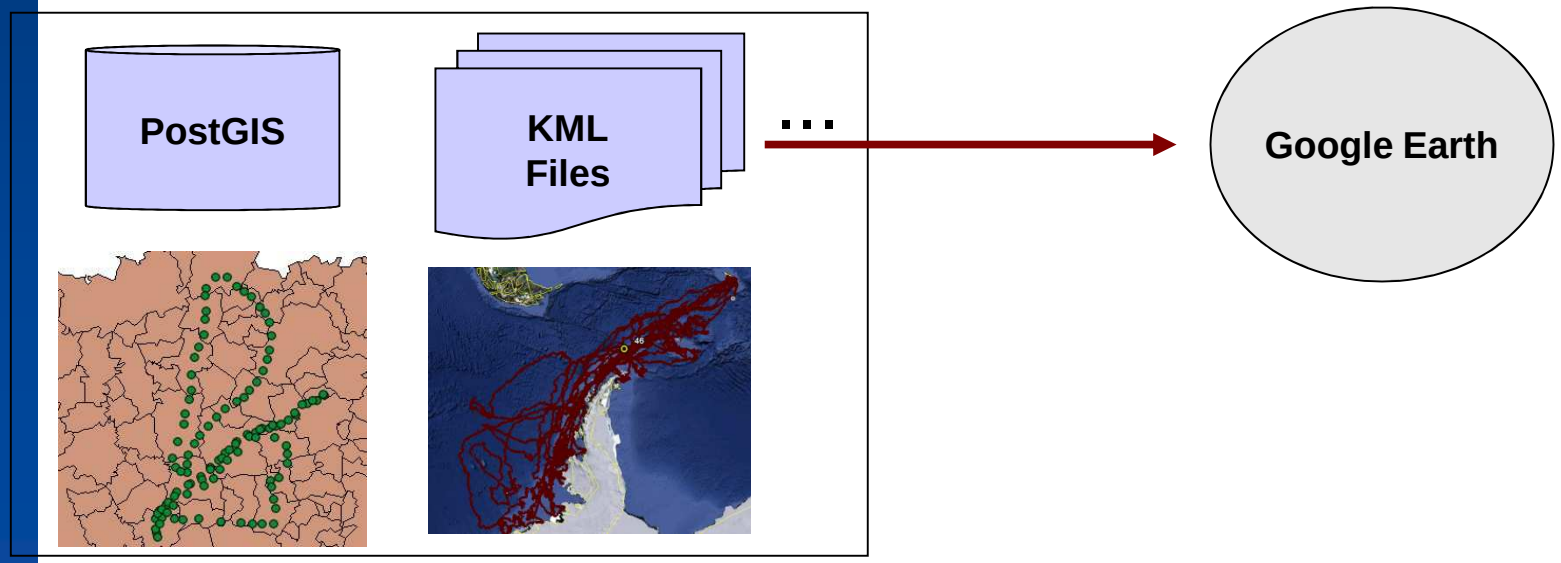
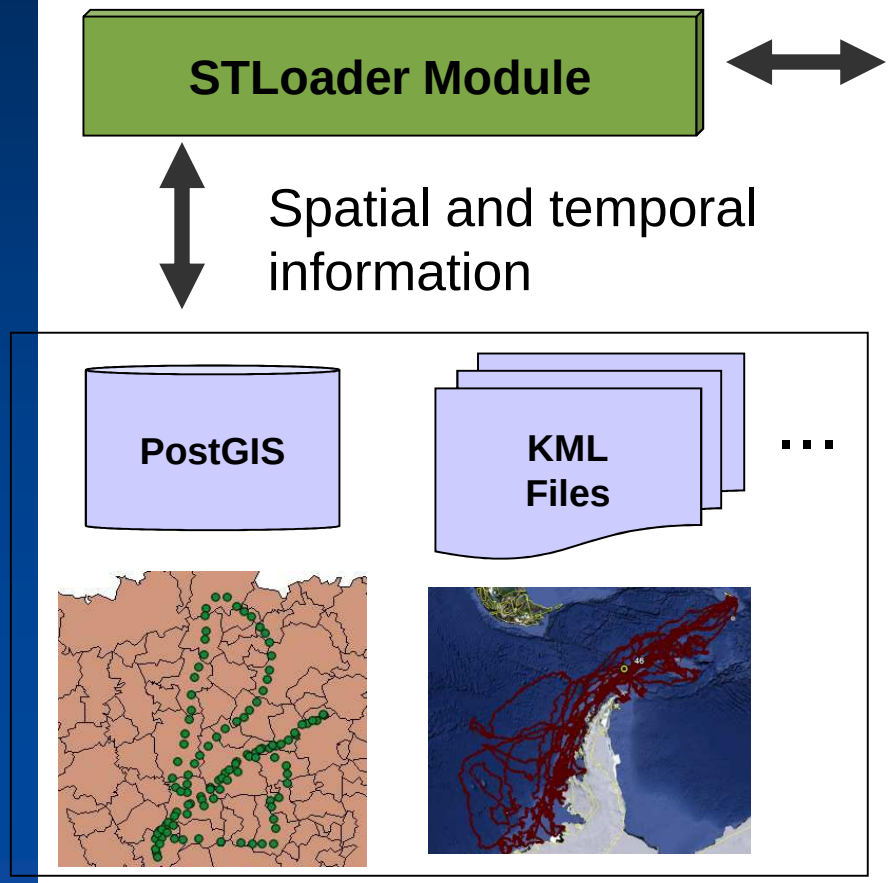


ST Loader Module: Trajectory

Our approach is based on the processing of an additional metadata file that describes *how* trajectories are stored in each data source.




```
<DataSourceInfo>
    <name>cars</name>
    <type>POSTGIS</type>
    <Params>
        <keyValuePair>NAME=stdatabase
                                </keyValuePair>
        <keyValuePair>HOST=localhost
                                </keyValuePair>
        <keyValuePair>PORT=5432
                                </keyValuePair>
        <keyValuePair>USER=postgres
                                </keyValuePair>
    </Params>
</DataSourceInfo>

...
```

XML metadata file

ST Loader Module: Trajectory

```
DataSource* ds = DataSourceFactory::make("OGR");

xmlMetadataFile = ".\\data\\kml\\sea_eleph_metadata.xml";

vector<Trajectory*> output;

DataLoader::loadTrajectories(ds, xmlMetadataFile, output);
```

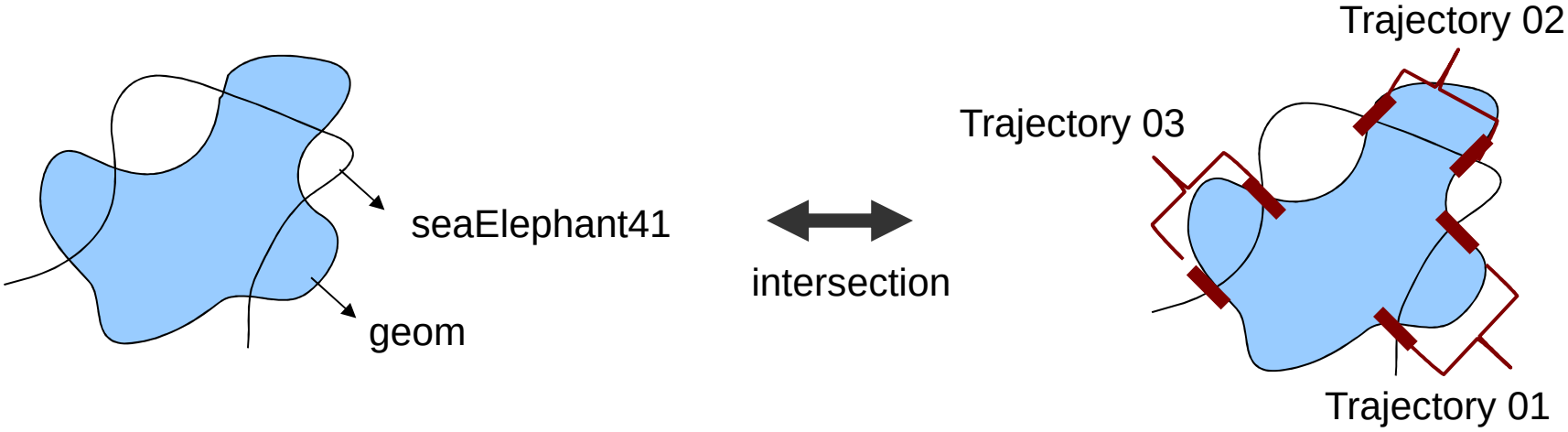
(1) OGR LIBKML Driver to read KML files
(2) Xerces-C++ to read and write XML files.

ST Loader Module: Trajectory

```
Trajectory* seaElephant40 = output[0];
Trajectory* seaElephant41 = output[1];

TimeSeries* dist = seaElephant40->distance(seaElephant41);

vector<Trajectory*> trajs;
seaElephant41->intersection(geom, trajs);
```



Events

events of “meeting of two animals” that occur when
“ the distance between two sea elephants is less than 10 units”