MINISTÉRIO DA CIÊNCIA E TECNOLOGIA
INSTITUTO NACIONAL DE PESQUISAS ESPACIAIS

Towards an Algebra for Spatio-Temporal Database

Karine Reis Ferreira

doctoral student - INPE
karine@dpi.inpe.br

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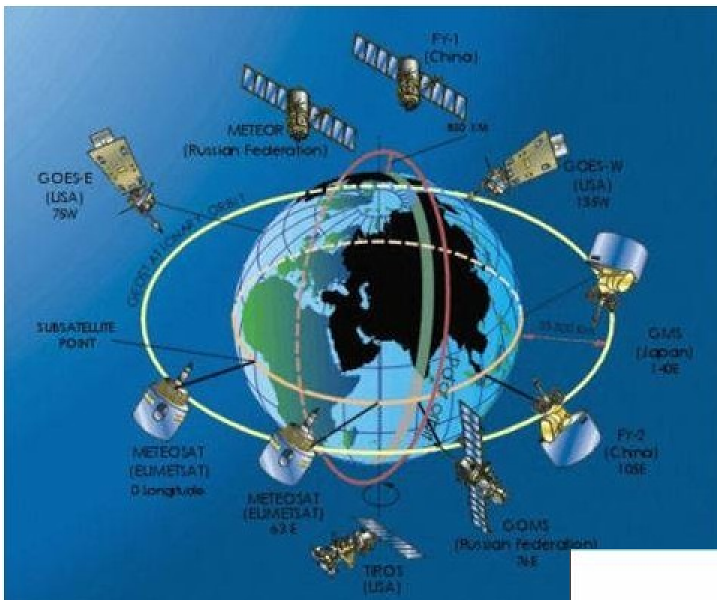
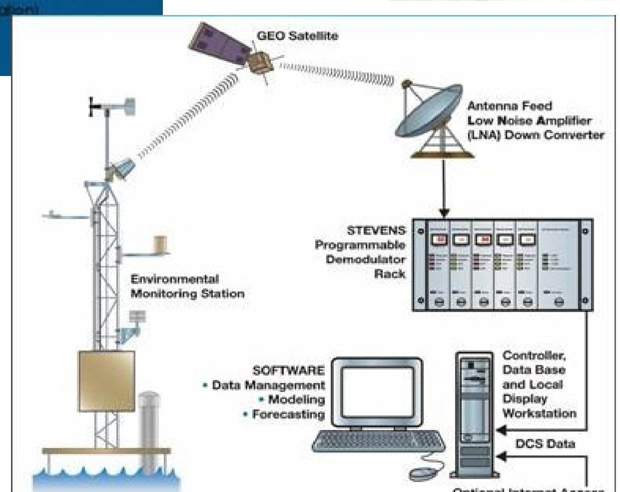
Motivation

Technological advances in geospatial data collection.



Earth observation and GPS satellites



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

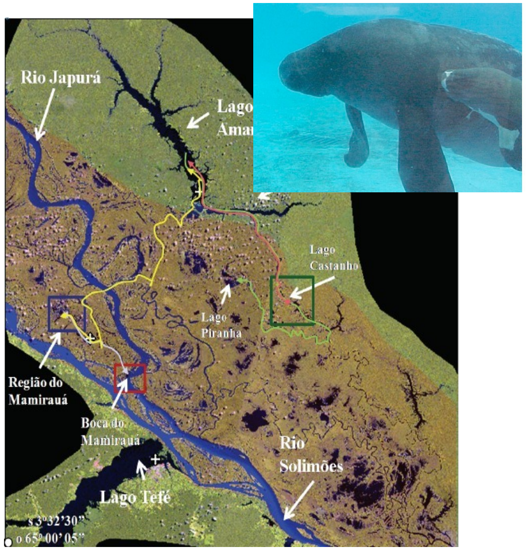
Motivation

Technological advances in geospatial data collection

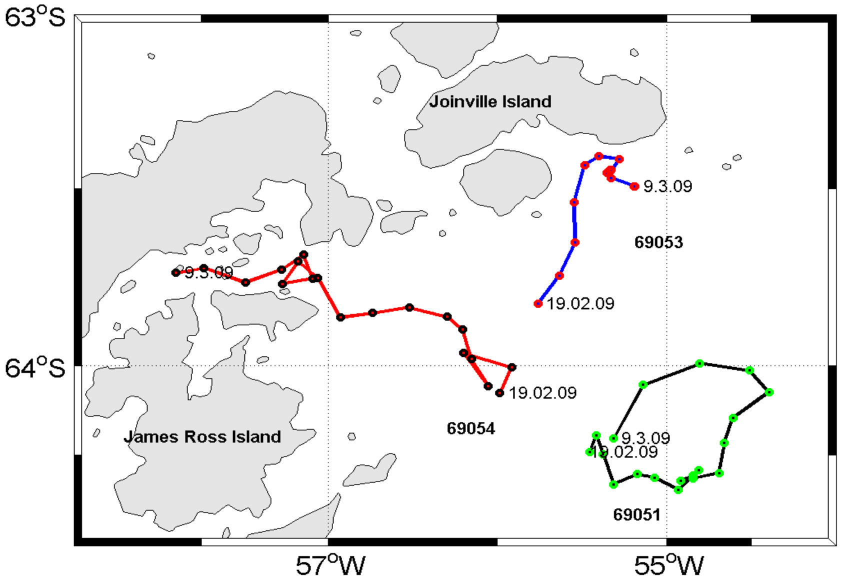
↓

Applications which handle spatio-temporal information

(Arraut, E. M. 2008)



Animal tracking monitoring - GEOMA



Iceberg tracking monitoring in Antarctica - SOS-Climate

oil spill on the ocean

hurricane and volcanic eruption monitoring

Motivation

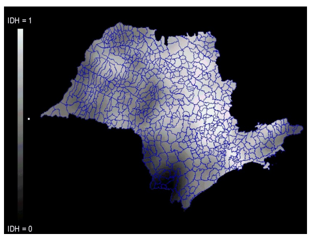
Technological advances in geospatial data collection

Applications which handle spatio-temporal information

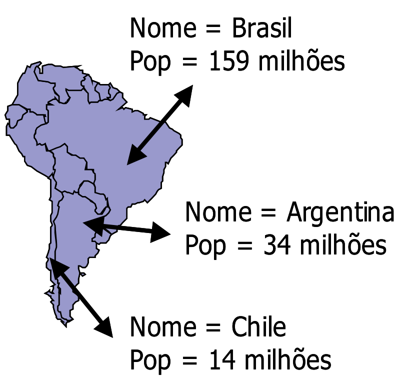
How to represent spatio-temporal information in geographical information systems (GIS)?

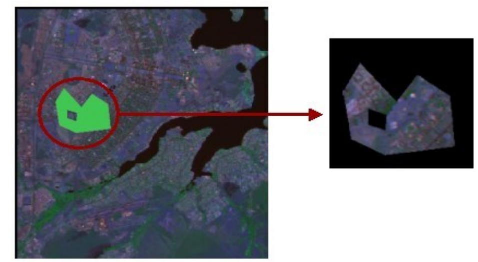
Motivation

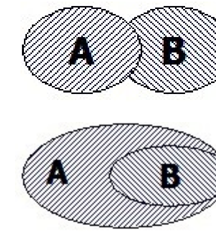
Static geospatial information is represented in GIS following well-established ideas.

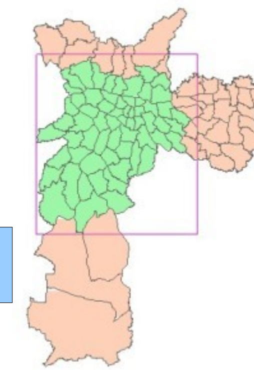


Geo-Fields and Geo-Objects

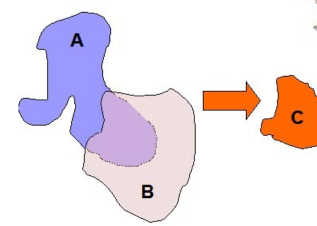




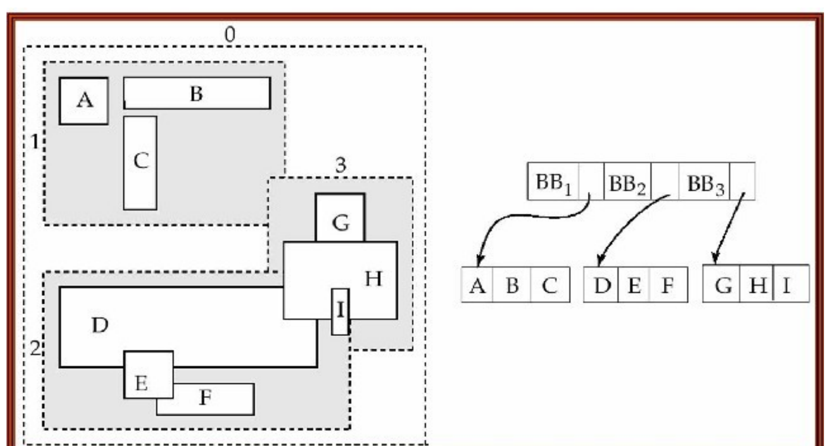




Spatial Operations



Spatial Index



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

Motivation

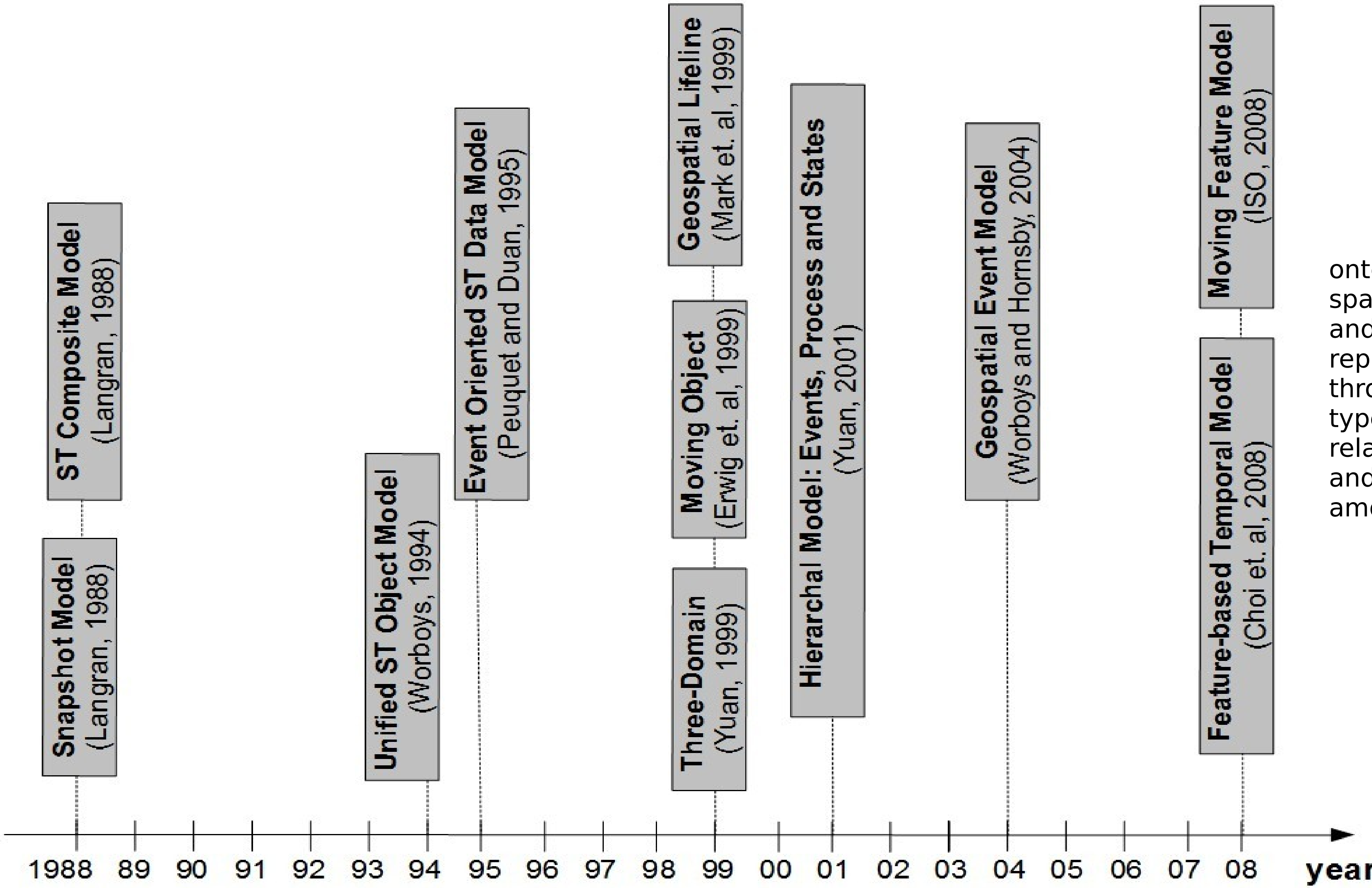
Static geospatial information is represented in GIS following well-established ideas.

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

“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.



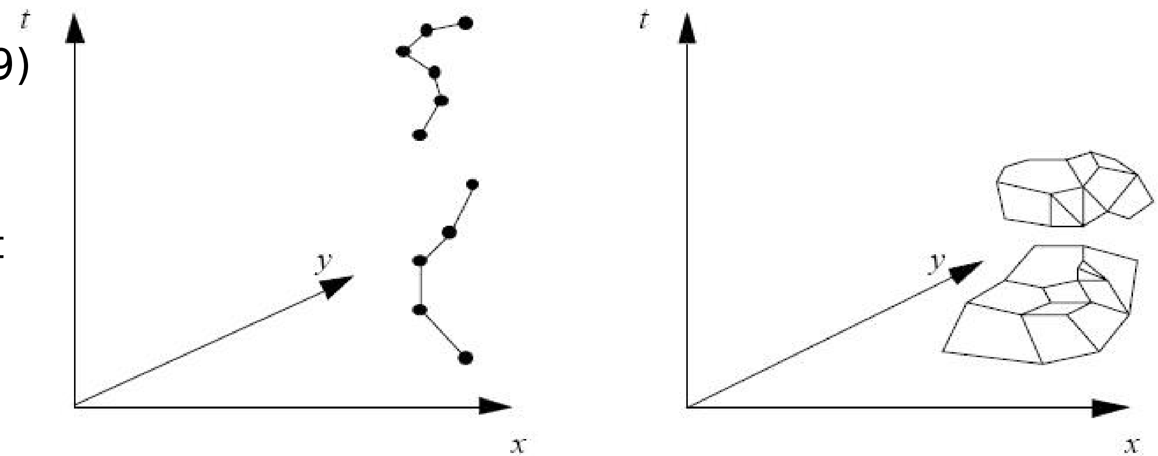
ontology of space and time and its representation through data types, relationships and operations among them.

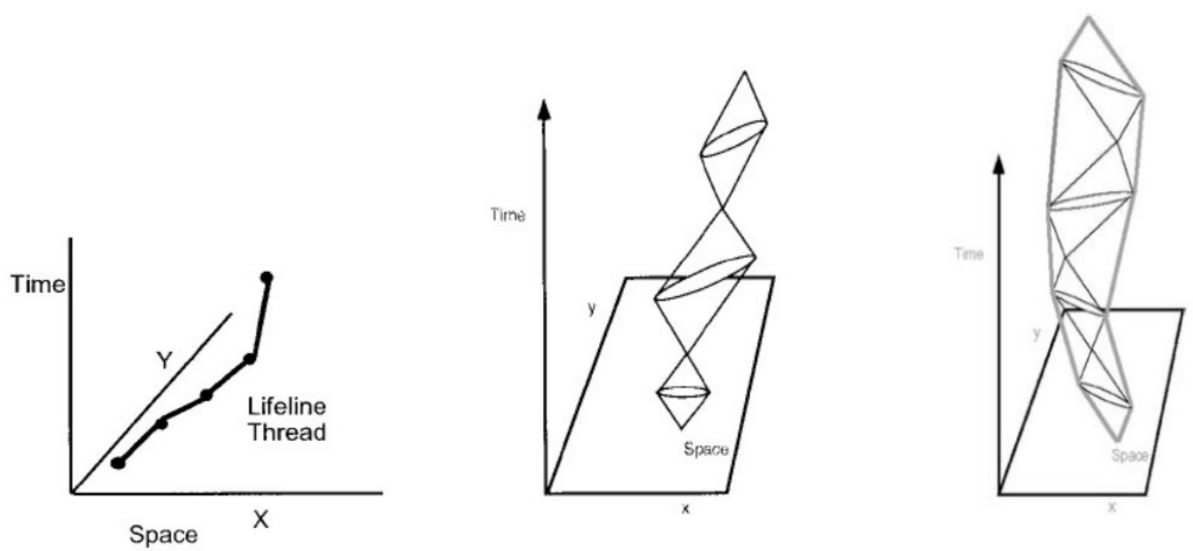
Existing Spatio-Temporal Database Models

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.

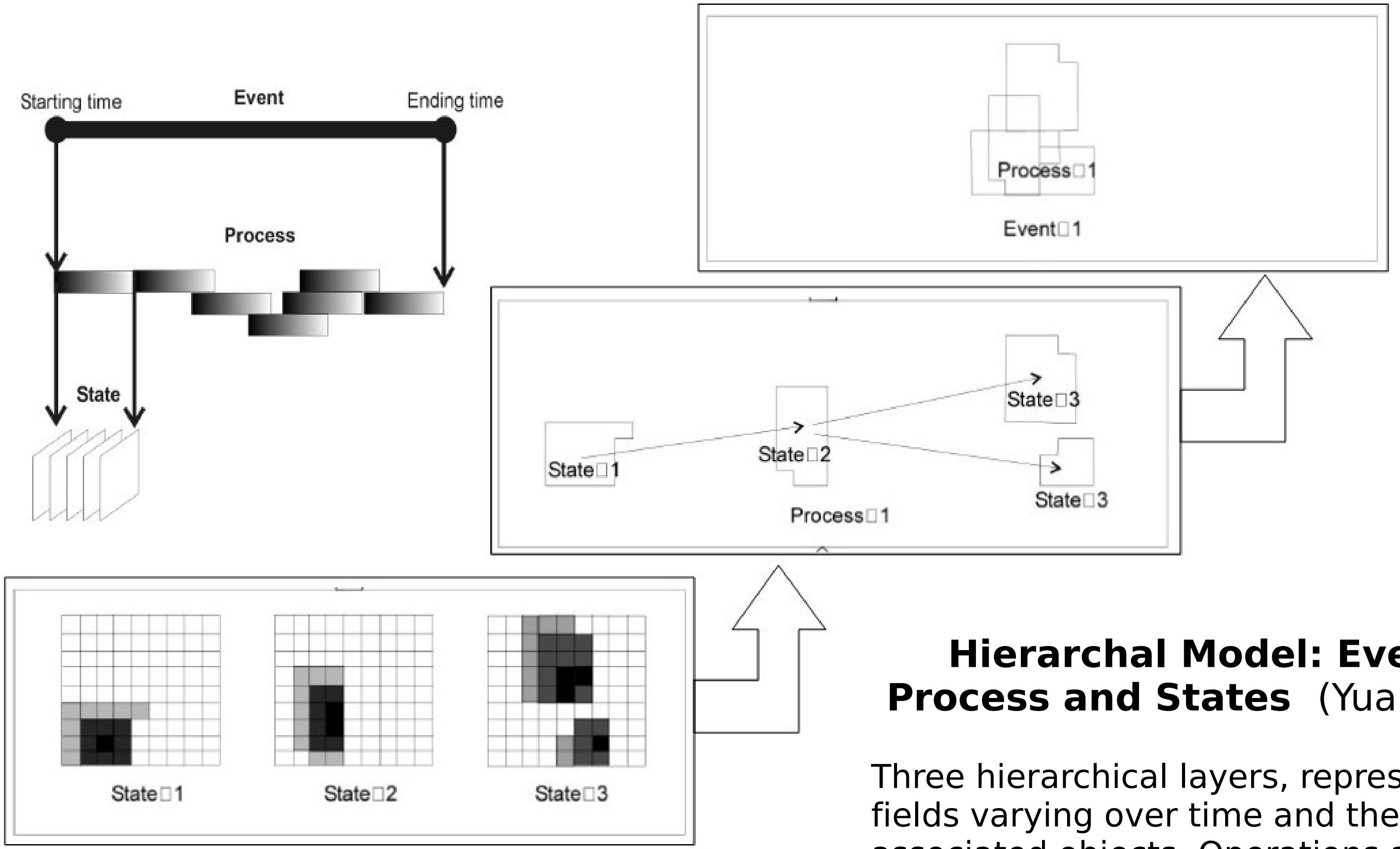




Geospatial Lifeline
(Mark et. al, 1999)
Different types of trajectories.

Existing Spatio-Temporal Database Models

There are many proposals of spatio-temporal database models.

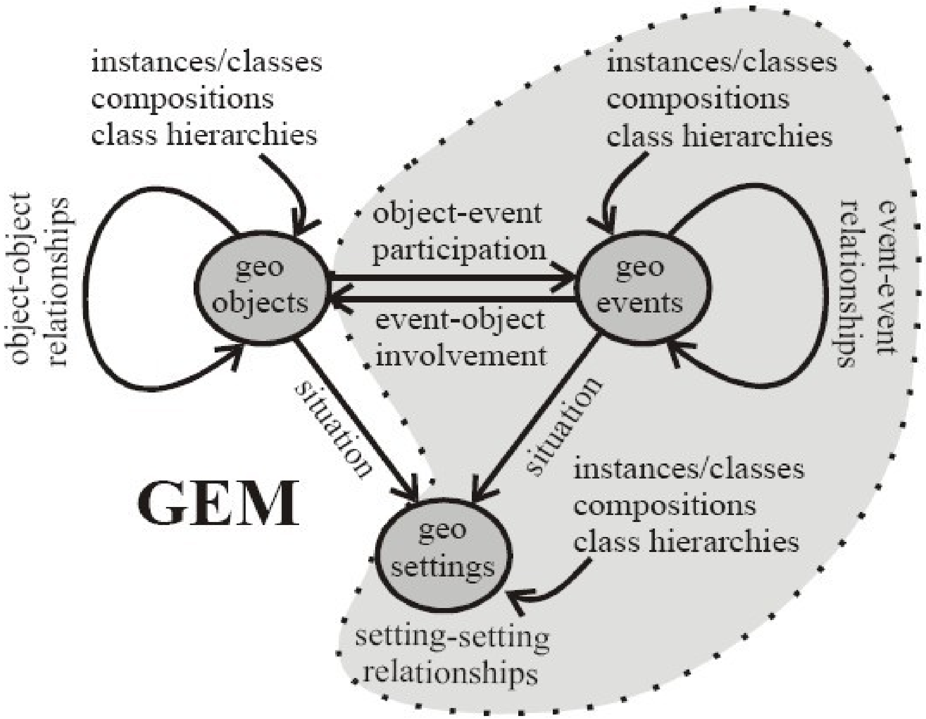


Hierarchal Model: Events, Process and States (Yuan, 2001)

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

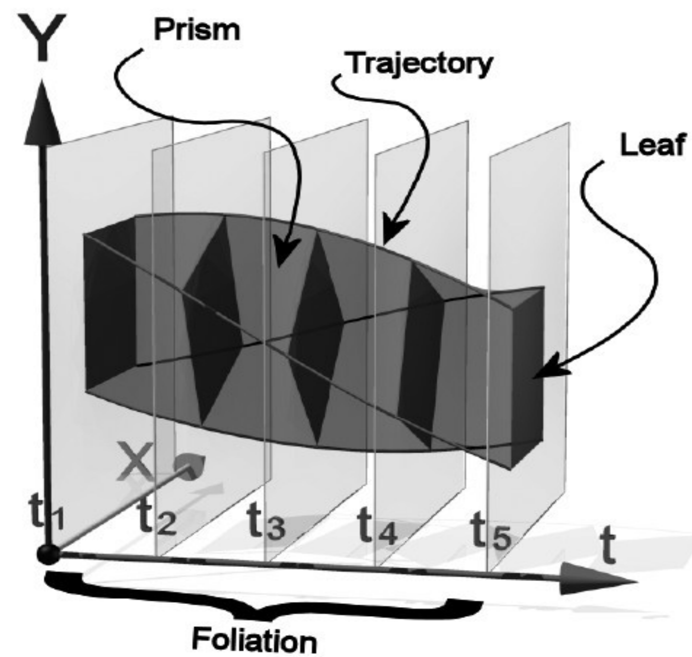
Existing Spatio-Temporal Database Models

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)

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

Existing Spatio-Temporal Database Models

There are many proposals of spatio-temporal database models.

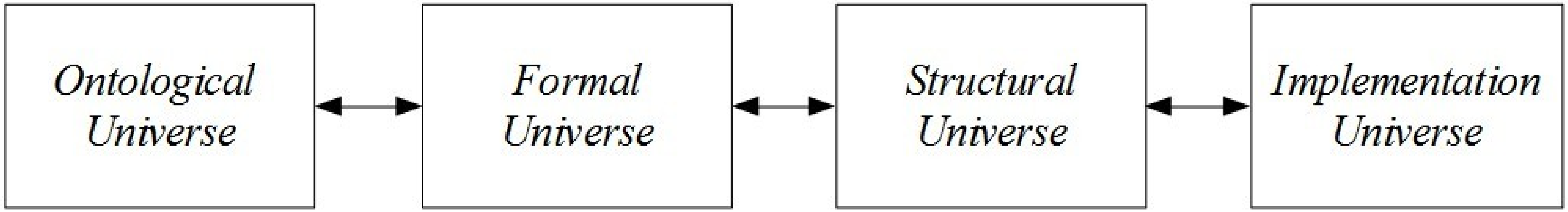
BUT ...

"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)

There is a need for a general-purpose spatio-temporal data model that can be used for a new generation of dynamic GIS.

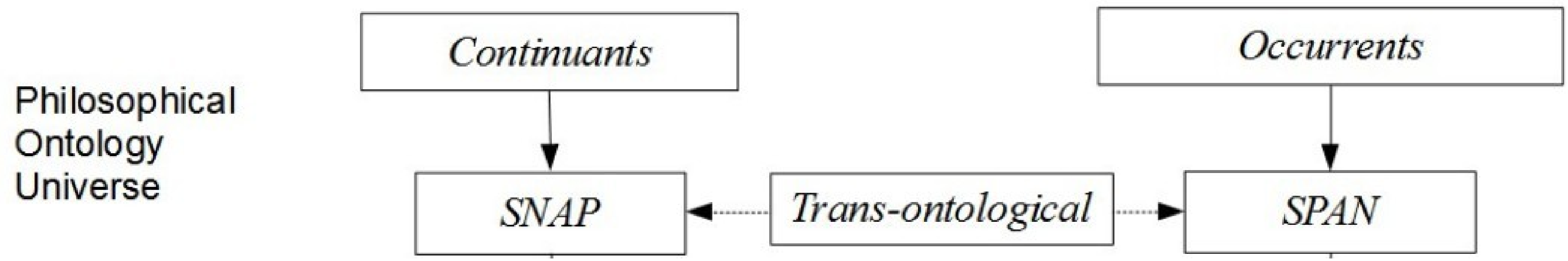
Main Goal

- Define an algebra for spatio-temporal database
  - Robust, clear and formal algebra as the one defined in the Moving Object Model (Guting et al, 1999).
  - Data types and operators to represent and handle fields and objects varying over time.



Four universes paradigm for geoinformatics (Camara, 1995)

Ontological Universe

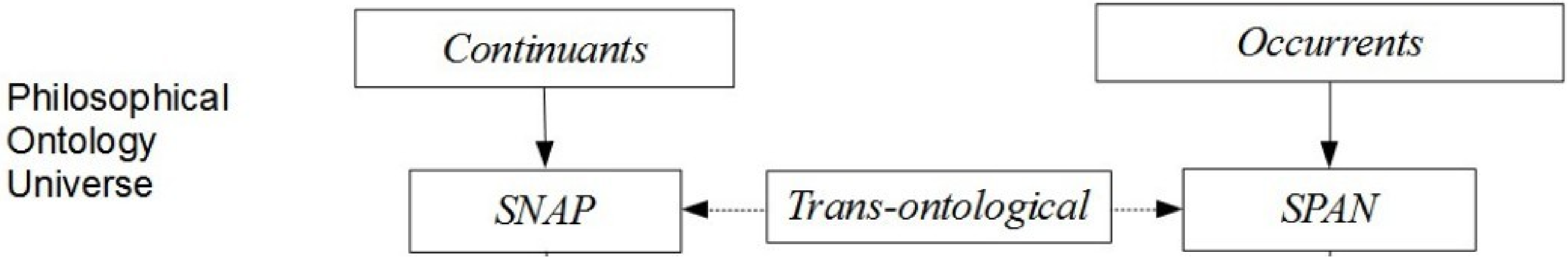


well-established classification of real world phenomena into:
continuants and ***occurrents*** (Galton, 2008)

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

Ontological Universe

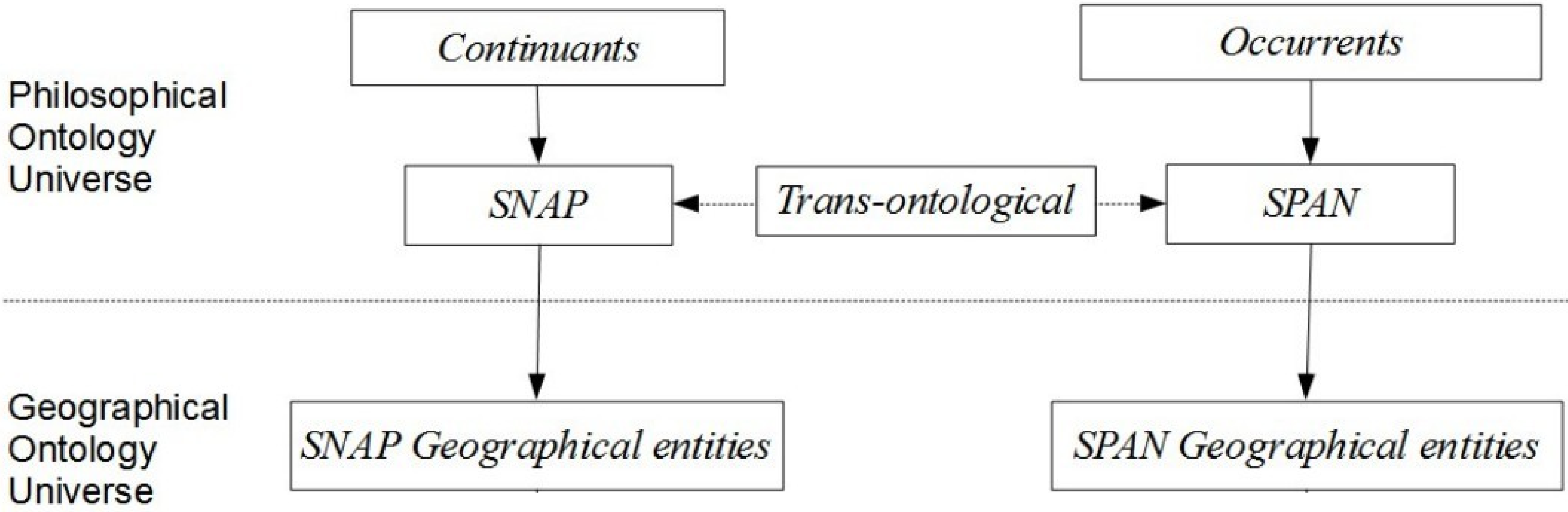


well-established classification of real world phenomena into:
continuants and ***occurrents*** (Galton, 2008).

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

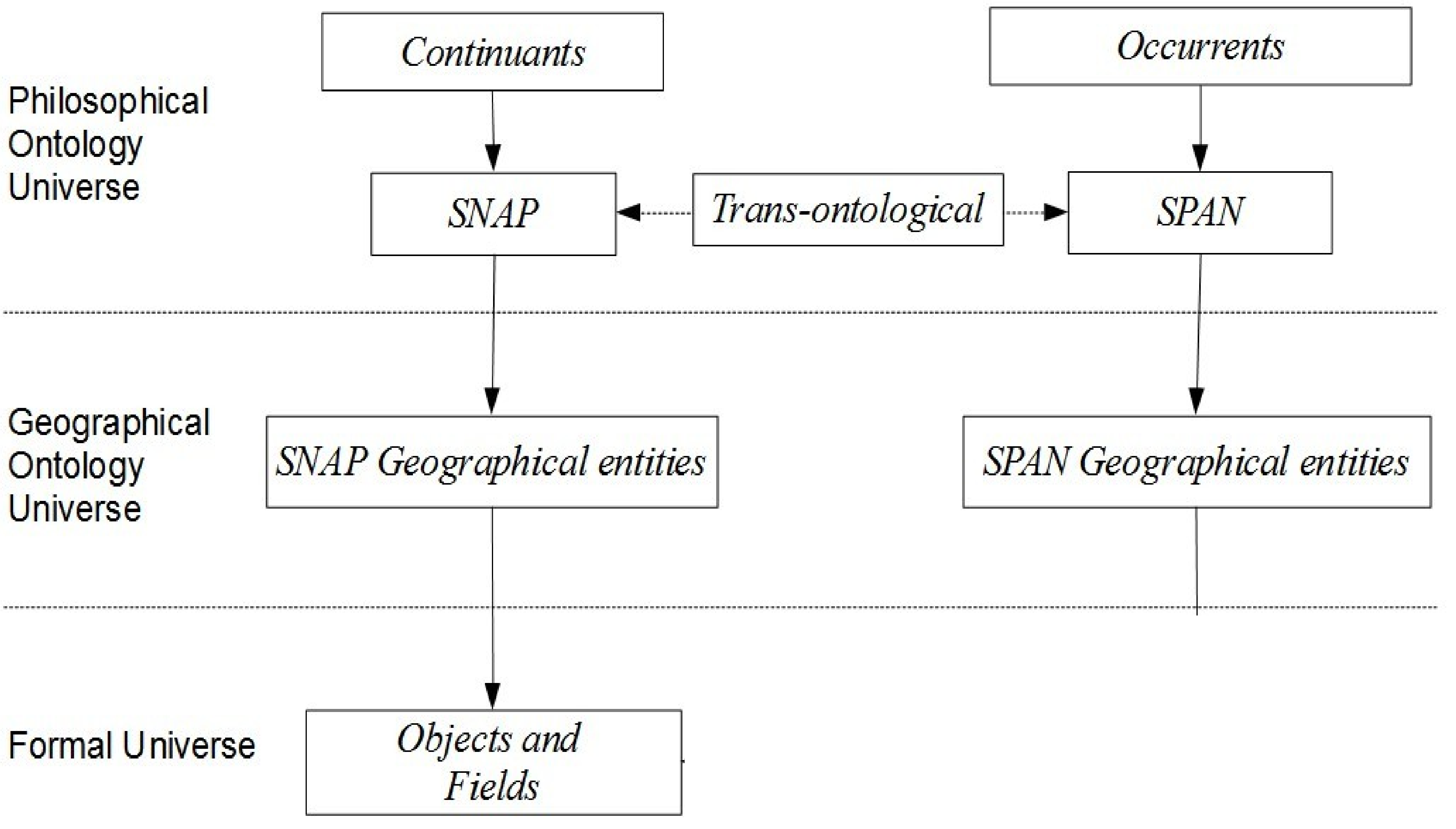
Ontological Universe



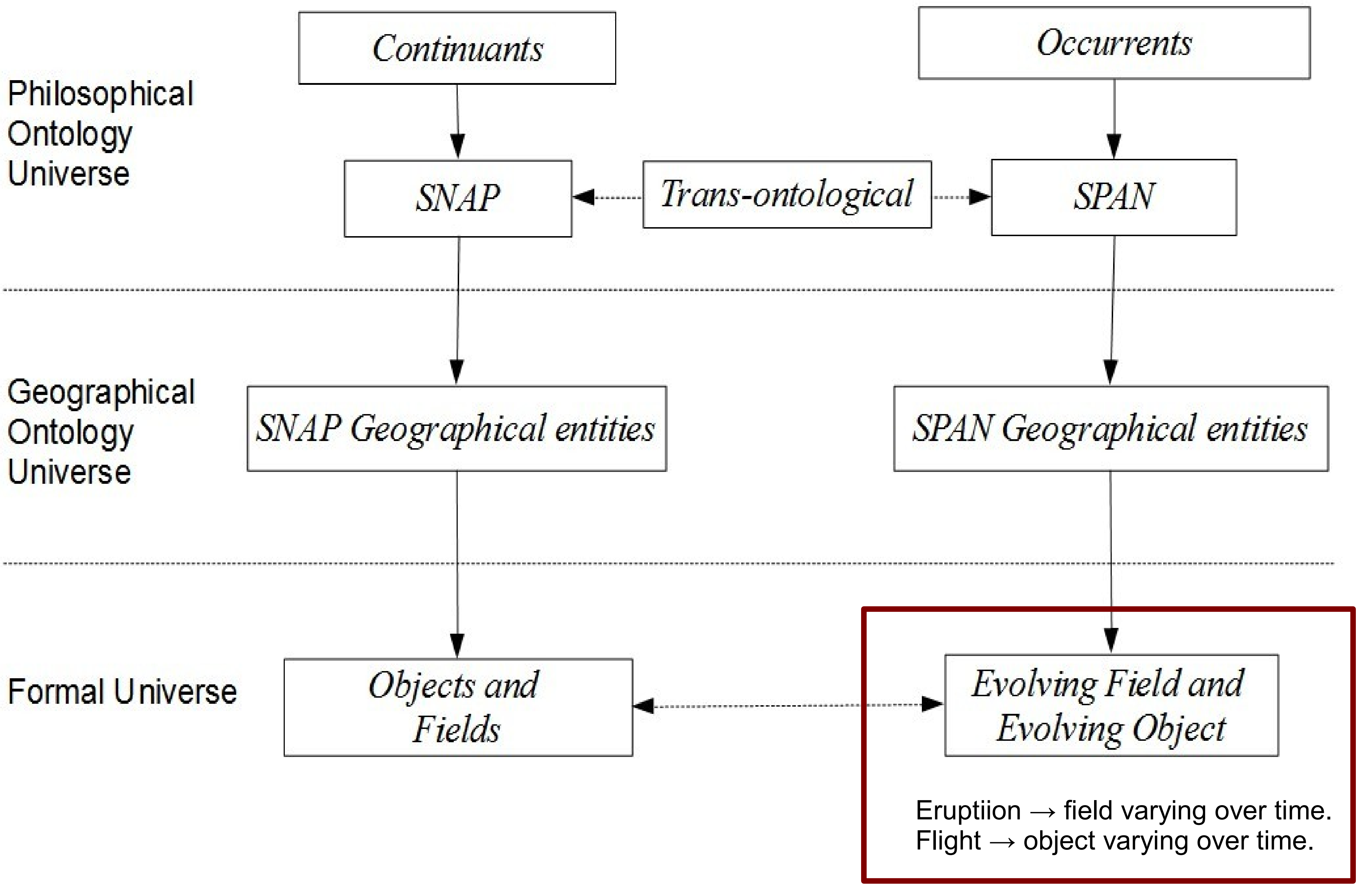
SNAP and SPAN ontologies (Grenon and Smith, 2004)

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

Formal Universe

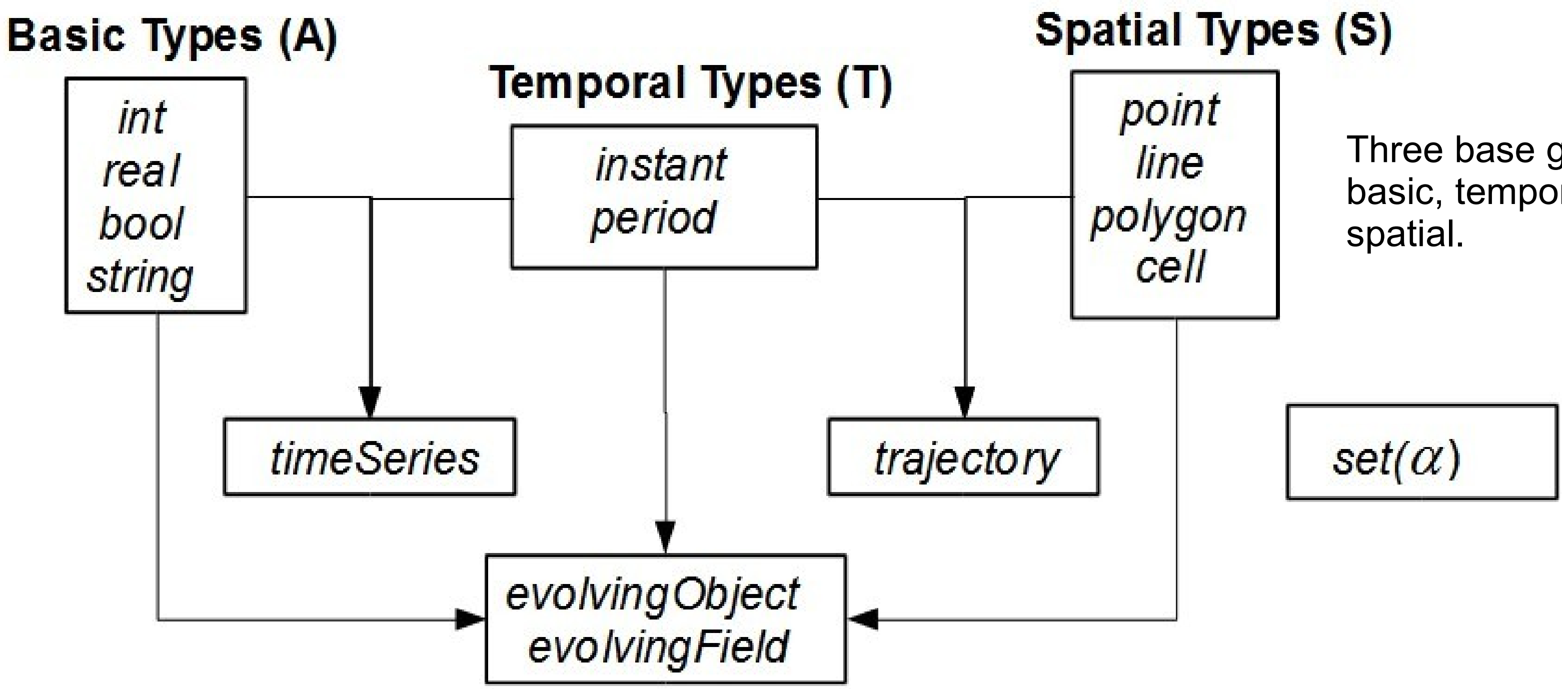


Formal Universe



An Algebra for Spatio-Temporal Database

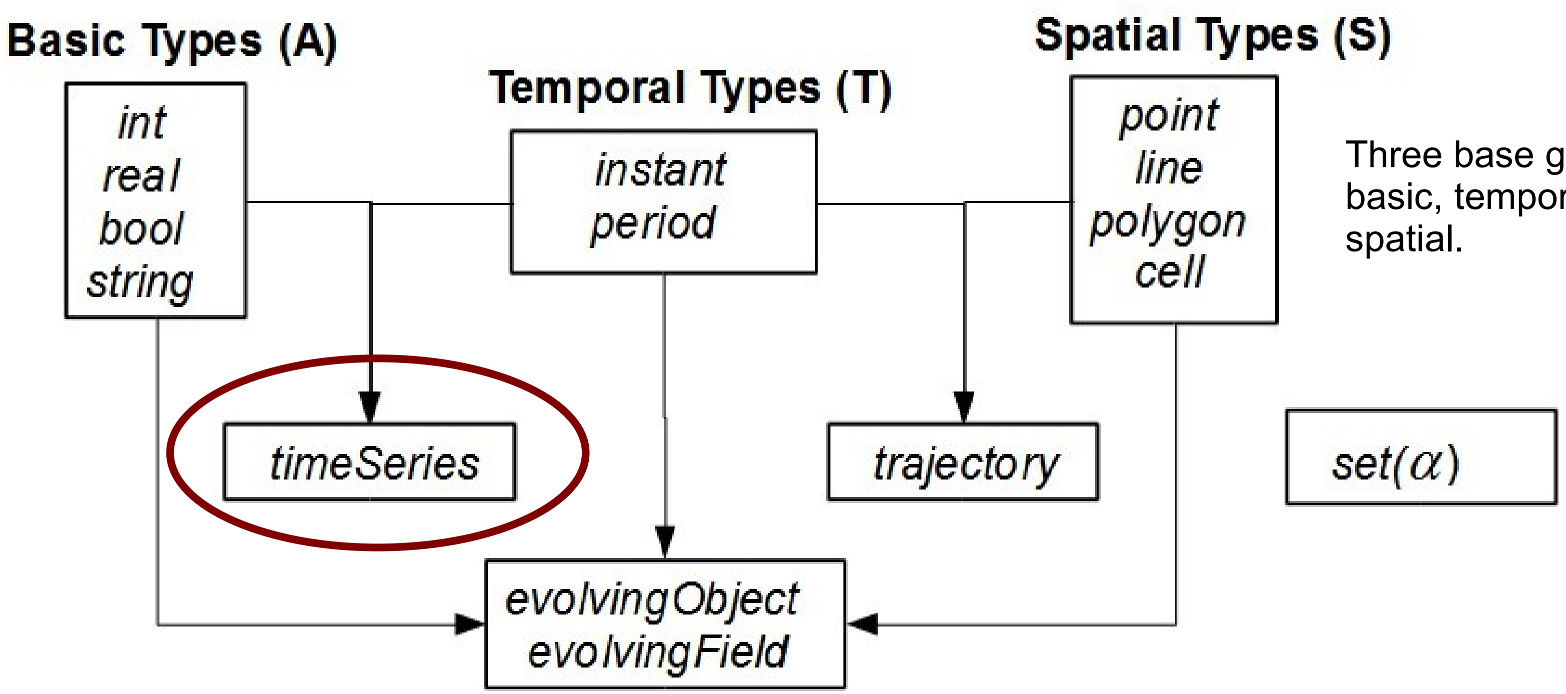
Data Types



Three base groups: basic, temporal and spatial.

An Algebra for Spatio-Temporal Database

Data Types

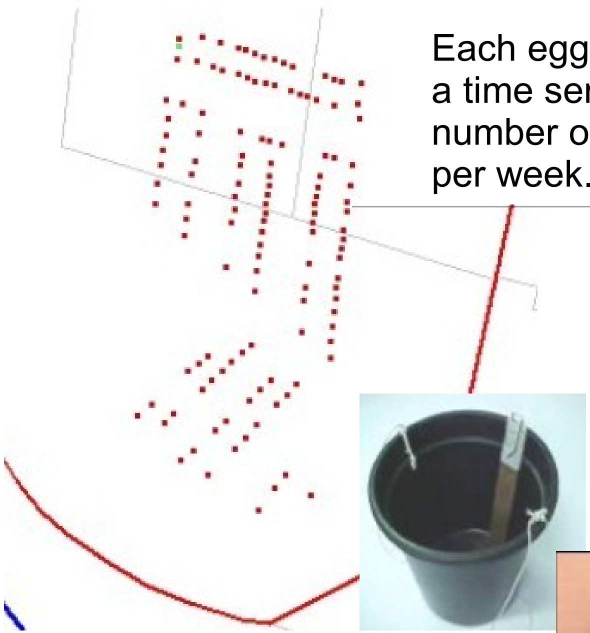


Three base groups: basic, temporal and spatial.

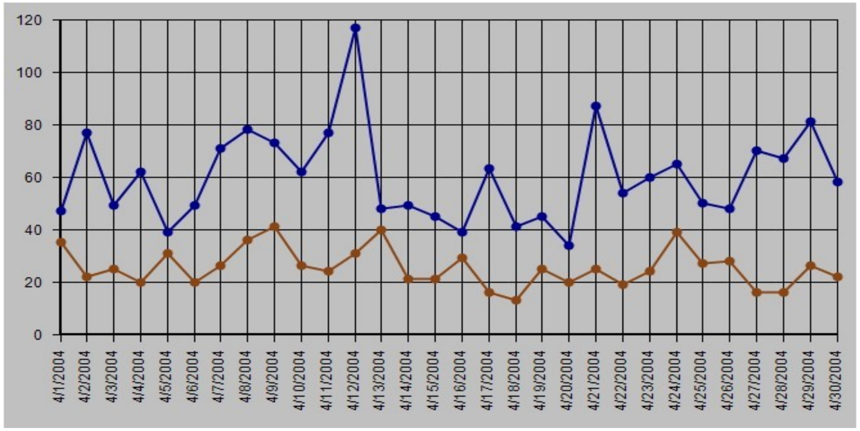
An Algebra for Spatio-Temporal Database

Time Series: T → A

Example 01: Monitoring of dengue fever.



Each egg trap generates a time series of the number of infected eggs per week.



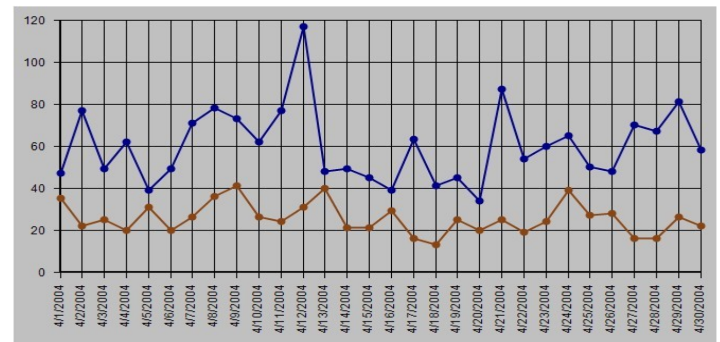
Sequence of measures, where each one is associated to a specific time.

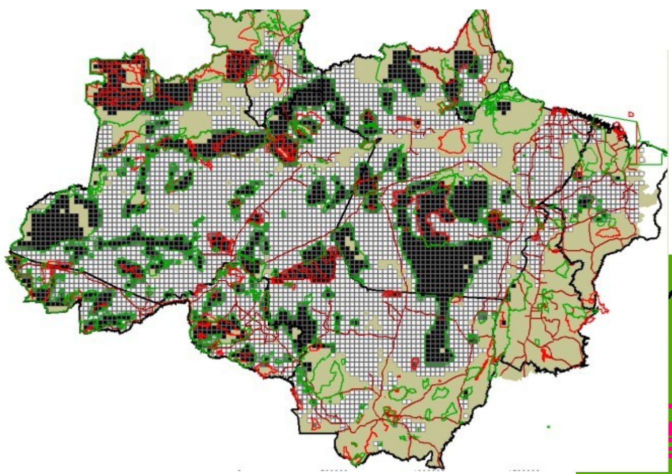
Space does not change, only attributes change over time

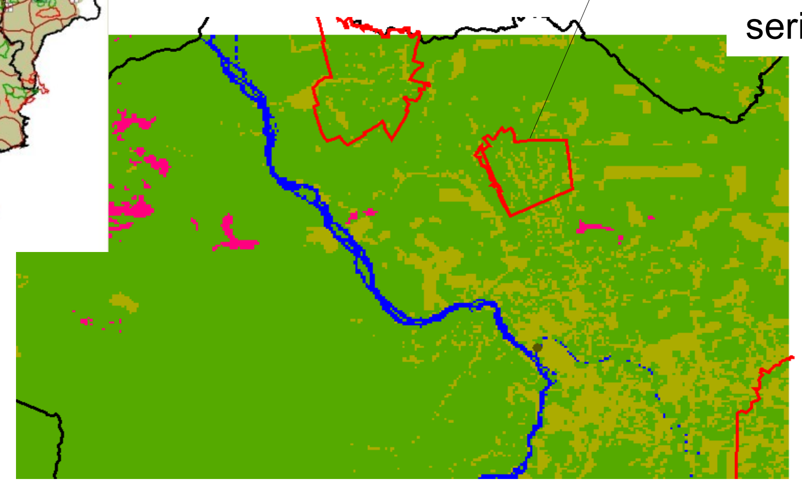
An Algebra for Spatio-Temporal Database

Time Series: T → A

Example 02: Environmental Modeling based on cellular space.





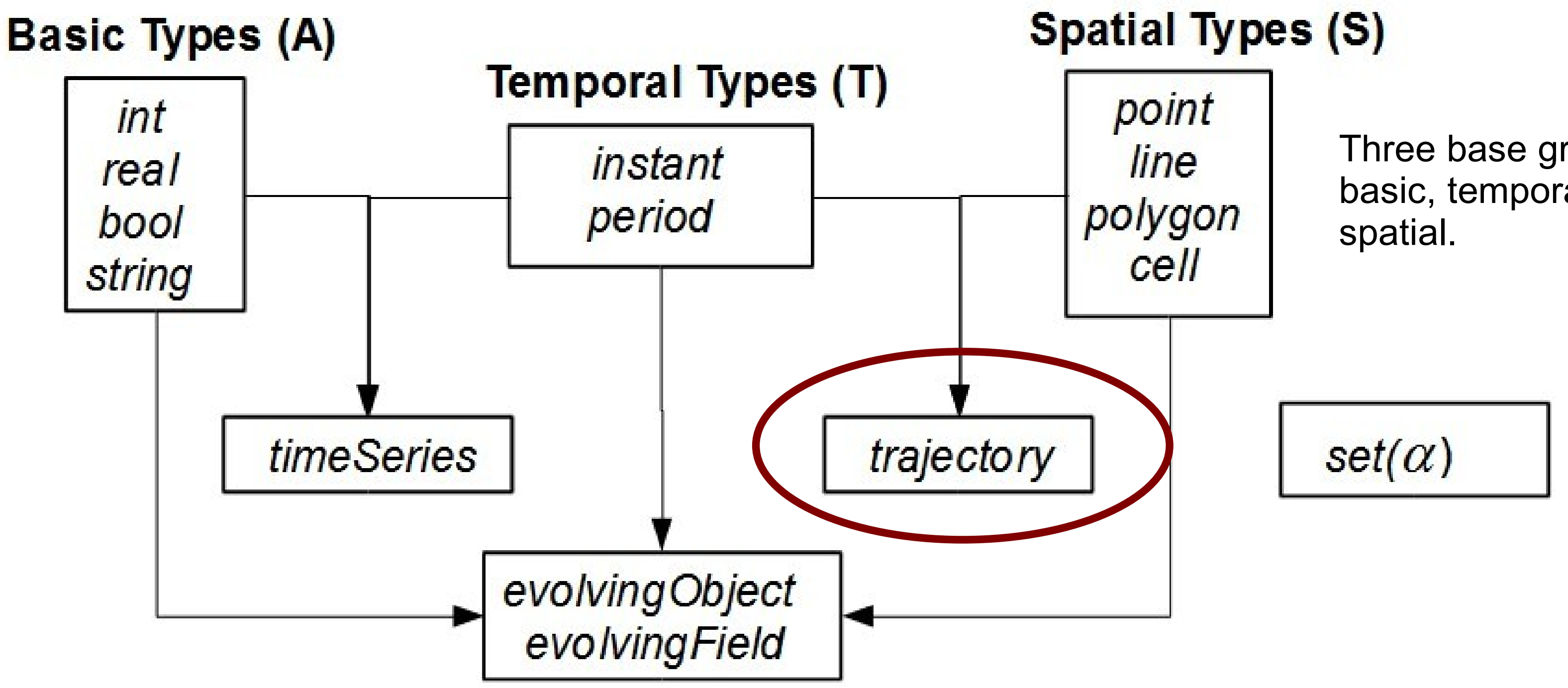


the space is divided in cells and each cell has a time series associated to it.

Space does not change, only attributes change over time

An Algebra for Spatio-Temporal Database

Data Types



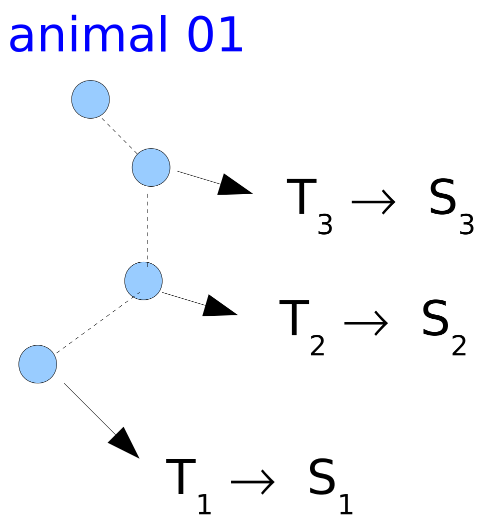
Three base groups: basic, temporal and spatial.

An Algebra for Spatio-Temporal Database

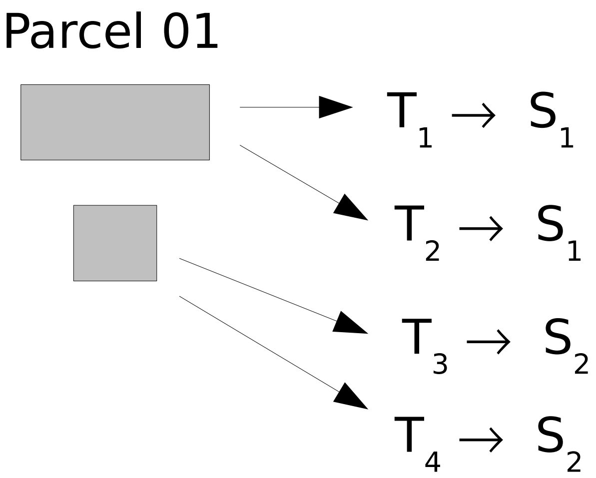
Trajectory: T $\rightarrow$ S

variation of space over time.

Examples: Trajectory of an animal or of a land parcel.



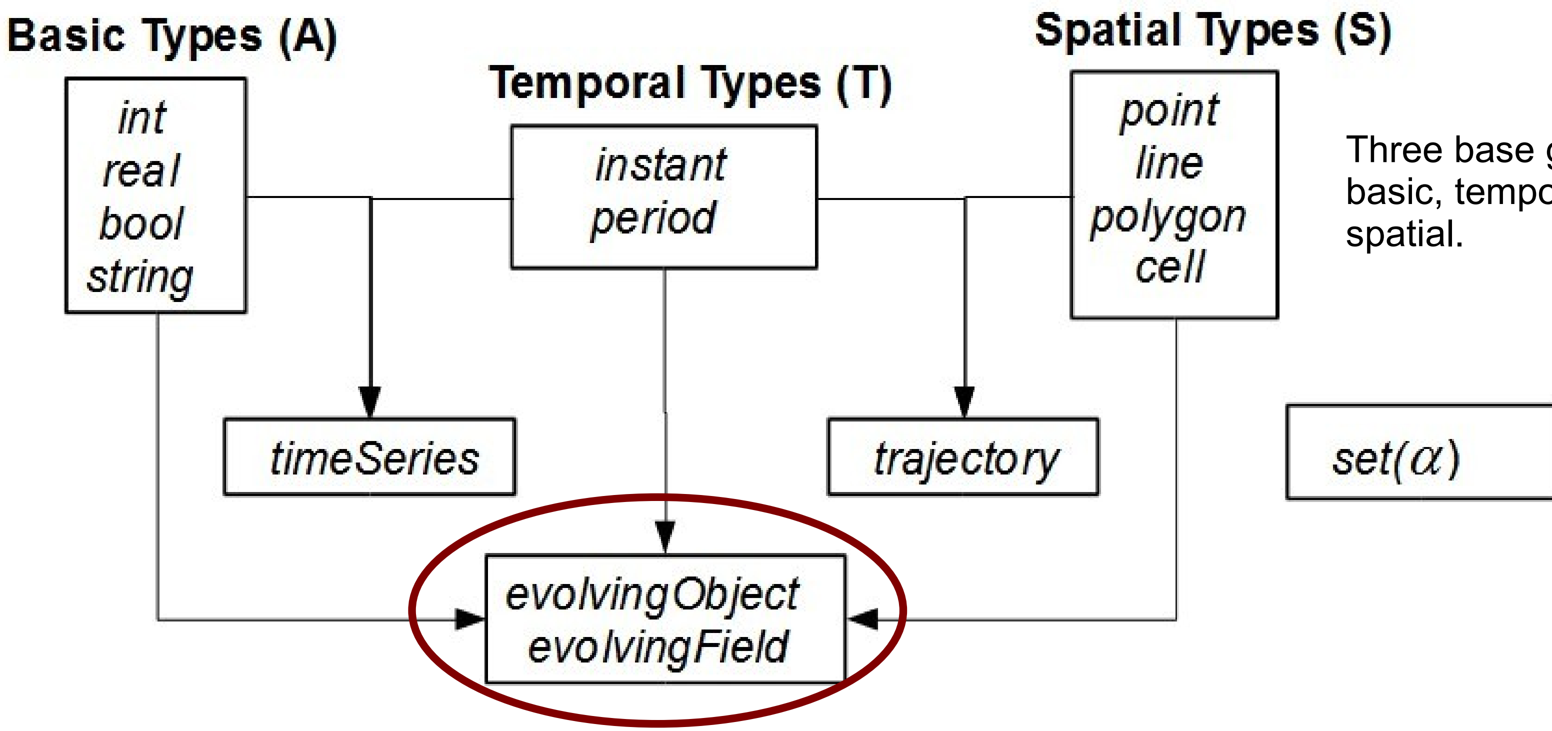
Space changing continuously



Space changing discretely

An Algebra for Spatio-Temporal Database

Data Types



Three base groups: basic, temporal and spatial.

An Algebra for Spatio-Temporal Database

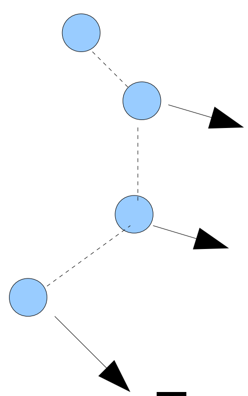
Evolving Object: $T \rightarrow (S, \{A\})$

object whose space (its location or form) and non-spatial attributes vary over time.

Examples: Animal tracking and Land Parcel history.

animal 01

temperature and location of an animal can be measured at different times.



$T_3 \rightarrow S_3, A_{13}, A_{23}$

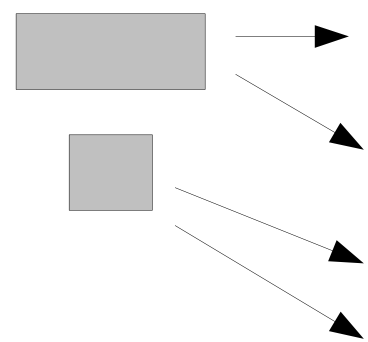
$T_2 \rightarrow S_2, A_{12}, A_{22}$

$T_1 \rightarrow S_1, A_{11}, A_{21}$

Space changing continuously

Parcel 01

boundaries and owner of a parcel can change over time.



$T_1 \rightarrow S_1, A_1$

$T_2 \rightarrow S_1, A_2$

$T_3 \rightarrow S_2, A_2$

$T_4 \rightarrow S_2, A_3$

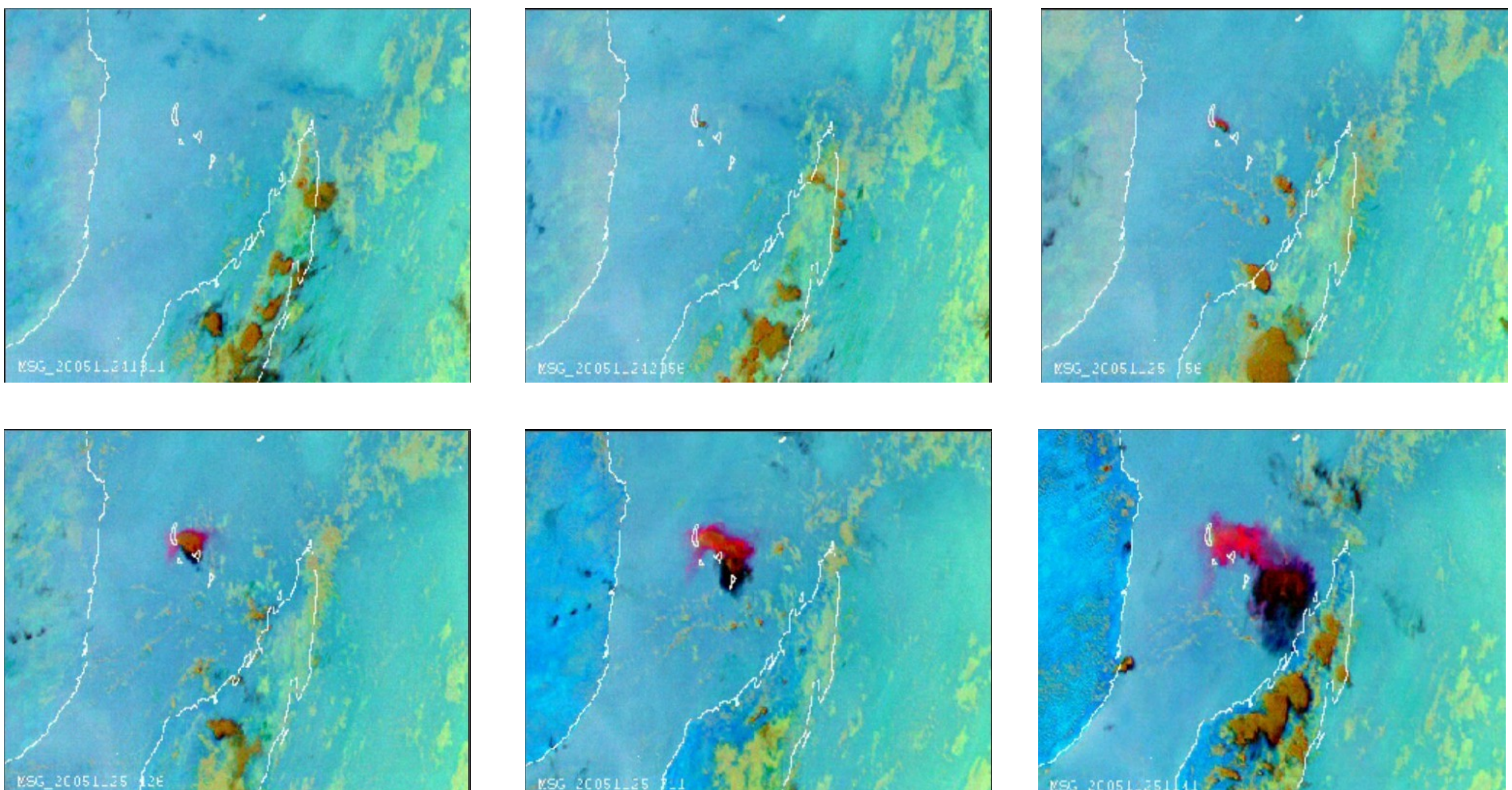
Space changing discretely

An Algebra for Spatio-Temporal Database

Evolving Field: T → S → {A}

Example: Volcanic eruption.

an eruption can be measured by three attributes: temperature, SO_2, and CO_2 emission.



An Algebra for Spatio-Temporal Database

Some operations

An Algebra for Spatio-Temporal Database

Operation	*Description*
`state: evolvingObject × T → object`	Returns the state of an evolving object in a given time.
`snapshot: evolvingField × T → field`	Returns the snapshot of an evolving field in a given time.

`timeSeries: evolvingObject × atName → timeSeries`
 	
`timeSeries: evolvingField × atName × aggrOp → timeSeries`
	Returns a time series: (1) of a specific attribute of an evolving object or (2) of a specific attribute of an evolving field, by using a aggregation operator, such as, SUM, AVG, and COUNT.

`trajectory: evolvingObject → trajectory`	Returns a trajectory from an evolving object.

An Algebra for Spatio-Temporal Database

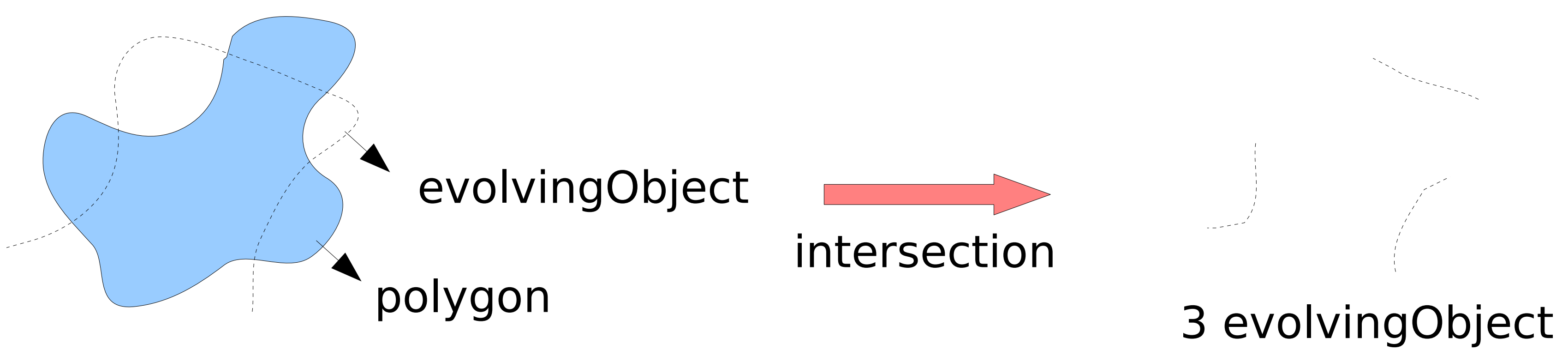
Operation	*Description*
time : evolvingObject → set(T) time : evolvingField → set(T) time : trajectory → set(T) time : timeSeries → set(T)	Returns the set of time values associated to an evolving object, an evolving field, a trajectory and a time series.
range: timeSeries → set(A) range: trajectory → set(S)	Returns the set of range values of a time series and a trajectory.
selection: timeSeries × condition → timeSeries selection: trajectory × condition → trajectory	Returns a selection of a time series or a trajectory, based on a specific condition.

An Algebra for Spatio-Temporal Database

Operation	*Description*

`intersetion: evolvingObject × S → {evolvingObjects}`
 	
`intersetion: evolvingField × S → evolvingField`
	Returns the intersection between a space (e g. a polygon or a line) and an evolving object or evolving field.

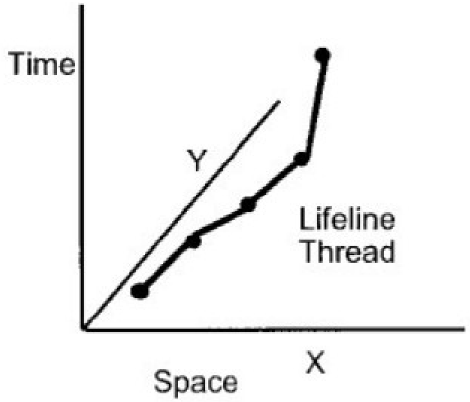
`distance: trajectory × trajectory → timeSeries`
 	
`distance: timeSeries × timeSeries → timeSeries`
	Returns, for each time, the spatial distances between two trajectories or the distances between attribute values of two time series.

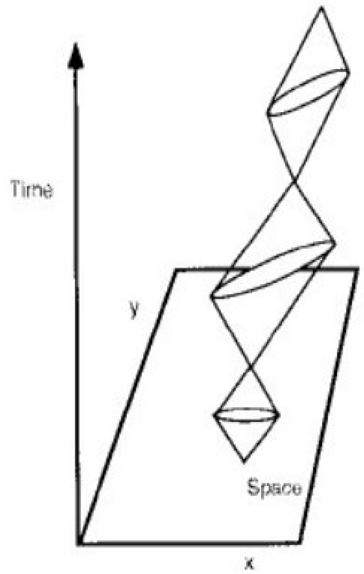


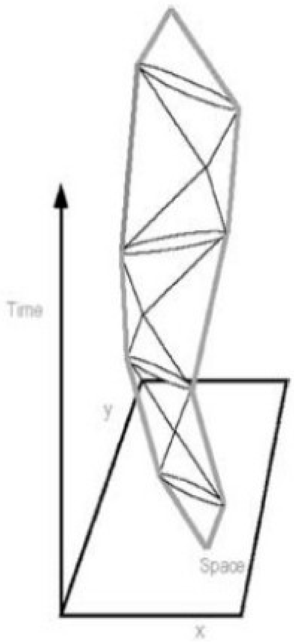
An Algebra for Spatio-Temporal Database

Operation	*Description*

`linearTrajectory: trajectory → line`
 	
`necklaceTrajectory: trajectory → polygonSet`
 	
`convexhullTrajectory: trajectory → polygon`
	Returns linear, necklace and convexhull trajectories, as described in section 2.6.







Ex.: animal habitat is defined by using the convexhull trajectory.

(Hornsby and Egenhofer, 2002)

An Algebra for Spatio-Temporal Database

egg_traps (id:string, address:string, location:point, infected_eggs: timeSeries)

parcels (id: string, history: evolvingObject)

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

eruptions (id: string, volcano:string, eruption: evolvingField)

An Algebra for Spatio-Temporal Database

1) What is the average of infected eggs in trap T01? When was the biggest number of infected eggs collected in this trap?

```
LET tSeries = ELEMENT(SELECT infected_eggs FROM
                      egg_traps WHERE id = 'T01');
PRINT avg(range(tSeries));
LET maxVal = max(range(tSeries));
PRINT time(select(tSeries, RANGE_VALUE == maxVal));
```

An Algebra for Spatio-Temporal Database

2)When was parcel P01 adjacent to street S01?

```
LET historyPA01 = ELEMENT(SELECT history FROM
                  parcels WHERE id = 'P01');
LET interP01S01 = intersection( historyPA01,
                                streetS01);
FOR EACH i IN interP01S01
     PRINT min(time(interP01S01[i]));
     PRINT max(time(interP01S01[i]));
```

An Algebra for Spatio-Temporal Database

3) Did animal A01 cross natural reservation X (considering the convexhull trajectory)?

```
LET animalA01 = ELEMENT(SELECT tracking FROM
                animal_tracking WHERE id = 'A01');
intersects(reserve_x,
convexhullTrajectory(trajectory(animalA01)));
```

An Algebra for Spatio-Temporal Database

4) When did animal A01 cross natural reservation X? And what was its temperatures inside the reservation X? And what was its mean temperature inside this reservation?

```
LET animalA01 = ELEMENT(SELECT tracking FROM
                animal_tracking WHERE id = 'A01');
LET interA01Resx = intersection(animalA01,
                   reserve_x);
FOR EACH i IN  interA01Resx
  min(time(interA01Resx[i]));
  max(time(interA01Resx[i]));
  PRINT timeSeries(interA01Resx[i], temperature);
  PRINT avg(range(timeSeries(interA01Resx[i],
                             temperature)));
```

An Algebra for Spatio-Temporal Database

5) When and where did animal A01 meet animal A02 (minimal distance between both is less than 2 meters)?

```
LET animalA01 = ELEMENT(SELECT tracking FROM
 animal_tracking WHERE id = 'A01');
LET animalA02 = ELEMENT(SELECT tracking FROM
 animal_tracking WHERE id = 'A02');

LET tSeries = distance(trajectory(animalA01),
                       trajectory(animalA02));
LET t = time(select(tSeries, RANGE_VALUE <= 2));
PRINT (state(animalA01, t));
```

An Algebra for Spatio-Temporal Database

6) When was the biggest SO2 emission of Karthala volcano eruption?

```
LET eruption = ELEMENT(SELECT eruption FROM
 eruptions WHERE volcano = 'Karthala');

LET tSeries = timeSeries(eruption, 'SO2', COUNT);

LET maxVal = max(range(tSeries));
PRINT time(select(tSeries, RANGE_VALUE == maxVal));
```

An Algebra for Spatio-Temporal Database

7) When did the SO2 emission of Karthala volcano eruption reach the city?

```
LET eruption = ELEMENT(SELECT eruption FROM
 eruptions WHERE volcano = 'Karthala');

LET eruptionInCity = intersection(eruption, city);

LET tSeries = timeSeries(eruptionInCity, 'SO2',
                         COUNT);
PRINT min(time(select(tSeries, RANGE_VALUE > 0))
```

Final Comments

- An initial version of an algebra for spatio-temporal data
- The idea is to work on this initial version in order to get an algebra as clear and robust as the one defined in the moving object model.
- As future work → to extend the algebra with:

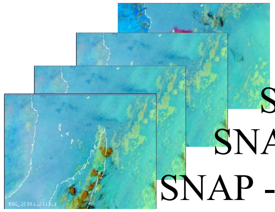
  (a) process and event concepts in order to represent the semantic of dynamic geographical processes and their relationships, for instance, “Katrina hurricane **started up** a flooding process”;

  (b) operators between evolving object and evolving field data types; and

  (c) operations over a set of evolving object and evolving field.

Thank you!

Formal Universe



SNAP – SPAN trans-ontological relation

SPAN – Process: Eruption of the Karthala volcano