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UNIVERSITY OF LEEDS

From Polygons and Timestamps to Dynamic Geographic Features: Grounding a Spatio-temporal Geo-ontology

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Outline

- Introduction.
- Representing Spatio-temporal Data.
- Modelling Dynamic Geographic Features.
- Linking the Ontology and Data Levels.
- Modelling Dynamic Geographic Elements.
- Conclusion.
- Future Work.

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Introduction

- Larger spatio-temporal datasets have begun to be produced and to be made available.
- The role that KRR approaches play in GIScience has been increasingly recognised.
- However, the ontology level has been traditionally developed separately from the data level.

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- Considering the temporal dimension leads to additional difficulties for linking ontology and data.

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- We propose an approach to modelling spatio-temporal data in a logical fashion which facilitates the linking between ontology and data.
- Of particular interest are geographic features which can change their spatial extension over time.
- A grounding layer is developed to connect ontology and data, so that conceptual elements representing dynamic geographic entities (e.g., events and processes) can be defined without concerns about data structure/representation.

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Representing Spatio-temporal Data

- 2D view of space.
- The earth surface is regarded as a set of spatial regions each of which is associated with attributes/qualities.
- Flexible/general so that it can be applied to represent a variety of scenarios in geographic space.

Representing Spatio-temporal Data

- STAR Data Model
  - “Spatio-temporal Attributed Regions”
- Triples of the form $\langle$ ***a*, *g*, *s*** $\rangle$
  - **Attribute** *a* holds for **geometry** *g* at time instant denoted by **timestamp** *s.*
- At the logical level, these triples are asserted as facts by using the predicate:

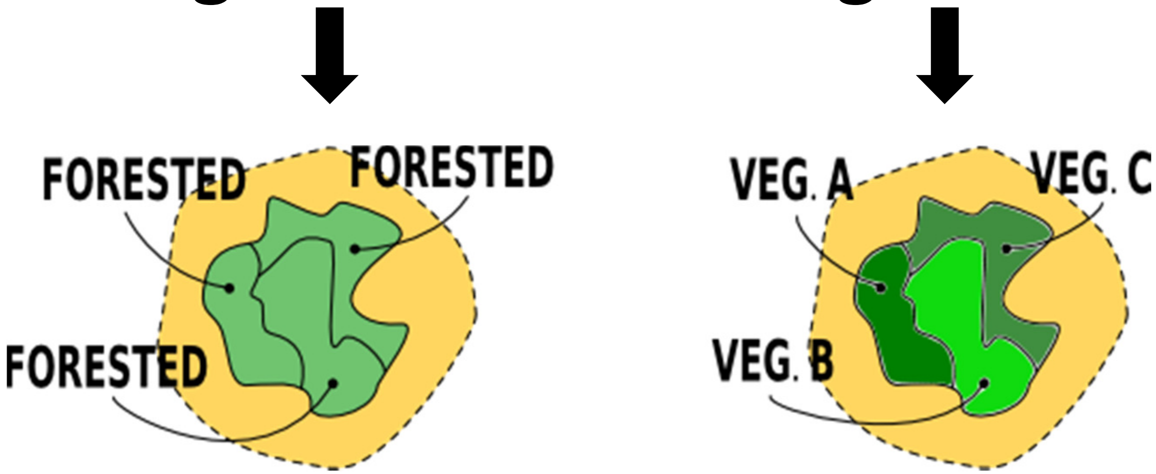
Star (*a*, *g*, *s*)

Types of Attributes

- **Homogeneous Coverages:**
  - Predicate: CAtt-Hom(a).
  - Examples: “forested”, “arid”, “water covered”.
- **Heterogeneous Coverages**
  - Predicate: CAtt-Het(a).
  - Examples: “urbanised” and “agricultural”.
- **Simple Features:**
  - Predicate: FAtt-Sim(a).
  - Examples: “ocean”, “desert”, “forest”.
- **Compound Features:**
  - Predicate: FAtt-Com(a).
  - Examples: “city”, “park”, “beach”.

Types of Attributes

- The actual denotation employed by these distinct types of attributes depends on the intended application / level of detail.
- For example, “forested” could be either **homogeneous** or **heterogeneous**:



Feature Attributes

- Of particular interest are **geographic features** which can be modelled as the maximal well-connected regions of some particular coverage. For example:
  - Forests (which can be regarded as the maximum extension of a certain type of vegetation).
  - Deserts (which can be defined based on the level of precipitation).
- An STAR associated with **feature attributes** can be either inferred or asserted explicitly.

Relation “Can be Part”

- At any given time instant, a spatial region *r1* can be part of a region *r2* only if their attributes (*a1* and *a2*, respectively) are related by CP.

- *CP(a1, a2)*, where:

  1. (Catt-Hom(*a1*) ^ Catt-Het(*a2*)) v
  2. (Catt-Hom(*a1*) ^ Catt-Hom(*a2*) ^ *a1=a2*) v
  3. (Catt-Het(*a1*) ^ Catt-Het(*a2*) ^ *a1=a2*)

  (1 is asserted explicitly, whilst 2 and 3 are specified in axioms.)

- Example: CP(*paved*, *urbanised*)

Relation "Must be Part"

- MP(a1, a2), where:
  1. (Catt-Hom(*a1*) ^ Catt-Het(*a2*)) v
  2. (Catt-Hom(*a1*) ^ Catt-Hom(*a2*) ^ *a1=a2*) v
  3. (Catt-Het(*a1*) ^ Catt-Het(*a2*) ^ *a1=a2*)

  (1 is asserted explicitly, whilst 2 and 3 are specified in axioms)
- If MP(*a1*,*a2*) holds, a spatial region *r2* (associated with *a2*) only exists at a certain time instant if there exists a region *r1* (associated with *a1*) which is part of r*1*.
- Example: MP(*built-up*, *urbanised*)

Relation “Cannot Intersect”

- Two spatial regions *r1* and *r2* cannot intersect each other if the attributes they are associated with are related by NI(*a1*,*a2*).
- NI(*urbanised*, *forested*).
- Useful for specifying regions which can change their spatial extension over time.

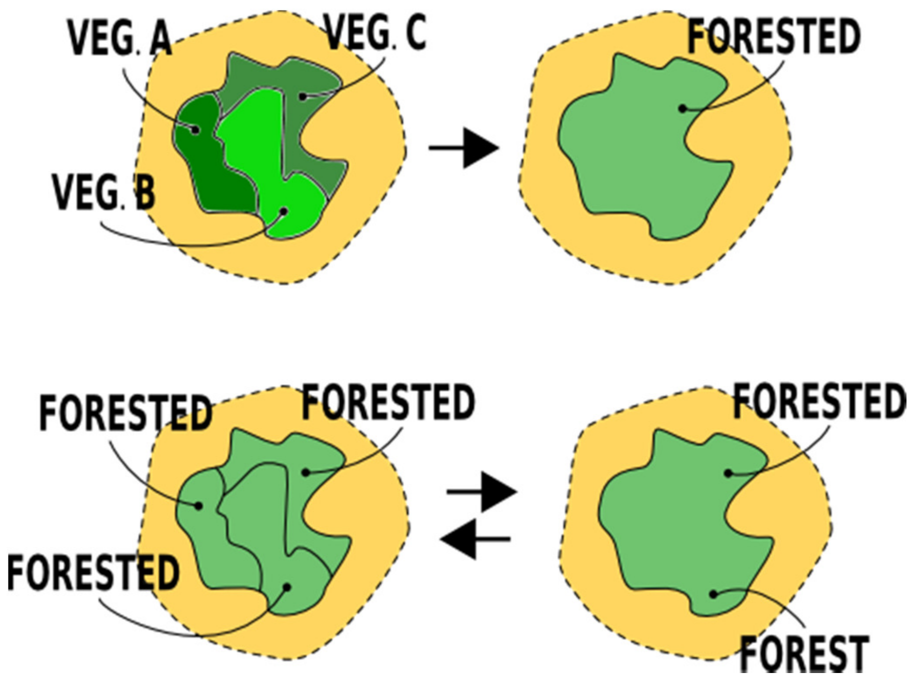
Axiomatisation

- A set of axioms are specified to determine data storage constraints. For example:
  - A heterogeneous region cannot be part of a homogeneous region at a given time instant.
  - Two attributes cannot be related by CP and NI simultaneously.
  - A heterogeneous attribute must be associated with at least 2 homogeneous attributes (by CP or MP).
  - Etc.

Axiomatisation

- A set of axioms are specified to determine inference rules for deriving implicit data.

For Example:



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Fundamentals

- Geographic features are regarded as the *material objects* which inhabit our spatio-temporal model.
  - They are discrete individuals with well-defined spatial and temporal extensions.
  - They are wholly present at any moment of its existence.
  - Change some of their parts while keeping their identity (e.g., a forest can be partially deforested while being still the same forest).

Concepts and Relations

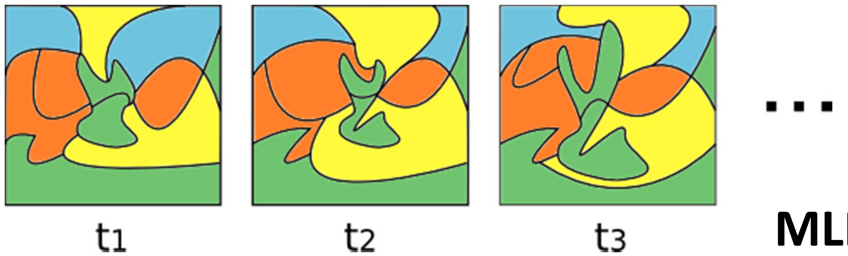
- The identity criteria of geographic features is defined in terms of connectivity of their spatial extension over a time interval.
- The maximum interval on which a feature maintains its identity is regarded as the interval on which the feature exists (i.e., it is “alive”).
- A feature's life is modelled as a sequence of Minimum Life Parts (MLP), which are the shortest stretches of the life-time within which the feature's spatial extensions are known.

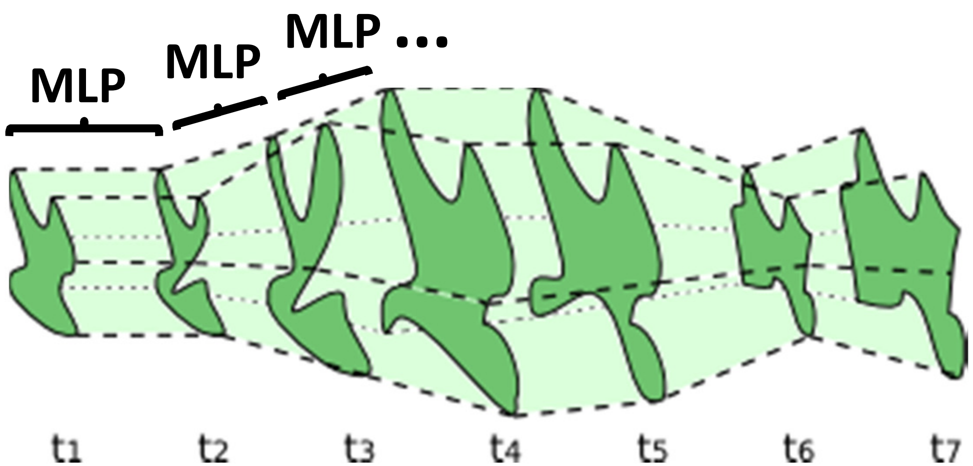
Concepts and Relations (cont.)

An MLP is a pair of the form

⟨ Star(a, g1, s1), Star(a, g2, s2) ⟩

representing consecutive snapshots of an individual feature (where *a* is a feature attribute).





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Linking the Ontology and Data Levels

- Once the concepts of feature, feature life, and minimum life part are defined, higher level concepts describing dynamic geographic entities (e.g., events and processes) can be defined in terms of them;
- Those higher level concepts do not need to refer to lower level concepts (i.e., Star).
- This makes the ontology independent from the data structure.

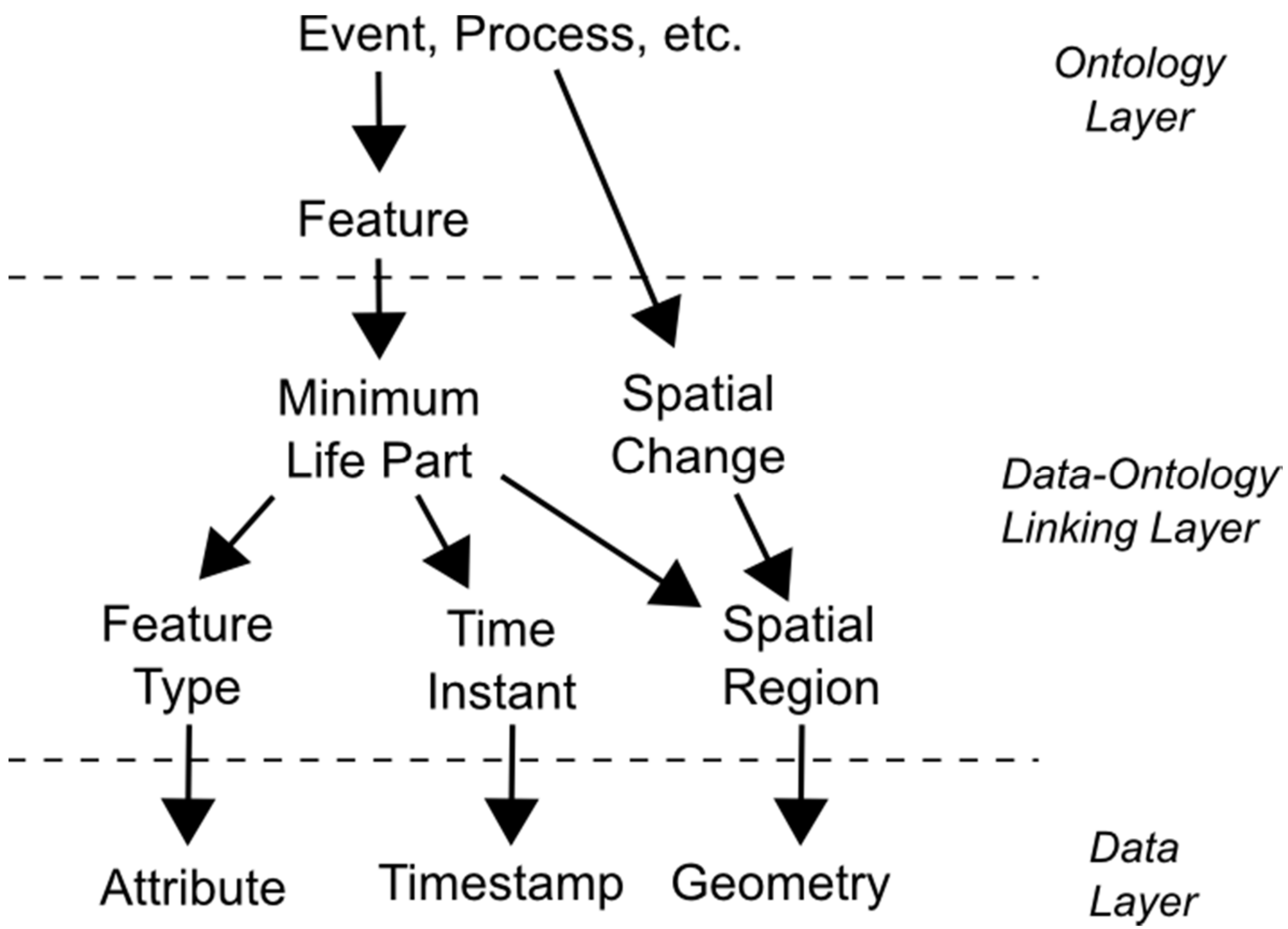
Linking the Ontology and Data Levels

The explicit link between the ontology and data levels is established by the definition of an MLP, which is given in terms of Stars .

$$\begin{aligned}
&\mathsf{MLP}(f, r_b, t_b, r_e, t_e) \equiv_{def} \exists u, r_b, t_b, r_e, t_e[u = \text{feature-type}(f) \\
&\quad \mathsf{Star}(u, r_b, t_b) \wedge \mathsf{Star}(u, r_e, t_e) \wedge t_b \prec t_e \wedge \mathsf{C}(r_b, r_e)] \wedge \\
&\quad \neg\exists r', t'[(t_b \prec t' \prec t_e) \wedge \mathsf{C}(r', r_b) \wedge \mathsf{Star}(u, r', t')]
\end{aligned}$$

Where f, r, t are variables of our logical language denoting, respectively, features, feature types, spatial regions and time instants.

Linking the Ontology and Data Levels



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Modelling Dynamic Geographic Elements.

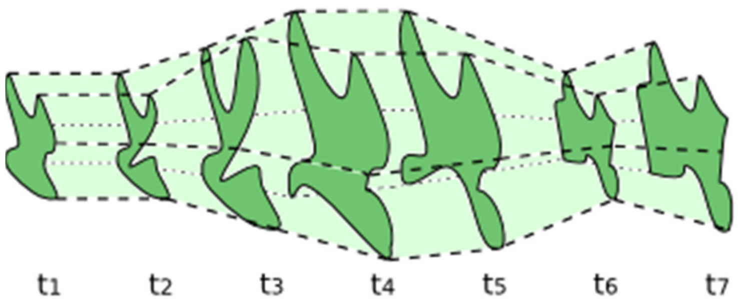
- This approach to modelling geographic features can be applied to support the representation of a variety of dynamic geographic elements.
- To illustrate, we describe an example of event occurrence.

$$\begin{aligned}&\mathsf{Occurs\text{-}On}(expansion, f, i) \equiv_{def} \exists r_{1b} r_{1e} r_{2b} r_{2e} t_{1b} t_{1e} t_{2b} t_{2e} [\\ &\quad \mathsf{MLP}(f, r_{1b}, t_{1b}, r_{1e}, t_{1e}) \wedge \mathsf{MLP}(f, r_{2b}, t_{2b}, r_{2e}, t_{2e}) \wedge (t_{1e} \prec t_{2b}) \wedge \\ &\quad \neg\mathsf{Expands}(r_{1b}, r_{1e}) \wedge \neg\mathsf{Expands}(r_{2b}, r_{2e}) \wedge \forall r_b r_e t_b t_e [\\ &\quad \mathsf{MLP}(f, r_b, t_b, r_e, t_e) \wedge (t_{1e} \preceq t_b \preceq t_e \preceq t_{2b}) \rightarrow \mathsf{Expands}(r_b, r_e)]]\end{aligned}$$

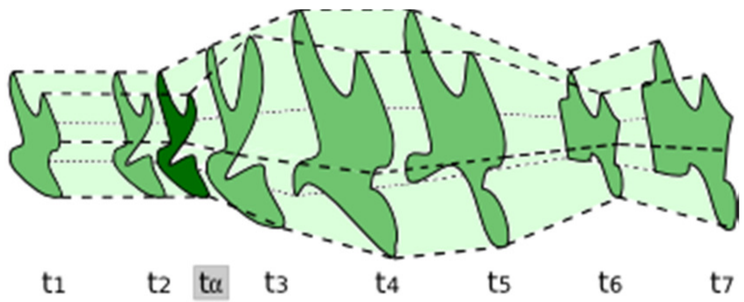
$$\mathsf{Expands}(r_1, r_2) \equiv_{def} \mathsf{area}(r_2) > \mathsf{area}(r_1)$$

Modelling Dynamic Geographic Elements.

- Predicate Star is not referred to at this level, which makes the definition independent from the data structure.
- However, a concrete link between the data and ontology layers is still maintained, so that changes in data reflects directly the meaning of conceptual elements:



$Occurs(e, [t_2, t_4])$



$\neg Occurs(e, [t_2, t_4])$

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Conclusion

- Modelling the spatio-temporal data in a logical fashion:
  - allows us to derive implicit data; and
  - provides a natural way to link the data and ontology layers.
- This is also a useful resource to support spatio-temporal data integration over multiple granularities and from distinct sources.

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Future Work

- Dealing with other types of geometries, such as points and lines.
- Extending the model to allow spatial regions to be modelled as an aggregation of other disconnected regions.
- More complex modelling of a feature life (e.g., which takes into account possible splits and merges).

Questions?

Thanks for listening!

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