Invited Talk

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Semantics of movement patterns
In this talk I will discuss progress in research relating to the semantics associated with patterns of moving objects. The talk will highlight how time in particular serves as an important foundation for extracting many different kinds of moving object semantics. I will discuss different temporal data models and how the choice of models exposes different moving object semantics.
Patterns of Moving Objects: Why so interesting?

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Moving objects

* Major research effort by numerous researchers that relates to analyzing and simulating different behaviors and activities through space-time

* Many of these studies involve modeling the movement of objects (people, vehicles, animals, natural phenomena) through a territory affording a focus on e.g.,
  * The trajectory or path of movement
  * Movement in constrained vs. unconstrained environments
  * Movement of individuals vs. groups
  * Uncertainty of movement
  * Spatiotemporal patterns of movement
Today’s talk

- Discuss the topic of patterns of moving objects with a particular focus on **semantics**
- Discuss semantics from the perspective of some of the underlying **temporal data models** that are possible for moving object applications
- **Spatiotemporal patterns** of movement

- Highlight the semantics that arise from
  - Modeling **linear sequences**
  - **Branching**
  - Modeling **cycles**
Today’s talk

* In addition...
* Provide a critical overview of progress and shortcomings relating to semantics that is relevant to movement pattern analysis
Modeling movement

Many efforts to model the movement of objects

Ships through harbor waters

Gulf of Mexico Oil spill July 2010

Track that car
Formalizations designed to reveal different semantics

Here elements of a trajectory are formalized including *Begin*, *End*, *Stop*, *Move*

Semantic trajectory ontology from Yan, Macedo, Parent, Spaccapietra
*Transactions in GIS*, 12: 75-91.
Activities and trips

Which activities, of the person $p$ during the day $d$, takes place at a given location of the place $x$?

$\text{Activities\_At\_Point}(\text{TP.traj, PL.x}) \land \text{TP} \in \text{TimePath} \land \text{PL} \in \text{place} \land \text{TP.idPers} = p \land \text{TP.day} = d$

A common interest...stops or stay points

Alternatively...

The path of the moving object is captured through an expression such as

\[
\left\{ \text{\textit{id e zone}}_{1}, \text{\textit{id e zone}}_{2}, \ldots, \text{\textit{id e zone}}_{m} \right\}
\]

where,

\[
\text{\textit{id e zone}}_{1} < \text{\textit{id e zone}}_{2} < \ldots < \text{\textit{id e zone}}_{m}
\]
Event-based model of movement

This transit through a harbor can be modeled as a sequence of events.
This allows us to model important characteristics of many different kinds of movements.

A vessel enters the harbor waters and then leaves again without ever reaching its intended destination.
And develop typologies of movement
Relative Motion Patterns


Speed, acceleration, and movement direction
Much of this work assumes one thing...

- An underlying **linear model** of time

- Focus on **before** and **after** relations

- Useful for **timeline** applications

- Temporal and spatial patterns of events commonly represented in simulations
Oculus’s **GeoTime** application

www.oculusinfo.com
Another model

* Let’s consider another temporal model that will support additional semantics important for moving object applications and give rise to distinct patterns of movement.
Branching events model

- Work underway with Shane Hubbard, UIowa

- This model captures **spatiotemporal alternatives**
  - E.g., what behaviors might occur in the **future** or what might have happened in the **past**

- Has two key elements
  - **Diverging**
  - **Converging**
Branching events model

* Work underway with Shane Hubbard, UIowa

* This model captures **spatiotemporal alternatives**

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Spatiotemporal alternatives

- Now possible future events including movements can be modeled
- Useful for “what if?” modeling
- Richer set of behaviors
Spatiotemporal alternatives

- Can explore how many alternatives exist for a given time
- How many alternatives are associated with a given location over time
Sometimes something else is needed…

- The **linear** and **branching** models emphasize **sequences**

- Want to capture the **repetitions** that are commonly present in behaviors and movements

- Need to expand modeling to allow for **cycles**
Spatiotemporal cycles are commonplace

- A ferry or ship’s movement in and out of the harbor may be cyclic
- Repeating events, locations, or times
  - Same event, same time, same location
  - Same event, different time, same location
- **Granularity matters…**
  - Individual or paths,
  - Event times, dates, combinations of both
  - Cycle times, dates
In a set of events, certain events may initiate a cycle, e.g.,

Other events will terminate a cycle, e.g.,

And an interval often exists between repetitions (granularity again...)

- Continuous cycles (daily ferry service),
- intermittent cycles (seasonal ferry service)
Combine branching and cyclic modeling

Cyclic events might always be associated with one branch

A diverging (or converging) component might be cyclic
Cycles and branching...
Interesting cases

Interrupted cycles

Partially completed
Initiating, no terminating
Branching events and cycles

- The parameters of $t$ and $l$ for time and location respectively are obviously very key here...and granularity matters

- $t = \text{time (st; et; (st,et); date; timestamp)}$
- $l = \text{location (x,y coordinates; region; path)}$
- Also the granularity of the entity of interest
  - Individual events? Several branches? Entire cycle?
Duration of events

- This temporal aspect is key for both branching and cycles
- Different durations will result in branches of different lengths of time
- And in cycles of different lengths
16 Cyclic Interval Relations
((Stewart) Hornsby et al. 1999)

- disjoint
- contained_by
- finishes
- met_by
- meets
- starts
- overlapped_by
- meets_twice
- overlaps
- equals
- started_by
- passed_by
- passes
- finished_by
- overlaps_twice
- contains
For a single moving object, can compare 2 or more branches and represent possible relations between branches.

- Capture similarities or differences.

Can compare 2 or more paths that are cyclic and look for relations between routes.

- Compare paths of different objects.
  - Maximize or minimize certain relations (e.g., to avoid gaps in route coverage).
Summary

* A **linear** temporal model is most commonly used as the basis for modeling moving objects

* Additional data models are possible and reveal **additional semantics**
  * **Branching model** captures semantics of spatiotemporal alternatives
  * and **cyclic model** captures semantics for **repeating movements**

* Identify primitives for modeling
  * time, location, identity, diverging, converging, initiating, terminating, **stops, moves, activities**

* Need to account for **granularity** of time and location, **event durations, interruptions** (branching and cyclic)

* **Ongoing**: spatiotemporal patterns in landscapes of risk and opportunity
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