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**

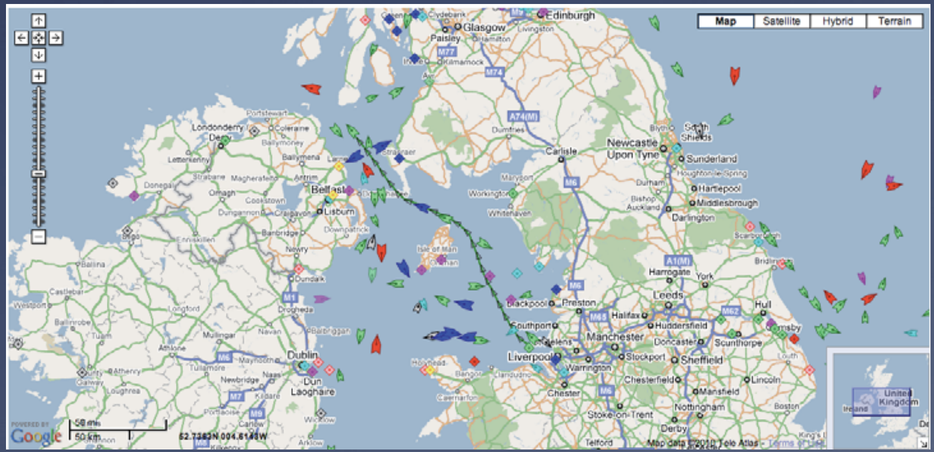
Today's talk

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

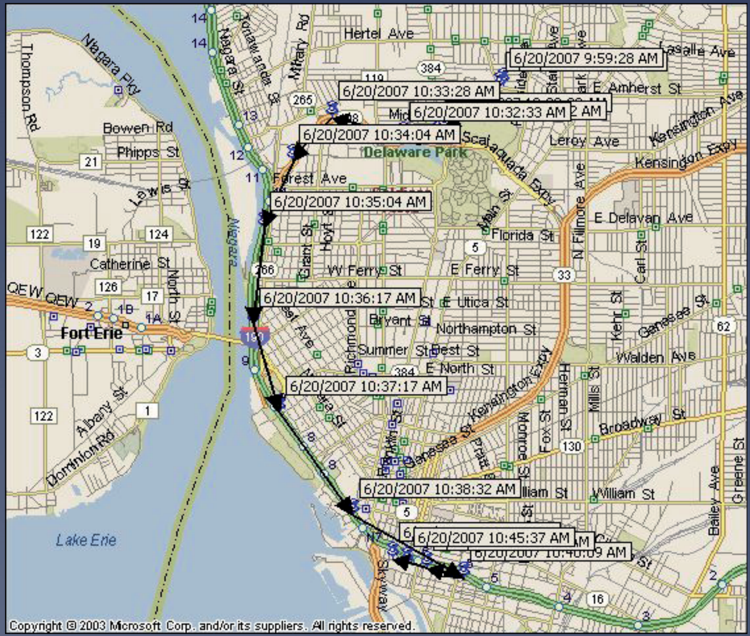
Modeling movement

Many efforts to model the movement of objects

Gulf of Mexico Oil spill July 2010

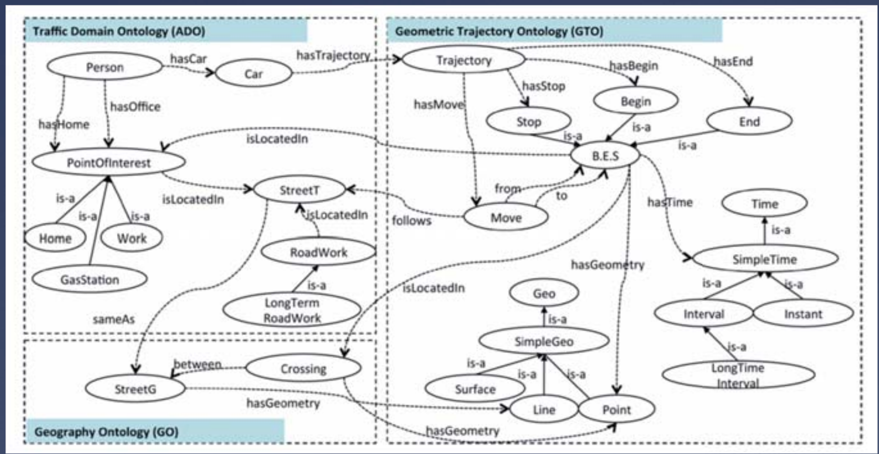


Ships through harbor waters



Track that car

Formalizations designed to reveal different semantics



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

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

Activities and trips

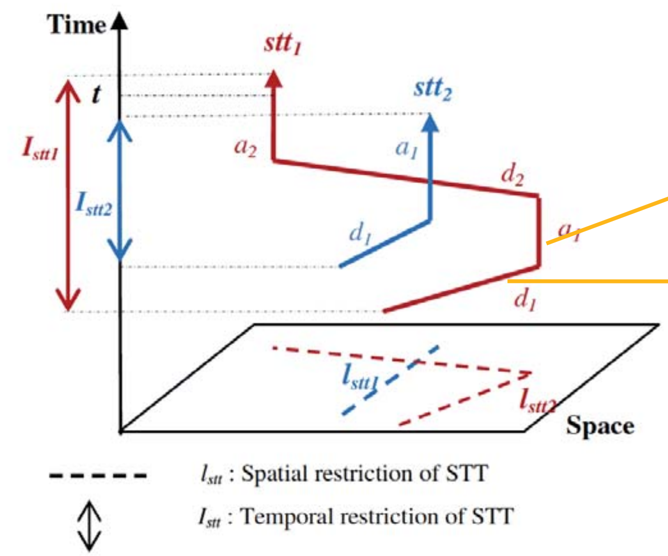


Fig. 1. Spatial and temporal projections of an STT

Activity

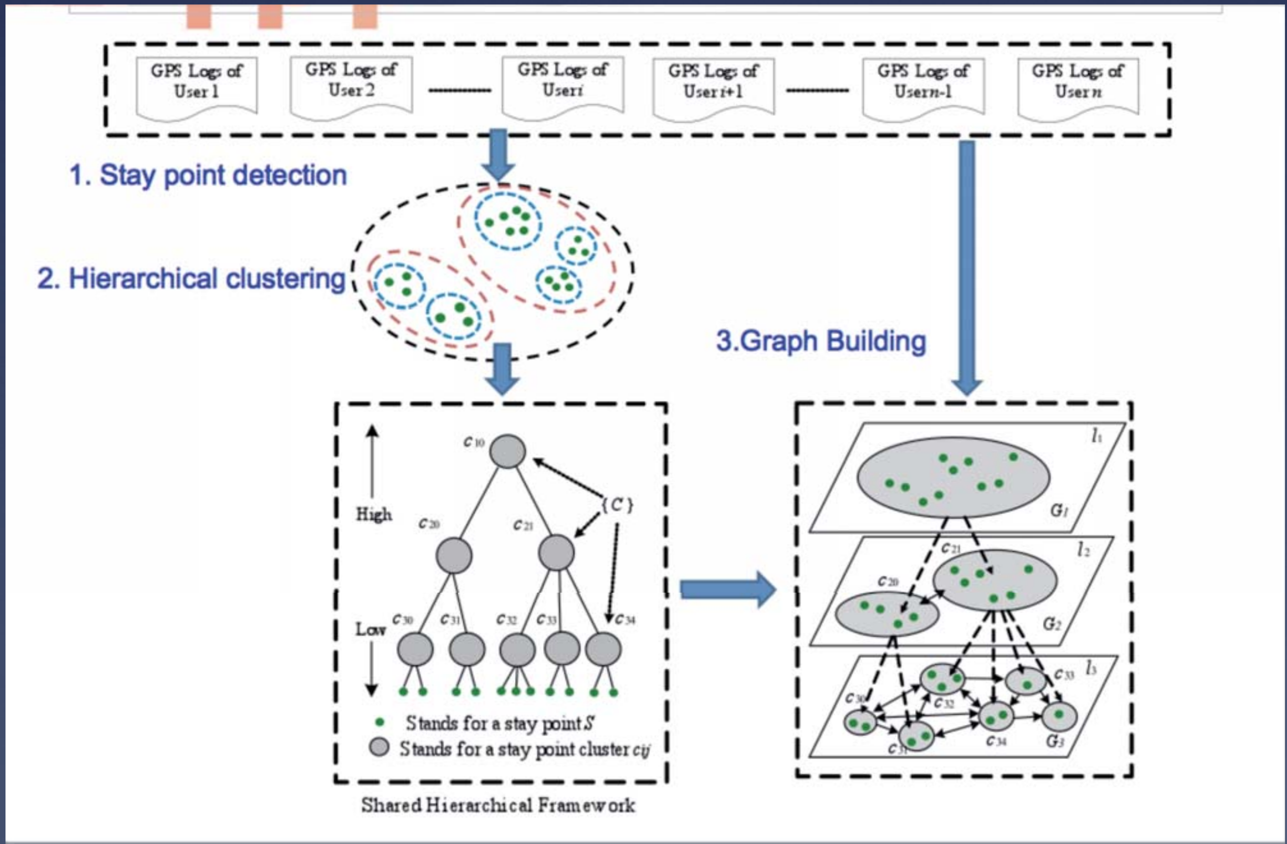
Trip

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

Activities_At_Point(TP.traj, PL.x) | TP ∈ TimePath ∧ PL ∈ place ∧ TP.idPers = p ∧ TP.day = d

Sheni, Frihida, Ben Ghezala, and Claramunt (2009) *ER 2009 Workshops*, pp. 347-356.

A common interest…stops or stay points



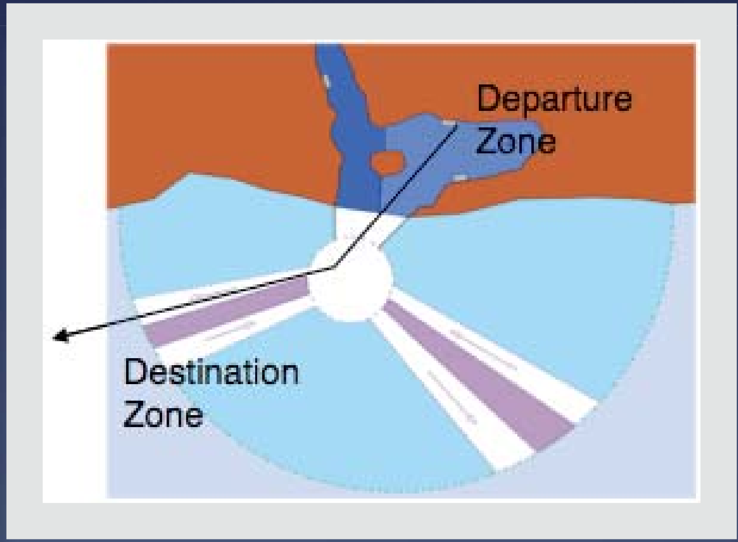
http://research.microsoft.com/apps/pubs/?id=79440 Y. Zheng and X. Xie (2009)

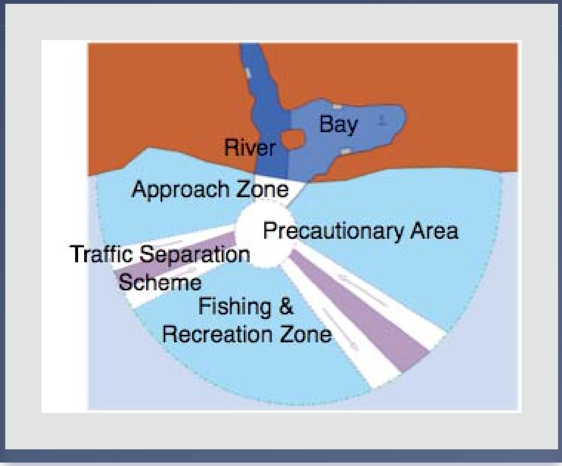
Alternatively…

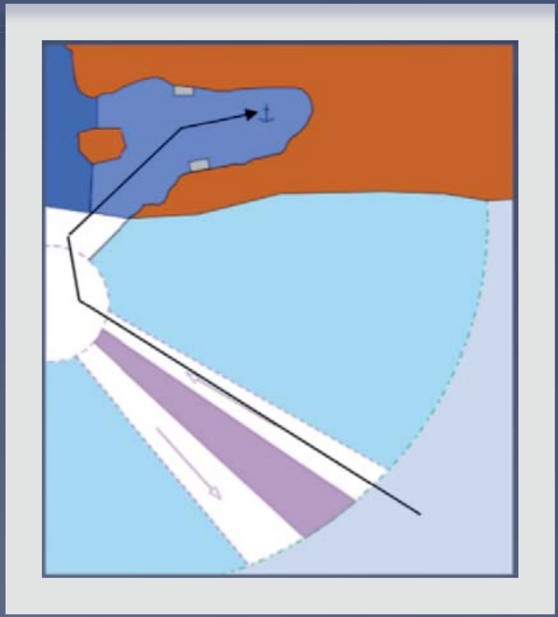
The path of the moving object is captured through an expression such as

$$\left\{ {}_{id}e^{zone}_{t1}, {}_{id}e^{zone}_{t2}, \ldots, {}_{id}e^{zone}_{tn} \right\} \text{ where,}$$

$${}_{id}e^{zone}_{t1} < {}_{id}e^{zone}_{t2} < \ldots < {}_{id}e^{zone}_{tn}$$

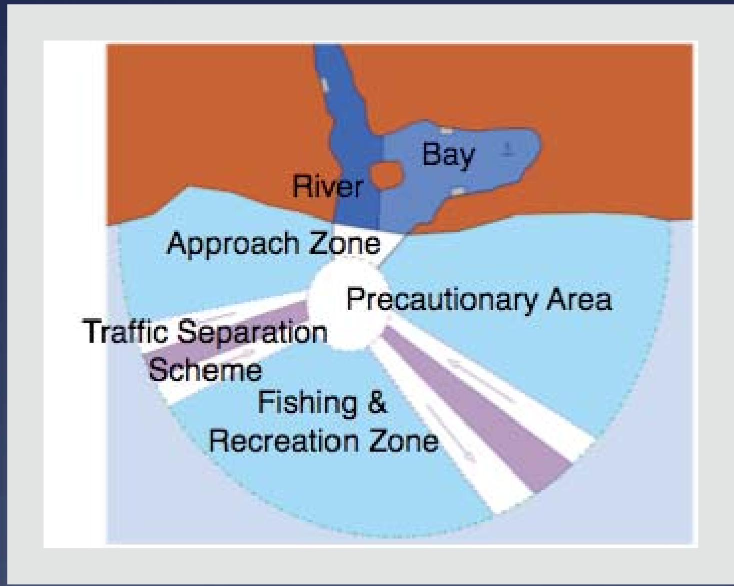




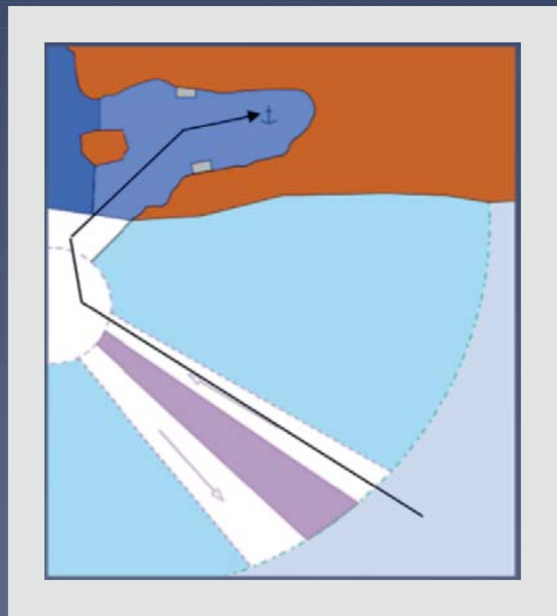


Event-based model of movement

This transit through a harbor can be modeled as a sequence of events

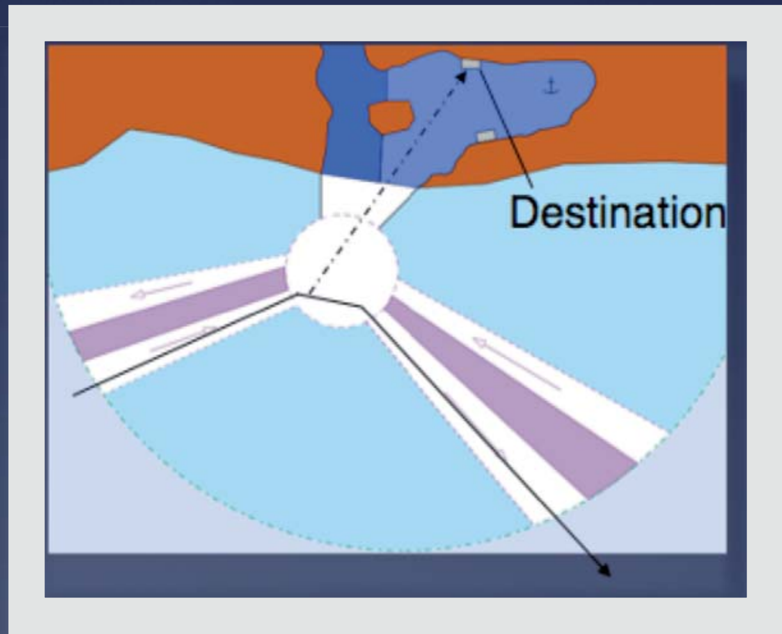


$$_{FRY}\,cze^{inbd\_SE\_TSS}_{t1} < {}_{FRY}\,cze^{precautionary}_{t2} < {}_{FRY}\,cze^{approach}_{t3} < {}_{FRY}\,cze^{bay}_{t4} < {}_{FRY}\,cze^{anchorage}_{t5}$$



This allows us to model important characteristics of many different kinds of movements

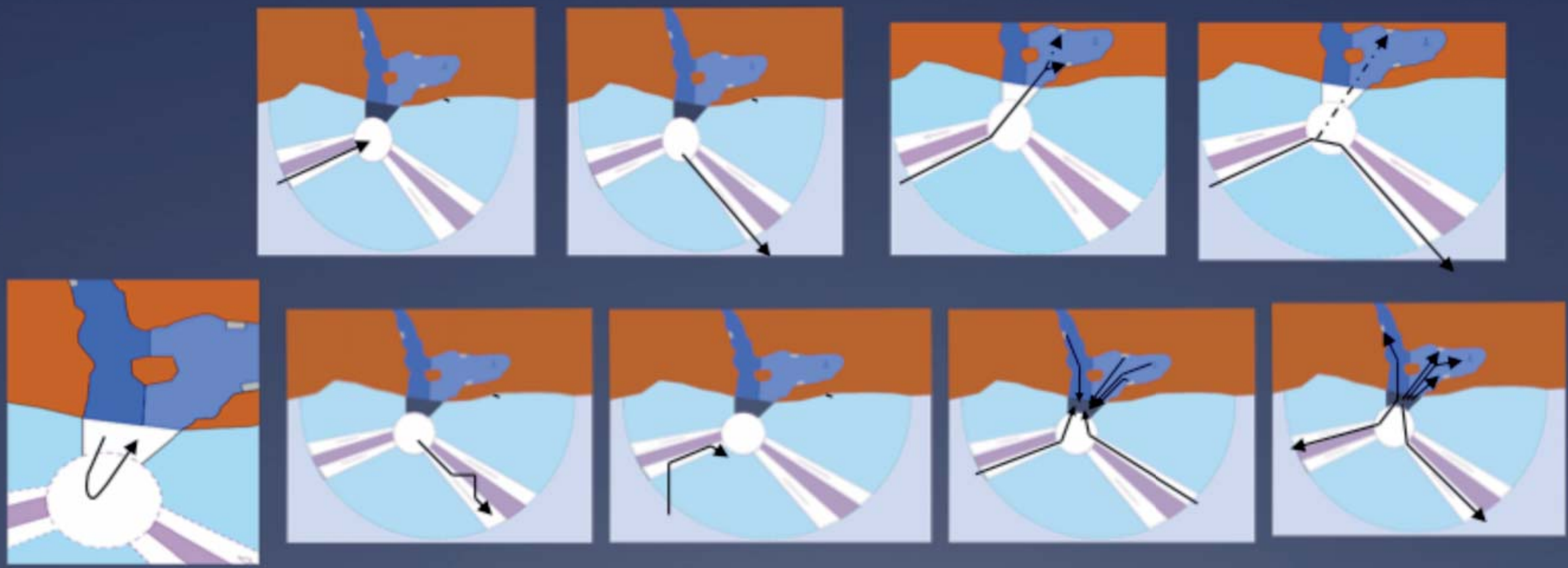
A vessel enters the harbor waters and then leaves again without ever reaching its intended destination



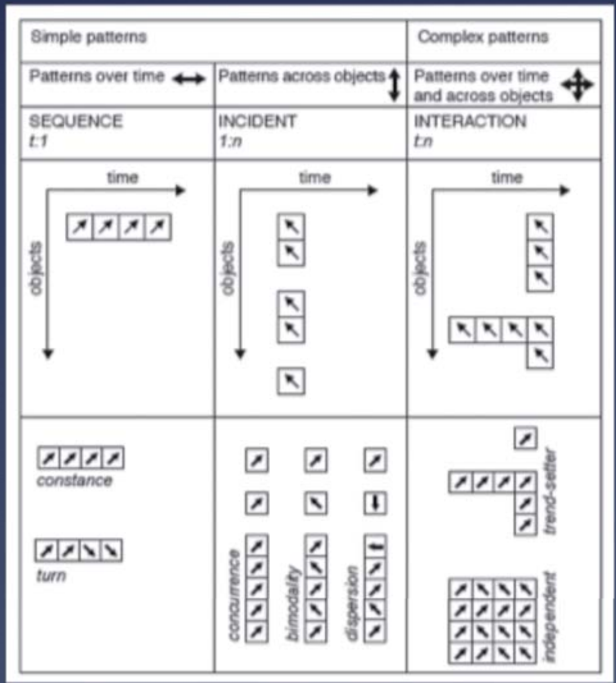
oldZone: offshore FRY1 dep inbd_W_TSS t1 < FRY1 cze precautionary t2 <

expectedNext:approach FRY1 uze outbd_SE_TSS t3 < expectedDest: ferryLanding ude offshore t4

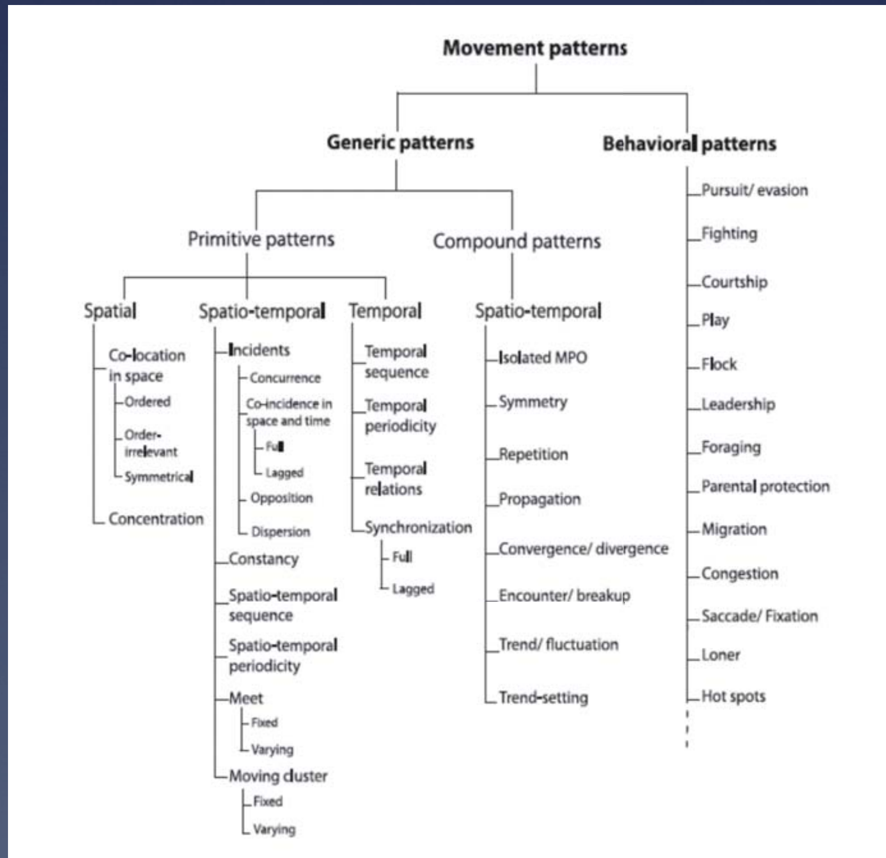
And develop typologies of movement



Relative Motion Patterns



Laube, P., and Imfeld, S. (2002) Proceedings of GIScience 2002, 132-144.

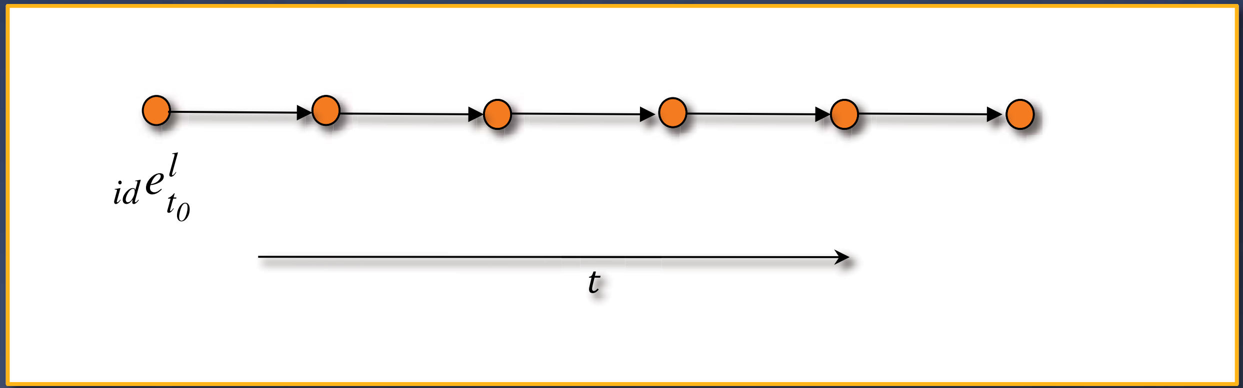


Dodge, S., Weibel, R., and Lautenschütz, A-K. (2008) Towards a taxonomy of movement patterns, Information Visualization, 7, 240-252

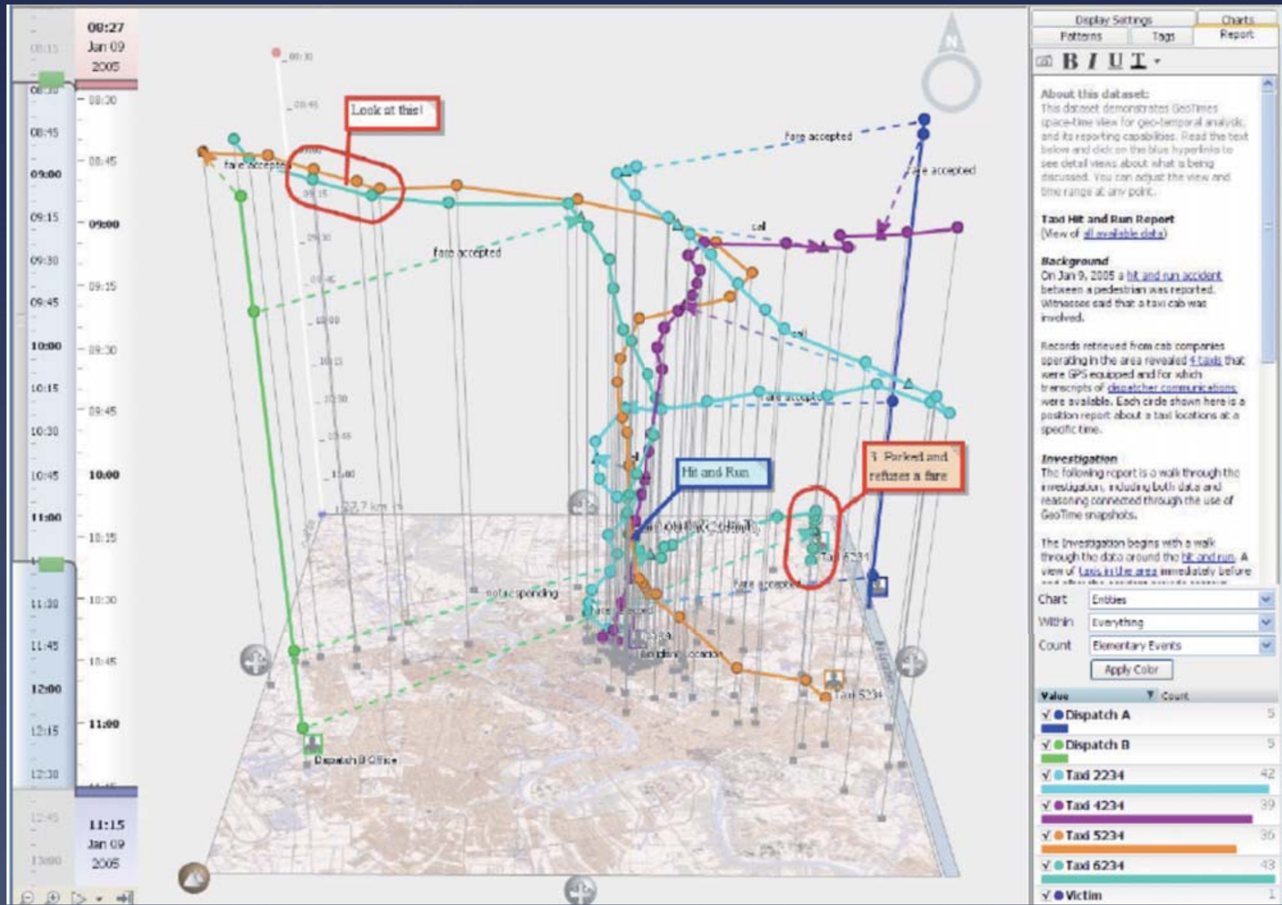
Speed, **acceleration**, and **movement direction**

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

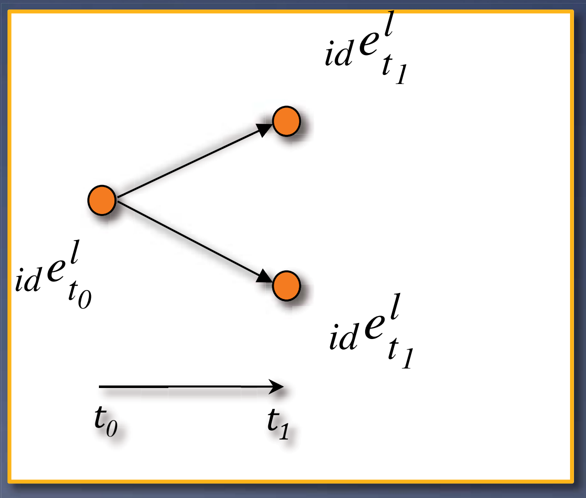
www.oculusinfo.com

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**



Diverging

Branching events model

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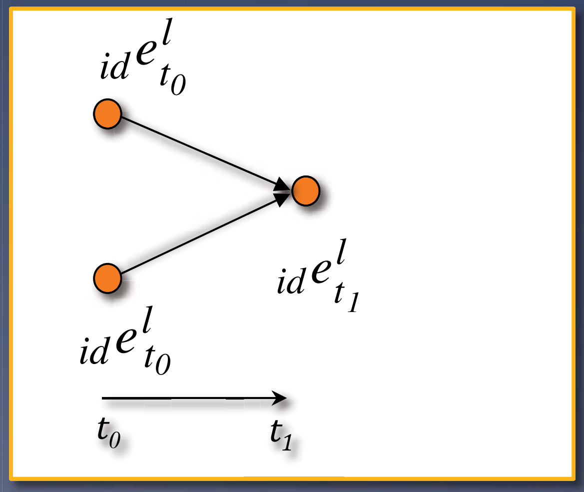


Converging

Spatiotemporal alternatives

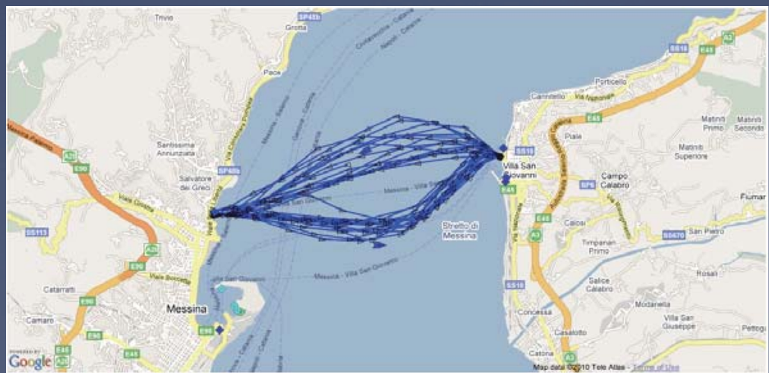
* Now **possible future events** including **movements** can be modeled
* Useful for "**what if?**" modeling
* Richer set of behaviors

Spatiotemporal alternatives

- Can explore how many alternatives exist for a **given time**
- How many alternatives are associated with a **given location** over time

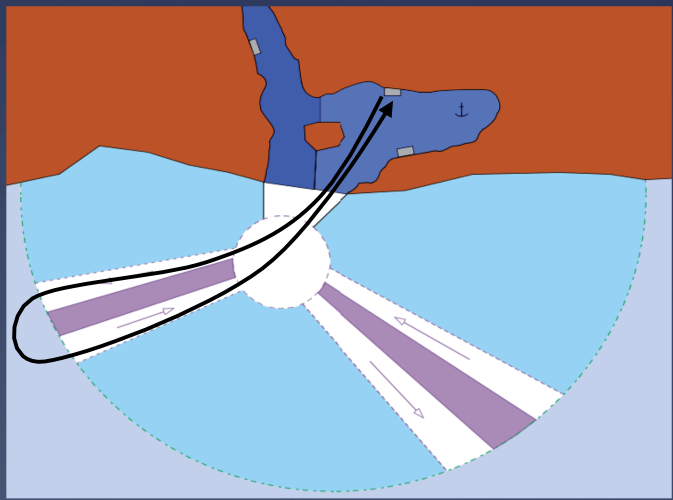
Sometimes something else is needed...

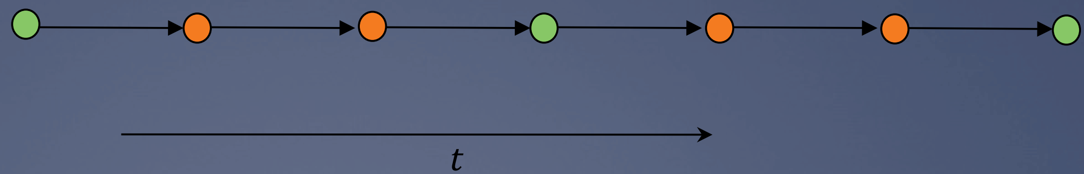
- The **linear** and **branching** models emphasize **sequences**
- Want to capture the **repetitions** that are commonly present in behaviors and movements
- Need to expand modeling to allow for **cycles**



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.,

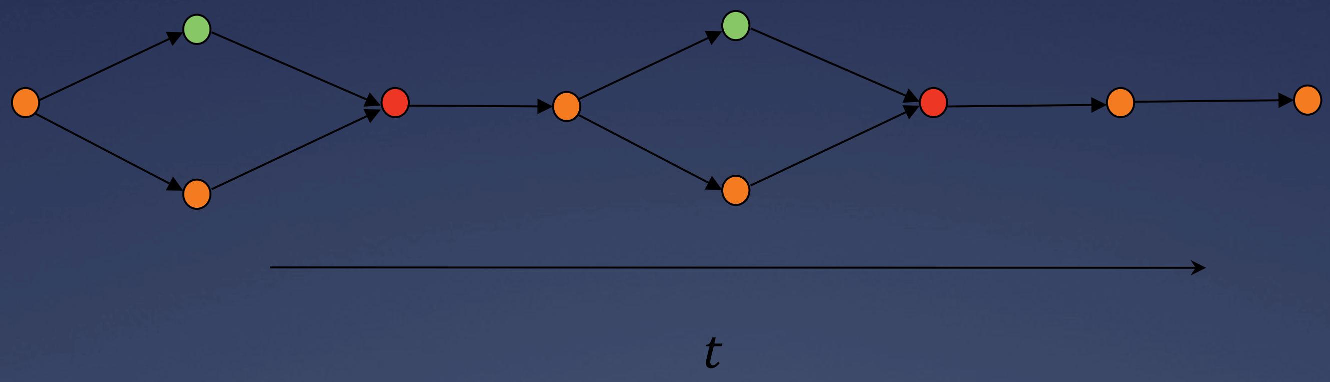
$$^{oldZone:offshore}_{WFG}dep^{inbd\_SE\_TSS}_{t_1}$$

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

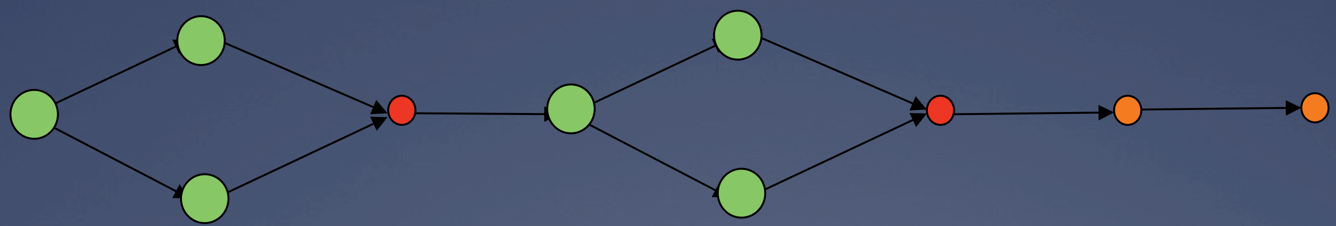
$$^{\exp ectedDest:anchorage}_{WFG}arr^{anchorage}_{t_5}$$

* And an **interval** often exists between repetitions (granularity again…)
  * **Continous** cycles (daily ferry service),
  * **intermittent** cycles (seasonal ferry service)

Combine branching and cyclic modeling

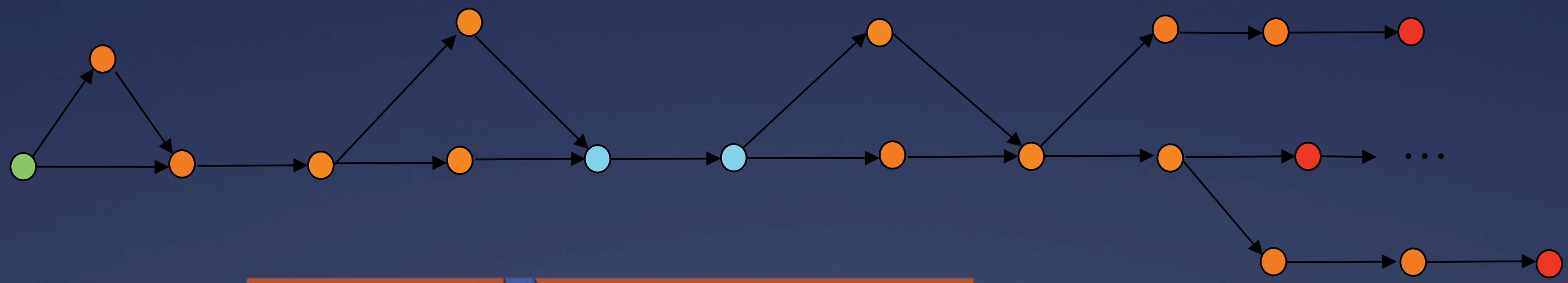


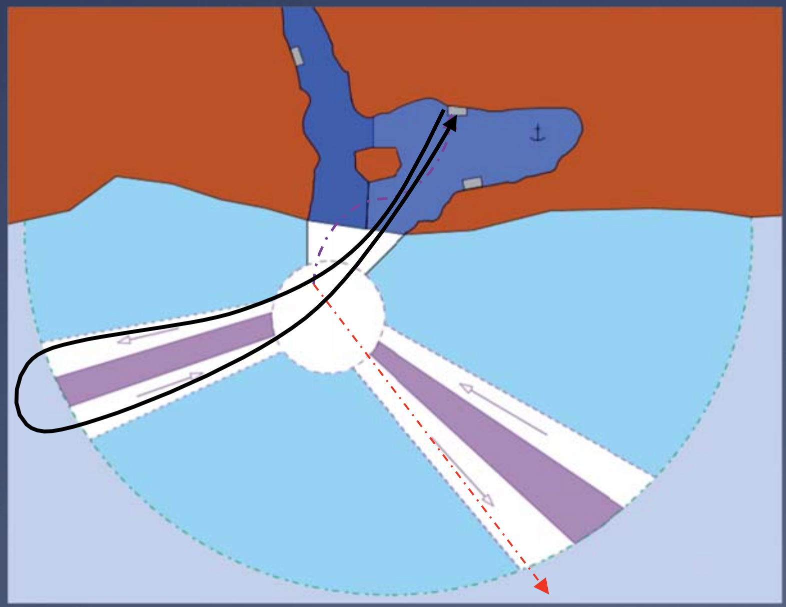
Cyclic events might always be associated with one branch



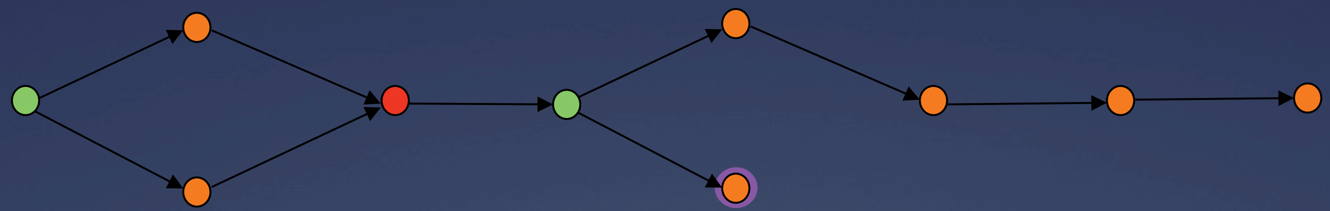
A diverging (or converging) component might be cyclic

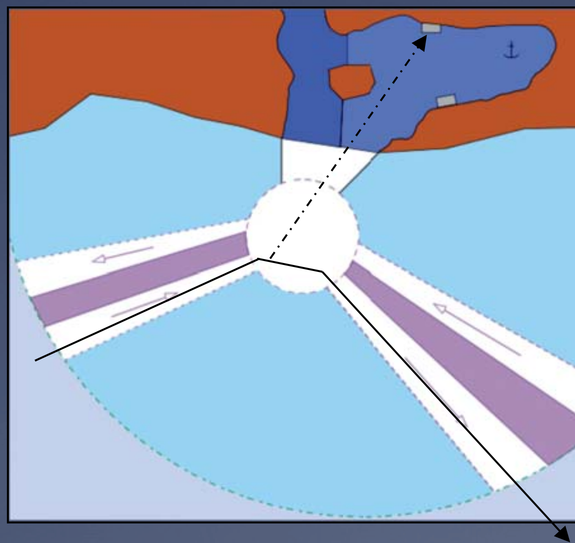
Cycles and branching…





Interesting cases





Interrupted cycles

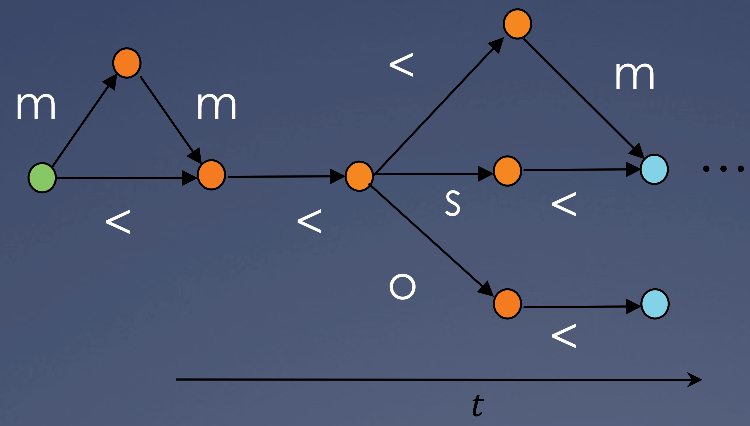
Partially completed
Initiating, no terminating

Branching events and cycles

- The parameters of *t* and *l* for ***time*** and ***location*** respectively are obviously very key here…and **granularity matters**
- *t*= time (st; et; (st,et); date; timestamp)
- *l* = location (x,y coordinates; region; path)
- Also the granularity of the **entity** of interest
  - Individual events? Several branches? Entire cycle?

Duration of events

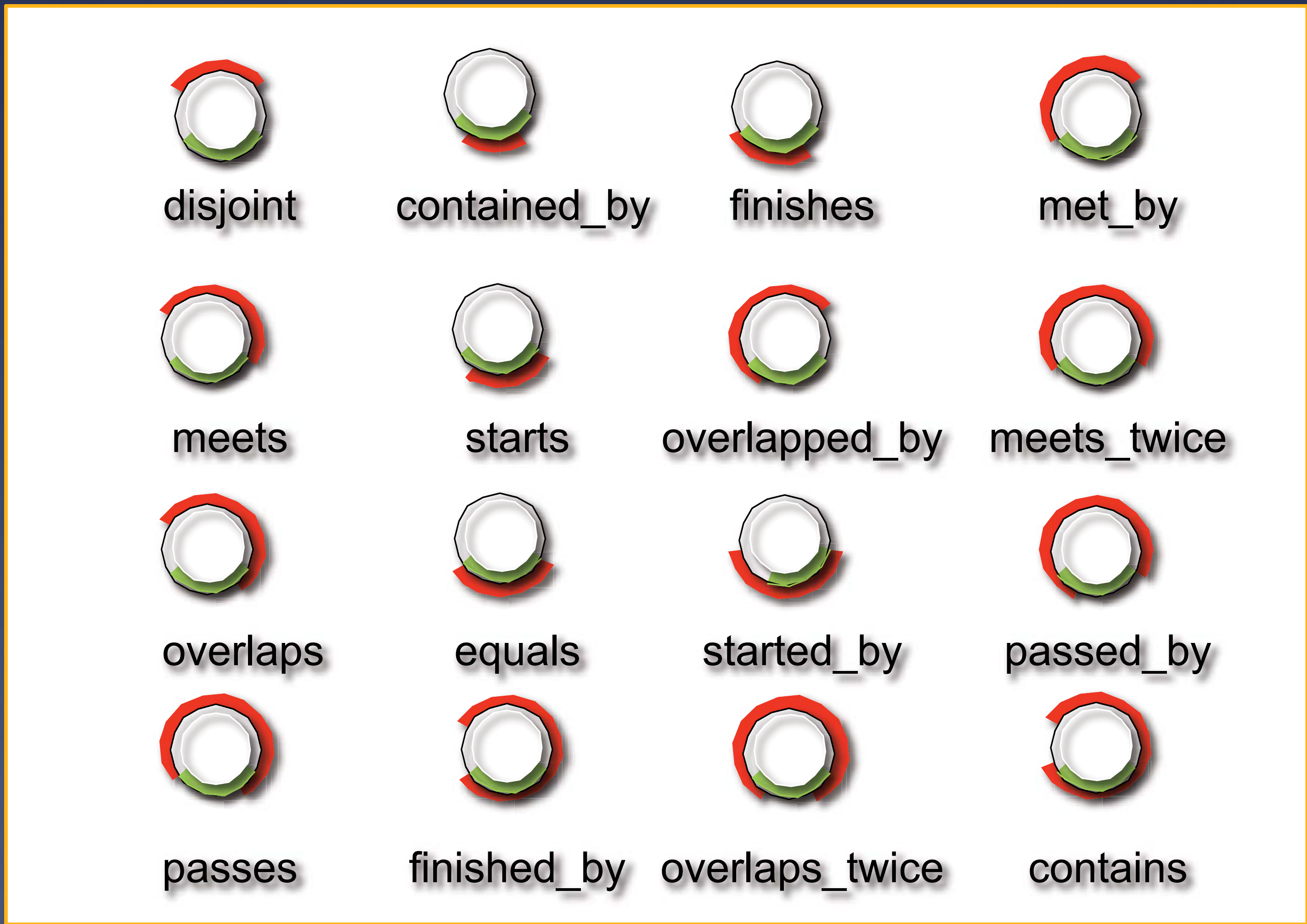
- This temporal aspect is key for both **branching** and **cycles**
- Different durations will result in **branches** of **different lengths** of time



- And in **cycles** of **different lengths**

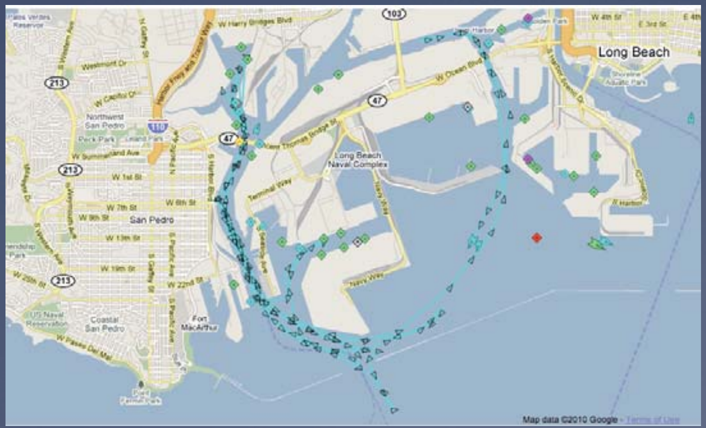
16 Cyclic Interval Relations

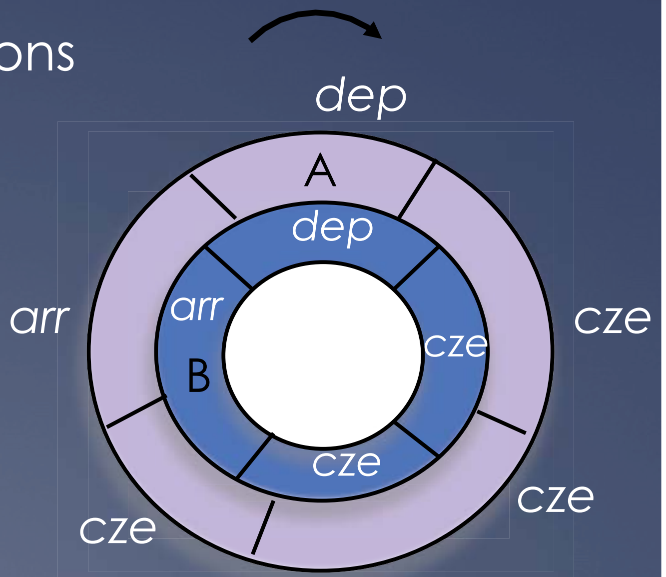
((Stewart) Hornsby et al. 1999)



- 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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