

Spatio-Temporal Event Notifications

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Introduction

Spatio-temporal events refer to patterns of change experienced by geographic phenomena, for example, a change in destination for ships entering a harbor, the occurrence of traffic jams on a road network, or people evacuating a building after a security alert. These events occur over time, and in this work where a database perspective is adopted, events are modeled as discrete and instantaneous change (Zhang and Unger, 1994; Hinze and Voisard 2002). A key aspect of spatio-temporal events is their geographic location. In many cases, spatio-temporal events involve a change in location of some object(s). Given the dynamic properties of the world, there is a need to distinguish these events for a given application and use a spatio-temporal event notification system (STENS) that matches tagged events and provides notice of these events. Such notification systems are particularly useful for dealing with occurrences of unexpected and possibly undesirable events, or any event for which a user desires warning.

This white paper discusses an approach to improved handling of unexpected or undesirable events for an application based on designing a spatio-temporal event notification system (STENS). There are a number of open research tasks related to this topic including the development of a general categorization or ontology of domain events that needs to be developed as part of this work. This ontology serves as the foundation for the STENS. A user requests notification of certain events as they occur in an application scenario. These events are then matched against the ontology using data mining and knowledge discovery tools. If a match is found, notification takes place. The topics of matching events and notifying users also require further research. This white paper discusses events related to the movement of ships in a harbor, but the principals apply more generally to other scenarios involving spatio-temporal events.

Event notifications

Numerous application areas including stock traders, traffic controllers, and dispatchers have benefited from the development of event notification systems or services where users are informed about the occurrence of certain relevant events on a provider's website (Krishnamurthy and Rosenblum 1995; Gruber, Krishnamurthy *et al.* 1998; Hinze and Voisard 2002) or as part of a wide-area network (Carzaniga, Rosenblum *et al.* 2001). Events published in an active database, are matched with events that correspond with a user's interests through user-defined subscriptions. When a match occurs, subscribed users who have selected notification about that event type receive an alert. Our work highlights the semantics of spatio-temporal events and focuses on notifications regarding these events.

Case Study: Modeling ship movements in a harbor

Modeling a harbor

Each ship entering a harbor from offshore is assigned a vessel identifier to distinguish ships from each other. A ship enters the harbor with a destination declared. A harbor is partitioned into n zones, where a *zone* is a two dimensional areal object with a directional component that constrains ship movement to a particular direction within that zone (Figure 1). Zones include a ship's intended destination (e.g., anchorage, ferry landing, shipyard, petrochemical terminal, or offshore if the ship is exiting the harbor). There is a temporal interval associated with each zone that describes the maximum time given the speed of travel that a ship is expected to be in a zone.

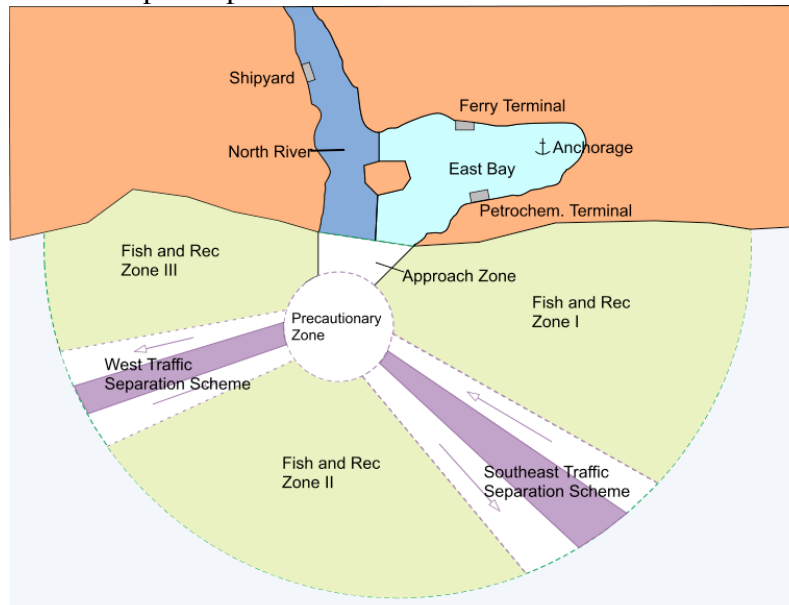


Figure 1: A harbor is partitioned into zones.

Modeling the movement of ships

The movement of a ship can be modeled as a sequence of zones. At any given time, a ship is associated with a `currentZone`. Given the `currentZone` and the destination of the ship, there is an `expectedNextZone` that describes the region of the harbor that the ship will next enter. For example, Vessel 101 transits the harbor from offshore (i.e., outside the harbor) to the Ferry Terminal and the sequence of zones is `Offshore > WTSS > PrecautionaryZone > ApproachZone > EastBay > FerryTerminal`. This would be considered a normal pattern of movement where the ship followed the expected sequence of zones and conformed to the directional constraints imposed by each zone. There are cases, however, where ship movement is irregular and unexpected events occur. For example, a ship may not go to its expected destination but may dock at another destination, or a ship may not enter one of the traffic separation schemes via the inbound lane but may enter and attempt to transit a lane designated for outgoing vessels. Another unexpected event occurs when a ship does not enter the harbor through one of the traffic separation scheme zones but instead enters harbor waters through one of the fishing and recreation zones. A harbormaster can request notification from the STENS should any of these events occur during a ship's transit through harbor waters.

Ontology of events

Given the domain setting, in this case ship movements in a harbor, an ontology of events is developed to describe events that are the basis for the STENS. For example, our ontology includes among others:

Illegal zone events – these events occur when a ship attempts to transit a zone contrary to the directional constraint of the zone.

Unexpected zone events – these events describe when a ship does not enter the expected next zone but some other zone signaling a change from the expected ship's movement pattern.

Unexpected destination events – describes cases where a ship does not go to its declared destination zone.

These events emphasize the spatial aspects of ship movement but other events in the ontology capture temporal aspects, for example, *overtime zone events* are generated when the time a ship has been in a zone exceeds the maximum time attribute of this zone. This type of event could signal a ship breakdown or something else unexpected.

A completed ship movement, i.e., from offshore to destination or *vice versa* is described by a completed sequence of zones or *transit*. Transits capture all zones encountered by a moving ship as well as zone-related events. Transits are useful for data mining, for example, patterns are revealed of *unsuccessful transits* where ships did not reach their declared destination zones but had to use alternative destinations; *aborted transits* that describe cases where ships enter a harbor and exit again without approaching their declared destination; illegal transits refer to transits where an illegal zone event occurred. In addition, patterns such as *successful transits* where ships reach their intended destinations and *preferred transits* that include no occurrences of unexpected zone events can also be retrieved from the ship movement data.

Matching events from the ontology with domain events

An event notification system provides a means for users to request that they be notified should certain conditions be fulfilled. Here we describe different types of spatio-temporal event patterns that a STENS user might request based on our event ontology for a harbor.

In the first case, a user might be interested in receiving notification for any of the events in the ontology as single events involving one or more objects (i.e., ships). A ship's movement through the harbor can be monitored for any one of the event types given in the underlying ontology of domain events. A more realistic setting has notifications based on events involving multiple objects. For both these cases—single objects or multiple objects—we are interested in matching events and exploiting spatial and temporal aspects of the scenarios. Possible spatio-temporal combinations include:

- Different events that occur at same time but in different places
- Different events that occur at same time and same place
- Different events that occur at different times but same place
- Different events that occur at different times and different places
- Same events that occur at the same time and same place
- Same events that occur at same time but in different places
- Same events that occur at different times but in the same place
- Same events that occur at different times and different places

For example, a notification occurs if *unexpected zone change* events, associated with two different ship movements, occur from the same zone within a given time span. (i.e., 2 different ships vary from their expected travel sequence at the same place in the harbor at different times). The semantics of these categories allow for notifications based on simultaneous events and duplicative events.

Extending our model further allows for combinations of events such that sequences of events underlie the notifications. These sequences may hold for single objects, for example, if a ship is not under command and is drifting into oncoming traffic (a *not under command* event followed by an *illegal zone change* event) or for two or more objects. The events in the ontology are compared to events extracted from the domain data to learn whether any matches exist signaling that some or all of these events have occurred.

Conclusions

A spatio-temporal event notification system is a useful tool for knowledge discovery, assisting users in uncovering patterns of events within their domain. It is particularly useful for alerting users to unexpected or undesirable events allowing users to take action and prevent these events from actually occurring or facilitating speedier remedies. We use harbor traffic movements as an example scenario for generating events, but the ideas are more generally applicable. There are a number of open research question related to this topic that require further study.

References

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