The Dynamic Spatio-Temporal Evolution of Hot-Spots – A Case Study into the GeoSpatial Aspects of Alcohol-Related Crime

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Extended Abstract

Macro-Level Analysis with Aggregates

Modelling and analysis of dynamic geospatial phenomena has emerged as a major research topic within the GIS community. Although present representational and analytical apparatus to examine the dynamics of such phenomena is nascent at best, the issue is increasingly being considered as a major research priority in the GIS area [Yuan et al., 2004]. In this context, our research is concerned with a macro-level analysis of a certain class of geospatial phenomena that can be modelled as *clusters* in space and time. We focus on the qualitative modelling and analysis of such spatial clusters (and their spatio-temporal evolution) that are representative of a wide range of geospatial phenomena in disparate domains such as crime analysis, wild-life biology, epidemiology, transportation planning, urban growth analysis etc. Clusters, popularly known as *hot-spots*, refer to the aggregation of raw locational data denoting sites of high incidence concentration, with an incidence typically denoting the spatio-temporal location of *events* or of *objects*. Although hot-spots have been used in different ways, varying only in the level of spatial analysis, it is commonly understood that hot-spots are regions of greater than average order/disorder (see [Eck et al., 2005] for a general introduction).

Qualitative Modelling of the Spatio-Temporal Evolution of Hot-Spots

Hot-spot identification techniques have received increasing attention both in specialised domains such as crime investigation and epidemiology [Eck et al., 2005, Levine, 2002, Ratcliffe and McCullagh, 1999] as well as within the general GIS research priority programme [Getis, 2002, Yuan et al., 2004]. However, whereas there has been considerable progress in quantitative hot-spot identification methods (e.g., STAC, heirarchical and k-means clustering etc.), there is little research into representing and reasoning about the patterns of their dynamic spatio-temporal evolution[1] from a qualitative analysis viewpoint – spatial relations or constraints existing between aggregates of the domain attributes are often most naturally represented and understood in qualitative terms, e.g., we may wish to specify that a certain hot-spot of criminal activity always *emerges* only in *regions* of a particular *type*. Furthermore, visual analysis (map based density distributions or point-based plotting of events, time-series etc.) of the available data is not sufficient – what is needed is an interactive query interface that can identify useful qualitative (cognitively adequate) spatio-temporal relationships between the available data attributes and the patterns (of the evolution of the said spatio-temporal relationships) resulting thereof. Finally, it must be emphasized that qualitative approaches are computationally efficient in comparison to precision oriented numerical or quantitative techniques, such as those from the field of computational geometry. This is because qualitative techniques discretisize the domain of continuously (and infinitely) varying quantities into a finite relational space by making only as many coarse distinctions as necessary for a given problem. This is especially important (in the context of a query-based system) since the available quantitative data (which is constantly updated) needs to be analysed for various purposes such as managerial decision making, policy formation or in the context of our application scenario: everyday policing.

Mereo-topological Analysis of Alcohol-Related Crime

Using a mereo-topological [Randell et al., 1992] theory as the basis of spatial information representation, the aim of this research is to develop a framework for the modelling and analysis of hot-spots and their patterns of spatio-temporal evolution. The study is being conducted in the context of data relevant to

[1] Most geospatial phenomena (involving people) are influenced by many other aspatial factors – socio-economic & political, cultural, psychological etc. In this study, we are only concerned with a strictly spatio-temporal analysis of the geospatial phenomena in question.

alcohol outlet distribution and alcohol-related incidence available from Police and other government sources. Specifically, the following data is available:

- The location of liquor-outlets as well as alcohol-related offences (such as an arrest for drunken behaviour).
- Temporal information relevant to the opening hours of alcohol distribution outlets (pubs, clubs, liquor-shops etc) and the time of an offence.

The dynamics of the evolution of hot-spots, essentially based on the continuity constraints and consistency of the mereo-topological relations, will be modelled using the situation calculus [McCarthy and Hayes, 1969], which is a general formalism to reason about dynamically changing domains. Previous and on-going work [Bhatt et al., 2006a,b] has focussed on the development of a *causal* perspective (encompassing events, actions and their effects) to qualitative spatial reasoning in the situation calculus with a broader aim to integrate qualitative spatial reasoning with reasoning about actions and change (i.e., integrating events, actions and their effects in the overall spatial reasoning process). The result is essentially a formal framework to represent and reason about dynamically changing (RCC-8) topological relationships whilst at the same time exploiting the structure & semantics of the situation calculus for modelling important computational tasks such as spatial planning, causal explanation (extracting events/actions that may have *caused* observed spatial changes) and spatial simulation. In this study, we are concerned with identifying and representing useful patterns of spatio-temporal evolution of hot-spots for the alcohol domain under consideration. We formally define a set of domain specific patterns characterising the manner in which certain topological relationships between regions evolve over a period of time so as to encompass behaviour such as *emergence*, *growth* & *shrinkage*[2], *disappearance*, *spread*, *stability* etc. Furthermore, it will also be possible to develop (macro) definitions involving the sequential/parallel composition of the behavioural primitives aforementioned, e.g., *emergence followed by growth, spread and stability or disappearance* during a time-interval. Note that growth and spread may happen at the same time and certain macro-patterns may be *periodic*, e.g., a incidence hot-spot region may emerge, grow and/or spread and then disappear and the entire pattern may *repeat* itself at various temporal scales (certain time of day, week, month etc.).

A generalisation of our causal approach, facilitating causal explanation, is useful for modelling and analysis in a wide range of geospatial phenomena or even in a real-time system involving the surveillance of spatial scenes where certain observable spatial changes can be directly linked to known actions or events. Additionally, this approach can also account for the teleological/purpose-directed aspects of spatial change, i.e., inferring purpose from observed change or prescribing change (spatial re-configuration) based on purpose. Note however that this is based on the premise that there is indeed such a teleological aspect to the

[2] A notion of the n-dimensional measure of a region, consistent with the mereo-topological primitives, will be used to define qualitative size constraints [Gerevini and Renz, 2002] between regions.

spatial changes being modelled per se. The rich ontology (events, actions, and a general mechanism to formalise change) of the situation calculus formalism and our representation of spatial reasoning lends itself to useful computational tasks such the one discussed here. In the context of the case-study (alcohol-domain) under consideration, *causal analysis* refers to functionality that enables us to derive a event-based model of the spatio-temporal evolution of clusters of the available data attributes and identify their resulting patterns thereof. Additionally, by relating observed events and patterns to distinct (macro-level) determinants such as alcohol policy measures that can be interpreted spatio-temporally (e.g., increase in outlets, changes in outlet-operating hours, increased/reduced policing in certain areas etc), the approach will also be useful toward useful hypothesis generation.

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