MODELING GEOGRAPHIC AWARENESS OF ROAD NETWORKS

FOR CONSISTENCY VERIFICATION

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to my

FAMILY

with love

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by

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Abstract

Problems related to transportation and inspection of valuable or sensitive assets such as commercial products and materials, cultural items and works of art, and hazardous materials share similarities and can be modeled by a core set of abstract entities including a payload, a vehicle, a driver, and an inspector. To make the load-handling capabilities of security monitoring and inspection systems more scalable, security can be increased by reducing the variability of transportation routes to a finite set of authorized routes between trip origin and destination locations. Then trip anomalies, which are unexpected trip variations, can be used in inspection targeting criteria. In addition, the effectiveness of the inspection sampling rate can be increased by always inspecting trips with unjustifiable anomalies and fulfilling the remainder of the sampling rate with other trips. While some anomalies can be automatically detected by vehicle tracking systems, other anomalies can be detected by inspectors based on information provided by drivers. This creates a need for an independent objective verification of the quality of the information provided by the driver, as this information can be used to detect transportation anomalies and, in some cases, justify the anomalies to avoid costly inspections. This thesis proposes the use of a geographic awareness modeling (GAM) system to determine whether route-following anomalies of monitored vehicles can be justified by driver detection of adverse road conditions. While current GIS applications provide geographically accurate representations of a road network, they do not provide mechanisms or information to corroborate or contradict scenarios describing trip conditions along a given route. This thesis also presents a design and one implementation of a GAM system which can provide independent, reliable verification of route-related information provided by vehicle drivers. A benefit of implementing such a system would be to complement the expertise and the experience of inspectors to increase the effectiveness of inspection targeting policies and sampling rates.

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Chapter 1

Introduction

Logistic monitoring environments in which vehicles must follow preassigned routes due to concerns such as scheduling control, fuel efficiency, environmental protection, and vehicle or cargo security, must detect and deal with route deviations, as they may represent increased operational costs or risks. In addition, cases in which deviations can be justified may be handled differently from the way cases without a justification are handled. In the former case, driver road awareness modeling can be used to determine if route deviations of monitored vehicles are justified by driver detection of adverse road conditions. In this case, road conditions of interest would be detected by the driver of the monitored vehicle in a route region ahead of the monitored vehicle current location. For instance, conditions such as traffic accidents, traffic congestions, road blockage due to maintenance, and weather-affected road segments could be justifications for route deviations, provided that the vehicle driver can see such conditions in time to divert from an authorized to another authorized route.

This thesis presents a geographic awareness modeling (GAM) system which can analyze the effects on a road network of events related to weather conditions, road traffic conditions, and other conditions on a trip instance in order to determine if a route deviation may be justified. While current GIS applications provide geographically accurate representations of the road network, they do not provide mechanisms or information to verify the consistency of trip descriptions along a given route. In addition, other sources of information, such as weather reports and road traffic reports, only provide aggregate data which identifies affected zones, but such sources do analyze the effect that such zones can have on a specific trip instance description. The GAM system is based on a stratified representation model

where the base stratum is provided by standard GIS information and the upper strata provide ancillary information that helps to create a complete analysis context for a trip instance.

The GAM system models a monitoring environment by using trip descriptions as independent analysis targets. A trip description, which may include information about the vehicle, the driver, the cargo, the source, the destination, and so on, is instantiated in the system with default or preassigned information for all of the instance attributes. Once the vehicle arrives at a trip inspection point, information collected while the vehicle is in route is compared to information captured during trip instantiation to assess the risk or threat level associated with the trip, i.e., actual data is compared to expected data. The architecture of the GAM system is based on stratified semantics where every stratum models and makes available information for upper strata. Models in a given stratum have independent semantics from those on other strata but they also provide the building blocks for upper strata models. While the lower strata information is modeled through a geographic information system (GIS), information in the upper strata is modeled in a knowledge base. Between the lowest stratum and the highest one, models transition from points in longitude-latitude coordinates to road networks and trip routes and from trip data to trip descriptions that can be analyzed to assess the trip threat level.

The interdisciplinary study of statistics, mathematics and computer science provide the foundation for geographic information science which, merging database and software technology with cartography, has produced geographic information systems. A GIS enables the user to represent spatial data of geographic objects (e.g. mountains and rivers in a region), maps (e.g. political boundaries) and demographic data (e.g. city population and road networks) in the same space while keeping relationships between objects in the data. The user can query and analyze the system to obtain information concerning both regular data and geographic data. For instance, a simple query would be the following: find all the gas stations where gas price is lower than 2.95 dlls per gallon within a radius of 20 miles from a specific geographic location. Query results could appear in a map for the

user to visualize. Applications of GIS include urban planning, archeology, and resource managing and logistics. A problem with GIS is that beginning users face a steep learning curve to learn how to operate such systems, as many GISs require the end user to become familiar with technical details of data representations and formal ways to query data and get reports.

The GAM system is focused on solving a problem which requires the strong spatial analysis included in a typical GIS and using the resulting data to infer potential risks or threats associated with transportation of mission critical assets. For instance, transportation of hazardous materials, cultural assets, unique objects, or expensive merchandize requires close monitoring. A logistic monitoring environment which must track the shipped cargo can rely on precise timing to satisfy its monitoring goals. However, the monitoring system must also take into consideration delays and route deviations in order to account for the impact of allowable events in the road network. For instance, a cargo vehicle driver might be forced to deviate from a preassigned route due to obstacles such as road work or accidents. A monitoring system must detect and deal with route deviations through strategies such as recommending cargo inspections or justifying the deviations to reduce or eliminate the need to perform cargo or vehicle inspections.

Any route deviation should be justified and the validity of the justification provided must be verified. The ability to prove if a driver could see a possible obstruction on the road ahead plays an important role in the justification validation.

This thesis presents a novel approach to solve the logistic monitoring problem described above using a GAM system based on GIS technology, analysis of visibility on a road network through line of sight computations, detection of route deviations and validation of deviation justifications through logical inferences, and visualization of inferences by a proof visualization tool.

This thesis is organized as follows: Chapter 2 presents theoretical concepts used as a basis for the work presented in this thesis. Chapter 3 discusses related research. Chapter 4 presents the solution approach and algorithms introduced by the GAM system. Chap-