Spatio-temporal Information in Intelligent Transportation Systems[1]

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The impact of Computer Science (CS) and Information Technology (IT) on transportation systems is not as dramatic as the one on finance or business in general. But in the last few years we have witnessed significant penetration of IT in surface transportation. Navigation systems with real-time traffic information and route planning capability, color coded traffic maps, and real-time information displays about public transport vehicles (e.g. nextbus and CTA's bus-tracker) are some examples of the improvements in urban transportation brought by IT. The rapid advances in mobile and ubiquitous computing and sensor networks are opening opportunities to revolutionize large complex systems, including transportation. Indeed, the purpose of the IntelliDrive^SM initiative of the U.S. Department of Transportation is "advancing connectivity among vehicles and roadway infrastructure in order to significantly improve the safety and mobility of the U.S. transportation system" [1]. Related developments are the emergence of increasingly more sophisticated geospatial and temporal information management capabilities, and advances in social networking and data mining research. These factors have the potential to dramatically alter traveler services, and the provision and analysis of related information.

In the envisioned environment, cars, trucks, public transportation vehicles, travelers, and the infrastructure will collectively have billions of sensors that can communicate with each other. The challenge we address is to integrate these sensors into a collaborative computing and communication environment, producing a sea change in the overall safety, energy consumption, and environmental impact of transportation, while preserving privacy and security. Overall, this environment will enable numerous novel applications and improvements of several orders of magnitude in the performance of existing applications. Some examples of novel applications are vehicle-to-vehicle and vehicle-to-intersection cooperation for safety improvement, road condition warning (e.g. anti-lock-brake system in a vehicles disseminating information about a detected patch of ice), curve/rollover warning, information about weather affects on visibility and road conditions at meters resolution, parking location assistance, incident information.

To build the environment and applications, we need effective information management systems, communication protocols, software tools and services, and research into the socio-technical aspects, human computer interactions, institutional policies, and the social impact of technology. These must be flexible, provide required latency for time-critical applications, security and privacy; and support multiple levels of granularity, precision, and accuracy.

Recent advances in data mining, spatio-temporal, mobile and sensor databases, wireless and social networking provide a starting point for the work. However, in spite of the recent advances, there still are no effective methods that take environmental issues such as pollution, energy conservation into consideration. For example, identifying environmental friendly driving patters, route planning, traffic planning and public transportation scheduling have not been well researched. Similarly, there still are no sound and accurate techniques for fusion of information from multiple sensors generating heterogeneous data generated at multiple levels of granularity,

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[1] Research supported by NSF awards DGE-0549489, IIS-0957394, and IIS-0847680

e.g., there are still no modeling abstractions for integrating distinct views of the same scene (e.g., an intersection) or representing transportation systems at granularities that range from individual vehicle sensors to metropolitan-wide regions. Existing systems cannot cope with the dynamism and scale of transportation environments. Advances in social networking and crowd sourcing have novel uses in transportation systems that need to be understood and taken into consideration. The main data management research areas are:

Route Planning (Routing), Navigation, and Tracking. This area studies methods of routing, navigation, and tracking in transportation networks (the spatio-temporal database) that may involve multiple modes such as train, bus, private car, and bicycle. Optimization criteria are traditional such as time, distance, and cost, but may also involve environmental and energy aspects. For example, the requested route should minimize exposure to, and/or generation of, pollution. Data models, query languages, and processing algorithms are key research issues. The maintenance of dynamic, up-to-date, and reliable travel time and incident information is another important research issue.

Abstraction of concepts from spatio-temporal sensor data. This area studies mining techniques for analyzing vast amounts of data related to moving objects. For example, map matching (i.e., matching the GPS traces of a traveler to the road network) extracts route information. A higher level abstraction would be extraction of semantic location and activity knowledge from GPS traces, possibly augmented with other information such as visited-web-sites lists. This will improve the accuracy and efficiency of household activity surveying for transportation planning, and also feed into location-based-services.

Mobile peer-to-peer data management. This area studies the problem of querying and dissemination of spatio-temporal traveler information via short-range wireless communication among vehicles, pedestrians, and road side facilities. The spatio-temporal traveler information includes, for example, accidents, transit vehicle on-time performance, parking availability, and ride share opportunities. The key research issue is query processing in a distributed and mobile ad hoc environment, without data-directory services. Bandwidth, energy, and memory constraints complicate the problem.

Social networks and crowd-sourcing. This area studies techniques based on social networks to crowd-source information that is valuable to travelers, traffic administrators, and long-range transportation planners. For example, traffic congestion, parking slot availability, ride share opportunities, and cooperative driving information will be obtained and disseminated via (possibly ad hoc) social networks. A major research issue is providing incentives for participation.

Research into the above issues is part of our NSF-sponsored Computational Transportation Science IGERT program. This is an interdisciplinary PhD program that addresses novel Computer Science approaches to improve surface transportation.

Further Reading:

[1] Research and Innovative Technology Administration. ITS Strategic Research Plan, 2010-2014. Executive Summary. http://www.its.dot.gov/strat plan/pdf/ITSStrategicResearch Jan2010.pdf

[2] J. Booth, A. P. Sistla, O. Wolfson, and I. Cruz. A Data Model and Query Language for Urban Transport Systems. *12th Int. Conf. on Extended Databased Technology*, Mar. 2009, pages 994-1005.

[3] O. Wolfson and B. Xu, Spatio-temporal Databases in Urban Transportation, *Bulletin of the IEEE Computer Society Technical Committee on Data Engineering, Vol. 33, No. 2, Issue on New Frontiers in Spatial and Spatio-temporal Database Systems,* June 2010.