OSGeo Journal

The Journal of the Open Source Geospatial Foundation — Volume 3 / December 2007

Proceedings of FOSS4G 2007

Integration & Development

- Portable GIS: GIS on a USB Stick
- Automatic Generation of Web-Based GIS/Database Applications
- db4o2D — Object Database Extension for 2D Geospatial Types
- Google Summer of Code for Geoinformatics

Topical Interest

- A Generic Approach to Manage Metadata Standards
- Towards Web Services Dedicated to Thematic Mapping
- Interoperability for 3D Geodata: Experiences with CityGML & OGC Web Services
- A Model-Driven Web Feature Service for Enhanced Semantic Interoperability
- Spatial-Yap: A Spatio-Deductive Database System

Case Studies

- DIVERT: Development of Inter-Vehicular Reliable Telematics
- GRASS GIS and Modeling of Natural Hazards: An Integrated Approach for Debris Flow Simulation
- A Spatial Database to Integrate the Information of the Rondonia Natural Resource Management Project
- GeoSIPAM: Free & Open Source Software Applied to the Protection of Brazilian Amazon
- The Amazon Deforestation Monitoring System: A Large Environmental Database Developed on TerraLib and PostgreSQL

Case Studies

The DIVERT Project: Development of Inter-Vehicular Reliable Telematics

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Introduction

The advent of wireless ad-hoc car-to-car (C2C) networks, i.e. groups of spatially-aware vehicles equipped with the ability to communicate over the ether and to self-organize into a collaborative mesh, opens a myriad of possibilities towards sharing and exploiting highly dynamic geospatial information. The CAR 2 CAR Communication Consortium Manifesto (1) describes several scenarios where these networks are used for purposes such as the improvement of driving safety (2), optimization of traffic efficiency or to provide information and entertainment to the driver. Examples of safety applications are *cooperative forward collision warning* (see e.g. (3)), *pre-crash sensing/warning* or *hazardous location notification*.

Regarding traffic efficiency, applications include *enhanced route guidance and navigation*, where equipped vehicles use information collected either from road infrastructures of from other vehicles about current traffic conditions to calculate optimal routes to destinations. Another application is the *green light optimal speed advisory*, where a traffic sign is able to transmit to vehicles the optimal speed to make their driving smoother and avoid stopping. Similarly, wireless communication between nearby vehicles can provide a *C2C merging assistance* to allow cars to join flowing traffic without disrupting it.

Wireless ad-hoc C2C networks will also enable applications not directly connected to safety or traffic efficiency, such as *point of interest notification* broadcasted to vehicles from local businesses or tourist attractions, or *remote diagnostics* of vehicles. Another application will be *internet access in vehicle* through the C2C network, allowing multi-hop routes to internet access points.

The deployment of a C2C network and its applications face some relevant challenges. It is clear that an inter-vehicular communication technology requires a significant distribution in the market before it can show any effect. The C2C Communication Consortium has estimated a required penetration rate of about 5% to enable traffic information propagation. A reluctant introduction may prevent potential new customers from equipping their vehicles with such communication systems. The scalability of the C2C communication system is another important issue that has to be studied. The system must work in scenarios with very small density of road traffic and in situations with a very high traffic density, which cause different technical challenges. The

development of collaborative navigation protocols is another major challenge faced by C2C networks. The goal of propagating traffic information is to allow vehicles to dynamically calculate the fastest route to their destination. Clearly, such dynamic calculation must be based on inter-vehicular collaboration, diverting routes in a global optimization perspective of the road network.

Given these challenges and the complexity in modeling the mobility behavior of large-scale distributed traffic systems (see e.g. (4)), the development of realistic simulation tools is arguably a vital element towards the success of the implementation of a C2C network. Motivated by this need, we present an open-source real-time simulation framework for moving vehicles in different road environments, that includes multiple driving states, inter-vehicle communication and sophisticated visualization. Our simulator provides the basis for a systematic approach towards quantifying the performance trade-offs between relevant metrics such as transmission radius, fraction of communicating vehicles, freshness of data, and network connectivity, thus highlighting the dynamics of cooperative navigation.

The DIVERT Simulator

From an abstract point of view, the road network can be seen as a large graph, whose topology is static and determined by geography, on top of which we have a random communications graph, whose spatial realization and connectivity pattern at each point in time is determined both by the position of the vehicles moving on the road network and by the transmission aspects of the wireless interface they use to communicate. To obtain a realistic road graph model, we may resort to increasingly available geospatial information, whereas the wireless transmission characteristics have been the object of intense study yielding useful random models with varying complexities (see e.g. (5)). Given these two aspects, we structured our simulation prototype (named DIVERT - Development of Inter-VEhicular Reliable Telematics) in two layers: a traffic simulation layer based on the road network graph; and a wireless telematics layer, based on the random communications graph. We next describe these layers.

Traffic Layer

The geospatial information over which the traffic simulation layer operates is conveyed to DIVERT using widely used formats, such as shapefiles, which describe the geometry and connectivity of the road network. DIVERT includes a sophisticated user interface which allows editing the basic road segments enriching them with low-level information describing traffic entities. A screenshot of this interface is shown in Fig. 1.

Currently, DIVERT has been setup using geospatial information of the city of Porto, the second largest in Portugal. Its road network covers an area of 62 square kilometers, with 1941 streets summing up to 965 kilometers of total length.

In DIVERT we model two types of vehicles: vehicles which circulate and communicate, called *sensors*; and vehicles which just circulate. Within each type of vehicle, DIVERT further distinguishes in normal and large-sized vehicles, associating appropriate mobility patterns to each. These mobility patterns are also individually influenced by random initialization of attributes such as acceleration, braking, aggressiveness and risk tolerance. Sensors add an attribute of wireless transmission range.

DIVERT uses the following layers of geospatial information about the road network:

1. Two simple layers of the road central axles, representing, through polylines, the geometry of intersection free road segments, and their topological connectivity. These layers can be given to DIVERT as shapefiles. A copy of these layers is present in every sensor, and is used for positioning of GPS readings and for the collaborative propagation of mobility conditions on road segments.
2. Low-level layers describing in detail the road network of Porto, including information of road segment lanes, lane-level connectivity, intersection visibility, traffic lights location, traffic lights inter-relationships, speed limits on segments, and parking. These layers must be edited through the DIVERT interface and are used by the traffic simulator.

A raster layer from satellite images of the simulation area further improves the visualization of traffic in our prototype, which is currently based on 2D data. Work is undergoing on a 3D model, which will not only allow more realistic accelerations parametrized by steepness, but also enable an improved modeling of wireless transmission ranges, which accounts for fading, reflection and shadowing effects based on a 3D layer for buildings.

Regarding vehicle routes, DIVERT currently uses an hybrid model of pre-defined routes and randomly

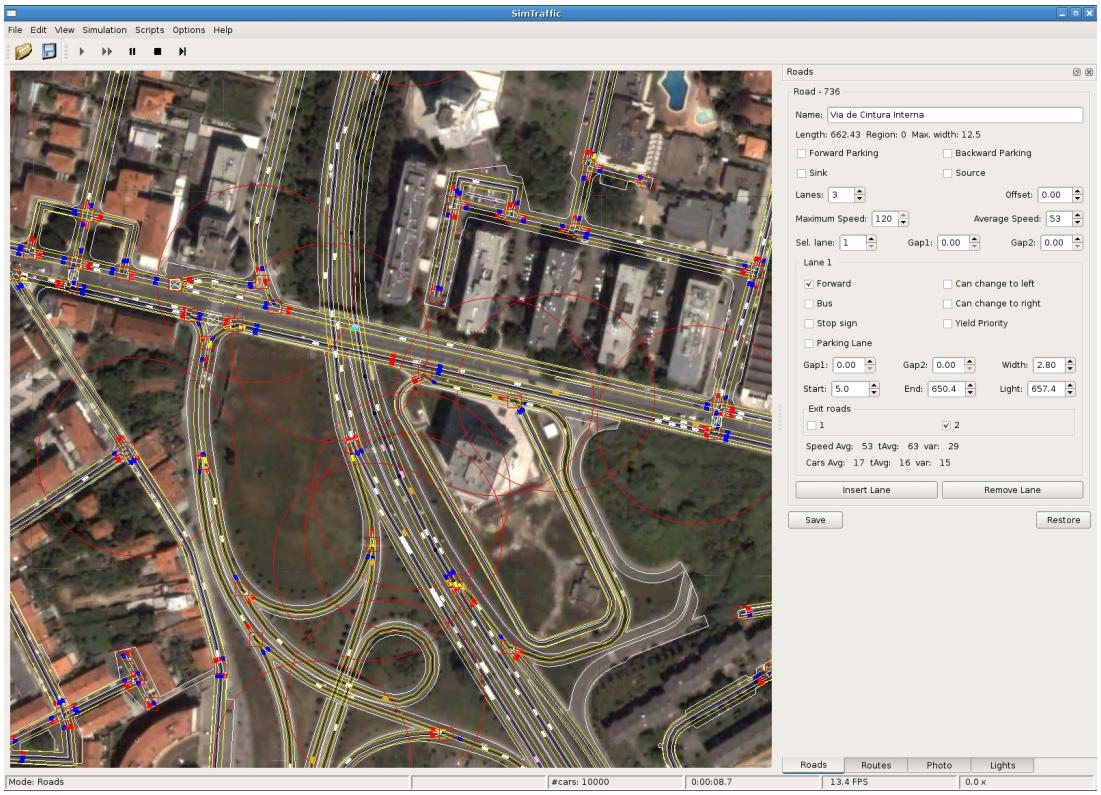

Figure 1: The DIVERT road editing interface

generated routes. For randomly generated routes, our system arbitrarily selects an origin and a destination and calculates the route based on a shortest-path algorithm, either parameterized by distance or by time. Shortest-path based on time uses not only the speed limits of segments, but mainly the dynamic calibration of average mobility derived from previous simulation results. Pre-defined routes have an associated frequency and have been carefully chosen to approximate the simulation to our perception of traffic distribution in our current work case, the city of Porto. Figure 2 shows the DIVERT interface for setting up a pre-defined route.

Traffic simulation is parameterized by the number of vehicles and the percentage of these vehicles which are sensors. Simulation is initialized by randomly placing each vehicle in an arbitrary point of its route. Vehicles which arrive at their destination are removed. New vehicles also show up during the simulation, either from entry points in the map, or from parking lanes of segments, as DIVERT tries to maintain the targeted number of vehicles for the simulation.

It should be noted that the simultaneous micro-simulation of thousands of vehicles, with the degree of sophistication offered by DIVERT, poses major challenges in term of optimization of algorithms and efficiency of data-structures. In particular, DIVERT implementation is multi-threaded, exploring multi-core architectures of current processors. A geographic partitioning of the simulation region is performed, allowing each partition to be independently simulated in a thread.

Wireless Telematics Layer

In order to capture the inter-vehicle communication aspects it is necessary to define the level of abstraction with respect to the physical communication channel and the protocol architecture. At the current preliminary stage, we opted for a very simple model, in which vehicles communicate with each other if their distance is below a certain threshold, determined by the transmission radius. The resulting random geometric graph is widely accepted as a simple yet reasonable first-order approximation of the connectivity pattern attained by a mobile ad-hoc network (6). A more elaborate approach would be to consider path loss, multi-path and shadowing effects, however this would incur in a high penalty

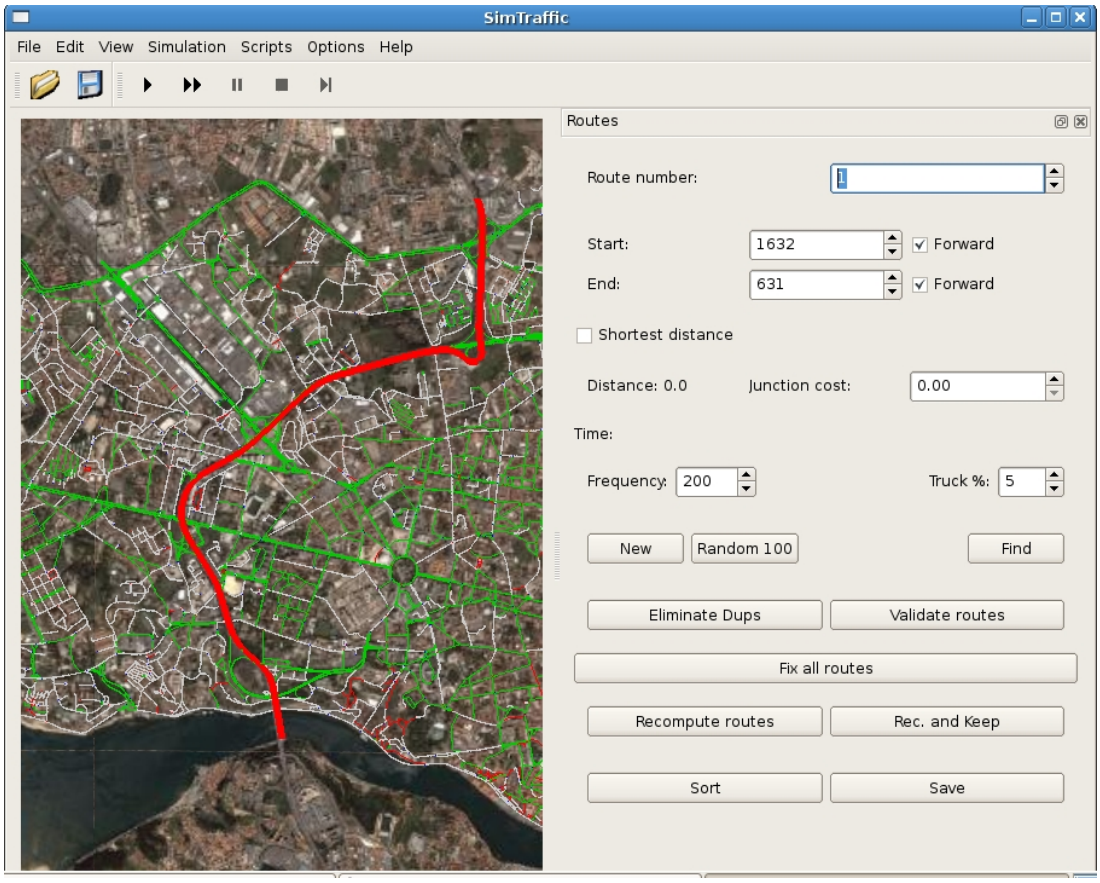

Figure 2: Setting up pre-defined routes in DIVERT

in terms of simulation complexity. Another alternative would be to consider collisions and packet losses over the wireless medium. We are currently considering the possibility of integrating these aspects in our simulation in order to obtain a richer connectivity profile.

The wireless telematics layer simulates the communication between vehicles. Several inter-vehicular protocols can be implemented in this layer, such as protocols for safety applications or for traffic conditions propagation and collaborative navigation. The implementation of this wireless telematics layer is supported by the traffic simulation layer, which acts as a global positioning server, emulating a GPS receiver in each of the sensors. The interface between the two layers is thus done through GPS-like sentences, where the traffic simulator generates the position of each sensor, in terms of latitude and longitude, and its velocity vector, together with a global timestamp which provides the time-synchronization among the inter-vehicle data exchange. It is a task of the wireless telematics layer to calculate the vehicles in the (parameterized) transmission range of a given sensor, to implement the message exchange protocols between vehicles, and to trigger actions based on the information collected, such as a route modification. The architecture of the two layers in DIVERT allows that a triggered action such as route modification can be conveyed back to the traffic simulation layer, affecting the behaviour of the vehicle.

Currently, the protocols we have implemented using DIVERT aim at the collaborative propagation of mobility information about road segments. Each sensor stores a common data structure, where the pair $(AverageSpeed, Freshness)$ describes the average speed attained by sensors traversing each of the road segments, together with a quantification of the timeliness of average speed estimate. These pairs are updated either by each sensor based on the road it is traversing and its GPS information, or by aggregated information collected from the wireless communications broadcasted by other sensors. Typically, sensors only transmit information about road segments for which the freshness value is above a predefined

threshold. DIVERT is able to simulate the propagation of this mobility information using different wireless transmission radii. Our results show that there exists a critical value for the transmission radius after which the dissemination of traffic information is sufficient for a large number of vehicles to be able to compute a comprehensive and accurate congestion map. This observation is strikingly related to the physical phenomenon of percolation, which is well known to govern the connectivity of large classes of wireless networks (7). Once the transmission radius is above the critical threshold, the graph representing wireless connectivity has a giant component on which traffic information flows very fast and over long distances.

Future Developments

DIVERT is under constant development. Currently the implementation lists 50000 lines of C++ code, including the graphical interface and visualization component. The DIVERT interface also allows launching simple programs written in Python, which are very useful to make the simulator produce several types of reports, generate videos of a simulation or help in the edition of maps. A redefinition of the simulator architecture in several independent modules is undergoing. Our goal is to have a larger number of independent modules which will make it simpler for a large community of users to modify the simulator to their specific needs.

A particular effort is being put on the development of a specification language that will allow making easier the setting up of DIVERT with different geospatial data. The geographic layers underpinning the simulation are already based on open standards, but there are still a number of areas where the lack of automation constitutes an obstacle to the wide use of DIVERT. In particular, the realistic calibration of routes and their frequency is a crucial problem. We are trying to approach such automation through the analysis and processing of cellular phone logs, a technique known as *floating car data*, which in urban environments are able to provide high-precision descriptions of travels in the road network. The automation of the construction of realistic origin/destination matrices, together with geospatial data defining the road network based on widely used standards, would provide the necessary data to test DIVERT in different scenarios.

We will continue designing, implementing and testing different protocols for inter-vehicular communications through DIVERT. Our focus will continue to center in traffic efficiency, where we have been able to find challenging problems related to collaborative optimization of traffic flow. We hope to see alternative protocols developed worldwide using the DIVERT framework, in all areas of C2C communication.

For those who missed the FOSS4G2007 DIVERT demonstration, a video of a simulation is available online.[23]

Acknowledgments

We would like to thank the Porto City Council for providing us with the maps of the road network. This work has been partially supported by the Portuguese Foundation for Science and Technology (FCT) under project MYDDAS (POSC/EIA/59154/2004) and by funds granted to LIACC and IT through the Programa de Financiamento Plurianual and POSC.

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GRASS GIS and Modelling of Natural Hazards

An Integrated Approach for Debris Flow Simulation — First results of an application in the Central Andes

Martin Mergili and Wolfgang Fellin

Background

Debris flows are rapid mass movements of water and debris, constituting a considerable hazard when interfering with people, buildings, or infrastructure. They are often triggered by heavy or prolonged rainfall or by extreme snow melt. Mobilization of the material occurs due to translational or rotational failure of saturated or undercut slopes, or by detachment due to surface runoff or the debris flow itself. Various models do exist for simulating sub-processes included into debris flows, for example for detachment (*r.sim.sediment* within the GRASS GIS environment), for soil hydrology and slope stability (14), or for debris flow runout (9; 7). More integrated GIS-based approaches as attempted for example by (1) or (11) are scarce. Such approaches would be valuable for a quick assessment of hydrological thresholds for potential debris flow hazard regarding specified features at risk. This paper describes and discusses the development of such a model as GRASS GIS raster module. The model is designed for small catchments (few square kms) and is tested at the moment with seven study areas along the international road corridor from Mendoza (Western Argentina) to Central Chile, crossing the highest section of the Andes (figure 1). The preliminary results for the study area *Guido A* are presented.

Model

Implementation and model design

The simulation model is implemented as a GRASS GIS raster module called *r.debrisflow*, based on the C programming language. Data management is facilitated using shell scripts. The model is in an intermediate stage of development right now, with major technical and methodical enhancements prospected for the near future. Additionally, a GUI for data management shall be created. By now, the latest development version can be downloaded from the homepage of the first author. *r.debrisflow* constitutes of a framework of a number of sub-modules described in more detail below, the general model design is illustrated in figure 2. The sub-modules can be combined in two different ways, depending on the availability of input information:

Simulation mode 1: The entire hydrological, stability, detachment and runout modelling is executed for a defined number of time steps during a rainfall or snowmelt event, requiring an extensive set of information as input, including

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Acknowledgements
Various reviewers & the GRASS News Project

The *OSGeo Journal* is a publication of the *OSGeo Foundation*. The base of this journal, the LaTeX 2_ε style source has been kindly provided by the GRASS and R News editorial board.

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ISSN 1994-1897

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