INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

Team Imara

Informatique, Mathématiques et Automatique pour la Route Automatisée

Paris - Rocquencourt

THEME NUM

Activity Report

2007

Table of contents

1. Team

Head of project-team
Michel Parent

Vice-head of project-team
Arnaud de La Fortelle

Administrative assistant
Chantal Chazelas [SAR]

Staff members
Philippe Deschamp [CR]
André Ducrot [DR]
Guy Fayolle [DR, HdR]
Jean-Marc Lasgouttes [CR]
Armand Yvet [AI]

External collaborator
Cyril Furtlehner [CR project-team TAO]

Visiting scientists
Oussama Khatib [Stanford University - USA]
Michael Leyton [DIMACS - USA]
José Prades [Université du Québec à Montréal - Canada]
Yoram Zvirin [Technion Institute of Technology - Israël]

PhD students
Rodrigo Benenson [UTFSM]
Yann Dumortier [Univ. Versailles]
Luis Alfredo Martinez-Gomez [ITAM]
Wided Miled [Orsay University]
Olivier Pauplin [Paris V University]
Jennie Lioris [Univ. Orsay]
Manabu Tsukada [Keio University - Japon]

Post-doctoral fellows
Hamada Alshaer [Université Pierre et Marie Curie]
Yacine Khaled [UTC]

Technical staff
Samer Ammoun [ENSMP]
Patrice Bodu [ESE]
Laurent Bouraoui [Project technical staff]
Alejandro Chinea [Project technical staff]
Thierry Ernst [Keio University]
Carlos Holguin [Paris I]
Séverin Lemaignan [Paris V]
Olivier Mehani [UTC]
Adrian Lucas Rogondino [FNAL]
Nicolas Simond [Education Nationale]
Philippe Zhang [ENSMP]

Student interns
Aymen Ben Bouzid [INSAT]
Guthemberg Da Silva Silvestre [GPRT/UFPE]
Hui Fang [SJTU Chine]
Jonathan Gramain [EPITECH]

Jean-Charles Mammana [EPITECH]
François Meric [Université Paris Descartes]
Romain Meson [EPITECH]
Sébastien Miquerolle [EPITECH]
Benjamin Scetbun [EPITECH]
Gaurav Taank [Delhi College of Engineering]
Ahmad Mahmood Tahir [Université de Genova - Italie]
Manabu Tsukada [Keio University - Japon]
Tingkai Xia [SJTU Chine]
Xiaoke Xu [University of Hong-Kong]
Zhiyu Xu [SJTU Chine]
Saber Zrelli [JAIST]

2. Overall Objectives

2.1. Overall Objectives

Keywords: *automated guided vehicle*, *environment*, *transportation systems*.

Imara is a “horizontal” project at INRIA. Its objective is the coordination and the transfer of all the research done at INRIA which can be applied to the concepts of “la Route Automatisée”. In particular, we will develop and transfer the results of a number of INRIA projects in the following domains:

- Signal processing (filtering, image processing, etc.);
- Control of the vehicle (acceleration, braking, steering);
- Communications;
- Modeling;
- Control and optimization of transportation systems.

The goal of these studies is to improve road transportation in terms of safety, efficiency, comfort and also to minimize nuisances.

- **Increase safety of road transportation** It is well known that road transport is not safe. This mode kills hundreds of thousands of people each year throughout the world and in particular young adults. Although safety has improved by one order of magnitude in the last decades through better infrastructure and safer cars, the limits of these improvements seems to have been reached if the travelling speeds remains constant (or are improved as is requested by the travelers). The techniques to improve drastically the safety are based on four approaches:
  - driver monitoring and warning;
  - partial control of the vehicle in emergency situations;
  - total control of some of the functions of the vehicle;
  - total control of all the vehicle.

  The technical approach proposed by Imara is based on drivers aids, going all the way to full driving automation. This is the core of the project’s research effort and our goal is both to demonstrate technical feasibility by creating new concepts of vehicles and to bring new technologies on the road.
- **Minimize energy consumption** Drastic reductions in the consumption of fossil fuels is one of the challenges of the next twenty years. Objectives have already been set for the reduction of carbon dioxide in many countries. Road transportation plays now the dominant role in the consumption of these fuels and the trend is towards great increases through two factors: increase in freight transport by road and very large increase in car ownership in emerging countries. Without a radical departure from existing technologies and practices, the goals set by the states cannot be met.

This goal is not directly a research topic but by promoting new systems of transportation with clean vehicles which can be optimized, Imara contribute to minimize energy consumption.

- **Minimize pollutions and nuisances** In all large cities through the world, air quality is now monitored at frequently unacceptable levels. Noise levels in cities and near highways is the main complain by a large percentage of the population. Citizen are not yet ready to change their habits on a voluntary basis but they are now supporting legislation to curb car usage in cities.

  One of the objective of Imara is to study new transportation modes and in particular to find ways to develop multimodality in order to find the most energy efficient way of satisfying transportation needs. In this respect, simulation and optimization of very complex transportation systems can give an insight of which solution should be deployed and where.
- **Offer a more pleasant living environment** Another nuisance often expressed by urban planners is the space taken by the automobile in cities which is responsible for many problems. The technical solutions to these problems of environment which are studied by Imara are all based on a better usage of the resources: space and energy. It is well known that mass transportation is most efficient in terms of space and energy but not very flexible and that the reverse is true for the private automobile. The solutions lie therefore in three directions:
  – make a better use of existing infrastructures by minimizing congestion and increasing throughput,
  – use a multi-modal approach with the automobile at its proper place when the public transportation cannot offer a good service,
  – develop new public transportation modes close to the service offered by the automobile.
- **Offer new transportation means available to more people** Access to the automobile does not have to be exclusively through private ownership. This mode of access discourage strongly the use of alternative modes (such as public transportation or non-motorized modes) since the marginal cost of each trip is so low (unless penalized by parking cost or toll). New modes of access such as car-sharing, instant rental and self-service are now developed thanks to modern technologies. Imara is strongly engaged in the development of such technologies as the team was involved in the Praxitèle experiment.

The project provides to the different cooperating teams some important means, such as a fleet of a dozen of computer driven vehicles, various sensors and advanced computing facilities including simulation tool.

3. Scientific Foundations

3.1. Sensors and information processing

Keywords: *data fusion*, *evolutionary algorithm*, *image processing*, *laser*, *localization*, *magnetic devices*, *obstacle detection*, *radar*, *sensors*, *signal processing*, *stereovision*, *vision*.

3.1.1. Sensors and single-sensor information processing

The first step in the design of a control system are sensors and the information we want to extract from them, either for driver assistance or for fully automated guided vehicles. We put aside the internal sensors which are rather well integrated. Internal sensors give information on the host vehicle state, such as its velocity and steering angle information. The necessary information from external sensors (laser, radar, image sensors, etc.) is of several types:

- localization of the vehicle with respect to the infrastructure, i.e. lateral positioning on the road can be obtained by mean of vision (lane markings) or by mean of magnetic, optic or radar devices;
- localization of the surrounding vehicles and determination of their behavior can be obtained by a mix of vision, laser or radar;
- detection of obstacles other than vehicles (pedestrians, animals objects on the road, etc.) that require many types of sensors.

Since INRIA is very involved in image processing, Imara emphasizes the vision technique, particularly stereo-vision, in relation with MIT and ENSMP.

3.1.1.1. Disparity Map Estimation

Stereo vision is a reliable technique for obtaining a 3D scene representation through a pair of left and right images and it is effective for various tasks in road environments. The most important problem in stereo image processing is to find corresponding pixels from both images, leading to the so-called disparity estimation. Many autonomous vehicle navigation systems have adopted stereo vision techniques to construct disparity maps as a basic obstacle detection and avoidance mechanism.

We are working on a new approach for computing the disparity field by directly formulating the problem as a constrained optimization problem in which a convex objective function is minimized under convex constraints. These constraints arise from prior knowledge and the observed data. The minimization process is carried out over the feasibility set, which corresponds to the intersection of the constraint sets. The construction of convex property sets is based on the various properties of the field to be estimated. In most stereo vision applications, the disparity map should be smooth in homogeneous areas while keeping sharp edges. This can be achieved with the help of a suitable regularization constraint. We propose to use the Total Variation information as a regularization constraint, which avoids oscillations while preserving field discontinuities around object edges.

The algorithm we are developing to solve the estimation disparity problem has a block-iterative structure. This allows a wide range of constraints to be easily incorporated, possibly taking advantage of parallel computing architectures. This efficient algorithm allowed us to combine the Total Variation constraint with additional convex constraints so as to smooth homogeneous regions while preserving discontinuities.

3.1.1.2. The Fly Algorithm

As an illustration of an innovative approach, we present briefly the Fly Algorithm: an evolutionary optimisation applied to stereovision and mobile robotics.

Based on the Parisian approach, the Fly Algorithm produces a set of 3-D points (the “flies”) which gather on the surfaces of obstacles. Flies are evolved following the classical steps of evolutionary algorithm.

A large number of internal parameters can affect the behavior of the Fly Algorithm. An inappropriate set of parameters can lead to a high convergence time and a low precision in detection. In order to apply the Fly Algorithm to real time and real scene situations, efforts have been made to increase the processing speed of the algorithm and to improve its efficiency through the use of various genetic operators.

The choice of the fitness function plays a crucial role in the detection of obstacles. The comparison of different fitness functions showed that precision can be significantly improved, in particular by adjusting the size of the correlation window used.

Another possible use of the Fly Algorithm could be to use its output as an odometric sensor. The results obtained so far are rather rough, but are not sensitive to the terrain irregularities like the usual odometry.

3.1.2. Multi-sensor data fusion

Advance Driver Assistance System (ADAS) and Cybercars applications are moving towards vehicle infrastructure cooperation. In such scenario, information from vehicle based sensors, roadside based sensors and a priori knowledge is generally combined thanks to wireless communications to build a probabilistic spatio-temporal model of the environment. Depending on the accuracy of such model, very useful applications from driver warning to fully autonomous driving can be performed.

Imara has developed a framework for data acquisition, spatio-temporal localization and data sharing. Such system is based on a methodology for integrating measures from different sensors in a unique spatio-temporal frame provided by GPS receivers/WGS-84. Communicant entities, i.e. vehicles and roadsides exhibit and share their knowledge in a database using network access. Experimental validation of the framework was performed by sharing and combining raw sensor and perception data to improve a local model of the environment. Communication between entities is based on WiFi ad-hoc networking using the Optimal Link State Routing (OLSR) algorithm developed by the HIPERCOM research project at INRIA.

The Collaborative Perception Framework (CPF) is a combined hardware/software approach that permits to see remote information as it own information. The CPF approach permits to a communicant entity to see another remote entity software objects as its own objects. For sensor objects, it permits to see sensor data of others entities as its own sensor data.

CPF relies on a software/hardware approach, a key component of the the hardware part is called the SensorHub (SH). The SH is a sensor gateway with very precise timestamping functionality based on an hardware based approach for fully parallel timestamping. The hardware part is a work done by the Joint Research Unit between Imara and the robotic groups of the CAOR team of the French engineering school École des Mines de Paris (ENSMP). The software part of CPF was developed by a subset of the Imara team; it consists in a Temporal Geographic Information System (TGIS) based on proxies to share information between communicant robotic entities.

The CPF approach was presented at the ITSC conference under the form of a cooperative driving demonstration with four communicant entities, two Cycabs, the LaRA-INRIA vehicle and a static communicant entity on the roadside. An Intersection Collision Warning System (ICWS) application was built on top of CPF to warn a driver in case of potential accident. The ICWS relies on precise spatio-temporal localization of entities and objects to compute the Time To Collision (TTC) variables.

The SensorHub was chosen in complementary with the RTMaps technology by the Localization Groups, a French research group on localization technologies for Advance Driver Assistance Systems. This informal group meet about six times a year. We are contributing to the evaluation of different data fusion methods for spatial localization. Several research groups are involved in the Localization Group: The University of Orsay/IEF group, the French Engineering school École des Mines de Paris, the French Engineering School UTC, the LASMEA, the LIVIC, the LCPC laboratory and Imara.
Associated projects: Sharp, Icare, Complex.

3.2. Control

Keywords: *command*, *control*, *dynamic behavior*, *generating trajectories*.

The task is to develop a command system designed to execute at best the orders given by either the driver (aided by the system) or the automated driving system. The command system sends orders to the mechanical parts of the vehicles using all the information raised by the sensors. For example, one can imagine a steering system that acts not only on the wheels angle through the steering wheel but also on the brakes of each wheel. This would yield a much more secure behavior of the vehicle.

The real difficulty with this kind of control comes from the complexity of the dynamic behavior of the vehicle: response are highly non linear, particularly the response to forces of the tires on various soils. INRIA has a great expertise in these control problems and Imara already demonstrated solutions for automatic driving of platoons of electrical cars. This research is still an active field. We want to enhance the system concerning the speed, the variety of wheel-soil contact. The lateral control problem is also studied, particularly in view of drivers assistance.

Another aspect of command systems is to generate correct trajectories which is another field of expertise for INRIA. These problems deal with obstacle avoidance or with generating complex trajectories in constraint environment (e.g. the parking problem).
Associated projects: Sharp, Icare, Sosso.

3.3. System modeling and management

Keywords: *information*, *infrastructure*, *management*, *modeling*, *multi-modality*, *simulation*, *system*.

The demand of transportation is a rapid growing sector. Even if some big cities try to limit the use of cars, there must be alternate transportation means (e.g. metro, taxi, bus etc.). The challenge to the community and for the research is to propose plan for the long term and solution for the integration of the new techniques into the real world. Since the problem of transportation (and particularly of cars) is most acute in cities, this is the place where we concentrate our research effort. Of course some systems could be then transposed into medium-sized cities or into the countryside.

In each of the following sections, there are 4 steps to achieve a good transportation system:

- measurement and analysis of the traffic,
- modeling of the transportation system,
- analysis of the model using mathematical tools or through simulation,
- optimization of the required performance.

There are several fields where system modeling and management are applied.

3.3.1. Better use of existing infrastructure and vehicles

One of the great challenge of automobile industry and of cities administrations in the next years is to integrate cars in a saturated environment (traffic congestion, parking, etc.). Research is currently done on regulation methods such as passage toll, car park toll, users information and multi-modality. This is a very topical theme as illustrated by the London toll zone. This implies modeling the traffic in urban areas, modeling the behavior of drivers, measuring by mathematical analysis or simulations the results of various scenarios and eventually optimizing parameters (toll, etc.).

Real time infrastructures management is also a problem of resources optimization, but a dynamic one. The question is to control access to avoid saturation phenomena which could make the performance of the system collapse. Studies should be led on real cases, such as for example a by-pass in Paris area.

3.3.2. Designing new infrastructure

With new infrastructures, the problem is to redesign the city transportation system and to measure the improvement linked to another kind of management. Since the space is very rare in central areas, deploying new infrastructures (e.g. tramway) often means replacing part of the existing infrastructures (e.g. roads). This can only be done properly when the impact of the new infrastructure has been correctly analyzed.

3.3.3. Increasing the transportation choice

With the automated road, dimensioning and management of infrastructures are crucial problems. Dimensioning can be approached by techniques of stochastic modeling at the microscopic level or more traditionally by techniques of operational research. Imara has already used successfully these techniques for the Praxitèle program and plans to develop them within the framework of the automated road to provide tools which will make it possible to justify (or to invalidate) the investments.

3.3.4. Telematics system

A growing category of vehicle-infrastructure cooperative (VIC) applications requires telematics software components distributed between an infrastructure-based management center and a number of vehicles. INRIA developed an approach based on a free software component suite under the CeCILL licence. The framework runs inside an infrastructure-based operations center and is conceived to interact with external systems like Advanced Traffic Management or Vehicle Relationship Management.

Hence INRIA framework for telematics provides support for modular, flexible, prototyping and implementation of VIC applications. As a software infrastructure it allows to integrate different decision modules, vehicle-management center communication support and an extensible data module. The pluggable decision modules are the key part of the framework as they incarnate the logic for the VIC applications.

The user of the framework develops and combines such modules for specific applications. A chain of dependencies is provided for each decision module and each module dependency is represented as a directed acyclic graph. The framework determines, through a topological sort over the graph, the correct order of execution. An event system has been developed to maintain low coupling between the software framework and the decision modules interaction. Two decision modules were implemented and validated during an experimentation (Project Mobivip, Nancy, June 2005): trip management for a Cybernetic Transportation System and dynamic traffic modeling.

This work has received the support of the European Commission in the context of the projects REACT and CyberCars.
Associated project: Metalau.

3.4. Probabilistic modeling of large systems

Keywords: *Markov process*, *Statistical physics*, *exclusion process*, *probabilistic modeling*, *thermodynamic limit*, *traffic model*.

This activity is a natural continuation of the research of the Preval team, which joined Imara in 2007. The traffic modeling field is very fertile in difficult problems, and it has been part of the activities of the members of Preval since the times of the Praxitèle project.

Following this tradition, the roadmap of the group is to pursue basic research on probabilistic modeling with a clear slant on applications related to LaRA activities. A particular effort is made to publicize our results among the traffic analysis community, and to implement our algorithms whenever it makes sense to use them in traffic management. Of course, as aforementioned, these activities in no way preclude the continuation of the methodological work achieved in the group for many years in various fields: random walks in Z_n^+, birth and death processes on trees, particle systems. The reader is therefore encouraged to read the recent activity reports for the Preval team for more details.

In practice, the group continues to explore the links between large random systems and statistical physics, since this approach proves very powerful, both for macroscopic (fleet management) and microscopic (car-level description of traffic, formation of jams) analysis. The general setting is mathematical modeling of large systems (mostly stochastic), without any a priori restriction: networks, random graphs or even objects coming from biology. When the size or the volume of those structures grows (this corresponds to the so-called thermodynamical limit), one aims at establishing a classification based on criteria of a twofold nature: quantitative (performance, throughput, etc) and qualitative (stability, asymptotic behavior, phase transition, complexity).

One of the simplest basic (but non trivial) probabilistic models for road traffic is the *exclusion process*. It lends itself to a number of extensions allowing to tackle some particular features of traffic flows: variable speed of particles, synchronized move of consecutive particles (platooning), use of geometries more complex than plain 1D (cross roads or even fully connected networks), formation and stability of vehicle clusters (vehicles close enough to establish an ad-hoc communication system) or two-lane roads with overtaking. Some of these models have already been investigated by members of the group, and they are part of wide ongoing research.

Large random systems are a natural part of macroscopic studies of traffic, where several models from statistical physics can be fruitfully employed. One example is fleet management, where one main issue is to find optimal ways of reallocating unused vehicles: it has been shown that Coulombian potentials might be an efficient tool to drive the flow of vehicles. Another case deals with the prediction of traffic conditions, when the data comes from probe vehicles instead of static sensors. Using some famous Ising models, together with the *belief propagation* (BP) algorithm (fairly popular in the computer science community), we have been able to show how real-time data can be used for traffic prediction and reconstruction (in the space-time domain). Currently, we are in the process of building a full-fledged prototype and we are in contact with companies interested by this approach.

Many of these activities are in cooperation with Cyril Furtlehner from the TAO Project-team, who has been a four-year collaborator of the Preval team. This cooperation is instrumental in the traffic modeling work done at Imara, in particular in terms of application of statistical physics concepts to both microscopic and macroscopic models.

3.4.1. Belief propagation inference with a prescribed fixed point

Participants: Cyril Furtlehner, Jean-Marc Lasgouttes.

In the context of inference with expectation constraints, we analyze the approach based on the BP algorithm, which consists in encoding into a graph an a priori information composed of correlations or marginal probabilities of variables, and to use a message passing procedure to estimate the actual state from some extra information. We show that, within this approach, the inference model is completely determined by the data which we encode, in terms of a prescribed fixed point. Some general properties of BP are established in this context, concerning the effect of normalizing the messages, the relation between fixed points and their stability. In particular, we shed light on the respective effects of the factor graph topology through its spectrum on one end, and the effects of the encoded data by means of the spectral properties of a set of stochastic matrices attached to the data on the other end.

This is a work in progress.

3.4.2. Belief propagation and Bethe approximation for traffic prediction

Participants: Cyril Furtlehner, Arnaud de La Fortelle, Jean-Marc Lasgouttes.

This work [29], [18] deals with real-time prediction of traffic conditions in a setting where the only available information is floating car data (FCD) sent by probe vehicles. The main focus is on finding a good way to encode some coarse information (typically whether traffic on a segment is fluid or congested), and to decode it in the form of real-time traffic reconstruction and prediction. Starting from the Ising model of statistical physics, we use a discretized space-time traffic description, on which we define and study an inference method based on the belief propagation (BP) algorithm. We propose a hybrid approach, by taking full advantage of the statistical nature of the information, in combination with a stochastic modeling of traffic patterns and a powerful message-passing inference algorithm. The idea is to encode into a graph the *a priori* information derived from historical data (marginal probabilities of pairs of variables), and to use BP to estimate the actual state from the latest FCD. Originally designed for bayesian inference on tree-like graphs, the BP algorithm has been widely used in a variety of inference problems (e.g. computer vision, coding theory, etc.), but to our knowledge it has not yet been applied in the context of traffic prediction.

3.4.3. Multi-speed exclusion processes

Participants: Cyril Furtlehner, Jean-Marc Lasgouttes.

We consider in [19] a one-dimensional stochastic reaction-diffusion generalizing the totally asymmetric simple exclusion process, and aiming at describing single lane roads with vehicles that can change speed. To each particle is associated a jump rate, and the particular dynamics that we choose (based on 3-sites patterns) ensures that clusters of occupied sites are of uniform jump rate.

The basic assumption is that if a car gets in close contact to another one, it will adopt its rate. Conversely, if it arrives at a site not in contact with any other car, the new rate will be freely determined according to some random distribution. This models the acceleration or deceleration process in an admittedly crude manner. This setting is different from usual exclusion processes with multi-type particles, each having its own jump rate. It is more in line with the Nagel-Schreckenberg model, with the difference that only local jumps are allowed and speed is replaced by jump rate.

When this model is set on a circle or an infinite line, classical arguments allow to map it to a linear network of queues (a zero-range process in theoretical physics parlance) with exponential service times, but with a twist: the service rate remains constant during a busy period, but can change at renewal events. We use the tools of queueing theory to compute the fundamental diagram of the traffic, and show the effects of a condensation mechanism.

3.4.4. Dynamical windings of random walks and exclusion models

Participants: Guy Fayolle, Cyril Furtlehner.

These last four years, several studies have been achieved about random walks evolving in the plane or even in $\mathbf{Z}^n$ and subjected to various local stochastic distortions (see activity reports of the Preval team 2004, 2005 and 2006).

In keeping with this general pattern, the article [10] deals with continuous limits of interacting one-dimensional diffusive systems, arising from stochastic distortions of discrete curves with various kinds of coding representations. These systems are essentially of a reaction-diffusion nature. In the non-reversible case, the invariant measure has generally a non Gibbs form. The corresponding steady-state regime is analyzed in detail with the help of a tagged particle and a state-graph cycle expansion of the probability currents. As a consequence, the constants appearing in Lotka-Volterra equations —which describe the fluid limits of stationary states— can be traced back directly at the discrete level to tagged particles cycles coefficients. Current fluctuations are also studied and the Lagrangian is obtained by an iterative scheme. The related Hamilton-Jacobi equation, which leads to the large deviation functional, is analyzed and solved in the reversible case, just for the sake of checking.

3.4.5. Statistical physics and hydrodynamic limits

Participants: Guy Fayolle, Cyril Furtlehner.

Having in mind a global project concerning the analysis of complex systems, we first focus on the interplay between discrete and continuous description: this is a recurrent question, which in some cases can be addressed quite rigorously via probabilistic methods.

To attack this class of problems, in touch with many applications domains (e.g. biology, telecommunications, transportation systems), we started from *paradigmatic* elements, namely the discrete curves subjected to stochastic deformations, as those mentioned in section 3.4.4.

After convenient mappings, it appears that most problems can be set in terms of interacting exclusion processes, the ultimate goal being to derive hydrodynamic limits for these systems after proper scalings. We extend the key ideas of [36], where the basic ASEP system on the torus was analyzed. The usual sequence of empirical measures, converges in probability to a deterministic measure, which is the unique weak solution of a Cauchy problem.

The crucial point relies on the analysis of a family of parabolic differential operators, involving variational calculus. Namely, the values of functions at given points play here the role of the usual variables, their number being possibly infinite. The method presents some new theoretical features. It is applied, in the ongoing work [28], to several multi-type exclusion systems, including the famous ABC model. Also, in the course of the study, several fascinating multi-scale problems emerge quite naturally, bringing to light quite natural connections with the so-called *renormalization* in theoretical physics.

3.4.6. Convergence of moments in the almost sure central Limit theorem for multivariate martingales

Participant: Guy Fayolle.

Let (ξ_n) be a sequence of i.i.d. random variables, with $\mathbb{E}[\xi_n] = 0$ and $\mathbb{E}[\xi_n^2] = \sigma^2$. Let $\Sigma_n = \xi_1 + \cdots + \xi_n$. The almost sure central limit theorem (ASCLT) asserts that, for any bounded continuous function h,

$$\lim_{n\to\infty} \frac{1}{\log n} \sum_{k=1}^{n} \frac{1}{k} h\left(\frac{\Sigma_k}{\sqrt{k}}\right) = \int_{\mathbb{R}} h(x) dG(x), \quad \text{a.s.},$$

where G is a gaussian measure $\mathcal{N}(0, \sigma^2)$. This theorem also holds for martingales.

In a joint work with Bernard Bercu (University Bordeaux 1) and Peggy Cénac (University Dijon), we aim at extending these results to the vectorial case, the classes of functions h being not necessarily bounded. The study [35], in which new almost sure convergence properties for multivariate martingale transforms were established, has been continued. Assuming some regularity conditions both on the increasing process and on the moments of the martingale, the normalized moments of any even order do also converge according to a ASCLT. A conjecture about convergence under wider hypotheses is formulated and partially analyzed, the goal being to cover a larger class of processes. Cases studies are proposed, including linear models and some branching processes with immigration, for which new asymptotic estimation and prediction errors can be obtained.

3.5. Communications

Keywords: *IPv6*, *MANET*, *NEMO*, *OLSR*, *V2I*, *V2V*, *VANET*, *Vehicular communications*, *ad-hoc networking*, *network mobility*, *service discovery*.

Early on, it was thought in the project that in order to improve significantly the performances of a transportation system, it was not sufficient to work on the cars alone. The introduction of localisation and communications technologies between vehicles was first initiated, then the use of ad-hoc routing protocols and various mechanisms to "sense" the traffic from individual vehicles and model it at the local or global level was investigated. This is very useful for cooperative systems. For example, at a crossroad, vehicle can exchange local maps and so know much better where they are located, hence preventing or mitigating collisions.

Communications are thus becoming essential to achieve Imara's objectives, and this opens up new research fields for Imara since a dedicated communication system must be designed to meet a number of requirements such as performance efficiency, scalability, privacy, security which vary over time with the location (availability of the technology, vehicle density), application types (safety or non-safety), regulations, etc.

As such, Imara is investigating into the selection, improvement and performance analysis of the required mechanisms and protocols that make up a dedicated communication system for intelligent transportation systems. These include the topics described in the following sub-sections.

3.5.1. IPv6

IPv6 is assumed as the de facto version of the Internet Protocol where Internet-based communications are necessary in vehicular networks. This is motivated by the deployment of the technology which will require an extended address space and the enhanced mechanisms that only IPv6 provides. Another motivation is our will to ensure that our research output will not become deprecated once IPv6 is widely deployed in the Internet, i.e. in a number of years. This is mainly done as part of our involvement in two FP6 European projects, CVIS and Anemone.

The use of IP (whatever its version) is still questioned by the automotive industry for time-critical safety applications. IP applicability must thus be investigated by conducting performance evaluation of the communication system.

3.5.2. Maintaining Internet Connectivity

Vehicles are moving and are thus changing their point of attachment to the Internet. While moving, the Internet connectivity must be maintained and session continuity must be ensured. Areas of investigation include:

- Mobility support for vehicle-infrastructure communications or maintaining Internet connectivity while on the move (e.g. NEMO)
- Addressing for vehicular networks: some vehicle may remain not connected to the Internet for a long time so the addressing format must be designed taking this into account.

3.5.3. Routing

Mobile Adhoc Network (MANET) routing protocols and network mobility (NEMO) support protocols are used in vehicular communications; MANET for vehicle-vehicle communications, and NEMO to maintain the Internet access for vehicle-infrastructure communications. The necessary interaction between MANET and NEMO (MANEMO) brings a number of benefits in terms of improved routing (routing optimization) and improved network accessibility (multihoming). However, protocols have been specified independently from one another and their interaction brings a number of technical and scientific issues. Areas of investigation include:

- routing protocols in infrastructure-less networks for direct or multihop vehicle-vehicle communications: ad-hoc routing protocols (MANET, e.g. OLSR) and geographic routing;
- selection of the appropriate path when multiple access technologies are available (multihoming) and when both multi-hop vehicle-vehicle or direct vehicle-infrastructure communications are possible;
- routing optimization: mobility management usually requires routing through some mobility support server in the Internet, which could lead to routing inefficiencies;
- network mobility has the particularity of allowing recursive mobility, i.e. where a mobile node is attached to another mobile node (e.g. a PDA is attached to the in-vehicle IP network). This is referred to as *nested mobility* and brings a number of research issues in terms of routing efficiency.

3.5.4. Service Discovery

Service discovery in vehicular networks: vehicles in a close vicinity need to discover what information can be made available to other vehicles (e.g. road traffic conditions, safety notification for collision avoidance). We are investigating both push and pull approaches and the ability of these mechanisms to scale to a large number of vehicles and services on offer.

3.5.5. Quality of Service (QoS)

The use of heterogeneous wireless technologies for vehicular networks incur varying delivering delays or loss, though safety and some non-safety data must be transmitted in a bounded time frame. Also, these wireless technologies are often offered by various access network operators with different billing and filtering policies. We therefore need to investigate into mechanisms to provision network resources across access networks with different characteristics.

3.5.6. Security

Data exchanged between vehicles must be clearly authenticated and should guarantee the privacy of the vehicle user, as much from a location point of view as from a data content point of view. Mechanisms must be embedded into the communication architecture to prevent intruders to corrupt the system which could cause accidents and traffic congestion as a result of overloading the network or targeting a vehicle with forged or fake information.
Associated project: Hipercom.

3.6. Tools for programming and certification

Keywords: *Programming*, *bugs*, *certification*, *distributed environment*, *hardware*, *software*.

Data processing will play an essential —even critical— part for the safety of automated guided vehicles or even for simply secured vehicles. It is thus of primary importance to minimize hardware or software failures and their consequences. For that, it became essential to bring new techniques of programming and certification. This work is already largely begun at INRIA and École des Mines (language Esterel and SynDEx), but the context of the automated road is even more critical than many applications than we try to approach. Imara thus proposes to continue the development of its certification and programming tools ORCCAD and SynDEx in this automobile context i.e. in a very distributed — and thus necessarily redundant — environment.

Associated projects: Sosso, Sharp, Icare

3.7. Ergonomics, Human-machine Interaction

Keywords: *Ergonomics*, *Human-machine Interaction*.

Systems of driving assistance as well as automated driving devices are undoubtedly going to change deeply interaction between drivers (or passengers if this one does not drive any more) and vehicles. As the concerned population will not be formed for that, it is imperative that interfaces be of a great simplicity and cannot be interpreted in an incorrect way. The safety of the system depends on it.

It will be particularly important to study the perverse effects of a diverted use of the considered systems and to include/understand the mental image of the system that users will build, including in its degraded modes.
Associated project: Eiffel

4. Application Domains

4.1. Introduction

While the preceding section focused on methodology, in connection with automated guided vehicles, it should be stressed that the evolution of the problems which we deal with remains often guided by the technological developments. We enumerate three fields of application, whose relative importance varies with time and who have strong mutual dependencies: driving assistance, cars available in self-service mode and fully automated vehicles (cybercars).

4.2. Driving assistance

Keywords: *Driving assistance*, *information*, *modeling*, *path planning*, *system management*.

Several techniques will soon help drivers. One of the first immediate goal is to improve security by alerting the driver when some potentially dangerous or dangerous situations arise, i.e. collision warning systems or lane tracking could help a bus driver and surrounding vehicle drivers to more efficiently operate their vehicles. Human factors issues could be addressed to control the driver workload based on additional information processing requirements.

Another issue is to optimize individual journeys. This means developing software for calculating optimal (for the user or for the community) path. Nowadays, path planning software is based on a static view of the traffic: efforts have to be done to take the dynamic component in account.

4.3. New transportation systems

Keywords: *Transportation systems*, *information system*, *on demand*, *self-service*.

The problems related to the abusive use of the individual car in large cities led the populations and the political leaders to support the development of public transport. A demand exists for a transport of people and goods which associates quality of service, environmental protection and access to the greatest number. Thus the tram and the light subways of VAL type recently introduced into several cities in France conquered the populations, in spite of high financial costs.

However, these means of mass transportation are only possible on lines on which there is a keen demand. As soon as one moves away from these “lines of desire” or when one deviates from the rush hours, these modes become expensive and offer can thus only be limited in space and time.

To give a more flexible offer, it is necessary to plan more individual modes which approach the car as we know it. However, if one wants to enjoy the benefits of the individual car without suffering from their disadvantages, it is necessary to try to match several criteria: availability anywhere and anytime to all, lower air and soils pollution as well as sound levels, reduced ground space occupation, security, low cost.

Electric or gas vehicles available in self-service as in the Praxitèle system bring a first response to these criteria. To be able to still better meet the needs, it is however necessary to re-examine the design of the vehicles on the following points:

- ease empty car moves to better distribute them;
- better use of information systems inboard and on ground;
- better integrate this system in the global transportation system.

These systems are now operating (i.e. in La Rochelle). The challenge is to bring them to an industrial phase by transferring technologies to these still experimental projects.

4.4. Cybercars

Keywords: *B2*, *Cybercars*.

The long term effort of the project is to put automatically guided vehicles (cybercars) on the road. It seems too early to mix cybercars and traditional vehicles, but data processing and automation now make it possible to consider in the relatively short term the development of such vehicles and the adapted infrastructures. Imara aims at using these technologies on experimental platforms (vehicles and infrastructures) to accelerate the technology transfer and to innovate in this field.

Other application can be precision docking systems that will allow buses to be automatically maneuvered into a loading zone or maintenance area, allowing easier access for passengers, or more efficient maintenance operations. Transit operating costs will also be reduced through decreased maintenance costs and less damage to the breaking and steering systems.

Regarding technical topics, several aspects of Cybercars have been developed at Imara this year. First, we have stabilized a generic Cycab architecture involving INRIA Syndex tool and CAN communications. The critical part of the vehicle is using a real time Syndex application controlling the actuators via two Motorola's MPC555.

This application has a second feature, it can receive commands from an external source (Asynchronously this time) on a second CAN bus. This external source can be a PC or a dedicated CPU, we call it high level. To work on the high level, we have developed a R&D framework (Taxi) which takes control of the vehicle (Cycab and Yamaha) and also processes data such as gyro, GPS, cameras, wireless communications and so on. We compile C++ selected class, and we get a small footprint binary. We have demonstrated with this Taxi framework: automatic line/road following techniques, PDA remote control, multi sensors data fusion, collaborative perception via ad-hoc network.

The second main topic is inter-vehicle communications using ad-hoc networks. We have worked with the HIPERCOM team for setting and tuning OLSR, a dynamic routing protocol for vehicles communications (see Section 3.5). Our goal is to develop a vehicle dedicated communication software suite, running on a specialised hardware. It can be linked also with the Taxi Framework for getting data such GPS information's to help the routing algorithm.

5. Contracts and Grants with Industry

5.1. Introduction

The Imara project is mainly funded by the numerous contracts obtained the past years and which show the guidelines of its works.

5.2. CyberC3

The CyberC3 Project will prolong the existing IST European CyberCars Project and apply advanced IT&C technologies in cars and transport system, on one hand, aiming to propose an innovative transportation for the city of tomorrow based on fully automated vehicles (Cybercars), which has advantages of high flexibility, efficiency, safety; on the other hand, aiming to protect the environment and improve the quality of life for Asian sustainable development.

Contractor: EU & Asia IT&C
Project duration: 24 months (2005–2006)
R&D investment: euros 100 550

5.3. PreVent

Imara is part of the PreVent sub-project InterSafe, which objective is to explore the accident prevention and mitigation potential of an integrated preventive safety system for intersections.

The effectiveness of the safety system for higher-risk scenarios is evaluated through implementation in a simulator environment as well as through demonstration of an application providing the driver with turning assistance and infrastructure status information.

Contractor: EU-IST
Project duration: 3 years (02/2004–01/2007)
R&D investment: euros 258 000.

5.4. MobiVIP

The project gathers 5 laboratories and 7 companies to implement, evaluate and demonstrate the NTIC impact on a new mobility service. More precisely, the goals are to implement:

- a transportation service base on free-use vehicles,
- a multimodal information system,
- a toolbox for integration in global management policy at downtown scale.

Contractor: PREDIT
Project duration:
R&D investment: euros 82 000.

5.5. Anemone

Anemone is small European project (STREP) aiming at deploying an IPv6 mobility testbed at several complementary sites providing third parties users support of mobile devices and enhanced services by integrating cutting edge IPv6 mobility and multihoming initiatives together with the majority of current and future wireless access technologies. Imara is associated with the ARMOR project-team in Rennes and is mostly committed to conduct research on network mobility and multihoming for which we hired a PhD student. As such, we have realized an experiment in Rennes in December involving two of our vehicles in order to evaluate the performance of an optimized routing solution between the two vehicles using a combination of NEMO and MANET technologies, integrated in the same hardware running Linux. We are also acting as a liaison between the Anemone and CVIS projects

Contractor: EU
Project duration: 2 years (2006-2008)
R&D investment: euros 100 000.

5.6. Citymobil

The objective of the CityMobil project is to focus on a number of cities in Europe and by careful study of their requirements design, evaluate and test the new approaches at three sites (Heathrow, Rome and Castellón). At the end of the project, we will have a better understanding of the capabilities of the new technologies and of what the gains to be expected in various city-situations could be and we will have proposals for certification of advanced transport systems on a European level. We will also have the tools to disseminate the results widely on the European level and therefore bring to the cities proven solutions to their problems while becoming, as was stated "a global leader in the development of a knowledge-based transport sector".

Contractor: EU
Project duration: 2 years (2006-2008)
R&D investment: euros 100 000.

5.7. COM2REACT

COM2REACT is a follow-up of the REACT project. COM2REACT's overall objective is to establish the feasibility of such a three-layer, scalable, cooperative system. Its implementation will involve the deployment of two two-way communication systems: vehicle to vehicle (V2V), and vehicle to infrastructure (V2I). This structure will facilitate significant improvement in the flow of information acquired by moving vehicles and in its quality and reliability, thereby enhancing road efficiency and traffic safety on urban, intercity and rural roads.

Contractor: EU
Project duration: 5 years (2006-2011)
R&D investment: euros 355 000.

5.8. CVIS

CVIS is a large European project (IP) specifying an IPv6-based communication architecture and a set of applications for vehicle-roadside and vehicle-Internet communications. The work is based on CALM standard from ISO. CVIS is now developing a multi-channel mobile router capable of maintaining connectivity with the roadside and the Internet through a number of wireless communications media (802.11a/b/g, 802.11p, 3G). INRIA is bringing the necessary IPv6 insight into this project and is leading all aspects related to IPv6 (specification, dissemination). In 2007, we contributed to the specification and validation work, and we spent a lot of time informing the partners about the impact of IPv6 on their work and investigating the interoperability with legacy systems deployed at test sites.

Contractor: EU
Project duration: 4 years (2006-2010)
R&D investment: euros 266 000.

5.9. Cybercars 2

Cybercars 2 goal is to further improve the technologies of the CTS in order to make them into a truly efficient urban transport system of the future. The existing systems can offer a good alternative to the private cars but only if the transportation demand is not very high. To attain capacities of the same order of magnitude as private cars we have to improve our technologies by one order of magnitude since present day cybercars cannot transport much more than a few hundreds of passengers per hour on a single lane (compared to 2,000 with private cars and more than 10,000 with trams).

Contractor: EU
Project duration: 3 years (2006-2008)
R&D investment: euros 484 000.

5.10. LOVe

LOVe is an initiative to gather players around the automotive electronics for detection and protection of vulnerable users (pedestrians, cyclists, etc.). This is part of the Num@tec cluster and of the French System@tic *pôle de compétitivité*.

Contractor: France
Project duration: 3 years (2006-2009)
R&D investment: euros 151 000.

5.11. Tiny6 (STIC-Asie)

Led by ENST Bretagne, Tiny6 is a STIC-Asie project with Indian, Korean, Chinese Taiwanese and French labs aiming at exchanging knowledge on IPv6 wireless sensor networks. The kick-off was held in September 2007 in Paris. Our main interest is to collect information in order to define wireless IPv6 sensors that could be developed for ITS, and to establish links leading to stronger cooperation with Asian partners.

5.12. Cristal

The French project Cristal is led by Lohr industrie and aims at building an advanced vehicle (3-8 people) that could move in platoons. This initiative is supported by the *pôle de compétitivité* “Véhicules du futur”, in the eastern part of France.

Contractor: FCE
Project duration: 3 years (2007-2010)
R&D investment: euros 100 000.

5.13. DIVAS

The French project DIVAS is a consortium of industry partners, research labs and road authorities. Its goal is to develop an architecture for road-vehicles cooperation and to build demonstration applications to validate the design. This initiative is supported by the *pôle de compétitivité* MOV’EO. There is also a cooperation with the US inside the project DIVAS America.

Contractor: ANR
Project duration: 3 years (2007-2010)
R&D investment: euros 95 000.

5.14. AROS

AROS is a consortium dedicated to the design and validation of a new advanced prototyping software aiming at decreasing seriously the development cycle of embedded distributed applications, particularly in the scope of automotive products. Partners are Mines Paris, VALEO and Intempora.

Contractor: ANR
Project duration: 3 years (2008-2010)
R&D investment: euros 142 000.

5.15. HAVE-IT

HAVE-IT aims at the long-term vision of highly automated driving. Within this proposal important intermediate steps towards highly automated driving will be developed, validated and demonstrated. First by optimizing the task repartition between driver and co-pilot system (ADAS) in the joint system. Then by further developing and implementing the failure tolerant, safe vehicle architecture including advanced redundancy management (from the SPARC predecessor project) to suit the needs of highly automated vehicle applications and to arrive at higher system availability and reliability. Finally by developing and validating next generation ADAS directed towards higher level of automation compared to the current state of the art.

Contractor: EU
Project duration: 3.5 years (2008-2011)
R&D investment: euros 400 000.

5.16. GeoNet

The GeoNet project will implement a reference specification of a geographic addressing and routing protocol with support for IPv6 to be used to deliver safety messages between cars but also between cars and the roadside infrastructure within a designated destination area.

INRIA (Arnaud de La Fortelle) is coordinator of this proposal.

Contractor: EU
Project duration: 2 years (2008-2009)
R&D investment: euros 400 000.

6. Other Grants and Activities

6.1. International relations

We are cooperating with a number of labs worldwide without contract commitment.

SwRI: in 2007, INRIA signed a collaboration agreement with the Southwest Research Institute (San Antonio, Texas, USA) for the joint development of autonomous vehicle technologies, focusing on the areas of perception, intelligence, command and control, communications, platforms and safety. SwRI is one of the oldest and largest nonprofit applied research and development organizations in the U.S. The partnership will conduct joint research and exchange intellectual property to foster rapid technology and system advancements in vehicle autonomy.

Keio University: Imara has established links with Jun Murai Lab at Keio University in Japan since 2005, which led Thierry Ernst to join Imara in 2006. Since then, we are working with Keio University and other labs in Japan and in France grouped into the Nautilus6 project which is working on IPv6 mobility enhanced mechanisms allowing continuous access to the Internet while on the move. From this cooperation, we were able to host a master intern from Keio University who then enrolled as a PhD at Imara. In addition, three labs from Keio University with different backgrounds (automatic vehicles, electric vehicles and Internet communications) have joined forces into the so-called co-Mobility project aiming at developing the vehicle of the future. The intersection between Keio University's activities on this project and Imara is a tremendous set of common research topics and we have been called in November to cooperate.

Moreover, the modeling group maintains longstanding bilateral relations with the following centers.

- University of Moscow (V. Malyshev);
- University of Saint-Petersburg (R. Iasnogorodski);
- IPPI, Dobrushin's Laboratory, Academy of sciences, Moscow (A. Rybko);
- Imperial College (E. Gelenbe);
- University of Cambridge (F. Kelly);
- several teams in USA (Berkeley, Columbia, Monterey, AT&T).

6.2. National relations

The modeling group collaborates more or less tightly with the following french universities and research centers.

- University of Bordeaux 1, Institut de Mathématiques de Bordeaux (B. Bercu);
- University of Paris 11, LPTMS (A. Comtet et S. Majumdar);
- France Télécom R&D, DAC/OAT (J. Roberts);
- ENS Ulm (P. Brémaud, B. Derrida, J.-F. Le Gall);
- ENSAE (P. Doukhan);
- CEA (C. Godrèche et K. Mallick);

7. Dissemination

7.1. Standardization

We are actively involved in the international standardization process in the communication area.

IETF (Internet Engineering Task Force): Thierry Ernst has served as Working Group chair in two Working Groups (NEMO standing for “Network Mobility” and MonAmi6 standing for “Mobile Nodes and Multiple Interfaces in IPv6”) he has contributed to set up while working at Keio University (in 2002 and 2005, respectively) until their closure in December 2007.

ISO: Thierry Ernst who was contributing as an observer to the ISO activities within the Technical Committee Working Group 16 (TC204 WG16) since 2002 has become in spring 2007 an official delegate representing French interests (AFNOR) in that group. TC204 WG16 is specifying the CALM communication architecture based on IPv6 and NEMO and currently implemented by the CVIS European project in which we are also involved.

C2C: INRIA (for Imara: Thierry Ernst, Arnaud de La Fortelle, Samer Ammoun) has joined the Car-to-Car Communication Consortium which is a European association of car manufacturers and electronic equipment suppliers. There are designing a communication architecture mainly for vehicle-vehicle safety communications. We are bringing our expertise on IPv6 communications.

COMeSafety: COMeSafety is a European forum whose aim is to ensure that the various European projects (CVIS, SafeSpot, Coopers) and the C2C, all working on vehicular communications, will provide interoperable solutions. We are bringing our expertise on IPv6 communications.

7.2. Animation

As part of our work in vehicular communications we served as session chairs, in technical committees, in panels of a number of events, and we also proposed sessions held in a number of ITS conferences, including the ITS in Europe conference. In addition to TPCs we participated actively, we also provided reviews for various journals and conferences.

Thierry Ernst has set-up and co-chaired the 2nd International Workshop on Network Mobility (WONEMO). He participated to various panel sessions and gave keynotes speeches at ITST, the IPv6 Global IPv6 Summit in Mexico and the Daidalos workshop at the Mobile IST Summit. He also served in a number of conference TPCs (ITST, IEEE ON-MOVE, NSTools) and provided reviews for various journal and conference papers (IFIP Networking, NGI, IEICE, M2NM, IEEE Transactions on Mobile Computing, IEEE Transactions on Vehicular Technology). He has organized a technical session on IPv6 deployment for ITS during the ITS in Europe conference. His IPv6 expertise was requested at many occasions in addition to the organizations (IETF, ISO, Car-to-Car Communication Consortium) and projects (CVIS, ANEMONE) he is involved in, particularly the EVAN association which issued an IPv6 study on vertical sectors at the demand of the European Commission. As part of his dissemination activities related to IPv6, he is in charge of the IPv6 Task Force France since September 2006 and is a member of the G6 association. Finally, he is in charge of the thematic group LARA-COM within the LaRA JRU.

Guy Fayolle is an editor of the journal *Markov Processes and Related Fields*. He is also member of the working group IFIP WG 7.3, which has about a hundred elected persons to scientific communities interested in various aspect of system modeling and performance evaluation.

Arnaud de La Fortelle has participated to various panels and seminars. He has been TPC member IEEE ON-MOVE and WNEPC. He is member of the AHB30 committee within the TRB. He is member of the national geographic committee (Static and Dynamic Positioning). He is deputy member of the scientific and technical committee of the *pôles de compétitivité* MTA and Véhicules du futur. He is in charge of the JRU LaRA gathering Mines Paris and INRIA, with a third member, LIVIC, joining in 2008 and organized the scientific exchanges.

Jean-Marc Lasgouttes is the organizer for Imara of the regular seminar “Probabilité, Optimisation, Contrôle”, which takes place in Rocquencourt, in collaboration with the Max-Plus project-team.

7.3. Teaching

Guy Fayolle has been a member of the committee of the French competitive examination *agrégation* of mathematics (from June 24 to July 15 2007), in which he was also in charge of the option Probability and Statistics.

Jean-Marc Lasgouttes gave a semester course in data analysis at the “Magistère de Finance” of University Paris 1.

7.4. Invitations

Guy Fayolle received invitations from the universities of Moscow, Newcastle and Cambridge; he was also asked to present some recent works at the seminars of ENS Ulm and IHP.

7.5. Miscellaneous

Guy Fayolle serves as elected member of the Scientific Board of INRIA

8. Bibliography

Major publications by the team in recent years

[1] G. Fayolle, A. de La Fortelle. *Large Deviation Principle for Markov Chains in Discrete Time*, in "Problems of Information Transmission", vol. 38, n^{o} 4, 2002.

[2] G. Fayolle, R. Iasnogorodski. *Two Coupled Processors: The Reduction to a Riemann-Hilbert Problem*, in "Z. Wahrscheinichkeitstheorie verw. Gebiete", vol. 47, 1979, p. 325-351.

[3] G. Fayolle, R. Iasnogorodski, V. A. Malyshev. *Random walks in the Quarter Plane*, Applications of Mathematics, n^{o} 40, Springer-Verlag, 1999.

[4] G. Fayolle, J.-M. Lasgouttes. *Partage de bande passante dans un réseau : approches probabilistes*, 70 pages, Technical report, n^{o} 4202, INRIA, 2001, http://hal.inria.fr/inria-00072420.

[5] G. Fayolle, J.-M. Lasgouttes. *Asymptotics and Scalings for Large Product-Form Networks via the Central Limit Theorem*, in "Markov Processes and Related Fields", vol. 2, n^{o} 2, 1996.

[6] G. Fayolle, V. A. Malyshev, M. V. Menshikov. *Topics in the constructive theory of countable Markov chains*, Cambridge University Press, 1995.

[7] M. KAIS, N. HAFEZ, M. PARENT. *An Intelligent Vehicle Architecture for Automated Transportation in Cities*, in "Proceedings of European Control Conference (ECC'01), Porto", September 2001.

[8] A. DE LA FORTELLE. *Contribution à la théorie des grandes déviations et applications*, Ph. D. Thesis, École nationale des ponts et chaussées, novembre 2000.

Year Publications

Books and Monographs

[9] *Risk Assessment Algorithms Based On Recursive Neural Networks*, I.: Computing Methodologies/I.2: ARTIFICIAL INTELLIGENCE/I.2.6: Learning/I.2.6.2: Connectionism and neural nets INTERSAFE, International Neural Network Society (INNS) and the IEEE Computational Intelligence Society (IEEE-CIS), Orlando, Florida/ USA, 08 2007, http://hal.inria.fr/inria-00129074/en/.

Articles in refereed journals and book chapters

[10] G. FAYOLLE, C. FURTLEHNER. *Stochastic Dynamics of Discrete Curves and Multi-TypeExclusion Processes*, in "Journal of Statistical Physics", [Rapport INRIA 5808, mars 2006], vol. 127, n^{o} 5, 2007, p. 1049-1094.

[11] Y. TOOR, A. LAOUITI, P. MÜHLETHALER, A. DE LA FORTELLE. *Vehicle Ad Hoc NETworks (VANETs): Applications and related technical issues*, in "IEEE Communications Surveys and Tutorials", to appear, 2007.

Publications in Conferences and Workshops

[12] S. AMMOUN, A. DE LA FORTELLE, F. NASHASHIBI. *Performance analysis of intervehicle Communication for Collaborative Traffic Applications*, in "Proceedings of ITST 2007", 2007.

[13] S. BOISSÉ, R. BENENSON, L. BOURAOUI, M. PARENT, L. VLACIC. *Cybernetic Transportation Systems Design and Development: Simulation Software cybercars*, in "2007 IEEE International Conference on Robotics and Automation - ICRA'2007, 10/04/2007, Roma, Italy", 2007, http://hal.inria.fr/inria-00126677/.

[14] L. BOKOR, N. MONTAVONT, P. DI FRANCESCO, T. ERNST. *ANEMONE: A Pan-European Testbed to Validate IPv6 Mobility Technologies*, in "2nd International Workshop on Network Mobility (WONEMO) co-located with the International Symposium on Applications and the Internet (SAINT), Hiroshima, Japan", January 2007, http://www.nautilus6.org/events/wonemo2007/.

[15] A. DELEPLACE, T. ERNST, T. NOËL. *Multihoming in Nested Mobile Networks with Route Optimization*, in "2nd International Workshop on Network Mobility (WONEMO) co-located with the International Symposium on Applications and the Internet (SAINT), Hiroshima, Japan", January 2007, http://www.nautilus6.org/events/wonemo2007/.

[16] T. ERNST, L. BOKOR, A. BOUTET, Y. LOPEZ. *An Open Network for Testing, Verification and Validation of IPv6-based ITS Components*, in "7th International Conference on ITS Telecommunications (ITST), Sophia-Antipolis, France", June 2007.

[17] T. ERNST. *IPv6 Network Mobility in the CVIS Project*, in "6th European Congress and Exhibition on Intelligent Transport Systems and Services, Aalborg, Netherlands", June 2007.

[18] C. FURTLEHNER, J.-M. LASGOUTTES, A. DE LA FORTELLE. *A Belief Propagation Approach to Traffic Prediction using Probe Vehicles*, in "Intelligent Transportation Systems Conference, ITSC'07", 2007, p. 1022-1027, http://hal.inria.fr/hal-00175627/.

[19] C. FURTLEHNER, J.-M. LASGOUTTES. *A queueing theory approach for a multi-speed exclusion process.*, in "Traffic and Granular Flow '07", to appear, Springer Verlag, 2007, http://hal.inria.fr/hal-00175628/.

[20] E. LIORIS, G. COHEN, A. DE LA FORTELLE. *Evaluation of collective taxi systems by event-driven simulations*, in "International Colloquium on Taxis, Lisbon, Portugal", September 20-21 2007.

[21] O. MEHANI, R. BENENSON, S. LEMAIGNAN, T. ERNST. *Networking Needs and Solutions for Road Vehicles at Imara*, in "ITST 2007, 7th International Conference onIntelligent Transport Systems Telecommunications, SophiaAntipolis, France, June 6-8, 2007", U. FINGER, M. FUJISE, C. BONNET, M. LENARDI, S. KOMAKI, G. WEN (editors), June 2007, p. 362-367, http://hal.inria.fr/inria-00147286/.

[22] O. MEHANI, A. DE LA FORTELLE. *Trajectory Planning in a Crossroads for a Fleet of Driverless Vehicles*, in "EUROCAST", R. MORENO-DÍAZ, F. PICHLER, A. QUESADA-ARENCIBIA (editors), Lecture Notes in Computer Science, Revised Selected Papers of the 11th International Conference on Computer Aided Systems Theory for publication in Lecture Notes in Computer Science, vol. 4739, Springer, February 2007, p. 1159-1166, http://hal.inria.fr/inria-00147208/.

[23] W. MILED, J.-C. PESQUET, M. PARENT. *Robust Obstacle Detection based on Dense Disparity Maps*, in "11th International Conference on Computer Aided Systems Theory, Eurocast'07", Accepted, February 12-16 2007.

[24] M. TSUKADA, T. ERNST. *Vehicle Communication Experiment Environment With MANET And NEMO*, in "2nd International Workshop on Network Mobility (WONEMO) co-located with the International Symposium on Applications and the Internet (SAINT), Hiroshima, Japan", January 2007, http://www.nautilus6.org/events/wonemo2007/.

[25] A. DE LA FORTELLE, C. LAURGEAU, P. MÜHLETHALER, Y. TOOR. *COM2REACT: V2V communication for cooperative local traffic management*, in "Proceedings of the ITS World Congress 2007", 2007.

Internal Reports

[26] T. ERNST. *Network Mobility Support Goals and Requirements*, Request For Comments, n^o 4886, IETF, July 2007.

[27] T. ERNST, H.-Y. LACH. *Network Mobility Support Terminology*, Request For Comments, n^o 4885, IETF, July 2007.

[28] G. FAYOLLE, C. FURTLEHNER. *Hydrodynamic Limit of Some Multi-type Exclusion Processes*, to appear, Technical report, INRIA, 2007.

[29] C. FURTLEHNER, J.-M. LASGOUTTES, A. DE LA FORTELLE. *Belief Propagation and Bethe approximation for Traffic Prediction*, Rapport de Recherche, n^o 6144, INRIA, March 2007, http://hal.inria.fr/inria-00136657/.

[30] N. MONTAVONT, R. WAKIKAWA, T. ERNST, C.-W. NG, K. KULADINITHI. *Analysis of Multihoming in Mobile IPv6*, Work in progress, Internet Draft, n° draft-ietf-monami6-mipv6-analysis-04.txt, IETF, November 2007.

[31] C.-W. NG, T. ERNST, E.-K. PAIK, M. BAGNULO. *Analysis of Multihoming in Network Mobility Support*, Request For Comments, n° 4980, IETF, October 2007.

[32] R. WAKIKAWA, T. ERNST, K. NAGAMI, V. DEVARAPALLI. *Multiple Care-of Address Registration on Mobile IPv6*, Internet Draft, n° draft-ietf-monami6-multiplecoa-04.txt, IETF, November 2007.

Miscellaneous

[33] A. DE LA FORTELLE, C. FURTLEHNER, J.-M. LASGOUTTES. *Statistical Physics Algorithms for Traffic Reconstruction*, vol. 67, January 2007, http://ercim-news.ercim.org/content/view/105/249/, ERCIM News.

[34] A. DE LA FORTELLE, A. TALAMONA, M. KAIS. *From Traffic Prediction to Collaborative Navigation Solutions*, vol. 67, January 2007, http://ercim-news.ercim.org/content/view/104/250/, ERCIM News.

References in notes

[35] B. BERCU, P. CÉNAC, G. FAYOLLE. *Convergence des moments dans le théorème de la limite centrale pour les martingales vectorielles*, Technical report, n° 6056, INRIA, December 2006, https://hal.inria.fr/inria-00118982.

[36] G. FAYOLLE, C. FURTLEHNER. *Stochastic Dynamics of Discrete Curves and Exclusion Processes. Part 1: Hydrodynamic limit of the ASEP System*, Technical report, n° 5793, INRIA, December 2005, http://hal.inria.fr/inria-00001131.