INSTITUT NATIONAL DE RECHERCHE EN INFORMATIQUE ET EN AUTOMATIQUE

# *Project-Team imara*

# *Informatics, Mathematics and Automation for La Route Automatisée*

*Paris - Rocquencourt*

Theme : Robotics

Activity Report

2010

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# 1. Team

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# 2. Overall Objectives

## 2.1. Introduction

The focus of the project-team is to develop the technologies linked to Intelligent Transportation Systems (ITS) with the objective to improve the safety, the efficiency and the ease of use of road transport according to the recent “Intelligent Vehicle Initiative” launched by the DG Information Society of the European Commission (for “Smarter, Cleaner, and Safer Transport”).

More specifically, we want to develop, demonstrate and test some innovative technologies under the framework of “La Route Automatisée” which covers all the advanced driver assistance systems (ADAS) and the traffic management systems going all the way to fully automated vehicles.

These developments are all based on the sciences and technologies of information and communications (STIC) and have the objective to bring significant improvements in the road transport sector through incremental or breakthrough innovation. The project-team covers fundamental R&D work on key technologies, applied research to develop techniques that solve specific problems, and demonstrator activities to evaluate and disseminate the results.

The scientific approach is focused on the analysis and optimisation of road transport system through a double approach:

1. the control of individual road vehicles to improve locally their efficiency and safety,
2. the modelling and control of large transportation systems.

The first theme on vehicle control is broadly based on signal processing and data fusion in order to have a better machine understanding of the situation a vehicle may encounter, and on robotics techniques to control the vehicle in order to help (or replace) the driver to avoid accidents while improving the performances of the vehicle (speed, throughput, comfort, mileage, emissions, noise...). The theme also includes software techniques needed to develop applications in a real-time distributed and complex environment with extremely high safety standards. In addition, data must be exchanged between the vehicles; communication protocols have thus to be adapted to and optimized for vehicular networks characteristics (e.g. mobility, road safety requirements, heterogeneity, density), and communication needs (e.g. network latency, quality of service, network security, network access control).

The second theme on modelling and control of large transportation systems is also largely dependent on STIC. The objective there is to improve significantly the performances of the transportation system in terms of throughput but also in terms of safety, emissions, energy while minimizing nuisances. The approach is to act on demand management (e.g. through information, access control or road charging) as well as on the vehicles coordination. Communications technologies are essential to implement these controls and are an essential part of the R&D, in particular in the development of technologies for highly dynamic networks.

These two themes are largely dependent on the expertise of numerous project teams within INRIA and the past developments of IMARA's activities (or previous activities carried under the Praxitèle R&D team) have been largely done in cooperation with these teams. Conversely, these teams have often been fed by technical challenges brought by IMARA. We can mention for example mathematical models developed to forecast traffic, image processing techniques to localise precisely a mobile in its environment, new network protocols to insure connectivity between highly mobile units...

## 2.2. Highlights

A major event occured this year: the emblematic leader of IMARA team has retired. After 20 years of leadership, Michel Parent has taken Imara at its peak and has been the source of his international reputation. He handed the leadership to Fawzi Nashashibi, a senior researcher who has worked with IMARA since 2008.

From the scientific point of view, Jennie Lioris was awarded the “best student paper award” at the IEEE SIMUL 2010 international conference for her works on the “Evaluation of Collective Taxi Systems by Discrete-Event Simulation”.

# 3. Scientific Foundations

## 3.1. Autonomous driving and sustainable mobility

There are three basic ways to improve the safety of road vehicles and these ways are all of interest to the project-team. The first way is to assist the driver by giving him better information and warning. The second way is to take over the control of the vehicle in case of mistakes such as inattention or wrong command. The third way is to completely remove the driver from the control loop.

All three approaches rely on information processing. Only the last two involve the control of the vehicle with actions on the actuators, which are the engine power, the brakes and the steering. The research proposed by the project-team is focused on the following elements:

- perception of the environment,
- planning of the actions,
- real-time control.

### *3.1.1. Perception of the road environment*

The perception and understanding of the environment is the key element which is needed whatever the application is (information to the driver, helping the driver or substitution of the driver). This research area continues therefore to be a focus point of our research. It starts with the processing of data from various sensors, the cameras being the most ubiquitous ones because of their large capabilities to apprehend the dynamic 3D environment. Obviously, fusion of data with various other sensors is also a focus of the research, since cameras alone cannot apprehend every possible complex situation. We already have large experience with Lidars (Ibeo) and we will now integrates also radar sensors in the fusion approach.

However, sensing the environment alone is not sufficient for the most complex road situation to help or replace the driver. We have to understand the situation, however complex it is. This is another key area of our research, which relies on various types of coding techniques to store the information about the environment and to interpret it. For example, we have coded the information using ontologies, allowing various subsystems of the vehicle or several vehicles to share information. We also store the environment information in normalized space-time representations to deal with the differences between road infrastructures measured in terms of their geometry and object entities.

We plan for example to use directed positional acyclic labelled graphs (DPAG’s) to cope with very complex situations. Communications between the vehicles can also use this formalism. Using information from others, the vehicle can reduce the uncertainty of its local model and extend its coverage (see beyond what the vehicle in front sees, the one of the other lane sees).

### *3.1.2. Planning vehicle actions*

The second level of our research on vehicle control concerns the planning of the actions to be taken. From the understanding of the situation, we have either to warn the driver, to help him in the control of his vehicle, or to take control in case of a driverless vehicle. In simple situations, the planning might also be quite simple, but in the most complex situations we want to explore, the planning must involve complex algorithms dealing with the trajectories of the vehicle and its surroundings (which might involve other vehicles and/or fixed or moving obstacles). In the case of fully automated vehicles, the perception will involve some map building of the environment and obstacles, and the planning will involve partial planning with periodical recomputation to reach the long term goal. In this case, with vehicle to vehicle communications, what we want to explore is the possibility to establish a negotiation protocol in order to coordinate nearby vehicles (what humans usually do by using driving rules, common sense and/or non verbal communication).

The idea of using communication to enhance map building or coordinating robots to achieve a task is not new. However, the vast majority of the works are done under constrains that are unrealistic for the urban environment scenario. Typical assumptions are perfect knowledge of the robots position and perfect communication (no delay, infinite throughput).

Even overlooking this, most of the algorithms do not match the application scenario where vehicles are expected to be part of a traffic flow, where sudden stops, forcing multiple encounters, revisiting places are not acceptable behaviours. The best teams in the world which took part of the DARPA Urban Challenge demonstrated that these problems have not yet been fully addressed.

### *3.1.3. Execution control*

The third level of our research on vehicle control concerns the execution of the actions which have been elaborated at the two first levels. Obviously, this does not concern applications where only advice is given to the driver. Here, we have to execute in real-time a particular action or set of actions. The research we want to conduct is mostly centered on the software tools to implement such real-time actions in an accurate and safe way. This is a difficult problem, which is the focus of many industrial projects with the development of standards for interfaces and development procedures.

The project-team builds on its experience with the development of safety critical software for the operation of its cybercars to take part of these standards, in particular in the field of fail-safe software and redundant architectures.

## 3.2. Sensors and information processing

**Participants:** Fawzi Nashashibi, Yann Dumortier, André Ducrot, Gwenaëlle Toulminet, Jianping Xie, Laurent Bouraoui, Paulo Lopes.

### *3.2.1. 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 proprioceptive sensors, which are rather well integrated. They give information on the host vehicle state, such as its velocity and the steering angle information. Thanks to sensor data processing, several objectives can be reached. The following topics are some applications validated or under development in our team:

- 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;
- detection and localization of the surrounding vehicles and determination of their behavior can be obtained by a mix of vision, laser or radar based data processing;
- detection of obstacles other than vehicles (pedestrians, animals objects on the road, etc.) that requires multisensor fusion techniques;
- simultaneous localization and mapping as well as mobile object tracking using a generic and robust laser based SLAMMOT algorithm.

Since INRIA is very involved in image processing, range imaging and multisensor fusion, IMARA emphasizes vision techniques, particularly stereo-vision, in relation with MIT, LITIS (Rouen) and Mines ParisTech.

#### *3.2.1.1. Disparity Map Estimation*

**Participants:** Yann Dumortier, Laurent Bouraoui, André Ducrot, Fawzi Nashashibi, Gwenaëlle Toulminet, Hao Li.

In a quite innovative approach presented in last year's report, we developed the Fly Algorithm, an evolutionary optimisation applied to stereovision and mobile robotics. Although successfully applied to real-time pedestrian detection using a vehicle mounted stereohead (see LOVe project), this technique couldn't be used for other robotics applications such as scene modeling, visual SLAM, etc. The need is for a dense 3D representation of the environment obtained with an appropriate precision and acceptable costs (computation time and resources).

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.

### 3.2.2. Multi-sensor data fusion

**Participants:** Fawzi Nashashibi, Yann Dumortier, André Ducrot, Jianping Xie, Laurent Bouraoui, François Charlot, Hao Li.

Advanced 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 its own information. Using this approach, a communicant entity can see another remote entity software objects as if it was local, and a sensor object, can see sensor data of others entities as its own sensor data. Last year's developments permitted the development of the basic hardware pieces that ensures the well functioning of the embedded architecture including perception sensors, communication devices and processing tools. The final architecture was relying on the *SensorHub* presented in last year's report. This year, we focused on the development of applications and demonstrators using this unique architecture. Thus, a canonical application was developed to demonstrate the ability of platooning using vehicle-to-vehicle communications to exchange vehicles absolute positions provided by respective GPS receivers.

This approach was presented at the ITS World Congress under the form of a cooperative driving demonstration with communicant vehicles. This demonstration was also the context of an international collaboration involving our team, the robotics center of ENSMP and the SwRI (see Section 7.1). A similar demonstration was presented in the context of the international workshop on "The automation for urban transport" that was held in the french city of La Rochelle. Here three Cycabs have shown platooning capacities and demonstrated the ability of supervising collision free insertion at an intersection. The Intersection Collision Warning System (ICWS) application was built here on top of CPF to warn a driver in case of potential accident. It relies on precise spatio-temporal localization of entities and objects to compute the Time To Collision (TTC) variables but also on a "Control Center" that collects the vehicles positions and sends back to them the appropriate instructions and speed profiles.

Finally, in a recent activity, we demonstrated an application of platooning in a public showcase in the town of Montbéliard. Two Cycabs were involved in a demonstration were vision-based and laser-based platooning capacities were demonstrated combined to dedicated controls.

**Associated projects:** Sharp, Icare, Complex.

## 3.3. Path planning and trajectory generation

**Participants:** Fawzi Nashashibi, Laurent Bouraoui, Paulo Lopes Resende, Clément Boussard, Cristian Sandu.

We tackle two main topics: robot (or vehicle) control and path planning.

Control addresses the command system designed to execute at best the orders given by either the driver (assisted by the system) or the automated driving system (the co-pilot). The command system sends orders to the mechanical parts of the vehicles using all the information raised by the sensors or coming from path planner or an advanced co-pilot.

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 recently designed and integrated a modular control architecture dedicated to the Cycabs. The system's low level is based on a DSPIC architecture while the system management and core system integrates the Syndex system developed by the AOSTE project-team.

From the modeling point of view, 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. This is studied jointly with our LaRA partners (Robotics Center of ENSMP).

Path planning is another aspect of command systems dedicated to the generation of correct trajectories for an autonomous mobile robot (Cycabs) and for the autonomous mode of a vehicle. We currently work on a generic planner capable of finding secure trajectories for both robots and intelligent vehicles.

**Associated projects:** Sharp, Icare, Sosso, E-Motion.

## 3.4. Managing the system (via probabilistic modeling)

**Participants:** Guy Fayolle, Cyril Furtlehner, Jean-Marc Lasgouttes, Jennie Lioris, Sami Mahani, Victorin Martin.

The research on the management of the transportation system is a natural continuation of the research of the Preval team, which joined IMARA in 2007. For many years, the members of this team (and of its ancestor Meval) have been working on understanding random systems of various origins, mainly through the definition and solution of mathematical models. The traffic modelling 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 modelling 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 $Z_+^n$ ([2], [3], [6]), large deviations ([1], [8]) 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 explores the links between large random systems and statistical physics, since this approach proves very powerful, both for macroscopic (fleet management [5]) and microscopic (car-level description of traffic, formation of jams) analysis. The general setting is mathematical modelling of large systems (mostly stochastic), without any a priori restriction: networks [4], 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).

### *3.4.1. Exclusion processes*

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 that are close enough to establish an ad-hoc communication system), two-lane roads with overtaking.

Most of these generalizations lead to models that are obviously difficult to solve and require upstream theoretical studies. Some of them models have already been investigated by members of the group, and they are part of wide ongoing research.

### *3.4.2. Message passing algorithms*

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 algorithm very 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).

This new use of BP algorithm raises some theoretical questions about the properties of the Bethe approximation of Ising models

- how do the stability of the BP fixed points relate the the minima of the free energy?
- what is the effect of the various extensions to BP (fractional, tree-reweighted, region-based,...) of these fixed points?
- what is the behaviour of BP in the situation where the underlying data have many different statistical components, representing a variety of independent patterns?

## 3.5. Communications with vehicles

**Participants:** Thierry Ernst, Yacine Khaled, JinHyeock Choi, Manabu Tsukada, Olivier Mehani, Jong-Hyouk Lee, Satoru Noguchi, Ines Ben Jemaa, Hongliang Zhang.

As witnessed by standardization activities, conferences, research work and ITS projects around the world, Internet-based communications in vehicular networks is now under the spotlight. Most of the research and development work in this area is only considering the Internet for multimedia communications or together with the use of 3G cellular links for Internet-based communications. Few teams are investigating the use of the TCP/IP suite of protocols and their extensions for real vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communications, i.e. not only for multimedia, but also for navigation and safety purposes where critical data are exchanged over the air between vehicles. Based on our expertise in both Internet-based communications in the mobility context and in ITS, we are now investigating the use of IPv6 (Internet Protocol version 6 which is going to replace the current version, IPv4, in a few years from now) for vehicular communications, in a combined architecture allowing both V2V and V2I.

Short term objectives in this domain is the development of routing protocols which are fast enough to allow cooperative manoeuvres between cybercars, the specification of IPv6 mobility features that will improve the known routing inefficiencies and the performance analysis of existing routing and path selection mechanisms. New standards for vehicle to vehicle communications are also expected from this activity through our involvement in standardization bodies (ISO, IETF and ETSI).

Longer term activities include studying novel routing mechanisms such as a geographic addressing and routing (geonetworking), specifying mechanisms that will allow to guarantee a minimum quality of service while a vehicle is moving across heterogeneous access networks, and the analysis of security threats on the vehicular networks. All of these are parts of our objective to provide a packet-switched communication architecture suitable for the vehicular networks needs.

Below follows a more detailed description of the related research issues.

### *3.5.1. Combination of MANET and NEMO*

Mobile Adhoc Network (MANET) - or more precisely VANET (Vehicular Adhoc Network) in our specific case - routing protocols are mostly used for vehicle-vehicle communications and network mobility (NEMO) support protocols to maintain the Internet access for vehicle-infrastructure communications. The necessary interaction between MANET and NEMO (known as MANEMO) brings a number of technical and scientific issues in terms of addressing requirements (infrastructure-less vs infrastructure-based), improved routing (routing optimization) and improved network accessibility (multihoming) because protocols have been specified independently from one another. In addition, we are investigating new routing protocol approaches adapted for the vehicular network characteristics. This includes GeoNetworking where a certain information, particularly safety information, is delivered to all or a set of vehicles located in a specific geographic area with minimum network overhead and minimum latency. GeoNetworking is the favored approach in the automotive industry.

### *3.5.2. Multihoming in Nested Mobile Networks with Route Optimization*

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. Another issue under such mobility configurations is the availability of multiple paths to the Internet (still in the same example, the PDA has a 3G interface and the in-vehicle network has some dedicated access to the Internet) and its appropriate selection.

### *3.5.3. Service Discovery*

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.

### *3.5.4. 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.

### *3.5.5. 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 intruder 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.

# 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

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

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

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. New Results

## 5.1. Autonomous navigation

In order to achieve autonomous driving, autonomous systems (robots, intelligent vehicles, UAV's, UGV's,...) must have a decisional system that integrates an advanced perception system that performs sensors data fusion and environment modeling. From perception to control, task planning and path planning algorithms have to plan safe and optimized itineraries while processing sensory data. Motion control is the last link of the processing chain where itineraries and dynamic trajectories are executed by the low level control system. IMARA works on each of the topics mentioned above.

With the European projects CityMobil and CityNet Mobil, IMARA had the opportunity to validate the autonomous driving architecture developped through the projects showcases held in European cities. In 2010, Formello (Italy) hosted IMARA team in charge of demonstrating autonomous driving and autonomous sensor-based navigation using lidars and GNSS (GPS). This event was a success and was the oppotunity to deploy and test the large-scale SLAM system used for environment mapping and vehicle localization.

The *The perception sub-system* on which we are focusing is a generic SLAM-based system that performs environment mapping, vehicle localization and obstacle détection and tracking [39]. The so-called Local SLAM is a part of a global localization architecture 1 as described in [40].

From a theoretical point of view, the SLAM algorithm calculates the joint posterior probability over all past observations and controls. A mobile vehicle builds an accurate SLAM map M of an unknown environment while concurrently using this map to recover its pose $x_t$ :

$$P(x_t, M|z_{1:t}, u_{1:t}, x_0 = \frac{P(z_t|x_t, M)P(x_t, M|z_{1:t-1}, u_{1:t}, x_0)}{P(z_t|z_{1:t-1}, u_{1:t})})$$

A motion prediction model and a grid-map based maximum likelihood mapping framework are proposed to tackle the local SLAM problem. We also developed an original pyramid grid-map based coarse-to-fine refining strategy to improve localization precision.

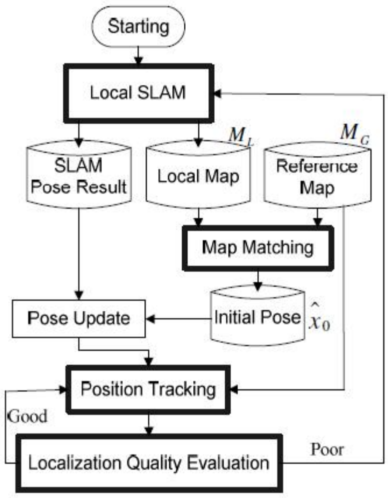


*Figure 1. The localzation architecture*

The proposed localization architecture has been implemented in two different vehicle platforms. As Fig. 2 shows, AGV is a fully autonomous vehicle equipped with two IBEO Alasca-XT laser scanners (left and right front corner). Cycab is a prototype of smart car mounted with a single IBEO-ML laser scanner in front. In Fig. 3, one can see the accuracy of the global model built by the lidar-based SLAM.

*Figure 2. Validation on a AGV and a Cycab*

In terms of motion planning, IMARA led researches on dynamic trajectories generation for high speed vehicles. Although this was motivated by the European HAVEit project; nevertheless the challenge is to design a generic approach adapted for both low and high speeds and for different kinds of vehicles. The implemented trajectory planning algorithms are integrated into the “Co-Pilot” component which role is to provide passive or active assistance to the driver according to the active automation level [24]. It is in the co-pilot module that the automation driving strategy is determined and where the trajectory planning is performed. Trajectory planning is based on a two stages approach: the maneuvre decision and the geometric trajectories generation. Two approaches were investigated : the Partial Motion Planner (PMP) as designed in the PhD thesis of R. Benenson; and the Quintic polynomials geometric trajectories. By choosing a 5th degree (quintic) polynomial, third degree behaviour is assured for the longitudinal and lateral accelerations [37].

To improve road vehicle navigation, it is necessary to perform advanced vehicle localization on its road in both global and local reference frames. A new approach was developed relying on multi-sensor fusion of data coming from: a single front camera used for lanes detection, a standard GPS and a digital map [27].

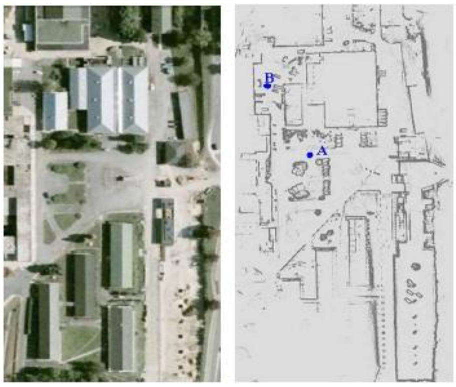


*Figure 3. Bird view of INRIA Rocquencourt and the corresponding SLAM-based built global map*

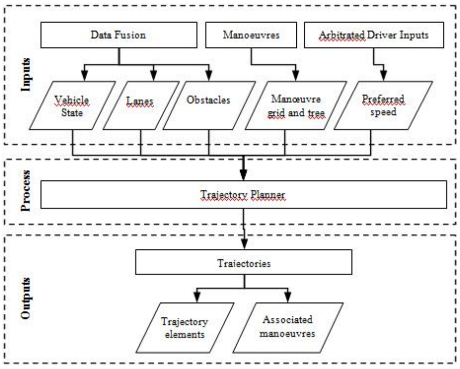


*Figure 4. Data flow of the trajectory functionality*

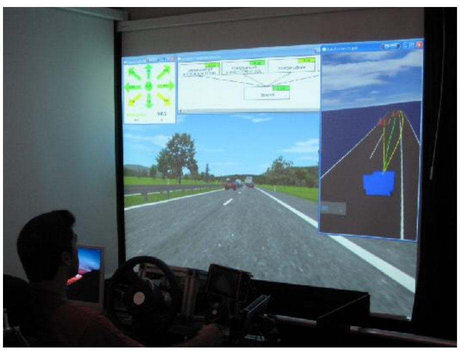

*Figure 5. Validation of the path planning on the HAVEit project use-cases on DLR's simulator.*

Vehicle positioning on the lane is maybe sufficient to perform a safe navigation while preventing lane departure. Nevertheless, in a pltoon mode where several vehicles must follow each others and especially a lead vehicle, the safe navigation consists of following exactly the leader path. To ensure this navigation, it is necessary to perform front vehicle accurate localization and precise control for path following. We developed an original linear camera based detection and localization system as well as a dedicated control command to perform the distance based platooning [34].

Performing autonomous navigation based on advanced perception and control is still a hard task. It becomes even more challenging in case of adverse weather conditions (fog, rain,...). It becomes then a necessity to detect adverse weather conditions in order to elaborate appropriate control-command to ensure a secure navigation. A great effort was dedicated to the detection of weather conditions based on a single camera architecture. In [47], [23], we demonstrated the ability to detect foggy situations and determine the corresponding visibility distance. In parallel, we also worked on rain detection thank to a monocular system mounted on the windshield [32].

## 5.2. GeoNetworking

The GeoNet project has completed very successfully in February 2010. The geographic addressing and routing (GeoNetworking) specifications from the project have been adopted by ETSI TC ITS and INRIA is developing, together with ESPRIT, an open-source implementation. The CVIS project has also completed successfully. The work initiated in GeoNet (FP7), CVIS (FP6), and MobiSeND (ANR) is leading IMARA to new projects (FP7 Drive-C2X, FUI SCORE@F, FP7 ITSSv6) where it will be exploited further.

## 5.3. Managing the system (via probabilistic modeling)

### *5.3.1. Belief propagation inference for traffic prediction*

**Participants:** Cyril Furtlehner, Jean-Marc Lasgouttes, Victorin Martin.

This work [56] 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. Our approach relies in particular on the belief propagation algorithm.

These studies are done in particular in the framework of the projects TRAVESTI (6.19) and Pumas (6.4)

This year's highlights are

- Our work on belief propagation with prescribed fixed points for real time inference has been published [13].
- The investigation of the effect of various types of normalization in the belief propagation algorithm has been continued and published as a technical report in january 2011.
- a particular effort has been done in the study of simulated data and the link between fixed points of BP and cluster exemplars found through data analysis [26].

### *5.3.2. Evaluation of collective taxi systems by event-driven simulation*

**Participants:** Jennie Lioris, Arnaud de La Fortelle, Sami Mahari.

We develop a made-to-measure simulation tool to study and evaluate the performance of a "collective taxis" transportation mode covering an entire urban area. In addition, we proceeded with the development and implementation of a technique to treat and analyse the results provided by the simulator.

- This year, the final touches were given to the work on the simulator and Jennie Lioris defended her PhD thesis [9].
- The results have been presented in several conferences [30], [29] and obtained a "best paper award" at SIMUL2010.

### 5.3.3. *Multi-speed exclusion processes and integrable models*

**Participants:** Cyril Furtlehner, Jean-Marc Lasgouttes, Maxim Samsonov.

We consider one-dimensional stochastic reaction-diffusion models generalizing the totally asymmetric simple exclusion process, and aiming at describing single lane roads with vehicles that can change speed. The motivation is to better understand the formation of traffic jams.

This year, we analyzed different available methods in the study of the exactly solvable stochastic models and their application to construction and modeling the road traffic with acceleration/deceleration dynamics [51], [46]

### 5.3.4. *Counting lattice walks in the quarter plane*

**Participant:** Guy Fayolle.

The enumeration of planar lattice walks is a classical topic in combinatorics. For a given set $\mathcal{S}$ of allowed unit jumps (or steps), it is a matter of counting the number of paths starting from some point and ending at some arbitrary point in a given time, and possibly restricted to some regions of the plane. A first basic and natural question arises: how many such paths exist? A second question concerns the nature of the associated counting generating functions (CGF): are they rational, algebraic, holonomic (or D-finite, i.e. solution of a linear differential equation with polynomial coefficients)?

A common starting point to study these walks relies on the following analytic approach. Let $f(i,j,k)$ denote the number of paths in $\mathbb{Z}_+^2$ starting from $(0,0)$ and ending at $(i,j)$ at time $k$. Then the corresponding CGF

$$F(x,y,z) = \sum_{i,j,k\geq 0} f(i,j,k)x^i y^j z^k$$

satisfies the functional equation

$$K(x,y)F(x,y,z) = c(x)F(x,0,z) + \widetilde{c}(y)F(0,y,z) + c_0(x,y).$$

In the article [12], in collaboration with K. Raschel (University of Bielefeld), we present several results (including new proofs of some existing theorems) about the nature of the bivariate generating function $(x,y) \mapsto F(x,y,z)$ for the 23 walks having a finite *group*. The method makes use of the general and powerful approach proposed in the book [3].

The 56 walks having an infinite group are the subject of an ongoing work with Ph. Flajolet (Inria) and K. Raschel.

### 5.3.5. *Markov growing trees*

**Participants:** Guy Fayolle, Arnaud de La Fortelle.

We continued the analysis of the height process of so-called *Markov growing trees*. New edges appear according to a Poisson process of parameter $\lambda$ and leaves can be deleted at a rate $\mu$. The basic model was introduced in [55]. In the pure birth case (i.e. $\lambda = 0$, the distribution function of the height of the tree at time $t$ does satisfy an interesting recursive nonlinear functional equation, which is studied mainly from an analytic point of view. The results obtained so far let appear interesting scalings, which apparently also hold for more general operators and should lead to a kind of *invariance principle*. The next step is to construct stationary laws from the transient process of interest.

### 5.3.6. *Statistical physics and hydrodynamic limits*

**Participant:** Guy Fayolle.

Having in mind a global project concerning the analysis of complex systems, we first focus on the interplay between discrete and continuous description: in some cases, this recurrent question 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 for instance in [54].

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 [54], 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 Gordian knot is the analysis of a family of differential operators in infinite dimension. Indeed, the values of functions at given points play here the role of usual variables, their number becoming infinite. The method presents some new theoretical features, involving promeasures (as introduced by Bourbaki), variational calculus and functional integration. In the ongoing work [50], these arguments are applied to various 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 some connections with the so-called *renormalization* in theoretical physics.

# 6. Contracts and Grants with Industry

## 6.1. CO-DRIVE

Co-Drive is a french FUI-10 project coordinated by Valeo which objective is to design and develop a user-end on-the-shelf product. This product will be embarked on a vehicle and is supposed to guide the driver and/or perform autonomous actions in order to optimize the driving process for enhanced mobility and security...

Contractor: CG78–Yvelines // Project duration: 3 years (2009-2012) // R&D grant: euros 134 000.

## 6.2. COREBOTS

Corebots is a french project financed by the ANR. This project aims at organizing scientific and technical challenges for advanced autonomous robots...

Contractor: ANR // Project duration: 3 years (2009-2012) // R&D grant: euros 84 000.

## 6.3. ABV

ABV is a french project financed by the french ANR. This ambitious project aims at demonstrating automated driving at low speed in urban areas and on peri-urban roads...

Contractor: ANR // Project duration: 3 years (2009-2012) // R&D grant: euros 393 000.

Website: http://www.projet-abv.fr/

## 6.4. PUMAS

PUMAS is a french project financed by the french ANR. The purpose of the project PUMAS is to create a platform for travel time information for cities and towns.

Contractor: Region IdF // Project duration: 2,5 years (2010-2012) // R&D grant: euros 354 000.

Website: http://pumas.inria.fr/

## 6.5. AMARE

AMARE is an innovative french project financed by ADEME aiming at developing an original system dedicated to the automated charging of electric vehicles....

Contractor: ADEME // Project duration: 2 years (2009-2011) // R&D grant: euros 371 000.

Website: http://www.modulowatt.com/

## 6.6. CityNetMobil

CityNetMobil is a large European project (IP) aiming at developing and deploying adavanced mobility solutions...

Contractor: EU // Project duration: 3 years (2008-2011) // R&D grant: euros 315 000.

Website: http://citynetmobil.paris-rocquencourt.inria.fr/overview

## 6.7. CityMobil

CityMobil is a large European project (IP) aiming at developing and deploying adavanced mobility solutions...

Contractor: EU // Project duration: 5 years (2006-2011) // R&D grant: euros 699 000.

Website: http://www.citymobil-project.eu/

## 6.8. 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.

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

Website: http://www.cvisproject.org/

## 6.9. 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 grant: euros 100 000.

Website: http://projet-cristal.net/

## 6.10. 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 grant: euros 95 000.

Website: http://or.lcpc.fr/divas-fr/

## 6.11. 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 (2008-2011) // R&D grant: euros 142 000.

Website: http://www.systematic-paris-region.org/fr/projets/aros

## 6.12. 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 grant: euros 443 000.

Website: http://www.haveit-eu.org/

## 6.13. GeoNet

The GeoNet project has been set up in order to combine IPv6 and geographic addressing and routing. This combination is needed in order to guarantee interoperability between ITS communication architectures and Internet-based communications. It is used to deliver safety messages between cars but also between cars and the roadside infrastructure within a designated destination area and over multiple hops. The objective of the project is to specify the architecture where geographic routing is combined together with IPv6 features (NEMO, etc.).

Contractor: EU // Project duration: 2 years (2009-2010) // R&D grant: euros 500 000.

Website: http://www.geonet-project.eu/

## 6.14. MobiSeND

This ANR project aims at securing neighbor discovery in wireless mobile environments.

Contractor: ANR // Project duration: 2 years (2008-2010).

Website: http://mobisend.org/

## 6.15. Intersafe-2

The INTERSAFE-2 project aims at developing and demonstrating a Cooperative Intersection Safety System (CISS) that is able to significantly reduce injuries and fatal accidents at intersections.

Contractor: EU // Project duration: 3 years (2008-2011) // R&D grant: euros 317 000.

Website: http://www.intersafe-2.eu/public/

## 6.16. CATS

Contractor: EU // Project duration: 4 years (2009-2013) // R&D grant: euros 400 000.

## 6.17. Merit

MERIT (Modules Electroniques Robotisés Intelligents pour les Transports: Smart Robotized Electronic Modules for Transport) is a French project aiming at the development and industrialization of electronic modules for driving assistance. The main focus is for ageing population. Afterward, the same modules could be used for helping beginners or disabled people, to automate public transport or for general driving assistance.

Contractor: ANR // Project duration: 2 years (2008-2009) // R&D grant: euros 40 000.

## 6.18. PICAV

PICAV (Personal Intelligent City Accessible Vehicle System) is a European FP-7 project which aims at designing a new personal vehicle able to demonstrate a new mobility concept for passengers ensuring accessibility for all in urban pedestrian environments. The new transport system integrates a fleet of PICAV units. These units have some features that are specifically designed for people whose mobility is restricted for different reasons the main drivers of PICAV design are: ergonomics, comfort, stability, small size, mobility dexterity on-board intelligence, assisted driving, eco-sustainability, parking, vehicle/infrastructures intelligent networking.

PICAV system usefully integrates the existing public transport system to make it become more accessible for older and disabled people by acting as a smooth link between walking, bicycle and conventional public transport.

Contractor: EU // Project duration: 4 years (2009-2013) // R&D grant: euros 500 000.

Website: http://www.dimec.unige.it/PMAR/picav/index.shtml

## 6.19. Travesti

This project addresses the problem of modelling large scale complex systems to provide predictions of their macroscopic behaviour. For application purpose, we focus here on the particular problem of the real-time prediction of traffic conditions on a road network.

Contractor: ANR // Project duration: 3 years (2009-2011) // R&D grant: euros 96 000.

Website: http://travesti.gforge.inria.fr/

# 7. Other Grants and Activities

## 7.1. International Initiatives

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 (Japan)*: 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 hire a PhD student who completed his MSc at Keio University. 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 as such we have been invited to a Co-Mobility workshop in Japan in January.

*University of Tokyo (Japan)*: During his 1-year stay within IMARA Dr. Yoshio Mita's (associate professor at Tokyo University) was successful into organizing a private workshop between University of Tokyo and IMARA. It was held in July and gathered 10 researchers from Japan. From this workshop a number of new collaboration items were identified, including on the communication research topic in which there was not previous cooperation with University of Tokyo. As a result from this, we participated to the internal "Associated Team" program call without success and to the Japanese-French AYAME program call to work on green transportation ITS communication technologies. The former was accepted, so we are likely to enforce our cooperation with University of Tokyo in 2009.

*NICTA (Australia)*: After first contacts established in 2007, a PhD student started his work on a join PhD program between NICTA and IMARA. This student is currently working in Australia. Our commitment on this joint PhD supervision guarantees an outstanding cooperation with NICTA. In addition to the ongoing joint PhD supervision, IMARA has welcomed an intern from NICTA who worked on security applied to ITS architecture communications.

*University of Murcia (Spain)*: After a first contact established at the Mobile IST Summit in summer 2007 with Antonio F. Gómez Skarmeta, a PhD student from University of Murcia (José Santa Lozano) was hosted by IMARA for 3 months. He studied our communication architectures and realized some performance evaluation of our communication system using our in-vehicle testbed. The evaluation tools developed during this work will be used again to evaluate forthcoming results on geographic networking.

*ESPRIT (École Supérieure PRivée d'Informatique et de Technologie, Tunis, Tunisia)*: IMARA is welcoming interns from this private school for the past 2 years and hired them as engineers. A joint seminary, involving IMARA, HIPERCOM, ESPRIT and ENSI took place in February 2010. A wider cooperation has been decided, based on the common interest in vehicular adhoc networking and more particularly geonetworking (geographic addressing and routing). ESPRIT and IMARA started in February 2010 the development of an open-source implementation of IPv6 GeoNetworking conforming with the specification of the FP7 GeoNet project now adopted by ETSI TC ITS. This code will be published as open-source early 2011.

*NAIST (Nara Institute of Sciences and Technologies - Nara - Japan)*: IMARA and NAIST are extending their cooperation on ITS communication architecture based on the work realised by a PhD student from NAIST who is spending more than half his PhD course at IMARA. An AYAME proposal has been submitted but this funding program has been aborted due to lack of funding on the Japanese side (JSPS). However, NAIST has secured an internal funding allowing to send interns in 2011.

*Technical University of Sophia (Bulgaria)*: IMARA is conducting a close partnership with the Technical University of Sophia (Department of Mechanical Engineering). Since 2009, Professor Plamen Petrov has been a visiting professor at INRIA. He contributed in conducting common advanced researches with IMARA researchers in the field of dynamic modeling and adaptive motion control for vehicles and robots. Joint works have been also driven to develop and validate platooning concepts for normal speed driving of automated vehicles. This collaboration will continue with further scientific challenges to tackle especially in the field of vehicle control and motion planning.

*University of Yeungnam (South-Korea)*: this year was the first year of collaboration with the Multimedia Signal Processing Laboratory of YEUNGNAM University, Korea. Topics of interest are image and signal processing for automotive applications. Together with SL Corporation (Korea), the SwRI (USA) and Mines ParisTech, this multinational cooperation is aiming at submitting common projects in automotive topics and conduct common researches in the vehicular technology field.

*French-Asian cooperations*: in the context of the Asian-French project *CityHome*, very close collaboration were driven between INRIA's IMARA and E-Motion project-teams and asian laboratories such as: NTU (Singapore), Dept. of Computer Science and Electrical Engineering Graduate School of Science and Technology Kumamoto University (Japan), Department of Automation of the Shanghai Jiao Tong University (SJTU University, China) and the Information and Communication Engineering and the Intelligent Systems Research Center at the SungKyunKwan University (SKKU), (Korea).

We also maintain 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 Oxford (J. Martin);
- several teams in USA (Berkeley, Columbia, Monterey, AT&T).

# 8. Dissemination

## 8.1. Animation of the scientific community

*Guy Fayolle* is scientific advisor at the Robotics laboratory of Mines ParisTech. and associate editor of the journal *Markov Processes and Related Fields*. He is also member of the working group *IFIP WG 7.3*, which has about 150 elected persons from scientific communities interested in various aspect of system modeling and performance evaluation. He serves as a reviewer for *Mathematical Reviews*.

*Jean-Marc Lasgouttes* has been reviewer for applied mathematics journals *QUESTA* and *European Journal of Operational Research*. He organizes the semi-regular seminar “Probabilité, Optimisation, Contrôle”, which takes place in Rocquencourt, in collaboration with the Max-Plus project-team.

## 8.2. Invitations

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

He was program committee member of the 25th “International Symposium on Computer and Information Sciences” (ISCIS 2010), held in London at the Royal Society (September 22-24, 2010) and organised by Imperial College, UK. He gave an invited talk on *Birth and Death Processes on Random Trees*.

He was invited at the *Journées de Probabilités 2010*, which took place at the university of Burgundy (Dijon, june 21-25), where he gave a conference entitled *Processus de naissance et de mort sur certains arbres aléatoires : classification, lois stationnaires, renormalisation*.

## 8.3. Teaching

*Guy Fayolle* was in the PhD Committee of K. Raschel, who defended a thesis entitled *Chemins confinés dans un quadrant*, november 4th, 2010, at Paris 6 University.

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

*Fawzi Nashashibi* is in charge of the “Vision” course and C++ programming at École des Mines de Paris (2nd year - MAREVA option); he gives lectures in 3-D graphics in the “Virtual reality and 3-D modelling” specialized course in the same establishment. He also gives two semesters courses on advanced programing at University of Saint-Denis (Paris 8).

*Arnaud de La Fortelle* is in charge of a Probability Theory course at École des Mines de Paris.

## 8.4. Miscellaneous

*Guy Fayolle* serves has been serving as elected member of the Scientific Board of INRIA.

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## Publications of the year

### Doctoral Dissertations and Habilitation Theses

[9] J. LIORIS. *Évaluation et optimisation de systèmes de taxis collectifs en simulation*, École Nationale des Ponts et Chaussées, December 2010.

### Articles in International Peer-Reviewed Journal

[10] S. AMMOUN, F. NASHASHIBI. *Design and efficiency measurement of cooperative driver assistance system based on wireless communication devices*, in "Transportation Research Part C: Emerging Technologies", 2010, vol. 38, n$^{o}$ 3, p. 408-428.

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### Articles in National Peer-Reviewed Journal

[18] F. DE ASÍS GARCÍA COLLADO, A. DE LA FORTELLE. *Conducción cooperativa en intersecciones*, in "Automática e Instrumentación", November 2010, vol. 423, Francisco Collado was ISA prize winner for his internship at Mines ParisTech “Cooperative driving at intersections”.

### Invited Conferences

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