



RESEARCH CENTER

FIELD

**Networks, Systems and Services,  
Distributed Computing**

Activity Report 2013

# Section Application Domains

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**ACES Project-Team (section vide)**

## **ADAM Project-Team**

# **4. Application Domains**

## **4.1. Introduction**

The ADAM project-team targets the software engineering of adaptive service-oriented applications and middleware. The application domain covered by ADAM is broad and spans from distribution applications to middleware. In all these cases, adaptability is the property which is sought: applications and middleware must be adaptable to new execution contexts, they must react to changes in the environment and they must be able to discover and integrate new services.

The ADAM project-team produces software and middleware building blocks. This explains why the application domain is broad, yet targeting applications where adaptability is the key requirement. This includes electronic commerce, embedded systems, health care information systems, and terrestrial transport information systems. These domains are in direct relation with our currently funded activities. They act as testbeds for the solutions that we propose in terms of middleware services, middleware platforms, runtime kernels, component libraries, languages design or domain modeling.

## **4.2. Electronic Commerce**

Applications in the domain of electronic commerce are by essence distributed. They involve many different participants with heterogeneous information systems which cannot be changed. The challenge is then to provide an adaptation layer to be able to compose and let these systems interoperate. In the context of the ANR TLog SCOrWare, the ICT SOA4All and the FUI CAPPUCINO projects, our activities in this domain aim at supporting service-oriented architectures. We want to have adaptive architectures that can be composed and orchestrated seamlessly. In this domain, the business relationship with customers is vital and many different usage scenarios must be supported. Customers are roaming, and the services must be kept operational across different devices. This puts some constraints on the server tier where technical services must be adapted to manage, for instance, long lasting transactions. The application server infrastructure must then provide a support for adapting technical services.

## **4.3. Embedded Systems**

Embedded systems form a domain where adaptation is a key requirement. The design and the implementation of modern embedded software uses advanced software engineering techniques such model-driven development or software component frameworks. In this domain, we have been involved in several projects, such as the ANR TLog Flex-eWare, and the FUI MIND projects. Several challenges must be addressed here. For example, when a model-driven developed application is adapted, designers have to ensure that the models and the operational level are kept synchronized. The co-evolution of these two levels is one of the challenges that we are addressing. A second challenge is related to software components that need to be customized in order to fit the requirements imposed by constrained environments. It is, for example, a matter of providing component frameworks that can accommodate various granularities of services.

## **4.4. Health Care Information Systems**

Health care information systems form a third application domain in which the ADAM project-team is involved, for instance through demonstrators which have been implemented in the context of the ANR TLog FAROS project. The challenge here is to provide a distributed infrastructure where information will be available to medical staff wherever they are. This imposes to be able to provide this information on many different devices (from high resolution screens to embedded devices on the scene of an accident), while ensuring the privacy of the medical data of a patient (several level of data access must be granted depending on the categories of medical staff). Given the vital role of such an information system, we want to provide guarantees that the services will be highly available and trustworthy. We envision to provide a service-oriented architecture which will be extended to support software contracts and multi-scale environments.

## **4.5. Information Systems for Terrestrial Transport**

Information systems for terrestrial transport are also a domain that we are relying on. Applications are here characterized by frequent disconnections, poor quality network links, and high mobility. We want to provide an infrastructure where the technical services, and among others the communication services, can be adapted to support new requirements. One of the paths that we propose to investigate is to include such a scenario in the general context of the adaptiveness of component frameworks.

## **ARLES Project-Team**

# **4. Application Domains**

## **4.1. Pervasive Software Applications**

The ARLES project-team is interested in the application of pervasive computing, and as such considers various application domains, especially considering the increasing pervasiveness of the digital world. However, we examine exploitation of our results for specific applications, as part of the experiments that we undertake to validate our research results through prototype implementation. Applications that we consider in particular include demonstrators developed in the context of the European and National projects to which we contribute (§ 7).



## **LOGNET Team**

# **4. Application Domains**

## **4.1. Applications**

Because of its generality, our overlay network can target many applications. We would like to list a small number of useful programmable overlay-network-related case studies that can be considered as “LogNet Grand Challenges”, to help potential readers understand the interest of our research program.

- Interconnecting overlay networks transparently;
- building a programmable social network platform relying on a cloud + P2P architecture;
- experimenting with our interconnecting algorithm in the domain of video streaming;
- studying and integrating mobile devices and mobile networks 3G/4G as a real peer in actual P2P systems;
- studying trust and reputation systems applied to P2P and web economy;
- studying new distributed models of computation (long term objective);
- studying new type theories and lambda-calculi to be the basis of new proof assistants based on Curry-Howard isomorphism.

## **ASAP Project-Team**

# **4. Application Domains**

## **4.1. Overview**

The results of the research targeted in ASAP span a wide range of applications. Below are a few examples.

- Personalized web search.
- Recommendation.
- Social networks.
- Notification systems.
- Distributed storage.
- Video streaming.

## **ATLANMOD Project-Team**

# **4. Application Domains**

## **4.1. Application domains**

By definition, MDE can be applied to any software domain. Core MDE techniques developed by the team have been successfully applied to a large variety of industrial domains from information systems to embedded systems. MDE is not even restricted to software engineering, but also applies to data engineering [49] and to system engineering [41]. There are a lot of problems in these application domains that may be addressed by means of modeling and model transformation techniques.

As a result, AtlanMod has collaborated with a great variety of different companies ranging from the Automotive to the Insurances domains and from SMEs to large enterprises through the projects described later on in this same report. AtlanMod hopes to continue this trend in the future.

## **CIDRE Project-Team**

# **4. Application Domains**

## **4.1. Application Domains**

With the infiltration of computers and software in almost all aspects of our modern life, security can nowadays be seen as an absolutely general concern. As such, the results of the research targeted by CIDRE apply to a wide range of domains. It is clear that critical systems, where security (and safety) is a major concern, may benefit from ideas such as dynamic security policy monitoring. On the other hand, systems used by general public (basically, the internet and services such as web or cloud services, social networks, location-based services, etc.) can also benefit from results obtained by CIDRE, especially with respect to privacy. In addition, systems are getting more and more complex, decentralized, distributed, or spontaneous. The emergence of cloud computing brings many challenges that could benefit from ideas, approaches and solutions studied by CIDRE in the context of distributed systems.

## **MYRIADS Project-Team**

# **4. Application Domains**

## **4.1. Overview**

The Myriads research activities address a broad range of application domains. We validate our research results with selected use cases from the following application domains:

- Web services, Service oriented applications,
- Business applications,
- Bio-informatics applications,
- Computational science applications,
- Numerical simulations.

**REGAL Project-Team (section vide)**

**SCORE Team (section vide)**

## **ALGORILLE Project-Team**

### **4. Application Domains**

#### **4.1. Promoting parallelism in applications**

In addition to direct contributions within our own scientific domain, numerous collaborations have permitted us to test our algorithmic ideas in connection with academics of different application domains and through our association with SUPELEC with some industrial partners: physics, geology, biology, medicine, machine learning or finance.

#### **4.2. Experimental methodologies for the evaluation of distributed systems**

Our experimental research axis has a *meta* positioning, targeting all large-scale distributed systems. This versatility allows us to factorize the efforts and maximize our efficiency. The resulting findings are typically used by researchers and developers of systems in the following domains:

- High Performance Computing systems (in particular MPI applications on high-end platforms)
- Cloud environments (in particular virtualized environments)
- Grids (in particular high throughput computing systems)
- Peer-to-peer systems



## ALPINES Team

# 4. Application Domains

## 4.1. Compositional multiphase Darcy flow in heterogeneous porous media

We study the simulation of compositional multiphase flow in porous media with different types of applications, and we focus in particular on reservoir/bassin modeling, and geological CO<sub>2</sub> underground storage. All these simulations are linearized using Newton approach, and at each time step and each Newton step, a linear system needs to be solved, which is the most expensive part of the simulation. This application leads to some of the difficult problems to be solved by iterative methods. This is because the linear systems arising in multiphase porous media flow simulations cumulate many difficulties. These systems are non-symmetric, involve several unknowns of different nature per grid cell, display strong or very strong heterogeneities and anisotropies, and change during the simulation. Many researchers focus on these simulations, and many innovative techniques for solving linear systems have been introduced while studying these simulations, as for example the nested factorization [Appleyard and Cheshire, 1983, SPE Symposium on Reservoir Simulation].

## 4.2. Inverse problems

The research of F. Nataf on inverse problems is rather new since this activity was started from scratch in 2007. Since then, several papers were published in international journals and conference proceedings. All our numerical simulations were performed in FreeFem++.

We focus on methods related to time reversal techniques. Since the seminal paper by [M. Fink et al., Imaging through inhomogeneous media using time reversal mirrors. *Ultrasonic Imaging*, 13(2):199, 1991.], time reversal is a subject of very active research. The main idea is to take advantage of the reversibility of wave propagation phenomena such as it occurs in acoustics, elasticity or electromagnetism in a non-dissipative unknown medium to back-propagate signals to the sources that emitted them. Number of industrial applications have already been developed: touchscreen, medical imaging, non-destructive testing and underwater communications. The principle is to back-propagate signals to the sources that emitted them. The initial experiment, was to refocus, very precisely, a recorded signal after passing through a barrier consisting of randomly distributed metal rods. In [de Rosny and Fink. Overcoming the diffraction limit in wave physics using a time-reversal mirror and a novel acoustic sink. *Phys. Rev. Lett.*, 89 (12), 2002], the source that created the signal is time reversed in order to have a perfect time reversal experiment. Since then, numerous applications of this physical principle have been designed, see [Fink, Renversement du temps, ondes et innovation. Ed. Fayard, 2009] or for numerical experiments [Larmat et al., Time-reversal imaging of seismic sources and application to the great sumatra earthquake. *Geophys. Res. Lett.*, 33, 2006] and references therein.

## 4.3. Numerical methods for wave propagation in multi-scale media

We are interested in the development of fast numerical methods for the simulation of electromagnetic waves in multi-scale situations where the geometry of the medium of propagation may be described through characteristic lengths that are, in some places, much smaller than the average wavelength. In this context, we propose to develop numerical algorithms that rely on simplified models obtained by means of asymptotic analysis applied to the problem under consideration.

Here we focus on situations involving boundary layers and *localized* singular perturbation problems where wave propagation takes place in media whose geometry or material characteristics are submitted to a small scale perturbation localized around a point, or a surface, or a line, but not distributed over a volumic sub-region of the propagation medium. Although a huge literature is already available for the study of localized singular perturbations and boundary layer phenomena, very few works have proposed efficient numerical methods that rely on asymptotic modeling. This is due to their natural functional framework that naturally involves singular functions, which are difficult to handle numerically. The aim of this part of our research is to develop and analyze numerical methods for singular perturbation methods that are prone to high order numerical approximation, and robust with respect to the small parameter characterizing the singular perturbation.

#### **4.4. Data analysis in astrophysics**

We focus on computationally intensive numerical algorithms arising in the data analysis of current and forthcoming Cosmic Microwave Background (CMB) experiments in astrophysics. This application is studied in collaboration with researchers from University Paris Diderot, and the objective is to make available the algorithms to the astrophysics community, so that they can be used in large experiments.

In CMB data analysis, astrophysicists produce and analyze multi-frequency 2D images of the universe when it was 5% of its current age. The new generation of the CMB experiments observes the sky with thousands of detectors over many years, producing overwhelmingly large and complex data sets, which nearly double every year therefore following the Moore's Law. Planck (<http://www.rssd.esa.int/index.php?project=PLANCK>) is a keystone satellite mission which has been developed under auspices of the European Space Agency (ESA). Planck has been surveying the sky since 2010, produces terabytes of data and requires 100 Petaflops per image analysis of the universe. It is predicted that future experiments will collect half petabyte of data, and will require 100 Exaflops per analysis as early as in 2020. This shows that data analysis in this area, as many other applications, will keep pushing the limit of available supercomputing power for the years to come.

## AVALON Team

# 4. Application Domains

## 4.1. Overview

The Avalon team targets applications with large computing and/or data storage needs, which are still difficult to program, maintain, and deploy. Those applications can be parallel and/or distributed applications, such as large scale simulation applications or code coupling applications. Applications can also be workflow-based as commonly found in distributed systems such as grids or clouds.

The team aims at not being restricted to a particular application field, thus avoiding any spotlight. The team targets different HPC and distributed application fields, which bring use cases with different issues. This will be eased by our various collaborations: the team participates to the INRIA-Illinois Joint Laboratory for Petascale Computing, the Physics, Radiobiology, Medical Imaging, and Simulation French laboratory of excellence, the E-Biothon project, the INRIA large scale initiative Computer and Computational Sciences at Exascale (C2S@Exa), and to BioSyL, a federative research structure about Systems Biology of the University of Lyon. Moreover, the team members have a long tradition of cooperation with application developers such as CERFACS and EDF R&D. Last but not least, the team has a privileged connection with CC IN2P3 that opens up collaborations, in particular in the astrophysics field.

In the following, some examples of representative applications we are targeting are presented. In addition to highlighting some application needs, they also constitute some of the use cases we will use to validate our theoretical results.

## 4.2. Climatology

The world's climate is currently changing due to the increase of the greenhouse gases in the atmosphere. Climate fluctuations are forecasted for the years to come. For a proper study of the incoming changes, numerical simulations are needed, using general circulation models of a climate system. Simulations can be of different types: HPC applications (*e.g.*, the NEMO framework [65] for ocean modelization), code-coupling applications (*e.g.*, the OASIS coupler [71] for global climate modeling), or workflows (long term global climate modeling).

As for most applications the team is targeting, the challenge is to thoroughly analyze climate-forecasting applications to model their needs in terms of programing model, execution model, energy consumption, data access pattern, and computing needs. Once a proper model of an application has been set up, appropriate scheduling heuristics could be designed, tested, and compared. The team has a long tradition of working with CERFACS on this topic, for example in the LEGO (2006-09) and SPADES (2009-12) French ANR projects.

## 4.3. Astrophysics

Astrophysics is a major field to produce large volume of data. For instance, the Large Synoptic Survey Telescope (<http://www.lsst.org/lsst/>) will produce 15 TB of data every night, with the goals of discovering thousands of exoplanets and of uncovering the nature of dark matter and dark energy in the universe. The Square Kilometer Array (<http://www.skatelescope.org/>) produces 9 Tbits/s of raw data. One of the scientific projects related to this instrument called Evolutionary Map of the Universe is working on more than 100 TB of images. The Euclid Imaging Consortium (<http://www.ias.u-psud.fr/imEuclid>) will generate 1 PB data per year.

Avalon collaborates with the *Institut de Physique Nucléaire de Lyon* (IPNL) laboratory on large scale numerical simulations in astronomy and astrophysics. Contributions of the Avalon members have been related to algorithmic skeletons to demonstrate large scale connectivity, the development of procedures for the generation of realistic mock catalogs, and the development of a web interface to launch large cosmological simulations on GRID'5000.

This collaboration, that continues around the topics addressed by the CLUES project (<http://www.clues-project.org>), has been extended thanks to the tight links with the CC-IN2P3. Major astrophysics projects execute part of their computing, and store part of their data on the resources provided by the CC-IN2P3. Among them, we can mention SNFactory, Euclid, or LSST. These applications constitute typical use cases for the research developed in the Avalon team: they are generally structured as workflows and a huge amount of data (from TB to PB) is involved.

#### **4.4. Bioinformatics**

Large-scale data management is certainly one of the most important applications of distributed systems in the future. Bioinformatics is a field producing such kinds of applications. For example, DNA sequencing applications make use of MapReduce skeletons.

The Avalon team is a member of BioSyL (<http://www.biosyl.org>), a Federative Research Structure attached to University of Lyon. It gathers about 50 local research teams working on systems biology. Moreover, the team cooperates with the French Institute of Biology and Chemistry of Proteins (IBCP <http://www.ibcp.fr>) in particular through the ANR MapReduce project where the team focuses on a bio-chemistry application dealing with protein structure analysis. These collaborations bring scientific applications that are both dynamic and data-intensive.

## CEPAGE Project-Team

# 4. Application Domains

## 4.1. Resource Allocation and Scheduling

### 4.1.1. Project-team positioning

CEPAGE has undertaken tasks related to the *high level modeling* of heterogeneous networks, both at logical level (overlay networks design) and performance level (latency, bandwidth prediction, connectivity artifacts) in order to optimize tasks such as *resource allocation* and *scheduling* of computations and communications. Objectives include replica placement, broadcasting (streaming) of large messages, independent tasks scheduling and optimization of OLAP databases. Such problems have received a lot of attention in research centers in the USA (Armherst, Colorado, ...), in Spain (Madrid), Poland (Wroclaw), Germany (Dortmund), and others. Papers on algorithmic aspects of platform modeling, scheduling and resource allocation appear at parallel processing conferences and journals in Parallel and Distributed Computing (IPDPS, EuroPar, HIPC, SPAA, IEEE TPDS, JPDC) and members of CEPAGE are strongly involved in many of these events (IPDPS, EuroPar, TPDS) as well as helping to animate well-established specialized workshops, such as HCW and HeteroPar.

Within Inria, studies on overlay networks are performed in the ASAP and GANG projects, and studies related to scheduling and resource allocation are done within the ROMA and the MOAIS projects (and to some extent within ALGORILLE).

### 4.1.2. Scientific achievements

The approach followed in the CEPAGE project, and our main originality, is to consider the whole chain, from gathering actual data on the networks to platform modeling and complexity analysis. Indeed, many complexity analysis studies are performed on models whose parameters cannot actually be evaluated (this applies, for instance, to all algorithms that assume that the topology of a platform running over the Internet is known in advance) and many platform models are intractable from an algorithmic perspective (this applies, for instance, to all models that represent latencies or bandwidths between all pairs of nodes as a general matrix). Our general goal is to provide models whose parameters can be evaluated at runtime using actual direct measurements, to propose algorithms whose worst-case (or average-case) behavior can be proved for this model, and finally to evaluate the whole chain (model + algorithm + implementation).

From an applicative perspective, in the framework of the PhD Thesis of Hejer Rejeb, we have considered several storage and resource allocation problems in collaboration with Cyril Banino-Rokkones at Yahoo! Trondheim (dealing with actual datasets enabled us to improve known approximation results in this specific context). We have in particular studied the modeling of TCP mechanism for handling contentions and its influence on the performance of several scheduling algorithms and advocated the use of QoS mechanisms for prescribed bandwidth sharing (IPDPS 2010 [78], ICPADS 2008 [63], AlgoTel 2009 [75], ICPADS 2009 [74], PDP 2010 [76]). In the PhD thesis of Hubert Larchevêque, we have considered the problem of aggregating resources (or placing replicas) in a distributed network (Sirocco 2008 [65], Opodis 2008 [66], ICPP 2011 [71], AlgoTel 2011 [67]) so that each group satisfies some properties (in terms of aggregated memory, CPU and maximal distance in terms of latency within a group). We proved several multi-criteria approximation results for this problem, and we compared several embedding tools (Vivaldi, Sequoia) in the context of resource aggregation. For these applications, we have also provided when possible distributed algorithms based on sophisticated overlay networks, in particular in order to deal with heterogeneity (IPDPS 2008 [72]). In the PhD Thesis of Przemyslaw Uznanski, we focus on the design of efficient streaming and broadcasting strategies, in particular in presence of connectivity artifacts like firewalls (IPDPS 2010 [73], ICPADS 2011 [70]). We have also worked on establishing under the bounded multiport model several new complexity results for classical distributed computing models such as divisible load theory (HCW 2008 [68], IPDPS 2008 [118], IPDPS 2012 [69]) that have been later extended to Continuous Integration (HCW 2012 [64]).

In the context of database query optimization, materializing some queries results for optimization is a standard solution when execution time performance is crucial. In the datacube context, the problem has been studied for a long time under the storage space limit constraint. Here also, we were able to reformulate this problem by considering instead the execution time as the hard constraint while the objective is to reduce the storage space. Even if the problem turns to be NP-hard, this reformulation allowed us to provide effective approximate solutions with both space and performance bounded guarantees (EDBT 2009 [107]). Moreover, reducing the storage space tends to reduce the maintenance time since the latter is linearly proportional to the former. Finally, we characterized the minimal number of updates to be performed before performance becomes no more guaranteed and a new solution must be recomputed (ADBIS 2008 [108]). One of the key concepts we used for solving this problem was that of a *border*. It turns out that this notion is equivalent to e.g., maximal frequent itemsets or minimal functional dependencies extensively studied by data mining community. In contrast to all previous proposals, we proposed the only parallel algorithm computing these borders with a speed-up guarantee regarding the number of processing units (CIKM 2011 [106]). Besides the analytical study, its implementation in maximal frequent itemset mining outperforms state of the art implementations (see Section 5.1).

To achieve these results, our efforts have also focused on analyzing and building realistic datasets (AlgoTel 2012 [97]) and proposing data analysis results for specific distributions (ISAAC 2011 [59]). On the modeling side, in general, for bandwidth and contention modeling, we have proved that the bounded multi-port model (where each node is associated to an incoming bandwidth, an outgoing bandwidth and a maximal number of simultaneous TCP connexions) is both implementable, realistic and tractable (EuroPar 2011 [77]). In particular, we have proved in strongly different contexts (allocation of virtual machines to physical machines, overlay design for broadcasting, server allocation for volunteer computing) that the use of resource augmentation enables to obtain quasi-optimal results. All our modeling efforts and algorithms have been included into the SimGRID Software (<http://simgrid.gforge.inria.fr>), which enables us both to compare several algorithms under the same exact conditions and to compare the results obtained with several communication models (see Section 5.1).

*Perspectives:* We believe that our approach based on sound models, approximation algorithms for these models, followed by experimental validation is a strong one and we intend to continue in this direction in the following years. Our goal of designing realistic solutions pushes towards considering average case analysis of our algorithms, as well as robust optimization techniques. Furthermore, the recent strong interest in Cloud systems from the community entices us to use our expertise in resource allocation for the optimization of Cloud systems, both from the provider and from the user points of view. We already have some interesting contacts with local companies to share start collaborating on these topics. In this context, reliability issues are very important, and we believe that robust optimization is a very relevant approach for these problems.

## 4.2. Compact Routing

### 4.2.1. Project-team positioning

In this axis, CEPAGE mainly works on the design on distributed and light data structures. One of the techniques consists in summarizing the topology and metric of the networks allowing to route or to approximate the original distances within the network. Such structures, often called *spanners*, does not require the storage of all the original network links. Then we get economic distributed data structures that can be updated without a high communication cost. Our main collaborations are done with the best specialists world-wide, in particular: Israel (Weizmann), USA (MIT, Microsoft, Chicago), Belgium (Alcatel Lucent-Bell), France (Paris, Nice).

Algorithms and Routing are also intensively studied in research labs in the USA (CAIDA). Our contributions appear regularly at all of the major conferences in Distributed Computing (PODC, DISC, SPAA), as well as at top venues with a more general algorithmic audience (STOC, SODA, ICALP, ESA). Members of CEPAGE actively participate in these events (ICALP 2010 and DISC 2009 were organized by members of CEPAGE).

Within Inria, studies of mobile agents are also performed in the GANG project and to some extent also within MASCOTTE within the european project EULER.



### 4.2.2. Scientific achievements

There are several techniques to manage sub-linear size routing tables (in the number of nodes of the platform) while guaranteeing almost shortest paths. Some techniques provide routes of length at most  $1 + \epsilon$  times the length of the shortest one while maintaining a poly-logarithmic number of entries per routing table. However, these techniques are not universal in the sense that they apply only on some class of underlying topologies. Universal schemes exist. Typically they achieve  $O(\sqrt{n})$ -entry local routing tables for a stretch factor of 3 in the worst case. Some experiments have shown that such methods, although universal, work very well in practice, in average, on realistic scale-free or existing topologies.

The space lower bound of  $O(\sqrt{n})$ -entry for routing with *multiplicative* stretch 3 is due to the existence of dense graphs with large girth. Dense graphs can be sparsified to subgraphs (spanners), with various stretch guarantees. There are spanners with *additive* stretch guarantees (some even have constant additive stretch) but only very few additive routing schemes are known.

In (SPAA 2012 [101]), we give reasons why routing in unweighted graphs with *additive* stretch is difficult in the form of space lower bounds for general graphs and for planar graphs. On the positive side, we give an almost tight upper bound: we present the first non-trivial compact routing scheme with  $o(\lg^2 n)$ -bit addresses, *additive* stretch  $O(n^{1/3})$ , and table size  $O(n^{1/3})$  bits for planar graphs.

We have recently considered the *forbidden-set* extension of distance oracles and routing schemes. Given an arbitrary set of edge/node failure  $F$ , a source  $s$  and a target  $t$  such that  $s, t \notin F$ , the goal is to route (or evaluate the distance) between  $s$  and  $t$  in the graph  $G \setminus F$ , so avoiding  $F$ . The classical problem is for  $F = \emptyset$ . This extension is considered as a first step toward fully dynamic data-structures, a challenging goal. For graphs of low doubling dimension we have shown in (PODC 2012 [58]) that it is possible to route from  $s$  to  $t$  in  $G \setminus F$  with stretch  $1 + \epsilon$ , for all  $s, t, F$ , given poly-logarithmic size labels of all the nodes invoked in the query  $(s, t, F)$ . This has been generalized to all planar graphs achieving similar stretch and label size performances. As a byproduct we have designed a fully dynamic algorithm for maintaining  $1 + \epsilon$  approximate distances in planar graphs supporting edge/node addition/removal within update and query time  $\sqrt{n}$  in the worst-case (STOC 2012 [57]).

$\Theta_k$ -graphs are geometric graphs that appear in the context of graph navigation. The shortest-path metric of these graphs is known to approximate the Euclidean complete graph up to a factor depending on the cone number  $k$  and the dimension of the space. We have introduced in (WG 2010 [79]) a specific subgraph of the  $\Theta_6$ -graph defined in the 2D Euclidean space, namely the half- $\Theta_6$ -graph, composed of the even-cone edges of the  $\Theta_6$ -graph. Our main contribution is to show that these graphs are exactly the TD-Delaunay graphs, and are strongly connected to the geodesic embeddings of orthogonal surfaces of coplanar points in the 3D Euclidean space. We also studied the asymptotic behavior of these spanners (*Adv. in Appl. Proba.* [116]) and in collaboration with Ljubomir Perković, we worked on the question of bounded degree planar spanner. We proposed an algorithm that computes a plane 6-spanner of degree at most 6 in (ICALP 2010 [80]). The previous best bound on the maximum degree for constant stretch plane spanners was only 14.

In order to cope with network dynamism and failures, and motivated by multipath routing, we introduce a multi-connected variant of spanners. For that purpose we introduce in (OPDIS 2011 [102]) the  $p$ -multipath cost between two nodes  $u$  and  $v$  as the minimum weight of a collection of  $p$  internally vertex-disjoint paths between  $u$  and  $v$ . Given a weighted graph  $G$ , a subgraph  $H$  is a  $p$ -multipath  $s$ -spanner if for all  $u, v$ , the  $p$ -multipath cost between  $u$  and  $v$  in  $H$  is at most  $s$  times the  $p$ -multipath cost in  $G$ . The  $s$  factor is called the stretch. Building upon recent results on fault-tolerant spanners, we show how to build  $p$ -multipath spanners of constant stretch and of  $O(n^{1+1/k})$  edges, for fixed parameters  $p$  and  $k$ ,  $n$  being the number of nodes of the graph. Such spanners can be constructed by a distributed algorithm running in  $O(k)$  rounds. Additionally, we give an improved construction for the case  $p = k = 2$ . Our spanner  $H$  has  $O(n^{3/2})$  edges and the  $p$ -multipath cost in  $H$  between any two node is at most twice the corresponding one in  $G$  plus  $O(W)$ ,  $W$  being the maximum edge weight.

We also worked on compact coding in data warehouses: in order to get quick answer in large data, we have to estimate, select and materialize (store) partial data structures. We got several solutions with a prescribed

guarantee in different models for the following problems: view size estimation with small samples, view selection, parallel computation of frequent itemsets. In (*Theor. Comp. Sci.* [105]) a new algorithm that allow the administrator or user of a DBMS to choose which part of the data cube to optimize (known as the *the views selection problem*), that takes as input a fact table and computes a set of views to store in order to speed up queries.

*Perspectives:* The compact coding activity in data-warehouse is promising since the amount of data collected keeps on increasing and being able to answer in real-time complex requests (data mining) is still challenging.

Some robust data structures already exist which, given a small number of  $k$  changes of topology or  $k$  faults, tolerate these faults, i.e., alternative routes with bounded stretch can be provided without any updates. This is a first step toward dynamic networks but the updates of these data structures are currently still quite complicated with a high communication cost.

## 4.3. Mobile Agents

### 4.3.1. Project-team positioning

CEPAGE has undertaken tasks related to the design of algorithms which control the behavior of so called *mobile agents*, moving around a network or a geometric environment, with the goal of achieving a specified objective. Objectives of central importance to the study include: exploration of unknown environments, terrain patrolling, network maintenance, and coordination of activities with other agents. Such problems have in recent years been the object of interest of numerous research teams working on Distributed Computing worldwide, in particular, at research centers in Canada (Quebec), Israel (Tel Aviv, Haifa), France (Paris, Marseille), the UK (London, Liverpool), and Switzerland (Zurich). Algorithms for mobile agents in social networking applications are also intensively studied in research labs in the USA (Stanford, Facebook). Papers on mobile agents appear regularly at all of the major conferences in Distributed Computing (PODC, DISC, SPAA), as well as at top venues with a more general algorithmic audience (SODA, ICALP, ESA). Members of CEPAGE actively participate in these events, and are also a recognizable part of the European community focused around mobile agents, helping to animate well-established specialized conferences, such as SIROCCO and OPODIS.

Within Inria, studies of mobile agents are also performed in the GANG project, and to some extent also within MASCOTTE. CEPAGE has active research links with both of these teams.

### 4.3.2. Scientific achievements

The work of CEPAGE has focused on contributing new decentralized algorithms for controlling mobile entities known as *agents*, deployed in unknown environments. We mainly considered the network setting, in which agents moving around the nodes of the network graph may be used to analyze the structure of the network and to perform maintenance tasks, such as detecting dynamic faults, improving/monitoring dissemination of information, etc. Our theoretical studies focused on designing new strategies for controlling the behavior of agents and answering crucial questions concerning the feasibility of solving fundamental problems, subject to different model assumptions and constraints on the knowledge and computational power of agents.

One major line of our research focused on the so called *anonymous graph model* in which an agent is unable to determine the identifier of the node of its current location, but can only see a local ordering of the links around it. Such a study is motivated e.g. by scenarios in which the identifiers of nodes may be too large for the agent to process using its bounded resources, or may change in time. In this model, we studied two of the most fundamental problems: that of traversing all of the nodes of the network (exploration) and of meeting another agent in the network (rendezvous), so as to coordinate with it. Our contributions include a precise characterization of the space requirements for agents solving both of these problems deterministically: exploration in (*Trans. Alg.* 2008 [84]) and rendezvous in (*Dist. Comp.* 2012 [92]), in a paper presented at the Best Paper Session of PODC 2010. We have also studied fast solutions for specific scenarios of the rendezvous problem (DISC 2010 [60], DISC 2011 [85], SPAA 2012 [93]) and the problem of approximate map construction within an anonymous graph (OPODIS 2010 [82]). A separate problem, intensively studied in recent years by several research teams, concerns the exploration of a network with pre-configured ports



so as to assist the agent. In our work on the topic, our team has proposed several new techniques for graph decomposition, leading in particular to the shortest currently known strategies of periodic exploration for both the case of memoryless (*Algorithmica* 2012 [112]) and small-memory agents (SIROCCO 2009 [88]).

A closely related line of research was devoted to the design of network exploration strategies which guarantee a fast and fair traversal of all the nodes, making use of agents with extremely restricted capabilities. Such strategies were inspired by the random walk, but had the additional advantage of deterministic and desirable behavior in worst-case scenarios. We presented a series of results in the area at notable conferences, involving both the design of new exploration strategies (ICALP 2009 [86]) and completely new insights into previously known approaches such as the so called “rotor-router model” (DISC 2009 [61], OPODIS 2009 [62]). All of the proposed algorithms were shown to be viable alternatives to the random walk, competing in terms of such parameters as cover time, steady-state exploration frequency, and stabilization in the event of faults.

Our efforts have also focused on the theory of coordinating activities of large groups of agents. We have conducted pioneering work in the so called look-compute-move model in networks, in which extremely restricted (asynchronous and oblivious) agents, relying on snapshot views of the system, are nevertheless able to perform useful computational tasks. Our solutions to the problems of collective exploration in trees (*Theor. Comp. Sci.* 2010 [99]) and gathering agents on a ring (*Theor. Comp. Sci.* 2008 [110] and 2010 [109]) have sparked a long line of follow-up research, accumulating more than 120 citations in total (according to Google Scholar). In a slightly different scenario, we have considered computations with teams of agents whose task is to collaboratively detect and mark potentially dangerous (faulty) links of the network, called “black holes”, which are capable of destroying agents which enter them. We have provided important contributions to the theory of black hole search in both undirected (SIROCCO 2008 [87], DISC 2008 [100]) and directed (*Theor. Comp. Sci.* [113]) graphs.

It is expected that the mobile agent theme of CEPAGE will give rise to 2 PhD theses. In 2013, Ahmed Wade will defend his thesis on mobile agent protocols for dynamic networks, whereas in 2014 Dominik Pajak will defend his thesis on multi-agent protocols for efficient graph exploration. Our scientific interests also include mobile agent protocols for geometric applications, more remote from the central themes of CEPAGE, but having extensive applications in robotics (providing protocols, e.g., for efficient patrolling and guarding of terrains, traversing terrains using groups of robots, etc.). We have already published several papers in this area (SIROCCO 2010 [90], SWAT 2010 [91], ESA 2011 [89]), building up the theoretical fundamentals of a new field, and already attracting the attention of a wider community of researchers working in robotics and AI.

*Perspectives:* Our goal is to explore applications of mobile agent techniques in domains of growing importance, namely, social networks and robotics. We are currently discussing applications of our techniques in problems of brand recognition on the web with a local industrial partner (Systonic KeepAlert), and other companies (through our research collaborators in Liverpool). We intend to undertake collaboration with European/American research labs and industrial partners.

**GRAND-LARGE Project-Team (section vide)**

## HIEPACS Project-Team

# 4. Application Domains

## 4.1. Material physics

**Participants:** Pierre Blanchard, Olivier Coulaud, Arnaud Etcheverry, Matthias Messner.

Due to the increase of available computer power, new applications in nano science and physics appear such as study of properties of new materials (photovoltaic materials, bio- and environmental sensors, ...), failure in materials, nano-indentation. Chemists, physicists now commonly perform simulations in these fields. These computations simulate systems up to billion of atoms in materials, for large time scales up to several nanoseconds. The larger the simulation, the smaller the computational cost of the potential driving the phenomena, resulting in low precision results. So, if we need to increase the precision, there is two ways to decrease the computational cost. In the first approach, we improve algorithms and their parallelization and in the second way, we will consider a multiscale approach.

A domain of interest is the material aging for the nuclear industry. The materials are exposed to complex conditions due to the combination of thermo-mechanical loading, the effects of irradiation and the harsh operating environment. This operating regime makes experimentation extremely difficult and we must rely on multi-physics and multi-scale modeling for our understanding of how these materials behave in service. This fundamental understanding helps not only to ensure the longevity of existing nuclear reactors, but also to guide the development of new materials for 4th generation reactor programs and dedicated fusion reactors. For the study of crystalline materials, an important tool is dislocation dynamics (DD) modeling. This multiscale simulation method predicts the plastic response of a material from the underlying physics of dislocation motion. DD serves as a crucial link between the scale of molecular dynamics and macroscopic methods based on finite elements; it can be used to accurately describe the interactions of a small handful of dislocations, or equally well to investigate the global behavior of a massive collection of interacting defects.

To explore i.e. to simulate these new areas, we need to develop and/or to improve significantly models, schemes and solvers used in the classical codes. In the project, we want to accelerate algorithms arising in those fields. We will focus on the following topics (in particular in the currently under definition **OPTIDIS** project in collaboration with CEA Saclay, CEA Ile-de-france and SIMaP Laboratory in Grenoble) in connection with research described at Sections 3.4 and 3.5 .

- The interaction between dislocations is long ranged ( $O(1/r)$ ) and anisotropic, leading to severe computational challenges for large-scale simulations. In dislocation codes, the computation of interaction forces between dislocations is still the most CPU time consuming and has to be improved to obtain faster and more accurate simulations.
- In such simulations, the number of dislocations grows while the phenomenon occurs and these dislocations are not uniformly distributed in the domain. This means that strategies to dynamically construct a good load balancing are crucial to achieve high performance.
- From a physical and a simulation point of view, it will be interesting to couple a molecular dynamics model (atomistic model) with a dislocation one (mesoscale model). In such three-dimensional coupling, the main difficulties are firstly to find and characterize a dislocation in the atomistic region, secondly to understand how we can transmit with consistency the information between the two micro and meso scales.

## 4.2. Co-design for scalable numerical algorithms in scientific applications

**Participants:** Pierre Brenner, Jean-Marie Couteyen, Luc Giraud, Xavier Lacoste, Guillaume Latu, Salli Moustapha, Pierre Ramet, Fabien Rozar, Jean Roman, Pablo Salas, Xavier Vasseur.

The research activities concerning the ITER challenge are involved in the Inria Project Lab (IPL) **C2S@EXA**.

#### 4.2.1. *MHD instabilities Edge Localized Modes*

The numerical simulations tools designed for ITER challenges aim at making a significant progress in understanding of largely unknown at present physics of active control methods of plasma edge MHD instabilities Edge Localized Modes (ELMs) which represent particular danger with respect to heat and particle loads for Plasma Facing Components (PFC) in ITER. Project is focused in particular on the numerical modeling study of such ELM control methods as Resonant Magnetic Perturbations (RMPs) and pellet ELM pacing both foreseen in ITER. The goals of the project are to improve understanding of the related physics and propose possible new strategies to improve effectiveness of ELM control techniques. The tool for the nonlinear MHD modeling (code **JOREK**) will be largely developed within the present project to include corresponding new physical models in conjunction with new developments in mathematics and computer science strategy in order to progress in urgently needed solutions for ITER.

The fully implicit time evolution scheme in the **JOREK** code leads to large sparse linear systems that have to be solved at every time step. The MHD model leads to very badly conditioned matrices. In principle the **PaStiX** library can solve these large sparse problems using a direct method. However, for large 3D problems the CPU time for the direct solver becomes too large. Iterative solution methods require a preconditioner adapted to the problem. Many of the commonly used preconditioners have been tested but no satisfactory solution has been found. The research activities presented in Section 3.3 will contribute to design new solution techniques best suited for this context.

#### 4.2.2. *Turbulence of plasma particules inside a tokamak*

In the context of the ITER challenge, the **GYSELA** project aims to simulate the turbulence of plasma particules inside a tokamak. Thank to a better comprehension of this phenomenon, it would be possible to design a new kind of source of energy based of nuclear fusion. Currently, **GYSELA** is parallalized in a MPI/OpenMP way and can exploit the power of the current greatest supercomputers (e.g., Juqueen). To simulate faithfully the plasma physic, **GYSELA** handles a huge amount of data. In fact, the memory consumption is a bottleneck on large simulations (449 K cores). In the meantime all the reports on the future Exascale machines expect a decrease of the memory per core. In this context, mastering the memory consumption of the code becomes critical to consolidate its scalability and to enable the implementation of new features to fully benefit from the extreme scale architectures.

In addition to activities for designing advanced generic tools for managing the memory optimisation, further algorithmic research will be conduced to better predict and limit the memory peak in order to reduce the memory footprint of **GYSELA**.

#### 4.2.3. *SN cartesian solver for nuclear core simulation*

As part of its activity, EDF R&D is developing a new nuclear core simulation code named COCAGNE that relies on a Simplified PN (SPN) method to compute the neutron flux inside the core for eigenvalue calculations. In order to assess the accuracy of SPN results, a 3D Cartesian model of PWR nuclear cores has been designed and a reference neutron flux inside this core has been computed with a Monte Carlo transport code from Oak Ridge National Lab. This kind of 3D whole core probabilistic evaluation of the flux is computationally very demanding. An efficient deterministic approach is therefore required to reduce the computation effort dedicated to reference simulations.

In this collaboration, we work on the parallelization (for shared and distributed memories) of the DOMINO code, a parallel 3D Cartesian SN solver specialized for PWR core reactivity computations which is fully integrated in the COCAGNE system.

#### 4.2.4. *3D aerodynamics for unsteady problems with moving bodies*

ASTRIUM has developed for 20 years the FLUSEPA code which focuses on unsteady phenomenon with changing topology like stage separation or rocket launch. The code is based on a finite volume formulation with temporal adaptive time integration and supports bodies in relative motion. The temporal adaptive integration

classifies cells in several temporal levels, zero being the level with the slowest cells and each level being twice as fast as the previous one. This repartition can evolve during the computation, leading to load-balancing issues in a parallel computation context. Bodies in relative motion are managed through a CHIMERA-like technique which allows building a composite mesh by merging multiple meshes. The meshes with the highest priorities recover the least ones, and at the boundaries of the covered mesh, an intersection is computed. Unlike classical CHIMERA technique, no interpolation is performed, allowing a conservative flow integration. The main objective of this research is to design a scalable version of FLUSEPA in order to run efficiently on modern parallel architectures very large 3D simulations.

#### **4.2.5. *Nonlinear eigensolvers for thermoacoustic instability calculation***

Thermoacoustic instabilities are an important concern in the design of gas turbine combustion chambers. Most modern combustion chambers have annular shapes and this leads to the appearance of azimuthal acoustic modes. These modes are often powerful and can lead to structural vibrations being sometimes damaging. Therefore, they must be identified at the design stage in order to be able to eliminate them. However, due to the complexity of industrial combustion chambers with a large number of burners, numerical studies of real 3D configurations are a challenging task. The modelling and the discretization of such phenomena lead to the solution of a nonlinear eigenvalue problem of size a few millions.

Such a challenging calculations performed in close collaboration with the [Computational Fluid Dynamic project](#) at CERFACS.

## **KERDATA Project-Team**

# **4. Application Domains**

## **4.1. Application Domains**

Below are three examples which illustrate the needs of large-scale data-intensive applications with respect to storage, I/O and data analysis. They illustrate the classes of applications that can benefit from our research activities.

### ***4.1.1. Joint genetic and neuroimaging data analysis on Azure clouds***

Joint acquisition of neuroimaging and genetic data on large cohorts of subjects is a new approach used to assess and understand the variability that exists between individuals, and that has remained poorly understood so far. As both neuroimaging- and genetic-domain observations represent a huge amount of variables (of the order of millions), performing statistically rigorous analyses on such amounts of data is a major computational challenge that cannot be addressed with conventional computational techniques only. On the one hand, sophisticated regression techniques need to be used in order to perform significant analysis on these large datasets; on the other hand, the cost entailed by parameter optimization and statistical validation procedures (e.g. permutation tests) is very high.

The A-Brain (AzureBrain) Project started in October 2010 within the Microsoft Research-Inria Joint Research Center. It is co-led by the KerData (Rennes) and Parietal (Saclay) Inria teams. They jointly address this computational problem using cloud related techniques on Microsoft Azure cloud infrastructure. The two teams bring together their complementary expertise: KerData in the area of scalable cloud data management, and Parietal in the field of neuroimaging and genetics data analysis.

In particular, KerData brings its expertise in designing solutions for optimized data storage and management for the Map-Reduce programming model. This model has recently arisen as a very effective approach to develop high-performance applications over very large distributed systems such as grids and now clouds. The computations involved in the statistical analysis designed by the Parietal team fit particularly well with this model.

### ***4.1.2. Structural protein analysis on Nimbus clouds***

Proteins are major components of the life. They are involved in lots of biochemical reactions and vital mechanisms for living organisms. The three-dimensional (3D) structure of a protein is essential for its function and for its participation to the whole metabolism of a living organism. However, due to experimental limitations, only few protein structures (roughly, 60,000) have been experimentally determined, compared to the millions of proteins sequences which are known. In the case of structural genomics, the knowledge of the 3D structure may be not sufficient to infer the function. A usual way to make a structural analysis of a protein or to infer its function is to compare its known, or potential, structure to the whole set of structures referenced in the *Protein Data Bank* (PDB).

In the framework of the MapReduce ANR project led by KerData, we focus on the SuMo application (*Surf the Molecules*) proposed by Institute for Biology and Chemistry of the Proteins from Lyon (IBCP, a partner in the MapReduce project). This application performs structural protein analysis by comparing a set of protein structures against a very large set of structures stored in a huge database. This is a typical data-intensive application that can leverage the Map-Reduce model for a scalable execution on large-scale distributed platforms. Our goal is to explore storage-level concurrency-oriented optimizations to make the SuMo application scalable for large-scale experiments of protein structures comparison on cloud infrastructures managed using the Nimbus IaaS toolkit developed at Argonne National Lab (USA).

If the results are convincing, then they can immediately be applied to the derived version of this application for drug design in an industrial context, called MED-SuMo, a software managed by the MEDIT SME (also a partner in this project). For pharmaceutical and biotech industries, such an implementation run over a cloud computing facility opens several new applications for drug design. Rather than searching for 3D similarity into biostructural data, it will become possible to classify the entire biostructural space and to periodically update all derivative predictive models with new experimental data. The applications in this complete chemo-proteomic vision concern the identification of new druggable protein targets and thereby the generation of new drug candidates.

#### ***4.1.3. I/O intensive climate simulations for the Blue Waters post-Petascale machine***

A major research topic in the context of HPC simulations running on post-Petascale supercomputers is to explore how to efficiently record and visualize data during the simulation without impacting the performance of the computation generating that data. Conventional practice consists in storing data on disk, moving them off-site, reading them into a workflow, and analyzing them. This approach becomes increasingly harder to use because of the large data volumes generated at fast rates, in contrast to limited back-end speeds. Scalable approaches to deal with these I/O limitations are thus of utmost importance. This is one of the main challenges explicitly stated in the roadmap of the Blue Waters Project (<http://www.ncsa.illinois.edu/BlueWaters/>), which aims to build one of the most powerful supercomputers in the world.

In this context, the KerData project-team started to explore ways to remove the limitations mentioned above through collaborative work in the framework of the Joint Inria-UIUC Lab for Petascale Computing (JLPC, Urbana-Champaign, Illinois, USA), whose research activity focuses on the Blue Waters project. As a starting point, we are focusing on a particular tornado simulation code called CM1 (Cloud Model 1), which is intended to be run on the Blue Waters machine. Preliminary investigation demonstrated the inefficiency of the current I/O approach, which typically consists in periodically writing a very large number of small files. This causes bursts of I/O in the parallel file system, leading to poor performance and extreme variability (jitter) compared to what could be expected from the underlying hardware. The challenge here is to investigate how to make an efficient use of the underlying file system by avoiding synchronization and contention as much as possible. In collaboration with the JLPC, we started to address these challenges through an approach based on dedicated I/O cores.

## MESCAL Project-Team

### 4. Application Domains

#### 4.1. Cloud, Grid, High Performance and Desktop Computing

**Participants:** Arnaud Legrand, Olivier Richard.

The research of MESCAL on desktop grids has been very active and fruitful during the evaluation period. The main achievements concern the collection and statistical exploitation of traces in volunteer computing systems and in cloud infrastructures. Such models have enabled to optimize the behavior of volunteer computing systems or to extend the scope of their applicability. Such traces have also been used in SimGrid to simulate volunteer computing systems at unprecedented scale. We can also mention the work conducted in SimGrid and which has also allowed to simulate HPC applications and platforms very accurately. Last, we should mention the continuous work on OAR and G5K, in particular on the experiment reconstructability aspect.

#### 4.2. Wireless Networks

**Participants:** Bruno Gaujal, Corinne Touati, Panayotis Mertikopoulos.

MESCAL is involved in the common laboratory between Inria and Alcatel-Lucent. Bruno Gaujal is leading the Selfnets research action. This action was started in 2008 and was renewed for four more years (from 2012 to 2016). In our collaboration with Alcatel we use game theory techniques as well as evolutionary algorithms to compute optimal configurations in wireless networks (typically 3G or LTE networks) in a distributed manner.

#### 4.3. On-demand Geographical Maps

**Participant:** Jean-Marc Vincent.

*This joint work involves the UMR 8504 Géographie-Cité, LIG, UMS RIATE and the Maisons de l'Homme et de la Société.*

Improvements in the Web developments have opened new perspectives in interactive cartography. Nevertheless existing architectures have some problems to perform spatial analysis methods that require complex computations over large data sets. Such a situation involves some limitations in the query capabilities and analysis methods proposed to users. The HyperCarte consortium with LIG, Géographie-cité and UMR RIATE proposes innovative solutions to these problems. Our approach deals with various areas such as spatio-temporal modeling, parallel computing and cartographic visualization that are related to spatial organizations of social phenomena.

Nowadays, analyses are done on huge heterogeneous data set. For example, demographic data sets at nuts 5 level, represent more than 100.000 territorial units with 40 social attributes. Many algorithms of spatial analysis, in particular potential analysis are quadratic in the size of the data set. Then adapted methods are needed to provide “user real time” analysis tools.



## MOAIS Project-Team

# 4. Application Domains

## 4.1. Virtual Reality

**Participants:** Thierry Gautier, Bruno Raffin, Jean-Louis Roch.

We are pursuing and extending existing collaborations to develop virtual reality applications on PC clusters and grid environments:

- Real time 3D modeling. An on-going collaboration with the MORPHEO project focuses on developing solutions to enable real time 3D modeling from multiple cameras using a PC cluster. An operational code base was transferred to the 4DViews Start-up in September 2007. 4DViews is now selling turn key solutions for real-time 3D modeling. Recent developments take two main directions:
  - Using a HMD (Head Mounted Display) and a Head Mounted Camera to provide the user a high level of interaction and immersion in the mixed reality environment. Having a mobile camera raises several concerns. The camera position and orientation need to be precisely known at anytime, requiring to develop on-line calibration approaches. The background subtraction cannot anymore be based on a static background learning for the mobile camera, required here too new algorithms.
  - Distributed collaboration across distant sites. In the context of the ANR DALIA we are developing a collaborative application where a user at Bordeaux (iParla project-team) using a real time 3D modeling platform can meet in a virtual world with a user in Grenoble also using a similar platform. We rely on the Grid'5000 dedicated 10 Gbits/s network to enable a low latency. The main issues are related to data transfers that need to be carefully managed to ensure a good latency while keeping a good quality, and the development of new interaction paradigms.

On these issues, Benjamin Petit started a Ph.D. in October 2007, co-advised by Edmond Boyer (PERCEPTION) and Bruno Raffin.

- Real time physical simulation. We are collaborating with the EVASION project on the SOFA simulation framework. Everton Hermann, a Ph.D. co-advised by François Faure (EVASION) and Bruno Raffin, works on parallelizing SOFA using the KAAPI programming environment. The challenge is to provide SOFA with a parallelization that is efficient (real-time) while not being invasive for SOFA programmers (usually not parallel programmer). We developed a first version using the Kaapi environment for SMP machines that relies on a mix of work-stealing and dependency graph analysis and partitioning. A second version targets machines with multiples CPUs and multiple GPUs. We extended the initial framework to support a work stealing based load balancing between CPUs and GPUs. It required to extend Kaapi to support heterogeneous tasks (GPU and CPU ones) and to adapt the work stealing strategy to limit data transfers between CPUs and GPUs (the main bottleneck for GPU computing).
- Distant collaborative work. We conduct experiments using FlowVR for running applications on Grid environments. Two kinds of experiments will be considered: collaborative work by coupling two or more distant VR environments ; large scale interactive simulation using computing resources from the grid. For these experiments, we are collaborating with the LIFO and the LABRI.
- Parallel cache-oblivious algorithms for scientific visualization. In collaboration with the CEA DAM, we have developed a cache-oblivious algorithm with provable performance for irregular meshes. Based on this work, we are studying parallel algorithms that take advantage of the shared cache usually encountered on multi-core architectures (L3 shared cache). The goal is to have the cores collaborating to efficiently share the L3 cache for a better performance than with a more traditional approach that leads to split the L3 cache between the cores. We are obtaining good performance gains with a parallel iso-surface extraction algorithm. This work is the main focus of Marc Tchiboukdjian Ph.D.

## 4.2. Code Coupling and Parallel Programming

**Participants:** Thierry Gautier, Jean-Louis Roch, Vincent Danjean, Frédéric Wagner.

Code coupling aim is to assemble component to build distributed applications by reusing legacy code. The objective here is to build high performance applications for multi-cores, cluster or grid infrastructures.

- **Parallel programming model and runtime support.** Programming parallel applications is a challenging problem. The MOAIS Team has a strong knowledge in parallel algorithms and develop a runtime support for scheduling parallel program written in a very high level interface. The parallelism from recursive divide and conquer applications and those from iterative simulation are studied. Scheduling heuristics are based on online work stealing for the former class of applications, and on hierarchical partitioning for the latter. The runtime support provides capabilities to hide latency by computation thanks to a non-blocking one-side communication protocol and by re-ordering computational tasks.
- **Grid application deployment.** To test grid applications, we need to deploy and start programs on all used computers. This can become difficult if the real topology involves several clusters with firewall, different runtime environments, etc. The MOAIS Team designed and implemented a new tool called *karun* that allows a user to easily deploy a parallel application wrote with the KAAPI software. This KAAPI tool relies on the TakTuk software to quickly launch programs on all nodes. The user only needs to describe the hierarchical networks/clusters involved in the experiment with their firewall if any.
- **Visualization of grid applications execution.** The analysis of applications execution on the grid is challenging both because of the large scale of the platform and because of the heterogeneous topology of the interconnections. To help users to understand their application behavior and to detect potential bottleneck or load unbalance, the MOAIS team designed and implemented a tool named *Triva*. This tool proposes a new three dimensional visualization model that combines topological information to space time data collected during the execution. It also proposes an aggregation mechanism that eases the detection of application load unbalance.

## 4.3. Safe Distributed Computations

**Participants:** Vincent Danjean, Thierry Gautier, Clément Pernet, Jean-Louis Roch.

Large scale distributed platforms, such as the GRID and Peer-to-Peer computing systems, gather thousands of nodes for computing parallel applications. At this scale, component failures, disconnections (fail-stop faults) or results modifications (malicious faults) are part of operation, and applications have to deal directly with repeated failures during program runs. Indeed, since failure rate in such platform is proportional to the number of involved resources, the mean time between failure is dramatically decreased on very large size architectures. Moreover, even if a middleware is used to secure the communications and to manage the resources, the computational nodes operate in an unbounded environment and are subject to a wide range of attacks able to break confidentiality or to alter the resources or the computed results. Beyond fault-tolerancy, yet the possibility of massive attacks resulting in an error rate larger than tolerable by the application has to be considered. Such massive attacks are especially of concern due to Distributed Denial of Service, virus or Trojan attacks, and more generally orchestrated attacks against widespread vulnerabilities of a specific operating system that may result in the corruption of a large number of resources. The challenge is then to provide confidence to the parties about the use of such an unbound infrastructure. The MOAIS team addresses two issues:

- fault tolerance (node failures and disconnections): based on a global distributed consistent state , for the sake of scalability;
- security aspects: confidentiality, authentication and integrity of the computations.

Our approach to solve those problems is based on the efficient checkpointing of the dataflow that described the computation at coarse-grain. This distributed checkpoint, based on the local stack of each work-stealer process, provides a causally linked representation of the state. It is used for a scalable checkpoint/restart protocol and for probabilistic detection of massive attacks.

Moreover, we study the scalability of security protocols on large scale infrastructures. One goal is trusting the usage of remote-platforms (such as high-performance cluster or cloud infrastructure) by providing quantified guarantees on integrity, accountability and confidentiality. Within the global competitiveness cluster Minalogic, and in collaboration with Privatics team and industrial partners, we have developed a high-rate systematic ciphering architecture that provides red-black segregation on an Internet network based on the coupling of a multicore architecture with security components (FPGA and smart card).

## **ROMA Team**

# **4. Application Domains**

## **4.1. Application of sparse direct solvers**

Sparse direct (multifrontal) solvers in distributed-memory environments have a wide range of applications as they are used at the heart of many numerical methods in simulation: whether a model uses finite elements or finite differences, or requires the optimization of a complex linear or nonlinear function, one often ends up solving a linear system of equations involving sparse matrices. There are therefore a number of application fields, among which some of the ones cited by the users of our sparse direct solver MUMPS (see Section 5.1 ) are: structural mechanics, biomechanics, medical image processing, tomography, geophysics, electromagnetism, fluid dynamics, econometric models, oil reservoir simulation, magneto-hydro-dynamics, chemistry, acoustics, glaciology, astrophysics, circuit simulation, and work on hybrid direct-iterative methods.

## **RUNTIME Project-Team**

# **4. Application Domains**

## **4.1. Application Domains**

HPC, simulation

The RUNTIME group is working on the design of efficient runtime systems for parallel architectures. We are currently focusing our efforts on High Performance Computing applications that merely implement numerical simulations in the field of Seismology, Weather Forecasting, Energy, Mechanics or Molecular Dynamics. These time-consuming applications need so much computing power that they need to run over parallel machines composed of several thousands of processors.

Because the lifetime of HPC applications often spreads over several years and because they are developed by many people, they have strong portability constraints. Thus, these applications are mostly developed on top of standard APIs (e.g. MPI for communications over distributed machines, OpenMP for shared-memory programming). That explains why we have long standing collaborations with research groups developing parallel language compilers, parallel programming environments, numerical libraries or communication software. Actually, all these “clients” are our primary target.

Although we are currently mainly working on HPC applications, many other fields may benefit from the techniques developed by our group. Since a large part of our efforts is devoted to exploiting multicore machines and GPU accelerators, many desktop applications could be parallelized using our runtime systems (e.g. 3D rendering, etc.).

## ASCOLA Project-Team

### 4. Application Domains

#### 4.1. Enterprise Information Systems and Services

Large IT infrastructures typically evolve by adding new third-party or internally-developed components, but also frequently by integrating already existing information systems. Integration frequently requires the addition of glue code that mediates between different software components and infrastructures but may also consist in more invasive modifications to implementations, in particular to implement crosscutting functionalities. In more abstract terms, enterprise information systems are subject to structuring problems involving horizontal composition (composition of top-level functionalities) as well as vertical composition (reuse and sharing of implementations among several top-level functionalities). Moreover, information systems have to be more and more dynamic.

Service-Oriented Computing (SOC) that is frequently used for solving some of the integration problems discussed above. Indeed, service-oriented computing has two main advantages:

- Loose-coupling: services are autonomous, in that they do not require other services to be executed;
- Ease of integration: services communicate over standard protocols.

Our current work is based on the following observation: similar to other compositional structuring mechanisms, SOAs are subject to the problem of crosscutting functionalities, that is, functionalities that are scattered and tangled over large parts of the architecture and the underlying implementation. Security functionalities, such as access control and monitoring for intrusion detection, are a prime example of such a functionality in that it is not possible to modularize security issues in a well-separated module. Aspect-Oriented Software Development is precisely an application-structuring method that addresses in a systemic way the problem of the lack of modularization facilities for crosscutting functionalities.

We are considering solutions to secure SOAs by providing an aspect-oriented structuring and programming model that allows security functionalities to be modularized. Two levels of research have been identified:

- Service level: as services can be composed to build processes, aspect weaving will deal with the orchestration and the choreography of services.
- Implementation level: as services are abstractly specified, aspect weaving will require to extend service interfaces in order to describe the effects of the executed services on the sensitive resources they control.

In 2013, we have developed techniques for the Service-Level Agreement (SLA) management for Cloud elasticity, see Sec. 6.3 , as well as models and type systems for service-oriented systems, see Sec. 6.1 . Furthermore, we take part in the European project A4Cloud on accountability challenges, that is, the responsible stewardship of third-party data and computations, see Sec. 8.2 .

#### 4.2. Capacity Planning in Cluster, Grid and Cloud Computing

Cluster, Grid and more recently Cloud computing platforms aim at delivering large capacities of computing power. These capacities can be used to improve performance (for scientific applications) or availability (e.g., for Internet services hosted by datacenters). These distributed infrastructures consist of a group of coupled computers that work together and may be spread across a LAN (cluster), across a WAN (Grid), and across the Internet (Clouds). Due to their large scale, these architectures require permanent adaptation, from the application to the system level and call for automation of the corresponding adaptation processes. We focus on self-configuration and self-optimization functionalities across the whole software stack: from the lower levels (systems mechanisms such as distributed file systems for instance) to the higher ones (i.e. the applications themselves such as J2EE clustered servers or scientific grid applications).

In 2013, we have confirmed the scalability of the DVMS proposal by conducting experiments on a very large scale involving up to 5K virtual machines (VM)s upon 500 nodes, thus establishing it as one of the most scalable placement algorithm for virtual machines. Moreover, we have extended the SimGrid framework by adding virtualization abstractions for hundreds of thousands of VMs. Finally, we have also provided several results on the energy efficient management of Cloud applications and infrastructures, see Sec. 6.3 .

In the energy field, we have designed a set of techniques, named Optiplace, for cloud management with flexible power models through constraint programming. OptiPlace supports external models, named views. Specifically, we have developed a power view, based on generic server models, to define and reduce the power consumption of a datacenter's physical servers. We have shown that OptiPlace behaves at least as good as our previous system, Entropy, requiring as low as half the time to find a solution for the constrained-based placement of tasks for large datacenters.

### **4.3. Pervasive Systems**

Pervasive systems are another class of systems raising interesting challenges in terms of software structuring. Such systems are highly concurrent and distributed. Moreover, they assume a high-level of mobility and context-aware interactions between numerous and heterogeneous devices (laptops, PDAs, smartphones, cameras, electronic appliances...). Programming such systems requires proper support for handling various interfering concerns like software customization and evolution, security, privacy, context-awareness... Additionally, service composition occurs spontaneously at runtime.

In 2013, we have extended the language EScala, which integrates reactive programming through events with aspect-oriented and object-oriented mechanisms, see Sec. 6.1 .

## FOCUS Project-Team

# 4. Application Domains

## 4.1. Ubiquitous Systems

The main application domain for Focus are ubiquitous systems, broadly systems whose distinctive features are: mobility, high dynamicity, heterogeneity, variable availability (the availability of services offered by the constituent parts of a system may fluctuate, and similarly the guarantees offered by single components may not be the same all the time), open-endedness, complexity (the systems are made by a large number of components, with sophisticated architectural structures). In Focus we are particularly interested in the following aspects.

- *Linguistic primitives* for programming dialogues among components.
- *Contracts* expressing the functionalities offered by components.
- *Adaptability and evolvability* of the behaviour of components.
- *Verification* of properties of component systems.
- Bounds on component *resource consumption* (e.g., time and space consumed).

## 4.2. Service Oriented Computing and Cloud Computing

Today the component-based methodology often refers to Service Oriented Computing. This is a specialized form of component-based approach. According to W3C, a service-oriented architecture is “a set of components which can be invoked, and whose interface descriptions can be published and discovered”. In the early days of Service Oriented Computing, the term services was strictly related to that of Web Services. Nowadays, it has a much broader meaning as exemplified by the XaaS (everything as a service) paradigm: based on modern virtualization technologies, Cloud computing offers the possibility to build sophisticated service systems on virtualized infrastructures accessible from everywhere and from any kind of computing device. Such infrastructures are usually examples of sophisticated service oriented architectures that, differently from traditional service systems, should also be capable to elastically adapt on demand to the user requests.

## 4.3. Software Product Lines

A Software Product Line is a set of software systems that together address a particular market segment or fulfill a particular mission. Today, Software Product Lines are successfully applied in a range of industries, including telephony, medical imaging, financial services, car electronics, and utility control [51]. Customization and integration are keywords in Software Product Lines: a specific system in the family is constructed by selecting its properties (often technically called “features”), and, following such selection, by customizing and integrating the needed components and deploying them on the required platform.



## OASIS Project-Team

# 4. Application Domains

## 4.1. Service Oriented Architectures (SOA)

Service Oriented Architectures aim at the integration of distributed services and more generally at the integration of distributed and heterogeneous data, at the level of the Enterprise or of the whole Internet (big data dimension).

The team seeks solutions to the problems encountered here, with the underlying motivation to demonstrate the usefulness of a large-scale distributed programming approach and runtime support as featured by ProActive and GCM:

- Interaction between services: the uniform usage of web services based *client-server* invocations, through the possible support of an Enterprise Service Bus, can provide a simple interoperability between them. For more loosely coupled interactions between services (e.g. compliant to the Web Services Notification standard), we pursue efforts to support *publish-subscribe* interaction models. Scalability in terms of number of notified events per time unit, and full interoperability through the use of semantic web notations applied to these events/data are some of the key challenges the community is addressing and we too. Events also correspond to data that may be worth to store, for future analytics, besides being propagated to interested parties (in the form of the event content). Our research can thus also contribute to the Big Data domain: we started to focus on how the use of flexible distributed and reconfigurable programming approaches through software components can allow us to devise powerful and flexible analytics on big data flows.
- Services compositions on a possibly large set of machines: if service compositions can even be turned as autonomic activities, these capabilities will really make SOA ready for the Open Internet scale (because at such a scale, a global management of all services is not possible). For service compositions represented as GCM-based component assemblies, we are indeed exploring the use of control components put in the components membranes, acting as sensors or actuators, that can drive the self-deployment and self-management of composite services, according to negotiated Service Level Agreements. For service orchestrations usually expressed as BPEL like processes, and expressing the *composition in time* aspect of the composition of services, supports for deployment, management, and execution capable to support dynamic adaptations are also needed. Here again we believe a middleware based upon distributed and autonomous components as GCM is really helpful.

## 4.2. Simulation tools and methodology

Components are being used in simulation since many years. However, given its many application fields and its high computation needs, simulation is still a challenging application for component-based programming techniques and tools.

We have been exploring the application of Oasis programming methods to simulation problems in various areas of engineering problems, but also of financial applications.

More recently, with the arrival of O. Dalle in the team, and following a work previously started in the Mascotte project-team in 2006 [42], we are pursuing research on applying distributed component-based programming techniques to simulation.

With respect to the simulation methodology, we have also started to address some fundamental questions such as the time representation in discrete event simulation.

## **PHOENIX Project-Team**

# **4. Application Domains**

## **4.1. Introduction**

Building on our previous work, we are studying software development in the context of communication services, in their most general forms. That is, going beyond human-to-human interactions, and covering human-to-machine and machine-to-machine interactions. Software systems revolving around such forms of communications can be found in a number of areas, including telephony, pervasive computing, and assisted living; we view these software systems as coordinating the communication between networked entities, regardless of their nature, human, hardware or software. In this context, our three main application domains are pervasive computing, avionics and cognitive assistance.

## **4.2. Pervasive Computing**

Pervasive computing systems are being deployed in a rapidly increasing number of areas, including building automation and supply chain management. Regardless of their target area, pervasive computing systems have a typical architectural pattern. They aggregate data from a variety of distributed sources, whether sensing devices or software components, analyze a context to make decisions, and carry out decisions by invoking a range of actuators. Because pervasive computing systems are standing at the crossroads of several domains (e.g., distributed systems, multimedia, and embedded systems), they raise a number of challenges in software development:

- **Heterogeneity.** Pervasive computing systems are made of off-the-shelf entities, that is, hardware and software building blocks. These entities run on specific platforms, feature various interaction models, and provide non-standard interfaces. This heterogeneity tends to percolate in the application code, preventing its portability and reusability, and cluttering it with low-level details.
- **Lack of structuring.** Pervasive computing systems coordinate numerous, interrelated components. A lack of global structuring makes the development and evolution of such systems error-prone: component interactions may be invalid or missing.
- **Combination of technologies.** Pervasive computing systems involve a variety of technological issues, including device intricacies, complex APIs of distributed systems technologies and middleware-specific features. Coping with this range of issues results in code bloated with special cases to glue technologies together.
- **Dynamicity.** In a pervasive computing system, devices may either become available as they get deployed, or unavailable due to malfunction or network failure. Dealing with these issues explicitly in the implementation can quickly make the code cumbersome.
- **Testing.** Pervasive computing systems are complicated to test. Doing so requires equipments to be acquired, tested, configured and deployed. Furthermore, some scenarios cannot be tested because of the nature of the situations involved (e.g., fire and smoke). As a result, the programmer must resort to writing specific code to achieve ad hoc testing.

## **4.3. Avionics**

In avionics, an aircraft can be seen as an environment full of sensors (e.g., accelerometers, gyroscopes, and GPS sensors) and actuators (e.g., ailerons and elevator trim). For example, a flight guidance system controls the aircraft using data produced by sensors. In a critical platform such as an aircraft, software systems have to be certified. Moreover the safety-critical nature of the avionics domain takes the form of stringent non-functional requirements, resulting in a number of challenges in software development:

- Traceability. Traceability is the ability to trace all the requirements throughout the development process. In the avionics certification processes, traceability is mandatory for both functional and non-functional requirements.
- Coherence. Functional and non-functional aspects of an application are inherently coupled. For example, dependability mechanisms can potentially deteriorate the overall performance of the application. The coherence of the requirements is particularly critical when the software evolves: even minor modifications to one aspect may tremendously impact the others, leading to unpredicted failures.
- Separation of concerns. Avionics platforms involve the collaboration of several experts (from low-level system to software, safety, QoS), making requirements traceability significantly more challenging. Providing development methodologies that allow a clear separation of concerns can tremendously improve traceability.

Our approach consists of enriching a design language with non-functional declarations. Such declarations allow the safety expert to specify at design time how errors are handled, guiding and facilitating the implementation of error handling code. The design is also enriched with Quality of Service (QoS) declarations such as time constraints. For each of these non-functional declarations, specific development support can be generated. We have validated this approach by developing flight guidance applications for avionics and drone systems.

#### **4.4. Assistive Technology for Cognition**

Cognitive impairments (memory, attention, time and space orientation, etc) affect a large part of the population, including elderly, patients with brain injuries (traumatic brain injury, stroke, etc), and people suffering from cognitive disabilities, such as Down syndrome.

The emerging industry of assistive technologies provide hardware devices dedicated to specific tasks, such as a telephone set with a keyboard picturing relatives (<http://www.doro.fr>), or a device for audio and video communication over the web (<http://www.technosens.fr>). These assistive technologies apply a traditional approach to personal assistance by providing an equipment dedicated to a single task (or a limited set of tasks), without leveraging surrounding devices. This traditional approach has fundamental limitations that must be overcome to significantly improve assistive technologies:

- they are not adaptable to one's needs. They are generally dedicated to a task and have very limited functionalities: no networking, limited computing capabilities, a limited screen and rudimentary interaction modalities. This lack of functionality may cause a proliferation of devices, complicating the end-user life. Moreover, they are rarely designed to adapt to the cognitive changes of the user. When the requirements evolve, the person must acquire a new device.
- they are often proprietary, limiting innovation. As a result, they cannot cope with the evolution of users' needs.
- they have limited or no interoperability. As a result, they cannot rely on other devices and software services to offer richer applications.

To break this model, we propose to offer an assistive platform that is open-ended in terms of applications and entities. (1) An online catalog of available applications enables every user and caregiver to define personalized assistance in the form of an evolving and adapted set of applications; this catalog provides a community of developers with a mechanism to publish applications for specific daily-activity needs. (2) New types of entities (whether hardware or software) can be added to a platform description to enhance its functionalities and extend the scope of future applications.

## **RMOD Project-Team**

# **4. Application Domains**

## **4.1. Programming Languages and Tools**

Many of the results of RMoD are improving programming languages or development tools for such languages.

As such the application domain of these results is as varied as the use of programming languages in general. Pharo, the language that RMoD develops, is used for a very broad range of applications. From pure research experiments to real world industrial use (the Pharo Consortium has over 10 company members).

Examples are web applications, server backends for mobile applications or even graphical tools and embedded applications.

## **4.2. Software Reengineering**

Moose is a language-independent environment for reverse- and re-engineering complex software systems. Moose provides a set of services including a common meta-model, metrics evaluation and visualization. As such Moose is used for analysing software systems to support understanding and continuous development as well as software quality analysis.

## **TRISKELL Project-Team**

# **4. Application Domains**

## **4.1. Application Domains**

SOA, telecommunication, distributed systems, Embedded Systems, software engineering, test, UML

From small embedded systems such as home automation products or automotive systems to medium sized systems such as medical equipment, office equipment, household appliances, smart phones; up to large Service Oriented Architectures (SOA), building a new application from scratch is no longer possible. Such applications reside in (group of) machines that are expected to run continuously for years without unrecoverable errors. Special care has then to be taken to design and validate embedded software, making the appropriate trade-off between various extra-functional properties such as reliability, timeliness, safety and security but also development and production cost, including resource usage of processor, memory, bandwidth, power, etc.

Leveraging ongoing advances in hardware, embedded software is playing an evermore crucial role in our society, bound to increase even more when embedded systems get interconnected to deliver ubiquitous SOA. For this reason, embedded software has been growing in size and complexity at an exponential rate for the past 20 years, pleading for a component based approach to embedded software development. There is a real need for flexible solutions allowing to deal at the same time with a wide range of needs (product lines modeling and methodologies for managing them), while preserving quality and reducing the time to market (such as derivation and validation tools).

We believe that building flexible, reliable and efficient embedded software will be achieved by reducing the gap between executable programs, their models, and the platform on which they execute, and by developing new composition mechanisms as well as transformation techniques with a sound formal basis for mapping between the different levels.

Reliability is an essential requirement in a context where a huge number of softwares (and sometimes several versions of the same program) may coexist in a large system. On one hand, software should be able to evolve very fast, as new features or services are frequently added to existing ones, but on the other hand, the occurrence of a fault in a system can be very costly, and time consuming. While we think that formal methods may help solving this kind of problems, we develop approaches where they are kept “behind the scene” in a global process taking into account constraints and objectives coming from user requirements.

Software testing is another aspect of reliable development. Testing activities mostly consist in trying to exhibit cases where a system implementation does not conform to its specifications. Whatever the efforts spent for development, this phase is of real importance to raise the confidence level in the fact that a system behaves properly in a complex environment. We also put a particular emphasis on on-line approaches, in which test and observation are dynamically computed during execution.

## **COATI Project-Team**

# **4. Application Domains**

## **4.1. Telecommunication networks**

COATI is mostly interested in telecommunications networks. Within this domain, we consider applications that follow the needs and interests of our industrial partners, in particular Orange Labs or Alcatel-Lucent Bell-Labs, but also SMEs like 3-Roam and Avisto.

We focus on the design and management of heterogeneous networks. The project has kept working on the design of backbone networks (optical networks, radio networks, IP networks). We also study routing algorithms such as dynamic and compact routing schemes in the context of the FP7 EULER led by Alcatel-Lucent Bell-Labs (Belgium), and the evolution of the routing in case of any kind of topological modifications (maintenance operations, failures, capacity variations, etc.).

## **4.2. Other domains**

Our combinatorial tools may be well applied to solve many other problems in various areas (transport, biology, resource allocation, chemistry, smart-grids, speleology, etc.) and we intend to collaborate with teams of these other domains.

For instance, we have recently started a collaboration in Structural Biology with EPI ABS (Algorithms Biology Structure) from Sophia Antipolis (described in Section 6.2 ). Furthermore, we are also working on robot moving problems coming from Artificial Intelligence/Robotic with Xavier Defago (Associate Professor at Japan Advanced Institute of Science and Technology, Japan).

## **DANTE Team**

# **4. Application Domains**

## **4.1. Life Science & Health**

In parallel to the advances in modern medicine, health sciences and public health policy, epidemic models aided by computer simulations and information technologies offer an increasingly important tool for the understanding of transmission dynamics and of epidemic patterns. The increased computational power and use of Information and Communication Technologies makes feasible sophisticated modelling approaches augmented by detailed in vivo data sets, and allow to study a variety of possible scenarios and control strategies, helping and supporting the decision process at the scientific, medical and public health level. The research conducted in the DANTE project finds direct applications in the domain of LSH since modelling approaches crucially depend on our ability to describe the interactions of individuals in the population. In the MOSAR project we are collaborating with the team of Pr. Didier Guillemot (Inserm/Institut. Pasteur/Université de Versailles). Within the TUBEXPO and ARIBO projects, we are collaborating with Pr. Jean-Christophe Lucet (Professeur des université Paris VII ? Praticien hospitalier APHP).

## **4.2. Network Science / Complex networks**

In the last ten years, the study of complex networks has received an important boost with large interdisciplinary efforts aimed at their analysis and characterisation. Two main points explain this large activity: on the one hand, many systems coming from very different disciplines (from biology to computer science) have a convenient representation in terms of graphs; on the other hand, the ever-increasing availability of large data sets and computer power have allowed their storage and manipulation. Many maps have emerged, describing many networks of practical interest in social science, critical infrastructures, networking, and biology. The DANTE project targets the study of dynamically evolving networks, from the point both of their structure and of the dynamics of processes taking place on them.

## DIANA Team

# 4. Application Domains

## 4.1. Internet Citizen Rights Observatory

Internet users are highly interested in knowing the expected and/or actual quality of experience and in detecting potential privacy leakages. These are two essential Internet citizen rights we plan to address in the Diana team. However, the Internet is based on the best effort model and therefore provides no quality of service support. The perceived quality depends on many factors as network and service provisioning, the behavior of the other users, peering agreements between operators, and the diverse practices of network administrators in terms of security and traffic engineering done manually today and probably automatically on programmable infrastructure tomorrow. The proliferation of wireless and mobile access have complicated further this unpredictability of the Internet by adding other factors such as the mobility of end users, the type of wireless technology used, the coverage and level of interference. In addition, the Internet does not have a standard measurement and control plane. Apart from basic information on routing tables, all the rest (delays, available bandwidth, loss rate, anomalies and their root cause, network topology, ISP commercial relationships, etc.) are to be discovered. Several monitoring tools were developed by projects such as CAIDA or Google's M-Lab to understand the performance of the Internet and provide end users with information on the quality of their access. However, existing tools and techniques are mostly host-oriented and provide network-level measurements that can hardly be interpreted by the end users in terms of Quality of Experience (QoE). In fact, as the usage model shifts toward Information-centric networking, there is a need to define solutions to monitor and even predict application-level performance at the access based on objective measurements from the network. In the future Internet, there should be some minimum level of transparency allowing end users to evaluate their Internet access regarding the different services and applications they are interested in, and in case of trouble, to identify its origin. This migration of measurements to contents and services, which can be qualified as "Future Internet Observatory", requires understanding the traffic generated by the applications, inferring the practices of content providers and operators, defining relevant QoE metrics, finding low cost techniques to avoid measurement traffic explosion and redundancy (based, for example, on crowd sourcing) and leveraging spatiotemporal correlations for better localization of network anomalies.

Unfortunately, the quality of Internet applications as perceived by end users depends on numerous factors influenced directly by the home network, the access link (either wireless or wired), the core network, or even the content provider infrastructure. The perceived quality also depends on the application requirements in terms of network characteristics and path performances. This multiplicity of factors makes it difficult for the end user to understand the reasons for any quality degradation. Understanding the reasons of the degradation is getting even more difficult with the mobility of end users and the complexity of applications and services themselves. Nevertheless, it is essential for end users to understand the quality they obtain from the Internet and in case of dissatisfaction, to identify the root cause of the problem and pinpoint responsibilities. This process implies two major challenges. On one hand, there is a need to have a mapping between the quality obtained and the network performance, and to understand the exact behavior of modern applications and protocols. This phase involves the measurements and analysis of applications' traffic and user feedback, and the calibration of models to map the perceived level of quality to network level performance metrics. On the other hand, there is a need for inference techniques to identify the network part hidden behind the observed problem, e.g. knowing which the part of the network causes a bandwidth decrease or high loss rate event. In the literature, this inference problem is often called network tomography, which consists of inferring internal network behavior from edge measurements. Network tomography can be done in two complementary ways. One approach is to run several tests from the end user access excluding each time different network parts, and by intersecting the observations, find the part very likely causing the problem. The advantage of this approach is that the user controls every point of the inference. Unfortunately, this technique requires extensive measurements from each user, which can be difficult to realize when resources are scarce such as on mobile



wireless networks. Another approach can be to distribute the measurement among different end points and share their observations. The advantage is clearly to reduce the load for every one but it comes at the expense of higher complexity to successfully performing the inference. A first difficulty is in the distribution of the measurement work among users and devices. Another issue is in the combination of observations (i.e., which weight to give to each end user according to its location, type of access, etc.) particularly as network conditions can vary from one to another.

The shift of measurements toward mobile devices and modern applications and services will require a completely new methodology. We have dealt up to now with network-level measurements to infer the performance of the current Internet architecture. This past measurement effort has mostly targeted well-known protocols and architectures that are mostly standardized. It has targeted laptops and desktops that are often easily programmable and not suffering from bandwidth and computing resource constraints. For this new project, we will deal with a large number of proprietary services and applications that require, each from its side, a considerable measurement effort to understand its behavior, and implement the appropriate network-level measurements to predict its quality. And given the large number of these applications and services, we will face a certain problem of measurement overhead explosion that we will have to solve and reduce by either measurement reutilization or crowd-sourcing approach. The consideration of mobiles with their close operating systems and limited resources will increase even further the complexity of this measurement effort.

QoE and user privacy are, in our vision, the most critical issue for end-users. There are daily headlines on issues linked to citizen rights degradation (such as, Google data retention, PRISM, mobile applications privacy leakages, targeted and differentiated advertisements, etc.) The common belief is that it is not possible to improve the situation as all technological choices are in the hands of big Internet companies and states. The long-term objective of our research is to study the validity of this statement and to propose to end-users (and possibly service providers) architectural solutions to improve transparency by exposing potential citizen rights violations. One way to improve this transparency is to leverage on the end-users set-top-box in order to implement an indirection infrastructure auditing and filtering all traffic from each end-user.

## **4.2. Open Network Architecture**

As discussed above, whereas the Internet can successfully interconnect billions of devices, it fails to provide a transparent and efficient sharing between information producers and consumers. Here Information producers and consumers must be considered in their broad definition, for instance a microphone, a speaker, a digital camera, a TV screen, a CPU, a hard drive, but also services such as email, storage in the cloud, a Facebook account, etc. In addition to classical contents, information can include a flow of content updated in real time, a description of a device, a Web service, etc. Enabling a transparent open access and sharing to information among all these devices will likely revolutionize the way the Internet is used today.

This research direction aims at proposing global solutions for easy and open content access and more generally to information interoperability. This activity will leverage on current efforts on information-centric networking (e.g., CCN, PSIRP, NetInf). In a first stage, the goal will consist in offering to users a personal overlay solution to publish and manage their own contents, at anytime and whatever the available network access technology (cable, Wi-Fi, 3G, 4G, etc.). The main challenge will be to design scalable mechanisms to seamlessly publish and access information in an efficient way, while preserving privacy. Another challenge will be to incrementally deploy these mechanisms and ensure their adoption by end users, content providers, and network operators. In the context of the evolution of the Internet architecture and in particular through Software defined Networking (SDN), there is a risk that some network operators or other tenants use the increased flexibility of the network against the benefits of the users. So, one of our concern will be to design innovative solutions to prevent possible violation of the network neutrality or to prevent illegitimate collection of private data. In parallel, we envision using SDN as an enabling technology to adapt the network in order to maximize user QoE. Indeed, virtualized network appliances are an efficient way to dynamically insert at strategic places in-network functionalities such as caching proxies, load balancers, cyphers, or firewalls. On this purpose, we plan to build a dedicated open infrastructure relying on a mix of middle boxes and mobile devices applications to capture, analyze and optimize traffic between mobile devices and the Internet.

SDN will introduce a deep shift in the way to design and deploy communications mechanisms. Traditionally, and mainly due to the ossification of the Internet, we used to enhance communication mechanisms by designing our solutions as overlays to the network infrastructure. Using SDN, we will have the opportunity to implement and use new functionalities within the network. If we make them available through well-defined API, those new network functions could be used to implement interoperable, transparent and open services for the benefit of the user. Indeed, implementing these functionalities within the network is not only more efficient than overlay solutions but this can facilitate the deployment of standard services. Important challenges will have to be solved to make this happen, and particularly, to ensure consistency, stability, scalability, reliability and privacy.

Our long-term objective in this research direction is to contribute to the design of network architecture providing native support for easy, transparent, secure, privacy preserving access to information. For instance, an objective is to enable end-users to leverage on their home infrastructure (set-top-boxes, computers, smartphones, tablets) to sanitize traffic and host information.

## **DIONYSOS Project-Team**

### **4. Application Domains**

#### **4.1. Networking**

Our global research effort concerns networking problems, both from the analysis point of view, and around network design issues. Specifically, this means the IP technology in general, with focus on specific types of networks seen at different levels: wireless systems, optical infrastructures, peer-to-peer architectures, Software Defined Networks, Content Delivery Networks, Content-Centric Networks, clouds.

#### **4.2. Complex systems**

Many of the techniques developed at Dionysos are useful for the analysis of complex systems in general, not only in telecommunications. For instance, our Monte Carlo methods for analyzing rare events have been used by different industrial partners, some of them in networking but recently also by companies building transportation systems.

## **DYOGENE Project-Team**

# **4. Application Domains**

## **4.1. Embedded Networks**

Critical real-time embedded systems (cars, aircrafts, spacecrafts) are nowadays made up of multiple computers communicating with each other. The real-time constraints typically associated with operating systems now extend to the networks of communication between sensors/actuators and computers, and between the computers themselves. Once a media is shared, the time between sending and receiving a message depends not only on technological constraints, but also, and mainly from the interactions between the different streams of data sharing the media. It is therefore necessary to have techniques to guarantee maximum network delays, in addition to local scheduling constraints, to ensure a correct global real-time behaviour to distributed applications/functions.

Moreover, pessimistic estimate may lead to an overdimensioning of the network, which involves extra weight and power consumption. In addition, these techniques must be scalable. In a modern aircraft, thousands of data streams share the network backbone. Therefore algorithm complexity should be at most polynomial.

## **4.2. Routing protocols**

Routing protocols enables to maintain paths for transmitting messages over a network. Those protocols, such as OSPF, are based on the transmission of periodic messages between neighbors. Nowadays, faulty behaviors result in the raising of alarms, but are mostly detected when a breakdown or a major misbehavior occurs. Indeed, alarms are so numerous that they cannot be analyzed efficiently. We aim at developing methods to detect misbehaviours of a router before a major fault occurs, and techniques to study the influence of the protocol parameters on the behavior of the network.

## **4.3. Wireless Networks**

Wireless networks can be efficiently modelled as dynamic stochastic geometric networks. Their analysis requires taking into account, in addition to their geometric structure, the specific nature of radio channels and their statistical properties which are often unknown a priori, as well as the interaction through interference of the various individual point-to-point links.

## **4.4. Peer-to-Peer Systems**

The amount of multimedia traffic accessed via the Internet, already of the order of exabytes ( $10^{18}$  bytes) per month, is expected to grow steadily in the coming years. A peer-to-peer (P2P) architecture, where peers contribute resources to support service of such traffic, holds the promise to support its growth more cheaply than by scaling up the size of data centers. More precisely, a large scale P2P system based on resources of individual users can absorb part of the load that would otherwise need to be served by data centers. In video-on-demand applications, the critical resources at the peers are storage space and uplink bandwidth. Our objective is to ensure that the largest fraction of traffic is supported by the P2P system.

## **4.5. Social and economic networks**

Networks are ubiquitous with the presence of different kinds of social, economic and information networks around us. The Internet is one of the most prominent examples of a geometric network. We also examine geometric networks from the perspective of sociologist and economist [70]. Network analysis is also attracting foundational research by computer scientists [63]. Diffusion of information, social influence, trust, communication and cooperation between agents are heavily researched topics in e-commerce and multi-agent systems. Our probabilistic techniques are very appropriate in this case and have been largely neglected so far. While the first works on geometric networks emanated from theoretical physicists, they stay more focused on static properties of such networks and do not consider game theoretical or statistical learning (like community detection) aspects of such networks. This leaves open a range of new problems to which we will contribute.

**FUN Project-Team (section vide)**

## **GANG Project-Team**

# **4. Application Domains**

## **4.1. Application Domains**

Application domains include evaluating Internet performances, the design of new peer-to-peer applications, enabling large scale ad hoc networks and mapping the web.

- The application of measuring and modeling Internet metrics such as latencies and bandwidth is to provide tools for optimizing Internet applications. This concerns especially large scale applications such as web site mirroring and peer-to-peer applications.
- Peer-to-peer protocols are based on a all equal paradigm that allows to design highly reliable and scalable applications. Besides the file sharing application, peer-to-peer solutions could take over in web content dissemination resistant to high demand bursts or in mobility management. Envisioned peer-to-peer applications include video on demand, streaming, exchange of classified ads,...
- Wifi networks have entered our every day life. However, enabling them at large scale is still a challenge. Algorithmic breakthrough in large ad hoc networks would allow to use them in fast and economic deployment of new radio communication systems.
- The main application of the web graph structure consists in ranking pages. Enabling site level indexing and ranking is a possible application of such studies.

## **HIPERCOM2 Team**

# **4. Application Domains**

## **4.1. Introduction**

The HIPERCOM2 team addresses the following application domains:

- military, emergency or rescue applications,
- industrial applications,
- vehicular networks,
- smart cities,
- Internet of Things.

These application domains use the four types of wireless networks:

- wireless mesh and mobile ad hoc networks,
- wireless sensor networks,
- vehicular networks,
- cognitive radio networks.

## **4.2. Wireless mesh and mobile ad hoc networks**

A mobile ad hoc network is a network made of a collection of mobile nodes that gather spontaneously and communicate without requiring a pre-existing infrastructure. Of course a mobile ad hoc network use a wireless communication medium. They can be applied in various contexts:

- military;
- rescue and emergency;
- high speed access to internet.

The military context is historically the first application of mobile ad hoc networks.

The rescue context is halfway between military and civilian applications. In emergency applications, heterogeneous wireless networks have to cooperate in order to save human lives or bring the situation back to normal as soon as possible. Wireless networks that can be quickly deployed are very useful to assess damages and take the first decisions appropriate to the disaster of natural or human origin. The primary goal is to maintain connectivity with the humans or the robots (in case of hostile environment) in charge of network deployment. This deployment should ensure the coverage of an interest area or of only some interest points. The wireless network has to cope with pedestrian mobility and robots/vehicles mobility. The environment, initially unknown, is progressively discovered and usually has many obstacles. These obstacles should be avoided. The nodes of the wireless network are usually battery-equipped. Since they are dropped by a robot or a human, their weight is very limited. The protocols supported by these nodes should be energy efficient to increase network lifetime. Furthermore, in case of aggressive environment, sensor nodes should be replaced before failing. Hence, in such conditions, it is required to predict the failure time of nodes to favor a predictive maintenance.

Mobile ad hoc network provide an enhanced coverage for high speed wireless access to the internet. The now very popular WLAN standard, WiFi, provides much larger capacity than mobile operator networks. Using a mobile ad hoc network around hot spots will offer high speed access to much larger community, including cars, busses, trains and pedestrians.

### 4.3. Vehicular Networks and Smart Cities

Vehicular ad hoc networks (VANET) are based on short- to medium-range transmission systems that support both vehicle-to-vehicle and vehicle-to-roadside communications. Vehicular networks will enable vehicular safety applications (safety warnings) as well as non-safety applications (real-time traffic information, routing support, mobile entertainment, and many others). We are interested in developing an efficient routing protocol that takes advantage of the fixed network infrastructure deployed along the roads. We are also studying MAC layer issues in order to provide more priority for security messages which have stringent delivery constraints.

Smart cities share with the military tactical networks the constraint on pedestrian and vehicular mobility. Furthermore, the coexistence of many networks operating in the same radio spectrum may cause interferences that should be avoided. Cognitive radio takes advantage of the channels temporarily left available by the primary users to assign them to secondary users. Such an opportunistic behavior can also be applied in wireless sensor networks deployed in the cities. Smart cities raise the problem of transmitting, gathering, processing and storing big data. Another issue is to provide the right information at the right place: where it is needed.

### 4.4. Wireless sensor networks in industrial applications and Internet of Things

Concerning wireless sensor networks, WSNs, we tackle the three following issues:

- Energy efficiency is a key property in wireless sensor networks. Various techniques contribute to save energy of battery-equipped sensor nodes. To name a few, they are: energy efficient routing protocols, node activity scheduling, adjustment of transmission power, reduction of protocols overhead, reduction of data generated and transmitted. In the OCARI network, an industrial wireless sensor network, we have designed and implemented an energy efficient routing protocol and a node activity scheduling algorithm allowing router nodes to sleep. We have applied a cross-layering approach allowing the optimization of MAC and network protocols taking into account the application requirements and the environment in which the network operates. We have observed the great benefit obtained with node activity scheduling. In networks with low activity, opportunistic strategies are used to address low duty cycles.
- Large scale WSNs constitute another challenge. Large autonomous wireless sensors in the internet of the things need very well tuned algorithms. Self-organization is considered as a key element in tomorrow's Internet architecture. A major challenge concerning the integration of self-organized networks in the Internet is the accomplishment of light weight network protocols in large ad hoc environments.
- Multichannel WSNs provide an opportunity:
  - on the one hand, to increase the parallelism between transmissions. Hence, it reduces the data gathering delays and improves the time consistency of gathered data.
  - on the other hand, to increase the robustness against interferences and perturbations possibly caused by the coexistence of other wireless networks.

### 4.5. Cognitive Radio Networks

Usually in cognitive radio, the secondary users are in charge of monitoring the channel to determine whether or not the primary users are active in the area. If they are not, the secondary users are allowed to use the spectrum left unused by the primary users. We are interested in two issues:

- Design and modeling of a new access scheme based on a generalized Carrier Sense Multiple Access scheme using active signaling. This scheme allows the primary users to capture the bandwidth even if the secondary users are transmitting in the area.
- Design of a time slot and channel assignment to minimize the data gathering performed by secondary users. This assignment should work with different detection schemes of primary user presence.



## MADYNES Project-Team

# 4. Application Domains

## 4.1. Mobile, ad-hoc and constrained networks

The results coming out from MADYNES can be applied to any dynamic infrastructure that contributes to the delivery of value added services. While this is a potentially huge application domain, we focus on the following environments at the network level:

1. multicast services,
2. ad-hoc networks,
3. mobile devices and IPv6 networks,
4. voice over IP infrastructure.

All these selected application areas exhibit different dynamicity features. In the context of multicast services, we focus on distribution, monitoring and accounting of key distribution protocols. On *ad-hoc* and dynamic networks we are investigating the provisioning, monitoring, configuration and performance management issues.

Concerning mobile devices, we are interested in their configuration, provisioning and monitoring. IPv6 work goes on in Information Models and on self-configuration of the agents.

## 4.2. Dynamic services infrastructures

At the service level, dynamics is also increasing very fast. We apply the results of our work on autonomous management on infrastructures which support dynamic composition and for which self-instrumentation and management automation is required.

The target service environments are:

- sensor networks,
- peer-to-peer infrastructures,
- information centric networks,
- ambient environments.

## **MAESTRO Project-Team**

# **4. Application Domains**

## **4.1. Main Application Domains**

MAESTRO's main application area is networking, to which we apply modeling, performance evaluation, optimization and control. Our primary focus is on protocols and network architectures, and recent evolutions include the study of the Web and social networks, as well as models for Green IT.

- Wireless (cellular, ad hoc, sensor) networks: WLAN, WiMAX, UMTS, LTE, HSPA, delay tolerant networks (DTN), power control, medium access control, transmission rate control, redundancy in source coding, mobility models, coverage, routing, green base stations,
- Internet applications: social networks, content distribution systems, peer-to-peer systems, overlay networks, multimedia traffic, video-on-demand, multicast;
- Information-Centric Networking (ICN) architectures: Content-Centric Network (CCN, also called Content-Oriented Networks);
- Internet infrastructure: TCP, high speed congestion control, voice over IP, service differentiation, quality of service, web caches, proxy caches.

**RAP Project-Team (section vide)**

## SOCRATE Project-Team

# 4. Application Domains

## 4.1. Example of SDR applications

The SDR concept is not new and many research teams have been working on its implementation and use in various contexts, however two elements are in favor of Socrate's orientation towards this technology:

1. The mobile SDR technology is becoming mature. Up to now, Software-Defined Radio terminals were too expensive and power consuming for mobile terminals, this should change soon. For instance, CEA's Magali platform has demonstrated part of LTE-Advanced standard recently. It is important for applied researchers to be ready when a new technology rises up, opening to many new software issues.
2. Rhône-Alpes is a strategic place for this emerging technology with important actors such as ST-Microelectronics, CEA, Minalogic and many smaller actors in informatics for telecommunication and embedded systems.

SDR technologies enable the following scenarios:

- *Transparent radio adaptation:* Depending on the available wireless protocols in the air (e.g. Wifi versus UMTS), a terminal may choose to communicate on the cheapest, or the fastest channel.
- *Radio resource allocation:* In order to minimize expensive manual cell planning and achieve "tighter" frequency reuse patterns, resulting in improved system spectral efficiency, dynamic radio resource management is a promising application of SDR.
- *White space:* By sensing the air, a terminal is able to communicate using a particular frequency which is not used even if it is reserved for another kind of application.
- *Cooperation:* Using the neighboring terminals, a user can reduce power consumption by using relay communication with the base station.
- *Saturated bands:* A fixed wireless object, e.g. a gas meter sending regular data through the air, might check if the frequency it uses is saturated and choose, alone or in a distributed manner with other gas meters, to use another frequency (or even protocol) to communicate.
- *Radars:* With numerical communications, passive radar technology is changing, these radars will have to be updated regularly to be able to listen to new communication standards.
- *Internet of things:* With the predicted massive arrival of wireless object, some reconfigurability will be needed even on the simplest smart object as mentioned above for facing the band saturation problem or simply communicating in a new environment.

## 4.2. Public wireless access networks

The commercial markets for wireless technologies are the largest markets for SDR and cognitive radio. These markets include *i*) the cellular market (4G, LTE), *ii*) the Wireless Local Area Network market (WLAN, e.g. Wifi), and *iii*) the Broadband Wireless Access market (e.g. WiMax). The key objective here is to improve spectrum efficiency and availability, and to enable cognitive radio and SDR to support multimedia and multi-radio initiatives.

The mobile radio access network referred to as 4G (4th generation) is expected to provide a wireless access of 100 Mbps in extended mobility and up to 1Gbps in reduced mobility as defined by the group IMT-Advanced of the ITU-R (radiocommunication) section. On the road towards the 4G, IMT-2000 standards evolutions are driven by the work of the WiMAX forum (IEEE 802.16e) on the one hand and by those of the LTE (Long Term Evolution) group of the 3GPP on the other hand. Both groups announced some targeted evolutions that could comply with the 4G requirements, namely the Gigabit Wimax (802.16m) and the LTE-Advanced proposal from the 3GPP.

In both technologies, the scarcity of the radio spectrum is taken care of by the use of MIMO and OFDMA technologies, combining the dynamic spatial and frequency multiple access. However, a better spectral efficiency will be achieved if the radio spectrum can be shared dynamically between primary and secondary networks, and if the terminals are reconfigurable in real-time. Socrate is active in this domain because of its past activity in Swing and its links to the telecommunication teaching department of Insa. The development of the FIT platform [37] is a strong effort in this area.

### 4.3. Military SDR and Public Safety

Military applications have developed specific solutions for SDR. In France, Thales is a major actor (e.g. project Essor defining inter-operability between European military radio) and abroad the Joint Tactical Radio System, and Darpa focus on Mobile Ad-hoc Networks (MANETS) have brought important deliverables, like the Software Communications Architecture (SCA) for instance [38].

Recent natural disasters have brought considerable attention to the need of enhanced public safety communication abroad [36]. Socrate is not currently implied in any military or public safety research programs but is aware of the potential importance this domain may take in Europe in a near future.

### 4.4. Ambient Intelligence: WSN and IoT

Sensor networks have been investigated and deployed for decades already; their wireless extension, however, has witnessed a tremendous growth in recent years. This is mainly attributed to the development of wireless sensor networks (WSNs): a large number of sensor nodes, reliably operating under energy constraints. It is anticipated that within a few years, sensors will be deployed in a variety of scenarios, ranging from environmental monitoring to health care, from the public to the private sector. Prior to large-scale deployment, however, many problems have to be solved, such as the extraction of application scenarios, design of suitable software and hardware architectures, development of communication and organization protocols, validation and first steps of prototyping, etc. The Citi laboratory has a long experience in WSN which led recently to the creation of a start-up company, led by two former Citi members: HIKOB(<http://openlab.hikob.com>).

The Internet of Things (IoT) paradigm is defined as a very large set of systems interconnected to provide a virtual twin world interacting with the real world. In our work we will mostly focus on wireless systems since the wireless link is the single media able to provide a full mobility and ubiquitous access. Wireless IoT is not a reality yet but will probably result from the convergence between mobile radio access networks and wireless sensor networks. If radio access networks are able to connect almost all humans, they would fail to connect a potential of several billions of objects. Nevertheless, the mutation of cellular systems toward more adaptive and autonomous systems is ongoing. This is why Socrate develops a strong activity in this applicative area, with its major industrial partners: Orange Labs and Alcatel-Lucent Bell labs.

For instance, the definition of a *smart node* intermediate between a WSN and a complex SDR terminal is one of the research directions followed in Socrate, explicitly stated in the ADT Snow project. Other important contributions are made in the collaboration with SigFox and Euromedia and in the EconHome project.

### 4.5. Body Area Networks

Body Area Network is a relatively new paradigm which aims at promoting the development of wireless systems in, on and around the human body. Wireless Body Area Networks (BAN) is now a well known acronym which encompasses scenarios in which several sensors and actuators are located on or inside the human body to sense different data, e.g. physiological information, and transfer them wirelessly towards a remote coordination unit which processes, forwards, takes decisions, alerts, records, etc. The use of BAN spans a wide area, from medical and health care to sport through leisure applications, which definitely makes the definition of a standard air interface and protocol highly challenging. Since it is expected that such devices and networks would have a growing place in the society and become more stringent in terms of quality of service, coexistence issues will be critical. Indeed, the radio resource is known to be scarce. The recent regulation difficulties of UWB systems as well as the growing interest for opportunistic radios show that any new system

has to make an efficient use of the spectrum. This also applies to short range personal and body area network systems which are subject to huge market penetrations.

Socrate was involved in the Banet ANR project (2008-2010), in which we contributed to the development of a complete PHY/MAC standard in cooperation with Orange Labs and CEA Leti, who participated in the standardization group 802.15.6. Recently, Inria has been added as a partner in the FET flagship entitled *Guardian Angels* (<http://www.fet-f.eu/>), an important european initiative to develop the BANS of the future. Socrate is currently involved in the Cormoran ANR project (2012-2015), in which we contribute to the definition of a MAC standard dedicated to localization based on UWBPHY layer.

We consider that BANS will probably play an important role in the future of Internet as the multiple objects connected on the body could also be connected to the Internet by the mobile phone owned by each human. Therefore the BAN success really depends on the convergence of WSN and radio access networks, which makes it a very interesting applicative framework for the Socrate team.

## URBANET Team

# 4. Application Domains

## 4.1. Smart urban infrastructure

Unlike the communication infrastructure that went through a continuous development in the last decades, the distribution networks in our cities including water, gas and electricity are still based on 19th century infrastructure. With the introduction of new methods for producing renewable but unpredictable energy and with the increased attention towards environmental problems, modernizing distribution networks became one of the major concerns in the urban world. An essential component of these enhanced systems is their integration with information and communications technology, the result being a smart distribution infrastructure, with improved efficiency and reliability. This evolution is mainly based on the increased deployment of automatic equipment and the use of machine-to-machine and sensor-to-actuator communications that would allow taking into account the behavior and necessities of both consumers and suppliers

Another fundamental urban infrastructure is the transportation system. The progress made in the transportation industry over the last century has been an essential factor in the development of today's urban society, while also triggering the birth and growth of other economic branches. However, the current transportation system has serious difficulties coping with the continuous growth in the number of vehicles, especially in an urban environment. As a major increase in the capacity of a city road infrastructure, already in place for tens or even hundreds of years, would imply dissuasive costs, the more realistic approach is to optimize the use of the existing transportation system. As in the case of distribution networks, the intelligence of the system can be achieved through the integration of information and communication capabilities. However, for smart transportation the challenges are somehow different, because the intelligence is no longer limited to the infrastructure, but propagates to vehicles themselves. Moreover, the degree of automation is reduced in transportation systems, as most actions resulting in reduced road congestion, higher reliability or improved safety must come from the human driver (at least in the foreseeable future)

Finally, smart spaces are becoming an essential component of our cities. The classical architecture tools used to design and shape the urban environment are more and more challenged by the idea of automatically modifying private and public spaces in order to adapt to the requirements and preferences of their users. Among the objectives of this new urban planning current, we can find the transformation of the home in a proactive health care center, fast reconfigurable and customizable workplaces, or the addition of digital content in the public spaces in order to reshape the urban scene. Bringing these changing places in our daily lives is conditioned by a major shift in the construction industry, but it also involves important advancements in digital infrastructure, sensing, and communications

## 4.2. Urban participatory sensing

Urban sensing can be seen as the same evolution of the environment digitalization as social networking has been for information flows. Indeed, besides dedicated and deployed sensors and actuators, still required for specific sensing operations such as the real-time monitoring of pollution levels, there is a wide range of relevant urban data that can be collected without the need for new communication infrastructures, leveraging instead on the pervasiveness of smart mobile terminals. With more than 80% of the population owning a mobile phone, the mobile market has a deeper penetration than electricity or safe drinking water. Originally designed for voice transmitted over cellular networks, mobile phones are today complete computing, communication and sensing devices, offering in a handheld device multiple sensors and communication technologies.

Mobile devices such as smartphones or tablets are indeed able to gather a wealth of informations through embedded cameras, GPS receivers, accelerometers, and cellular, WiFi and bluetooth radio interfaces. When collected by a single device, such data may have small value per-se, however its fusion over large scales could prove critical for urban sensing to become an economically viable mainstream paradigm.

This is even more true when less traditional mobile terminals are taken into account: privately-owned cars, public transport means, commercial fleets, and even city bikes are starting to feature communication capabilities and the Floating Car Data (FCD) they generate can bring a dramatic contribution to the cause of urban sensing. Indeed, other than enlarging the sensing scope even further, e.g., through Electronic Control Units (ECUs), these mobile terminals are not burdened by strong energy constraints and can thus significantly increase the granularity of data collection. This data can be used by authorities to improve public services, or by citizens who can integrate it in their choices. However, in order to kindle this hidden information, important problems related to data gathering, aggregation, communication, data mining, or even energy efficiency need to be solved.

### **4.3. User-centric services**

Combining location awareness and data recovered from multiple sources like social networks or sensing devices can surface previously unknown characteristics of the urban environment, and enable important new services. As a few examples, one could think of informing citizens about often disobeyed (and thus risky) traffic signs, polluted neighborhoods, or queue waiting times at current exhibitions in the urban area.

Beyond letting their own devices or vehicles autonomously harvest data from the environment through embedded or onboard sensors, mobile users can actively take part in the participatory sensing process because they can, in return, benefit from citizen-centric services which aim at improving their experience of the urban life. Crowdsourcing applications have the potential to turn citizens into both sources of information and interactive actors of the city. It is not a surprise that emerging services built on live mobile user feedback are rapidly meeting a large success. In particular, improving everyone's mobility is probably one of the main services that a smart city shall offer to its inhabitants and visitors. This implies providing, through network broadcast data or urban smart-furniture, an accurate and user-tailored information on where people should head in order to find what they are looking for (from a specific kind of shop to a free parking slot), on their current travel time estimates, on the availability of better alternate means of transport to destination. Depending on the context, such information may need to be provided under hard real-time constraints, e.g., in presence of road accidents, unauthorized public manifestations, or delayed public transport schedules.

In some cases, information can also be provided to mobile users so as to bias or even enforce their mobility: drivers can be alerted of the arrival of an emergency vehicle so that they leave the leftmost lane available, or participants leaving vast public events can be directed out of the event venue through diverse routes displayed on their smartphones so as to dynamically balance the pedestrian flows and reduce their waiting times.