RESEARCH CENTER
Sophia Antipolis - Méditerranée

FIELD

Activity Report 2012

Section Application Domains

Edition: 2013-04-24

AOSTE Project-Team

4. Application Domains

4.1. Multicore System-on-Chip design

Synchronous formalisms and GALS or multiclock extensions are natural model representations of hardware circuits at various abstraction levels. They may compete with HDLs (Hardware Description Languages) at RTL and even TLM levels. The main originality of languages built upon these models is to be based on formal *synthesis* semantics, rather than mere simulation forms.

The flexibility in formal Models of Computation and Communication allows specification of modular Latency-Insensitive Designs, where the interconnect structure is built up and optimized around existing IP components, respecting some mandatory computation and communication latencies prescribed by the system architect. This allows a real platform view development, with component reuse and timing-closure analysis. The design and optimization of interconnect fabric around IP blocks transform at modeling level an (untimed) asynchronous versions into a (scheduled) multiclock timed one.

Also, Network on Chip design may call for computable switching patterns, just like computable scheduling patterns were used in (predictable) Latency-Insensitive Design. Here again formal models, such as Cyclo-static dataflow graphs and extended Kahn networks with explicit routing schemes, are modeling elements of choice for a real synthesis/optimization approach to the design of systems.

Multicore embedded architecture platform may be represented as Marte UML component diagrams. The semantics of concurrent applications may also be represented as Marte behavior diagrams embodying precise MoCCs. Optimized compilations/syntheses rely on specific algorithms, and are represented as model transformations and allocation (of application onto architecture).

Our current work aims thus primarily at providing Theoretical Computer Science foundations to this domain of multicore embedded SoCs, with possibly efficient application in modeling, analysis and compilation wherever possible due to some natural assumptions. We also deal with a comparative view of Esterel and SystemC TLM for more practical modeling, and the relation between the Spirit IP-Xact interface standard in SoC domain with its Marte counterpart.

4.2. Automotive and avionic embedded systems

Model-Driven Engineering is in general well accepted in the transportation domains, where design of digital software and electronic parts in usually tighly coupled with larger apsects of system design, where models from physics are being used already. The formalisms AADL (for avionics) and AutoSar [55] (for automotive) are providing support for this, unfortunately not always with a clean and formal semantics. Thus there is a strong need here for approaches that bring closer together formal methods and tools on the one hand, engineering best practices on the other hand.

From a structural point of view AUTOSAR succeeded in establishing a framework that provides significant confidence in the proper integration of software components from a variety of distinct suppliers. But beyond those structural (interface) aspects, dynamic and temporal views are becoming more of a concern, so that AUTOSAR has introduced the AUTOSAR Specification of Timing Extension. AUTOSAR (discrete) timing models consist of timing descriptions, expressed by events and event chains, and timing constraints that are imposed on these events and event chains.

An important issue in all such formalisms is to mix in a single design framework heterogeneous time models and tasks: based on different timebases, with different triggering policy (event-triggered and time-triggered), and periodic and/or aperiodic tasks, with distinct periodicity if ever. Adequate modeling is a prerequisite to the process of scheduling and allocating such tasks onto complex embedded architectural platforms (see AAA approach in foundation section 3.3). Only then can one devise powerful synthesis/analysis/verification techniques to guide designers towards optimized solutions.

Traceability is also an important concern, to close the gap between early requirements and constraints modelling on the one hand, verification and correct implementation of these constraints at the different levels of the development on the other hand.

GALAAD Project-Team

4. Application Domains

4.1. Shape modeling

Geometric modeling is increasingly familiar for us (synthesized images, structures, vision by computer, Internet, ...). Nowadays, many manufactured objects are entirely designed and built by means of geometric software which describe with accuracy the shape of these objects. The involved mathematical models used to represent these shapes have often an algebraic nature. Their treatment can be very complicated, for example requiring the computations of intersections or isosurfaces (CSG, digital simulations, ...), the detection of singularities, the analysis of the topology, etc. Optimising these shapes with respect to some physical constraints is another example where the choice of the models and the design process are important to lead to interesting problems in algebraic geometric modeling and computing. We propose the developments of methods for shape modeling that take into account the algebraic specificities of these problems. We tackle questions whose answer strongly depends on the context of the application being considered, in direct relationship with the industrial contacts that we are developing in Computer Aided Geometric Design.

4.2. Shape processing

Many problems encountered in the application of computer sciences start from measurement data, from which one wants to recover a curve, a surface, or more generally a shape. This is typically the case in image processing, computer vision or signal processing. This also appears in computer biology where the geometry of distances plays a significant role, for example, in the reconstruction from NMR (Nuclear Magnetic Resonance) experiments, or the analysis of realizable or accessible configurations. In another domain, scanners which tend to be more and more easily used yield large set of data points from which one has to recover compact geometric model. We are working in collaboration with groups in agronomy on the problems of reconstruction of branching models (which represent trees or plants). We are investigating the application of algebraic techniques to these reconstruction problems. Geometry is also highly involved in the numerical simulation of physical problems such as heat conduction, ship hull design, blades and turbines analysis, mechanical stress analysis. We apply our algebraic-geometric techniques in the isogeometric approach which uses the same (bspline) formalism to represent both the geometry and the solutions of partial differential equations on this geometry.

GEOMETRICA Project-Team

4. Application Domains

4.1. Geometric Modeling and Shape Reconstruction

Modeling 3D shapes is required for all visualization applications where interactivity is a key feature since the observer can change the viewpoint and get an immediate feedback. This interactivity enhances the descriptive power of the medium significantly. For example, visualization of complex molecules helps drug designers to understand their structure. Multimedia applications also involve interactive visualization and include e-commerce (companies can present their products realistically), 3D games, animation and special effects in motion pictures. The uses of geometric modeling also cover the spectrum of engineering, computer-aided design and manufacture applications (CAD/CAM). More and more stages of the industrial development and production pipeline are now performed by simulation, due to the increased performance of numerical simulation packages. Geometric modeling therefore plays an increasingly important role in this area. Another emerging application of geometric modeling with high impact is medical visualization and simulation.

In a broad sense, shape reconstruction consists of creating digital models of real objects from points. Example application areas where such a process is involved are Computer Aided Geometric Design (making a car model from a clay mockup), medical imaging (reconstructing an organ from medical data), geology (modeling underground strata from seismic data), or cultural heritage projects (making models of ancient and or fragile models or places). The availability of accurate and fast scanning devices has also made the reproduction of real objects more effective such that additional fields of applications are coming into reach. The members of GEOMETRICA have a long experience in shape reconstruction and contributed several original methods based upon the Delaunay and Voronoi diagrams.

4.2. Scientific Computing

Meshes are the basic tools for scientific computing using finite element methods. Unstructured meshes are used to discretize domains bounded by complex shapes while allowing local refinements. GEOMETRICA contributes to mesh generation of 2D and 3D possibly curved domains. Most of our methods are based upon Delaunay triangulations, Voronoi diagrams and their variants. Anisotropic meshes are also investigated. We investigate in parallel both greedy and variational mesh generation techniques. The greedy algorithms consist of inserting vertices in an initial coarse mesh using the Delaunay refinement paradigm, while the variational algorithms consists of minimizing an energy related to the shape and size of the elements. Our goal is to show the complementarity of these two paradigms. Quadrangle surface meshes are also of interest for reverse engineering and geometry processing applications. Our goal is to control the final edge alignment, the mesh sizing and the regularity of the quadrangle tiling.

MARELLE Project-Team (section vide)

APICS Project-Team

4. Application Domains

4.1. Introduction

These domains are related to the problems described in sections 3.2.1 and 3.2.2 . They are handled using the techniques described in section 3.3 .

4.2. Inverse problems for elliptic PDE

Participants: Laurent Baratchart, Juliette Leblond, Ana-Maria Nicu, Dmitry Ponomarev.

This work is done in collaboration with Maureen Clerc and Théo Papadopoulo from the Athena project-team.

Solving overdetermined Cauchy problems for the Laplace equation on a spherical layer (in 3-D) in order to extrapolate incomplete data (see section 3.2.1) is a necessary ingredient of the team's approach to inverse source problems, in particular for applications to EEG since the latter involves propagating the initial conditions through several layers of different conductivities, from the boundary down to the center of the domain where the singularities (*i.e.* the sources) lie. Actually, once propagated to the innermost sphere, it turns out that that traces of the boundary data on 2-D cross sections (disks) coincide with analytic functions in the slicing plane, that has branched singularities inside the disk [4]. These singularities are related to the actual location of the sources (namely, they reach in turn a maximum in modulus when the plane contains one of the sources). Hence, we are back to the 2-D framework of section 3.3.3 where approximately recovering these singularities can be performed using best rational approximation.

Numerical experiments gave very good results on simulated data and we are now proceeding with real experimental magneto-encephalographic data, see also sections 5.6 and 6.1 . The PhD thesis of A.-M. Nicu [13] was concerned with these applications, see [16], in collaboration with the Athena team at Inria Sophia Antipolis, and neuroscience teams in partner-hospitals (hosp. Timone, Marseille).

Similar inverse potential problems appear naturally in magnetic reconstruction. A particular application, which is the object of a joint NSF project with Vanderbilt University and MIT, is to geophysics. There, the remanent magnetization of a rock is to be analysed to draw information on magnetic reversals and to reconstruct the rock history. Recently developed scanning magnetic microscopes measure the magnetic field down to very small scales in a “thin plate” geological sample at the Laboratory of planetary sciences at MIT, and the magnetization has to be recovered from the field measured on a plane located at small distance above the slab.

Mathematically speaking, EEG and magnetization inverse problems both amount to recover the (3-D valued) quantity m (primary current density in case of the brain or magnetization in case of a thin slab of rock) from measurements of the vector potential:

$$\int_{\Omega} \frac{\operatorname{div} m(x')\, dx'}{|x-x'|}\,,$$

outside the volume Ω of the object, from Maxwell's equations.

The team is also getting engaged in problems with variable conductivity governed by a 2-D conjugate-Beltrami equation, see [5], [58], [35]. The application we have in mind is to plasma confinement for thermonuclear fusion in a Tokamak, more precisely with the extrapolation of magnetic data on the boundary of the chamber from the outer boundary of the plasma, which is a level curve for the poloidal flux solving the original div-grad equation. Solving this inverse problem of Bernoulli type is of importance to determine the appropriate boundary conditions to be applied to the chamber in order to shape the plasma [54]. These issues are the topics of the PhD theses of S. Chaabi and D. Ponomarev [27], and of a joint collaboration with the Laboratoire J.-A. Dieudonné at the Univ. of Nice-SA (and the Inria team Castor), and the CMI-LATP at the Univ. of Aix-Marseille I (see section 6.2).

4.3. Identification and design of microwave devices

Participants: Laurent Baratchart, Sylvain Chevillard, Martine Olivi, Fabien Seyfert.

This work is done in collaboration with Stéphane Bila (XLim, Limoges) and Jean-Paul Marmorat (Centre de mathématiques appliquées (CMA), École des Mines de Paris).

One of the best training grounds for the research of the team in function theory is the identification and design of physical systems for which the linearity assumption works well in the considered range of frequency, and whose specifications are made in the frequency domain. This is the case of electromagnetic resonant systems which are of common use in telecommunications.

In space telecommunications (satellite transmissions), constraints specific to on-board technology lead to the use of filters with resonant cavities in the microwave range. These filters serve multiplexing purposes (before or after amplification), and consist of a sequence of cylindrical hollow bodies, magnetically coupled by irises (orthogonal double slits). The electromagnetic wave that traverses the cavities satisfies the Maxwell equations, forcing the tangent electrical field along the body of the cavity to be zero. A deeper study (of the Helmholtz equation) states that essentially only a discrete set of wave vectors is selected. In the considered range of frequency, the electrical field in each cavity can be seen as being decomposed along two orthogonal modes, perpendicular to the axis of the cavity (other modes are far off in the frequency domain, and their influence can be neglected).

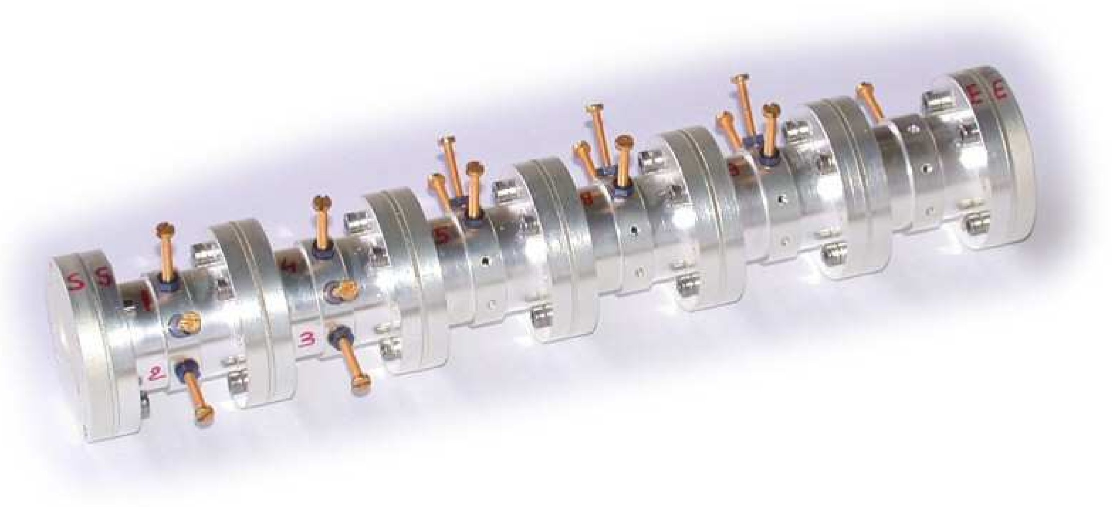

Figure 1. Picture of a 6-cavities dual mode filter. Each cavity (except the last one) has 3 screws to couple the modes within the cavity, so that 16 quantities must be optimized. Quantities such as the diameter and length of the cavities, or the width of the 11 slits are fixed during the design phase.

Each cavity (see Figure 1) has three screws, horizontal, vertical and midway (horizontal and vertical are two arbitrary directions, the third direction makes an angle of 45 or 135 degrees, the easy case is when all cavities show the same orientation, and when the directions of the irises are the same, as well as the input and output slits). Since the screws are conductors, they act more or less as capacitors; besides, the electrical field on the surface has to be zero, which modifies the boundary conditions of one of the two modes (for the other mode, the electrical field is zero hence it is not influenced by the screw), the third screw acts as a coupling between the two modes. The effect of the iris is to the contrary of a screw: no condition is imposed where there is a hole, which results in a coupling between two horizontal (or two vertical) modes of adjacent cavities (in fact the iris is the union of two rectangles, the important parameter being their width). The design of a filter consists in finding the size of each cavity, and the width of each iris. Subsequently, the filter can be constructed and tuned by adjusting the screws. Finally, the screws are glued. In what follows, we shall consider a typical example, a filter designed by the CNES in Toulouse, with four cavities near 11 Ghz.

Near the resonance frequency, a good approximation of the Maxwell equations is given by the solution of a second order differential equation. One obtains thus an electrical model for our filter as a sequence of electrically-coupled resonant circuits, and each circuit will be modelled by two resonators, one per mode, whose resonance frequency represents the frequency of a mode, and whose resistance represent the electric losses (current on the surface).

In this way, the filter can be seen as a quadripole, with two ports, when plugged on a resistor at one end and fed with some potential at the other end. We are then interested in the power which is transmitted and reflected. This leads to defining a scattering matrix S, that can be considered as the transfer function of a stable causal linear dynamical system, with two inputs and two outputs. Its diagonal terms $S_{1,1}$, $S_{2,2}$ correspond to reflections at each port, while $S_{1,2}$, $S_{2,1}$ correspond to transmission. These functions can be measured at certain frequencies (on the imaginary axis). The filter is rational of order 4 times the number of cavities (that is 16 in the example), and the key step consists in expressing the components of the equivalent electrical circuit as a function of the S_{ij} (since there are no formulas expressing the lengths of the screws in terms of parameters of this electrical model). This representation is also useful to analyze the numerical simulations of the Maxwell equations, and to check the design, particularly the absence of higher resonant modes.

In fact, resonance is not studied via the electrical model, but via a low-pass equivalent circuit obtained upon linearising near the central frequency, which is no longer conjugate symmetric (*i.e.* the underlying system may not have real coefficients) but whose degree is divided by 2 (8 in the example).

In short, the identification strategy is as follows:

- measuring the scattering matrix of the filter near the optimal frequency over twice the pass band (which is 80Mhz in the example).
- Solving bounded extremal problems for the transmission and the reflection (the modulus of he response being respectively close to 0 and 1 outside the interval measurement, cf. section 3.3.1). This provides us with a scattering matrix of order roughly 1/4 of the number of data points.
- Approximating this scattering matrix by a rational transfer-function of fixed degree (8 in this example) via the Endymion or RARL2 software (cf. section 3.3.2.2).
- A realization of the transfer function is thus obtained, and some additional symmetry constraints are imposed.
- Finally one builds a realization of the approximant and looks for a change of variables that eliminates non-physical couplings. This is obtained by using algebraic-solvers and continuation algorithms on the group of orthogonal complex matrices (symmetry forces this type of transformation).

The final approximation is of high quality. This can be interpreted as a validation of the linearity hypothesis for the system: the relative L^2 error is less than 10^{-3}. This is illustrated by a reflection diagram (Figure 2). Non-physical couplings are less than 10^{-2}.

The above considerations are valid for a large class of filters. These developments have also been used for the design of non-symmetric filters, useful for the synthesis of repeating devices.

The team also investigates problems relative to the design of optimal responses for microwave devices. The resolution of a quasi-convex Zolotarev problems was for example proposed, in order to derive guaranteed optimal multi-band filter's responses subject to modulus constraints [11]. This generalizes the classical single band design techniques based on Tchebychev polynomials and elliptic functions. These techniques rely on the fact that the modulus of the scattering parameters of a filters, say $|S_{1,2}|$, admits a simple expression in terms of the filtering function $D = |S_{1,1}|/|S_{1,2}|$ namely,

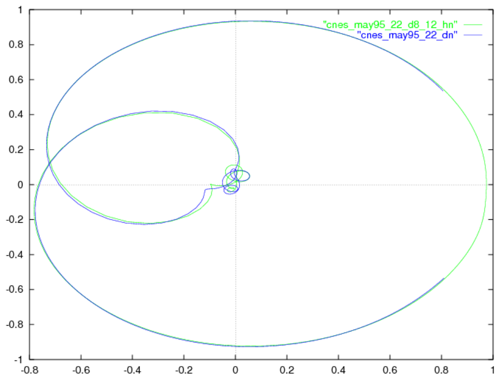

Figure 2. Nyquist Diagram. Rational approximation (degree 8) and data - S_{22}.

$$|S_{1,2}|^2 = \frac{1}{1 + D^2}.$$

The filtering function appears to be the ratio of two polynomials p_1/p_2, the numerator of the reflection and transmission scattering factors, that can be chosen freely. The denominator q is obtained as the unique stable and unitary polynomial solving the classical Feldtkeller spectral equation:

$$qq^* = p_1 p_1^* + p_2 p_2^*.$$

The relative simplicity of the derivation of filter's responses under modulus constraints is due to this ability to "forget" about latter spectral equation, and express all design constraints on the filtering functions D. This no longer the case when considering the synthesis N-port devices for $N > 3$, like multiplexers, routers power dividers or when considering the synthesis of filters under matching conditions. The efficient derivation of multiplexers responses is one of the team's active recent research area, where technique based on constrained Nevanlinna-Pick interpolation problems are under study (see section 6.4.1).

CASTOR Team (section vide)

COFFEE Project-Team

4. Application Domains

4.1. Analysis of PDEs

We are led to consider coupled non linear systems of PDEs. We are mainly interested here in systems exhibiting hyperbolic structures, possibly with (partial) diffusive corrections. It includes non linear kinetic equations (of Vlasov-Fokker-Planck or Vlasov-Boltzmann type, say). It is also possible that the coefficients depend on the unknown in a non–local way. Generally speaking, we are concerned in the project with flows where the multiphase character is crucial and makes part of the difficulty. Models involve PDEs systems of hybrid type, and we expect to be able to exhibit common structures between several models coming from different physical motivation.

4.2. Numerical analysis of FV methods

We wish to design and analyze new numerical schemes, mostly in the FV framework. For hyperbolic systems the theory is well-advanced, but there remain many challenging questions, of crucial relevance for the applications:

- While the general FV framework is clear for conservation laws, the design of numerical fluxes and the discussion of stability issues can be "application-dependent". In particular, we wish to use the underlying microscopic description of particulate and mixtures flows to design dedicated kinetic schemes.
- Stability issues become more intricate when we try to increase the consistency accuracy and when we deal with complex meshes. For instance preserving positivity of certain fields could be absolutely crucial not only for physical reasons, but also to preserve the stability of the simulation of a coupled system. We will therefore continue our work on MUSCL-like methods working on vertex-based discretization, with limiters defined by using multislope analysis.
- Finally, source terms have to be considered appropriately, in particular in order to preserve equilibrium states and to capture correct asymptotic regimes. It requires to UpWind the numerical fluxes by taking into account the source terms. Among others, we are particularly interested in Asymptotic High Order (AHO) schemes.

Besides, the conception of new methods based on Finite Volume discretizations for diffusion has known very intense activities after pioneering works at the beginning of the '00s. The FV framework, dealing with very general meshes, is very appropriate to deal with complex flows in highly heterogeneous media. The difficulty consists in defining additional unknowns to evaluate diffusion fluxes on the interfaces of the control volumes: using as unique numerical unknown the cell average of the continuous unknown requires unrealistic conditions on the mesh geometry. We are highly involved in the developments of such methods, which are strongly motivated by industrial needs (and our research is enhanced by a 12 years-long experience in the industrial context). We plan to investigate in particular the VAG (Vertex Approximate Gradient) method, based on cell center discretizations involving additional unknowns stored at the vertices, and the DDFV (Discrete Duality Finite Volume) method, which uses a dual mesh.

4.3. Asymptotic analysis

Asymptotic analysis has a crucial role in our activity. We are interested in the derivation of hierarchies of models based on asymptotic arguments: it allows to design reduced models, that can be relevant under well-identified assumptions of the physical coefficients. In particular, the discussion of hydrodynamic regimes which start from kinetic equations and lead to macroscopic equations will be the object of a specific attention.

4.4. Particulate flows, Mixture flows

We will investigate fluid mechanics models referred to as “multi–fluids” flows where a disperse phase interacts with a dense phase. Such flows arise in numerous applications, like for pollutant transport and dispersion, the combustion of fuel particles in air, the modeling of fluidized beds, the dynamic of sprays and in particular biosprays with medical applications, engine fine particles emission... There are many possible modeling of such flows: microscopic models where the two phases occupy distinct domains and where the coupling arises through intricate interface conditions; macroscopic models which are of hydrodynamic (multiphase) type, involving non standard state laws, possibly with non conservative terms, and the so–called mesoscopic models. The latter are based on Eulerian–Lagrangian description where the disperse phase is described by a particle distribution function in phase space. Following this path we are led to a Vlasov-like equation coupled to a system describing the evolution of the dense phase that is either the Euler or the Navier-Stokes equations

4.5. Interface problems

We are faced difficulties related to the coupling of models, methods and codes at interfaces. We distinguish several questions, which are nevertheless intimately connected on the technical viewpoint.

- As far as we consider flows in porous media, interface conditions and domain decomposition methods have been thoroughly investigated. However, the question of their numerical treatment left many questions open, which naturally depend on the underlying discretization techniques. A typical question, which is strongly motivated by collaborations with our industrial partners, relies on the simulations of mass and heat exchanges between a porous medium and an adjacent free-flow region. It is also remarkable that, despite the existing literature on the subject, techniques have still a reduced spreading out of the academics: in many industrial simulations, two different (commercial) codes are used and the interface coupling is managed more or less “manually” at each time step! Therefore, the challenge consists in dealing with compositional non-isothermal two-phase systems, including vaporization effects, and, again, the application fields make the use of FV schemes in the porous media more appropriate.
- The situation is a bit different for hyperbolic problems because the design of the interface condition itself is less clear. We are concerned with the coupling of hyperbolic systems involving different propagation properties, and possibly different set of unknowns. It raises modeling issues in order to design the coupling condition, problems of mathematical analysis, as well as complicated questions in order to match numerical methods. The framework of kinetic schemes might be a possible way to define consistent numerical fluxes. The problem is again strongly motivated by industrial needs, with the additional constraint of not to modify too much existing computational tools. We are involved in a collaboration with physicists specifically dedicated to such problems of wave propagations through complex interfaces.

4.6. Biological degradation

biodegradation of monuments is due, in part, to the formation of biofilms, namely a colony of bacteria embedded within an extra-cellular matrix. Biofilms can also be used a a protection device against corrosion of well cement in CO2 storage reservoir. More generally the formation of biofilms is a common feature of the behavior of bacteria and has potentially many applications in medical and industrial settings; for instance, the cyanobacteria are seriously considered in order to produce energy as bio-fuel and there are also researches to set up bio-devices to avoid human or plant diseases. We are particularly interested in mathematical models of such phenomena based on arguments coming from mixture theory (thus with a natural connection to the previous item); it leads to a complex multi-dimensional hydrodynamic-type system, with polyphasic features.

Besides, when considering proliferation of micro-algae in a large domain, it is relevant to distinguish two phases : a development one on the sea bed as a biofilm and a spreading one in water which can be described thanks to kinetic equations subject to coagulation-fragmentation dynamics. We wish to derive a complete system, describing the two phases, including the design of coupling interface conditions. This is definitely an interesting and original modeling challenge. We also wish to identify scaling parameters which will allow to bring out hierarchies of reduced models. Of course, the program has to be completed with the conception of the corresponding numerical schemes, so that we will be able to validate, at least on qualitative grounds, our approach, which, in turn, will be decisive to strengthen the collaborations with biologists.

Another question, which is equally related technically to the other problems addressed in the project, is concerned with the analysis and simulation of equations of hyperbolic type in inhomogeneous media, like porous media or networks. This is a direction to improve the existing models in biology and it can give rise in analytical and numerical viewpoints to fruitful exchanges between the biological domain and the environmental one. We are particularly interested in PDEs describing chemotactic behaviors, namely the movement of cells in response to a chemical signal and have potential applications, for example to model the movement of fibroblasts on scaffold

MCTAO Team

4. Application Domains

4.1. Space engineering, satellites, low thrust control

Space engineering is very demanding in terms of safe and high-performance (for instance in terms of fuel consumption, because only a finte amount of fuel is onborad a sattelite for all its “life”) control laws. It is therefore prone to real industrial collaborations.

We are especially interested in trajectory control of space vehicles using their own propulsion devices, outside the atmosphere. Here we discuss “non-local” control problems (in the sense of section 3.1 point 1): in the geocentric case, orbit transfer rather than station keeping; also we do not discuss attitude control.

A space vehicle is subject to
- gravitational forces, from one or more central bodies (the corresponding acceleration is denoted by $F_{\mathrm{grav.}}$ below),
- other forces of small amplitude (the corresponding acceleration is denoted by F_2 below),
- a thrust, the control, produced by a propelling device; it is the $G\,u$ term below; assume for simplicity that control in all directions is allowed, *i.e.*G is an invertible matrix.
In position-velocity coordinates, its dynamics can be written as

$$\ddot{x} \quad = \quad F_{\mathrm{grav.}}(x,t) \ \left[+\ F_2(x,\dot{x},t)\right]\ +\ G(x,\dot{x})\,u\ , \qquad \|u\|\leq u_{\max}. \tag{1}$$

The second term is often neglected in the design of the control. Time-dependence reflects the movement of attracting celestial bodies if there is more than one (see below).

4.1.1. Low thrust

means that $u_{\max}$ is small, or more precisely that the maximum magnitude of $G\,u$ is small with respect to the one of $F_{\mathrm{grav.}}$ (but is usually large compared to F_2). Hence the influence of the control is very weak instantaneously, and trajectories can only be significantly modified by accumulating the effect of this low thrust on a long time. Obviously this is possible only because the free system is somehow conservative. This was “abstracted” in section 3.5 .

Why low thrust ? The common principle to all propulsion devices is to eject particles, with some relative speed with respect to the vehicle; conservation of momentum then induces, from the point of view of the vehicle alone, an external force, the “thrust” (and a mass decrease). Ejecting the same mass of particles with a higher relative speed results in a proportionally higher thrust; this relative speed (specific impulse, I_{sp}) is a characteristic of the engine; the higher the I_{sp}, the smaller the mass of particles needed for the same change in the vehicle momentum. Engines with a higher I_{sp} are highly desirable because, for the same maneuvers, they reduce the mass of "fuel" to be taken on-board the satellite, hence leaving more room (mass) for the payload. “Classical” chemical engines use combustion to eject particles, at a somehow limited speed even with very efficient fuel; the more recent electric engines use a magnetic field to accelerate particles and eject them at a considerably higher speed; however electrical power is limited (solar cells), and only a small amount of particles can be accelerated per unit of time, inducing the limitation on thrust magnitude.

Electric engines theoretically allow many more maneuvers with the same amount of particles, with the drawback that the instant force is very small; sophisticated control design is necessary to circumvent this drawback. High thrust engines allow simpler control procedures because they almost allow instant maneuvers (strategies consist in a few burns at precise instants).

4.1.2. Typical problems

Let us mention two.

- *Orbit transfer or rendez-vous*. It is the classical problem of bringing a satellite to its operating position from the orbit where it is delivered by the launcher; for instance from a GTO orbit to the geostationary orbit at a prescribed longitude (one says rendez-vous when the longitude, or the position on the orbit, is prescribed, and transfer if it is free). In equation (1) for the dynamics, $F_{\mathrm{grav.}}$ is the Newtonian gravitation force of the earth (it then does not depend on time); F_2 contains all the terms coming either from the perturbations to the Newtonian potential or from external forces like radiation pressure, and the control is usually allowed in all directions, or with some restrictions to be made precise.
- *Three body problem*. This is about missions in the solar system leaving the region where the attraction of the earth, or another single body, is preponderant. We are then no longer in the situation of a single central body, $F_{\mathrm{grav.}}$ contains the attraction of different planets and the sun. In regions where two central bodies have an influence, say the earth and the moon, or the sun and a planet, the term $F_{\mathrm{grav.}}$ in (1) is the one of the restricted three body problem and dependence on time reflects the movement of the two "big" attracting bodies.

  In the 2003 mission SMART-1, the project was to send a small observation vehicle from the Earth to the Moon using low-thrust propulsion. The vehicle was launched and reached the moon: the goal was achieved; precise reports on the control used can be found in [73]. There was no attempt to minimize fuel consumption, or transfer time, and it is not a surprise that the implemented solution is far from optimal with respect to these criteria. In a recent work in the Dijon team, and in collaboration with J. Gergaud from APO team at IRIT- ENSEEIHT (Toulouse) we have computed optimal trajectories for the Earth-Moon transfer according to the energy minimization problem, the time minimal transfer or the propellant minimization consumption. These results combine geometric optimal control and numerical simulations with adapted numerical codes. The contributions are described in G. Picot Phd thesis, (Dijon November 2010), B. Daoud (Phd thesis defended at Dijon in October 2011) and the numerical codes are developed by O. Cots (Phd thesis to be defended at Dijon in June 2012). Our previous work [29] gives a *feedback* solution for this problem, divided in three phases, the design being based on a two-body model in the first and last phase, where the effect of the primaries is preponderant and the second phase is in the neighborhood of the L2 Lagrange point. This opens perspectives in trajectory optimization; see the recent work [32]. For a state of the art, the reader may refer to [62] or [28].

  An issue for future experimental missions in the solar system is interplanetary flight planning with gravitational assistance. Tackling this global problem, that even contains some combinatorial problems (itinerary), goes beyond the methodology developed here, but the above considerations are a brick in this puzzle.

4.1.3. Properties of the control system.

If there are no restrictions on the thrust direction, i.e., in equation (1), if the control u has dimension 3 with an invertible matrix G, then the control system is "static feedback linearizable", and a fortiori flat, see section 3.2 . However, implementing the static feedback transformation would consist in using the control to "cancel" the gravitation; this is obviously impossible since the available thrust is very small. As mentioned in section 3.1 , point 3 , the problem remains fully nonlinear in spite of this "linearizable" structure [2].

4.1.4. Context for these applications

The geographic proximity of Thales Alenia Space, in conjunction with the "Pole de compétitivité" PEGASE in PACA region is an asset for a long term collaboration between Inria - Sophia Antipolis and Thales Alenia

[2] However, the linear approximation around *any* feasible trajectory is controllable (a periodic time-varying linear system); optimal control problems will have no singular or abnormal trajectories.

Space (Thales Alenia Space site located in Cannes hosts one of the very few European facilities for assembly, integration and tests of satellites).

B. Bonnard and J.-B. Caillau in Dijon have had a strong activity in optimal control for space, in collaboration with the APO Team from IRIT at ENSEEIHT (Toulouse), and sometimes with EADS, for development of geometric methods in numerical algorithms.

4.2. Quantum Control

The activity of B. Bonnard in quantum control started as a collaboration with D. Sugny (a physicist from ICB) in the ANR project Comoc, localized mainly at the University of Dijon; the problem was the control of the orientation of a molecule using a laser field, with a model that does take into account the dissipation due to the interaction with the environment, molecular collisions for instance. The model is a dissipative generalization of the finite dimensional Schrödinger equation, known as Lindblad equation. In particular we have computed the minimum time control and the minimum energy control for the orientation or a two-level system, using geometric optimal control and adapted numerical methods (shooting and numeric continuation) [36], [35]. The model is a 3-dimensional system depending upon 3 parameters, yielding a very complicated optimal control problem that we have solved for prescribed boundary conditions.

More recently, based on this project, we have reoriented our control activity towards Nuclear Magnetic Resonance (MNR). In MNR medical imaging, the contrast problem is the one of designing a variation of the magnetic field with respect to time that maximizes the difference, on the resulting image, between two different chemical species; this research is conducted with Prof. S. Glaser (TU-München); it was evidenced experimentally that the current contrast of the image is significantly improved by using "our" exact optimal control methods. The model is the Bloch equation for spin $\frac{1}{2}$ particles, that can be interpreted as a sub-case of Lindblad equation for a two-level system; the control problem to solve amounts to driving in minimum time the magnetization vector of the spin to zero (for parameters of the system corresponding to one of the species), and generalizations where such spin $\frac{1}{2}$ particles are coupled: double spin inversion for instance. This research project is supported on the french side by a PEPS INSIS (Control-Image).

4.3. Applications of optimal transport

Optimal Transportation in general has many applications. Image processing, biology, fluid mechanics, mathematical physics, game theory, traffic planning, financial mathematics, economics are among the most popular fields of application of the general theory of optimal transport. Many developments have been made in all these fields recently. Two more specific fields:
- In image processing, since a grey-scale image may be viewed as a measure, optimal transportation has been used because it gives a distance between measures corresponding to the optimal cost of moving densities from one to the other, see e.g. the work of J.-M. Morel and co-workers [66].
- In representation and approximation of geometric shapes, say by point-cloud sampling, it is also interesting to associate a measure, rather than just a geometric locus, to a distribution of points (this gives a small importance to exceptional "outlier" mistaken points); this was developed in Q. Mérigot's PhD [69] in the GEOMETRICA project-team. The relevant distance between measures is again the one coming from optimal transportation. Such approach, combined with evolution of densities mentioned above, may help to perform robust stabilization of set of particles.

McTAO is not directly involved in applications of transport. A starting point may be Alice Erlinger's PhD, in co-supervision with Ludovic Rifford and Robert McCann from the University of Toronto, that will comprehend applications of optimal transportation to the modeling of markets in economy; it is starting in september, 2012.

Applications that would be *specific to the type of costs that we consider*, i.e. these coming from optimal control are concerned with evolutions of densities under state or velocity constraints. A fluid motion or a crowd movement can be seen as the evolution of a density in a given space. If constraints are given on the directions in which these these densities can evolve, we are in the framework of non-holonomic transport problems. Such approach could be useful to stabilize a large set of particles.

4.4. Applications to some domains of mathematics.

Control theory (in particular thinking in terms of inputs and reachable set) has brought novel ideas and progresses to mathematics. For instance, some problems from classical calculus of variations have been revisited in terms of optimal control and Pontryagin's Maximum Principle [55]; also, closed geodesics for perturbed Riemannian metrics where constructed in [58], [59] with control techniques.

The work in progress [45] is definitely in this line, applying techniques from control to construct some perturbations under constraints of Hamiltonian systems to solve longstanding open questions in dynamical systems. Other work by Rifford and Ruggiero [13] applied successfully geometric control techniques to obtain genericity properties for Hamiltonian systems.

NACHOS Project-Team

4. Application Domains

4.1. Computational electromagnetics

Electromagnetism has found and continues to find applications in a wide range of areas, encompassing both industrial and societal purposes. Applications of current interest include those related to communications (e.g transmission through optical fiber lines), to biomedical devices and health (e.g tomography, power-line safety, etc.), to circuit or magnetic storage design (electromagnetic compatibility, hard disc operation), to geophysical prospecting, and to non-destructive evaluation (e.g crack detection), to name but just a few. Although the principles of electromagnetics are well understood, their application to practical configurations of current interest is significantly complicated and far beyond manual calculation in all but the simplest cases. These complications typically arise from the geometrical characteristics of the propagation medium (irregular shapes, geometrical singularities), the physical characteristics of the propagation medium (heterogeneity, physical dispersion and dissipation) and the characteristics of the sources (wires, etc.). The significant advances in computer technology that have taken place over the last two decades have been such that numerical modeling and computer simulation is nowadays ubiquitous in the study of electromagnetic interactions. The team is actively contributing to the design of advanced numerical methodologies for the solution of the PDE models of electromagnetism with a focus on problems relevant to computational bioelectromagnetics on one hand, and computational nanophotonics on the other hand. In the first case, the objective is to develop numerical methodologies for the simulation of the interaction of electromagnetic waves with biological tissues at microwave frequencies (see Fig. 1). Potential applications are concerned with the evaluation of potential sanitary effects of human exposure to electromagnetic waves, or with the design of biomedical devices and systems (i.e. imaging systems, implantable antennas, etc.). In the second case, the target simulations involve the interaction of electromagnetic wave with nanoparticules at optical frequencies. Indeed, nanophotonics is the branch of nanotechnology that deals with the study and behaviour of light and optics at nanometer scale. It directly deals with the optics and is widely used in optic engineering. It includes all the phenomenas that are used in optical sciences for the development of optical devices. Therefore, nanophotonics finds numerous applications such as in optical microscopy, the design of optical switches and electromagnetic chips circuits, trasistor filaments, etc.

4.2. Computational geoseismics

Computational challenges in geoseismics span a wide range of disciplines and have significant scientific and societal implications. Two important topics are mitigation of seismic hazards and discovery of economically recoverable petroleum resources. The team is before all considering the fist of these topics. Indeed, to understand the basic science of earthquakes and to help engineers better prepare for such an event, scientists want to identify which regions are likely to experience the most intense shaking, particularly in populated sediment-filled basins. This understanding can be used to improve building codes in high risk areas and to help engineers design safer structures, potentially saving lives and property. In the absence of deterministic earthquake prediction, forecasting of earthquake ground motion based on simulation of scenarios is one of the most promising tools to mitigate earthquake related hazard. This requires intense modeling that meets the spatial and temporal resolution scales of the continuously increasing density and resolution of the seismic instrumentation, which record dynamic shaking at the surface, as well as of the basin models. Another important issue is to improve our physical understanding of the earthquake rupture processes and seismicity. Large-scale simulations of earthquake rupture dynamics, and of fault interactions, are currently the only means to investigate these multi-scale physics together with data assimilation and inversion. High resolution models are also required to develop and assess fast operational analysis tools for real time seismology and early warning systems. Modeling and forecasting earthquake ground motion in large basins is a challenging and

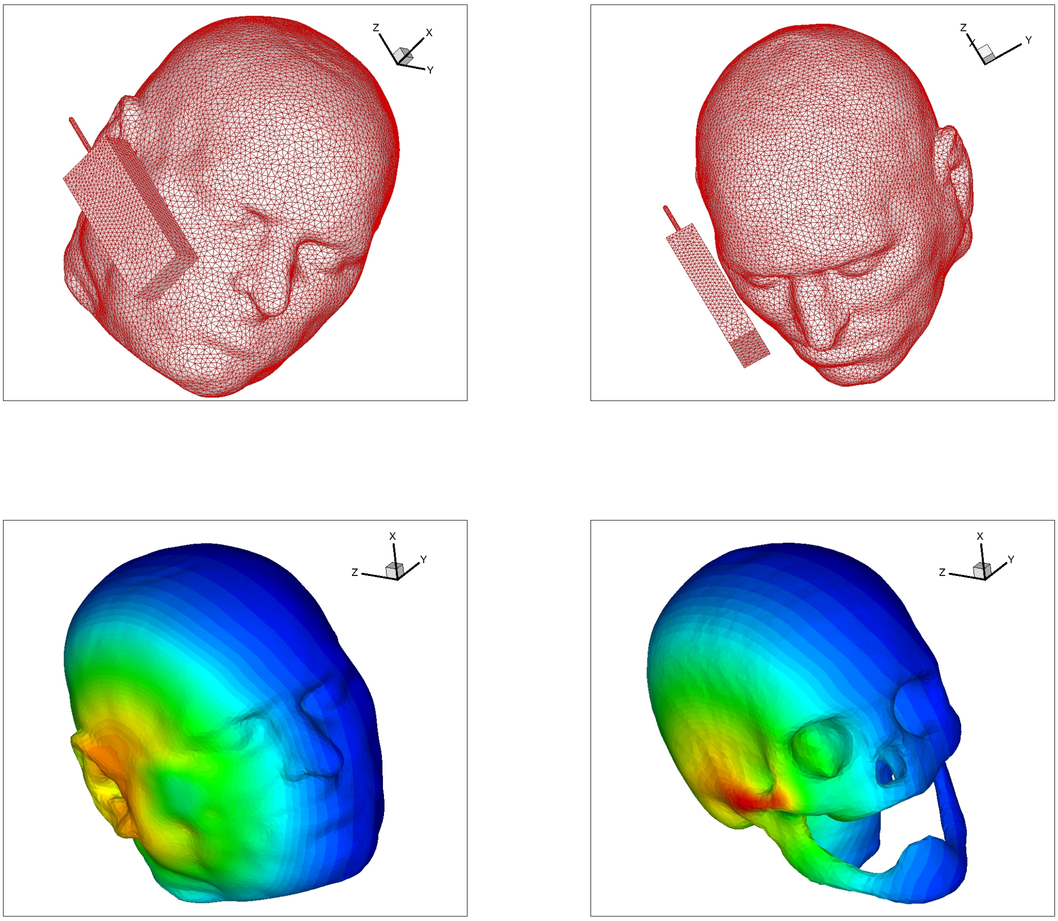

Figure 1. Exposure of head tissues to an electromagnetic wave emitted by a localized source. Top figures: surface triangulations of the skin and the skull. Bottom figures: contour lines of the amplitude of the electric field.

complex task. The complexity arises from several sources. First, multiple scales characterize the earthquake source and basin response: the shortest wavelengths are measured in tens of meters, whereas the longest measure in kilometers; basin dimensions are on the order of tens of kilometers, and earthquake sources up to hundreds of kilometers. Second, temporal scales vary from the hundredth of a second necessary to resolve the highest frequencies of the earthquake source up to as much as several minutes of shaking within the basin. Third, many basins have a highly irregular geometry. Fourth, the soil's material properties are highly heterogeneous. And fifth, geology and source parameters are observable only indirectly and thus introduce uncertainty in the modeling process. In this context, the team undertakes research and development activites aiming at the design of numerical modeling strategies for accurately and efficiently handling the interaction of seismic waves generated by an earthquake source with complex geological media. These activities are conducted in the framework of a collaboration with CETE Méditerranée http://www.cete-mediterranee.fr/gb which is a regional technical and engineering centre whose activtites are concerned with seismic risk assessment studies.

OPALE Project-Team

4. Application Domains

4.1. Aeronautics and space

The demand of the aeronautical industry remains very strong in aerodynamics, as much for conventional aircraft, whose performance must be enhanced to meet new societal requirements in terms of economy, noise (particularly during landing), vortex production near runways, etc., as for high-capacity or supersonic aircraft of the future. Our implication concerns shape optimization of wings or simplified configurations.

Our current involvement with Space applications relates to software platforms for code coupling.

4.2. Mechanical industry

A new application domain related to the parameter and shape optimization of mechanical structures is under active development. The mechanical models range from linear elasticity of 2D or 3D structures, or thin shells, to nonlinear elastoplasticity and structural dynamics. The criteria under consideration are multiple: formability, stiffness, rupture, fatigue, crash, and so on. The design variables are the thickness and shape, and possibly the topology, of the structures. The applications are performed in collaboration with world-leading industrials, and involve the optimization of the stamping process (Blank Force, Die and Tools shapes) of High Performance steel structures as well as the optimal design of structures used for packaging purposes (cans and sprays under high pressure). Our main contribution relies on providing original and efficient algorithms to capture Pareto fronts, using smart meta-modelling, and to apply game theory approaches and algorithms to propose stable compromise solutions (e.g. Nash equilibria).

4.3. Electromagnetics

In the context of shape optimization of antennas, we can split the existing results in two parts: the two-dimensional modeling concerning only the specific transverse mode TE or TM, and treatments of the real physical 3-D propagation accounting for no particular symmetry, whose objective is to optimize and identify real objects such as antennas.

Most of the numerical literature in shape optimization in electromagnetics belongs to the first part and makes intensive use of the 2-D solvers based on the specific 2-D Green kernels. The 2-D approach for the optimization of *directivity* led recently to serious errors due to the modeling defect. There is definitely little hope for extending the 2-D algorithms to real situations. Our approach relies on a full analysis in unbounded domains of shape sensitivity analysis for the Maxwell equations (in the time-dependent or harmonic formulation), in particular, by using the integral formulation and the variations of the Colton and Kreiss isomorphism. The use of the France Telecom software SR3D enables us to directly implement our shape sensitivity analysis in the harmonic approach. This technique makes it possible, with an adequate interpolation, to retrieve the shape derivatives from the physical vector fields in the time evolution processes involving initial impulses, such as radar or tomography devices, etc. Our approach is complementary to the “automatic differentiation codes” which are also very powerful in many areas of computational sciences. In Electromagnetics, the analysis of hyperbolic equations requires a sound treatment and a clear understanding of the influence of space approximation.

4.4. Biology and medicine

A particular effort is made to apply our expertise in solid and fluid mechanics, shape and topology design, multidisciplinary optimization by game strategies to biology and medicine. Two selected applications are privileged: solid tumors and wound healing.

Opale's objective is to push further the investigation of these applications, from a mathematical-theoretical viewpoint and from a computational and software development viewpoint as well. These studies are led in collaboration with biologists, as well as image processing specialists.

4.5. Traffic flow

The modeling and analysis of traffic phenomena can be performed at a macroscopic scale by using partial differential equations derived from fluid dynamics. Such models give a description of collective dynamics in terms of the spatial density $\rho(t, x)$ and average velocity $v(t, x)$. Continuum models have shown to be in good agreement with empirical data. Moreover, they are suitable for analytical investigations and very efficient from the numerical point of view. Finally, they contain only few variables and parameters and they can be very versatile in order to describe different situations encountered in practice.

Opale's research focuses on the study of macroscopic models of vehicular and pedestrian traffic, and how optimal control approaches can be used in traffic management. The project opens new perspectives of inter-disciplinary collaborations on urban planning and crowd dynamics analysis.

4.6. Multidisciplinary couplings

Our expertise in theoretical and numerical modeling, in particular in relation to approximation schemes, and multilevel, multi-scale computational algorithms, allows us to envisage to contribute to integrated projects focused on disciplines other than, or coupled with fluid dynamics, such as structural mechanics, electromagnetics, biology and virtual reality, image processing, etc in collaboration with specialists of these fields. Part of this research is conducted in collaboration with ONERA.

SCIPORT Team

4. Application Domains

4.1. Automatic Differentiation

Automatic Differentiation of programs gives sensitivities or gradients, that are useful for many types of applications:

- optimum shape design under constraints, multidisciplinary optimization, and more generally any algorithm based on local linearization,
- inverse problems, such as parameter estimation and in particular 4Dvar data assimilation in climate sciences (meteorology, oceanography),
- first-order linearization of complex systems, or higher-order simulations, yielding reduced models for simulation of complex systems around a given state,
- mesh adaptation and mesh optimization with gradients or adjoints,
- equation solving with the Newton method,
- sensitivity analysis, propagation of truncation errors.

4.2. Multidisciplinary optimization

A CFD program computes the flow around a shape, starting from a number of inputs that define the shape and other parameters. From this flow one can define optimization criteria e.g. the lift of an aircraft. To optimize a criterion by a gradient descent, one needs the gradient of the output criterion with respect to all the inputs, and possibly additional gradients when there are constraints. Adjoint-mode AD is a promising way to compute these gradients.

4.3. Inverse problems and Data Assimilation

Inverse problems aim at estimating the value of hidden parameters from other measurable values, that depend on the hidden parameters through a system of equations. For example, the hidden parameter might be the shape of the ocean floor, and the measurable values the altitude and speed of the surface.

One particular case of inverse problems is *data assimilation* [33] in weather forecasting or in oceanography. The quality of the initial state of the simulation conditions the quality of the prediction. But this initial state is largely unknown. Only some measures at arbitrary places and times are available. A good initial state is found by solving a least squares problem between the measures and a guessed initial state which itself must verify the equations of meteorology. This boils down to solving an adjoint problem, which can be done though AD [36]. Figure 1 shows an example of a data assimilation exercise using the oceanography code OPA [34] and its AD adjoint produced by TAPENADE.

The special case of *4Dvar* data assimilation is particularly challenging. The 4^{th} dimension in “4D” is time, as available measures are distributed over a given assimilation period. Therefore the least squares mechanism must be applied to a simulation over time that follows the time evolution model. This process gives a much better estimation of the initial state, because both position and time of measurements are taken into account. On the other hand, the adjoint problem involved grows in complexity, because it must run (backwards) over many time steps. This demanding application of AD justifies our efforts in reducing the runtime and memory costs of AD adjoint codes.

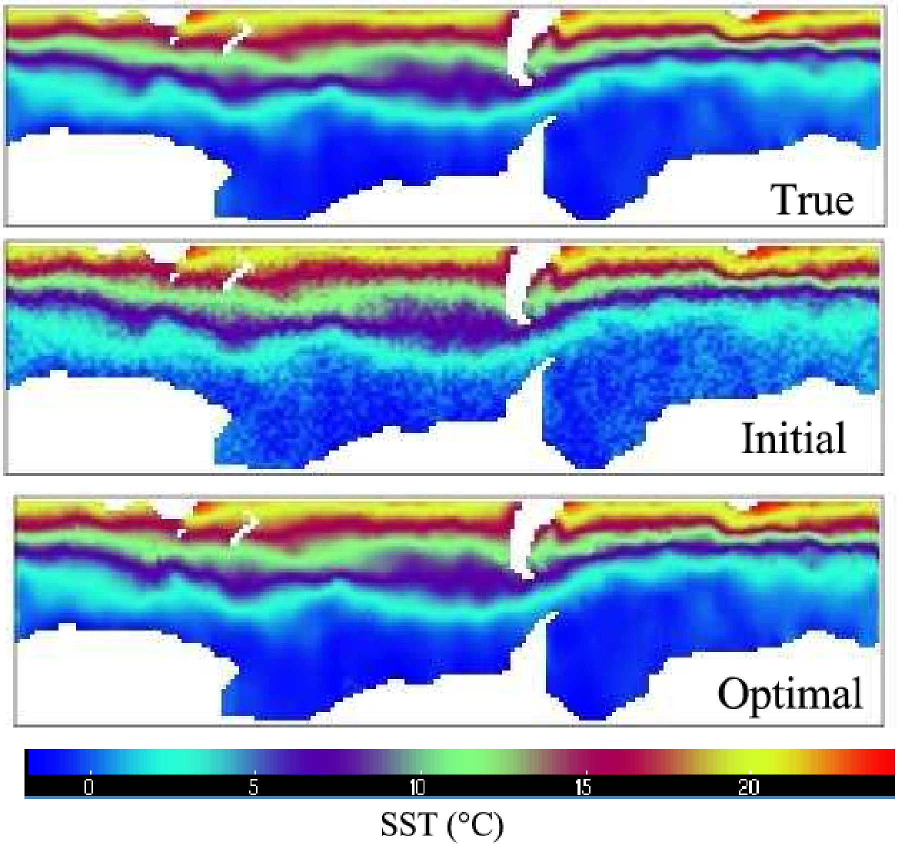

Figure 1. Twin experiment using the adjoint of OPA. We add random noise to a simulation of the ocean state around the Antarctic, and we remove this noise by minimizing the discrepancy with the physical model

4.4. Linearization

Simulating a complex system often requires solving a system of Partial Differential Equations. This is sometimes too expensive, in particular in the context of real time. When one wants to simulate the reaction of this complex system to small perturbations around a fixed set of parameters, there is a very efficient approximate solution: just suppose that the system is linear in a small neighborhood of the current set of parameters. The reaction of the system is thus approximated by a simple product of the variation of the parameters with the Jacobian matrix of the system. This Jacobian matrix can be obtained by AD. This is especially cheap when the Jacobian matrix is sparse. The simulation can be improved further by introducing higher-order derivatives, such as Taylor expansions, which can also be computed through AD. The result is often called a *reduced model*.

4.5. Mesh adaptation

Some approximation errors can be expressed by an adjoint state. Mesh adaptation can benefit from this. The classical optimization step can give an optimization direction not only for the control parameters, but also for the approximation parameters, and in particular the mesh geometry. The ultimate goal is to obtain optimal control parameters up to a precision prescribed in advance.

TOSCA Project-Team

4. Application Domains

4.1. Application Domains

TOSCA is interested in developing stochastic models and probabilistic numerical methods. Our present motivations come from Finance, Neuroscience and Biology, Fluid Mechanics and Meteorology, Chemical Kinetics, Diffusions in random media, Transverse problems, Software and Numerical experiments.

Finance For a long time now TOSCA has collaborated with researchers and practitioners in various financial institutions and insurance companies. We are particularly interested in calibration problems, risk analysis (especially model risk analysis), optimal portfolio management, Monte Carlo methods for option pricing and risk analysis, asset and liabilities management. We also work on the partial differential equations related to financial issues, for example the stochastic control Hamilton–Jacobi–Bellman equations. We study existence, uniqueness, qualitative properties and appropriate deterministic or probabilistic numerical methods. At the moment we pay special attention to the financial consequences induced by modelling errors and calibration errors on hedging strategies and portfolio management strategies.

Neuroscience and Biology The interest of TOSCA in biology is developing in three main directions: neuroscience, molecular dynamics and population dynamics. In neuroscience, stochastic methods are developed to analyze stochastic resonance effects, to solve inverse problems and to investigate mean-field/McKean-Vlasov equations. For example, we are studying probabilistic interpretations and Monte Carlo methods for divergence form second-order differential operators with discontinuous coefficients, motivated by the 3D MEG inverse problem. Our research in molecular dynamics focuses on the development of Monte Carlo methods for the Poisson-Boltzmann equation which also involves a divergence form operator, and of original algorithms to construct improved simulation techniques for protein folding or interaction. Finally, our interest in population dynamics comes from ecology, evolution and genetics. For example, we are studying the emergence of diversity through the phenomenon of evolutionary branching in adaptive dynamics. Some collaborations in biostatistics on cancer problems are also being initiated.

Fluid Mechanics and Meteorology In Fluid Mechanics we develop probabilistic methods to solve vanishing vorticity problems and to study the behavior of complex flows at the boundary, and their interaction with the boundary. We elaborate and analyze stochastic particle algorithms. Our studies concern the convergence analysis of these methods on theoretical test cases and the design of original schemes for applicative cases. A first example concerns the micro-macro model of polymeric fluids (the FENE model). A second example concerns Pope's Lagrangian modelling of turbulent flows, motivated by the problem of modelling and computing characteristic properties of the local wind activity in areas where windmills are built. Our goal is to estimate local energy resources which are subject to meteorological randomness by combining large scale wind models and small scale Monte Carlo techniques, and to simulate management strategies of wind resources.

Chemical Kinetics The TOSCA team is studying coagulation and fragmentation models, that have numerous areas of applications (polymerization, aerosols, cement industry, copper industry, population dynamics...). Our current motivation comes from the industrial copper crushers in Chile. We aim to model and calibrate the process of fragmentation of brass particles of copper in industrial crushers, in order to improve their efficiency at a low cost.

Diffusions in random media A *random medium* is a material with a lot of heterogeneity which can be described only statistically. Typical examples are fissured porous media within rocks of different types, turbulent fluids or unknown or deficient materials in which polymers evolve or waves propagate. For the last few years, the TOSCA team has been collaborating with the Geophysics community on problems related to underground diffusions, especially those which concern waste transport or oil extraction. We are extending our previous results on the simulation of diffusion processes generated by divergence form operators with discontinuous coefficients. Such an operator appears for example in the Darcy law for the behavior of a fluid in a porous media. We are also developing another class of Monte Carlo methods to simulate diffusion phenomena in discontinuous media.

Transverse problems Several of the topics of interest of TOSCA do not only concern a single area of application. This is the case in particular for long time simulation methds of nonlinear McKean-Vlasov PDEs, the problem of simulation of multivalued models, variance reduction techniques or stochastic partial differential equations. For example, multivalued processes have applications in random mechanics or neuroscience, and variance reduction techniques have applications in any situation where Monte Carlo methods are applicable.

Software, numerical experiments TOSCA is interested in designing algorithms of resolution of specific equations in accordance with the needs of practitioners. We benefit from our strong experience of the programming of probabilistic algorithms of various architectures including intensive computation architectures. In particular, our activity will concern the development of grid computing techniques to solve large dimensional problems in Finance. We are also interested in intensively comparing various Monte Carlo methods for PDEs and in the development of open source libraries for our numerical methods in Fluid Mechanics, Meteorology, MEG or Chemical Kinetics.

ABS Project-Team (section vide)

ASCLEPIOS Project-Team (section vide)

ATHENA Project-Team

4. Application Domains

4.1. Applications of Diffusion MRI

Various examples of CNS diseases as Alzheimer's and Parkinson's diseases and others like multiple sclerosis, traumatic brain injury and schizophrenia have characteristic abnormalities in the micro-structure of brain tissues that are not apparent and cannot be revealed reliably by standard imaging techniques. Diffusion MRI can make visible these co-lateral damages to the fibers of the CNS white matter that connect different brain regions. This is why in our research, Diffusion MRI is the major anatomical imaging modality that will be considered to recover the CNS connectivity.

Clinical domain: Diagnosis of neurological disorder

- *Parkinson's and Alzheimer's diseases* are among the most important CNS diseases. Six million patients (among which 850.000 in France) are suffering from Alzheimer's, making it the most important neurodegenerative disease in Europe. Over 85 years of age, 1 woman in 4 and 1 man in 5 are affected in Europe. In France, the number of Alzheimer's patients is expected to reach at least 2 million in 2025 and will probably double in 2050, with the increasing age of the population. Parkinson's disease is the second most important neurodegenerative disease. There are six and a half million patients in the world and roughly 150.000 patients in France, among which 10% are under 40 and 50% over 58. Together with our partners from NeuroSpin (Saclay), Inserm U678 and CENIR (CHUPS, Paris), we are involved in the ANR project NucleiPark which is about high field MRI of the braintem, the deep nuclei and their connections in the Parkinsonian syndromes.
- *Spinal Cord Injury* (SCI) has a significant impact on the quality of life since it can lead to motor deficits (paralysis) and sensory deficits. In the world, about 2.5 million people live with SCI (http://www.campaignforcure.org). To date, there is no consensus for full rehabilitative cure in SCI, although many therapeutic approaches have shown benefits [69], [71]. It is thus of great importance to develop tools that will improve the characterization of spinal lesions as well as the integrity of remaining spinal tracts to eventually establish better prognosis after spinal injury. We have already started to be active in this domain with our collaborators at Inserm U678 (H. Benali) and CRSN/Faculté de médecine Université de Montréal (Pr. S. Rossignol).

4.2. Applications of M/EEG

Applications of EEG and MEG cover:

- **Clinical domain:** diagnosis of neurological disorders such as
  - Diagnosis of neurological disorders such as epilepsy, schizophrenia, tinnitus, ...
  - Presurgical planning of brain surgery.
- **Cognitive research** aims at better understanding the brain spatio-temporal organisation.
- **Brain Computer Interfaces** look at allowing a direct control of the world using brain signal such as EEG signals. Those can be considered both as an application of EEG processing techniques and as a tool for fundamental and applied research as it opens the way for more dynamical and active brain cognitive protocols.

The dream of all M/EEG researchers is to alleviate the need for invasive recordings (electrocorticograms or intracerebral electrodes), which are often necessary prior to brain surgery, in order to precisely locate both pathological and vital functional areas. We are involved in this quest, particularly through our collaboration with the La Timone hospital in Marseille. M/EEG are also used in **cognitive research**, and we collaborate with the *Laboratory for Neurobiology of Cognition* in order to develop methods that suit their needs for sophisticated data analysis.

BIOCORE Project-Team

4. Application Domains

4.1. Bioenergy

Finding sources of renewable energy is a key challenge for our society. We contribute to this topic through two main domains for which a strong and acknowledged expertise has been acquired over the years. First, we consider anaerobic digesters, the field of expertise of the LBE members of the team, for the production of methane and/or biohydrogen from organic wastes. The main difficulty is to make these processes more reliable and exploit more efficiently the produced biogas by regulating both its quality and quantity despite high variability in the influent wastes. One of the specific applications that needs to be tackled is the production of biogas in a plant when the incoming organic waste results from the mixing of a finite number of substrates. The development of control laws that optimize the input mix of the substrates as a function of the actual state of the system is a key challenge for the viability of this industry.

The second topic consists in growing microalgae, the field of expertise of the LOV members of the team, to produce biofuel. These microorganisms can synthesize lipids with a much higher productivity than terrestrial oleaginous species. The difficulty is to better understand the involved processes, which are mainly transient, to stimulate and optimize them on the basis of modeling and control strategies. Predicting and optimizing the productivity reached by these promising systems in conditions where light received by each cell is strongly related to hydrodynamics, is a crucial challenge.

Finally, for the energy balance of the process, it is important to couple microalgae and anaerobic digestion to optimize the solar energy that can be recovered from microalgae, as was explored within the ANR Symbiose project (2009-2012) [72].

4.2. CO_2 fixation and fluxes

Phytoplanktonic species, which assimilate CO_2 during photosynthesis, have received a lot of attention in the last years. Microalgal based processes have been developed in order to mitigate industrial CO_2. As for biofuel productions, many problems arise when dealing with microalgae which are more complex than bacteria or yeasts. Several models have been developed within our team to predict the CO_2 uptake in conditions of variable light and nitrogen availability. The first modeling challenge in that context consists in taking temperature effects and light gradient into account.

The second challenge consists in exploiting the microalgal bioreactors which have been developed in the framework of the quantification of carbon fluxes between ocean and atmospheres. The SEMPO platform (simulator of variable environment computer controlled), developed within the LOV team, has been designed to reproduce natural conditions that can take place in the sea and to accurately measure the cells behavior. This platform, for which our team has developed models and control methods over the years, is an original and unique tool to develop relevant models which stay valid in dynamic conditions. It is worth noting that a better knowledge of the photosynthetic mechanisms and improved photosynthesis models will benefit both thematics: CO_2 mitigation and carbon fluxes predictions in the sea.

4.3. Biological control for plants and micro-plants production systems

This work concentrates on the protection of cultures of photosynthetic organisms against their pests or their competitors. The forms of cultures that we study are crop and micro-algae productions. In both cases, the devices are more or less open to the outside, depending on the application (greenhouse/field, photobioreactor/raceway) so that they may give access to invading species which can be harmful to the cultures; we opt for protecting the culture through the use of biocontrol agents which are, generically, natural enemies of these noxious populations [9].

In crop production, biological control is indeed a very promising alternative to pesticide usage; the use of predators, parasitoids or pathogens of crop pests in order to fight them has many advantages with respect to environmental protection, health of the consumers and the producers, the limited development of resistance (compared to chemicals),... It is however not widespread yet because it often lacks efficiency in real-life crop production systems (while its efficiency in the laboratory is much higher) and can fail to be economically competitive. Our objective is to propose models that would help to explain which factors are locks that prevent the smooth transition from the laboratory to the agricultural crop as well as develop new methods for the optimal deployment of the pests natural enemies.

Microalgae production is faced with exactly the same problems since predators of the produced microalgae (e.g. zooplankton) or simply other species of microalgae can invade the photobioreactors and outcompete or eradicate the one that we wish to produce. Methods need therefore to be proposed for fighting the invading species; this could be done by introducing predators of the pest and so keeping it under control, or by controling the conditions of culture in order to reduce the possibility of invasion; the design of such methods could greatly take advantage of our knowledge developed in crop protection since the problems and models are related.

4.4. Biological depollution

These works will be carried out with the LBE , mainly on anaerobic treatment plants. This process, despite its strong advantages (methane production and reduced sludge production) can have several locally stable equilibria. In this sense, proposing reliable strategies to stabilize and optimise this process is a key issue. Because of the recent (re)development of anaerobic digestion, it is crucial to propose validated supervision algorithms for this technology. A problem of growing importance is to take benefit of various waste sources in order to adapt the substrate quality to the bacterial biomass activity and finally optimize the process. This generates new research topics for designing strategies to manage the fluxes of the various substrate sources meeting at the same time the depollution norms and providing a biogas of constant quality. In the past years, we have developed models of increasing complexity. However there is a key step that must be considered in the future: how to integrate the knowledge of the metabolisms in such models which represent the evolution of several hundreds bacterial species? How to improve the models integrating this two dimensional levels of complexity? With this perspective, we wish to better represent the competition between the bacterial species, and drive this competition in order to maintain, in the process, the species with the highest depollution capability. This approach, initiated in [103] must be extended from a theoretical point of view and validated experimentally.

4.5. Experimental Platforms

To test and validate our approach, we use experimental platforms developed by our partner teams; these are highly instrumented for accurately monitoring the state of biological species:

- A photobioreactor (SEMPO) for Lagrangian simulation of the dynamical environment of marine microalgae (LOV) with computer controlled automata for high frequency measurement and on-line control. This photobioreactor is managed by Amélie Talec.
- Several pilot anaerobic digesters that are highly instrumented and computerized and the algotron, that is the coupling of a digester and a photobioreactor for microalgae production (LBE). Eric Latrille is our main contact for this platform at LBE.
- Experimental greenhouses of various sizes (from laboratory to semi-industrial size) and small scale devices for insect behavior testing at ISA.

Moreover, we may use the data given by several experimental devices at EPI IBIS/ Hans Geiselmann Laboratory (University J. Fourier, Grenoble) for microbial genomics.

DEMAR Project-Team

4. Application Domains

4.1. Objective quantification and understanding of movement disorders

One main advantage of developping a model based on a physical description of the system is that the parameters are meaningful. Therefore, these parameters when identified on a given individual (valid or deficient), give objective and quantitative data that characterize the system and thus can be used for diagnosis purposes.

Modelling provides a way to simulate movements for a given patient and therefore based on an identification procedure it becomes possible to analyse and then understand his pathology. In order to describe complex pathology such as spasticity that appears on paraplegic patients, you need not only to model the biomechanics parts - including muscles -, but also parts of the peripheral nervous system - including natural sensors - to assess reflex problems. One important application is then to explore deficiencies globally due to both muscles and peripheral neural nets disorders.

4.2. Palliative solutions for movement deficiencies

Functional electrical stimulation is one possibility to restore or control motor functions in an evolutive and reversible way. Pacemaker, cochlear implants, deep brain stimulation (DBS) are successful examples. DEMAR focuses on movement disorder restoration in paraplegic and quadriplegic patients, enhancements in hemiplegic patients, and some other motor disorders such as bladder and bowel control. Nevertheless, since some advances in neuroprosthetic devices can be exploited for the next generation of cochlear implants, the team also contributes to technological and scientific improvements in this domain.

The possibility to interface the sensory motor system, both activating neural structure with implanted FES, and sensing through implanted neural signal recordings open a wide application area:

- Restoring motor function such as grasping for quadriplegic patient, standing and walking for paraplegic patient, compensating foot drop for hemiplegic patients. These applications can be firstly used in a clinical environment to provide physiotherapist with a new efficient FES based therapy (using mainly surface electrodes) in the rehabilitation process. Secondly, with a more sophisticated technology such as implanted neuroprostheses, systems can be used at home by the patient himself without a clinical staff.
- Modulating motor function such as tremors in Parkinsonian patient using DBS. Techniques are very similar but for the moment, modelling is not achieved because it implies the central nervous system modelling in which we are not implied.
- Sensing the afferent pathways such as muscle’s spindles, will be used to provide a closed loop control of FES through natural sensing and then a complete implanted solution. Sensing the neural system is a necessity in some complex motor controls such as the bladder control. Indeed, antagonist muscle’s contractions, and sensory feedbacks interfere with FES when applied directly on the sacral root nerve concerned. Thus, enhanced activation waveforms and sensing feedback or feedforward signals are needed to perform a highly selective stimulation.

To achieve such objectives, experimentations in animals and humans are necessary. This research takes therefore a long time in order to go from theoretical results to real applications. This process is a key issue in biomedical research and is based on: i) design of complex experimental protocols and setups both for animals and humans, ii) ethical attitude both for humans and animals, with ethical committee approval for human experiments iii) volunteers and selected, both disabled and healthy, persons to perform experiments with the adequate medical staff.

MODEMIC Project-Team

4. Application Domains

4.1. Preservation of water resources

The biological decontamination of wastewater is our main application domain, in the continuation of the long collaboration with the INRA research laboratory LBE. We target applications from the decontamination industry, held by large groups as well as small companies specialized in specific pollutants (for instance in fish farming). We aim also to study connected application domains for

- the aquatic ecology where microorganisms play an important role in the quality of natural water resources,
- the re-use of water in arid climates for countries of North of Africa, within the euro-Mediterranean project TREASURE.

4.2. Microbial ecology of soil

This application domain is more recent for the team members. We target

- the research questions raised by agronomists, about the better understanding of the interactions and the biodiversity of microbial communities in soils, with the help of models and numerical simulations,
- the role of spatial structures on the functions or *ecological services* of microbial ecosystems, notably the soil fertility and the carbon sequestration.

4.3. Control of fermentation processes

Very closely to our studies about wastewater bioreactors and chemostat models, we target applications in fermentation processes:

- either for agro-food products. A typical application is the control of cascade fermenters in the study of wine fermentation with UMR SPO (Sciences Pour l'Œnologie, Montpellier), within the European project CAFE.
- either for the green chemistry. A typical application is the consideration of spatialization in enzymatic models of production of agro-polymers with UMR IATE (Ingénierie des Agro-polymères et Technologies Émergentes, Montpellier).

4.4. Animal digestive ecosystem

Ruminants absorb plant cells, mainly constituted by cellulose, from which the microbial population of their digestive system extracts carbon and energy to provide proteins and energetic molecules. This bio-conversion produces also important quantities of methane, a gas responsible of part of the greenhouse effect (the billion of cows on earth reject 20% of the methane linked to human activities). INRA researchers have shown that this methane production could be reduced by 30% by changing the proportion of fat acids in the their food, that also implies that the composition of their microbial ecosystem is modified.

This application domain of the microbial ecology is at an early stage. URH team (Unité de Recherche sur les Herbivores, Clermont) has developed an artificial rumen that is close to a chemostat, for testing different kind of nutrition diets. Preliminaries contacts have been taken, and a modelling demand has been clearly formulated and will be taken up my MODEMIC. This theme falls into the research priorities for the environment preservation.

MORPHEME Team (section vide)

NEUROMATHCOMP Project-Team (section vide)

VIRTUAL PLANTS Project-Team (section vide)

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 [54]. 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.

INDES Project-Team

4. Application Domains

4.1. Web programming

Along with games, multimedia applications, electronic commerce, and email, the web has popularized computers in everybody's life. The revolution is engaged and we may be at the dawn of a new era of computing where the web is a central element. The web constitutes an infrastructure more versatile, polymorphic, and open, in other words, more powerful, than any dedicated network previously invented. For this very reason, it is likely that most of the computer programs we will write in the future, for professional purposes as well as for our own needs, will extensively rely on the web.

In addition to allowing reactive and graphically pleasing interfaces, web applications are de facto distributed. Implementing an application with a web interface makes it instantly open to the world and accessible from much more than one computer. The web also partially solves the problem of platform compatibility because it physically separates the rendering engine from the computation engine. Therefore, the client does not have to make assumptions on the server hardware configuration, and vice versa. Lastly, HTML is highly durable. While traditional graphical toolkits evolve continuously, making existing interfaces obsolete and breaking backward compatibility, modern web browsers that render on the edge web pages are still able to correctly display the web pages of the early 1990's.

For these reasons, the web is arguably ready to escape the beaten track of n-tier applications, CGI scripting and interaction based on HTML forms. However, we think that it still lacks programming abstractions that minimize the overwhelming amount of technologies that need to be mastered when web programming is involved. Our experience on reactive and functional programming is used for bridging this gap.

4.2. Multimedia

Electronic equipments are less and less expensive and more and more widely spread out. Nowadays, in industrial countries, computers are almost as popular as TV sets. Today, almost everybody owns a mobile phone. Many are equipped with a GPS or a PDA. Modem, routers, NASes and other network appliances are also commonly used, although they are sometimes sealed under proprietary packaging such as the Livebox or the Freebox. Most of us evolve in an electronic environment which is rich but which is also populated with mostly isolated devices.

The first multimedia applications on the web have appeared with the Web 2.0. The most famous ones are Flickr, YouTube, or Deezer. All these applications rely on the same principle: they allow roaming users to access the various multimedia resources available all over the Internet via their web browser. The convergence between our new electronic environment and the multimedia facilities offered by the web will allow engineers to create new applications. However, since these applications are complex to implement this will not happen until appropriate languages and tools are available. In the Indes team, we develop compilers, systems, and libraries that address this problem.

4.3. House Automation

The web is the de facto standard of communication for heterogeneous devices. The number of devices able to access the web is permanently increasing. Nowadays, even our mobile phones can access the web. Tomorrow it could even be the turn of our wristwatches! The web hence constitutes a compelling architecture for developing applications relying on the "ambient" computing facilities. However, since current programming languages do not allow us to develop easily these applications, ambient computing is currently based on ad-hoc solutions. Programming ambient computing via the web is still to be explored. The tools developed in the Indes team allow us to build prototypes of a web-based home automation platform. For instance, we experiment with controlling heaters, air-conditioners, and electronic shutters with our mobile phones using web GUIs.

LOGNET Team

3. Application Domains

3.1. Introduction

We study overlay networks and peer-to-peer systems. Our skills are applied to studying protocols to interconnect heterogeneous networks, while guaranteeing backward compatibility. We experiment with those networks and systems in various fields, such as social networks and video streaming.

We design and implement a generic social platform, which is able to "program" and "run" (in a cloud based platform hosting a NoSQL data base) generic social networks. This is the first step towards a full decentralized P2P-based social network platform.

We also study Trust and Reputation Systems for P2P networks, and for Network Web Economy.

The final objective of those research veins is to move the computer and the computability at the edge of the network.

As another topic, we also study logics and type theory for improving proof assistants based on the Curry-Howard Isomorphism.

3.2. 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.

MAESTRO Project-Team

4. Application Domains

4.1. Application Domains

MAESTRO's main application area is networking and in particular, modeling, performance evaluation, optimization and control of protocols and network architectures. It includes:

- 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.

MASCOTTE Project-Team

4. Application Domains

4.1. Application Domains

In the last year the main application domain of the project remained Telecommunications. 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 .

MASCOTTE is mainly interested in the design and management of heterogeneous networks. The project has kept working on the design of backbone networks (optical networks, radio networks, IP networks).

The project has also been working on routing algorithms such as dynamic and compact routing schemes in the context of the FP7 EULER leaded by Alcatel-Lucent Bell-Labs (Belgium). It also studied the evolution of the routing in case of any kind of topological modifications (maintenance operations, failures, capacity variations, etc.). Finally, an emphasis is done on green networks with low power consumption. This work is in collaboration with Orange Labs and the SME 3-Roam and partly supported by the ANR DIMAGREEN.

OASIS Project-Team

4. Application Domains

4.1. Grid and Cloud Computing

Grid, peer-to-peer, group communication, mobile object systems, Cloud, fault tolerance, distribution, security, synchronisation

As distributed systems are becoming ubiquitous, Grid computing, and the more recent concept of Cloud computing are facing a major challenge for computer science: seamless access and use of large-scale computing resources, world-wide. It is believed that by providing pervasive, dependable, consistent and inexpensive access to advanced computational capabilities, large-scale computing infrastructures allow new classes of applications to emerge.

There is a need for models and infrastructures for grid and peer-to-peer computing, and we promote programming models based on communicating mobile and distributed objects and components that can allow to harness these infrastructures. Another challenge is to use, for a given computation, unused CPU cycles of desktop computers in a Local Area Network, or even from wide area interconnected nodes. This is local or wide area Computational Peer-To-Peer, a concept that can contribute to a global energy footprint reduction. This is a challenge that also appears to be pregnant in more stable and homogeneous environments compared to P2P systems, such as datacenters under the problematics known as Virtual Machines consolidation.

4.2. Service Oriented Architectures (SOA)

Distributed Service Composition, Distributed Service Infrastructure, Peer-to-Peer data storage and lookup, Autonomic Management, Large-Scale deployment and monitoring

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.

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. GCM components can be exposed as web services [61], and we have conducted research and development to permit a GCM component to invoke an external web service through a client interface. We also have provided a Service Component Architecture (see SCA specifications at http://www.oasis-opencsa.org/sca) personality for GCM components (GCM/SCA) so they can be integrated in SCA-based applications relying on SCA bindings configured as web services. 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 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, a currently hot topic in ICT.
- 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 can really help.

4.3. Simulation tools and methodology

simulation, component-based modeling, parallel and distributed simulation, reproducibility, architecture description language

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 [59], we are pursuing research on applying distributed component-based programming techniques to simulation. More precisely, new results are sought in three directions:

- improvement of simulation tools and methodology with techniques and tools borrowed from latest research in component-based software engineering;
- improvement of simulation scalability using high performance and distributed computing techniques;
- application of the results in the previous directions, in particular to the simulation of very large-scale distributed systems, such as peer-to-peer networks.

PLANETE Project-Team

4. Application Domains

4.1. Next Generation Networks

The next-generation network must overcome the limitations of existing networks and allow adding new capabilities and services. Future networks should be available anytime and anywhere, be accessible from any communication device, require little or no management overhead, be resilient to failures, malicious attacks and natural disasters, and be trustworthy for all types of communication traffic. Studies should therefore address a balance of theoretical and experimental researchs that expand the understanding of large, complex, heterogeneous networks, design of access and core networks based on emerging wireless and optical technologies, and continue the evolution of Internet. On the other hand, it is also highly important to design a next-generation Internet which we will call the "Future Internet" from core functionalities in order to ensure security and robustness, manageability, utility and social need, new computing paradigms, integration of new network technologies and higher-level service architectures.

To meet emerging requirements for the Internet's technical architecture, the protocols and structures that guide its operation require coordinated, coherent redesign. A new approach will require rethinking of the network functions and addressing a range of challenges. These challenges include, but are not limited to, the following examples:

- New models for efficient data dissemination;
- Coping with intermittent connectivity;
- The design of secured, privacy protecting, and robust networked systems;
- Understanding the Internet behavior;
- Building network evaluation platforms.

The following research directions are essential building blocks we are contributing to the future Internet architecture.

Towards Data-Centric Networking

From the Internet design, back to 1970, the resources to be addressed and localized are computers. Indeed, at that time there were few machines interconnected, and nobody believed this number would ever be larger than a few tens of thousand of machines. Moreover, those machines where static machines with well identified resources (e.g., a given hierarchy of files) that were explicitly requested by the users. Today, the legacy of this architecture is the notion of URLs that explicitly address specific resources on a specific machine. Even if modern architectures use caches to replicate contents with DNS redirection to make those caches transparent to the end-users, this solution is only an hack that do not solve today's real problem: Users are only interested in data and do not want anymore to explicitly address where those data are. Finding data should be a service offered by the network. In this context of data-centric network, which means that the network architecture is explicitly built to transparently support the notion of content, a data can be much more than a simple content. In such a network you can, of course, request a specific file without explicitly specifying its location, the network will transparently return the closest instance of the content. You can also request a specific service from a person without knowing its explicit network location. This is in particular the case of a VoIP or an instant messaging conversation. A data-centric architecture is much more than a simple modification of the naming scheme currently used in the Internet. It requires a major rethinking a many fundamental building blocks of the current Internet. Such networking architecture will however allow seamless handling of the tricky problematic of *episodic connectivity*. It also shifts the focus from transmitting data by geographic location, to *disseminating* it via named content. In the Planète project-team, we start to work on such data-centric architectures as a follow-up and federating axe for three of our current activities (adaptive multimedia transmission protocols for heterogeneous networks, data dissemination paradigms and peer-to-peer systems). It is important to study such data-centric architectures considering in particular the corresponding naming problem, routing and resource allocation, reliable transport, data security and authentication, content storage.

Today's Internet is characterized by high node and link heterogeneity. Nodes may vary substantially in terms of their processing, storage, communication, and energy capabilities. They may also exhibit very different mobility characteristics, from static nodes to nodes that are considerably mobile (e.g., vehicles). Links may be wired or wireless and thus operate at widely varying rates and exhibit quite different reliability characteristics. One of the challenges of data-centric architecture is to provide access to data anytime anywhere in the presence of high degree of heterogeneity. This means that the network will not be connected all the time, due to a number of factors such as node mobility, link instability, power-aware protocols that, for example, turn nodes off periodically, etc. Additionally, disconnections may last longer than what "traditional" routing protocols (e.g., MANET routing) can handle. These types of network, a.k.a, intermittently connected networks, or even episodically connected networks, have recently received considerable attention from the networking research community. Several new routing paradigms have been proposed to handle possibly frequent, long-lived disconnections. However, a number of challenges remain, including: (1) The support of scalable and transparent integration with "traditional" routing mechanisms including wired infrastructure, infrastructure-based wireless and MANET routing. (2) The study of heuristics for selecting forwarding nodes (e.g., based on node's characteristics such as node's speed, node's resources, sociability level, node's historic, etc. (3) The design of unicast and multicast transmission algorithms with congestion and error control algorithms tailored for episodically connected networks and taking into account the intrinsic characteristics of flows. (4) The design of incentive-based mechanisms to ensure that nodes forward packets while preventing or limiting the impact of possible misbehaving nodes. The solutions proposed, which are likely to extensively use cross-layer mechanisms, will be evaluated using the methodology and the tools elaborated in our new *Experimental Platform* research direction.

On the other hand, multicast/broadcast content delivery systems are playing an increasingly important role in data-centric networking. Indeed, this is an optimal dissemination technology, that enables the creation of new commercial services, like IPTV over the Internet, satellite-based digital radio and multimedia transmission to vehicles, electronic service guide (ESG) and multimedia content distribution on DVB-H/SH networks. This is also an efficient way to share information in WiFi, WiMax, sensor networks, or mobile ad hoc infrastructures. Our goal here is to take advantage of our strong background in the domain to design an *efficient, robust (in particular in case of tough environments) and secure (since we believe that security considerations will play an increasing importance) broadcasting system*. We address this problem by focusing on the following activities: (1) The protocols and applications that enable the high level control of broadcasting sessions (like the FLUTE/ALC sessions) are currently missing. The goal is to enable the content provider to securely control the underlying broadcasting sessions, to be able to launch new sessions if need be, or prematurely stop an existing session and to have feedback and statistics on the past/current deliveries. (2) The AL-FEC building block remains the cornerstone on which the whole broadcasting system relies. The goal is to design and evaluate new codes, capable of producing a large amount of redundancy (thereby approaching rateless codes), over very large objects, while requiring a small amount of memory/processing in order to be used on lightweight embedded systems and terminals. (3) The security building blocks and protocols that aim at providing content level security, protocol level security, and network level security must be natively and seamlessly integrated. This is also true of the associated protocols that enable the initialization of the elementary building blocks (e.g. in order to exchange security parameters and keys). Many components already exist. The goal here is to identify them, know how to optimally use them, and to design/adapt the missing components, if any. (4) It is important seamlessly integrated these broadcasting systems to the Internet, so that users can benefit from the service, no matter where and how he is attached to the network. More precisely we will study the potential impacts of a merge of the broadcasting networks and the Internet, and how to address them. For instance there is a major discrepancy when considering flow control aspects, since broadcasting networks are using a constant bit rate approach while the Internet is congestion controlled.

When a native broadcasting service is not enabled by the network, data should still be able to be disseminated to a large population in a scalable way. A peer-to-peer architecture supports such an efficient data dissemination. We have gained a fundamental understanding of the key algorithms of BitTorrent on the Internet. We plan to continue this work in two directions. First, we want to study how a peer-to-peer architecture can be natively supported by the network. Indeed, the client-server architecture is not robust to increase in load. The consequence is that when a site becomes suddenly popular, it usually becomes unreachable. The peer-to-peer architecture is robust to increase in load. However, a native support in the network of this architecture is a hard problem as it has implications on many components of the network (naming, addressing, transport, localization, etc.). Second, we want to evaluate the impact of wireless and mobile infrastructures on peer-to-peer protocols. This work has started with the European project Expeshare. The wireless medium and the mobility of nodes completely change the properties of peer-to-peer protocols. The dynamics becomes even more complex as it is a function of the environment and of the relative position of peers.

Network security and Privacy

The Internet was not designed to operate in a completely open and hostile environment. It was designed by researchers that trust each other and security at that time was not an issue. The situation is quite different today and the Internet community has drastically expanded. The Internet is now composed of more than 300 millions computers worldwide and the trust relationship has disappeared. One of the reason of the Internet success is that it provides ubiquitous inter-connectivity. This is also one of the its main weakness since it allows to launch attacks and to exploit vulnerabilities in a large-scale basis. The Internet is vulnerable to many different attacks, for example, Distributed Denial-of Service (DDoS) attacks, epidemic attacks (Virus/Worm), spam/phishing and intrusion attacks. The Internet is not only insecure but it also infringes users' privacy. Those breaches are due to the Internet protocols but also to new applications that are being deployed (VoIP, RFID,...). A lot of research is required to improve the Internet security and privacy. For example, more research work is required to understand, model, quantify and hopefully eliminate (or at least mitigate) existing attacks. Furthermore, more and more small devices (RFIDs or sensors) are being connected to the Internet. Current security/cryptographic solutions are too expensive and current trust models are not appropriate. New protocols and solutions are required : security and privacy must be considered in the Internet architecture as an essential component. The whole Internet architecture must be reconsidered with security and privacy in mind. Our current activities in this domain are on security in wireless, ad hoc and sensor networks, mainly the design of new key exchange protocols and of secured routing protocols. We also work on location privacy techniques, authentication cryptographic protocols and opportunistic encryption. We plan to continue our research on wireless security, and more specifically on WSN and RFID security focusing on the design of real and deployable systems. We started a new research topic on the security of the Next-Generation Internet. The important goal of this new task is to rethink the architecture of the Internet with security as a major design requirement, instead of an after-thought.

Wireless Sensor Networks: A lot of work has been done in the area of WSN security in the last years, but we believe that this is still the beginning and a lot of research challenges need to be solved. On the one hand it is widely believed that the sensor networks carry a great promise: Ubiquitous sensor networks will allow us to interface the physical environment with communication networks and the information infrastructure, and the potential benefits of such interfaces to society are enormous, possibly comparable in scale to the benefits created by the Internet. On the other hand, as with the advent of the Internet, there is an important associated risk and concern: How to make sensor network applications resilient and survivable under hostile attacks? We believe that the unique technical constraints and application scenarios of sensor networks call for new security techniques and protocols that operate above the link level and provide security for the sensor network application as a whole. Although this represents a huge challenge, addressing it successfully will result in a very high pay-off, since targeted security mechanisms can make sensor network operation far more reliable and thus more useful. This is the crux of our work. Our goal here is to design new security protocols and algorithms for constrained devices and to theoretically prove their soundness and security. Furthermore, to complement the fundamental exploration of cryptographic and security mechanisms, we will simulate and evaluate these mechanisms experimentally.

RFID: As already mentioned, the ubiquitous use of RFID tags and the development of what has become termed "the Internet of things" will lead to a variety of security threats, many of which are quite unique to RFID deployment. Already industry, government, and citizens are aware of some of the successes and some of the limitations or threats of RFID tags, and there is a great need for researchers and technology developers to take up some of daunting challenges that threaten to undermine the commercial viability of RFID tags on the one hand, or to the rights and expectations of users on the other. We will focus here on two important issues in the use of RFID tags: (1) *Device Authentication*: allows us to answer several questions such as: Is the tag legitimate? Is the reader a tag interacts with legitimate? (2) *Privacy*: is the feature through which information pertaining to a tag's identity and behavior is protected from disclosure by unauthorized parties or by unauthorized means by legitimate parties such as readers. In a public library, for example, the information openly communicated by a tagged book could include its title or author. This may be unacceptable to some readers. Alternatively, RFID- protected pharmaceutical products might reveal a person's pathology. Turning to authenticity, if the RFID tag on a batch of medicines is not legitimate, then the drugs could be counterfeit and dangerous. Authentication and privacy are concepts that are relevant to both suppliers and consumers. Indeed, it is arguable that an RFID deployment can only be successful if all parties are satisfied that the integrity between seller and buyer respects the twin demands of authentication and privacy. Our main goal here, therefore, is to propose and to prototype the design of cryptographic algorithms and secure protocols for RFID deployment. These algorithms and protocols may be used individually or in combination, and we anticipate that they will aid in providing authentication or privacy. One particular feature of the research in the RFID-AP project is that the work must be practical. Many academic proposals can be deeply flawed in practice since too little attention has been paid to the realities of implementation and deployment. This activity will therefore be notable for the way theoretical work will be closely intertwined with the task of development and deployment. The challenges to be addressed in the project are considerable. In particular there are demanding physical limits that apply to the algorithms and protocols that can be implemented on the cheapest RFID tags. While there often exist contemporary security solutions to issues such as authentication and privacy, in an RFID-based deployment they are not technically viable. And while one could consider increasing the technical capability of an RFID-tag to achieve a better range of solutions, the solution is not economically viable.

Next Generation Internet Security: The current Internet has reached its limits; a number of research groups around the world are already working on future Internet architectures. The new Internet should have built-in security measures and support for wireless communication devices, among other things. A new network design is needed to overcome unwanted traffic, malware, viruses, identity theft and other threats plaguing today's Internet infrastructure and end hosts. This new design should also enforce a good balance between privacy and accountability. Several proposals in the area have been made so far, and we expect many more to appear in the near future. Some mechanisms to mitigate the effects of security attacks exist today. However, they are far from perfect and it is a very open question how they will behave on the future Internet. Cyber criminals are very creative and new attacks (e.g. VoIP spam, SPIT) appear regularly. Furthermore, the expectation is that cyber criminals will move into new technologies as they appear, since they offer new attack opportunities, where existing countermeasures may be rendered useless. The ultimate goal of this research activity is to contribute to the work on new Internet architecture that is more resistant to today's and future security attacks. This goal is very challenging, since some of future attacks are unpredictable. We are analyzing some of the established and some of the new architectural proposals, attempting to identify architectural elements and patterns that repeat from one architectural approach to another, leading to understanding how they impact the unwanted traffic issue and other security issues. Some of the more prominent elements are rather easy to identify and understand, such as routing, forwarding, end-to-end security, etc. Others may well be much harder to identify, such as those related to data-oriented networking, e.g., caching. The motivation for this work is that the clean slate architectures provide a unique opportunity to provide built in security capabilities that would enable the prevention of phenomenon like unwanted traffic. New architectures will most likely introduce additional name-spaces for the different fundamental objects in the network and in particular for routing objects. These names will be the fundamental elements that will be used by the new routing architectures and security must be a key consideration when evaluating the features offered by these new name-spaces.

Network Monitoring

The Planète project-team contributes to the area of network monitoring. Our focus is on the monitoring of the Internet for the purpose of access quality assessment, problem detection and troubleshooting. Indeed, in the absence of an advanced management and control plan in the Internet, and given the simplicity of the service provided by the core of the network and the increase in its heterogeneity, it is nowadays common that users experience a service degradation and are unable to understand the reasons for the access quality they perceive. Problems at the access can be in the form of a pure disconnection, a decrease in the bandwidth or an increase in the delay or loss rate of packets. Service degradation can be caused by protocol anomalies, an attack, an increase in the load, or simply a problem at the source or destination machines. Actually, it is not easy to diagnose the reasons for service degradation. Basic tools exist as ping and trace-route, but they are unable to provide detailed answers on the source of the problem nor on its location. From operator point of view, the situation is not better since an operator has only access to its own network and can hardly translate local information into end-to-end measurements. The increase in the complexity of networks as is the case of wireless mesh networks will not ease the life of users and operators. The purpose of our work in this direction is to study to which extent one can troubleshoot the current Internet and estimate the quality at the access either with end-to-end solutions or core network solutions. Our aim is to propose an architecture that allows end-users by collaborating together to infer the reasons for service degradation and to estimate the quality of access they perceive. This architecture can be purely end-to-end or can rely on some information from the core of the network as BGP routing information. We will build on this study to understand the limitations in the current Internet architecture and propose modifications that will ease the troubleshooting and make it more efficient in future network architectures. The proposed architecture will be the subject of validation over large scale experimental platforms as PlanetLab and OneLab.

Experimental Environment for future Internet architecture

The Internet is relatively resistant to fundamental change (differentiated services, IP multicast, and secure routing protocols have not seen wide-scale deployment). A major impediment to deploy these services is the need for coordination: an Internet service provider (ISP) that deploys the service garners little benefit until other domains follow suit. Researchers are also under pressure to justify their work in the context of a federated network by explaining how new protocols could be deployed one network at a time, but emphasizing incremental deployability does not necessarily lead to the best architecture. In fact, focusing on incremental deployment may lead to solutions where each step along the path makes sense, but the end state is wrong. The substantive improvements to the Internet architecture may require fundamental change that is not incrementally deployable.

Network virtualisation has been proposed to support realistic large scale shared experimental facilities such as PlanetLab and GENI. We are working on this topic in the context of the European OneLab project.

Testing on PlanetLab has become a nearly obligatory step for an empirical research paper on a new network application or protocol to be accepted into a major networking conference or by the most prestigious networking journals. If one wishes to test a new video streaming application, or a new peer-to-peer routing overlay, or a new active measurement system for geo-location of internet hosts, hundreds of PlanetLab nodes are available for this purpose. PlanetLab gives the researcher login access to systems scattered throughout the world, with a Linux environment that is consistent across all of them.

However, network environments are becoming ever more heterogeneous. Third generation telephony is bringing large numbers of handheld wireless devices into the Internet. Wireless mesh and ad-hoc networks may soon make it common for data to cross multiple wireless hops while being routed in unconventional ways. For these new environments, new networking applications will arise. For their development and evaluation, researchers and developers will need the ability to launch applications on endhosts located in these different environments.

It is sometimes unrealistic to implement new network technology, for reasons that can be either technological - the technology is not yet available -, economical - the technology is too expensive -, or simply pragmatical - e.g. when actual mobility is key. For these kinds of situations, we believe it can be very convenient and powerful to resort to emulation techniques, in which real packets can be managed as if they had crossed, e.g., an ad hoc network.

In our project-team, we work to provide a realistic environment for the next generation of network experiments. Such a large scale, open, heterogeneous testbed should be beneficial to the whole networking academic and industrial community. It is important to have an experimental environment that increases the quality and quantity of experimental research outcomes in networking, and to accelerate the transition of these outcomes into products and services. These experimental platforms should be designed to support both research and deployment, effectively filling the gap between small-scale experiments in the lab, and mature technology that is ready for commercial deployment. As said above, in terms of experimental platforms, the well-known PlanetLab testbed is gaining ground as a secure, highly manageable, cost-effective world-wide platform, especially well fitted for experiments around New Generation Internet paradigms like overlay networks. The current trends in this field, as illustrated by the germinal successor known as GENI, are to address the following new challenges. Firstly, a more modular design will allow to achieve federation, i.e. a model where reasonably independent Management Authorities can handle their respective subpart of the platform, while preserving the integrity of the whole. Secondly, there is a consensus on the necessity to support various access and physical technologies, such as the whole range of wireless or optical links. It is also important to develop realistic simulators taking into account the tremendous growth in wireless networking, so to include the many variants of IEEE 802.11 networking, emerging IEEE standards such as WiMax (802.16), and cellular data services (GPRS, CDMA). While simulation is not the only tool used for data networking research, it is extremely useful because it often allows research questions and prototypes to be explored at many orders-of-magnitude less cost and time than that required to experiment with real implementations and networks.

Simulations allow a fast evaluation process, fully controlled scenarios, and reproducibility. However, they lack realism and the accuracy of the models implemented in the simulators is hard to assess. Emulation allows controlled environment and reproducibility, but it also suffers from a lack of realism. Experiments allow more realistic environment and implementations, but they lack reproducibility and ease of use. Therefore, each evaluation technique has strengths and weaknesses. However, there is currently no way to combine them in a scientific experimental workflow. Typical evaluation workflows are split into four steps: topology description and construction, traffic pattern description and injection, trace instrumentation description and configuration, and, analysis based on the result of the trace events and the status of the environment during the experimentation. To achieve the integration of experimental workflows among the various evaluation platforms, the two following requirements must be verified:

- Reproducibility: A common interface for each platform must be defined so that a same script can be run transparently on different platforms. This also implies a standard way to describe scenarios, which includes the research objective of the scenario, topology description and construction, the description of the traffic pattern and how it is injected into the scenario, the description and configuration of the instrumentation, and the evolution of the environment during the experimentation
- Comparability: As each platform has different limitations, a way to compare the conclusions extracted from experiments run on different platforms, or on the same platform but with different conditions (this is in particular the case for the wild experimental platforms) must be provided.

Benchmarking is the function that provides a method of comparing the performance of various subsystems across different environments. Both reproducibility and comparability are essential to benchmarking. In order to facilitate the design of a general benchmarking methodology, we plan to integrate and automate a networking experiments workflow within the OneLab platform. This requires that we:

- Automate the definition of proper scenario definition taking in consideration available infra-structure to the experiment.
- Automate the task of mapping the experimentation topology on top of the available OneLab topology. We propose to first focus on a simple one-to-one node and link mapping the beginning.
- Define and provide extensive instrumentation sources within the OneLab system to allow users to gather all interesting trace events for offline analysis
- Measure and provide access to "environment variables" which measure the state of the OneLab system during an experimentation
- Define an offline analysis library which can infer experimentation results and comparisons based on traces and "environment variables".

To make the use of these components transparent, we plan to implement them within a simulation-like system which should allow experiments to be conducted within a simulator and within the OneLab testbed through the same programming interface. The initial version will be based on the ns-3 programming interface.

AXIS Project-Team

3. Application Domains

3.1. Panorama: Living Labs, Smart Cities

AxIS addresses applicative field which has the following features:

a) requiring usage/data storage, preprocessing and analysis tools

- for designing, evaluating and improving huge evolving hypermedia information systems (mainly Web-based ISs), for which end-users are of primary concern,
- for a better understanding of service/product used with data mining techniques and knowledge management
- for social network analysis (for example in Web 2.0 applications, Business Intelligence, Sustainable Development, etc.)

b) requiring user-driven innovation methods.

Even if our know-how, methods and algorithms have a cross domain applicability, our team chooses to focus on **Living Lab projects** (and mainly related to **Sustainable Development for Smart Cities**) (cf. section 5.5.5 which imply user involvement for the generation of future services/products. Indeed, following the Rio Conference (1992) and the Agenda for the 21st Century, local territories are now directly concerned with the set up of actions for a sustainable development. In this frame, ICT tools are supposed to be very efficient to re-engage people in the democratic process and to make decision-making more transparent, inclusive and accessible. So, sustainable development is closely associated with citizen participation. The emerging research field of e-democracy (so called Digital Democracy or eParticipation), concerned with the use of communications technologies such as the Internet to enhance the democratic processes is now a very active field. Though still in its infancy, a lot of literature is already available (see for instance: http://itc.napier.ac.uk/ITC/publications.asp or http://www.demo-net.org/ for a global view of work in Europe) and numerous different topics are addressed in the field.

Our experience particularly stressed on the following applicative domains:

- Transportation systems & Mobility (cf. section 3.2),
- Tourism (cf. section 3.3),
- User Involvement in Energy, Environment, Well Being & Health and e-governement (cf. section 3.4).

3.2. Transportation Systems & Mobility

Major recent evolutions in Intelligent Transportation Systems (ITS) are linked to rapid changes in communication technologies, such as ubiquitous computing, semantic web, contextual design. A strong emphasis is now put on mobility improvements. In addition to development of sustainable transportation systems (better ecological vehicles' performance, reduction of impacts on town planning ...) these improvements concern also mobility management, that is specific measures to encourage people to adopt new mobility behaviour such as public transportation services rather than their personal car. These prompting measures concern for instance the quality of traveller's information systems for trip planning, the ability to provide real time recommendations for changing transportation means according to traffic information, and the quality of embedded services in vehicles to provide enhanced navigation aids with contextualised and personalised information.

Since 2004, AxIS has been concerned with mobility projects :

- PREDIT (2004-2007): The MobiVIP project has been an opportunity to collaborate with local Institutions (Communauté d'Agglomération de Sophia Antipolis - CASA) and SMEs (VU Log) and to apply AxIS' know-how in data and web mining to the field of transportation systems.
- Traveller's information systems and recommender systems have been studied with the evaluation of two CASA web sites : the "Envibus" web site which provides information about a bus network and the "Otto&co" web site support car-sharing.
- Advanced transportation systems has been studied in PREDIT TIC TAC (2010-2012): this project (cf. section 6.1.1) aimed at optimizing travel time by providing in an aera with weak transportation services, a just in time on demand shuttle based on real time information. It was for AxIS the opportunity to experiment user implication in the design of a new travel information system called MOBILTIC
- User Experience: in the ELLIOT project (cf. section 6.3.1.1), the mobility scenario is addressed in relation to information on air quality and noise and the use of internet of things.

3.3. Tourism

As tourism is a highly competitive domain, local tourism authorities have developed Web sites in order to offer of services to tourists. Unfortunately, the way information is organised does not necessarily meet Internet users expectations and numerous improvements are necessary to enhance their understanding of visited sites. Thus, even if only for economical reasons, the quality and the diversity of tourism packages have to be improved, for example by highlighting cultural heritage.

Again to illustrate our role in such a domain, let us cite some past projects where AxIS is involved related mainly to **Semantic Web Mining**[3]. In our case, a) we exploit ontologies and semantic data for improving usage analysis, personnalised services, the quality of results of search engines and for checking the content of an IS and also b) we exploit usage data for updating ontologies.) and Information Retrieval.

- Research has been carried out using log files from the city of Metz. This city was chosen because its Web site is in constant development and has been awarded several times, notably in 2003, 2004 and 2005 in the context of the Internet City label. The objective was to extract information about tourists behaviours from this site log files and to identify possible benefits in designing or updating a tourism ontology.
- Providing Tourism Information linked to Transportation information: AxIS has already studied recommender systems in order to provide users with personalised transportation information while looking for tourism information such as cultural information, leisure etc (cf. our recommender Be-TRIP (2006) based on CBR*tools).
- In the context of HOTEL-REF-PACA project (cf. section 6.1.2 , we aimed to better refer the web sites of hotels/campings from the region of TOURVAL in PACA (mainly Vésubie territory), with an approach based on a better understanding of usage from the internauts. To address this, we proposed and adopted a multidisicplinary approach combining various AxIs know-how: knowledge engineering (ontology in tourism), data mining (analysis of Google logs, hotel web site logs and user queries, visual behaviours from eye tracker), Ergonomics (clustering of hotel web sites based on their ergonomical quality).
- Several contacts (PACA, France Living Labs, Island of the Reunion) have been done related to projects in tourism and eco-tourism.

[3] By Semantic Web Mining, we mean the mutual benefits between two communities Semantic Web and Web Mining

3.4. User Involvement in Energy, Environment, Health and E-governement

Below are some topics where AxIS was or is involved in:

- **Preprocessing and analysing collective usage data and social networks** from group discussions related to design process: cf. ANR Intermed (2009) and FP7 Elliot (cf. section 6.3.1.1) where citizen generate ideas in terms of specific environmental sensors based services according to their needs.
- **Methods and tools for supporting open innovation based on public data**: a first work was made in 2010 with the CDISOD Color action related Public Data in collaboration with Fing (Marseille) and ADEME (Sophia Antipolis). We pursue such a study in the context of FP7 Elliot by providing to citizen environnemental data (air quality and noise) issued from citizen and/or territories sensors.

All AxIS topics are relevant for these domains. let us cite: social network analysis, personalization and information retrieval, recommender systems, expert search, design and evaluation of methods and tools for open innovation and user co-creation in the context of Living Labs, usage mining, mining data streams.

We have addressed specific works:

- Energy (cf. section 6.1.3): the main AxIS topic here was usage analysis in the context of an energy challenge in an enterprise (ECOFFICES) taking into account the complex and real situation (installation fo more than 400 sensors, differences between the three concerned teams, differences between the offices). Such an analysis aims to correlate team/office energy consuming, team/office eco-responsible behaviours and team/office profile.
- Health (cf. section 3.4): Axis contributed in 2011 to a Living Lab characterisation in Health domain through the visit of several Living Labs, which operate in the domain of Health and Autonomy, and conducted interviews. This work was done in relation with the CGIET [4].
- E-gov: The future Internet will bring a growing number of networked applications (services), devices and individual data (including private ones) to end-users. The important challenges are the organization of their access, and the guarantee of trust and privacy. The objectives of the PIMI [5] project (cf. section 6.2.1) are the definition of a design environment and a deployment platform for Personal Information Management system (PIM). The future PIM must provide the end-user personal data access with services that are relevant to his needs. In order to take mobility into account, the PIM will be accessed both by mobile devices (smartphone) and Personal Computers. With the increasing number of services and associated data being accessible through Internet, the number and complexity of PIM will augment dramatically in the near future. This will require strong research investment in a number of topics, all contributing to the expected usability and accessibility of Individual Information Spaces for the end-user.

[4] CGIET: “Conseil Général de l’Economie, de l’Industrie, de l’Energie et des technologies” http://www.cgeiet.economie.gouv.fr

[5] Personal Information Management through Internet

AYIN Team

4. Application Domains

4.1. Remote sensing

The first application domain of the AYIN team concerns analysis and classification of remote sensing images. The very high spatial, spectral and temporal resolution of the last generation of imaging sensors (for instance, GeoEye, Ikonos, Pleiades, COSMO-SkyMed, TerraSAR-X, ...) provides rich information about environment and is very useful in a range of applications, such as investigating urban environments, precision agriculture, natural disasters and mineralogy. The development of these applications presents new challenges of high-dimensional and high-volume data analysis. The methods proposed by the AYIN team are applied for analysis of SAR, multi- and hyperspectral remote sensing images. In particular, the team develops approaches for image segmentation and classification, change detection, extraction of structures and object tracking.

4.2. Skin care

The second application domain of the AYIN team is skin care imaging which mainly consists in image analysis and classification for dermatology and cosmetology. Here we also deal with very high spatial, spectral and temporal resolution of the most recent imaging sensors. In dermatology we are particularly interested in hyperpigmentation detection and disorders severity evaluation (for instance, for melasma, acne, ...). In cosmetology our main goals are analysis, modeling and characterization of the condition of human skin, as well as evaluation of means to influence that condition. Some of the changes in skin over time have to do with chronological aging (such as pinheads for teenagers or wrinkles for mature people), others with extrinsic aging, caused for instance by sun exposure and smoking.

COPRIN Project-Team

4. Application Domains

4.1. Application Domains

While the methods developed in the project can be used for a very broad set of application domains (for example we have an activity in CO2 emission allowances [32]), it is clear that the size of the project does not allow us to address all of them. Hence we have decided to focus our applicative activities on *mechanism theory*, where we focus on *optimal design* and geometrical modeling of mechanisms. Along the same line our focus is *robotics* and especially *service robotics* which includes rescue robotics, rehabilitation and assistive robots for elderly and handicapped people (section 6.2.1.3). Although these topics were new for us in 2008 we have spent two years determining priorities and guidelines by conducting about 200 interviews with field experts (end-users, praticians, family and caregivers, institutes), establishing strong collaboration with them (e.g. with the CHU of Nice-Cimiez) and putting together an appropriate experimental setup for testing our solutions (see 6.2.1.4). A direct consequence of setting up this research framework is a reduction in our publication and contract activities. But this may be considered as an investment as assistance robotics will constitute the major research axis of the project on the long term (COPRIN will reach its twelve years of existence in 2014 but we intend to propose in 2013 a new project on this topic, code-named HEPHAISTOS).

GRAPHIK Project-Team

4. Application Domains

4.1. Introduction

We currently focus on two application domains: knowledge representation in agronomy, more precisely applied to the quality in agri-food chains, and metadata management, in particular for bibliographic metadata.

The choice of the agronomy domain is motivated both by the local context of GraphIK (UMR IATE) and by its adequation to our research themes. Indeed, the agri-food domain seems to be particularly well-adapted to artificial intelligence techniques: there are no mathematical models available to solve the problems related to the quality of agrifood chains, which need to be stated at a more conceptual level; solving these problems requires an integrated approach that takes into account expert knowledge, which is typically symbolic, as well as numeric data, vague or uncertain information, multi-granularity knowledge, multiple and potentially conflicting viewpoints and actors.

The second area, metadata management, is not strictly speaking an application domain, but rather a cross-cutting axis. Indeed, metadata can be used to describe data in various areas (including for instance scientific publications in agronomy). We have a long experience in this domain, and we currently focus on document metadata.

4.2. Agronomy

Quality control within agri-food chains, but also non-food chains relies on numerous criteria (environmental, economical, functional, sanitary quality, etc.). The objectives of quality are based on several actors. The current structure of chains is questioned as for system perenniality, protection of the environment, cost and energy. In all cases, the following questions have to be taken into account:

1. the actors' viewpoints are divergent, hence it is necessary to define reasoning mechanisms able to model and take into account the balance between viewpoints, and the risks and benefits they imply;
2. the successive steps involved in a chain, impacting the quality of end products, have limiting factors. Their improvement is a complex objective that has no simple solution;
3. data from literature are dispersed and scattered, which makes their use difficult.

These questions highlight the need for an integrated approach of agri-food chains, respectively with symbolic reasoning mechanisms, reverse engineering methods, and knowledge organization and modelling.

Our general objective is the conception of a decision support tool for the actors of an agri-food chain, in presence of contradictory viewpoints and priorities, including the concepts of gravity and certainty of a risk or a benefit. The first step is to build a knowledge-based system able to represent the different kinds of knowledge needed, and provided with consistency checking, querying and symbolic simulation mechanisms, which will allow to refine and validate the modelling.

Our results in Sect. 6.1 and Sect. 6.2 can be seen as theoretical requirements towards this objective.

4.3. Document Metadata

Semantic metadata, in particular semantic annotations for multimedia documents, are at the core of the applications we are working on for several years. In the applications we developed in the previous years, mainly with INA (National Institute of Audiovisual) and FMSH (Fondation Maison des Sciences de l'Homme), we have built tools aimed at helping the manual construction of semantic annotations. In these projects, manual construction was unavoidable because semantically rich annotations, not obtainable by automatic processes, had to be built. In our current project Qualinca (see Sect. 8.1), the semantic metadata considered consists of information present in bibliographic databases and authority notices (which respectively describe documents and so-called authorities, such as authors typically). The challenge is not to build these metadata, which have been built by human specialists and already exist, but, for instance, to check their validity, to link or to merge different metadata bases.

LAGADIC Project-Team

4. Application Domains

4.1. Overview

The natural applications of our research are obviously in robotics. In fact, researches undertaken in the Lagadic group can apply to all the fields of robotics implying a vision sensor. They are indeed conceived to be independent of the system considered (and the robot and the vision sensor can even be virtual for some applications).

Currently, we are mostly interested in using visual servoing for aerial and space application, micromanipulation, autonomous vehicle navigation in large urban environments or for disabled or elderly people.

We also address the field of medical robotics. The applications we consider turn around new functionalities of assistance to the clinician during a medical examination: visual servoing on echographic images, needle insertion, compensation of organ motions, etc.

Robotics is not the only possible application field to our researches. In the past, we were interested in applying visual servoing in computer animation, either for controlling the motions of virtual humanoids according to their pseudo-perception, or for controlling the point of view of visual restitution of an animation. In both cases, potential applications are in the field of virtual reality, for example for the design of video games, or virtual cinematography.

Applications also exist in computer vision and augmented reality. It is then a question of carrying out a virtual visual servoing for the 3D localization of a tool with respect to the vision sensor, or for the estimation of its 3D motion. This field of application is very promising, because it is in full rise for the realization of special effects in the multi-media field or for the design and the inspection of objects manufactured in the industrial world.

REVES Project-Team (section vide)

STARS Team

4. Application Domains

4.1. Introduction

While in our research the focus is to develop techniques, models and platforms that are generic and reusable, we also make effort in the development of real applications. The motivation is twofold. The first is to validate the new ideas and approaches we introduce. The second is to demonstrate how to build working systems for real applications of various domains based on the techniques and tools developed. Indeed, Stars focuses on two main domains: **video analytics** and **healthcare monitoring**.

4.2. Video Analytics

Our experience in video analytics [7], [1], [9] (also referred to as visual surveillance) is a strong basis which ensures both a precise view of the research topics to develop and a network of industrial partners ranging from end-users, integrators and software editors to provide data, objectives, evaluation and funding.

For instance, the Keeneo start-up was created in July 2005 for the industrialization and exploitation of Orion and Pulsar results in video analytics (VSIP library, which was a previous version of SUP). Keeneo has been bought by Digital Barriers in August 2011 and is now independent from Inria. However, Stars continues to maintain a close cooperation with Keeneo for impact analysis of VSIP and for exploitation of new results.

Moreover new challenges are arising from the visual surveillance community. For instance, people detection and tracking in a crowded environment are still open issues despite the high competition on these topics. Also detecting abnormal activities may require to discover rare events from very large video data bases often characterized by noise or incomplete data.

4.3. Healthcare Monitoring

We have initiated a new strategic partnership (called CobTek) with Nice hospital [62], [81] (CHU Nice, Prof P. Robert) to start ambitious research activities dedicated to healthcare monitoring and to assistive technologies. These new studies address the analysis of more complex spatio-temporal activities (e.g. complex interactions, long term activities).

To achieve this objective, several topics need to be tackled. These topics can be summarized within two points: finer activity description and longer analysis. Finer activity description is needed for instance, to discriminate the activities (e.g. sitting, walking, eating) of Alzheimer patients from the ones of healthy older people. It is essential to be able to pre-diagnose dementia and to provide a better and more specialised care. Longer analysis is required when people monitoring aims at measuring the evolution of patient behavioural disorders. Setting up such long experimentation with dementia people has never been tried before but is necessary to have real-world validation. This is one of the challenge of the European FP7 project Dem@Care where several patient homes should be monitored over several months.

For this domain, a goal for Stars is to allow people with dementia to continue living in a self-sufficient manner in their own homes or residential centers, away from a hospital, as well as to allow clinicians and caregivers remotely proffer effective care and management. For all this to become possible, comprehensive monitoring of the daily life of the person with dementia is deemed necessary, since caregivers and clinicians will need a comprehensive view of the person's daily activities, behavioural patterns, lifestyle, as well as changes in them, indicating the progression of their condition.

The development and ultimate use of novel assistive technologies by a vulnerable user group such as individuals with dementia, and the assessment methodologies planned by Stars are not free of ethical, or even legal concerns, even if many studies have shown how these Information and Communication Technologies (ICT) can be useful and well accepted by older people with or without impairments. Thus one goal of Stars team is to design the right technologies that can provide the appropriate information to the medical carers while preserving people privacy. Moreover, Stars will pay particular attention to ethical, acceptability, legal and privacy concerns that may arise, addressing them in a professional way following the corresponding established EU and national laws and regulations, especially when outside France.

As presented in 3.1 , Stars aims at designing cognitive vision systems with perceptual capabilities to monitor efficiently people activities. As a matter of fact, vision sensors can be seen as intrusive ones, even if no images are acquired or transmitted (only meta-data describing activities need to be collected). Therefore new communication paradigms and other sensors (e.g. accelerometers, RFID, and new sensors to come in the future) are also envisaged to provide the most appropriate services to the observed people, while preserving their privacy. To better understand ethical issues, Stars members are already involved in several ethical organizations. For instance, F. Bremond has been a member of the ODEGAM - “Commission Ethique et Droit” (a local association in Nice area for ethical issues related to older people) from 2010 to 2011 and a member of the French scientific council for the national seminar on “La maladie d’Alzheimer et les nouvelles technologies - Enjeux éthiques et questions de société” in 2011. This council has in particular proposed a chart and guidelines for conducting researches with dementia patients.

For addressing the acceptability issues, focus groups and HMI (Human Machine Interaction) experts, will be consulted on the most adequate range of mechanisms to interact and display information to older people.

WIMMICS Team

4. Application Domains

4.1. Introduction

A number of evolutions have changed the face of information systems in the past decade but the advent of the Web is unquestionably a major one and it is here to stay. From an initial wide-spread perception of a public documentary system, the Web as an object turned into a social virtual space and, as a technology, grew as an application design paradigm (services, data formats, query languages, scripting, interfaces, reasoning, etc.). The universal deployment and support of its standards led the Web to take over nearly all of our information systems. As the Web continues to evolve, our information systems are evolving with it.

Today in organizations, not only almost every internal information system is a Web application, but these applications also more and more often interact with external Web applications. The complexity and coupling of these Web-based information systems call for specification methods and engineering tools. From capturing the needs of users to deploying a usable solution, there are many steps involving computer science specialists and non-specialists.

We defend the idea of relying on Semantic Web formalisms to capture and reason on the models of these information systems supporting the design, evolution, interoperability and reuse of the models and their data as well as the workflows and the processing.

4.2. Linked Data on the Web and on Intranets

With billions of triples online (see Linked Open Data initiative), the Semantic Web is providing and linking open data at a growing pace and publishing and interlinking the semantics of their schemas. Information systems can now tap into and contribute to this Web of data, pulling and integrating data on demand. Many organisations also started to use this approach on their intranets leading to what is called linked enterprise data.

A first application domain for us is the publication and linking of data and their schemas through Web architectures. Our results provide software platforms to publish and query data and their schemas, to enrich these data in particular by reasoning on their schemas, to control their access and licences, to assist the workflows that exploit them, to support the use of distributed datasets, to assist the browsing and visualization of data, etc.

Examples of collaboration and applied projects include: Corese/KGRAM, Datalift, DBpedia, ALU/BLF Convention, ADT SeGViz.

4.3. Assisting Web-based Epistemic Communities

In parallel to linked open data on the Web, social Web applications also spread virally (e.g. Facebook growing toward 800 million users) first giving the Web back its status of a social read-write media and then leading it to its full potential of a virtual place where to act, react and interact. In addition, many organizations are now considering deploying social Web applications internally to foster community building, expert cartography, business intelligence, technological watch and knowledge sharing in general.

Reasoning on the linked data and the semantics of the schemas used to represent social structures and Web resources, we intend to provide applications supporting communities of practice and interest and fostering their interactions.

We use typed graphs to capture and mix: social networks with the kinds of relationships and the descriptions of the persons; compositions of Web services with types of inputs and outputs; links between documents with their genre and topics; hierarchies of classes, thesauri, ontologies and folksonomies; recorded traces and suggested navigation courses; submitted queries and detected frequent patterns; timelines and workflows; etc.

Our results assist epistemic communities in their daily activities such as biologists exchanging results, business intelligence and technological watch networks informing companies, engineers interacting on a project, conference attendees, students following the same course, tourists visiting a region, mobile experts on the field, etc. Examples of collaboration and applied projects include: Kolflow, OCKTOPUS, ISICIL, SAP Convention.

ZENITH Project-Team

4. Application Domains

4.1. Data-intensive Scientific Applications

The application domains covered by Zenith are very wide and diverse, as they concern data-intensive scientific applications, i.e. most scientific applications. Since the interaction with scientists is crucial to identify and tackle data management problems, we are dealing primarily with application domains for which Montpellier has an excellent track record, i.e. agronomy, environmental science, life science, with scientific partners like INRA, IRD, CIRAD and IRSTEA (prev. CEMAGREF). However, we are also addressing other scientific domains (e.g. astronomy, oil extraction) through our international collaborations (e.g. in Brazil).

Let us briefly illustrate some representative examples of scientific applications on which we have been working on.

- **Management of astronomical catalogs**. An example of data-intensive scientific applications is the management of astronomical catalogs generated by the Dark Energy Survey (DES) project on which we are collaborating with researchers from Brazil. In this project, huge tables with billions of tuples and hundreds of attributes (corresponding to dimensions, mainly double precision real numbers) store the collected sky data. Data are appended to the catalog database as new observations are performed and the resulting database size is estimated to reach 100TB very soon. Scientists around the globe can query the database with queries that may contain a considerable number of attributes. The volume of data that this application holds poses important challenges for data management. In particular, efficient solutions are needed to partition and distribute the data in several servers. An efficient partitioning scheme should try to minimize the number of fragments accessed in the execution of a query, thus reducing the overhead associated to handle the distributed execution.
- **Pesticide reduction**. In a pesticide reduction application, with CEMAGREF, we plan to work on sensor data for plant monitoring. Sensors are used to observe the development of diseases and insect attacks in the agricultural farms, aiming at using pesticides only when necessary. The sensors periodically send to a central system their data about different measures such as plants contamination, temperature or moisture level. A decision support system analyzes the sent data, and triggers a pesticide treatment only when needed. However, the data sent by sensors are not entirely certain. The main reasons for uncertainty are the effect of climate events on sensors, e.g. rain, unreliability of the data transmission media, fault in sensors, etc. This requires to deal with uncertain data in modeling and querying to be used for data analysis and data mining.
- **Botanical data sharing**. Botanical data is highly decentralized and heterogeneous. Each actor has its own expertise domain, hosts its own data, and describes them in a specific format. Furthermore, botanical data is complex. A single plant's observation might include many structured and unstructured tags, several images of different organs, some empirical measurements and a few other contextual data (time, location, author, etc.). A noticeable consequence is that simply identifying plant species is often a very difficult task; even for the botanists themselves (the so-called taxonomic gap). Botanical data sharing should thus speed up the integration of raw observation data, while providing users an easy and efficient access to integrated data. This requires to deal with social-based data integration and sharing, massive data analysis and scalable content-based information retrieval. We address this application in the context of the French initiative Pl@ntNet, with CIRAD and IRD.
- **Deepwater oil exploitation**. An important step in oil exploitation is pumping oil from ultra-deepwater from thousand meters up to the surface through long tubular structures, called risers. Maintaining and repairing risers under deep water is difficult, costly and critical for the environment. Thus, scientists must predict risers fatigue based on complex scientific models and observed data for the risers. Risers fatigue analysis requires a complex workflow of data-intensive activities which

may take a very long time to compute. A typical workflow takes as input files containing riser information, such as finite element meshes, winds, waves and sea currents, and produces result analysis files to be further studied by the scientists. It can have thousands of input and output files and tens of activities (e.g. dynamic analysis of risers movements, tension analysis, etc.). Some activities, e.g. dynamic analysis, are repeated for many different input files, and depending on the mesh refinements, each single execution may take hours to complete. To speed up risers fatigue analysis requires parallelizing workflow execution, which is hard to do with existing SWfMS. We address this application in collaboration with UFRJ, and Petrobras.

These application examples illustrate the diversity of requirements and issues which we are addressing with our scientific application partners (CIRAD, INRA, CEMAGREF, etc.). To further validate our solutions and extend the scope of our results, we also want to foster industrial collaborations, even in non scientific applications, provided that they exhibit similar challenges.