IN PARTNERSHIP WITH:
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Université de Lorraine

Activity Report 2012

Project-Team TOSCA

TO Simulate and CAlibrate stochastic models

IN COLLABORATION WITH: Institut Elie Cartan Nancy (IECN)

RESEARCH CENTERS
Sophia Antipolis - Méditerranée
Nancy - Grand Est

THEME
Stochastic Methods and Models

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Project-Team TOSCA

Keywords: Stochastic Modeling, Numerical Probability, Stochastic Analysis, Monte Carlo Methods, Financial Mathematics, Population Dynamics

The Inria Research team TOSCA *is located both at Inria Sophia-Antipolis – Méditerranée and Inria Nancy – Grand Est.*

Creation of the Project-Team: January 01, 2007 .

1. Members

Research Scientists

Denis Talay [Team Leader, Senior Researcher, Inria, Sophia Antipolis - Méditerranée, HdR]
Mireille Bossy [Senior Researcher, Inria, Sophia Antipolis - Méditerranée, HdR]
Madalina Deaconu [Junior Researcher, Inria, Nancy - Grand Est, HdR]
Antoine Lejay [Junior Researcher, Inria, Senior resercher since September 01, Nancy - Grand Est, HdR]
Etienne Tanré [Junior Researcher, Inria, Sophia Antipolis - Méditerranée]
Nicolas Champagnat [Junior Researcher, Inria, Nancy - Grand Est]
James Inglis [Starting Research Position (part time with EPI NEUROMATHCOMP), since October, PostDoc Inria until September, Sophia Antipolis - Méditerranée]

Faculty Member

Samuel Herrmann [Professor, Université de Bourgogne, Nancy - Grand Est, HdR]

External Collaborators

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François Delarue [Professor, Université de Nice Sophia Antipolis, Sophia Antipolis - Méditerranée, HdR]
Sylvain Maire [Associate Professor, Université de Toulon et du Var, Sophia Antipolis - Méditerranée, HdR]

PhD Students

Paul Charton
Julien Claisse
Dalia Ibrahim [until October, Sophia Antipolis - Méditerranée]
Sebastian Niklitschek Soto
Nicolas Perrin [until August, Sophia Antipolis - Méditerranée]
Laurent Violeau

Post-Doctoral Fellows

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Jacques Morice [until July, Sophia Antipolis - Méditerranée]
Denis Villemonais [until August, Nancy - Grand Est]

Administrative Assistants

Sophie Drouot [TR, Inria, Nancy - Grand Est]
Christine Faber [TR, Inria, Sophia Antipolis - Méditerranée]

2. Overall Objectives

2.1. Overall Objectives

The team develops and analyzes stochastic models and probabilistic numerical methods. The present fields of applications are in fluid mechanics, molecular dynamics, chemical kinetics, neuroscience, population dynamics, and financial mathematics.

The problems where stochastic models arise are numerous, and the critical reasons for which stochastic models are used make analysis and simulations difficult.

The TOSCA team thus aims to develop calibration and simulation methods for stochastic models in cases where **singularities** in the coefficients or **boundary conditions** make them hard to discretize and estimate. For this, we are willing to tackle theoretical and numerical questions which are motivated by real applications.

We are interested in developing **stochastic numerical methods** and **transverse methodologies** that cover several fields of applications, instead of having chosen a particular field of application (e.g., Biology, or Fluid Mechanics, or Chemistry). We justify this way to proceed as follows:

- For a couple of years now, we have attacked singular problems to answer questions coming from economists, meteorologists, biologists and engineers with whom we collaborate within industrial contracts or research programs such as ACI, ANR, GDR. To solve their problems which are so complex that stochastic processes are involved in the modelling, these colleagues need to combine expertise and knowledge in many fields: deterministic computing, computer science, vision, algorithm analysis, etc. We are incompetent in these fields, and therefore we could not pretend to fully treat any of these problems. A contrario, we are requested to bring our expertise in stochastic modelling and simulation to extremely various domains of applications.
- In spite of this diversity, whatever the application is, one has to simulate stochastic processes as solutions to equations of the type

$$\left\{\begin{array}{rl} X_t(\omega) & = X_0(\omega) + \left(\displaystyle\int_0^t \int_{\mathbb{R}^d} b(X_s, y)\mu_s(dy)ds\right)(\omega) \\ & \quad + \left(\displaystyle\int_0^t \int_{\mathbb{R}^d} \sigma(X_s, y)\mu_s(dy)dZ_s\right)(\omega), \\ \mu_s & = \text{Law of } X_s \text{ for all } s \geq 0, \end{array}\right. \tag{1}$$

  in order to compute statistics of the laws of functionals of these solutions. In addition, several fields often produce very similar "pathologies" of the model (1) or of the statistics to compute: for example, Pope's Lagrangian stochastic particles in Fluid Mechanics and models in Molecular Dynamics produce the same degeneracy in (1), namely, one has to substitute 'conditional law of components of X_s given the other ones' for 'law of X_s'; as well, when studying chartist strategies in Finance and stochastic resonance in the electrical working of neurons, we encounter close questions on the density functions of the random passage times of processes (X_t) at given thresholds.
- Theory and numerical experiments show that each 'pathology' of the model (1) requires specific analysis and numerical methods. However, they require common abstract tools (Malliavin calculus, propagation of chaos theory, nonlinear PDE analysis, etc.) and common numerical methodologies (stochastic particle systems, Monte Carlo simulations, time discretization of stochastic differential equations, etc.). Thus each application takes benefit from the modelling and numerical knowledge developed for all the others.

The TOSCA team is currently studying models in relation with Geophysics, Neuroscience, Fluid Mechanics, Chemical Kinetics, Meteorology, Molecular Dynamics, Population Dynamics, Evolutionary Dynamics and Finance. We also construct and study stochastic particle systems for Fluid Mechanics, coagulation–fragmentation, stationary nonlinear PDEs, variance reduction techniques for Monte-Carlo computations and numerical methods combining deterministic and stochastic steps to solve nonlinear PDEs in Finance.

3. Scientific Foundations

3.1. Scientific Foundations

Most often physicists, economists, biologists, engineers need a stochastic model because they cannot describe the physical, economical, biological, etc., experiment under consideration with deterministic systems, either because of its complexity and/or its dimension or because precise measurements are impossible. Then they abandon trying to get the exact description of the state of the system at future times given its initial conditions, and try instead to get a statistical description of the evolution of the system. For example, they desire to compute occurrence probabilities for critical events such as the overstepping of a given thresholds by financial losses or neuronal electrical potentials, or to compute the mean value of the time of occurrence of interesting events such as the fragmentation to a very small size of a large proportion of a given population of particles. By nature such problems lead to complex modelling issues: one has to choose appropriate stochastic models, which require a thorough knowledge of their qualitative properties, and then one has to calibrate them, which requires specific statistical methods to face the lack of data or the inaccuracy of these data. In addition, having chosen a family of models and computed the desired statistics, one has to evaluate the sensitivity of the results to the unavoidable model specifications. The TOSCA team, in collaboration with specialists of the relevant fields, develops theoretical studies of stochastic models, calibration procedures, and sensitivity analysis methods.

In view of the complexity of the experiments, and thus of the stochastic models, one cannot expect to use closed form solutions of simple equations in order to compute the desired statistics. Often one even has no other representation than the probabilistic definition (e.g., this is the case when one is interested in the quantiles of the probability law of the possible losses of financial portfolios). Consequently the practitioners need Monte Carlo methods combined with simulations of stochastic models. As the models cannot be simulated exactly, they also need approximation methods which can be efficiently used on computers. The TOSCA team develops mathematical studies and numerical experiments in order to determine the global accuracy and the global efficiency of such algorithms.

The simulation of stochastic processes is not motivated by stochastic models only. The stochastic differential calculus allows one to represent solutions of certain deterministic partial differential equations in terms of probability distributions of functionals of appropriate stochastic processes. For example, elliptic and parabolic linear equations are related to classical stochastic differential equations, whereas nonlinear equations such as the Burgers and the Navier–Stokes equations are related to McKean stochastic differential equations describing the asymptotic behavior of stochastic particle systems. In view of such probabilistic representations one can get numerical approximations by using discretization methods of the stochastic differential systems under consideration. These methods may be more efficient than deterministic methods when the space dimension of the PDE is large or when the viscosity is small. The TOSCA team develops new probabilistic representations in order to propose probabilistic numerical methods for equations such as conservation law equations, kinetic equations, and nonlinear Fokker–Planck equations.

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.

5. Software

5.1. CarbonQuant

Participant: Mireille Bossy [correspondant].

CarbonQuant is a simulator project of CO2 allowances prices on a EU-ETS type market, by an indifference price approach.

It aims to demonstrate the high potentiality of stochastic control solvers, to quantify sensibilities of a carbon market with respect to its design.

Starting in September 2011, CarbonQuant is an ADT [1] Inria.

See also the web page http://carbonvalue.gforge.inria.fr.

- Version: 0.1

6. New Results

6.1. Probabilistic numerical methods, stochastic modelling and applications

Participants: Mireille Bossy, Nicolas Champagnat, Julia Charrier, Julien Claisse, Madalina Deaconu, Samuel Herrmann, James Inglis, Antoine Lejay, Sylvain Maire, Sebastian Niklitschek Soto, Nicolas Perrin, Denis Talay, Etienne Tanré, Denis Villemonais, Laurent Violeau.

6.1.1. Published works and preprints

- In collaboration with P.-E. Jabin (University of Maryland), J.-F. Jabir and J. Fontbona (CMM and Universidad de Chile, Santiago de Chile), M. Bossy have studied the link between the Lagrangian version of divergence free constraint (and the uniform density constraint), with an additional potential term in the Lagrangian equation, having some similarity with the role of the Eulerian pressure term. They obtained the local existence of analytical solutions to an incompressible Lagrangian stochastic model in periodic domain. The paper is in positive revision for publication in *Communications in Partial Differential Equations* [33]. http://hal.inria.fr/hal-00691712
- N. Champagnat worked with A. Lambert (Univ. Paris 6) on splitting trees with Poissonian mutations. Assuming that each mutation is neutral and gives a new type in the population, they obtained in [13], [14] large time convergence results on the sizes of the largest families and the ages of the oldest families in the population. http://hal.inria.fr/inria-00515481, http://hal.inria.fr/inria-00616765. In collaboration with Mathieu Richard (Ecole Polytechnique, Palaiseau), they also extended some of these results to the case of splitting trees with mutations occuring at birth of individuals [15], http://hal.inria.fr/hal-00736036.
- N. Champagnat obtained with P. Diaconis (Stanford Univ.) and L. Miclo (Univ. Toulouse 3) the full spectral decomposition of the transition matrix of two-dimensional Markov chains $(X_n, Y_n)_{n\geq 0}$ in $\mathbb{Z}_+^2$, without immigration or mutation, which are *neutral* in the sense that $(X_n + Y_n)_{n\geq 0}$ is a Markov process. Because of the specific form of the eigenvectors, they were also able to characterize all the Dirichlet eigenvectors in subdomains of $\mathbb{Z}_+^2$ of the form $\{(i,j) \in \mathbb{Z}_+^2 : i + j \geq d\}$ for all $d \geq 0$. As an application, they could determine the quasi-stationary and quasi-limiting distributions of such processes [12], http://hal.inria.fr/hal-00672938.
- N. Champagnat studied with F. Campillo (EPI MODEMIC, Inria Sophia Antipolis — Méditerrannée) individual based models of clonal plants where plants interact through the network formed by the rizhomes or stolons linking plants. In the limit of large population, they obtained a PDE governing the dynamics of population densities in space [11], http://hal.inria.fr/hal-00723209.

[1] Technology Development Action

- M. Deaconu and S. Herrmann introduced a new method for the simulation of the hitting times of nonlinear boundaries for Bessel processes. This method combines the method of images and the random walk on spheres method. They construct the so called walk on moving spheres algorithm. This approach can be applied for the hitting time of a given level for the Cox-Ingersoll-Ross process and thus be used in models coming from finance and neuroscience [17], http://hal.inria.fr/hal-00636056/en. This work is part of the ANR MANDy project.
- J. Inglis and E. Tanré studied with F. Delarue and S. Rubenthaler (Univ. Nice – Sophia Antipolis) the global solvability of a networked system of integrate-and-fire neurons proposed in the neuroscience literature. In the mean-field limit the equation resembles a McKean-Vlasov equation, but is highly non-standard and previous attempts at rigorous analysis were not satisfactory. They here bridge this gap, and shed light on a surprisingly complicated problem [35], http://hal.inria.fr/hal-00747565.
- A. Lejay continued his long term investigations on probabilistic interpretations and Monte Carlo simulations of interfaces conditions, such as ones arising in discontinuous media. With G. Pichot (IRISA, Rennes), he has developed a series of tests and benchmarks regarding one-dimensional Monte Carlo methods, such as the ones proposed in [19], http://hal.inria.fr/hal-00649170. He has also developed a new family of stochastic diffusion processes, called the *snapping out Brownian motion*, in order to take into account an interface condition where the concentration of the fluid is proportional to its gradient. Finally, A. Lejay and S. Maire also proposed new methods and tested a few ones to deal with the locally isotropic case for multidimensional problems [18], http://hal.inria.fr/hal-00689581.
- With A. Kohatsu-Higa (Ristumeikan University) and K. Yasuda (Hosei university), A. Lejay has continued his work [25] on the simulation of SDE with a discontinuous drift. http://hal.inria.fr/hal-00670123
- With L. Coutin (University of Toulouse), A. Lejay has developed an appropriate framework to deal with linear rough differential equations, extending some results (Magnus formula, Dyson series...) to this case. Using theses properties, they have studied the sensitivites of solutions of rough differential equations with respect to the signal, the vector field or the starting point. They have provided new results such as the Hölder continuity of the derivative of the so called Itô map which transforms a rough path to the solution of a rough differential equation [34]. http://hal.inria.fr/hal-00722900
- S. Maire and C. Prissette (Univ. du Sud – Toulon – Var) have developed in [21] a stochastic algorithm to solve Sudoku puzzles using estimation of distribution coupled with restart techniques. http://hal.inria.fr/inria-00591852
- S. Maire and E. Tanré have generalised the spectral methods for elliptic PDEs developed in [42], [43] to the case of pure Neumann boundary conditions. Some additional difficulties occur because the stochastic representation of the solutions is defined only up to an additive constant and as a limit involving local time approximations [40]. By taking into account these additional properties, they still obtained a spectral matrix having a condition number converging to one [36]. http://hal.inria.fr/hal-00677529
- C. Graham (Ecole Polytechnique) and D. Talay wrote the first volume [27] of their series of books published by Springer on the Foundations of Stochastic Simulations. They started to write the second volume.
- D. Villemonais wrote with S. Méléard (École Polytechnique) a survey on quasi-stationary distributions and Q-processes for stochastic models of population dynamics. This survey also contains a detailed numerical study of the behaviour of classical models with extinction [23]. http://hal.inria.fr/hal-00653834
- D. Villemonais worked on the empirical distribution of Fleming-Viot type particle systems. Using couplings with reflected diffusion processes, he proved the uniform tightness of such empirical distributions and deduced the non-degeneracy of the law of diffusion processes conditioned not to hit a boundary [39]. http://hal.inria.fr/hal-00681601

- D. Villemonais proved in [38] a general approximation method for Markov processes conditioned not be killed. The method is based on a mean field interacting particles system which is easy to simulate. The study also details the particular case of time/environment dependent diffusion processes. http://hal.archives-ouvertes.fr/hal-00598085

6.1.2. Other works in progress

- N. Champagnat and D. Villemonais obtained criterions for existence and uniqueness of quasi-stationary distributions and Q-processes for general absorbed Markov processes. A quasi-stationary distribution is a stationary distribution conditionnally on non-absorbtion, and the Q-process is defined as the original Markov process conditionned to never be absorbed. The criterion that they obtain also ensures exponential convergence of the conditionned t-marginal of the process conditionned not to be absorbed at time t to the quasi-stationary distribution and the exponential ergodicity of the Q-process. This work is currently being written.
- N. Champagnat and D. Villemonais work on time-reversal of absorbed processes, which allow to characterize the path to extinction in extinct populations which are known to be non-extinct at some time in the past. They plan to apply these results on practical ecological situations.
- J. Claisse continued his PhD. under the supervision of N. Champagnat and D. Talay on stochastic control of population dynamics. He completed a finite-horizon and an infinite-horizon optimal control problem on a birth-death process. He is currently working on a finite-horizon optimal control problem on a branching-diffusion process. In addition, he is working on modelling of a pH-mediated cancer treament.
- M. Deaconu and S. Herrmann continue the study of the hitting times for Bessel processes in the situation of noninteger dimensions and also in the application of this method to the simulation of the Brownian hitting time,
- M. Deaconu starts a collaboration with L. Beznea (Simion Stoilow Institute of Mathematics of the Romanian Academy) on coagulation-fragmentation models and their connection with branching processes.
- M. Deaconu studies in collaboration with F. Nobile and F. Tesei (EPFL) a pollution model by using hitting times of stochastic processes.
- S. Herrmann and E. Tanré worked on a scheme to construct an efficient algorithm to simulate the first hitting time of curves by a one dimensional Brownian motion. They apply the result to estimate the spiking time of leaky integrate fire models in neuroscience. This work is part of the ANR MANDy project.
- S. Larnier joined the team in September as a post-doctoral researcher and began working with A. Lejay on data assimilation in order to predict the ocean wave energy from the knowledge of near-shore incoming waves. They started a collaboration on video data with R. Almar (LEGOS, Toulouse) and R. Cienfuegos (Pontificia Universidad Católica de Chile).
- S. Maire works with M. Simon (Mainz Univ.) on electrical impedance tomography problems using new Monte Carlo schemes that deal with Robin and transmission boundary conditions.
- S. Maire develops with I. Dimov (Bulgarian academy of sciences) a Monte Carlo method called the walk on equations to solve linear systems of algebraic equations.
- S. Niklitschek has continued his PhD. work under the supervision of D. Talay. They were able to extended their first work in which they gave a probabilistic interpretation of a parabolic equation with discontinuous drift and proved the weak rate of convergence of the Euler method using the accurate pointwise estimates obtained for the derivatives of the solution, to the case in which both drift and diffusion coefficients are discontinuous. Both results are consistent with each other, and also with the results obtained by M. Martinez and D. Talay in [22].

- N. Perrin continued his PhD. on stochastic methods in molecular dynamics under the supervision of M. Bossy, N. Champagnat and D. Talay. This year, he studied a stochastic interpretation of parabolic PDEs with divergence form operators involved in the Poisson-Boltzmann PDE of molecular dynamics, and the associated numerical Monte Carlo method. He also continued his study of a method due to P. Malliavin (French Academy of Science) based on the Fourier analysis of covariance matrices with delay in order to identify the fast and slow components of a molecular dynamics.
- P. Guiraud (University of Valparaiso) and E. Tanré study the effect of noise in the phenomenon of spontaneous synchronisation in a network of full connected integrate-and-fire neurons. They detail cases in which the phenomenon of synchronization persists in a noisy environment, cases in which noise permits to accelerate synchronization, and cases in which noise permits to observe synchronization while noiseless model does not have synchronization.
- P. Orio (Centro Interdisciplinario de Neurociencia de Valparaiso) and E. Tanré work on the comparison of global properties of the solution of mathematical models and the associated measurements obtained by experiments.
- L. Violeau continued his PhD. on *Stochastic Lagrangian Models and Applications to Downscaling in Fluid Dynamics* under the supervision of M. Bossy and A. Rousseau (MOISE team, Inria Sophia Antipolis – Méditerranée, Montpellier). Laurent studied this year the rate of convergence of the Nadaraya-Watson conditional estimator for "linear" kinetic processes. He is currently working on the rate of convergence of the particle approximation of kinetic conditional McKean-Vlasov stochastic models.
- P-E. Jabin and D. Talay continue to develop their innovating approach, which combines stochastic analysis and PDE analysis, for the time varying Hamilton-Jacobi-Bellman-McKean-Vlasov equations of the Lasry and Lions mean-field stochastic control theory.
- D. Talay is working with J. Bion-Nadal (Ecole Polytechnique) on applications of risk measures to the calibration of stochastic models, with N. Touzi (Ecole Polytechnique) on the stochastic control of stochastic differential equations with weighted local times, and with O. Bardou (GDF) on Edgeworth expansions for the Central Limit Theorem for Brownian martingales whose integrands depend on ergodic diffusion processes.

6.2. Financial Mathematics

Participants: Mireille Bossy, Paul Charton, Dalia Ibrahim, Denis Talay, Etienne Tanré.

- Mireille Bossy, in collaboration with H. Quinteros (Univ. Chile) worked on the rate of convergence of non Lipschitz diffusion processes discretized with the symetrized Milstein scheme. Under the same kind of hypotheses than in [41] on the symetrized Euler scheme, they obtained the expected improvement of the strong rate of convergence, when the diffusion coefficient is of the form $\sigma(x) = x^\alpha$, with $\alpha \in [1/2, 1[$.

  A preprint is being written.
- P. Charton continued his PhD. under the supervision of M. Deaconu and A. Lejay. He studied some storage strategies for wind farms.
- **Mathematical modelling for technical analysis techniques** Since November 2009, D. Ibrahim has been working on her PhD. thesis on Mathematical modeling of technical analysis in finance, under supervision of D. Talay and E. Tanré. The aim of her work is to study the performances of a technical analysis tool designed to detect changes in the volatility term: The Bollinger Bands. She studied the performances of this indicator in a modified Black-Scholes model such that the volatility is equal to σ_0 up to a random time τ, independent of the Brownian motion governing the prices. After τ, the volatility is equal to σ_1. She proved that Bollinger Bandwidth indicator can detect the time change (at which the volatility changes its value), in the case of small and large volatilities. She has also exhibited a mathematical optimal allocation strategy, by decomposing the initial allocation problem into an allocation problem before the change time τ and an allocation problem after τ, in order to circumvent some technical problems brought from the change of volatility.

This work is part of the contract with FINRISK.

- In collaboration with C. Michel (CA-CIB) and V. Reutenauer (Citi), D. Talay and E. Tanré worked on the
  - the study of the liquidity risk in the interest rate options market;
  - the minimization of the hedging error in interest rates Gaussian models by means of strategies designed in an effective way by using stochastic optimization algorithms.
- P. Protter (Columbia University) and D. Talay continue to work on bubbles time evolution models, which leads them to try to extend Feller's results on explosion times for stochastic differetential equations.

7. Bilateral Contracts and Grants with Industry

7.1. Bilateral Contracts with Industry

- TOSCA Nancy had a bilateral contract with the SME Alphability on the evaluation of the Value at Risk with applications in portfolio management. This collaboration will be continued in 2013.

8. Partnerships and Cooperations

8.1. National Initiatives

8.1.1. ANR

- N. Champagnat and D. Villemonais are members of the ANR MANEGE (Modèles Aléatoires eN Écologie, Génétique et Évolution, started in 2009) whose aim is to provide methodological and conceptual advances in the study of stochastic processes modeling ecology, population genetics and evolution of life. This work is sustained by regular exchanges with biologists from several teams in France. In addition, the three working groups that operate in each of the three poles of the MANEGE project (Paris, Palaiseau, Marseille) gather all local probabilistic interests in the issues of this project. http://www.cmap.polytechnique.fr/~anr-manege/index_en.html
- N. Champagnat is member of the ANR MODECOL (Using mathematical MODeling to improve ECOLogical services of prairial ecosystems, which ended in August 2012), whose goal is to develop computational ecological modeling of terrestrial plants communities via the simulation of a prairie in relation with environmental data. This project focuses on developing an original toolbox that takes advantage of complementary mathematical disciplines (partial differential equations, individual-based stochastic modelling...) to assess ecological problems. Simulations will be extensively processed using distributed computing and webcomputing. Our target application concerns the setup of herbal strips around intensive cereal fields for purificating water from extra nitrate and pesticides, imposed by the European Common Agricultural Policy. http://ecobio.univ-rennes1.fr/modecol/gb/description.php
- S. Herrmann, J. Inglis, D. Talay and E. Tanré are member of the ANR MANDy (Mathematical Analysis of Neuronal Dynamics, started in 2009 under the direction of M. Thieullen, Univ. Paris 6). This project, which gathers mathematicians and neuroscientists, aims at developing mathematically rigorous approaches to neuroscience considering single neurons as well as interconnected neuronal populations. Our target is to conduct the mathematical analysis of existing models where there is still much work to be done and to enrich the modelling by proposing new models. See http://www.proba.jussieu.fr/pageperso/thieullen/MANDy/accueil.html for a more complete description of this project.

- A. Lejay is member of the ANR SIMUDMRI (Simulation of diffusion MRI signals in biological tissues) which started in November 2010 (directed by Jing-Rebecca Li, Inria Rocquencourt). http://www.cmap.polytechnique.fr/~jingrebeccali/grants/simudmri.html
- A. Lejay is member of the ANR H2MNO4 (ANR Cosinus, 2012–2015) on Original Optimized Object Oriented Numerical Model for Heterogeneous Hydrogeology which started in November 2012 (directed by Joceyline Erhel, IRISA, Rennes).

8.1.2. Contract with ADEME

Participants: Mireille Bossy, Jacques Morice.

Carbon value and carbon tax in the context of renewable energies deployment Since January 2009, M. Bossy was member of a collaboration funded by the French Environment and Energy Management Agency (ADEME), involving the Center for Applied Mathematics (CMA) at Mines ParisTech, and COPRIN and TOSCA teams at Inria Sophia Antipolis. It focuses on a short term carbon value derived from the so-called financial *carbon market*, the European Union Emission Trading Scheme (EU ETS), which is a framework for GHG emissions reduction in European industry.

The objective of this project is to study the compatibility and complementarity of a carbon tax and a target for renewable energy deployment. As a first step, we are developing a method for assessing the EU ETS value. We consider the constraints related to emission allowances distributed through national plans of allocation (NAP) and the mechanisms of taxes that are taking place. The work will focus on electricity producers, key players in the market in its first phase (NAP-I, 2005-2007). The impact of the *Renewable Energies* park of the electricity producers on their own carbon value will be particularly studied.

We have selected the financial concept of indifference price as a relevant methodology to assess the European Union Emission Trading Scheme (EU ETS) value. In this setting, modelling strategies of production and emission of market quotas rely on stochastic optimal control problems and associated Hamilton-Jacobi-Bellman equations.

This year, we worked on game theoretic approach for the carbon market price, in the framewrok of a cap&trade program. Based on the Nash equilibrium concept, we derive an equilibrium price equation for the allowances. The analysis of this equation and its wellposedness strongly depend on the design of the penalty function.

The final report [30] synthesizes of the results of all the work of this 2009-2012 ADEME Convention

8.1.3. Promotion of Mathematics in the industry

D. Talay is the Vice-President of the Fondation d'Entreprise Natixis which aims to contribute to develop research in quantitative finance. He also serves as a member of the Scientific Committee of the Foundation.

D. Talay is a member of the Scientific Committee of the AMIESNational Agency aimed to promote interactions between Mathematics and Industry.

8.2. European Initiatives

8.2.1. FP7 Projects

- A. Lejay participates to the *Multifractionality* (action Marie Curie *International Research Staff Exchange Scheme* FP7-PEOPLE-IRSES-2008) with Nancy, Kiev, Israël and Cardiff (2009–2012).

8.3. International Initiatives

8.3.1. Inria Associate Team: ANESTOC

Title: Stochastic modelling of renewable energies

Inria principal investigator: Denis Talay

International Partner (Institution - Laboratory - Researcher):

Pontificia Universidad Católica de Chile (Chile) - ANESTOC - Rolando Rebolledo

Duration: 2011 - 2013

See also: http://www.anestoc.cl/es/?page_id=1112

This associate team complements a CIRIC research program in Chile. We refer to the TOSCA-ANESTOC project on stochastic modelling of renewable energies, especially wind farms, and oceanic resources. Our associate team (”équipe associée Inria”) will conduct its joint research at two different levels. Firstly, the mathematical work on its own which we have called the ”Mathematical Kernel” (MK), motivated by a number of fundamental problems raised by the specific applications in which we are interested. The second level of research concerns two main axes of Applications: (A1) Applications to Engineering (Renewable energies) and (A2) Applications to Neuroscience. The Mathematical Kernel includes a number of fields in the domains of Stochastic Analysis, Statistics and Numerical Analysis. In particular, it is worth mentioning the following: 1. Probabilistic resolution of Boussinesq non-linear partial differential equations; 2. Stochastic approach to Pope’s equations on wind dynamics; 3. Open system dynamics as a bridge between Molecular Dynamics and Stochastic Differential Equations; 4. Inference on Stochastic Processes; 5. Algorithms and simulation. The Applications include the stochastic modelling of renewable energy through ocean resources and wind farms (CIRIC-subproject). This subject will be developed with engineers of the Catholic University of Chile. In addition, applications to ion-channel dynamics through cell membranes will be considered jointly with biophysicists of the CINV (Neuroscience Centre of Valparaíso).

8.3.2. Inria International Partners

- TOSCA participates to the NCCR FINRISK (Financial Risk) forum launched by the Swiss National Science Foundation and managed by the University of Zürich.

8.3.3. Participation In International Programs

- D. Talay was the international coordinator of the MathAmsud program 08MATH05 - Stochastic Analysis and Mathematical Physics Research Network which started in 2009, also involved M. Bossy, A. Lejay and E. Tanré, and ended this year.
- M. Bossy, , A. Lejay, D. Talay and E. Tanré are members of the CIRIC project *Stochastic Analysis of Renewable Energies: Ocean Energy and Wind Farms; dynamics and numerics* with Chile.

8.4. International Research Visitors

8.4.1. Visits of International Scientists

- L. Beznea (Simion Stoilow of the Institute of Mathematics of the Romanina Academy) has been visiting TOSCA Nancy for five weeks in April, November and December.
- Patricio Orio (Univ. of Valparaiso) visited TOSCA Sophia-Antipolis one week in October.
- The TOSCA *seminar* organized by J. Charrier and J. Inglis in Sophia Antipolis has received the following speakers: Rolando Rebolledo (Universidad de Chile), François Dufour (Université Bordeaux), Nicole El Karoui (Ecole Polytechnique, Palaiseau), Huyên Pham (Université Paris Diderot), Pierre Patie (Université Libre de Bruxelles), Pierre-Louis Lions (Collège de France), Nicolas Perrin (Inria Sophia Antipolis – Méditerranée), Philip Protter (Columbia University, USA), Mathieu Rosenbaum (CREST), Nicolas Bouleau (ENPC), Jean Jacod (Université Pierre et Marie Curie, Paris), Jonathan Mattingly (Duke University, USA), Patricio Orio (Universidad de Valparaìso, Chile), Carl Graham (Ecole Polytechnique, Palaiseau).

8.4.2. Internships

Souhail BOUKHEROUAA (from Mar 2012 until Aug 2012)

Subject: Evaluation of Value-at-Risk and applications to portfolio management

Institution: Université de Lorraine and Alphability

Yi LU (from May 2012 until July 2012)

Subject: Asymptotic expansions methods for options prices.

Institution: École Polytechnique

Rajarshi SARKHAR (from March 2012 until August 2012)

Subject: The First Passage Time Problem

Institution: University of Nice - Master Erasmus Mundus Mathmodes

Khaled SALHI (from Feb 2012 until Jun 2012)

Subject: Uncertainties and stochastic volatility models

Institution: Ecole Polytechnique de Tunisie (Tunisia)

8.4.3. Visits to International Teams

- M. Deaconu was invited one week by Fabio Nobile at the *Ecole Polytechnique Fédérale de Lausanne* in July.
- A. Lejay spend a month at the Bernoulli Center at Ecole Polytechnique Fédérale de Lausanne during the SPDE Semester.
- E. Tanré has visited University of Valparaìso and Pontifical University in Chile in January and March.

9. Dissemination

9.1. Scientific Animation

- M. Bossy is a member of the Scientific Committee of the *École Doctorale "Sciences Fondamentales et Appliquées"* of the Université de Nice – Sophia Antipolis.
- M. Bossy is a member of the *Collectif Andromede* of the PACA Region council.
- M. Bossy is a elected member of the Inria Evaluation Board, a member of the NICE Committee of Inria Sophia Antipolis –Méditerranée.
- M. Deaconu is a member of the *COST-GTAI (Groupe de Travail Actions Incitatives)* of Inria, of *Comité des Projets* and *Bureau du Comité des Projets* at Inria Nancy, Grand-Est.
- M. Deaconu is a member of the *Conseil de Laboratoire* at Elie Cartan Institute in Nancy.
- M. Deaconu organized the session *Probabilités Numériques* in the *11th Colloque Franco-Roumain de Mathématiques Appliquées* held in Bucharest in August.
- A. Lejay is member of a editorial board of the collection *Séminaire de Probabilités*.
- A. Lejay is member of the scientific committee of the *Journées de Probabilités*.
- A. Lejay is general Secretary of Société des Mathématiques Appliquées et Industrielles (SMAI).
- A. Lejay is elected member of the Commission du Personnel of the Institut Élie Cartan.
- A. Lejay is member of the COMIPERS at Inria Nancy Grand-Est.
- D. Talay served as the Scientific Deputy of Inria Sophia Antipolis — Méditerrannée.
- D. Talay, jointly with F. Delarue (Université de Nice Sophia Antipolis) and G. Pagès (Paris 6 University), organized the workshop ERGONUM in Sophia Antipolis in June.
- D. Talay served as an Associate Editor of: *Stochastic Processes and their Applications*, *ESAIM Probability and Statistics*, *Stochastics and Dynamics*, *SIAM Journal on Numerical Analysis*, *SIAM Journal in Financial Mathematics*, *Journal of Scientific Computing*, *Monte Carlo Methods and Applications*, *Oxford IMA Journal of Numerical Analysis*, *Communications in Applied Mathematics and Computational Science*, *Éditions de l'École Polytechnique*. He also served as the Co-editor in chief of *MathematicS in Action*.

- D. Talay is serving as a member of the Advisory Board of the Centro de Mathematica da Universidade do Porto (Portugal).
- D. Talay participated to a junior position recruitment committee at Paris 6 University.

9.2. Teaching - Supervision - Juries

9.2.1. Teaching

Master : M. Bossy, *Continuous Probabilistic Models with Applications in Finance*, 45h, M2 IMAFA (*Informatique et Mathématiques Appliquées à la Finance et à l'Assurance*), *Ecole Polytechnique Universitaire*, Univ. Nice – Sophia Antipolis, France.

Master : M. Bossy, *Risk management on energetic financial markets*, 13.5h, Master *Ingénierie et Gestion de l'Energie*, École des Mines de Paris at Sophia-Antipolis, France.

Master : M. Bossy *Particle Methods*, 18 h, Master 2 *Probabilité et Applications* at Université Paris 6, France.

Master: N. Champagnat, *Introduction to Quantitative Finance*, 13.5h, M1, Ecole des Mines de Nancy, France.

Master: N. Champagnat, *Introduction to Quantitative Finance*, 22.5h, M2, Ecole des Mines de Nancy, France.

Licence: P. Charton *Evaluation des méthodes d'analyse appliquées aux sciences de la vie et de la santé*, 27h, L1, Univ. de Lorraine, France.

Licence: P. Charton *Outils théoriques : probabilités statistiques*, 37h, L3, Univ. de lorraine, France.

Master: M. Deaconu, *Stochastic modeling*, 30h, M2, Université de Lorraine, France.

Master: M. Deaconu, *Simulation of random variables*, 9h, M1, Ecole des Mines de Nancy, France.

Master : A. Lejay, *Probabilistic Numerical methods for Mathematical Finance*, 28.5h, M2, Université de Lorraine (Metz), France.

Master : A. Lejay, *Numerical methods*, 22.5h, M2, Université de Lorraine (Nancy), France.

Master: D. Talay, *Stochastic Flows*, 12h, M2 *Probabilités et Applications* and M2 *Probabilités et Finance* at Université Paris 6, France.

Master: E. Tanré, *Advanced numerics for Computational Finance*, 30 h, M2, UNSA (Mathmodes Erasmus Mundus), France.

Master: E. Tanré, *Numerical Probability in Finance*, 12 h, M2, Ecole PolytechNice (IMAFA), France.

Master: E. Tanré, *Numerical Methods in Finance*, two sessions with 18 h, M2, ULB (University Certificates in Financial and Insurance Risk Modelling And Quantitative Methods in Finance), Belgium.

Licence : D. Villemonais, *Probabilités*, 21h, L3, École des Mines de Nancy, France.

Master: L. Violeau, *Continuous Probabilistic Models with Applications in Finance* (exercice classes), 20h, M2 IMAFA (*Informatique et Mathématiques Appliquées à la Finance et à l'Assurance*), Ecole Polytechnique Universitaire, Univ. Nice, France.

Licence: L. Violeau, *Probabilty and Statistics* (exercice classes), 20h, L3, Ecole Polytechnique Universitaire, Univ. Nice, France.

9.2.2. Supervision

- PhD in progress: Paul Charton, *Hedging strategies for wind energy prices*, September 2010, M. Deaconu and A. Lejay.
- PhD in progress: Julien Claisse, *Stochastic control of population dynamics*, September 2010, N. Champagnat, D. Talay.

- PhD in progress: Dalia Ibrahim, *Mathematical modelling for technical analysis techniques*, November 2009, D. Talay and E. Tanré.
- PhD in progress : Lionel Lenôtre, *Monte Carlo methods for discontinuous media*, Université Rennes 1, started in October 2012, Jocelyne Erhel (IRISA), Antoine Lejay and Géraldine Pichot (IRISA).
- PhD in progress : Geoffrey Nichil, *Provisionnement en assurance non-vie et optimisation du calcul du SCR*, 2011, S. Herrmann and P. Vallois.
- PhD in progress: Sebastian Niklitschek-Soto, *Discretized stochastic differential equations related to one-dimensional partial differential equations of parabolic type involving a discontinuous drift coefficient*, September 2010, D. Talay.
- PhD in progress: Nicolas Perrin, *Stochastic methods in molecular dynamics*, October 2009, M. Bossy, N. Champagnat, D. Talay.
- PhD in progress: Laurent Violeau, *Stochastic Lagrangian Models and Applications to Downscaling in Fluid Dynamics*, October 2010, M. Bossy and A. Rousseau.

9.2.3. Juries

- M. Bossy reported on the Ph.D. thesis of Lokman Abbas-Turki, Université Paris-Est.
- A. Lejay was an expert for the thesis of N. Marie (Université Paul Sabatier, Toulouse, France).
- D. Talay reported on the Habilitation à Diriger les Recherches of M. Benalaya (Université Paris 13), and on the Ph.D. thesis of N. Millot (Ecole Centrale) and N. Belaribi (University Paris 13). He also chaired the Committee for the Habilitation à Diriger les Recherches of A. Gloria (Université de Lille).

9.3. Popularization

- A. Lejay is a member of the organizing committee of the *Forum des lauréats des prix en informatique et mathématiques appliquées* (Inria & SMAI) held in Paris in December 2012.

9.4. Participation to congresses, conferences, invitations...

- M. Bossy gave invited talks at the *IMA Workshop Mathematics of the New Financial Systems University of Minnesota* in May and at the *Journees MAIRCI, Bull Grenoble* in September.
- M. Bossy gave talks at the *workshop MathAmSud* at Santiago, Chile in January and at the *Conference in Energy Finance at WPI* at Vienna, Austria in September.
- N. Champagnat gave a 4h lecture on *Modèles stochastiques individu-centrés en dynamique adaptative et étude du branchement évolutif* at the Summer School *Modélisation en dynamique des populations et Évolution: Probabilités et EDP* in September at La Londe les Maures.
- N. Champagnat gave talks at the MBI Workshop on *Evolution and Spread of Disease* in Columbus, Ohio, USA in March, at the Conference on *Probability, Population Genetics and Evolution* at the CIRM in Marseille in June, at the *6th European Congress of Mathematics (6ECM)* in Krakow in July and at the *XIème Colloque Franco-Roumain de Mathématiques Appliquées (CFR2012)* in Bucarest in August.
- N. Champagnat gave seminar talks at the SMILE Seminar on *Stochastic Models for the Inference of Life Evolution* at Collège de France, Paris, in March, at the *Rencontres de la Chaire MMB (Modélisation Mathématique et Biodiversité)* at Ecole Polytechnique, Palaiseau in June, at the workshop *Modèles stochastiques pour l'écologie et la biologie* of the Labex Numev in Montpellier in October, and at the *Séminaire de Probabilités de l'Institut de Mathématiques de Toulouse* in Toulouse in November.

- M. Deaconu gave invited talks at the *Workshop, Sequential Monte Carlo Methods and Efficient Simulation in Finance* at the Ecole Polytechnique in Paris in October, at the *Workshop, Perspective asupra cecetarii matematice in societatea bazata pe cunoastere*, organisé dans le cadre de la Conférence *Diaspora in Cercetarea Stiitifica si Invatamantul Superior in Romania*, in October, at the *Ecole Polytechnique Fédérale de Lausanne (EPFL)* in Lausanne in July.
- M. Deaconu gave a seminar talk at the *Séminaire de Probabilités et Statistiques de l'Institut de Mathématiques de Bourgogne*, in January.
- D. Ibrahim gave a talk at the *Chair of Quantitative Finance seminar* of Centrale Paris, in April.
- J. Inglis participated in the international colloquium *Random Models in Neuroscience* at the Université Pierre et Marie Curie (Paris) in July.
- A. Lejay gave a talk at the conference *Recent Developments in Stochastic Analysis* at Lausanne (Switzerland) in February and at the workshop *Rough Paths and PDEs* at Oberwolfach (Germany) in August.
- A. Lejay gave seminar talks at the probability seminars of Université du Maine (Le Mans), Université de Bourgogne, Université de Grenoble and Université de Rennes.
- D. Talay gave talks at the *workshop MathAmSud* at Santiago, Chile in January and at the XV Ecole Franco-Espagnole Jacques-Louis Lions at Malaga in September. He also gave several seminars at Ecole Polytechnique and a seminar at Columbia University in October.
- D. Talay gave a plenary conference at ICNAAM 2012 in Greece in September.
- D. Talay gave mini-courses at the Séminaire Bachelier (Institut H. Poncaré, Paris) in January and February, and at ICERM (Brown Univeristy) in October.
- E. Tanré gave one talk at the *MathAmSud Workshop* in Santiago, Chile in January and two talks at the *CLAPEM (Latin American Congress of Probability and Mathematical Statistics)* in March at Vina del Mar, Chile.
- E. Tanré gave an invited talk at the International Colloquium *Random Models in Neuroscience* at the Université Pierre et Marie Curie (Paris) in July.
- E. Tanré gave a seminar talk at the *Probability Seminar* of Univ. of Bourgogne (Dijon).
- D. Villemonais gave a 6h lecture on *Distributions quasi-stationnaires* at the *Université de Marseille* in June 2012.
- D. Villemonais gave talk at the *Inhomogeneous random systems* annual workshop at the Institut Henri Poincaré in Paris in January 2012.
- L. Violeau gave a talk at the *XIème Colloque Franco-Roumain de Mathématiques Appliquées (CFR2012)* in Bucarest in August.

10. Bibliography

Major publications by the team in recent years

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[2] M. BOSSY, E. GOBET, D. TALAY. *A symmetrized Euler scheme for an efficient approximation of reflected diffusions*, in "J. Appl. Probab.", 2004, vol. 41, n^{o} 3, p. 877–889.

[3] M. BOSSY, B. JOURDAIN. *Rate of convergence of a particle method for the solution of a 1D viscous scalar conservation law in a bounded interval*, in "Ann. Probab.", 2002, vol. 30, n^{o} 4, p. 1797–1832.

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[13] N. CHAMPAGNAT, A. LAMBERT. *Splitting trees with neutral Poissonian mutations I: Small families*, in "Stochastic Processes and their Applications", 2012, vol. 122, n^{o} 3, p. 1003-1033 [*DOI :* 10.1016/J.SPA.2011.11.002], http://hal.inria.fr/inria-00515481.

[14] N. CHAMPAGNAT, A. LAMBERT. *Splitting trees with neutral Poissonian mutations II: Largest and Oldest families*, in "Stochastic Processes and their Applications", 2013 [*DOI :* 10.1016/J.SPA.2012.11.013], http://hal.inria.fr/inria-00616765.

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[25] A. KOHATSU-HIGA, A. LEJAY, K. YASUDA. *On Weak Approximation of Stochastic Differential Equations with Discontinuous Drift Coefficient*, in "Mathematical Economics", Kyoto, Japan, C. HARA (editor), RIMS Kôkyûroku, April 2012, vol. 1788, p. 94-106, This is an abridged version submitted in a conference proceedings., http://hal.inria.fr/hal-00670123.

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