RESEARCH CENTRE

**Nancy - Grand Est**

2020

ACTIVITY REPORT

Team

# TOSCA-NGE

## TO Simulate and CAlibrate stochastic models

Inria teams are typically groups of researchers working on the definition of a common project, and objectives, with the goal to arrive at the creation of a project-team. Such project-teams may include other partners (universities or research institutions)

**DOMAIN**

**Applied Mathematics, Computation and Simulation**

**THEME**

**Stochastic approaches**

# Contents

# Team TOSCA-NGE

*Creation of the Team: 2018 December 20, end of the Team: 2020 November 30*


## Keywords

### Computer sciences and digital sciences

A6.1.2. – Stochastic Modeling

A6.2.2. – Numerical probability

A6.2.3. – Probabilistic methods

### Other research topics and application domains

B1.1.8. – Mathematical biology

B2.2.3. – Cancer

B3.2. – Climate and meteorology

# 1 Team members, visitors, external collaborators

### Research Scientists

- Madalina Deaconu [Team leader, Inria, Researcher, until Nov 2020, HDR]
- Nicolas Champagnat [Inria, Senior Researcher, until Nov 2020, HDR]
- Coralie Fritsch [Inria, Researcher, until Nov 2020]
- Antoine Lejay [Inria, Senior Researcher, until Nov 2020, HDR]

### Faculty Member

- Denis Villemonais [Univ de Lorraine, Associate Professor, until Nov 2020, HDR]

### Post-Doctoral Fellows

- William Ocafrain [Inria, from Oct 2020 until Nov 2020]
- Edouard Strickler [Inria, until Sep 2020]

### PhD Students

- Alexis Anagnostakis [Univ de Lorraine, until Nov 2020]
- Vincent Hass [Inria, until Nov 2020]
- Rodolphe Loubaton [Univ de Lorraine, until Nov 2020]
- Christophe Reype [Univ de Lorraine, until Nov 2020]
- Nicolas Zalduendo Vidal [Inria, from Oct 2020 until Nov 2020]

### Interns and Apprentices

- Tomas Ochoa Abett De La Torre [Inria, until Mar 2020]
- Nicolas Zalduendo Vidal [Inria, from Apr 2020 until Aug 2020]

### Administrative Assistant

- Isabelle Blanchard [Inria, until Nov 2020]

### External Collaborator

- Samuel Herrmann [Univ de Bourgogne, HDR]

# 2 Overall objectives

TOSCA-NGE aims to significantly contribute to discern and explore new horizons for stochastic modeling. To this end we need to better understand the issues of stochastic modeling and the objectives pursued by practitioners who need them: we thus need to deeply understand other scientific fields than ours (e.g., Fluid Mechanics, Ecology, Biophysics) and to take scientific risks. Indeed, these risks are typified by the facts that often new and complex models do not behave as expected, mathematical and numerical difficulties are harder to overcome than forecast, and the increase of our knowledge in target fields is slower than wished.

In spite of these risks we think that our scientific approach is relevant for the following reasons:

- On the one hand, physicists, economists, biologists and engineers use a stochastic model because they cannot describe the physical, economical, biological, etc., experiment under consideration with deterministic systems, either because the experiment has a huge complexity, or because accurate calibrations of the parameters of the models would be impossible. However it is far from being enough to add noise to a dynamical system or to substitute random variables as parameters: the probability distribution of the random noises and parameters themselves is a modeling issue and, in addition, the qualitative behavior of the model may dramatically change as a function of this choice; in other terms, adding randomness to capture uncertainties may increase uncertainty instead of aiding. This issue is not so well understood in the literature, where most often probabilistic structures are given A PRIORI rather than studied as questionable choices. **Therefore our works, which concern application fields where stochastic modeling is still in its very beginning, include analysis of the limitations of the models we are elaborating. This analysis is based, either on theoretical estimates, or on our unique experience in stochastic simulations.**

- On the other hand, STOCHASTIC COMPUTATIONAL MODELS are being developed here and there, including by our team, with a fully different point of view from classical modeling approaches: these models are aimed to approximate complex physical laws (e.g. Fluid Mechanics laws for turbulent flows or folding processes for proteins) by statistical properties of artificial objects (e.g. particles interacting with turbulent flows or low dimensional stochastic systems having suitable correlation structures). The design of the stochastic dynamics of these objects is part of the problem to deal with, and the complexity of the underlying physical phenomena leads to huge simulation difficulties. **Therefore we are exploring new frontiers for stochastic numerical methods and developing advanced techniques far beyond our previous works and most of the literature.**

To bring relevant analytical and numerical answers to the preceding problems, we feel necessary to attack in parallel several problems arising from different fields. Each one of these problems contributes to our better understanding of the advantages and limitations of stochastic models and algorithms.

Of course, this strategy allows each researcher in the team to have her/his own main topic. However **we organize the team in order to maximize internal collaborations**. We consider this point, which justifies the existence of Inria project-teams, as essential to the success of our programme of research. It relies on the fact that, to develop our mathematical and numerical studies, we share a common interest for collaborations with engineers, practitioners, physicists, biologists and numerical analysts, and we also share the following common toolbox:

- Stochastic differential calculus;

- Mathematical combinations of both partial differential equations (PDEs) analysis and stochastic analysis for deterministic non-linear PDEs, notably stochastic control equations and McKean-Vlasov-Fokker-Planck equations;

- Original stochastic numerical analysis techniques to get theoretical estimates on stochastic numerical methods, and numerical experiments to calibrate these methods.

We finally emphasize that the unifying theme of our research is to develop analytical tools that can be effectively applied to various problems that come from extremely diverse subjects. For example, as described in more detail below, we study: branching processes and their simulation with the view of advancing our understanding of population dynamics, molecular dynamics, and cancer models; the theory and numerical analysis of McKean-Vlasov interacting particle systems in order to develop our models in biology, computational fluid dynamics, coagulation and fragmentation; hitting times of domains by stochastic processes so that we can improve on the current methods and theory used in finance and neuroscience.

Our recent directions of research, combining stochastic modelling and data analysis, will conduct to a new Inria team, named PASTA. PASTA research program is focused on spatio-temporal stochastic processes and their applications.

# 3 Research program

Most often physicists, economists, biologists and 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. Therefore, 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 threshold 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 (SDEs), 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

TOSCA-NGE is interested in developing stochastic models and probabilistic numerical methods. Our present motivations come from models with singular coefficients, with applications in Geophysics, Molecular Dynamics and Neurosciences; Population Dynamics, Evolution and Genetics; and Financial Mathematics.

## 4.1 Stochastic models with singular coefficients: Analysis and simulation

Stochastic differential equations with discontinuous coefficients arise in Geophysics, Chemistry, Molecular Dynamics, Neurosciences, Oceanography, etc. In particular, they model changes of diffusion of fluids, or diffractions of particles, along interfaces.

For practitioners in these fields, Monte Carlo methods are popular as they are easy to interpret — one follows particles — and are in general easy to set up. However, dealing with discontinuities presents many numerical and theoretical challenges. Despite its important applications, ranging from brain imaging to reservoir simulation, very few teams in mathematics worldwide are currently working in this area. The Tosca project-team has tackled related problems for several years providing rigorous approach. Based on stochastic analysis as well as interacting with researchers in other fields, we developed new theoretical and numerical approaches for extreme cases such as Markov processes whose generators are of divergence form with discontinuous diffusion coefficient.

The numerical approximation of singular stochastic processes can be combined with backward stochastic differential equations (BSDEs) or branching diffusions to obtain Monte Carlo methods for quasi-linear PDEs with discontinuous coefficients. The theory of BSDEs has been extensively developed since the 1980s, but the general assumptions for their existence can be quite restrictive. Although the probabilistic interpretation of quasi-linear PDEs with branching diffusions has been known for a long time, there have been only a few works on the related numerical methods.

Another motivation to consider stochastic dynamics in a discontinuous setting came to us from time evolution of fragmentation and coagulation phenomena, with the objective to construct stochastic models for the avalanche formation of soils, snow, granular materials or other geomaterials. Most of the models and numerical methods for avalanches are deterministic and involve a wide variety of physical parameters such as the density of the snow, the yield, the friction coefficient, the pressure, the basal topography, etc. One of these methods consists in studying the safety factor (or limit load) problem, related to the shallow flow of a visco-plastic fluid/solid with heterogeneous thickness over complex basal topography. The resulting nonlinear partial differential equation of this latter theory involves many singularities, which motivates us to develop an alternative stochastic approach based on our past works on coagulation and fragmentation. Our approach consists in studying the evolution of the size of a typical particle in a particle system which fragments in time and to study particular fragmentation kernels.

## 4.2 First hitting times distributions

Diffusion hitting times are of great interest in many domains as in finance (a typical example is the study of barrier options), in Geophysics and Neurosciences. On the one hand, analytic expressions for hitting time densities are well known and studied only in some very particular situations (essentially in Brownian contexts). On the other hand, the study of the approximation of the hitting times for stochastic differential equtions is an active area of research since very few results still are available in the literature. The mainly existing methods are based on Euler and Monte Carlo procedures. We work on alternative methods based on the construction of particular nonlinear boundaries for which we can express explicitly the distribution of the hitting time. We couple this explicit form with the construction of the exit time and exit position for well chosen domains.

## 4.3 Population Dynamics, Evolution and Genetics

The activity of the team on stochastic modeling in population dynamics and genetics mainly concerns application in adaptive dynamics, a branch of evolutionary biology studying the interplay between ecology and evolution, ecological modeling, population genetics in growing populations, and stochastic control of population dynamics, with applications to cancer growth modeling. Stochastic modeling in these areas mainly considers individual-based models, where the birth and death of each individual is described. This class of model is well-developed in Biology, but their mathematical analysis is still fragmentary. Another important topic in population dynamics is the study of populations conditioned to non-extinction, and of the corresponding stationary distributions, called quasi-stationary distributions (QSD). This domain has been the object of a lot of studies since the 1960's, but we made recently significant progress on the questions of existence, convergence and numerical approximation of QSDs using probabilistic tools rather than the usual spectral tools.

Our activity in population dynamics also involves a fully new research project on cancer modeling at the cellular level by means of branching processes. In 2010 the International Society for proton dynamics in cancer was launched in order to create a critical mass of scientists engaged in research activities on these subjects, leading to the facilitation of international collaboration and translation of research to clinical development. Actually, a new branch of research on cancer evolution is developing intensively; it aims in particular to understand the role of proteins acting on cancerous cells' acidity, their effects on glycolysis and hypoxia, and the benefits one can expect from controlling pH regulators in view of proposing new therapies.

## 4.4 Stochastic modeling in Financial Mathematics

### 4.4.1 Technical Analysis

In the financial industry, there are three main approaches to investment: the fundamental approach, where strategies are based on fundamental economic principles; the technical analysis approach, where strategies are based on past price behavior; and the mathematical approach where strategies are based on mathematical models and studies. The main advantage of technical analysis is that it avoids model specification, and thus calibration problems, misspecification risks, etc. On the other hand, technical analysis techniques have limited theoretical justifications, and therefore no one can assert that they are risk-less, or even efficient.

### 4.4.2 Financial Risk Estimation and Hedging

Popular models in financial mathematics usually assume that markets are perfectly liquid. In particular, each trader can buy or sell the amount of assets he/she wants at the same price (the “market price”). They moreover assume that the decision taken by the trader does not affect the price of the asset (the small investor assumption). In practice, the assumption of perfect liquidity is never satisfied but the error due to liquidity is generally negligible with respect to other sources of error such as model error or calibration error, etc.

Derivatives of interest rates are singular for at least two reasons: firstly the underlying (interest rate) is not directly exchangeable, and secondly the liquidity costs usually used to hedge interest rate derivatives have large variation in times.

Due to recurrent crises, the problem of risk estimation is now a crucial issue in finance. Regulations have been enforced (Basel Committee II). Most asset management software products on the markets merely provide basic measures (VaR, Tracking error, volatility) and basic risk explanation features (e.g., “top contributors” to risk, sector analysis, etc).

# 5 New results

## 5.1 Probabilistic numerical methods, stochastic modeling and applications: published works and preprints

- Together with M. Benaïm (Univ, Neuchâtel), N. Champagnat and D. Villemonais studied stochastic algorithms to approximate quasi-stationary distributions of diffusion processes absorbed at the boundary of a bounded domain. They study a reinforced version of the diffusion, which is resampled according to its occupation measure when it reaches the boundary. They show that its occupation measure converges to the unique quasi-stationary distribution of the diffusion process [8].

- N. Champagnat, C. Fritsch and S. Billiard (Univ. Lille) studied models of food web adaptive evolution. They identified the biomass conversion efficiency as a key mechanism underlying food web evolution and discussed the relevance of such models to study the evolution of food web [17].

- N. Champagnat and D. Villemonais solved a general conjecture on the Fleming-Viot particle systems approximating quasi-stationary distributions (QSD): in cases where several quasi-stationary distributions exist, it is expected that the stationary distributions of the Fleming-Viot processes approach a particular QSD, called minimal QSD. They proved that this holds true for general absorbed Markov processes with soft obstacles [10].

- N. Champagnat and D. Villemonais studied the geometric convergence of normalized unbounded semigroups. They proved that general criteria for this convergence can be easily deduced from their recent results on the theory of quasi-stationary distributions.

- N. Champagnat, S. Méléard (École Polytechnique) and V.C. Tran (Univ. Paris Est Marne-la-Vallée) studied evolutionary models of bacteria with horizontal transfer. They considered in [9] a scaling of parameters taking into account the influence of negligible but non-extinct populations, allowing them to study specific phenomena observed in these models (re-emergence of traits, cyclic evolutionary dynamics and evolutionary suicide).

- M. Deaconu worked with L. Beznea (IMAR Bucarest) and O. Lupaşcu-Stamate (ISMMA Bucarest) on the scaling property for fragmentation stochastic processes related to avalanches [14].
- M. Deaconu and S. Herrmann worked on new techniques for the path approximation, more precisely the $\varepsilon$-strong approximation of one-dimensional stochastic processes, as the Brownian motion and families of stochastic differential equations sharply linked to the Brownian motion (usually known as L and G-classes).They proposed an explicit and easy to implement procedure that constructs jointly, the sequences of exit times and corresponding exit positions of some well chosen domains [16].
- M. Deaconu worked with L. Hurtado-Gil, (University CEU Sao Paulo, Madrid), A. Philippe (University of Nantes) and R. Stoica (University of Lorraine) on a new algorithm called shadow simulated annealing algorithm that represents a new tool for global optimisation and statistical inference [22].
- M. Deaconu and C. Reype worked with R. Stoica (University of Lorraine) and A. Richard (University of Lorraine) on the Bayesian statistical analysis of hydrogeochemical data using point processes. This is used as a new tool for source detection in multicomponent fluid mixtures [13].
- M. Deaconu, A. Lejay and L. Lesage worked on applications of Hawkes processes in insurance [19].
- A. Lejay worked with R. Stoica (University of Lorraine) on the application of Hawkes process for seismic data analysis [12].
- A. Anagnostakis, A. Lejay and D. Villemonnais worked on a new method to simulate SDE with degenerate coefficients [15].
- A. Lejay worked on the construction of rough flows and generalization of the structure allowing to define rough differential equations [18].

### 5.2 Other works in progress

- A. Anagnostakis, A. Lejay and D. Villemonnais are working on the estimation of the parameter of the sticky Bronwian motion.
- N. Champagnat and C. Fritsch are working with A. Harlé (Institut de Cancérologie de Lorraine), J.-L. Merlin (ICL), E. Pencreac'h (CHRU Strasbourg), U. Herbach, A. Gégout-Petit, P. Vallois, A. Muller-Gueudin (Inria BIGS team) and A. Kurtzmann (Univ. Lorraine) within an ITMO Cancer project on modeling and parametric estimation of dynamical models of circulating tumor DNA (ctDNA) of tumor cells, divided into several clonal populations. The goal of the project is to predict the emergence of a clonal population resistant to a targeted therapy in a patient's tumor, so that the therapy can be modulated more efficiently.
- N. Champagnat and R. Loubaton are working with P. Vallois (Univ. Lorraine and Inria BIGS team) and L. Vallat (CHRU Strasbourg) on the inference of dynamical gene networks from RNAseq and proteome data.
- N. Champagnat, E. Strickler and D. Villemonais are working on the characterization of convergence in Wasserstein distance of conditional distributions of absorbed Markov processes to a quasi-stationary distribution.
- N. Champagnat and V. Hass are studying evolutionary models of adaptive dynamics under an assumption of large population and small mutations. They expect to recover variants of the canonical equation of adaptive dynamics, which describes the long time evolution of the dominant phenotype in the population, under less stringent biological assumptions than in previous works.

- N. Champagnat, W. Oçafrain and D. Villemonais are working on the quasi-stationary behaviour of time-inhomogeneous Markov processes conditioned to stay within time-varying domains. This work is a follow-up of two recent articles by W. Oçafrain [11, 20]. They are also working with M. Benaïm on existence and uniqueness of quasi-stationary distributions of general hypoelliptic Markov processes.
- M. Deaconu is working with L. Beznea (IMAR Bucarest) and O. Lupaşcu-Stamate (ISMMA Bucarest) on non-local branching stochastic processes associated to the Navier-Stokes equation.
- M. Deaconu and S. Herrmann are working on the $\varepsilon$-strong approximation for the Bessel processes.
- M. Deaconu and S. Herrmann are working with C. Zucca (University of Turin) on the approximation of first exit times, passage times and hitting times of multi-dimensional diffusions. This is done in a research in pairs collaboration and a grant from University of Burgundy.
- M. Deaconu is working with O. Lupaşcu-Stamate (ISMMA) on an interacting particles system for avalanches and the construction of an adapted numerical scheme.
- M. Deaconu and A. Lejay are working with E. Mordecki (University of the Republic, Uruguay) on the optimal stopping problem for the Snapping out Brownian motion.
- M. Deaconu and A. Lejay are working on the fragmentation processes with applications to avalanches. They are also working on this subject and the integration of real data in the model with geophysicits in Grenoble.
- C. Fritsch, D. Villemonais and N. Zalduendo Vidal are working on bisexual multitypes branching processes.
- C. Fritsch and D. Villemonais are working with E. Horton (Inria, Bordeaux) on stochastic models for the evolution of telomeres.
- C. Fritsch is working with B. Cloez (INRAE, Montpellier) on the long time behavior of the Crump-Young model of a chemostat.
- C. Fritsch is working with A. Gégout-Petit (Univ. Lorraine and EPI Bigs ), B. Marçais (INRAE, Nancy) and M. Grosdidier (INRAE, Avignon) on a statistical analysis of a Chalara Fraxinea model [21]
- A. Lejay and S. Mazzonetto (IECL) are working on the estimation of the parameter of the Skew Brownian motion.

# 6 Partnerships and cooperations

## 6.1 International initiatives

### 6.1.1 BRN

- Title: Biostochastic Research Network
- Funding: Conicyt Chile
- International Partner (Institution - Laboratory - Researcher):
  - Universidad de Valparaiso (Chile) - CIMFAV – Facultad de Ingenieria - Soledad Torres, Rolando Rebolledo
  - CNRS, Inria & IECL - Institut Élie Cartan de Lorraine (France) - N. Champagnat, A. Lejay (coordinator for France), D. Villemonnais, R. Schott.
- Duration: 2018 - 2022
- Goal: scientific exchange around probabilistic models in population ecology.

#### 6.1.2 ANR EDDA

- Title: EnhanceD Data stream Analysis
- International Partner (Institution - Laboratory - Researcher):
  - Japan Agency for Marine-Earth Science and Technology
  - University of Greifswald
  - CNRS, Inria & IECL - Institut Élie Cartan de Lorraine (France) - M. Clausel (coordinator for France), A. Lejay.
- Duration: Dec 2019 - 2022
- Goal: Develop new machine learning techniques based on the signature methods and iterated integrals.

### 6.2 National initiatives

#### 6.2.1 ITMO Cancer

- Title: Modeling ctDNA dynamics for detecting targeted therapy resistance
- Funding: INSERM
- Partners (Institution - Laboratory - Researcher):
  - CHRU Strasbourg (Centre Hospitalier Régional Universitaire)
  - CRAN (Centre de Recherche en Automatique de Nancy)
  - ICL (Institut de Cancérologie de Lorraine)
  - CNRS, Inria & IECL - Institut Élie Cartan de Lorraine (France) - N. Champagnat (coordinator), C. Fritsch
  - Inria teams BIGS and TOSCA
- Duration: 2017-2022

## 7 Dissemination

### 7.1 Promotion of Mathematics in the Industry

- A. Lejay is a member of the board of AMIES (Agence Mathématiques en Intéractions avec l'Entreprise et la Société). A. Lejay is an editor of the *success stories* project.
- M. Deaconu is leading the Fédération Charles Hermite which organized the Forum Fédération Charles Hermite - Entreprises on 23rd January 2020. Five Pôles de Competitivité were participating.

### 7.2 Promoting scientific activities

#### 7.2.1 Scientific events: organisation

**General chair, scientific chair** C. Fritsch organized with Pascal Moyal (Univ. de Lorraine) the weekly Seminar of Probability and Statistics of IECL, Nancy until June 2020.

**Member of the organizing committees** N. Champagnat was a member of the organizing committee of the conference *Mathematical Models in Evolutionary Biology*, part of the Thematic Month on Mathematical Issues in Biology (CIRM, Luminy, 10–14 Feb. 2020).

A. Lejay was a member of the organizing committee of the conference *TRAG 2020* (Toulouse, 4-6 Nov. 2020) on rough paths.

### 7.2.2 Journal

**Member of the editorial boards**

- N. Champagnat serves as an associate editor of *Stochastic Models*.
- N. Champagnat serves as co-editor-in-chief with Béatrice Laurent-Bonneau (IMT Toulouse) of *ESAIM: Probability & Statistics*.
- A. Lejay is one of the three editors of the *Séminaire de Probabilités* and *Mathematics and Computers in Simulation* (MATCOM).

**Reviewer - reviewing activities**

- N. Champagnat wrote reviews for *Stochastic Processes and their Applications* and *Electronic Journal of Probability*.
- M. Deaconu wrote reviews for *Bernoulli*, *Journal of Computational and Applied Mathematics*, *Journal of Statistical Physics*, *Mathematics and Computer in Simulation and Stochastic* and *Partial Differential Equations: Analysis and Computation*.
- C. Fritsch wrote reviews for *the SIAM Journal on Applied Dynamical Systems*.
- A. Lejay wrote reviews for *Computers and Mathematics with Applications*, *Applied Economics Letter*, *Physical Review Research*, *Journal of Computational Physics*, *Mathematics and Computers in Simulation*, *Annals of the Institute of Statistical Mathematics*, *Physica A*, *Annals of Applied Probability*, *Numerical Algorithms* and *AIMS Mathematics*.
- D. Villemonais wrote reviews for *Electronic Communication in Probability*, *ESAIM: Probability & Statistics*, *Annals of Applied Probability*, *Stochastic Processes and their Applications*, *ALEA Latin American Journal of Probability and Mathematical Statistics*.

### 7.2.3 Invited talks

- N. Champagnat has been invited to give a mini-course "Population dynamics with extinction and quasi-stationary distributions" at the Research School of the *Chaire Modélisation Mathématique et Biodiversité* at Aussois, in September 2020.
- N. Champagnat has been invited to give a talk at the MFO-Workshop on "Stochastic Processes under Constraints", Mathematisches Forschungsinstitut Oberwolfach, Oberwolfach, Germany, in September 2020.
- C. Fritsch has been invited to give a talk at the conference *Mathematical Models in Evolutionary Biology*, part of the Thematic Month on Mathematical Issues in Biology, at CIRM, Luminy in February 2020.
- C. Fritsch has been invited to give a talk at the probability and statistics Seminar of *University of Montpellier* in January 2020.
- A. Lejay has been invited to give a talk at the probability Seminar of *Universitaät Duisburg-Essen* and *TU Berlin* in July 2020.

### 7.2.4 Leadership within the scientific community

- M. Deaconu is head of the Fédération Charles Hermite, a joint research federation between the CNRS and the Univ. of Lorraine. Three laboratories are composing it: CRAN, IECL and LORIA.
- A. Lejay is head of the Probability and Statistics team of Institut Élie Cartan de Lorraine.
- A. Lejay is head of the GdR TRAG (CNRS-INSMI), a national network on rough paths theory.

#### 7.2.5 Scientific expertise

- N. Champagnat evaluated a research project submitted to the ESF FWO's 2020 Call for Junior and Senior Research Projects.

#### 7.2.6 Research administration

- N. Champagnat is a member of the coordination committee of MODCOV19, a platform of coordination of research actions about modeling of SARS-CoV-2 (Covid-19) pandemic. He heads the bibliographic awareness group. https://modcov19.math.cnrs.fr/presentation/
- N. Champagnat is a member of the *Comité de Centre*, the *COMIPERS* and the *Commission Information Scientifique et Technique* of Inria Nancy - Grand Est, *Responsable Scientifique* for the library of Mathematics of the IECL, member of the *Conseil du laboratoire* of IECL (as *responsable scientifique* of the library). He is also local correspondent of the COERLE (*Comité Opérationel d'Évaluation des Risques Légaux et Éthiques*) for the Inria Research Center of Nancy - Grand Est.
- M. Deaconu is a member of the Bureau and Comité de Projets at Inria Research Center, Nancy - Grand Est, of the Bureau and Conseil de la Fédération Charles Hermite, of the Bureau and Conseil de Pôle AM2I (Univ. of Lorraine) and of the Conseil de l'IECL.
- C. Fritsch is a member of the *Commission du Développement Technologique* of Inria Nancy - Grand Est, of the *Commission du personnel* and the *Commission Parité-Égalité* of IECL. She is the local Radar correspondent for the Inria Research Center of Nancy - Grand Est.
- A. Lejay is a member of the Executive board of *LUE Impact project DigisTrust* (Univ. Lorraine), of the Conseil de Pôle AM2I (Univ. Lorraine) and of the CUMI (Inria NGE).
- D. Villemonais heads the "Ingénierie Mathématique" cursus of École des Mines de Nancy and is elected member of the conseil de l'École des Mines de Nancy.

### 7.3 Teaching - Supervision - Juries

#### 7.3.1 Teaching

- Master: N. Champagnat, *Introduction to Quantitative Finance*, 18h, M1, École des Mines de Nancy, France.
- Master: N. Champagnat, *Introduction to Quantitative Finance*, 13.5h, M2, École des Mines de Nancy, France.
- Master: N. Champagnat, *Problèmes inverses*, 22.5h, M1, École des Mines de Nancy, France.
- Master:M. Deaconu, *Stochastic Differential Equations: Numerical Scheme and Applications*, 24h École des Mines de Nancy.
- Master: M. Deaconu, *Stochastic modeling*, 30h, M2, École des Mines de Nancy and Univ. Lorraine.
- Master: M. Deaconu, *Simulation of random variables*, 18h, M1, École des Mines de Nancy.
- Master: M. Deaconu, *Monte Carlo Simulation*, 24h, M1 Ingénierie Financière de Marché, Univ. Lorraine.
- Master: C. Fritsch, *Probabilités*, 40h, L3, École des Mines de Nancy, France.
- Master: A. Lejay, *Probabilités*, 9h, 1st year École des Mines de Nancy, France.
- Master: A. Lejay, *Simulation des marchés financiers*, 29h, M2, Master PSA, Univ. Lorraine, France.
- Licence: D. Villemonais, *Probabilités*, 57h, L3, École des Mines de Nancy, France.

- Master: D. Villemonais, *Probabilités pour l'étude des processus aléatoires en temps discret*, 63h, M1, École des Mines de Nancy, France.
- Master: D. Villemonais, *Modélisation des séries temporelles*, 14h, M1, École des Mines de Nancy, France.
- Master: D. Villemonais, *Processus stochastiques*, 36h, M2, Univ. Lorraine, France.

#### 7.3.2 Supervision

- PhD in progress: Alexis Anagnostakis, *Étude du mouvement brownien collant*, Univ. Lorraine, October 2018, A. Lejay and D. Villemonais.
- PhD in progress: Vincent Hass, *Individual-based models in adaptive dynamics and long time evolution under assumptions of rare advantageous mutations*, Univ. Lorraine, October 2018, N. Champagnat.
- PhD in progress: Laurent Lesage, *Data Analysis for Insurance*, Univ. Luxembourg and Univ. Lorraine, September 2018, M. Deaconu and R. State (Univ. of Luxembourg).
- PhD in progress: Rodolphe Loubaton, *Caractérisation des cibles thérapeutiques dans un programme génique tumoral*, Univ. Lorraine, October 2018, N. Champagnat and L. Vallat (CHRU Strasbourg).
- PhD in progress: Christophe Reype, *Simultaneous parameter estimation and pattern detection in spatial data. Applications to the analysis of the dynamic in multi-component fluid mixtures in Geology*, Univ. Lorraine, October 2019, LUE grant, M. Deaconu and R. Stoica (Univ. Lorraine).
- PhD in progress: Nicolas Zalduendo Vidal, *Bisexual multitypes branching processes*, Univ. Lorraine, October 2020, C. Fritsch and D. Villemonais.

#### 7.3.3 Juries

- N. Champagnat served as an examiner for the habilitation thesis of Nicolas Gast, *Refinements of Mean Field Approximation*, Univ. Grenoble, January 2020.
- N. Champagnat served as a referee for the Ph.D. theses of Aurélien Velleret, *Mesures Quasi-Stationnaires et applications à l'adaptation de populations*, Aix-Marseille Univ., July 2020 and Léo Darrigade, *Modélisation du dialogue hôte-microbiote au voisinage de l'épithélium de l'intestin distal*, Univ. Paris Saclay, December 2020.
- M. Deaconu served as an examiner for the Ph.D. thesis of Florine Greciet, *Régression polynomiale par morceaux pour la propagation de fissures*, Univ. Lorraine, January 2020.
- A. Lejay serves as a referee for the Ph.D. theses of Anna Melnykova, *Statistical and numerical analysis of jump and diffusion models in biology*, University Cergy-Pointoise and Grenoble-Alpes, December 2020 and of Rancy El Nmeir, *Quantification gloutonne: nouvelle approche et applications aux E.D.S. rétrogrades réfléchies*, Sorbonne Université, December 2020.

### 7.4 Popularization

#### 7.4.1 Creation of media or tools for science outreach

A. Lejay is a editor of the project *Success Stories* (AMIES and FSMP) dedicated to create 2-page sheets to present successful interactions between industry and academia.

# 8 Scientific production

## 8.1 Major publications

[1] L. Beznea, M. Deaconu and O. Lupascu. 'Branching processes for the fragmentation equation'. In: *Stochastic Processes and their Applications* 125.5 (2015), pp. 1861–1885. DOI: 10.1016/j.spa.2014.11.016. URL: https://hal.inria.fr/hal-00948876.

[2] N. Champagnat, P.-E. Jabin and S. Méléard. 'Adaptation in a stochastic multi-resources chemostat model'. In: *Journal de Mathématiques Pures et Appliquées* 101.6 (June 2014), pp. 755–788. DOI: 10.1016/j.matpur.2013.10.003. URL: https://hal.inria.fr/hal-00784166.

[3] N. Champagnat and D. Villemonais. 'Exponential convergence to quasi-stationary distribution and Q-process'. In: *Probability Theory and Related Fields* 164.1 (2016). 46 pages, pp. 243–283. DOI: 10.1007/s00440-014-0611-7. URL: https://hal.archives-ouvertes.fr/hal-00973509.

[4] B. Cloez and C. Fritsch. 'Gaussian approximations for chemostat models in finite and infinite dimensions'. In: *Journal of Mathematical Biology* 75.4 (Oct. 2017), pp. 805–843. DOI: 10.1007/s00285-017-1097-6. URL: https://hal.archives-ouvertes.fr/hal-01371591.

[5] L. Coutin and A. Lejay. 'Perturbed linear rough differential equations'. In: *Annales mathématiques Blaise Pascal* 21.1 (Apr. 2014), pp. 103–150. DOI: 10.5802/ambp.338. URL: https://hal.inria.fr/hal-00722900.

[6] M. Deaconu and S. Herrmann. 'Hitting time for Bessel processes - walk on moving spheres algorithm (WoMS)'. In: *Annals of Applied Probability* 23.6 (2013), pp. 2259–2289. DOI: 10.1214/12-AAP900. URL: https://hal.archives-ouvertes.fr/hal-00636056.

[7] A. Lejay. 'The snapping out Brownian motion'. In: *Annals of Applied Probability* 26.3 (2016), pp. 1727–1742. DOI: 10.1214/15-AAP1131. URL: https://hal.inria.fr/hal-00781447.

## 8.2 Publications of the year

### International journals

[8] M. Benaïm, N. Champagnat and D. Villemonais. 'Stochastic approximation of quasi-stationary distributions for diffusion processes in a bounded domain'. In: *Annales de l'Institut Henri Poincaré (B) Probabilités et Statistiques* (2021). URL: https://hal.archives-ouvertes.fr/hal-02101739.

[9] N. Champagnat, S. Méléard and V. C. Tran. 'Stochastic analysis of emergence of evolutionary cyclic behavior in population dynamics with transfer'. In: *Annals of Applied Probability* (2021). URL: https://hal.inria.fr/hal-01974289.

[10] N. Champagnat and D. Villemonais. 'Convergence of the Fleming-Viot process toward the minimal quasi-stationary distribution'. In: *ALEA : Latin American Journal of Probability and Mathematical Statistics* 18 (2021), pp. 1–15. URL: https://hal.archives-ouvertes.fr/hal-01895618.

[11] W. Oçafrain. 'Quasi-stationarity for one-dimensional renormalized Brownian motion'. In: *ESAIM: Probability and Statistics* 24 (2020), pp. 661–687. DOI: 10.1051/ps/2020012. URL: https://hal.archives-ouvertes.fr/hal-02989002.

### Conferences without proceedings

[12] L. Ben Allal, A. Lejay and R. S. Stoica. 'Hawkes point processes based inference applied to seismic data analysis'. In: 2020 RING MEETING. Nancy, France: https://2020ringmeeting.event.univ-lorraine.fr/program, 2nd Sept. 2020. URL: https://hal.archives-ouvertes.fr/hal-02928408.

[13] C. Reype, A. Richard, M. Deaconu and R. S. Stoica. 'Bayesian statistical analysis of hydrogeochemical data using point processes: a new tool for source detection in multicomponent fluid mixtures'. In: RING Meeting 2020. Nancy, France, 7th Sept. 2020. URL: https://hal.archives-ouvertes.fr/hal-02933268.

### Scientific book chapters


[14] L. Beznea, M. Deaconu and O. Lupaşcu-Stamate. 'Scaling property for fragmentation processes related to avalanches'. In: *Applications of Mathematics and Informatics in Natural Sciences and Engineering*. Springer Proceedings in Mathematics & Statistics. 2020. URL: https://hal.archives-ouvertes.fr/hal-02942710.


### Reports & preprints


[15] A. Anagnostakis, A. Lejay and D. Villemonais. *General diffusion processes as the limit of time-space Markov chains*. 12th July 2020. URL: https://hal.inria.fr/hal-02897819.

[16] M. Deaconu and S. Herrmann. *Strong approximation of particular one-dimensional diffusions*. 14th Dec. 2020. URL: https://hal.archives-ouvertes.fr/hal-02799638.

[17] C. Fritsch, S. Billiard and N. Champagnat. *Identifying conversion efficiency as a key mechanism underlying food webs evolution : a step forward, or backward ?* 9th Feb. 2021. URL: https://hal.archives-ouvertes.fr/hal-02129313.

[18] A. Lejay. *Constructing general rough differential equations through flow approximations*. 4th Aug. 2020. URL: https://hal.inria.fr/hal-02871886.

[19] L. Lesage, M. Deaconu, A. Lejay, J. A. Meira, G. Nichil and R. State. *Hawkes processes framework with a Gamma density as excitation function: application to natural disasters for insurance*. 3rd Dec. 2020. URL: https://hal.inria.fr/hal-03040090.

[20] W. Oçafrain. *Ergodic theorem for asymptotically periodic time-inhomogeneous Markov processes, with application to quasi-stationarity with moving boundaries*. 11th Oct. 2020. URL: https://hal.archives-ouvertes.fr/hal-02963683.


## 8.3 Cited publications


[21] A. Gégout-Petit, C. Fritsch, M. Grosdidier and B. Marçais. 'Spatio-temporal modelling of the spread of chalara (illness of the ash tree) in France'. In: *CMStatistics 2018 - 11th International Conference of the ERCIM WG on Computational and Methodological Statistics*. Pisa, Italy, Dec. 2018. URL: https://hal.inria.fr/hal-01925454.

[22] R. Stoica, M. Deaconu, A. Philippe and L. Hurtado-Gil. 'Shadow simulated annealing algorithm : a new tool for global optimisation and statistical inference'. under review. July 2019. URL: https://hal.archives-ouvertes.fr/hal-02183506.