PÉRIODE D'ACCRÉDITATION : 2016 / 2021

UNIVERSITÉ PAUL SABATIER

SYLLABUS MASTER

Mention Mathematiques et applications

M2 mathématiques Research and Innovation

http://www.fsi.univ-tlse3.fr/
http://departement-math.univ-tlse3.fr/
master-mention-mathematiques-et-applications-620690.kjsp

2019 / 2020

17 JANVIER 2020

SUMMARY OF THE CONTENT

PRESENTATION

PRESENTATION OF DISCIPLINE AND SPECIALTY

DISCIPLINE MATHEMATIQUES ET APPLICATIONS

The goal of the master "Mathematics and Applications" is to train mathematicians for careers in three possible directions :
mathematical engineering (tracks MApI3, SID, RO, SE, RI), research, innovation and development (tracks RI, RO, MApI3) and teaching (track ES).
The number of students trained in mathematics in France is much lower than the number of job offers, so that the career perspectives in mathematics are excellent.

SPECIALITY

L'objectif du parcours Research and Innovation du Master mention Mathématiques et Applications est de former des mathématiciens pouvant travailler dans les métiers de la recherche qui peut être de nature académique, théorique et/ou appliquée, ou être tournée vers l'innovation et le développement dans le secteur privé.
The goal of the specialty Research and Innovation of the Master Mathematics and Applications is to train mathematicians able to work in the research domains ranging from the academic research (both theoretical and applied) to the innovation and developpement in the private sector.

PRESENTATION OF THE YEAR OF M2 MATHÉMATIQUES RESEARCH AND INNOVATION

Le M2 MAT RI est structuré en deux semestres suivis d'un stage de 4 mois.
Au premier semestre les étudiants devront valider 3 cours du type "Basic course" et un "Reading Seminar".
Au deuxième semestre deux cours "Advanced Course" et le cours d'anglais complèteront la formation.
Le stage pourra être en entreprise ou dans un laboratoire de recherche et représentera une introduction à l'activité de recherche.
The M2 MAT RI is structured in two semesters followed by a 4 months stage.
During the first semester the students will validate 3 "Basic courses" and one "Reading Seminar".
During the second semester they will validate two "Advanced courses" and the english course.
The stage will be either in the industry or in a Research Laboratory, and will represent an introduction to the research activity.

CONTACTS SECTION

CONTACT INFORMATION CONCERNING THE SPECIALTY

PERSON IN CHARGE OF TEACHING AFFAIRS OF M2 MATHÉMATIQUES RESEARCH AND INNOVATION

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TABLE SUMMARIZING THE MODULES THAT MAKE UP THE TRAINING PROGRAM

page	Code	Title of the module	ECTS	Mandatory Optional	Cours	TD	TP	Projet	Stage ne
First semester									
Choose 3 module among the following 13 modules :									
8	EIMAR3AM	BASIC COURSE 1	8	O	30				
9	EIMAR3BM	BASIC COURSE 2	8	O	30				
10	EIMAR3CM	BASIC COURSE 3	8	O	30				
11	EIMAR3DM	BASIC COURSE 4	8	O	30				
12	EIMAR3EM	BASIC COURSE 5	8	O	30				
13	EIMAR3FM	BASIC COURSE 6	8	O	30				
14	EIMAR3GM	BASIC COURSE 7	8	O	30				
15	EIMAR3HM	BASIC COURSE 8	8	O	30				
16	EIMAR3IM	SCIENTIFIC COMPUTING	8	O	30				
17	EIMAR3JM	COURS PROPOSÉ PAR UT1	8	O	30				
18	EIMAR3KM	COURS PROPOSÉ PAR UT2	8	O	30				
19	EIMAR3LM	COURS PROPOSÉ PAR L'INSA	8	O	30				
	EIMAR3MM	MACHINE LEARNING	8	O					
20	EIMAI3B1	Machine Learning			18		12		
21	EIMAI3B2	Machine Learning (projet)						25	
Choose 1 module among the following 4 modules :									
22	EIMAR3QM	READING SEMINAR 1	6	O		36			
23	EIMAR3RM	READING SEMINAR 2	6	O	24				
24	EIMAR3SM	READING SEMINAR 3	6	O		36			
25	EIMAR3TM	READING SEMINAR 4	6	O		36			
Second semester									
26	EIMAR4BM	DISSERTATION	15	O					0,1
Choose 2 module among the following 10 modules :									
27	EIMAR4CM	ADVANCED COURSE 1	6	O	24				
28	EIMAR4DM	ADVANCED COURSE 2	6	O	24				

page	Code	Title of the module	ECTS	Mandatory Optional	Cours	TD	TP	Projet	Stage ne
29	EIMAR4EM	ADVANCED COURSE 3	6	O	24				
30	EIMAR4FM	ADVANCED COURSE 4	6	O	24				
31	EIMAR4GM	ADVANCED COURSE 5	6	O	24				
32	EIMAR4HM	ADVANCED COURSE 6	6	O	24				
33	EIMAR4IM	COURS PROPOSÉ PAR L'ISAE	6	O	24				
34	EIMAR4JM	COURS PROPOSÉ PAR UT1	6	O	24				
35	EIMAR4KM	COURS PROPOSÉ PAR UT2	6	O	24				
36	EIMAR4LM	COURS PROPOSÉ PAR L'INSA	6	O	24				
Choose 1 module among the following 4 modules :									
37	EIMAR4VM	ANGLAIS	3	O		24			
38	EIMAR4WM	ALLEMAND	3	O		24			
39	EIMAR4XM	ESPAGNOL	3	O		24			
40	EIMAR4YM	FRANÇAIS GRANDS DÉBUTANTS	3	O		24			

LIST OF THE MODULES

UE	BASIC COURSE 1	8 ECTS	1^{st} semester
EIMAR3AM	Cours : 30h		

TEACHER IN CHARGE OF THE MODULE

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LEARNING GOALS

The purpose of this course is to provide an introduction to Riemann Surfaces

SUMMARY OF THE CONTENT

This course is meant to provide a broad introduction to Riemann surfaces. We aim to study the notion of Riemann surfaces from various point of views like complex analysis or differential geometry with detours involving an introduction to sheaves and cohomology. The content of the course will include :•Definitions and examples of Riemann surfaces, finite coverings•Line bundles, divisors, meromorphic forms, residues, Riemann-Hurwitz formula•Sheaves, Cech cohomology, Riemann-Roch theorem, embedding into projective space

PREREQUISITES

Complex analysis, differential geometry

REFERENCES

O.Forster, Lectures on Riemann Surfaces. Grad Texts in Math. 81 ;Springer
R.Narasimhan, Compact Riemann Surfaces. Lect. in Math., ETH Zurich, Birkhauser
R.Miranda, Algebraic Curves and Riemann Surfaces. Grad Studies in Math. Volume 5 ; Springer

KEYWORDS

Riemann Surface

UE	BASIC COURSE 2	8 ECTS	1^{st} semester
EIMAR3BM	Cours : 30h		

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LEARNING GOALS

The goal of this course is to introduce both metric and Riemannian geometry. Since the pioneeering work of Gromov in the early eighties, a tremendous amount of work has been devoted to Metric Measure Spaces. The idea is to encode the geometry of the space into a distance and a measure (modeling the volume of the space and its subsets) through their interactions. The classical tools from Riemannian geometry remain relevant for fine studies of the underlying space and will also be addressed. Finally, I will discuss the central notion of curvature through a metric characterization of spaces with curvature bounded from above and/or below by a number k. This notion can be described rather simply in metric terms and will beuseful for the advanced course on geometric group theory and 3 manifolds.

SUMMARY OF THE CONTENT

Length spaces : Length structures,Examples,Length structures induced by metrics,Shortest paths
Smooth length structures/ Riemannian metric : Riemannian metric,Examples, Nash's isometric embedding theorem,Levi-Civita connection,Geodesics from an analytical point of view ,Normal coordinates.
Densities and Volume : Densities on a Riemannian manifold, Volume estimate
Space forms : The sphere,The hyperbolic space
Variation formula(s) : Jacobi fields,Gauss lemma,Conjugate points
Metric spaces with bounded curvature : Definitions,Angles. Analysis of distance function , Examples,First properties,A survey of more adavanced facts (globalization theorem).

REFERENCES

D. Burago, Y. Burago, and S. Ivanov , A course in Metric Geometry, AMS, 2001. S. Gallot, D. Hulin, J. Lafontaine, Riemannian Geometry, Springer,third edition, 2004

KEYWORDS

Riemannian geometry

UE	BASIC COURSE 3	8 ECTS	1^{st} semester
EIMAR3CM	Cours : 30h		

LEARNING GOALS

These lectures aim to provide an introduction to the general ergodic theory of dynamical systems. We will also illustrate the main concepts on the special case of polynomial dynamical systems. Course by François Berteloot.

SUMMARY OF THE CONTENT

1. Invariant measures. Ergodicity. Mixing.
2. Birkhoff ergodic theorem.
3. Lyapunov exponents.
4. Multiplicative ergodic theorem.
5. Applications to the study of the Mandelbrot set.

PREREQUISITES

Elementary topology, Functional analysis, Measure theory.

REFERENCES

Y. Coudène, Théorie ergodique et systèmes dynamiques. EDP-Sciences.
M. Viana, Lectures on Lyapunov exponents, Camb. stud. on adv. math., 2015.
F. Berteloot, Bifurcation currents in holomorphic families of rational maps,Springer LNM, 2013.

KEYWORDS

Dynamical systems

UE	BASIC COURSE 4	8 ECTS	1^{st} semester
EIMAR3DM	Cours : 30h		

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LEARNING GOALS

Elliptic PDEs and evolution problems
The aim of this lecture is to provide a background of methods and techniques for the analysis of elliptic partial differential equations and evolution problems and their numerical approximations.
Course by P. Laurençot and M.H. Vignal

SUMMARY OF THE CONTENT

Variational models : elasticity, least action principle, Euler-Lagrange equation.
2. Sobolev spaces in a domain of R^n. Traces. Embeddings. Poincaré inequalities.
3. Elliptic partial differential equations in divergence form : (a) Lax-Milgram lemma, H^2-regularity, spectral theory of the Laplace operator, maximum principle.
(b) Elliptic partial differential equations in divergence form : Galerkin approximations, finite elements methods.
4. Evolution problems :
(a) semigroups, Hille-Yosida theorem, linear parabolic and dispersive equations, Duhamel's formula.
(b) Dynamical systems : Stability, Liapunov functional, LaSalle Invariance principle.
(c) Nonlinear parabolic problems

PREREQUISITES

L^p-spaces. Hilbert spaces. Ordinary differential equations

REFERENCES

H. Brézis, Analyse fonctionnelle. L. C. Evans, Partial Differential Equations.
Th. Cazenave -A. Haraux. Introduction aux problèmes d'évolution semi-linéaires.
A. Ern-J.L. Guermond.Eléments finis : théorie, applications, mise en oeuvre.

KEYWORDS

Partial Differential Equation. Sobolev Spaces. Laplace equation. Heat equation. Wave equation. Fourier transform.Finite Elements.

UE	BASIC COURSE 5	8 ECTS	1^{st} semester
EIMAR3EM	Cours : 30h		

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LEARNING GOALS

Convex Analysis / Optimization and Applications.
This course is meant to provide a broad introduction to Convex analysis ; numerical optimization ; and to study the properties of optimization models commonly used in image processing.
Course by : C. Dossal, F. Malgouyres and A. Rondepierre

SUMMARY OF THE CONTENT

Elements of convex analysis :
1.Convexity (strict/strong), continuity, lower semi-continuity, functions with a lipschitz gradient, sub-differential. Coercivity. Existence of a minimizer. Optimality conditions.
2. Constrained optimization : Lagrange multipliers, Karush-Kuhn-Tucker Conditions.
3. Duality : Legendre-Fenchel transform. Fenchel-Rockafellar duality.
4. Numerical optimization : gradient descent, Newton and quasi-Newton algorithms. Non-smooth optimization : proximal gradient algorithm, Accelerated proximal gradient algorithm, projected gradient algorithm.
5. Applications in image processing : Compressed sensing : Sparse modeling, algorithms and their guarantees (l^0 and l^1 minimization under Restricted Isometry Property)
Dictionary learning : Model, algorithms and their guarantees.

PREREQUISITES

Differential calculus, linear algebra, Functional analysis

REFERENCES

Rockafellar, Convex analysis. Nesterov, Introductory lectures on convex optimization.
Bertsekas, Nonlinear Programming Athena Scientific. Elad, Sparse and Redundant Representations : From Theory to Applications in Signal and Image
Processing.

KEYWORDS

convexity, optimisation, image processing

UE	BASIC COURSE 6	8 ECTS	1^{st} semester
EIMAR3FM	Cours : 30h		

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LEARNING GOALS

Convergence of probability measures, functional limit theorems and applications.
The goal of this course is to present the fundamental principles of weak convergence of probability measures in metric spaces, as well as classical functional limit theorems.
The course will begin by recalling the notions of convergence for sequences of random vectors and of measures in finite dimension. It may be completed by topics chosen by the instructors (as for example : concentration of measure phenomenon, law of iterated logarithm, extreme laws, attraction domains for stable laws, applications of large deviations to spin systems....)
Course by : P. Fougères.

SUMMARY OF THE CONTENT

Among the main topics :
- Tight families of probability measures (theorem of Prokhorov),
- Functional limit theorems and invariance principles (Donsker's theorem),
- Gaussian measures in in nite dimension (Wiener measure),
- In nitely divisible laws, LØevy-Khinchine theorem, stable laws,
- Basics of large deviation theory in nite and in nite dimension (theorems of Cramer, GØartner-Ellis, Schilder, Sanov,...).
The course will begin by recalling the notions of convergence for sequences of random vectors and of measures in nite dimension. It may be completed by topics chosen by the instructors (as for example : concentration of measure phenomenon, law of iterated logarithm, extreme laws, attraction domains for stable laws, applications of large deviations to spin systems....)

REFERENCES

R. M. Dudley, Real Analysis and Probability.
A. Dembo, O. Zeitouni, Large Deviations Techniques and Applications

UE	BASIC COURSE 7	8 ECTS	1^{st} semester
EIMAR3GM	Cours : 30h		

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LEARNING GOALS

Stochastic calculus and Markov processes.
The Brownian Motion plays a fundamental role in the theory of stochastic processes. The construction of integrals with respect to this process needs the development of a specific integration theory. In the first part of the course, we will focus on this topic going from the probabilistic construction of integrals with respect to continuous martingales to the study of Stochastic Differential Equations (SDEs). Different extensions can be then studied towards integration with respect to more general processes like Levy processes or study of Malliavin Calculus.
Course by F. Barthe.

SUMMARY OF THE CONTENT

Stochastic Calculus
(a) Brownian Motion
(b) Martingales and Semimartingales
(c) Stochastic Integrals
(d) Ito Formula and Applications
(e) Stochastic Differential Equations
(f) Levy processes (or/and) Malliavin Calculus

REFERENCES

Chung-Williams, Introduction to stochastic integration. Ethier-Kurtz, Markov processes, characterization and convergence. Karatzas-Shreve, Brownian motion and stochastic calculus.Revuz-Yor, Continuous martingales and Brownian motion.

KEYWORDS

Brownian motion, Stochastic Differential Equation, Markov process

UE	BASIC COURSE 8	8 ECTS	1^{st} semester
EIMAR3HM	Cours : 30h		

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LEARNING GOALS

Asymptotic statistics.
The goal of this course is to introduce classical asymptotic results in parametric and non-parametric statistics, and some of the tools that can be used to establish these results. The course will be illustrated using examples in estimation and regression.
Course by F. Bachoc and P. Neuvial

SUMMARY OF THE CONTENT

After a reminder on basic topics in parametric estimation (least squares estimation, consistency and asymptotic normality of maximum likelihood estimators in regular models), the first part of the course will study non-parametric estimation [1], with a focus on kernel density estimation and non-parametric regression. The following topics will be covered : bias-variance tradeoffs, convergence rates of estimators in Hölder classes, minimax lower bounds, curse of dimensionality.
The second part of the course will focus on more advanced topics in parametric estimation [2]. We will address consistency and asymptotic normality of general M and Z estimators. We will then study the notions of contiguity, local asymptotic normality and efficiency.

REFERENCES

Tsybakov, A. B. Introduction to nonparametric estimation. Revised and extended from the 2004.Van der Vaart, A. W. Asymptotic statistics (Cambridge series in statistical and probabilistic mathematics)

KEYWORDS

parametric and non parametric estimation

UE	SCIENTIFIC COMPUTING	8 ECTS	1^{st} semester
EIMAR3IM	Cours : 30h		

LEARNING GOALS

This course is organized as follows : 10 academic lessons, joint with 4 numerical labs with Matlab or FreeFEM++. Each slot (either lesson or lab) lasts 2 hours.The introduction (2 slots) deals with first linear systems, second with the principles of the Finite Difference Method (FDM) for Ordinary Differential Equations (ODEs). The second part of the course (7 slots) consists in advanced material on the Finite Element Method (FEM) applied to elasticity, and on Mixed Finite Elements applied to incompressible fluid mechanics. In the last 5 slots, the last part of the course, numerical methods being used for the simulation of the propagation of electromagnetic waves are presented.

SUMMARY OF THE CONTENT

Part 1 : Introduction

1. Linear systems, condition number, decomposition of matrices for solving linear systems (EVD, SVD), least squares.
2. the Finite Difference Method (FDM) for ODEs : stability, consistency, convergence.

Part 2 : More on the Finite Element Method3&4. The case of coupled system of PDEs5. Lab 1 : Finite element computations in 2D elasticity 5'. Lab 1' : Introduction to FreeFem++6&7&8. Mixed Finite Element Method : intro on the Stokes equation. Variational formulation, link with constrained optimization, inf-sup condition 9. Lab 2 : Numerical solution of the Stokes equation thanks to FreeFem++
Part 3 : Propagation models of electromagnetic waves

1. Maxwell eqns in 2D : hyperbolicity of the system, boundary conditions, energy conservation. The Yee scheme
2. FVM for Maxwell eqns in 2D. Centered fluxes scheme. L2-stability. Study of the Riemann problem. Upwind scheme

12&13. : High order local approximation : GD methods. Variational formulation. Approximation of ordre p on triangles. Computation of the mass and stiffness matrices. Weak formulation of the boundary conditions. L2-stability of the GD method with a leap-frog scheme in the time domain14. Lab 3 : Numerical modelling of a waveguide

REFERENCES

See the Syllabus on the M2RI's web-site for a full bibliography.

UE	COURS PROPOSÉ PAR UT1	8 ECTS	1^{st} semester
EIMAR3JM	Cours : 30h		

UE	COURS PROPOSÉ PAR UT2	8 ECTS	1^{st} semester
EIMAR3KM	Cours : 30h		

UE	COURS PROPOSÉ PAR L'INSA	8 ECTS	1^{st} semester
EIMAR3LM	Cours : 30h		

UE	MACHINE LEARNING	8 ECTS	1st semester
Sous UE	Machine Learning		
EIMAI3B1	Cours : 18h , TP : 12h		

TEACHER IN CHARGE OF THE MODULE

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LEARNING GOALS

Ce cours a pour vocation d'introduire le concept d'apprentissage statistique et de proposer des méthodes classiques de résolution de problèmes en estimation (régression) ou classification. Une importance spécifique sera donnée aux phases de codage des méthodes statistiques.

SUMMARY OF THE CONTENT

B-A-BA de l'apprentissage statistique

1. Apprentissage Supervisé. Décomposition biais/variance. Complexité et bornes de Vapnik-Chervonenkis. Sur-apprentissage.
2. Présentation de problèmes concrets de différents domaines.
3. Training Set, Test Set. Erreur de validation croisée. Méthode bootstrap. Classification Classification CART. Etude de la méthode des K plus proches voisins. Algorithme de réseaux de neurones. Régression
   Estimation non paramétrique. Approximation par Fourier. Extension aux ondelettes. Régression CART. Extension à Random Forest.
   Régression Ridge. Critères AIC/BIC.

Apprentissage non supervisé
Présentation de situations typiques.
Méthodes de mélanges gaussien.
Classification Ascendante Hiérarchique. Algorithmes de K-means.

UE	MACHINE LEARNING	8 ECTS	1st semester
Sous UE	Machine Learning (projet)		
EIMAI3B2	Projet : 25h		

TEACHER IN CHARGE OF THE MODULE

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UE	READING SEMINAR 1	6 ECTS	1^{st} semester
EIMAR3QM	TD : 36h		

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LEARNING GOALS

Algebraic topology.
The aim of this reading seminar is to let students read and expose publicly an advanced text in a bracnh of fundamental mathematics which is not covered by but is near to the themes of the other basic courses. This year the chose theme is Algebraic Topology and the book will be that of Allen Hatcher, available online on his web page. Each student will have to prepare two public seminars in english of the duration of one hour and half announced to the researchers of the Institut de Mathmatiques de Toulouse and will attend the others by actively participating to the discussion following each seminar.
Course by : J.F. Barraud

SUMMARY OF THE CONTENT

The contents which will be treated in the course of the year include : the fundamental group, covering spaces, CW complexes, simplicial complexes, simplicial homology and singular homology, cohomology, cup product and Poincaré duality, some homotopy theory.

PREREQUISITES

Basic topology (topological spaces, continuous functions, Haussdorf spaces, compact spaces).

REFERENCES

References : A. Hatcher, Algebraic topology, https ://www.math.cornell.edu/ hatcher/..

KEYWORDS

Homology, Cohomology, Homotopy theory.

UE	READING SEMINAR 2	6 ECTS	1st semester
EIMAR3RM	Cours : 24h		

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LEARNING GOALS

PDEs and applications.
This reading seminar will be divided into three independent parts. Each of them will deal with a particular topic aiming at illustrating/developping the basic courses or at preparing the advanced courses of the second semester.
Part 1 : Ordinary differential equations and numerical schemes Coordinator : Jean-François Coulombel
Part 2 : Parabolic Equations in Biology : Growth, reaction, movement and diffusion Coordinator : Francis Filbet
Part 3 : Optimisation of PDEs coefficients Coordinator : Frédéric de Gournay

SUMMARY OF THE CONTENT

Part 1 :
ODEs and PDEs play a crucial role in the modeling of physical phenomena. In this field, numerical simulations are important either to illustrate known theoretical results or to predict phenomena that are beyond the reach of analytical techniques. We shall review the stability and convergence theory for some numerical approximations of ODEs, focusing specifically on Runge-Kutta and multistep methods. Specific attention will be paid to large time stability issues through the notion of A -stability.
The results seen within the reading seminar will be useful when dealing with the numerical approximation of dispersive equations (second semester).
Part 2 :
We will present a variety of phenomena arising in the analysis of PDEs modelling biological, physical and chemical processes. Several fundamental questions in mathematical biology such as Turing instability, pattern formation, reaction-diffusion systems, invasion waves and Fokker-Planck equations will be addressed.
Part 3 :
problems coupled with elliptic PDEs. In that respect, the seminar will use and illustrate the basic courses A4 and A5.

KEYWORDS

Partial Differential Equations, Numerical Analysis

UE	READING SEMINAR 3	6 ECTS	1^{st} semester
EIMAR3SM	TD : 36h		

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LEARNING GOALS

Markov Processes
This reading seminar will be divided in two parts, the first on Markov chains and their applications and the second on Markov processes. The students will be assigned scientific talks to report on specific topics.
Course by : G. Fort and A. Joulin

SUMMARY OF THE CONTENT

Part 1 will be devoted to Markov chains with general state space and applications to the design and analysis of a simulation-based integration method called Markov chain Monte Carlo (MCMC) sampling. We will introduce the tools for the long-time behavior analysis of the chains ; then, we will introduce the classical algorithms. The talks will either investigate further the theory of Markov chains, or explore the use of MCMC in Bayesian Statistics or in Stochastic Algorithms for statistical Learning.
Part 2 will further complement the understanding of Markov processes,
with special emphasis on diffusion processes, mainly the Ornstein-Uhlenbeck process associated to the standard Gaussian distribution. We will study the long run behavior of these processes by means of modern tools.

REFERENCES

Analysis and geometry of Markov diffusion operators. D. Bakry, I. Gentil and M. Ledoux.
Autour de l'inégalité de Sobolev logarithmique. C. Ané, S. Blachère, D. Chafai, P. Fougères, I. Gentil, F. Malrieu, C. Roberto and G. Scheffer.

UE	READING SEMINAR 4	6 ECTS	1st semester
EIMAR3TM	TD : 36h		

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UE	DISSERTATION	15 ECTS	2^{nd} semester
EIMAR4BM	Stage ne : 0,1h		

TEACHER IN CHARGE OF THE MODULE

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LEARNING GOALS

Permettre aux étudiants d'avoir une première expérience de recherche indépendante

SUMMARY OF THE CONTENT

Le contenu de la dissertation de stage de M2 (mémoire) est à détérminer avec l'encadrant choisi par chaque étudiant.
Une liste de propositions de stages est présentée aux étudiants au cours de l'année par les résponsable du M2.
Chaque stage dure au moins quatre mois et se conclut par la présentation d'un mémoire originel écrit de façon indépendant par chaque étudiant.

REFERENCES

Ils sont à définir avec les encadrants des stages

UE	ADVANCED COURSE 1	6 ECTS	2^{nd} semester
EIMAR4CM	Cours : 24h		

TEACHER IN CHARGE OF THE MODULE

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LEARNING GOALS

Special functions and q-calculus.
The course will be composed of two parts, roughly equal in volume : special functions, applications to q-calculus.
Course by J. Sauloy

SUMMARY OF THE CONTENT

Special functions : This part is of general interest. We shall concentrate on : elliptic curves and elliptic functions ; modular functions ; theta functions.
Applications to q-calculus : This part is devoted to a more specialized subject, but one which interacts with various domains in mathematics and physics. We shall insist on the basic theory of q-difference equations and the phenomenon of q-degeneracy to classical calculus when q tends to 1. Then, according to time and mood, we shall tackle some historical and exciting examples such as partition numerorum, Ramanujan (pseudo-)identities, the q-analog of Stokes phenomenon and q-difference Galois theory.

PREREQUISITES

General and linear algebra and analytic functions at L3 level ; and the first semester course on Riemann surfaces.

REFERENCES

Apostol, Modular Functions and Dirichlet Series in Number Theory ; Lang, Elliptic Functions ; Whittaker & Watson, A Course of Modern Analysis
Gasper-Rahman, Basic Hypergeometric Series ; Sauloy, Analytic Study of q-Difference Equations.

KEYWORDS

q-series, q-difference equations

UE	ADVANCED COURSE 2	6 ECTS	2^{nd} semester
EIMAR4DM	Cours : 24h		

TEACHER IN CHARGE OF THE MODULE

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LEARNING GOALS

Introduction to geometric group theory and 3-manifolds topology
The goal of the course is to study the interplay between geometry, algebra and topology occuring in geometric group theory (GGT). We will be interested in the applications of these ideas to the study of 3-manifolds. In GGT one studies actions of groups on geometric spaces and relates them to algebraic properties of the group.
The spaces on which groups act are mostly negatively curved in the sense of J. Bertrand's first semester course. A major aim of the course is to introduce examples of such spaces and actions, and in particular hyperbolic manifolds. The topological part of the course will focus on 3-manifolds and their fundamental groups.
Course by : J. Raimbault

SUMMARY OF THE CONTENT

• **First part : generalities**
- Cayley graphs, quasi-isometries, the Milnor-Schwarz lemma and the geometry of a finitely generated group ;
- ØAbstractØ examples : free groups, free products, surface groups ;
- Fundamental groups of compact manifolds, asphericity.

•**Second part : construction of hyperbolic manifolds**
-Geometric constructions via Poincar ́e's polyhedron theorem, Coxeter groups ;
-Dimension 3 : Geometrisation and related constructions ;
-Some arithmetic constructions in higher dimensions ;
-A survey of rigidity results (Mostow-Prasad and Calabi-Weil).

•Cubulation and 3-manifolds (most results in this part will not be completely proven) The structure of aspherical 3-manifolds : Thurston-Perelman's geometrisation and Thurston's conjectures ;
-Wise's program and Agol's theorem : cubulating hyperbolic groups

PREREQUISITES

Metric and differential geometry (as in the first semester course), basic group theory, point-set topology. An entry-level knowledge of graph theory is useful.

REFERENCES

Bowditch, A course on geometric group theory
Aschenbrenner, Friedl, Wilton, 3-manifold groups

KEYWORDS

Geometric group theory 3-manifolds

UE	ADVANCED COURSE 3	6 ECTS	2^{nd} semester
EIMAR4EM	Cours : 24h		

TEACHER IN CHARGE OF THE MODULE

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LE COZ Stefan
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LEARNING GOALS

Theoretical and numerical analysis of dispersive partial differential equations.
The analysis of dispersive PDEs has known tremendous developments in the last thirty years, both on its theoretical and numerical aspects. It benefited from the introduction of techniques coming from harmonic analysis, dynamical systems or calculus of variations. This series of lectures will present some of the recent developments on a prototype case, the time dependent Nonlinear Schrodinger Equation (NLS) which is one of the famous model of quantum theory but also arises in various fields of physics, e.g. in nonlinear optics for laser beam propagation or in cold atom physics to describe Bose Einstein condensation.
Course by C. Besse and S. Le Coz

SUMMARY OF THE CONTENT

The NLS presents remarkable properties, e.g. the preservation in time of several quantities and the existence of soliton solutions (waves which travel at a constant speed in time, keep the same spatial profile along the evolution in te and do not scatter). Its numerical approximation requires specific care to be able to preserve the theoretical properties and to compute soliton solutions over long time.
In the theoretical part of this series of lectures, we will cover the Cauchy theory of NLS, the existence and classification of soliton profiles by variational method, the stability of ground state solitons, and Merle's classification of the blow-up dynamics at minimal mass.
In the numerical part of this series of lectures, we will introduce and analyse some numerical schemes that turn out to be well adapted to the study of the Schrodinger equation. We will split the analysis between time discretization and space approximation. The time discretization is at the heart of the strategy to preserve conserved quantities in the numerical approximation, whereas space approximation will be concerned with the boundary conditions. Many numerical tests will be performed during real time experiments

PREREQUISITES

basic notions of (functional) analysis, distributions, differential equations studied in M1 and licence, as well as the PDE courses of the 1st semester in M2

REFERENCES

Besse, A relaxation scheme for the nonlinear Schrodinger equation. Besse-Dujardin-Lacroix-Violet, High order exponential integrators for nonlinear Schrodinger equations with application to rotating Bose-Einstein condensates.

UE	ADVANCED COURSE 4	6 ECTS	2^{nd} semester
EIMAR4FM	Cours : 24h		

TEACHER IN CHARGE OF THE MODULE

FAYE Grégory
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LEARNING GOALS

Qualitative studies of PDEs : a dynamical systems approach
We will consider the design and the mathematical analysis of numerical methods for kinetic equations. Kinetic theory describes the time evolution of a system of a large number of particles. This class of models is essential to make a rigorous link between a microscopic and a macroscopic description of the physical reality. Due to the high number of dimensions and their physical properties, the construction of numerical methods is a challenge and requires a careful balance between accuracy and computational complexity.
We focus on a classical system dealing with Coulombian (or Newtonian) interactions between particles in the presence of a strong magnetic field and present the analysis of the Vlasov-Poisson system.
Course by : G. Faye

SUMMARY OF THE CONTENT

We will focus on coherent structures, such as periodic patterns and traveling waves in spatially extended systems. The lectures will be illustrated and motivated by a variety of simple model problems, such as the Allen-Cahn or Nagumo equation, reaction-diffusion systems and pattern-formation models such as the Swift-Hohenberg equation. We will learn about techniques to study existence and stability of such coherent structures, including bifurcation theory, center manifold theory, and spatial dynamics. More specifically, there will be two different parts in these lectures.
1. **On periodic patterns** :presentation of the model (Swift-Hohenberg equation) ; introduction to spatial dynamics and bifurcation theory ; center manifold theorem (CMT) in finite dimension ; application of the CMT to the Swift-Hohenberg equation in dimension 1 ; extension of the CMT to infinite dimension ; application to the Swift-Hohenberg equation in dimension 2 : existence of grain boundaries
2. **On traveling wave :** presentation of the model (Allen-Cahn equation) ; fixed-point method for existence and uniqueness of solutions ; existence and uniqueness of monotone traveling waves ;long time dynamics & stability of traveling waves

PREREQUISITES

There is no real prerequisite except some basic knowledge on ODEs. We encourage students to take the course : A4 - Elliptic PDEs and evolution problems

REFERENCES

M. Haragus G. Iooss, Local Bifurcations, Center Manifolds, and Normal Forms in Infinite-Dimensional Dynamical Systems
T. Kapitula K. Promislow, Spectral and Dynamical Stability of Nonlinear Waves , Applied Mathematical Sciences

KEYWORDS

PDEs, dynamical systems, center manifolds, periodic patterns, traveling waves

UE	ADVANCED COURSE 5	6 ECTS	2^{nd} semester
EIMAR4GM	Cours : 24h		

TEACHER IN CHARGE OF THE MODULE

PAUWELS Edouard
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LEARNING GOALS

Learning. Classical parametric statistics deal with d real parameters estimated based on a sample, whose size n tends to infinity. There exists sharp analyses of properties of common estimators, but they do not take into account :
-Increasing number of descriptors
-The number of descriptors is bigger than the number of observations
-Data could be observed as a continuous flow
These motivates to reconsider the setting by considering :
-If both d and n increase, powerful estimators are not the same as in the classical setting.
-Restrictions on the estimators : computation becomes an issue.
-Constraints on n : distributed storage, flow, or simply n very big.
This course will provide an overview of available approaches for these questions and a complete description the LASSO estimator.
Course by E. Pauwels

SUMMARY OF THE CONTENT

Linear regression in high dimension.
The linear model for regression will be used as a canonical example
to illustrate most concepts and algorithms presented in the course.
Elements of convex analysis and optimization. Optimization is one of the crucial building block of data analysis and modeling applications for model parameter tuning based on a sample of observations.
Stochastic approximation.
Stochastic approximation algorithms are widespread to circumvent computational burden associated to large sample size n.
Random coordinate descent.
Block coordinate approaches allow to work with large number of descriptors d. They also have an interesting duality interpretation with stochastic methods for finite sums.
Dimension reduction and non convex optimization.
Most optimization algorithms have natural extensions in nonconvex settings for which dimension reduction techniques provide a large number of applications.

PREREQUISITES

The course requires comfortable knowledge of basic concepts in probability, statistics, linear algebra and analysis.

UE	ADVANCED COURSE 6	6 ECTS	2^{nd} semester
EIMAR4HM	Cours : 24h		

TEACHER IN CHARGE OF THE MODULE

CHHAIBI Reda
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LEARNING GOALS

Integrable particle systems in mathematical physics
The goal of this course is to serve as an introduction to the KPZ universality class by presenting a complete treatment of a few integrable particle systems.
course by R. Chhaibi

SUMMARY OF THE CONTENT

Consider a random system of size N.
One could qualify the problem as belonging to the ØGaussian universality classØ as fluctuations
scale as N^(1/2) and have Gaussian behavior. The central limit theorem is the prototypical example.
Recently, a tremendous amount of research focused on a new class called the ØKPZ
universality classØ and where fluctuations are of size N^(1/3).
Physical situations expected to fall in this class include : random matrices, polymers, bacterial-growth, heavy traffic and fire-fronts. An ideal model consists in exclusion processes i.e particle systems where particles cannot occupy the same position.
The goal of this course is to serve as an introduction to the KPZ universality class by presenting a complete treatment of a few integrable particle systems.

PREREQUISITES

Prerequisites are minimal. We will use basic probability theory, combinatorics and determinantal identities.

REFERENCES

Reda Chhaibi. Lecture Notes. In preparation.
Ivan Corwin. Kardar-Parisi-Zhang Universality. Notices of the AMS. Volume 63,
Timo Seppäläinen. Lecture Notes on the Corner Growth Model.

UE	COURS PROPOSÉ PAR L'ISAE	6 ECTS	2$^{\mathrm{nd}}$ semester
EIMAR4IM	Cours : 24h		

UE	COURS PROPOSÉ PAR UT1	6 ECTS	2^{nd} semester
EIMAR4JM	Cours : 24h		

UE	COURS PROPOSÉ PAR UT2	6 ECTS	2^{nd} semester
EIMAR4KM	Cours : 24h		

UE	COURS PROPOSÉ PAR L'INSA	6 ECTS	2nd semester
EIMAR4LM	Cours : 24h		

UE	ANGLAIS	3 ECTS	2nd semester
EIMAR4VM	TD : 24h		

TEACHER IN CHARGE OF THE MODULE

CHAPLIER Claire
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LEARNING GOALS

Niveau C1 du CECRL (Cadre Européen de Certification en Langues)
Développer les compétences indispensables aux étudiant/es en vue de leur intégration dans la vie professionnelle.
Perfectionner les outils de communication permettant de s'exprimer dans le contexte international d'aujourd'hui et acquérir l'autonomie linguistique nécessaire à cette intégration

SUMMARY OF THE CONTENT

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Contenu linguistique de la discipline :
Enseignement axé sur le travail de l'expression orale
Documents du domaine de spécialité pouvant faire l'objet de collaboration entre enseignants de science et enseignants de langue
Nécessité d'un parcours individualisé répondant aux attentes de chaque étudiant.
Compétences
CO - EE - EO - EE
- Savoir communiquer en anglais scientifique
- Savoir repérer les éléments constitutifs d'une communication écrite ou orale dans le domaine de spécialité
- Savoir prendre la parole en public (conférence ou réunion) dans le cadre d'un colloque, projet de recherche, projet professionnel

PREREQUISITES

N/A

REFERENCES

N/A

KEYWORDS

Projet - Repérer - Rédaction anglais scientifique - style - registre - critique - professionnel - commenter

UE	ALLEMAND	3 ECTS	2^{nd} semester
EIMAR4WM	TD : 24h		

TEACHER IN CHARGE OF THE MODULE

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UE	**ESPAGNOL**	**3 ECTS**	**2^{nd} semester**
EIMAR4XM	TD : 24h		

TEACHER IN CHARGE OF THE MODULE

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UE	**FRANÇAIS GRANDS DÉBUTANTS**	**3 ECTS**	**2nd semester**
EIMAR4YM	TD : 24h		

TEACHER IN CHARGE OF THE MODULE

JASANI Isabelle
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GLOSSARY

GENERAL TERMS

DEPARTMENT

The departments are teaching structures within components (or faculties). They group together teachers lecturing in one or more disciplines.

MODULE

A semester is structured into modules that may be mandatory, elective (when there is a choice) or optional (extra). A module corresponds to a coherent teaching unit whose sucessful completion leads to the award of ECTS credits.

ECTS: EUROPEAN CREDITS TRANSFER SYSTEM

The ECTS is a common unit of measure of undergraduate and postgraduate university courses within Europe, created in 1989. Each validated module is thus assigned a certain number of of ECTS (30 per teaching semester). The number of ECTS depends on the total workload (lectures, tutorials, practicals, etc.) including individual work. The ECTS system aims to facilitate student mobility as well as the recognition of degrees throughout Europe.

TERMS ASSOCIATED WITH DEGREES

Degrees have associated domains, disciplines and specialities.

DOMAIN

The domain corresponds to a set of degrees from the same scientific or professional field. Most of our degrees correspond to the domain Science, Technology and Health.

DISCIPLINE

The discipline corresponds to a branch of knowledge. Most of the time a discipline consists of several specialities.

SPECIALITY

The speciality constitutes a particular thematic orientation of a discipline chosen by a student and organised as a specific trajectory with specialised modules.

TERMS ASSOCIATED WITH TEACHING

LECTURES

Lectures given to a large group of students (for instance all students of the same year group) in lecture theatres. Apart from the presence of a large number of students, lectures are characterized by the fact they are given by a teacher who defines the structure and the teaching method. Although its content is the result of a collaboration between the teacher and the rest of the educational team, each lecture reflects the view of the teacher giving it.

TD : TUTORIALS

Tutorials are work sessions in smaller groups (from 25 to 40 students depending on the department) led by a teacher. They illustrate the lectures and allow students to explore the topics deeper.

TP : PRACTICALS

Teaching methods allowing the students to acquire hands-on experience concerning the knowledge learned during lectures and tutorials, achieved through experiments. Practical classes are composed of 16 to 20 students. Some practicals may be partially supervised or unsupervised. On the other hand, certain practicals, for safety reasons, need to be closely supervised (up to one teacher for four students).

PROJECT

A project involves putting into practice in an autonomous or semi-autonomous way knowledge acquired by the student at the university. It allows the verification of the acquisition of competences.

FIELD CLASS

Field classes are a supervised teaching method consisting of putting into practice knowledge acquired outside of the university.

INTERNSHIPS

Internships are opportunities enabling students to enrich their education with hands-on experience and to apply lessons learned in the classroom to professional settings, either in industry or in research laboratories. Internships are strongly regulated and the law requires, in particular, a formal internship convention established between the student, the hosting structure and the university.

UNIVERSITÉ TOULOUSE III PAUL SABATIER

Université de Toulouse