

## Master in Mathematics

### Semestre 1

	CM (UE)	TD (UE)	ECTS
Module 1.1 : Module 1 is compulsory			12
Commutative Algebra	30	15	5
Differential Geometry	45		5
Student Project	60		2
Module 1.2 : Module 2 is compulsory			10
Partial Differential Equations I	45		5
Probability (Martingale Theory)	45		5
Module 1.3 : The students are requested to choose at least two courses in Module 3 (the total number of ECTS points must be 8 or higher). They will be individually advised by the course director, who must validate their choice.			8
Algorithmic Number Theory (optionnel)	30		4
Basics of Discrete Mathematics (optionnel)	30		4
Discrete and Polyhedral Geometry (optionnel)	30		4
Introduction to Programming (optionnel)	30		4
Probabilistic Models in Finance (optionnel)	30		4
Allgemeines Deutsch für Anfänger - A1.1 (optionnel)	28		3

### Semestre 2

	CM (UE)	TD (UE)	ECTS
Module 2.1			13
Homological Algebra	45		5
Partial Differential Equations II	45		5
Student Seminar		60	3

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	CM (UE)	TD (UE)	ECTS
<b>Module 2.2</b>			<b>10</b>
Complex Geometry	45		5
Probability (Stochastic Analysis)	45		5
<b>Module 2.3 : the students are requested to choose two of the following option courses</b>			<b>0</b>
Algebraic Number Theory (optionnel)	30		4
Introduction to Continuous Time Models in Mathematical Finance (optionnel)	30		4
Topics in Graph Theory (optionnel)	30		4
Numerical Analysis (optionnel)	30		4
An introduction to mathematical statistics (optionnel)	30		5

### Semestre 3

#### option Financial Mathematics

	CM (UE)	TD (UE)	ECTS
<b>Module 3.1 : Module 1 is compulsory</b>			<b>25</b>
Advanced Stochastic Modeling and Financial Applications	30		5
American options: Optimal Stopping Theory and numerical methods	30		5
Continuous-Time Stochastic Calculus and Interest Rate Models	30		5
Gaussian processes and applications	30		5
Numerical Methods in Finance	22		5
<b>Module 3.2 : The students are requested to choose altogether at least 2 courses in Modules 2, 3, 4 (the total number of ECTS points must be 10 or higher). They will be individually advised by the course director, who must validate their choice.</b>			<b>5</b>
Advanced Econometrics (optionnel)	45	15	6
Data Science (optionnel)	30		5

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	CM (UE)	TD (UE)	ECTS
Finite Element Method (optionnel)		30	5
Internship in a financial institution (optionnel)	1		5
Linear Optimization (optionnel)	30		5

### option General Mathematics

	CM (UE)	TD (UE)	ECTS
Module 3.1 : The students are requested to make a coherent selection of at least 6 courses from Modules 1, 2, 3 and 4 (the total number of ECTS points must be 30 or higher). They will be individually advised by the course director, who must validate their choice. Depending on the orientation opted for Module 1 or 2 is compulsory.			20
Algebraic Geometry and Number Theory	30		5
Geometric Methods in Mathematical Physics	30		5
Lie Algebras and Lie Groups	30		5
Combinatorial Geometry (optionnel)	30		5
Module 3.2 : The students are requested to make a coherent selection of at least 6 courses from Modules 1, 2, 3 and 4 (the total number of ECTS points must be 30 or higher). They will be individually advised by the course director, who must validate their choice. Depending on the orientation opted for Module 1 or 2 is compulsory.			10
Finite Element Method (optionnel)		30	5
Continuous-Time Stochastic Calculus and Interest Rate Models (optionnel)	30		5
Gaussian processes and applications (optionnel)	30		5
Reading course I: (optionnel)	30		5
Reading course II: (optionnel)	30		5

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### option Industrial Mathematics

	CM (UE)	TD (UE)	ECTS
<b>Module 3.1</b>			<b>20</b>
Advanced Discretization Methods	30		5
Data Science	30		5
Finite Element Method		30	5
Linear Optimization	30		5
<b>Module 3.2</b>			<b>10</b>
Advanced Stochastic Modeling and Financial Applications (optionnel)	30		5
American options: Optimal Stopping Theory and numerical methods (optionnel)	30		5
Continuous-Time Stochastic Calculus and Interest Rate Models (optionnel)	30		5
Gaussian processes and applications (optionnel)	30		5
Numerical Methods in Finance (optionnel)	22		5

### Semestre 4

#### option Financial Mathematics

	CM (UE)	TD (UE)	ECTS
Module 4.1 : the students are requested to choose a lecture course of the curriculum Master in Mathematics -Study Track "General Mathematics" (30h, 5 ECTS) of the curriculum "Master in Mathematics" -Study Track "General Mathematics"			10
Stochastic calculus of variations in finance & statistics (optionnel)	30		5
Internship in a financial institution (optionnel)	1		5
SDE and PDE (Solving PDE by Running a Brownian Motion) (optionnel)	30		5

## Master in Mathematics

	CM (UE)	TD (UE)	ECTS
Module 4.2			20
Master Thesis	1		20

### option General Mathematics

	CM (UE)	TD (UE)	ECTS
Module 4.1			0
Infinite-dimensional Lie Algebras (optionnel)	48		5
Siegel modular forms (optionnel)	30		5
SDE and PDE (Solving PDE by Running a Brownian Motion) (optionnel)	30		5
Module 4.2			20
Master Thesis			20

### option Industrial Mathematics

	CM (UE)	TD (UE)	ECTS
Internship in Industry including a Master Thesis			30
Internship in Industry including a Master Thesis			30
Reading course I: Statistics			5
Reading course I: Statistics	30		5
Reading course II: TBA			5
Reading course II: TBA	30		5

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### Semestre 1

#### Commutative Algebra

**Module:** Module 1.1 (Semestre 1)

**ECTS:** 5

**Objectif:** Learn the concepts of commutative algebra in relation to applications in algebraic number theory, algebraic geometry and other fields of mathematics

**Course learning outcomes:** On successful completion of the course the student should be able to:

- Demonstrate knowledge of the theory of commutative rings, their ideals and modules
- Recognize the relation between ideals and varieties
- Apply the general theory to explicit examples in algebra, geometry and number theory
- Solve problems in number theory, geometry and algebra by using the fundamental theorems of commutative algebra
- Demonstrate knowledge of the fundamental theorems, like Hilbert's Nullstellensatz, Hilbert's Basissatz

**Description:** In number theory one is naturally led to study more general numbers than just the classical integers and, thus, to introduce the concept of integral elements in number fields. The rings of integers in number fields have certain very beautiful properties (such as the unique factorisation of ideals) which characterise them as Dedekind rings. Parallely, in geometry one studies affine varieties through their coordinate rings. It turns out that the coordinate ring of a curve is a Dedekind ring if and only if the curve is non-singular (e.g. has no self intersection).

With this in mind, we shall work towards the concept and the characterisation of Dedekind rings. Along the way, we shall introduce and demonstrate through examples basic concepts of algebraic geometry and algebraic number theory. Moreover, we shall be naturally led to treat many concepts from commutative algebra.

Depending on the previous knowledge of the audience, the lecture will cover all or parts of the following topics:

- General concepts in the theory of commutative rings
  - + rings, ideals and modules
  - + Noetherian rings
  - + tensor products
  - + localisation
  - + completion

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- + dimension
- Number rings
- + integral extensions
- + ideals and discriminants
- + Noether's normalisation theorem
- + Dedekind rings
- + unique ideal factorisation
- Plane Curves
- + affine space
- + coordinate rings and Zariski topology
- + Hilbert's Nullstellensatz
- + resultant and intersection of curves
- + morphisms of curves
- + singular points

**Modalité d'enseignement:**

Lecture course and problem sessions

**Langue:**

Anglais

**Obligatoire:**

Oui

**Evaluation:**

Continuous control and written exam

**Remarque:**

Lecture notes, exercise sheets (available on Moodle)

Literature :

There are many books on commutative algebra, for example:

- E. Kunz, Introduction to Commutative Algebra and Algebraic Geometry.

- Dino Lorenzini. An Invitation to Arithmetic Geometry, Graduate Studies in Mathematics, Volume 9, American Mathematical Society.

- M. F. Atiyah, I. G. Macdonald. Introduction to Commutative Algebra, Addison-Wesley Publishing Company.

**Professeur:**

WIESE Gabor, SGOBBA Pietro

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### Differential Geometry

**Module:** Module 1.1 (Semestre 1)

**ECTS:** 5

**Objectif:** Differential Geometry has applications in many fields of science, e.g. in Physics, Economics, Computer Science, Engineering... The central investigated objects are differential manifolds - roughly, higher dimensional analogs of curves and surfaces. The goal of this lecture course is to extend crucial mathematical concepts, such as derivatives, integrals... to these more general spaces and to introduce further basic notions of modern geometry.

**Course learning outcomes:** On successful completion of the **course** the student should be able to:

- Explain the main definitions and results of Classical Differential Geometry
- Comment on fundamental features and on new concepts
- Apply the new techniques, especially differential and integral calculus on manifolds, and solve related problems
- Reorganize the acquired abilities and summarize essential aspects adopting a higher standpoint
- Give a pedagogic talk for peers on a related topic
- Write clear and concise lecture notes, including appropriate exercises and applications

**Description:** Content:  
1. Category of differential manifolds  
2. Vector fields  
3. Tensor analysis on manifolds  
4. Differential calculus  
5. Integration

**Modalité d'enseignement:** Lecture course

**Langue:** Anglais

**Obligatoire:** Oui

**Evaluation:** Oral exam

**Remarque:** D. Chruscinski, A. Jamiolkowski: Geometric Phases in Classical and Quantum Mechanics (chapter 1)  
M. Nakahara: Geometry, Topology and Physics (chapter 5)  
M. Spivak: A Comprehensive Introduction to Differential Geometry



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F.W. Warner: Foundations of Differentiable Manifolds and Lie groups (chapters 1-5)

P.W. Michor: Topics in Differential Geometry (chapters 1-3)

**Professeur:** PONCIN Norbert

### Student Project

**Module:** Module 1.1 (Semestre 1)

**ECTS:** 2

**Course learning outcomes:** Learning outcomes: On successful completion of the project the student should be able to:

- Cooperate effectively in a team and work independently - at least partially
- Approach other related areas of knowledge and recognize interconnections

**Description:** The Student Project in Module 1 is an activity, which starts around October 15. The student contacts a lecturer of his choice. Together with the student, the consenting supervisor defines a list of tasks, the volume of which is compatible with the 2 ECTS credits (60 working hours) attributed to this activity. The student communicates these tasks, as well as all other relevant information for approval to the Course Director on October 22 at the latest. He submits the results of his work to the Course Director, with copy to the Adjunct Course Director and the supervisor, by email, in a Latex PDF document, on December 31 at the latest. The text should be of high mathematical quality. It must be written compactly and in accordance with usual standards (15-20 pages are an average length). Each lecturer may supervise at most two Student Projects per semester. Any deviation from the above rules requires the written consent of the Course Director.

The Course Director advises the students individually and he validates their choices. Calling for the Course Director's written consent is the responsibility of the student

**Langue:** Français

**Obligatoire:** Oui

### Partial Differential Equations I

**Module:** Module 1.2 (Semestre 1)

**ECTS:** 5

**Objectif:** The goal of the course is to get acquainted with Partial differential equations (PDE) as a powerful tool for modeling problems in science, providing functional analytic techniques in order to deal with PDE.

**Course learning outcomes:** On successful completion of the **course** the student should be able to:

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- Apply methods of Fourier Analysis to the discussion of constant coefficient differential equations
- Work freely with the classical formulas in dealing with boundary value problems for the Laplace equation
- Prove acquaintance with the basic properties of harmonic functions (maximum principle, mean value property) and solutions of the wave equation (Huygens property)
- Solve Cauchy problems for the heat and the wave equations
- Give a pedagogic talk for peers on a related topic

**Description:** Fourier transform, the classical equations, spectral theory of unbounded operators, distributions, fundamental solutions.

**Modalité d'enseignement:** Lecture course

**Langue:** Anglais

**Obligatoire:** Oui

**Evaluation:** Written exam

**Remarque:**

1. Rudin: Functional analysis
2. Jost: Postmodern analysis
3. Folland: Introduction to partial differential equations.
4. Reed-Simon: Methods of mathematical physics I-IV

**Professeur:** OLBRICH Martin, PALMIROTTA Guendalina

### Probability (Martingale Theory)

**Module:** Module 1.2 (Semestre 1)

**ECTS:** 5

**Objectif:** Introduction to basic concepts of modern probability theory

**Course learning outcomes:** On successful completion of the course, the student should be able to:

- Understand and use concepts of modern probability theory (e.g., filtrations, martingales, stopping times)
- Apply the notion of martingale to model random evolutions
- Know and apply classical martingale convergence theorems
- Describe and manipulate basic properties of Brownian motion

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<b>Description:</b>	Filtrations, conditional expectations, martingales, stopping times, optional stopping, Doob inequalities, martingale convergence theorems, canonical processes, Markov semigroups and processes, Brownian motion
<b>Modalité d'enseignement:</b>	Lecture course
<b>Langue:</b>	Anglais
<b>Obligatoire:</b>	Oui
<b>Evaluation:</b>	Written exam
<b>Remarque:</b>	H. Bauer, Wahrscheinlichkeitstheorie D. Williams, Probability with Martingales
<b>Professeur:</b>	CAMPESE Simon

### Algorithmic Number Theory

<b>Module:</b>	Module 1.3 (Semestre 1)
<b>ECTS:</b>	4
<b>Course learning outcomes:</b>	On successful completion of the course, the student should be able to: <ul style="list-style-type: none"><li>- Explain the main algorithms for primality testing, factorizing large integers, solving the discrete logarithm problem, both in the multiplicative group of finite fields, as well as in the context of elliptic curves defined over finite fields</li><li>- Read and understand some scientific articles published in the domain, and ask relevant questions</li><li>- Give a talk for peers on related topics</li><li>- Organize his approach to general problems in an algorithmic way</li></ul>
<b>Langue:</b>	Anglais
<b>Obligatoire:</b>	Non
<b>Professeur:</b>	LEPREVOST Franck

### Basics of Discrete Mathematics

<b>Module:</b>	Module 1.3 (Semestre 1)
<b>ECTS:</b>	4
<b>Course learning outcomes:</b>	More important than the actual content of the course (given below), is the development of the student's mathematical maturity. Upon completing this course a student should be able to: <ol style="list-style-type: none"><li>1. recall basic concepts and tools which should be present in any science curriculum, not only in mathematics and computer science, but also in engineering and other applied sciences,</li><li>2. formulate and solve mathematically several logical and combinatorial problems arising in science as well as in quotidian life, and</li></ol>

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3. recognize the genuine pleasure in tackling problems and the blissful joy by attaining their solution.

<b>Description:</b>	The content includes but is not limited to : <ol style="list-style-type: none"><li>1. Discrete calculus: sums and recurrences; manipulation of sums; multiple sums; general methods; finite calculus; summation by parts.</li><li>2. Binomial coefficients: basic identities; binomial theorem; multinomial coefficients; Vandermonde's convolution; Newton series.</li><li>3. Generating functions: basic maneuvers; solving recurrences; exponential generating functions.</li><li>4. Special numbers: Stirling numbers; Eulerian numbers; Harmonic numbers; Harmonic summations; Bernoulli numbers; Fibonacci numbers.</li><li>5. Asymptotics: O Notation, Euler's summation formula.</li></ol>
<b>Modalité d'enseignement:</b>	Lecture course Course slides
<b>Langue:</b>	Anglais
<b>Obligatoire:</b>	Non
<b>Evaluation:</b>	Written exam
<b>Remarque:</b>	Littérature / Literatur / Literature (recommended but not mandatory) : <ul style="list-style-type: none"><li>• R. L. Graham, D. E. Knuth, and O. Patashnik, Concrete Mathematics, Addison-Wesley, 2nd edition, 2003.</li><li>• W. G. Kelley and A. C. Peterson, Difference Equations. An Introduction with Applications, Academic Press, 2nd edition, 2001.</li><li>• C. Mariconda and A. Tonolo, Discrete Calculus. Methods for Counting, Springer, 2016.</li><li>• D. E. Knuth, The Art of Computer Programming, Volume 1: Fundamental Algorithms, 3rd edition, Addison Wesley, 1997.</li></ul>
<b>Professeur:</b>	MARICHAL Jean-Luc

### Discrete and Polyhedral Geometry

<b>Module:</b>	Module 1.3 (Semestre 1)
<b>ECTS:</b>	4
<b>Objectif:</b>	Understand, master and be able to apply some key notions of discrete and polyhedral geometry.
<b>Course learning outcomes:</b>	On successful completion the course, the student should be able to: <ul style="list-style-type: none"><li>- Explain notions of metric geometry on polyhedral surfaces, in particular geodesics</li><li>- Use combinatorial properties of polyhedra</li><li>- Understand the rigidity of convex polyhedra in Euclidean space, and its proof (Cauchy-Legendre)</li><li>- Provide examples of flexible (non-convex) polyhedra and comment on their properties (bellows theorem)</li></ul>

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**Description:** The course will explore a number of classical or recent results on the geometry of polygons and polyhedra.

Content:

- 1) geodesics in polygons and on polytopes
- 2) the Steinitz theorem
- 3) Rigidity of convex polyhedra
- 4) The Bellows conjecture
- 5) Folding and unfolding of polyhedra

**Modalité d'enseignement:** lecture

**Langue:** Anglais

**Obligatoire:** Non

**Evaluation:** Examen final, contrôle continu

**Remarque:** Support and Litterature:

Lectures on Discrete and Polyhedral Geometry

Igor Pak, UCLA

<http://www.math.ucla.edu/~pak/book.htm>

**Professeur:** SCHLENKER Jean-Marc

## Introduction to Programming

**Module:** Module 1.3 (Semestre 1)

**ECTS:** 4

**Course learning outcomes:** On successful completion of the course, the student should be able to:

- Apply the basic grammar of programming in Python
- Write professional scripts and analyze and debug a flawed script
- Use functions/modules/classes, as well as a 2D-graphic environment
- Understand complexity issues arising in algorithmic
- Comment on the difference between public key and private key cryptographies, between Monte-Carlo and Las Vegas algorithms, between various data structures (lists, sets, trees), and between different text encodings
- Write a script which encrypts the binary data file, a script that cracks a message encrypted with the Hill cipher, and a script that tests the primality of a number

**Langue:** Anglais

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**Obligatoire:** Non  
**Professeur:** CASINI Giovanni, PARENT Xavier

### Probabilistic Models in Finance

**Module:** Module 1.3 (Semestre 1)

**ECTS:** 4

**Objectif:** Introductory course to basic concepts of Mathematical Finance, also suitable for students who are not going to choose their specialization in Finance. The goal is to deepen the knowledge of modern probability theory by studying applications of general interest in an actual field of applied mathematics.

**Course learning outcomes:** On successful completion of the course, the student should be able to:

- Derive and apply formulas for option pricing and hedging strategies
- Carry out calculations based on arbitrage arguments
- Calculate the price of European call and put options using the Cox, Ross and Rubinstein model
- Apply the techniques of Snell envelopes to evaluate American options
- Derive the classical Black-Scholes formulas as limiting case of a sequence of CRR markets

**Description:** Discrete financial markets, the notion of arbitrage, discrete martingale theory, martingale transforms, complete markets, the fundamental theorem of asset pricing, European and American options, hedging strategies, optimal stopping, Snell envelopes, the model of Cox, Ross and Rubinstein.

**Modalité d'enseignement:** Lecture course

**Langue:** Anglais

**Obligatoire:** Non

**Evaluation:** Written exam

**Remarque:** Literature :

D. Lamberton, B. Lapeyre: Introduction au calcul stochastique appliqué à la finance.  
Ellipses, 1997

S. E. Shreve: Stochastic calculus for finance. I: The binomial asset pricing model.  
Springer Finance, 2004

H. Föllmer, A. Schied: Stochastic finance. An introduction in discrete time. 2nd ed.,  
de Gruyter, 2004

F. Delbaen, W. Schachermayer: The mathematics of arbitrage. Springer Finance, 2006



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**Professeur:** THALMAIER Anton

### Allgemeines Deutsch für Anfänger - A1.1

**Module:** Module 1.3 (Semestre 1)

**ECTS:** 3

**Course learning outcomes:** By the end of this course, students should be able to:

- understand and provide information about themselves and general private matters
- understand and give information about their spare time activities and making appointments
- understand and provide information about rooms, apartments and furniture
- understand and provide information about clothes and fashion and how to buy things
- understand and give information about attractions and towns in the German speaking countries
- linguistic actions in the everyday life like telling time, etc.
- understand and provide simple texts like e-mails or sms.

**Description:** This course starts with basic language skills. The course will be based on the manual DaF-Kompakt A1 (Hueber)

**Communication skills** : The students will learn to understand simple written texts and oral communication about presenting yourself, giving personal information, giving information about time and seasons, buying things and food, hobbies and spare time activities, making appointments, furniture and living, tourist attractions and urban living.

**Grammar:** articles, verbs (with vowel change) in the present, negation, modal verbs, irregular verbs in the present tense, possessive articles, sentence structure, etc. The course ends with a language examination in all four communicative activities on the level A1 GER.

**Langue:** Allemand

**Obligatoire:** Non

**Evaluation:** Speaking, listening, writing and reading skills will be evaluated in task based active-ties

- Listening: key information from listening text has to be understood (radio, TV, etc.)
- Reading: key information in (or answer question to) a short reading text has to be found
- Writing: simple texts are to be summarized and simple text production

Students will be evaluated on their active participation in the course, their regular homework (which can also be grammar or vocabulary exercises) and on their final test (written and spoken).

**Remarque:** Prerequisites

none

Bibliography



## Master in Mathematics

BirgitBraunet.al.:DaFkompaktA1(DeutschalsFremdsprache)Kurs-undÜbungsbuch  
+2AudioCDs.Klett.Stuttgart2015.

**Professeur:** CICHELLI-RÖSSLER Birgit



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Semestre 2

### Homological Algebra

**Module:** Module 2.1 (Semestre 2)

**ECTS:** 5

**Objectif:** Homological algebra is roughly a collection of techniques that allow extracting information encoded in a widespread type of sequences of objects and arrows. It originates from topology, became an independent field of Mathematics in the mid 1940s, and developed in close connection with category theory. Nowadays homological algebra plays an important role in numerous areas of Mathematics, e.g. in algebraic number theory, algebraic geometry, mathematical physics... Since a modern approach to homological algebra falls outside the scope of a general first year Master course, we will try to present a more classical viewpoint.

**Course learning outcomes:** On successful completion of the lecture course the student should be able to:

- State the main definitions and results of Homological Algebra
- Comment on fundamental features and concepts
- Apply the new techniques and solve related problems
- Categorize the main methods and characteristic proofs
- Reorganize the acquired abilities and summarize essential aspects adopting a higher standpoint
- Give a talk for peers on a related topic

**Description:**

- Basic concepts
- Examples of cohomology theories
- Computations of cohomologies
- Spectral sequences
- Functors Tor and Ext

**Modalité d'enseignement:** Lecture course

**Langue:** Anglais

**Obligatoire:** Oui

**Evaluation:** Oral exam

**Remarque:** Course and lecture notes under construction

C. A. Weibel, An introduction to homological algebra, Cambridge studies in advanced mathematics 38, 1997, ISBN 0-521-55987-1

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P.J. Hilton, U. Stammbach, A course in homological algebra, Springer, 1997, 0-387-94823-6

S. Mac Lane, Homology, Springer, 1995, 3-540-58662-8

Professeur: PONCIN Norbert

### Partial Differential Equations II

**Module:** Module 2.1 (Semestre 2)

**ECTS:** 5

**Objectif:** Learning tools in order to deal with PDE, understanding the interplay between local and global problems and techniques.

**Description:** Distributions as generalized functions continued, Sobolev spaces, elliptic regularity, elliptic operators on compact manifolds, some non-linear equations.

**Modalité d'enseignement:** Lecture course

**Langue:** Anglais

**Obligatoire:** Oui

**Evaluation:** Written exam

**Remarque:**

1. Jost: Postmodern analysis
2. Folland: Introduction to partial differential equations
3. Reed-Simon: Methods of mathematical physics I-IV
4. Aubin: Nonlinear analysis on manifolds

**Professeur:** OLBRICH Martin, PALMIROTTA Guendalina

### Student Seminar

**Module:** Module 2.1 (Semestre 2)

**ECTS:** 3

**Course learning outcomes:** On successful completion of the seminar, the students should be able to:

- Fully benefit from seminar talks

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- Acquire good insight into a field by means of individual work
- Give themselves lectures on specific topics
- Share their knowledge with others

**Description:** Each student will give at least one talk on a topic selected jointly with the supervising professor. A typewritten version of this (these) lecture(s) will be requested.

**Modalité d'enseignement:** Student Seminar

**Langue:** Anglais

**Obligatoire:** Oui

**Evaluation:** Participation and lecture(s) in the seminar.

**Remarque:** Provided by the supervisor

**Professeur:** PONCIN Norbert, THALMAIER Anton

### Complex Geometry

**Module:** Module 2.2 (Semestre 2)

**ECTS:** 5

**Objectif:** The aim of the lecture course is to give an introduction to the theory of complex manifolds as it is needed for further studies in the field. After the course the students should understand the notion of a complex manifold, know the most important examples, be acquainted with the basic theorems of the theory, and master the basic techniques of the theory. The lecture course serves on one hand as a preparation for more specialized lectures in the second year of the master, and on the other hand as a preparation for writing a master thesis in the subject.

**Course learning outcomes:** On successful completion of the lecture course the students should be able to

- Demonstrate knowledge of the notion of a complex manifold
- Identify the most important examples
- Master the basic techniques of the theory
- Demonstrate knowledge of the basic theorems
- Relate the notion of vector bundles with the notion of sheaves
- Apply cohomological techniques to geometric problems

**Description:** 1. Holomorphic functions in 1 variable

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2. Holomorphic functions in  $n$  variables
3. Repetition: differentiable manifolds
4. Complex manifolds and their basic properties
5. Examples: projective space, Grassmannians, ...
6. Sheaf of holomorphic functions
7. Meromorphic functions
8. Analytic sets and singularities
9. Tangent space and differentials, real picture
10. Tangent space and differentials, complex picture
11. Multidifferential forms, DeRham and Dolbeault operators
12. Vector bundles
13. Line bundles

<b>Modalité d'enseignement:</b>	Lecture Course
<b>Langue:</b>	Anglais
<b>Obligatoire:</b>	Oui
<b>Evaluation:</b>	Written or oral examination
<b>Remarque:</b>	<ol style="list-style-type: none"><li>1. S.S. Chern: Complex Manifolds without Potential Theory</li><li>2. Wells: Differential Analysis on Complex Manifolds</li><li>3. Griffiths&amp;Harris: Principles of Algebraic Geometry</li><li>4. R.O. Wells, Differential Analysis on Complex Manifolds</li><li>5. M. Schlichenmaier, An Introduction to Riemann Surfaces, Algebraic Curves and Moduli Spaces</li><li>6. F. Warner, Foundations of Differentiable Manifolds</li></ol>
<b>Professeur:</b>	GHOSH Sourav

## Probability (Stochastic Analysis)

<b>Module:</b>	Module 2.2 (Semestre 2)
<b>ECTS:</b>	5

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<b>Objectif:</b>	<b>Introduction to basic concepts of Stochastic Analysis</b>
<b>Description:</b>	<b>Continuous martingales, stochastic integration, quadratic variation, Itô calculus, theorem of Girsanov, stochastic differential equations, Markov property of solutions, connection of stochastic differential equations and partial differential equations, martingale representation theorems, chaotic expansions, Feynman-Kac formulas</b>
<b>Modalité d'enseignement:</b>	<b>Lecture course</b>
<b>Langue:</b>	<b>Anglais</b>
<b>Obligatoire:</b>	<b>Oui</b>
<b>Evaluation:</b>	<b>Written exam</b>
<b>Remarque:</b>	<b>I. Karatzas, S. Shreve: Brownian motion and stochastic calculus. 2<sup>nd</sup> edition. Springer, 1991</b> <b>B. Oksendal: Stochastic differential equations. Springer, 2003</b> <b>D. Revuz, M. Yor: Continuous Martingales and Brownian Motion. Springer Grundle., 1999</b>
<b>Professeur:</b>	<b>PECCATI Giovanni</b>

## Algebraic Number Theory

<b>Module:</b>	<b>Module 2.3 (Semestre 2)</b>
<b>ECTS:</b>	<b>4</b>
<b>Objectif:</b>	<b>Introduce the students to Algebraic Number Theory.</b>
<b>Course learning outcomes:</b>	<b>On successful completion of the course, the students should be able to:</b> <ul style="list-style-type: none"><li><b>- appreciate the role played by abstract algebraic number theory for the solution of concrete Diophantine equations,</b></li><li><b>- define number rings and enumerate their fundamental properties,</b></li><li><b>- solve certain Diophantine equations,</b></li><li><b>- outline the proofs of the fundamental results of the lecture,</b></li><li><b>- apply the quadratic reciprocity law,</b></li><li><b>- calculate class numbers and rings of integers in simple cases.</b></li></ul>

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<b>Description:</b>	<b>Explicit Diophantine equations</b> <b>Number rings</b> <b>Cyclotomic fields</b> <b>Quadratic reciprocity</b> <b>Geometry of numbers</b>
<b>Modalité d'enseignement:</b>	<b>Lecture with integrated exercises</b>
<b>Langue:</b>	Anglais
<b>Obligatoire:</b>	Non
<b>Evaluation:</b>	<b>Oral exam</b>
<b>Remarque:</b>	Support and Literature: <b>to be announced in the lecture</b>
<b>Professeur:</b>	PERUCCA Antonella

### Introduction to Continuous Time Models in Mathematical Finance

<b>Module:</b>	Module 2.3 (Semestre 2)
<b>ECTS:</b>	4
<b>Objectif:</b>	<b>Introduction to continuous time models in mathematical finance (Black-Scholes model)</b>
<b>Description:</b>	<b>Arbitrage, risk-neutral measures, option pricing, hedging, Black-Scholes-Merton equation, call-put parity, connections with partial differential equations, forwards and futures, american options, exotic options , change of numéraire, Garman-Kohlhagen formula, term-structure models, Vasicek model, Heath-Jarrow-Morton model, forward LIBOR model</b>
<b>Modalité d'enseignement:</b>	<b>Lecture course</b>
<b>Langue:</b>	Anglais
<b>Obligatoire:</b>	Non
<b>Evaluation:</b>	<b>Written exam</b>
<b>Remarque:</b>	<b>M. Baxter, A. Rennie: Financial calculus. An introduction to derivative pricing. CUP, 1996</b>

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**F. E. Benth: Option Theory with Stochastic Analysis. Springer, 2004**

**R. J. Elliot, P. E. Kopp: Mathematics of Financial Markets. 2<sup>nd</sup> ed., Springer Finance, 2004**

**J. C. Hull: Options, futures, and other derivatives. 6th ed., Prentice-Hall, 2005**

**S. E. Shreve: Stochastic calculus for finance. II: Continuous-time models. Springer, 2004**

**J. Michael Steele: Stochastic Calculus and Financial Mathematics. Springer, 2001**

**Professeur:** PECCATI Giovanni

### Topics in Graph Theory

**Module:** Module 2.3 (Semestre 2)

**ECTS:** 4

**Objectif:** Through a presentation of selected topics, the course aims to be an introduction to certain modern aspects of graph theory. It is designed as a self-contained course, but some familiarity with graph theoretic notions is an asset.

**Description:** According to time and taste, topics covered will be chosen among the following ones:

- Expander graphs and applications
- Graph minors and reconstruction problems
- Ramsey theory for graphs
- Existence of disjoint spanning trees (and applications to combinatorial games)
- Advanced coloring results
- Combinatorics on graph

**Modalité d'enseignement:** **Lecture course**

**Obligatoire:** Non

**Evaluation:** **Oral exam**

**Remarque:** Literature :

Jiri Matousek and Jaroslav Nešetřil, An Invitation to Discrete Mathematics, Oxford University Press, USA; 2<sup>nd</sup> edition

W.D. Wallis: A Beginner's Guide to Graph Theory, Birkhäuser 2007

## Master in Mathematics

### Numerical Analysis

<b>Module:</b>	Module 2.3 (Semestre 2)
<b>ECTS:</b>	4
<b>Langue:</b>	Français
<b>Obligatoire:</b>	Non
<b>Professeur:</b>	ANTOINE Xavier

### An introduction to mathematical statistics

<b>Module:</b>	Module 2.3 (Semestre 2)
<b>ECTS:</b>	5
<b>Objectif:</b>	The course provides an introduction to Mathematical Statistics and addresses more specifically the problems of estimation and testing in parametric models.
<b>Course learning outcomes:</b>	A student should be able to  test the goodness-of-fit of the distribution of the data to some parametric models,  estimate and test a hypothesis in parametric models. Build a confidence region for the parameter
<b>Description:</b>	<ol style="list-style-type: none"><li>1. Introduction the statistical paradigm and statistical models.</li><li>2. The main statistical issues I. Estimation, risk, asymptotic normality, confidence intervals. The main probabilistic tools: Markov's inequality, Hoeffding's inequality, Berry-Esseen's theorem, the central limit theorem, Slutsky's lemma, the delta method.</li><li>3. The main statistical issues II. Hypothesis testing. First and second kind errors. Construction of tests from confidence regions. The pivot method.</li><li>4. The empirical measure and its applications. The empirical moments, the empirical distribution function, the empirical variance. The moment method, Kolmogorov-Smirnov's tests, estimation based on the empirical quantiles. Robustness.</li><li>5. The maximum likelihood estimator (MLE). Example and counter-examples. Consistency of the MLE.</li><li>6. One dimensional exponential families. Properties of the MLE.</li><li>7. Tests in parametric models. The Neyman-Pearson's test, the likelihood ratio test. The monotone likelihood ratio property.</li></ol>
<b>Langue:</b>	Anglais
<b>Obligatoire:</b>	Non
<b>Evaluation:</b>	Written exam
<b>Remarque:</b>	Literature : Mathematical Statistics (vol 1), Bickel, P. and Doksum, K.





## Master in Mathematics

**Professeur:** BARAUD Yannick

## Master in Mathematics

### Semestre 3

#### Advanced Stochastic Modeling and Financial Applications

<b>Module:</b>	Module 3.1 (Semestre 3)
<b>ECTS:</b>	5
<b>Objectif:</b>	
<b>Course learning outcomes:</b>	On successful completion of the course, the student should be able to: <ul style="list-style-type: none"><li>- Calculate probabilities and expectations related to possibly discontinuous and non-semi-martingale financial models</li><li>- Carry out computations related to models involving general Gaussian processes (e.g., fractional)</li><li>- Apply variational techniques of Malliavin calculus</li><li>- Apply transaction costs to deal with incomplete markets</li><li>- Use basic stochastic optimization techniques</li></ul>
<b>Description:</b>	Discontinuous Stochastic Calculus; Malliavin Calculus of Variations; Transaction Costs; Fractional Processes; Incomplete Markets; Stochastic Optimization.
<b>Modalité d'enseignement:</b>	Lecture course
<b>Langue:</b>	Anglais
<b>Obligatoire:</b>	Oui
<b>Evaluation:</b>	Oral exam Personal work Continuous assessment
<b>Remarque:</b>	T. Björk (2009). Arbitrage Theory in Continuous Time. Oxford.  P. Malliavin and A. Thalmaier (2005). Stochastic Calculus of Variations in Mathematical Finance. Springer-Verlag.  M. Musiela and M. Rutkowski (1997). Martingale Methods in Financial Modeling. Springer Verlag.
<b>Professeur:</b>	PECCATI Giovanni

#### American options: Optimal Stopping Theory and numerical methods

<b>Module:</b>	Module 3.1 (Semestre 3)
<b>ECTS:</b>	5

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<b>Objectif:</b>	The lectures provide an introduction to American options and optimal stopping problems (theoretical foundation and numerical implementation).
<b>Course learning outcomes:</b>	On successful completion of the course, the student should be able to: <ul style="list-style-type: none"><li>- Explain pricing and hedging of 'Vanilla' American options in a multi-asset Black-Scholes model using bi- or multinomial trees</li><li>- Extend multinomial tree methods to the pricing and hedging of American options in local volatility or stochastic volatility models (CEV, SABR, Heston...)</li><li>- Implement efficiently a regression method 'à la Longstaff-Schwarz' for solving multi-dimensional optimal stopping problems like the pricing and the hedging of multi-asset American options or energy derivatives like swing options (take-or-pay gas contracts)</li><li>- Implement an optimal quantization based numerical scheme to price and hedge multi-asset American style derivatives</li><li>- Analyze these numerical methods and their respective ranges of efficiency, especially compared to PDE methods</li></ul>
<b>Description:</b>	<ul style="list-style-type: none"><li>- Discrete time optimal stopping theory: Snell envelope, Rogers' dual representation, optimal stopping times</li><li>- Backward dynamical programming principle</li><li>- American options pricing and hedging in a complete market, with and without dividends</li><li>- Bermuda options (discrete time)</li><li>- Swing options on energy markets</li><li>- Numerical methods: variational inequality (PDE method), regression methods (Longstaff-Schwarz), Quantization methods with a priori error bounds</li><li>- Continuous time optimal stopping theory and applications to complete markets</li><li>- Réduites, variational inequalities, free boundary</li></ul>
<b>Modalité d'enseignement:</b>	Lecture course
<b>Langue:</b>	Anglais
<b>Obligatoire:</b>	Oui
<b>Evaluation:</b>	Written or oral exam (depending on the number of enrolled students)
<b>Remarque:</b>	Support :  provided in class ***  Literature :  V. Bally, G. Pagès, J. Printems (2005). A quantization tree method for pricing and hedging multidimensional American options, <i>Mathematical Finance</i> , 15(1):119-168.

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É. Clément, P. Protter, D. Lamberton (2002). An analysis of a least squares regression method for American option pricing, *Finance & Stochastics*, 6(2):449-47

N. El Karoui (1981). Les aspects probabilistes du contrôle stochastique, *Lecture Notes in Mathematics* 876, 72-238, Springer Verlag.

N. El Karoui, J.P.Lepeltier, and A. Millet (1988). A probabilistic approach of the réduite in optimal stopping, *Probab. Math. Statist.* 13 , no. 1, 97-121.

D. Lamberton, B. Lapeyre (1996). Introduction to stochastic calculus applied to finance. Chapman & Hall, London, 185 pp. ISBN: 0-412-71800-6.

F.A. Longstaff, E.S. Schwarz (2001). Valuing American options by simulation: a simple least-squares approach, *Review of Financial Studies*, 14:113-148.

J. Neveu (1964). Bases mathématiques du calcul des Probabilités, Masson, Paris; English translation *Mathematical Foundations of the Calculus of Probability* (1965), Holden Day, San Francisco.

A. N. Shyriaev (2008). Optimal stopping rules. Translated from the 1976 Russian second edition by A. B. Aries. Reprint of the 1978 translation. *Stochastic Modeling and Applied Probability*, 8, Springer-Verlag, Berlin, 217 pp.

**Professeur:** PAGES Gilles

### Continuous-Time Stochastic Calculus and Interest Rate Models

**Module:** Module 3.1 (Semestre 3)

**ECTS:** 5

**Course learning outcomes:** On successful completion of the course, the student should be able to:

- Calculate probabilities and expectations related to the semi-martingale models presented in the lectures
- Carry out calculations based on change of numéraire and no-arbitrage pricing
- Compute the prices of interest rate derivatives
- Apply stochastic volatility models to deal with implied volatility surfaces

**Description:** Basic Notions of Fixed Income Markets; Semimartingale Modeling; Stochastic Differential Equations; No-Arbitrage Pricing; Change of Numéraire; Short Rate Models; Heath-Jarrow-Morton Framework; Market Models; Stochastic Volatility

**Modalité d'enseignement:** Lecture course

**Langue:** Anglais

**Obligatoire:** Oui

**Evaluation:** Written exam

**Remarque:** D. Brigo and F. Mercurio (2006) *Interest Rate Models : Theory and Practice*. Springer Verlag  
M. Musiela and M. Rutkowski (1997) *Martingale Methods in Financial Modeling*. Springer Verlag

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**Professeur:** PECCATI Giovanni

### Gaussian processes and applications

**Module:** Module 3.1 (Semestre 3)

**ECTS:** 5

**Course learning outcomes:** On successful completion of the course, the student should be able to:

- Explain the language, basic concepts and techniques associated with Gaussian variables, vectors, and processes
- Identify, analyse, and prove relevant properties of models based on a Gaussian structure
- Solve exercises involving a Gaussian structure

**Langue:** Anglais

**Obligatoire:** Oui

**Professeur:** NOURDIN Ivan

### Numerical Methods in Finance

**Module:** Module 3.1 (Semestre 3)

**ECTS:** 5

**Objectif:** The objective of this course is to present the numerical methods currently used in finance, especially in option pricing and portfolio optimization.

The course will be organized in three parts:

- PDE methods for option pricing and numerical methods in stochastic control: 15h (A. Sulem)
- Monte Carlo methods: 8h (Bernard Lapeyre)
- Applied sessions with computer with the computational finance software "Premia" ( [www.premia.fr](http://www.premia.fr) ): 7h (Jérôme Lelong)

**Course learning outcomes:** On successful completion of the course, the student should be able to:

- Explain and apply relevant numerical methods currently used in finance
- Carry out calculations based on Monte Carlo methods, especially in option pricing and portfolio optimization

**Modalité d'enseignement:** Course and practical exercises on the computer.

**Langue:** Anglais

**Obligatoire:** Oui

**Evaluation:** Witten exam.

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<b>Remarque:</b>	D. Lambertson and B. Lapeyre. Introduction to Stochastic Calculus Applied to Finance. Chapman and Hall, 2nd edition, 2007.  B. Lapeyre, A. Sulem and D.Talay. Simulation of Financial Models: Mathematical Foundations and Applications, to appear. Cambridge University Press.  B. Jourdain. Probabilités et statistique. Ellipes, 2009.
<b>Professeur:</b>	SULEM Agnès, LAPEYRE Bernard

### Advanced Econometrics

<b>Module:</b>	Module 3.2 (Semestre 3)
<b>ECTS:</b>	6
<b>Objectif:</b>	This course is intended for research track masters students. However, Ph.D. students interested in learning this material are also welcome to enroll. Its objective is to familiarize students with microeconomic models and methods that are widely used in applied economics and social science research. We will focus on linear models in this course; nonlinear models will be covered in a subsequent course.
<b>Course learning outcomes:</b>	<p>Expected outcome</p> <p>After taking this course, the students should have a good understanding of some widely used econometric models and techniques used by economists to answer policy related questions. Students should be able to understand how these models are identified, estimated, and tested, how the asymptotic distributions of the various estimators and test statistics are obtained, and the fundamental assumptions underlying these results. This will not only enable the students to process and interpret empirical data and test whether they are in accordance with economic theory, but should also help them read, understand, and critically evaluate the econometrics articles in peer-reviewed journals encountered during the course of their own research.</p>
<b>Description:</b>	This course is intended for research track masters students. However, Ph.D. students interested in learning this material are also welcome to enroll. Its objective is to familiarize students with microeconomic models and methods that are widely used in applied economics and social science research. We will focus on linear models in this course; nonlinear models will be covered in a subsequent course.
<b>Langue:</b>	Anglais
<b>Obligatoire:</b>	Non
<b>Evaluation:</b>	Written exam
<b>Professeur:</b>	TRIPATHI Gautam, KOSTYRKA Andreï

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### Data Science

<b>Module:</b>	Module 3.2 (Semestre 3)
<b>ECTS:</b>	5
<b>Objectif:</b>	The successful candidate understands the fundamental theoretical concepts of selected aspects of Data Science. (S)he will be able to work on appropriate solutions to data-centric problems. A continuation with concerned aspects, for example through a Master Thesis, will be motivated and supported.
<b>Course learning outcomes:</b>	On successful completion of the course the student should be able to: <ul style="list-style-type: none"><li>- Explain and apply the fundamental theoretical concepts of selected aspects of Data Science</li><li>- Elaborate appropriate solutions to data-centric problems</li><li>- Deepen her/his competence in the field through a Master Thesis or self-learning</li></ul>
<b>Description:</b>	The course is split into a lecture (Week 1 – 8; 13 - 14) and a seminar phase (Week 9 – 12). We concern selected aspects of <ul style="list-style-type: none"><li>• Data Mining and Machine Learning</li><li>• Data Modeling and SQL</li><li>• Database Systems</li><li>• Data Quality and Preprocessing</li><li>• Data Privacy and Security</li><li>• Data and Information Visualization</li><li>• Information Retrieval</li></ul>
<b>Modalité d'enseignement:</b>	CM (67%), SEM (33%)
<b>Langue:</b>	Anglais
<b>Obligatoire:</b>	Non
<b>Evaluation:</b>	50% Seminar, 50% Oral examination
<b>Remarque:</b>	Support: <ul style="list-style-type: none"><li>• Elmasri, Navathe: Fundamentals of Database Systems. Pearson Addison Wesley. 2006.</li><li>• Han, Kamber: Data Mining – Concepts and Techniques. Morgan Kaufmann. 2011.</li><li>• Manning, Raghavan, Schütze: Introduction to Information Retrieval. Cambridge University Press.</li><li>• Ware: Information Visualization. Morgan Kaufmann. 2012.</li><li>• Witten, Kamber: Data Mining: Practical Machine Learning Tools and Techniques. Morgan Kaufmann.</li><li>• Aggarwal, Yu: Privacy-Preserving Data Mining – Models and Algorithms. Springer. 2008.</li><li>• Marz: Big Data: Principles and best practices of scalable realtime data systems. Manning. 2015.</li></ul> as well as different articles, reports, and journals contributions.
<b>Professeur:</b>	SCHOMMER Christoph

### Finite Element Method

<b>Module:</b>	Module 3.2 (Semestre 3)
<b>ECTS:</b>	5
<b>Objectif:</b>	The objectives of the course are to provide to students a global overview of the finite element method. Not only the mathematical foundations will be developed but also the concrete implementation of finite element approximation techniques in view of their application to engineering problems. Some problems will be fully solved by using some computer programs written by the students (by using the PDE toolbox of Matlab or some bricks written by students).
<b>Course learning outcomes:</b>	On successful completion of the course, the student should be able to: <ul style="list-style-type: none"><li>- Explain the mathematical foundations of the finite element method</li><li>- Master its concrete implementation for nontrivial engineering boundary-value problems</li><li>- Adapt, if necessary, the finite element method to the problem under consideration</li></ul>
<b>Description:</b>	<ol style="list-style-type: none"><li>1. Complements on Sobolev spaces; trace theorems; Green's formulae</li><li>2. The Lax-Milgram theory ; variational formulations</li><li>3. The Finite Element Method for stationary elliptic Partial Differential Equations (PDEs): theoretical aspects</li><li>4. The Finite Element Method for stationary elliptic Partial Differential Equations (PDEs): implementation and computational aspects</li></ol>
<b>Modalité d'enseignement:</b>	Lecture course, exercises of applications
<b>Langue:</b>	Anglais
<b>Obligatoire:</b>	Non
<b>Evaluation:</b>	The students will have to provide some reports that will be evaluated. In addition, a final written examination will be organized.
<b>Remarque:</b>	Support / Arbeitsunterlagen / Support:  Lecture notes (french), exercise sheets (english)  Littérature / Literatur / Literature: <ol style="list-style-type: none"><li>1) X. Antoine, Numerical solution of PDEs, lecture notes</li><li>2) X. Antoine, Numerical Analysis, course at the University of Luxembourg</li><li>3) G. Allaire, Analyse Numérique et Optimisation, Presses de l'Ecole Polytechnique</li><li>4) P.A. Raviart et J.M. Thomas, Introduction à l'Analyse Numérique des Equations aux Dérivées Partielles, Dunod.</li></ol>
<b>Professeur:</b>	ANTOINE Xavier



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### Internship in a financial institution

<b>Module:</b>	Module 3.2 (Semestre 3)
<b>ECTS:</b>	5
<b>Course learning outcomes:</b>	On successful completion of the course the student should be able to: <ul style="list-style-type: none"><li>- Get acquainted with the local job market and possible career tracks in finance</li><li>- Gain insight in the functioning and the operational business of financial institutions and firms outside the academic world</li><li>- Apply and adapt the theoretical skills and techniques learned in the master program to the practical needs of the chosen company</li><li>- Acquire first experiences for the future professional life</li></ul>
<b>Langue:</b>	Français
<b>Obligatoire:</b>	Non

### Linear Optimization

<b>Module:</b>	Module 3.2 (Semestre 3)
<b>ECTS:</b>	5
<b>Objectif:</b>	Provide the mathematical background for linear programming with some applications to management problems.
<b>Course learning outcomes:</b>	On successful completion of the course the student should be able to: <ul style="list-style-type: none"><li>- Explain the central role of mathematics in linear programming, mainly through the application of the simplex method to certain management and industrial problems</li><li>- Master relevant mathematical tools used in linear optimization, including duality and sensitivity analysis</li></ul>
<b>Description:</b>	<ul style="list-style-type: none"><li>- Introduction to linear programming, including two-variable models and graphical solution</li><li>- The algebraic approach: the simplex method</li><li>- Duality and sensitivity analysis</li><li>- Some applications: transportation model and some of its variants</li><li>- Basic notions of integer linear programming</li></ul>
<b>Modalité d'enseignement:</b>	Lecture course with exercises
<b>Langue:</b>	Anglais, Français
<b>Obligatoire:</b>	Non

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**Evaluation:** Written exam

**Remarque:** Suggested references (not compulsory):

1. Vasek Chvatal, Linear Programming (Series of Books in the Mathematical Sciences), W. H. Freeman; 1st edition, 1983
2. Hamdy A. Taha, Operations Research: An Introduction, Pearson; 9th edition, 2010

**Professeur:** MARICHAL Jean-Luc

### Algebraic Geometry and Number Theory

**Module:** Module 3.1 (Semestre 3)

**ECTS:** 5

**Course learning outcomes:** On successful completion of the **course** the student should be able to:

- Give examples of and explain the continuity of mathematics, from classical problems to more modern questions
- Understand the relevance of knowing modern mathematics for being able to teach a comprehensive picture
- Comprehend nowadays mathematical concepts - beyond secondary school and Bachelor level
- Master the basics of local fields and compute with p-adic numbers, as generalization of the rational numbers
- Master the basics of the theory of quadratic forms, explain its origin in the study of conics, and handle examples
- Master the basics of elliptic curves, know about their classical origin, their application in cryptography, and understand their relevance for current number theory

**Langue:** Anglais

**Obligatoire:** Oui

**Professeur:** MAKSOUD Alexandre

### Geometric Methods in Mathematical Physics

**Module:** Module 3.1 (Semestre 3)

**ECTS:** 5

**Course learning outcomes:** On successful completion of the **course**, the student should be able to:

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- Explain and apply some geometric tools which are of importance in applications in mathematical physics
- Use these new tools and their local coordinate descriptions to solve problems
- Compute the curvature of pseudo-Riemannian and Lorentzian manifolds, thus relating the course to General Relativity
- Construct a new approach to electromagnetism, thereby connecting the course with Gauge Field Theory
- Give a pedagogic talk for peers on a related topic
- Write clear and concise lecture notes, including appropriate exercises and applications

**Langue:** Anglais  
**Obligatoire:** Oui  
**Professeur:** PONCIN Norbert

### Lie Algebras and Lie Groups

**Module:** Module 3.1 (Semestre 3)  
**ECTS:** 5  
**Objectif:** The purpose of this course is to give an introduction into the theory of finite dimensional Lie groups and Lie algebras, assuming some basic knowledge of differentiable manifolds.

**Course learning outcomes:** On successful completion of the course, the student should be able to:

- Expound the mathematical foundation behind symmetries of solid bodies, dynamics of mechanical systems, and geometric structures in nature
- Explain the deep interrelations between Lie groups and Lie algebras, as well as the technical tools behinds these interrelations
- Simplify mathematical problems admitting symmetry Lie groups actions to problems admitting symmetry actions of their Lie algebras
- Master applications to the theory of manifolds and representation theory, which in turn have applications in physics, engineering and mechanics

**Description:** The Lie algebra of a Lie group, the exponential map, , the adjoint representation, actions of Lie groups and Lie algebras on manifolds, the universal enveloping algebra, basics of the representation theory.

**Modalité d'enseignement:** Lecture course  
**Langue:** Anglais  
**Obligatoire:** Oui  
**Evaluation:** Written examination

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**Remarque:** Littérature / Literatur / Literature:

- 1) "Lie groups and Lie algebras" by Eckhard Meinrenken, 83 pages (free to download)
- 2) "Prerequisites from Differential Geometry" by Sergei Merkulov (free to download)

**Professeur:** MERKOULOV (MERKULOV) Serguei

### Combinatorial Geometry

**Module:** Module 3.1 (Semestre 3)

**ECTS:** 5

**Objectif:** Introduction to the theory of Riemann surfaces

**Course learning outcomes:** On successful completion of the course, the student should be able to:

- Illustrate the main results and concepts with well-chosen pedagogical examples
- Master the main techniques of the theory
- Apply the Riemann-Roch theorem to problems in geometry and analysis
- Relate Riemann surfaces and algebraic curves
- Summarize the essential features of the global study versus the local study of a mathematical phenomenon
- Demonstrate a broad understanding of the interaction between geometric concepts and analytic concepts
- Contextualize, unify and relate various mathematical notions that may seem unrelated and give a pedagogical presentation of these concepts and their interconnections

**Description:**

1. Repetition of complex manifolds, Riemann surfaces as 1-dimensional complex manifolds.
2. Topology of Riemann surfaces.
3. Analytic structures, holomorphic and meromorphic functions.
4. Divisors, sheaves of modules associated to divisors.
5. Holomorphic and meromorphic differential forms.
6. The Riemann-Roch Theorem.
7. Integration of differential forms along curves, residue theorem.
8. Projective curves (projective varieties).
9. Complex tori and elliptic curves.
10. Jacobians of compact Riemann surfaces, Abel's theorem and Jacobi's theorem.
11. Sheaves and Cohomology

**Modalité d'enseignement:** Lecture course

**Langue:** Anglais

**Obligatoire:** Non

**Evaluation:** Oral exam

**Remarque:** 1. Forster, Otto. - Lectures on Riemann surfaces. Transl. by Bruce Gilligan, New York: Springer-Verlag, 1999.

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2. Schlichenmaier, Martin. -An Introduction to Riemann Surfaces, Algebraic Curves and Moduli Spaces, Berlin: Springer, 2007.
3. Freitag, Eberhard; Busam, Rolf. - Complex analysis. Transl. by Dan Fulea, Berlin: Springer, 2009.
4. Freitag, Eberhard. - Complex analysis 2. Riemann surfaces, several complex variables, Abelian functions, higher modular functions, Berlin: Springer, 2011.
5. Miranda, Rick. - Algebraic curves and Riemann surfaces, Providence RI: American Mathematical Society, 1995.
6. Farkas, Hershel M.; Kra, Irwin . - Riemann surfaces, Springer, 1992.
- 7.Griffiths, Philip; Harris, Joseph. - Principles of algebraic geometry, New York: J. Wiley, 1994.

**Professeur:** PARLIER Hugo

### Reading course I:

**Module:** Module 3.2 (Semestre 3)

**ECTS:** 5

**Course learning outcomes:** On successful completion of the course, the student should be able to:

- Acquire and deepen specialized knowledge while working in a group and working independently
- Analyze complex problems, plan strategies for their resolution, and apply advanced tools to solve them
- Function professionally and give proof of open-mindedness, dynamism, competence, sense of responsibility, and willingness to take leadership if needed
- Manage risk appropriately and handle failure in a constructive manner
- Hone continuously own personal and professional qualities

**Langue:** Français

**Obligatoire:** Non

**Professeur:** N.N.

### Reading course II:

**Module:** Module 3.2 (Semestre 3)

**ECTS:** 5

**Course learning outcomes:** On successful completion of the course, the student should be able to:

- Acquire and deepen specialized knowledge while working in a group and working independently

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- Analyze complex problems, plan strategies for their resolution, and apply advanced tools to solve them
- Function professionally and give proof of open-mindedness, dynamism, competence, sense of responsibility, and willingness to take leadership if needed
- Manage risk appropriately and handle failure in a constructive manner
- Hone continuously own personal and professional qualities

**Langue:** Anglais

**Obligatoire:** Non

**Professeur:** N.N.

### Advanced Discretization Methods

**Module:** Module 3.1 (Semestre 3)

**ECTS:** 5

**Objectif:** The objectives of the course are to introduce some advanced discretization techniques for the numerical solution of partial differential equations arising in engineering and applied sciences. The schemes will be explained in details as well as their mathematical properties (e.g. order of accuracy, stability). In addition, these methods will be implemented by using Matlab and tested on concrete problems.

**Course learning outcomes:** On successful completion of the course the student should be able to:

- Explain the mathematical foundation of advanced discretization techniques for PDEs
- Master their concrete implementation on nontrivial engineering boundary-value problems
- Adapt them according to the problem under consideration

**Description:**

1. Complements the Finite Element Method
2. Finite difference schemes in space
3. Finite difference schemes for the discretization of time-dependent PDEs
4. Introduction to integral equations

**Modalité d'enseignement:** Lecture course, exercises of applications

**Langue:** Anglais

**Obligatoire:** Oui

**Evaluation:** The students will have to provide some reports that will be evaluated. In addition, a final written examination will be organized.

**Remarque:** Support / Arbeitsunterlagen / Support: Lecture notes (french), exercise sheets (english)

Littérature / Literatur / Literature:

- 1) X. Antoine, Numerical solution of PDEs, lecture notes
- 2) X. Antoine, Numerical Analysis, course at the University of Luxembourg
- 3) G. Allaire, Analyse Numérique et Optimisation, Presses de l'Ecole Polytechnique



## Master in Mathematics

4) P.A. Raviart et J.M. Thomas, Introduction à l'Analyse Numérique des Equations aux Dérivées Partielles, Dunod

**Professeur:** BORDAS Stéphane

## Master in Mathematics

### Semestre 4

#### Stochastic calculus of variations in finance & statistics

<b>Module:</b>	Module 4.1 (Semestre 4)
<b>ECTS:</b>	5
<b>Langue:</b>	Français
<b>Obligatoire:</b>	Non
<b>Professeur:</b>	CAMPESE Simon

#### Internship in a financial institution

<b>Module:</b>	Module 4.1 (Semestre 4)
<b>ECTS:</b>	5
<b>Langue:</b>	Français
<b>Obligatoire:</b>	Non
<b>Professeur:</b>	THALMAIER Anton

#### SDE and PDE (Solving PDE by Running a Brownian Motion)

<b>Module:</b>	Module 4.1 (Semestre 4)
<b>ECTS:</b>	5
<b>Objectif:</b>	The lecture gives an introduction to the interplay of diffusion processes and partial differential equations. The goal is to develop path integral methods with applications in Analysis, Physics and Mathematical Finance.
<b>Course learning outcomes:</b>	Upon successful completion of the course students should be able to <ul style="list-style-type: none"><li>- evaluate functionals of Brownian motion and relate them to PDE;</li><li>- manipulate Feynman-Kac formulas;</li><li>- derive stochastic representation of classical initial value and boundary value problems;</li><li>- calculate Monte-Carlo formulas for Greek parameters in financial models</li></ul>



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<b>Description:</b>	Stochastic flows associated to second order differential operators, stochastic differential equations and L-diffusions, Feynman-Kac formulas and Dirichlet problems, boundary value problems (elliptic and parabolic), spectral problems of Schrödinger operators, differentiation of heat semigroups, computation of price sensitivities (Greeks)
<b>Langue:</b>	Anglais
<b>Obligatoire:</b>	Non
<b>Evaluation:</b>	Written exam
<b>Remarque:</b>	Bass, Richard F. Diffusions and elliptic operators. Springer-Verlag, 1998. Bass, Richard F. Probabilistic techniques in analysis. Springer-Verlag, 1995. Durrett, Richard. Brownian motion and martingales in analysis. Wadsworth, 1984. Varadhan, S. R. S. Lectures on diffusion problems and partial differential equations. Tata Institute, 1980.
<b>Professeur:</b>	THALMAIER Anton

### Master Thesis

<b>Module:</b>	Module 4.2 (Semestre 4)
<b>ECTS:</b>	20
<b>Course learning outcomes:</b>	<b>On successful completion of the Master Thesis, the students should be able to:</b> <ul style="list-style-type: none"><li>- Organize a comprehensive literature review</li><li>- Discuss and communicate scientific ideas</li><li>- Approach mathematical problems efficiently and identify appropriate theories or conceptual techniques</li><li>- Discover original mathematics</li><li>- Verify results and apply them</li><li>- Write mathematical texts that are consistent with the tradition</li></ul>
<b>Description:</b>	The master thesis in mathematics consists of the definition of a research project, the detailed explanation of research articles and/or monographs aimed at a mathematics audience, as well as of potential further developments of these. The project, which should contain parts of original mathematics, will be designed to suit the individual objectives of the students, to deepen their competence in a selected field of mathematics, and to open a door towards mathematical research.
<b>Langue:</b>	Anglais, Français, Allemand

## Master in Mathematics

<b>Obligatoire:</b>	Oui
<b>Evaluation:</b>	<b>Supervisor, director of studies</b>
<b>Remarque:</b>	<b>Admission to the Master Thesis will be granted only to students who acquired at least 75 ECTS credit points during the first three semesters of the Master's program (in a well-founded case, an exception to this rule might be decided by the study director).</b>
<b>Professeur:</b>	THALMAIER Anton, MERKOULOV (MERKULOV) Serguei

### Infinite-dimensional Lie Algebras

<b>Module:</b>	Module 4.1 (Semestre 4)
<b>ECTS:</b>	5
<b>Objectif:</b>	Infinite dimensional Lie algebras appear as symmetries in systems of infinitely many degrees of freedom. Their knowledge will help to understand the systems better. It is the goal of this lecture course to give an introduction to the field. In particular, the stress is put on those properties which are different from the case of finite dimensional Lie algebras. Also an introduction to Lie algebra cohomology and central extensions is given
<b>Course learning outcomes:</b>	<b>Demonstrate knowledge of the notions of an infinite-dimensional Lie algebra, gradings, and representations</b>  <b>identify the most important examples</b>  <b>master the basic techniques of the theory</b>  <b>demonstrate the ability to study and understand written mathematical material</b>  <b>demonstrate the ability to present mathematical topics in a coherent manner</b>  <b>apply the techniques to similar objects</b>
<b>Description:</b>	<ol style="list-style-type: none"><li>1. Recall of Lie graded Lie algebras</li><li>2. The Witt algebra</li><li>3. The Virasoro algebra as central extension</li><li>4. Lie algebra cohomology and central extensions</li><li>5. Representations of the Virasoro algebra</li><li>6. The Heisenberg algebra</li><li>7. Highest weight representations and Verma modules</li><li>8. Infinite matrix algebras</li><li>9. Current algebras</li></ol>

## Master in Mathematics

10. Selected topics based on the wishes of the participants

**Modalité d'enseignement:** **Lecture Course**

**Langue:** Anglais

**Obligatoire:** Non

**Evaluation:** **oral examination at the end of the course**

**Remarque:** 1. Kac/Raina : Bombay Lectures on Highest Weight Representations of Infinite Dimensional Lie Algebras, World Scientific, Singapore, 1987  
2. future literature will be given during the course.

**Professeur:** SCHLICHENMAIER Martin

### Siegel modular forms

**Module:** Module 4.1 (Semestre 4)

**ECTS:** 5

**Langue:** Français

**Obligatoire:** Non

**Professeur:** VAN DER GEER Gerard

### Master Thesis

**Module:** Module 4.2 (Semestre 4)

**ECTS:** 20

**Course learning outcomes:** **On successful completion of the Master Thesis, the students should be able to:**

- **Organize a comprehensive literature review**
- **Discuss and communicate scientific ideas**
- **Approach mathematical problems efficiently and identify appropriate theories or conceptual techniques**
- **Discover original mathematics**
- **Verify results and apply them**
- **Write mathematical texts that are consistent with the tradition**

## Master in Mathematics

<b>Description:</b>	<b>The master thesis in mathematics consists of the definition of a research project, the detailed explanation of research articles and/or monographs aimed at a mathematics audience, as well as of potential further developments of these. The project, which should contain parts of original mathematics, will be designed to suit the individual objectives of the students, to deepen their competence in a selected field of mathematics, and to open a door towards mathematical research.</b>
<b>Langue:</b>	Anglais, Français, Allemand
<b>Obligatoire:</b>	Oui
<b>Evaluation:</b>	<b>Supervisor, director of studies</b>
<b>Remarque:</b>	<b>Admission to the Master Thesis will be granted only to students who acquired at least 75 ECTS credit points during the first three semesters of the Master's program(in a well-founded case, an exception to this rule might be decided by the study director).</b>
<b>Professeur:</b>	MERKOULOV (MERKULOV) Serguei, THALMAIER Anton

### Internship in Industry including a Master Thesis

<b>Module:</b>	Internship in Industry including a Master Thesis (Semestre 4)
<b>ECTS:</b>	30
<b>Langue:</b>	Français
<b>Obligatoire:</b>	Oui

### Reading course I: Statistics

<b>Module:</b>	Reading course I: Statistics (Semestre 4)
<b>ECTS:</b>	5
<b>Langue:</b>	Français
<b>Obligatoire:</b>	Oui
<b>Professeur:</b>	BARAUD Yannick

### Reading course II: TBA

<b>Module:</b>	Reading course II: TBA (Semestre 4)
<b>ECTS:</b>	5
<b>Langue:</b>	Français



## Master in Mathematics

**Obligatoire:** Oui  
**Professeur:** CAMPESE Simon