Année universitaire 2024/2025

Mathématiques de l'Assurance de l'Economie et de la Finance - 2e année de Master

Crédits ECTS : 60

LES OBJECTIFS DE LA FORMATION

Le parcours MASEF forme des mathématiciens probabilistes de haut niveau aux techniques mathématiques utilisées en gestion des risques et en économie. L'équilibre entre les cours fondamentaux et les cours à vocation plus appliquée assure aux étudiants une formation leur permettant selon leur choix d'options de s'orienter vers la recherche académique ou vers des postes à forte composante quantitative dans l'industrie. Les principaux débouchés sont les banques mais également les secteurs nécessitant des compétences rares en matière d'optimisation en environnement aléatoire et/ou incertain (industrie de l'énergie, enchères sur le web, etc.).

Les objectifs de la formation :

- Maitriser les fondamentaux de l'optimisation, de la décision et de la couverture de risques en environnement incertain avec ou sans interactions.
- Maitriser des outils numériques et statistiques, dont les techniques d'apprentissage automatique.
- Maitriser des techniques de finance quantitative avancées.
- Acquérir du recul nécessaire à s'adapter aux évolutions, que ce soit dans le domaine de la recherche ou de l'industrie.

PRÉ-REQUIS OBLIGATOIRES

- Titulaires d'un diplôme BAC+4 (240 crédits ECTS) ou équivalent à Dauphine, d'une université, d'une grande école ou d'un autre établissement de l'enseignement supérieur dans les domaines suivants : mathématiques pures, mathématiques Appliquées

POURSUITE D'ÉTUDES

La majorité des étudiants trouve un poste à fort contenu quantitatif dans les banques, fonds d'investissement, brokers, compagnies d'assurance, sociétés de service en finance de marché (quant, structuration, trading, gestion quantitative de portefeuille).

La formation prépare naturellement, selon les options choisies, à une thèse de doctorat en finance mathématique, assurance, économie mathématique, mais également en probabilités numérique. Chaque année, deux à cinq étudiants poursuivent la spécialité par une thèse de doctorat, soit purement académique (thèse classique) soit en partenariat avec une cellule de recherche d'une entreprise privée (thèse Cifre)

Les thèses classiques sont en général effectuées au Ceremade ou au Crest et sont encadrées par l'école doctorale EDDIMO de Dauphine. Elles peuvent également être effectuées dans d'autres établissements (Université Paris 6, Paris 7, Ecole Polytechnique par exemple).

Débouchés : Analyste quantitatif, Chargé de modélisation, Consultant en Finance, Contrôleur des risques, Trading assistant, Valuation Analyst, ect.

PROGRAMME DE LA FORMATION

- Semestre 3
  - UE Obligatoires S3
    - A review of probability theory foundations
    - Stochastic Calculus
    - Stochastic Control
    - Monte Carlo and Finite Differences Methods with Applications to Finance
  - UE Optionnelles S3
    - Machine Learning in finance
    - Continuous Optimization
    - Valuation of financial assets and arbitrage
    - Game theory, applications in economics and finance
    - Macro-économiques et gestion de portefeuille
    - Computational methods and MCMC
    - Term structures: interest rates, commodities and other assets
    - Derivative products in finance and insurance
- Semestre 4
  - UE fondamentale S4
    - Cycle of conferences: strategies and actors of portfolio management
  - Bloc 1 : Apprentissage pour l'économie et la finance
    - Python/Pytorch project
    - Reinforcement Learning
  - Bloc 2 : Finance et gestion des risques
    - Gestion globale des risques : VAR
    - Microstructure des marchés financiers
    - Contrôle stochastique et marchés de l'énergie
    - Modélisation stochastique des courbes de taux
  - Bloc 3 : Economie et jeux
    - Mean field games theory
    - Variational problems and optimal transport
    - Managing nature : the case of Fisheries

DESCRIPTION DE CHAQUE ENSEIGNEMENT

A review of probability theory foundations

ECTS : 0

Volume horaire : 15

Description du contenu de l'enseignement :

Outline :

1. Basics of measure theory and integration

2. Probability : random variables, independence

3. Convergence of random variables

4. Law of Large Numbers and Central Limit Theorem

5. Conditional expectations

6. Martingales in discrete time

7. Gaussian vectors

8. Brownian motion : definition, existence, first properties

Compétence à acquérir :

The aim of this class is to provide a quick review of the probability theory that is required to follow the 1st semester classes in

MATH, MASEF and MASH.

Most of the content should already be familiar to students with a M1 in Mathematics.

Computational methods and MCMC

ECTS : 4

Volume horaire : 21

Description du contenu de l'enseignement :

Motivations
Monte-Carlo Methods
Markov Chain Reminders
The Metropolis-Hastings method
The Gibbs Sampler
Perfect sampling
Sequential Monte-Carlo methods

Compétence à acquérir :

This course aims at presenting the basics and recent developments of simulation methods used in statistics and especially in Bayesian statistics. Methods of computation, maximization and high-dimensional integration have indeed become necessary to deal with the complex models envisaged in the user disciplines of statistics, such as econometrics, finance, genetics, ecology or epidemiology (among others!). The main innovation of the last ten years is the introduction of Markovian techniques for the approximation of probability laws (and the corresponding integrals). It thus forms the central part of the course, but we will also deal with particle systems and stochastic optimization methods such as simulated annealing.

Continuous Optimization

ECTS : 6

Volume horaire : 24

Description du contenu de l'enseignement :

This course will review the mathematical foundations of convex/continuous (iterative) optimization methods. We will focus on the theory and mathematical analysis of a few algorithmic methods and showcases some modern applications of a broad range of optimization techniques. The course will be composed of classical lectures and one numerical session in Python. The first part covers the basic methods of smooth optimization (gradient descent) and convex optimization (optimality condition, constrained optimization, duality) with some general approach (monotone operators) and a focus on convergence rates. We will then address more advanced methods (non-smooth optimization and proximal methods, stochastic gradient descent).

Compétence à acquérir :

The objective of this course is to introduce the students to classical and modern methods for the optimization of (mostly convex) objectives, possibly nonsmooth or high dimensional. These arise in areas such as learning, finance or signal processing.

Mode de contrôle des connaissances :

Examen écrit

Bibliographie, lectures recommandées :

Exemples de livres généraux sur l'optimisation (souvent convexe) couvrant des aspects à la fois théoriques (complexité) et pratique (implémentations):

Boris Polyak: Introduction to optimization, (1987).

J.-B. Hiriart-Urruty and C. Lemarechal, Convex Analysis and Minimization Algorithms (1993).

Yurii Nesterov: Introductory lectures on convex optimization, 2004 / Lectures on convex optimization 2018

Jorge Nocedal and Stephen J. Wright: Numerical Optimization, 2006.

Dimitri Bertsekas: Convex Optimization Algorithms. Athena Scientific 2015.

Amir Beck: First-Order Methods In Optimization, 2019.

R. Tyrell Rockafellar: Convex analysis, 1970 (1997).

H. Bauschke and P.L. Combettes: Convex analysis and monotone operator theory in Hilbert spaces (Springer 2011)

Ivar Ekeland and Roger Temam: Convex analysis and variational problems, 1999.

Juan Peypouquet: Convex Optimization in Normed Spaces, 2015

Contrôle stochastique et marchés de l'énergie

ECTS : 6

Volume horaire : 15

Compétence à acquérir :

Energy markets are a natural field of applications for stochastic control modelling framework. Historical applications go from water management to the pricing of swing and demand-side contracts. With the deregulation of electricity and gas markets, new applications have raised the attention of financial economists. In particular, the question of the optimal investment in generation assets in the context of climate change and the questions linked to retail competition. These domains are conducive to the utilization of stochastic differential games. This course is intended to provide a short introduction to the physics of energy market and extensive applications taken for financial and economical research papers. For their evaluation, students are expected to realize a study of a research paper for which they will provide a critical analysis of their understanding of the model, together with the reproduction of the results of the paper.

Cycle of conferences: strategies and actors of portfolio management

ECTS : 2

Volume horaire : 12

Derivative products in finance and insurance

ECTS : 6

Volume horaire : 21

Description du contenu de l'enseignement :

Participants will lear how financial institutions can build and structured products, how they value and hedge them, and what they are done for.

Compétence à acquérir :

The aim of this lecture is to train students in the practical evaluation of derivative products and the control of the associated risks. It also introduces them to the new hybrid structured products that have recently appeared in insurance.

Game theory, applications in economics and finance

ECTS : 6

Volume horaire : 18

Description du contenu de l'enseignement :

A- Basics of game theory:
1. Zero-sum games: value, optimal strategies, saddle points, minmax theorem.
2. N-layers normal form games: equilibria in dominant strategies, Nash equilibria, dominated strategies, Nash’s existence theorem.
3. Extensive form: backward induction, subgame perfection, theorem of Kuhn-Zermelo, behavior strategies and Kuhn’s theorem.

B- Applications:
1. Repeated games and cooperation, folk theorems.
2. Zero-sum repeated games with incomplete information on one side (Aumann-Maschler’s model). Splitting lemma, uniform value.
3. Zero-sum stochastic games: dynamic structure, Shapley operator, theorems of Bewley-Kohlberg and Mertens-Neyman.

Compétence à acquérir :

The first part deals with the basics of game theory, the second one with applications in economics and finance. There will only be time to study 2 of the 3 applications (to be decided).

Gestion globale des risques : VAR

ECTS : 2

Volume horaire : 21

Description du contenu de l'enseignement :

Mesures de risque et régulation (Solvency, Bale): exemple de calculs. Modèles dynamiques pour les prix d'actifs financiers. Agrégation des risques de manière très générale, c'est à dire pour différents types de risque sur des exemples, aussi bien en assurance qu'en finance. Risques des produits dérivés également. Modèles multivariés. Implémentation en Python.

Compétence à acquérir :

Analyse des modèles mathématiques du risque de marché, étude des méthodes de gestion globales du risque de marché lorsque les sources d'incertitude sont multiples.

Mode de contrôle des connaissances :

0.3*CC+0.7*E avec E=examen sur table et CC=contrôle continu.

Bibliographie, lectures recommandées :

Ce cous est "self-content" mais ne pas hésiter à combler ses lacunes en lisant un cours de calcul stochastique+EDS et discretisation Euler.

Machine Learning in finance

ECTS : 6

Volume horaire : 21

Description du contenu de l'enseignement :

- Introduction to statistical learning: The Vapnik Chervonenkis dimension, PAC learning and the calibration versus prediction paradigm.
- Supervised learning: SVM, Mercer's theorem and the kernel trick, C-SVMs, mu-SVMs, a few words on SVMs for regressions.
- Unsupervised learning: Single class SVMs, clustering, anomaly detection, equivalence of different approaches via duality.
- Introduction to random forests and ensemble methods: bias variance tradeoff, bootstrap method
- A few words on neural networks: backpropagation, deep learning.
- Remarks on parsimony and penalisation : Ridge and Lasso regressions, dual interpretation of Lasso.

Compétence à acquérir :

Some Statistical Learning results are presented and applied to credit rating, anomalies detection and yield curves modeling. The principal notions are presented in the context of these case studies in finance.

Mode de contrôle des connaissances :

Final exam

Bibliographie, lectures recommandées :

https://web.stanford.edu/~hastie/ISLR2/ISLRv2_website.pdf

Macro-économiques et gestion de portefeuille

ECTS : 6

Volume horaire : 21

Compétence à acquérir :

Les gestionnaires de portefeuille ont besoin de posséder certaines connaissances macroéconomiques de base pour mieux fonder leurs décisions d'investissement. La valeur dite fondamentale des différents actifs financiers ne peut être analysée sans une prise en compte des évolutions macroéconomiques prévisibles à moyen et long terme. De plus, les performances de court terme des différentes classes d'actifs financiers dépendent crucialement des indicateurs macro-économiques, notamment en matière d'inflation et de croissance. Ce cours présentera notamment les méthodes dominantes utilisées par les praticiens de marché (économistes de marché, gestionnaires…) pour analyser et anticiper les évolutions macro-économiques, ainsi que les inflexions de politique monétaire. Il a une vocation appliquée et vise à donner à de futurs gestionnaires une bonne connaissance des instruments pratiques de prévision macroéconomique ainsi que des indications sur la meilleure façon d'utiliser ces instruments pour améliorer la performance de leur gestion.

Managing nature : the case of Fisheries

ECTS : 6

Volume horaire : 21

Description du contenu de l'enseignement :

The purpose of the course is to provide scientific insight into the way modern society interacts with its environment. Fisheries provide a good example. They have been exploited since the earliest times to feed human populations, but since the industrial revolution they have undergone a dramatic transformation, leading in some cases to collapse, and transformation of the oceanic ecosystem. The first part of the course will model fish populations, the effect of commercial fishing, and of regulations such as subsidies and quotas. In the second part, the course will investigate how to take into account, not only the needs of the present generation, but also the needs of future generations, so that fisheries management strikes a balance between profit and conservation.

Program

Part 1: bioeconomics (6 sessions of 1:30 hour)

I. Introduction to the oceans

1. Global warming, acidification, desoxygenation. Consequences on marine populations
2. The two sides of fisheries: catches and alimentation. North/South disequilibrium

II. The Economics : Gordon-Schaefer model and beyond

1. The model, Allee effect, MSY
2. Economics: open vs. restricted access, the role of interest rates
3. Managements instruments :

-Subsidies and taxes
-Quotas, transferable or not
-Protected marine areas

III. Ecosystem models

1. Using ECOPATH and ECOSYM
2. Alternative models and complementarity : OSMOSE APECOSM ATLANTIS EWE viability : what are they used for ? What is the complementarity ?

Part 2: Beyond optimization (6 sessions of 1:30 hour)

IV. The concept of optimization (1 session)

1. Individuals: utility function, expectations, time preference
2. Groups: Condorcet paradox, Pareto optimum,
3. Groups: Nash equilibrium

V. The economics of natural resources (1 session)

1. The unitary model : Ramsey
2. Solving for optimality :

-Finding the equilibrium
-Writing the HJB equation
-Solving the HJB equation

3. Non-renewable resources :

-The Hotelling rule
-The Hubbert curve

VI. **The economics of fisheries (1 session)**

1. The Gordon-Schaefer model as a particular case of the Ramsey model
2. The tipping point

VII. **Intergenerational equity part 1 (2 sessions)**

1. The Chichilnisky criterion and time inconsistency
2. The intergenerational game and equilibrium Markov strategies
3. The HJB equation
4. Finding equilibrium strategies

VIII. **Intergenerational equity part 2 (1 session)**
1. The Sumaila-Walters criterion and time inconsistency
2. The HJB equation
3. Finding equilibrium strategies

Mean field games theory

ECTS : 6

Volume horaire : 18

Description du contenu de l'enseignement :

Stochastic Control cours (1rst semester) is a necessary prerequisite.

Mean field games is a new theory developed by Jean-Michel Lasry and Pierre-Louis Lions that is interested in the limit when the number of players tends towards infinity in stochastic differential games. This gives rise to new systems of partial differential equations coupling a Hamilton-Jacobi equation (backward) to a Fokker-Planck equation (forward). We will present in this course some results of existence, uniqueness and the connections with optimal control, mass transport and the notion of partial differential equations on the space of probability measures.

Compétence à acquérir :

Mastering of the mean field games technics.

Bibliographie, lectures recommandées :

Notes on the course: https://www.ceremade.dauphine.fr/~cardaliaguet/Enseignement.html#ENSEIGNEMENT

Microstructure des marchés financiers

ECTS : 6

Volume horaire : 15

Description du contenu de l'enseignement :

The field of market microstructure combines theoretical modeling, institutional knowledge, and empirical analysis to understand how prices result from the interactions of traders in financial markets. The course aims to acquaint students with (i) the canonical models in microstructure, and (ii) econometric models used to test the predictions of microstructure models.

Course structure:

1. Trading Mechanisms
2. Measuring Liquidity
3. Price Dynamics and Liquidity
4. Trade Size and Market Depth
5. Empirical Analysis

Compétence à acquérir :

Master the concepts of financial markets microstructure

Mode de contrôle des connaissances :

Evaluation: assignment and final exam

Bibliographie, lectures recommandées :

Foucault, Thierry, Marco Pagano, and Ailsa Röell, Market Liquidity: Theory, Evidence, and Policy, Oxford University Press, 2013.

Modélisation stochastique des courbes de taux

ECTS : 3

Volume horaire : 21

Description du contenu de l'enseignement :

1. Quelques outils de calcul stochastique : rappels
2. Généralités sur les taux d'intérêt

3. Produits de taux classiques
4. Modèle LGM à un facteur
5. Modèle BGM (Brace, Gatarek et Musiela) / Jamishidian
6. Modèles à volatilité stochastique

Compétence à acquérir :

Ce cours est consacré aux modèles de taux d'intérêts à temps continu. Au travers de nombreux exemples, on décrira leurs utilisations pour évaluer les produits dérivés sur taux d'intérêt.

Monte Carlo and Finite Differences Methods with Applications to Finance

ECTS : 6

Volume horaire : 30

Description du contenu de l'enseignement :

Generalities on Monte-Carlo methods
1. Generalities on the convergence of moment estimators
2. Generators of uniform law
3. Simulation of other laws (rejection method, transformation, …)
4. Low discrepancy sequences

Variance reduction
1. Antithetical control
2. Payoff regularization
3. Control Variable
4. Importance sampling

Process simulation and payoff discretization
1. Black-Scholes model
2. Discretisation of SDEs
3. Diffusion's bridges and applications to Asian, barrier and lookback options.

Calculation of sensitivities (greeks)
1. Finite differences
2. Greeks in the Black-Scholes model
3. Tangent process and Greeks
4. Malliavin calculus, Greeks, conditional expectations and pricing of American options

Calculation of conditional expectations and valuation of American options.
1. Nested Monte Carlo approach
2. Regression Methods (Tsitsiklis Van Roy, Longstaff Schwartz)
3. Rogers' Duality

Finite difference methods: the linear case
1. Construction of classical schemes (explicit, implicit, theta-scheme)
2. Conditions for stability and convergence

Finite difference methods: the non-linear case
1. Monotonous schemes: General conditions of stability and convergence
2. Examples of numerical schemes: variational problems, Hamilton-Jacobi-Bellman equations.

Compétence à acquérir :

This course provides an in-depth presentation of the main techniques for the evaluating of options using Monte Carlo techniques.

Python/Pytorch project

ECTS : 6

Volume horaire : 15

Description du contenu de l'enseignement :

The Python and PyTorch languages are commonly used to build ML/IA algorithms. The classroom course is complemented by a practical application thesis in economics or finance (e.g. Deep hedging, rapid calculation of expected shortfall, optimal portfolio management, high-frequency trading, solving semi-linear equations of the second order, variance reduction, etc.).

Compétence à acquérir :

- Mastery of Python and PyTorch. Ability to build an ML/IA algorithm.

Reinforcement Learning

ECTS : 6

Volume horaire : 24

Stochastic Calculus

ECTS : 6

Volume horaire : 45

Description du contenu de l'enseignement :

The course consists of four parts, each occupying roughly 6 hours:

- Preliminaries (Gaussian processes, Brownian motion, martingales, local martingales, variation, quadratic variation)
- Stochastic integration (Isometry extension, Wiener integral, Ito integral, martingale property)
- Stochastic differentiation (Itô processes, Itô's Formula, Girsanov's Theorem)
- Stochastic differential equations (existence and uniqueness, Markov property, generator, connections with PDEs).

Compétence à acquérir :

This course is a practical introduction to the theory of stochastic calculus, with an emphasis on examples and applications rather than abstract subtleties. Click here for more information

Mode de contrôle des connaissances :

Final written exam, in class.

Bibliographie, lectures recommandées :

Click here for more information

Stochastic Control

ECTS : 6

Volume horaire : 24

Description du contenu de l'enseignement :

Relationship between conditional expectations and parabolic linear PDEs.
Formulation of standard stochastic control problems: dynamic programming principle.
Hamilton-Jacobi-Bellman equation
Verification approach
Viscosity solutions (definitions, existence, comparison)
Application to portfolio management, optimal shutdown and switching problems

Teacher : Bruno BOUCHARD

Compétence à acquérir :

PDEs and stochastic control problems naturally arise in risk control, option pricing, calibration, portfolio management, optimal book liquidation, etc. The aim of this course is to study the associated techniques, in particular to present the notion of viscosity solutions for PDEs.

Term structures: interest rates, commodities and other assets

ECTS : 6

Volume horaire : 21

Description du contenu de l'enseignement :

The term structure is defined as the relationship between the spot price and the futures prices of a derivative instrument, for any delivery date. It provides useful information for hedging, arbitrage, investment and evaluation: it indeed synthesizes the information available in the market and the operators' expectations concerning the future price of the underlying asset.

In many derivative markets, especially in interest rates and in commodity markets, the concept of term structure is very important, because the contract's maturity increases as the markets come to fruition. In the Eurodollar market, for example the maturities reach 10 years.

Chapter 1 presents a general introduction to derivatives today.

Chapter 2 examines the traditional theories of commodity prices and the explanation of the relationships between spot and futures prices. It proposes an empirical review of the results obtained through these frameworks and explains why these theories are still investigated today. It finally shows how to apply these theories to other assets: exchange rates and interest rates.

The traditional theories are however a bit limited when the whole term structure is considered. As a result, there is a need for a long-term extension of the analysis, which is the very subject of the Chapter 3. We first present a dynamic analysis of the term structure. Then the focus turns towards term structure models. The examples rely on the case commodity prices but can be extended to interest rates. Simulations highlight the influence of the assumptions concerning the stochastic process retained for the state variables and the number of state variables. We then explain the econometric method usually employed for the estimation of the parameters. In the presence of non-observable variables, there is a need for filtering techniques. We present the method of the Kalman filters. Finally, we study two main applications, i.e. dynamic hedging and investment valuation.

Chapter 4 is devoted to the study of structural models, ie micro-founded equilibrium models that also examine the interactions between the physical and the derivative markets. In this situation the spot price becomes endogenous. The interactions between prices are studied thanks to rational expectations equilibriums.

Compétence à acquérir :

At the end of this course, the students must have a broad knowledge about the term structures of derivative prices: the theories, the valuation methods, the econometric techniques, the empirical tests as well as the applications.

They will also be trained to use their knowledge on this topic in order to develop a critical view on recent research articles.

Mode de contrôle des connaissances :

Ongoing assessment, 20%

Final exam, 80%.

Bibliographie, lectures recommandées :

- Danthine J.P., Donaldson J.B., Intermediate Financial Theory, 2d Ed., Elsevier, 2005.

- Hull J., Options, futures and other derivatives, 15th Ed.

- Kolb R.W. , Overdahl J.A. , Futures, options, and swaps, 5th Ed., Blackwell, 2007.

- Williams J., The economic function of futures markets, Cambridge University Press, 1986

- Wilmott P., Paul Wilmott on Quantitative Finance, 3-volume set, 2nd Ed., Wiley, 2006.

Valuation of financial assets and arbitrage

ECTS : 6

Volume horaire : 30

Description du contenu de l'enseignement :

Course outline:

I. Discrete time modelling

I.1. Financial assets

I.2. The No arbitrage condition and martingale measures (FTAP)

I.3. Pricing and hedging of European options; market completeness and 2nd FTAP

I.4. Pricing and hedging of American options (in a complete market)

II. Continuous time modelling

II.1. Financial assets as Itô processes : general theory

II.2. Markovian models : PDE pricing, delta-hedging (European options, barrier options, American options)

II.3. Local volatility models and Dupire's formula

II.4. Stochastic volatility models : how to deal with market incompleteness; (semi-)static hedging; specific models and their properties

Compétence à acquérir :

The lecture starts with discrete time models which can be viewed as a proxy for continuous settings, and for which we present in detail the theory of arbitrage pricing. We then develop on the theory of continuous time models. We start with a general Itô-type framework and then specialize to different situations: Markovian models, local and stochastic volatility models. For each of them, we discuss the valuation and the hedging of different types of options : plain Vanilla and barrier options, American options, options on realized variance, etc. Finally, we present several specific volatility models (Heston, CEV, SABR,...) and discuss their specificities.

Bibliographie, lectures recommandées :

Bouchard B. et Chassagneux J.F., Fundamentals and advanced Techniques in derivatives hedging, Springer, 2016.
Lamberton D. et B. Lapeyre, Introduction au calcul stochastique appliqué à la finance, Ellipses, Paris, 1999.

Variational problems and optimal transport

ECTS : 6

Volume horaire : 24

Description du contenu de l'enseignement :

Chapter 1: Convexity in the calculus of variations
-separation theorems, Legendre transforms, subdifferentiability,
-convex duality by a general perturbation argument, special cases (Fenchel-Rockafellar, linear programming, zero sum games, Lagrangian duality)
-calculus of variations: the role of convexity, relaxation, Euler-Lagrange equations

Chapter 2: The optimal transport problem of Monge and Kantorovich
-The forrmulations of Monge and Kantorovich, examples and special cases (dimension one, the assignment problem, Birkhoff theorem), Kantorovich as a relaxation of Monge
-Kantorovich duality
-Twisted costs, existence of Monge solutions, Brenier's theorem, Monge-Ampère equation, OT proof of the isoperimetric inequality
-the distance cost case and its connection with minimal flows

Chapter 3: Dynamic optimal transport, Wasserstein spaces, gradient flows
-Wasserstein spaces
-Benamou-Brenier formula and geodesics, displacement convexity
-gradient flows, a starter: the Fokker-Planck equation, general theory for lambda-convex functionals

Chapter 4: Computational OT and applications
-Entropic OT, Sinkhorn algorithm and its convergence
-Matching problems, barycenters,
-Wasserstein distances as a loss, Wasserstein GANs

Compétence à acquérir :

Mastering of variational and optimal transport methods used in economy.

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