Anastasis Kratsios

Geometric Deep Learning and Foundations of Data Science

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Profile

Specialization: *I develop and study universal deep learning models capable of leveraging complicated geometric structures in data science and stochastic analysis.*
Expertise (Mathematics): Approximation theory, mathematical finance, geometric topology, optimal transport, analysis on metric spaces.
Expertise (Data Science): Geometric deep learning, deep learning, meta-learning.
Select Research:

- NEU: A Meta-Algorithm for Universal UAP-Invariant Feature Representation - (JMLR) The Journal of Machine Learning Research, 2021.
- Non-Euclidean Universal Approximation - (NeurIPS) Conference on Neural Information Processing Systems, 2020.
- Universal Approximation Under Constraints is Possible with Transformers - ArXiV: 2110.03303.

Employment History

Academic

2021-Current **Postdoctoral Researcher - Geometric Deep Learning**, *University of Basel* , Basel, Switzerland.

- Achievements: *"Universal approximation under constraints is possible with transformers"*:
  - ICRL 2022 ($\#1$ ML Conference, H-score 253) submission: ranked in the top 0.05% in the current (first) round.
  - ICRL 2022 submission received one of the only 39 total $10/10$s awarded out of the total ≈ 3400 submissions.
- Select Contributions:
  - First neural network architecture capable of universal approximation with exact constraint satisfaction,
  - First deep neural version of Berge's Maximum Theorem (1963) with exact constraint satisfaction.
- Co-supervision: Doctoral Student - T. Liu
  - Completed Collaboration (Numerical Part): Universal Approximation under constraints is possible with transformers,
  - Working Paper: Generalization bounds for random feature models between Banach, supporting Schauder basises, when data-generating distribution is supported on an unknown manifold,
- Ongoing Research Projects:
  - Adapted universal approximation of stochastic processes by recurrent transformer networks - B. Acciaio and G. Pammer (ETH Math. Finance) - Expected Dec. 1^{rst},
  - PAC-Bayesian Bounds in Function Space - P. Kassraie and J. Rothfuss (ETH Comp. Sci.) - Expected January 15^{th},
  - Canonical Quantitative Universal Approximators for General Metric Spaces - M. Lassas (U. Helsinki), M. de Hoop (Rice U.) - Expected March 1^{rst},
  - Regret-Optimal Stochastic Gradient Descent Algorithms - G. Livieri (S. Normale Superior, Pisa), P. Casgrain (ETH Zürich) - Expected TBA.

2018-2021 **Postdoctoral Researcher - Stochastic Finance and Geometric Deep Learning**, *ETH Zürich*, Zürich, Switzerland

- Select contributions:
  - Introduced the first (quantitative) universal approximation theorems for general input-output spaces,
  - Developed the first universal approximator from the space of Gaussian measures with Wasserstein metric, to itself,
  - Developed the first meta-optimization procedure for learning regret-optimal gradient-descent algorithms,
  - Developed the first penalty for arbitrage-free machine learning in finance,
  - Proved first deterministic universal classification theorems,
  - Introduce meta-algorithm for generating optimal UAP-invariant feature maps,
  - Developed an architecture capable of uniformly approximating discontinuous functions,
  - Obtained the first characterization of the universal approximation property.
- Supervision:
  - Guide: L. Papon (Master's Student from EPFL),
  - Master's Semester Project: An Overview of Risk-Averse Valuation.
  - Student: Nikolaos Mourdoukoutas.

2014-2015 **Lecturer**, *Concordia University*, Montreal, Canada.

- Transferred my intuition to new students in the field,
- Framed classical theory in the context of modern applications; such as data-science examples to motivate linear algebraic ideas,
- Provided extended lectures outside of requirements to help students go beyond their requirements and succeed in their exams.

Private Sector

2017 **Risk Management Research**, *CIBC Capital Markets*, Toronto, Canada

- Modelled for non-modellable risk-factors for the FRTB under Basel III,
- Developed clustering based model selection methodology for liquid bonds proxying,
- Part of the team working on stochastic filtering-based methods for predicting IPO prices.
- Developed algorithms for Bloomberg to R interphasing.

Outreach

2016–2017 **Mathematics Educator for Students with Learning Disabilities**, *Epsilon Learning Center*, Toronto (Leslieville), Canada.

- Tutored 6-13 year old students with learning disabilities,
- Help to discover and overcome each student's learning barriers,
- Identified personalized learning tools (e.g. visual, analytic, mechanical, etc..) helping each student best connect to the material,
- Helped build student's "mathematical self-confidence".

Education

2014–2018 **PhD Mathematical Finance**, *Concordia University*, Montreal

- Thesis: *Arbitrage-free Regularization, Geometric Learning, And Non-Euclidean Filtering In Finance.*
- Contributions:
  - Developed the NEU meta-algorithm, a procedure which learns an optimal loss function given a learning task and a data-set,
  - Applied the NEU meta-algorithm to stock prediction and yield-curve dimensionality reduction tasks,

- Introduced no-arbitrage penalty in the generalized HJM framework and used it to learn arbitrage-free forward-rate curve models,
- Introduced a non-Euclidean filtering algorithm for Cartan-Hadamard spaces and used it to predict efficient portfolios.

○ Research Groups: Quantact and Montreal Analysis Seminar.

2012–2014 **MSc Pure Mathematics**, *University of Montreal*, Montreal

○ Thesis: *Bounding The Hochschild Cohomological Dimension*
○ Major Contributions:
- Developed a lower-bound on the Hochschild cohomological dimension for any $\mathbb{K}$-algebra,
- Used this lower-bound to show that most commutative $\mathbb{K}$-algebras fail to be smooth.

○ Research Groups: CIRGET, Graduate Students Seminar in Mathematics.

2009–2012 **BA Pure and Applied Mathematics**, *Concordia University*, Montreal.

Research Articles

Publications

2021 **NEU: A Meta-Algorithm for Universal UAP-Invariant Feature Representation**, *(JMLR) The Journal of Machine Learning Research*.
Joint work with: C. Hyndman

2021 **Optimizing Optimizers: Regret-optimal gradient descent algorithms**, *(COLT)* 34^{th} *Conference on Learning Theory*.
Joint work with: P. Casgrain

2021 **The Universal Approximation Property**, *Annals of Mathematics and Artificial Intelligence*.

2020 **Non-Euclidean Universal Approximation**, *(NeurIPS)* 33^{th} *- Conference on Neural Information Processing Systems*.
Joint work with: I. Bilokopytov

2020 **Arbitrage-Free Regularization**, *Risks - Special Issue on Machine Learning in Finance, Insurance and Risk Management*.
Joint work with: C. Hyndman

2020 **The Entropic Measure Transform**, *Canadian Journal of Statistics - Special Issue: Special Issue on Stochastic Models, Statistics, and Finance*.
Joint work with: C. Hyndman and R. Wang

2021 **Lower-Estimates on the Hochschild (Co)Homological Dimension of Commutative Algebras and Applications to Smooth Affine Schemes and Quasi-Free Algebras**, *Mathematics - Special Issue: New Trends in Algebraic Geometry and Its Applications*.

Under Review

2021 **Universal Approximation Under Constraints is Possible with Transformers**, *ArXiV: 2110.03303*.
Joint work with: I. Dokmanič, T. Liu, and B. Zamanlooy

2021 **Universal Approximation Theorems for Geometric Deep Learning**, *ArXiV: 2101.05390*.
Joint work with: L. Papon

2021 **Universal Regular Conditional Distributions via Probability Measure-Valued Deep Neural Models**, *ArXiV: 2105.07743*.

2021 **Learning Sub-Patterns in Piece-Wise Continuous Functions**, *ArXiV: 2010.15571*.
Joint work with: B. Zamanlooy

2021 **Denise: Deep Robust Principal Component Analysis for Positive Semidefinite Matrices**, *ArXiV: 2004.13612*.
Joint work with: J. Teichmann, P. Ruyssen, C. Herrera, and F. Krach

2021 **A Canonical Transform for Strengthening the Local L^p-Type Universal Approximation Property**, *ArXiV: 2006.14378*.
Joint work with: B. Zamanlooy

White Papers

2017 **Replication of a Real-Estate Market Index (Teranet)**, *Proceedings: Proceedings: Eighth Montreal Industrial Problem Solving Workshop*.

2014 **Hochschild Cohomological Dimension is Not Upper Semi-Continuous**, *Note. ArXiV: 1407.4825*.

Conferences and Talks

2021 **Generic Geometric Priors via Probabilistic Transformers**, *Rice University's: MATH+X Symposium*, Costra Rica, Costra Rica

2022 **Regular Conditional Distributions via Probabilistic Transformers**, *Bachelier Colloquium*, Metabief, Metabief, France

2021 **Universal Approximation with Exact Constraint Satisfaction is Possible with Transformers**, *TU Munich*, Munich, Munich, Germany

2021 **Geometric Deep Learning for High-Dimensional Option Pricing and Constrained Approximation**, *AIMS Lab Seminar*, McMaster University, Hamilton, Canada

2021 **Universal Approximation with Exact Constraint Satisfaction is Possible with Transformers**, *Talks in Financial and Insurance Mathematics*, ETH Zürich

2021 **Universal Probability Measure-Valued Deep Neural Networks**, *Probability Days*, University of Mannheim (Remote)

2021 **Optimizing Optimizers: Regret-optimal gradient descent algorithms**, *COLT 2021*, Boulder, Colorado (Remote)

2021 **Quantitative Non-Euclidean Universal Approximation**, *ML Explained - Aggregate Intellect - AI.Science*, Online, Toronto, Canada (Remote)

2021 **Universal Probability Measure-Valued Deep Neural Networks** , *Quantact (CRM)*, Montreal, Canada,

2020 **Non-Euclidean Universal Approximation**, *34th NeurIPS - 2020*, Online, NA

2020 **Universal Feature Map Generation**, *ETH Zürich*, Zürich, Switzerland

2020 **Limit Orderbook Geometry and Arbitrage-Free Volume Adjustments**, *Imperial College*, London, United Kingdom
Invited by: Damiano Brigo

2019 **NEU Meta-Learning, Universal Approximation Properties, and Learning Model-Free Loss-Functions**, *ETH Zürich*, Zürich, Switzerland

2019 **Universal Approximation Theorems**, *Concordia Data Science Seminar*, Montreal, Canada.

2019 **A Universal Feature Space** , *12th Freiburg-Wien-Zürich (FWZ) Seminar*, Zürich, Switzerland.

2019 **Universal Approximation Theorems**, *Österreichische Mathematische Gesellschaft Conference 2019*, Dornbirn, Austria.

2019 **Universal Approximation Theorems**, *Vienna Congress on Mathematical Finance - VCMF 2019*, Vienna, Austria.

2019 **Arbitrage-Free Regularization**, *10th Freiburg-Wien-Zürich (FWZ) Seminar*, Vienne, Autstria.

2019 **Risk-Averse Conditional Expectation and Shortfall-Regression**, *ETH Zürich*, Zürich, Switzerland.

2018 **Geometric Learning and Filtering in Finance** , 10^{th} *Bachelier World Congres*, Dublin, Ireland.

2018 **Arbitrage-Free Regularization**, 10^{th} *Bachelier World Congres*, Dublin, Ireland.

2018 **Arbitrage-Free Regularization**, *5th Workshop on Insurance Mathematics with a Special Session on Big-Data and Machine Learning in Risk Management* , Montreal, Canada.

2017 **A Geometric Approach to Arbitrage-Free Modeling, Estimation, and Prediction**, *International Conference on Mathematical Finance*, Waterloo, Canada.
Presentation by coauthor.

2017 **Geometric Learning and Non-Euclidean Filtering in Finance**, *Canadian Mathematical Society Winter Meeting*, Waterloo, Canada.

2017 **A Geometric Approach to Arbitrage-Free Modeling, Estimation, and Prediction**, *11th Bachelier Colloquium on Mathematical Finance and Stochastic Calculus*, Métabief, France.
Presentation by coauthor.

2016 **Manifold Learning Algorithms for Arbitrage-Free Low-Dimensional on-Linear Model Selection** , *Pacific Institute for the Mathematical Sciences (PIMS); High-Frequency Trading Workshop*, Edmonton, Canada.

2016 **A Geometric Approach to Arbitrage-Free Modeling, Estimation, and Prediction** , *Canadian Mathematical Society Winter Meeting*, Niagra, Canada.
Presentation by coauthor.

2016 **Manifold learning algorithms for arbitrage-free low-dimensional nonlinear model selection**, *AMS - AMS Fall Meeting*, Brunswick, USA.
Presentation by coauthor.

2016 **Arbitrage-Free Regularization for Forward Rates**, *ENCS Data Science Research Centre*, Montreal, Canada.

Extracurricular Activities

Academic Community

2018–present **Weekly Geometric Deep Learning Seminar**, *University of Basel*, Basel, Switzerland.
- Give feedback and guide 3^{rd} of PhD students in same area,
- Invite Speakers and possible group collaborators,
- Organize seminar.

2018–2021 **Organiser of the Weekly Financial and Insurance Mathematics Seminar**, *ETH Zürich*, Zürich, Switzerland.
- Organize the weekly seminar,
- Align schedules with international researchers,
- Author the weekly news bulletin.

2017–2018 **Vice-President - Mathematics and Statistics Graduate Students Association**, *Concordia University*, Montreal, Canada.
- Organised student social events and outings,
- Helped maintain graduate student's positive morale by introducing a free coffee system.