

Anastasis Kratsios

*Foundations of Geometric Deep Learning
and Applications in Stochastic Finance*

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Profile

Specialization: *I develop and study universal deep learning models that can leverage the infinite-dimensional curved geometries arising in stochastic analysis and mathematical finance.*

Primary Areas: Geometric deep learning, Approximation theory of neural networks.

Applied Areas: Deep Learning in for Stochastic Analysis and in Finance.

Select Publications:

- Universal Approximation Theorems for Differentiable Geometric Deep Learning - JMLR 2022.
- Universal Approximation Under Constraints is Possible with Transformers - ICLR 2022 *Spotlight*.
- NEU: A Meta-Algorithm for Universal UAP-Invariant Feature Representation - JMLR 2021.

Employment History

Academic

2022-Current **Assistant Professor - Data Science in Mathematical Finance**, *McMaster University*, Hamilton, Canada.

- Investigating the foundations of deep learning in finance,
- Building the mathematical foundations of geometric deep learning.
- Ph.D. Student: T. Liu (joint with I. Dokmanić)
- Postdoctoral Researcher: Xuwei Yang (joint with M. Grasselli).

2021-2022 **Postdoctoral Researcher - Geometric Deep Learning**, *University of Basel*, Basel, Switzerland.

- Achievements: *"Universal approximation under constraints is possible with transformers"*:
 - Spotlight at ICRL 2022 (#1 ML Conference, H-score 253) (Scored in the top 3%) 5% acceptance rate for spotlights ,
 - Received one of the only 39 10/10s given out of ≈ 3400 total 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.

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.
- o Supervision:
 - Guide: L. Papon (Master's Student from EPFL),
 - Master's Semester Project: An Overview of Risk-Averse Valuation.
 - Student: Nikolaos Mourdoukoutas.

Private Sector

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

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

Outreach

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

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

Education

2014–2018 **PhD Mathematics (Mathematical Finance and Analysis)**, *Concordia University*, Montreal

- o Thesis: *Arbitrage-free Regularization, Geometric Learning, And Non-Euclidean Filtering In Finance*.
- o Supervisors: C. Hyndman and A. Stancu.
- o 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.
- o Research Groups: Quantact and Montreal Analysis Seminar.

2012–2014 **MSc Mathematics (Non-Commutative Geometry)**, *University of Montreal*, Montreal

- o Thesis: *Bounding The Hochschild Cohomological Dimension*
- o Supervisor: A. Broer.
- o 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.
- o Research Groups: CIRGET, Graduate Students Seminar in Mathematics.

2009–2012 **BA Mathematics (Specialization: Pure and Applied)**, *Concordia University*, Montreal.

Research Articles

Publications

- 2022 **Universal Approximation Theorems for Geometric Deep Learning**, (*JMLR*) *Journal of Machine Learning Research*.
Joint work with: L. Papon
- 2022 **Universal Approximation Under Constraints is Possible with Transformers**, *ICLR 2022 Spotlight*.
Joint work with: B. Zamanlooy, I. Dokmanić, and T. Liu
- 2022 **Do ReLU Networks Have An Edge When Approximating Compactly-Supported Functions?**, *Transactions on Machine Learning Research*.
Joint work with: B. Zamanlooy
- 2022 **Learning Sub-Patterns in Piece-Wise Continuous Functions**, *Neurocomputing*.
Joint work with: B. Zamanlooy
- 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*) *34th 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*) *33th - Conference on Neural Information Processing Systems*.
Joint work with: I. Bilokopytov
- 2020 **Deep Arbitrage-Free Learning in a Generalized HJM Framework via Arbitrage-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*.

Minor Revisions

- 2022 **Designing Universal Causal Deep Learning Models: The Geometric (Hyper) Transformer**, *Minor Revision: Mathematical Finance*.
Joint work with: B. Acciaio and G. Pammer
- 2021 **Universal Regular Conditional Distributions**, *Minor Revision: Constructive Approximation*.

Submitted

- 2022 **Instance-Dependent Generalization Bounds via Optimal Transport**, *Submitted* .
Joint work with: A. Krause, S. Hou, P. Kassrai, and J. Rothfuss
- 2022 **Designing Universal Causal Deep Learning Models: The Case of Infinite-Dimensional Dynamical Systems from Stochastic Analysis**, *Submitted* .
Joint work with: L. Galimberti and G. Livieri
- 2022 **Small Transformers Compute Universal Metric Embeddings**, *Submitted* .
Joint work with: V. Debarnot and I. Dokmanić
- 2021 **Denise: Deep Robust Principal Component Analysis for Positive Semi-definite Matrices**, *Submitted* .
Joint work with: J. Teichmann, P. Ruyssen, C. Herrera, and F. Krach
- Workshop Papers and White Papers**
- 2022 **SinkGAT: Doubly-Stochastic Graph Attention**, *SLOWDNN (Workshop on Seeking Low-Dimensionality in Deep Neural Networks)* 3.
Joint work with: T. Liu, C. Shi, and I. Dokmanić
- 2017 **Replication of a Real-Estate Market Index (Teranet)**, *Proceedings: Proceedings: Eighth Montreal Industrial Problem Solving Workshop*.
Joint work with: Bruno Remillard and Behnoosh Zamanlooy

Supervision

- 2022-2024 **Postdoctoral Researcher - Optimal Control**, Xuwei Yang, McMaster University, Xuwei and I have just begun developing new stochastic optimal control approaches to regret-optimal algorithm design, for random neural networks; which builds on *Casgrain and Kratsios*, “*Optimizing Optimizers: Regret-optimal gradient descent algorithms*”, (COLT), 2021.
- 2021-2025 **Ph.D. Student**, Tianlin Liu, University of Basel, Tianlin has worked on a variety of topics during his Ph.D. from operator learning to and I have just begun developing new stochastic optimal control approaches to regret-optimal algorithm design, for random neural networks; which builds on *Casgrain and Kratsios*, “*Optimizing Optimizers: Regret-optimal gradient descent algorithms*”, (COLT), 2021.

Conferences and Talks

- 2023 **International Conference on Learning Representations (Talk)**, Rwanda, Kigali
- 2022 **Finance - AI Seminar**, CIBC, Toronto, Canada
- 2022 **Generic Geometric Priors via Probabilistic Transformers**, *Rice University's: MATH+X Symposium*, Conservatorio Castella, Costra Rica
- 2022 **Regular Conditional Distributions via Probabilistic Transformers**, *Bachelier Colloquium*, 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, Austria.

- 2019 **Risk-Averse Conditional Expectation and Shortfall-Regression**, *ETH Zürich*, Zürich, Switzerland.
- 2018 **Geometric Learning and Filtering in Finance**, *10th Bachelier World Congress*, Dublin, Ireland.
- 2018 **Arbitrage-Free Regularization**, *10th Bachelier World Congress*, 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 3rd 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.

References (Ordered)

1. **Beatrice Acciaio**, *ETH Zürich*, beatrice.acciaio@math.ethz.ch.
2. **Josef Teichmann**, *ETH Zürich*, josef.teichmann@math.ethz.ch.
3. **Juan-Pablo Ortega**, *NTU*, juan-pablo.ortega@ntu.edu.sg.
4. **Cody Hyndman**, *Concordia University*, cody.hyndman@concordia.ca.
5. **Thorsten Schmidt**, *University of Freiburg*, thorsten.schmidt@stochastik.uni-freiburg.de.