

Tutorial

Applied Fractional Calculus in Big Data and Machine Learning (AFC4BD+ML)

The 12th IFAC Conference on Fractional Differentiation and its Applications,
Bordeaux, France, July 9-12, 2024

<https://icfda2024.sciencesconf.org/>

1. Title of tutorial:

Applied Fractional Calculus in Big Data and Machine Learning (AFC4BD+ML)

<https://mechatronics.ucmerced.edu/afc>

2. Outline of the tutorial/workshop (topic and description): Workshop Abstract (why important and why timely and why good for audience):

Fractional order calculus is about differentiation and integration of non-integer orders. Fractional calculus based fractional order thinking (FOT) has been shown to help us to better understand complex systems, better process complex signals, better control complex systems, better perform optimizations, and even better enable creativity. In this tutorial, we will briefly talk on basics of fractional calculus, fractional order thinking, and its rich stochastic models. Then we will justify why fractional calculus is needed in machine learning when we ask “what is the more optimal way to optimize?”. We will also ask why fractional calculus is needed in data when we ask “how to quantify variability and the complexity of the systems that generate the big data?” We will share rich future research opportunities and a new forum to publish the related results.

This tutorial workshop prepares our audience with

- *Basics: The triangle of fractional calculus (FC), inverse power law (IPL) and Complexity © (FC-IPL-C)*
- *Big data, variability and fractional calculus: the root of FODA fractional order data analytics*
- *A new triangle: Machine Learning, Renormalization Group and Machine Learning (ML-RG-ML)*
- *From physic-informed machine learning (PIML) to Complexity informed machine learning (CIML)*

Topics: Half day – 14:00-18:00 (4 hours) July 9th Tuesday 2024

- 1) 14:00-14:20. Introduction to the Tutorial Workshop program (YangQuan Chen)
- 2) 14:20-15:00. Tutorial overview of what are FC, BD and ML? (YangQuan Chen, Yuquan Chen)
- 3) 15:00-16:00 Triangle-1: FC-IPL-Complexity (YangQuan Chen, Yuquan Chen)



- 4) 16:00-16:30. Coffee break and free chats.
- 5) 16:30-17:00. Heavytailedness, outliers, diversity, emergence, creativity & fractional calculus for big data (YangQuan Chen, Yuquan Chen)
- 6) 17:00-18:00. More optimal machine learning and complexity-informed machine learning –the use of fractional calculus – Triangle-2: FC-RG-ML (Yuquan Chen, YangQuan Chen)
- 7) Discussions continue to group lunch and/or dinner time if needed.

More background information: Recent books from the presenters:

- Haoyu Niu and YangQuan Chen. "Smart Big Data in Digital Agriculture Applications: Acquisition, Advanced Analytics, and Plant Physiology-informed Artificial Intelligence" Springer series on [Agriculture Automation and Control](#) [accepted and contracted Oct. 2022] [~240 pages] To appear in early 2024. [[Nov. 2023 version frontmatter PDF](#)]
- Bruce J West and YangQuan Chen. "Fractional Order Calculus for Skeptics I: The Fractal Paradigm". Vol. 1 of the [CRC Press Book Series on Fractional Order Thinking in Exploring the Frontiers of STEM \(Science Technology Engineering and Math\) \(FOT4STEM\)](#), Nov. 2023, in printing. Series service website with more info: <https://mechatronics.ucmerced.edu/FOT4STEM>
- Yanan Wang and YangQuan Chen. "Fractional Order Intelligent Modeling for Lithium-Ion Batteries". Vol. 3 of the [CRC Press Book Series on Fractional Order Thinking in Exploring the Frontiers of STEM \(Science Technology Engineering and Math\) \(FOT4STEM\)](#), planned April 2024, under book proposal peer review (as of Nov. 2023). Series service website with more info: <https://mechatronics.ucmerced.edu/FOT4STEM>
- Chen Yuquan. "Fundamental Principles for Fractional Order Gradient Methods" [Doctoral Thesis] https://kns.cnki.net/kcms2/article/abstract?v=j6HAoO1nZAw7t2EZ0PBcFHv0jQPig8Nz8UmMLbt5_9yDLZX8CDzUpm9dg0tX_fQmJ0sCCSs7pA86DBaxDZybWfSVwYjPKNIkMVtSZChuZVLQ3Pns3Lcezb2It6AYxowO5zotr2IFsc3xYG3cI9Jk5A==&uniplatform=NZKPT&language=CHS

Recent papers from the presenters:

- Niu, Haoyu, YangQuan Chen, and Bruce J. West. 2021. "Why Do Big Data and Machine Learning Entail the Fractional Dynamics?" *Entropy* 23, no. 3: 297. <https://doi.org/10.3390/e23030297>
- Y Chen, Y Wei, Y Wang, YQ Chen [Fractional order gradient methods for a general class of convex functions](#) 2018 Annual American Control Conference (ACC), 3763-3767
- [Yuquan Chen](#), [Yiheng Wei](#), [Yong Wang](#), [YangQuan Chen](#). On the Unified Design of Accelerated Gradient Descent. [15th IEEE/ASME International Conference on Mechatronic and Embedded Systems and Applications](#) at the ASME IDETC 2019, Anaheim, CA.
- Chen Yuquan, Wei Yiheng, Chen YangQuan. Finite-time and Fixed-time Convergence in Continuous-time Optimization[J]. arXiv preprint arXiv:2109.15064, 2021.
- Chen Yuquan, Hollenbeck Derek, Wang Yong, Chen YangQuan. On optimal tempered Lévy flight foraging[J]. *Frontiers in Physics*, 2018, 6: 111.
- Chen Yuquan, Wang Bing, Chen YangQuan, Wang Yong. On the accelerated extremum seeking driven by optimal stochastic perturbations[C] 2021 China Automation Congress (CAC), 2021: 6371-6375.

3. **Duration and sessions:** Half day, 14-18 7/9/2024 Tuesday afternoon



4. Description of the intended audience and the expected learning outcomes: Graduate students, postdocs, engineers, and faculty members dealing with complex process control, health monitoring, fault diagnosis and predictive maintenance tasks.

5. Expected learning outcomes:

- 1) A big picture view of the new research opportunities when using FC in BD and ML
- 2) Basic knowledge on why fractional calculus should be used in big data
- 3) Basic knowledge on why fractional calculus should be used in machine learning
- 4) Basic knowledge on how fractional calculus should be used in big data
- 5) Basic knowledge on how fractional calculus should be used in machine learning

6. Desired prerequisite knowledge of the audience

- 1) Basic knowledge of signals and systems, classical control system (Control-I).
- 2) Optional: Optimization; deep learning; machine learning, big data, stochastic processes

7. The tutorial speaker(s)

- **Prof. YangQuan Chen**, MESA (Mechatronics, Embedded Systems and Automation Lab, University of California, Merced, CA 95343, USA, Email: yqchen@ieee.org;
- **Prof. Yuquan Chen**, College of Artificial Intelligence and Automation, Hohai University, Nanjing, China (Email: cyq@mail.ustc.edu.cn)

8. Brief biographies for each tutorial/workshop speaker (no more than 300 words per person)

Details can be found in this link (workshop service webpage):

<https://mechatronics.ucmerced.edu/afc>

Dr. YangQuan Chen earned his Ph.D. from [Nanyang Technological University](https://www.nanyang.edu.sg/), Singapore, in 1998. He had been a faculty of Electrical Engineering at Utah State University (USU) from 2000-12. He joined the School of Engineering, University of California, Merced (UCM) in summer 2012 teaching “Mechatronics”, “Engineering Service Learning” and “Unmanned Aerial Systems” for undergraduates; “Fractional Order Mechanics”, “Nonlinear Controls” and “Advanced Controls: Optimality and Robustness” for graduates. His research interests include mechatronics for sustainability, cognitive process control, small multi-UAV based cooperative multi-spectral “personal remote sensing”, applied fractional calculus in controls, modeling and complex signal processing; distributed measurement and control of distributed parameter systems with mobile actuator and sensor networks. He is listed in Highly Cited Researchers by Clarivate Analytics from 2018 to 2021. He received Research of the Year awards from USU (12) and UCM (20). yqchen@ieee.org; <https://mechatronics.ucmerced.edu/chenbios> <https://scholar.google.com/citations?user=RDEIRbcAAAAJ&hl=en>

Dr. Yuquan Chen received the B.E. degree in automation and the Ph.D. degree in control science and engineering from the University of Science and Technology of China, Hefei, China, in 2014 and 2020, respectively. He participated in the Ph.D. joint training program between the University of Science and Technology of China and the University of California at Merced, Merced, CA, USA, from 2017 to 2019. He has been a faculty of the College of Artificial Intelligence and Automation, Hohai University, Nanjing, China, since 2020. He is also an Entrepreneurship and the Innovation Doctor of Jiangsu Province. His current research interests include fractional-order system and control, distributed control and optimization, and system-based learning algorithms. Please visit <https://scholar.google.com/citations?user=-vS-96sAAAAJ&hl=zh-CN&oi=sra> for the publications. (cyq@mail.ustc.edu.cn)

