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PROGRAM AND PROCEEDINGS

Machine Learning for Scientific Imaging 2022

Conference Chairs
Marc Louis Klasky, Los Alamos National Laboratory (United States)
Jong Chul Ye, Korea Advanced Institute of Science & Technology (KAIST) (Republic of Korea)

This document details the conference program, held as part of the 2022 IS&T International Symposium on Electronic Imaging, online 15–26 January 2022. Manuscripts of conference papers are reproduced from PDFs as submitted and approved by authors; no editorial changes were made.

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Machine Learning for Scientific Imaging 2022

Conference overview

Machine learning for scientific imaging is a rapidly growing area of research used to characterize physical, material, chemical, and biological processes in both large and small scale scientific experiments. Physics inspired machine learning differs from more general machine learning research in that it emphasizes quantitative reproducibility and the incorporation of physical models. ML methods used for scientific imaging typically incorporate physics-based imaging processes or physics-based models of the underlying data. These models can be based on partial differential equations (PDEs), integral equations, symmetries or other regularity conditions in two or more dimensions. Physics aware models enhance the ability of the ML methods to generalize and robustly operate in the presence of modeling error, incomplete data, and measurement uncertainty. Contributions to the conference are solicited on topics ranging from fundamental theoretical advances to detailed implementations and novel applications for scientific discovery.

Conference Chairs: **Marc Louis Klasky,** Los Alamos National Laboratory (United States); and **Jong Chul Ye,** Korea Advanced Institute of Science & Technology (KAIST) (Republic of Korea)

Program Committee: **Raja Giryes,** Tel Aviv University (Israel); **Ulugbek Kamilov,** Washington University in St. Louis (United States); **Christopher Vincent Rackauckas,** Massachusetts Institute of Technology (United States); **Daniel M. Tartakovsky,** Stanford University (United States); **Lei Tian,** Boston University (United States); and **Nathaniel Trask,** Sandia National Laboratories (United States)

Paper authors listed as of 1 January 2022; refer to manuscript for final authors. Titles that are not listed with the proceedings files were presentation-only.

MONDAY 17 JANUARY 2022

PLENARY: Quanta Image Sensors: Counting Photons Is the New Game in Town

10:00 – 11:10

Eric R. Fossum, Dartmouth College (United States)

The Quanta Image Sensor (QIS) was conceived as a different image sensor—one that counts photoelectrons one at a time using millions or billions of specialized pixels read out at high frame rate with computation imaging used to create gray scale images. QIS devices have been implemented in a CMOS image sensor (CIS) baseline room-temperature technology without using avalanche multiplication, and also with SPAD arrays. This plenary details the QIS concept, how it has been implemented in CIS and in SPADs, and what the major differences are. Applications that can be disrupted or enabled by this technology are also discussed, including smartphone, where CIS-QIS technology could even be employed in just a few years.

Eric R. Fossum is best known for the invention of the CMOS image sensor "camera-on-a-chip" used in billions of cameras. He is a solid-state image sensor device physicist and engineer, and his career has included academic and government research, and entrepreneurial leadership. At Dartmouth he is a professor of engineering and vice provost for entrepreneurship and technology transfer. Fossum received the 2017 Queen Elizabeth Prize from HRH Prince Charles, considered by many as the Nobel Prize of Engineering "for the creation of digital imaging sensors," along with three others. He was inducted into the National Inventors Hall of Fame, and elected to the National Academy of Engineering among other honors including a recent Emmy Award. He has published more than 300 technical papers and holds more than 175 US patents. He co-founded several startups and co-founded the International Image Sensor Society (IISS), serving as its first president. He is a Fellow of IEEE and OSA.

WEDNESDAY 19 JANUARY 2022

PLENARY: In situ Mobility for Planetary Exploration: Progress and Challenges

10:00 – 11:15

Larry Matthies, Jet Propulsion Laboratory (United States)

This year saw exciting milestones in planetary exploration with the successful landing of the Perseverance Mars rover, followed by its operation and the successful technology demonstration of the Ingenuity helicopter, the first heavier-than-air aircraft ever to fly on another planetary body. This plenary highlights new technologies used in this mission, including precision landing for Perseverance, a vision coprocessor, new algorithms for faster rover traverse, and the ingredients of the helicopter. It concludes with a survey of challenges for future planetary mobility systems, particularly for Mars, Earth's moon, and Saturn's moon, Titan.

Larry Matthies received his PhD in computer science from Carnegie Mellon University (1989), before joining JPL, where he has supervised the Computer Vision Group for 21 years, the past two coordinating internal technology investments in the Mars office. His research interests include 3-D perception, state estimation, terrain classification, and dynamic scene analysis for autonomous navigation of unmanned vehicles on Earth and in space. He has been a principal investigator in many programs involving robot vision and has initiated new technology developments that impacted every US Mars surface mission since 1997, including visual navigation algorithms for rovers, map matching algorithms for precision landers, and autonomous navigation hardware and software architectures for rotorcraft. He is a Fellow of the IEEE and was a joint winner in 2008 of the IEEE's Robotics and Automation Award for his contributions to robotic space exploration.

Machine Learning for Scientific Imaging 2022 Posters

11:20 – 12:20

Poster interactive session for all conferences authors and attendees.

MLSI-202

P-17: Advantage of machine learning over maximum likelihood in limited-angle low-photon x-ray tomography, *Zhen Guo[1], Jung Ki Song[1], George Barbastathis[1], Michael A. Glinsky[2], Courtenay T. Vaughan[2], Kurt W. Larson[2], Bradley K. Alpert[3], and Zachary H. Levine[4]; [1]Massachusetts Institute of Technology, [2]Sandia National Laboratory, [3]Applied and Computational Mathematics Division, National Institute of Standards and Technology, and [4]Quantum Measurement Division, National Institute of Standards and Technology (United States)*

MLSI-203

P-18: CNN to mitigate atmospheric turbulence effect on Shack-Hartmann Wavefront Sensing: A case study on the Magdalena Ridge Observatory Interferometer, *Siavash Norouzi[1], James J. Luis[2], Ramyaa Ramyaa[1], John S. Young[2], Eugene B. Seneta[2], Morteza Darvish Morshedi Hosseini[3], and Edgar R. Ligon[4]; [1]New Mexico Institute of Mining and Technology (United States), [2]University of Cambridge (United Kingdom), [3]Binghamton University (United States), and [4]CHARA Array (United States)*

MLSI-204

P-19: ISP distillation [Presentation-Only], *Eli Schwartz[1], Alex Bronstein[2], and Raja Giryes[1]; [1]Tel Aviv University and [2]Technion (Israel)*

MONDAY 24 JANUARY 2022

Inverse Problems in Imaging

Session Chair: Marc Klasky, Los Alamos National Laboratory (United States)

10:00 – 11:05

10:00

Conference Introduction

10:05 MLSI-315

KEYNOTE: Tackling tough inverse problems in imaging using PINNs and DeepOnets [Presentation-Only], *George E. Karniadakis, Brown University (United States)*

We will review physics-informed neural networks (PINNs) and operator regression networks (DeepOnets) with emphasis on discovering missing physics and system identification in diverse applications in fluid mechanics, solid mechanics, bioengineering, and beyond. We will demonstrate that we can use multimodality inputs from images and point measurements to discover effects in materials, obtain three-dimension fields, and improve greatly existing techniques such as particle tracking in fluid mechanics. The diverse problems we consider are ill-posed and cannot be solved with any traditional methods. For example, in one application in aortic dissections we identify from mechanical measurements the genotype that corresponds to the specific mouse tested among five different classes.

George E. Karniadakis received his SM (1984) and PhD (1987) from Massachusetts Institute of Technology. He was appointed Lecturer in the department of mechanical engineering at MIT in 1987 and subsequently he joined the Center for Turbulence Research at Stanford / Nasa Ames. He joined Princeton University as assistant professor in the department of mechanical and aerospace engineering and as associate faculty in the lrogram of applied and computational mathematics. He was a Visiting Professor at Caltech (1993) in the Aeronautics department. He joined Brown University as associate professor of applied mathematics in the Center for Fluid Mechanics on January 1, 1994. He became a full professor on July 1, 1996. He has been a Visiting Professor and Senior Lecturer of Ocean/Mechanical Engineering at MIT since September 1, 2000. He was Visiting Professor at Peking University (Fall 2007 & 2013). He has a joing appointment with PNNL since 2013. He is a Fellow of the Society for Industrial and Applied Mathematics (SIAM, 2010-), Fellow of the American Physical Society (APS, 2004-), Fellow of the American Society of Mechanical Engineers (ASME, 2003-) and Associate Fellow of the American Institute of Aeronautics and Astronautics (AIAA, 2006-). He received the SIAM CSE/ACM prize (2021), the SIAM Ralf E Kleinman award (2015), the (inaugural) J. Tinsley Oden Medal (2013), and the CFD award (2007) by the US Association in Computational Mechanics. His h-index is 112 and he has been cited more than 59,500 times.

10:45 MLSI-316

Signal reconstruction of sparse, nano-scale metrology data using neural networks [Presentation-Only], *Eva Natinsky[1] and Remi Dingreville[2]; [1]The University of Texas at Austin and [2]Sandia National Laboratories (United States)*

Video -- Intelligent Manufacturing -- Dynamic Tomography

Session Chair: Marc Klasky, Los Alamos National Laboratory (United States)

11:30 – 12:30

11:30 MLSI-320

Video from coded motion blur using dynamic phase coding [Presentation-Only], *Erez Yosef, Shay Elmalem, and Raja Giryes, Tel Aviv University (Israel)*

11:50 MLSI-321

Feature anomaly detection system (FADS) for intelligent manufacturing [Presentation-Only], *Anthony Garland, Sandia National Laboratories (United States)*

12:10 MLSI-322

Learning from hydrodynamics simulations with mass constraints for density reconstruction in dynamic tomography [Presentation-Only], *Zhishen Huang[1], Michael T. McCann[2], Jennie Disterhaupt[2], Marc Klasky[2], and Saiprasad Ravishankar[1]; [1]Michigan State University and [2]Los Alamos National Laboratory (United States)*

Machine Learning - High Data Volume

Session Chair: Marc Klasky, Los Alamos National Laboratory (United States)

13:00 – 14:00

13:00 MLSI-327

KEYNOTE: Physics based machine learning [Presentation-Only], *David Rousseau, Université Paris-Saclay (France)*

High Energy Physics experiments aim at establishing fundamental laws of physics by measuring the product of high energy particle collision with increasingly complex detectors. For example, tracking detectors deliver point clouds of micron precision over cubic meters, calorimeter detectors provide energy deposits in irregularly shapes voxels. Dedicated Machine Learning techniques are developed to deal with the specificities of the data, with the constraints of: dealing with large volume of data (many PetaBytes) within resources, maximise sensitivity to rare phenomenons, master unknowns along the full pipe line to be able to quote uncertainties. In addition, a long history of building accurate complex simulators is being supplemented by ML generators orders of magnitude faster but which have to demonstrate their ability to reproduce all details of the feature space.

David Rousseau is a High Energy Physicist at IJCLab, CNRS/IN2P3 and Université Paris-Saclay, currently working for the ATLAS experiment at CERN on the Large Hadron Collider. After a dozen years designing and implementing many pieces of the ATLAS experiment software, a chance meeting in 2013 with a machine learning computer scientist decided a new path in his career: develop the interface between high energy physics (and science in general) and machine learning (or artificial intelligence). Current research topics include: simulation based inference, machine learning for fast particle tracking at the large hadron collider, generator models for fast detector simulation, using an OPU for event classification, and uncertainty aware training. Rousseau received his PhD (1992) in high energy physics from the Université Aix-Marseille II. Since 2009, Rousseau has been senior researcher (Directeur de Recherche) at CNRS/IN2P3 LAL-Orsay, which merged into IJCLab-Orsay in 2020. He began his career at CERN as a CERN Fellow in 1997.

13:40 MLSI-328

Learning optimal wavefront shaping for multi-channel imaging [Presentation-Only], *Elias Nehme[1], Boris Ferdman[1], Lucien E. Weiss[1], Tal Naor[1], Daniel Freedman[2], Tomer Michaeli[1], and Yoav Shechtman[1]; [1]Technion – Israel Institute of Technology and [2]Google Machine Perception (Israel)*

Super Resolution -- Toroidal Magnetic Fields -- Nonlocal Kernel Network

Session Chairs: Marc Klasky, Los Alamos National Laboratory (United States) and Jong Chul Ye, Korea Advanced Institute of Science and Technology (KAIST) (Republic of Korea)

18:00 – 19:00

18:00 MLSI-336

Fast neural Poincare maps for toroidal magnetic fields [Presentation-Only], *Joshua W. Burby, Los Alamos National Laboratory (United States)*

18:20 MLSI-337

Nonlocal Kernel Network (NKN): A stable and resolution-independent deep neural network [Presentation-Only], *Marta D'Elia, Sandia National Laboratories (United States)*

Computational Imaging Pipelines

Session Chairs: Marc Klasky, Los Alamos National Laboratory (United States) and Jong Chul Ye, Korea Advanced Institute of Science and Technology (KAIST) (Republic of Korea)

19:15 – 20:15

19:15 MLSI-368

KEYNOTE: Learning to image the invisible [Presentation-Only], *Katherine L. Bouman, California Institute of Technology (United States)*

As imaging requirements become more demanding, we must rely on increasingly sparse and/or noisy measurements that fail to paint a complete picture. Computational imaging pipelines, which replace optics with computation, have enabled image formation in situations that are impossible for conventional optical imaging. For instance, seismic and black hole imaging have only been made possible through the development of computational imaging pipelines. However, these computational "cameras" often suffer from (a) being difficult to analyze for image uncertainties, and (b) forward model mismatch. This talk will discuss how we are leveraging and building upon recent advances in machine learning in order to achieve more efficient uncertainty quantification and to better recover solutions in the presence of unknown model mismatch. The proposed approaches will be presented in the context of discussing the methods and procedures used to capture the first and future images of a black hole from the Event Horizon Telescope, as well as seismic localization and tomography.

Katherine L. Bouman is a Rosenberg Scholar and assistant professor of computing and mathematical sciences (CMS) and by courtesy in Electrical Engineering and Astronomy at Caltech in Pasadena, California. Bouman's research focuses on computational imaging: designing systems that tightly integrate algorithm and sensor design, making it possible to observe phenomena previously difficult or impossible to measure with traditional approaches. Her group at Caltech combines ideas from signal processing, computer vision, machine learning, and physics to find and exploit hidden signals for both scientific discovery and technological innovation. Prior to starting at Caltech, Bouman was a postdoctoral fellow with the Event Horizon Telescope, which published the first picture of a black hole in April of 2019. She received her PhD (2017) in electrical engineering and computer science from the Massachusetts Institute of Technology (MIT) and previously received a BSE (2011) in electrical engineering from the University of Michigan, Ann Arbor, MI, and an SM (2013) in electrical engineering and computer science from MIT. Bouman is a recipient of an NSF CAREER Award, the Electronic Imaging Scientist of the Year Award, an Okawa Research Grant, a Caltech faculty teaching award, a finalist for the AAAS Early Career Award for Public Engagement with Science, and is a co-recipient of the Breakthrough Prize.

19:55 MLSI-369

Limited-angle CT with deep physics and image priors [Presentation-Only], *Semih Barutcu[1], Selin Aslan[2], Aggelos Katsaggelos[1], and Doga Gursoy[1,2]; [1]Northwestern University and [2]Argonne National Laboratory (United States)*

TUESDAY 25 JANUARY 2022

PLENARY: Physics-based Image Systems Simulation

10:00 – 11:00

Joyce Farrell, Stanford Center for Image Systems Engineering, Stanford University, CEO and Co-founder, ImagEval Consulting (United States)

Three quarters of a century ago, visionaries in academia and industry saw the need for a new field called photographic engineering and formed what would become the Society for Imaging Science and Technology (IS&T). Thirty-five years ago, IS&T recognized the massive transition from analog to digital imaging and created the Symposium on Electronic Imaging (EI). IS&T and EI continue to evolve by cross-pollinating electronic imaging in the fields of computer graphics, computer vision, machine learning, and visual perception, among others. This talk describes open-source software and applications that build on this vision. The software combines quantitative computer graphics with models of optics and image sensors to generate physically accurate synthetic image data for devices that are being prototyped. These simulations can be a powerful tool in the design and evaluation of novel imaging systems, as well as for the production of synthetic data for machine learning applications.

Joyce Farrell is a senior research associate and lecturer in the Stanford School of Engineering and the executive director of the Stanford Center for Image Systems Engineering (SCIEN). Joyce received her BS from the University of California at San Diego and her PhD from Stanford University. She was a postdoctoral fellow at NASA Ames Research Center, New York University, and Xerox PARC, before joining the research staff at Hewlett Packard in 1985. In 2000 Joyce joined Shutterfly, a startup company specializing in online digital photofinishing, and in 2001 she formed ImagEval Consulting, LLC, a company specializing in the development of software and design tools for image systems simulation. In 2003, Joyce returned to Stanford University to develop the SCIEN Industry Affiliates Program.

PANEL: The Brave New World of Virtual Reality

11:00 – 12:00

Advances in electronic imaging, computer graphics, and machine learning have made it possible to create photorealistic images and videos. In the future, one can imagine that it will be possible to create a virtual reality that is indistinguishable from real-world experiences. This panel discusses the benefits of this brave new world of virtual reality and how we can mitigate the risks that it poses. The goal of the panel discussion is to showcase state-of-the art synthetic imagery, learn how this progress benefits society, and discuss how we can mitigate the risks that the technology also poses. After brief demos of the state-of-their-art, the panelists will discuss: creating photorealistic avatars, Project Shoah, and digital forensics.

Panel Moderator: Joyce Farrell, Stanford Center for Image Systems Engineering, Stanford University, CEO and Co-founder, ImagEval Consulting (United States)
Panelist: Matthias Neissner, Technical University of Munich (Germany)
Panelist: Paul Debevec, Netflix, Inc. (United States)
Panelist: Hany Farid, University of California, Berkeley (United States)

CT Reconstruction -- Decomposition

Session Chairs: Marc Klasky, Los Alamos National Laboratory (United States) and Jong Chul Ye, Korea Advanced Institute of Science and Technology (KAIST) (Republic of Korea)

19:15 – 20:15

19:15 MLSI-378

Limited-view cone beam CT reconstruction using 3D patch-based supervised and adversarial learning: Validation using hydrodynamic simulations and experimental tomographic data [Presentation-Only], *Marc Klasky[1], Anish Lahiri[2], Jeff Fessler[2], Saiprasad Ravishankar[3], Michelle Espy[1], Michael T. McCann[1], Trevor Wilcox[1], and Ajeeta Khatiwada[1]; [1]Los Alamos National Laboratory, [2]University of Michigan, and [3]Michigan State University (United States)*

19:35 MLSI-379

Machine learning and spatial decomposition for large CT scans [Presentation-Only], *Gary J. Saavedra and Eric C. Cyr, Sandia National Laboratories (United States)*

19:55 MLSI-380

X-ray CT reconstruction leveraging CAD models, physics-based information and GANs [Presentation-Only], *Amir K. Ziabari[1], Abhishek Dubey[2], Singanallur Venkatakrishnan[1], Paul Brackman[3], Curtis Frederick[3], Philip R. Bingham[1], Ryan Dehoff[1], and Vincent Paquit[1]; [1]Oak Ridge National Laboratory, [2]Center of Cancer Research (NCI-NIH), and [3]Carl Zeiss Metrology LLC (United States) (United States)*

WEDNESDAY 26 JANUARY 2022

2D Unknown View Tomography -- Phase Imaging and Artificial Intelligence

Session Chairs: Marc Klasky, Los Alamos National Laboratory (United States) and Jong Chul Ye, Korea Advanced Institute of Science and Technology (KAIST) (Republic of Korea)

18:00 – 19:00

18:00 MLSI-405

KEYNOTE: An adversarial learning approach for 2D unknown view tomography [Presentation-Only], *Mona Zehni and Zhizhen J. Zhao, University of Illinois at Urbana-Champaign (United States)*

The goal of 2D tomographic reconstruction is to recover an image given its projection lines from various views. It is often presumed that projection angles associated with the projections are known in advance. Under certain situations, however, these angles are known only approximately or are completely unknown, when imaging moving objects. It becomes challenging to reconstruct the image from a collection of random projection. We introduce an adversarial learning based approach to recover the image and the projection angle distribution by matching the empirical distribution of the measurements with the generated data. Fitting the distributions is achieved through solving a min-max game between a generator and a critic based on Wasserstein generative adversarial network structure. To accommodate the update of the projection angle distribution through gradient back propagation, we approximate the loss using the Gumbel-Softmax reparameterization of samples from discrete distributions. Our theoretical analysis verifies the unique recovery of the image and the projection distribution up to a rotation and reflection upon convergence. Our numerical experiments showcase the potential of the method to accurately recover the image and the projection angle distribution under noise contamination.

Zhizhen J. Zhao is an assistant professor in the department of electrical and computer engineering at the University of Illinois, Urbana-Champaign, with affiliation to the Coordinated Science Laboratory and the National Center Supercomputing Applications. She is also an affiliate assistant professor in the department of mathematics and the department of statistics. Her areas of research include geometric data analysis, dimensionality reduction, mathematical signal processing, scientific computing, and machine learning. Applications to imaging sciences and inverse problems, including cryo-electron microscopy image processing, data-driven methods for dynamical systems, and uncertainty quantification. Prior to joining ECE Illinois in 2016, she was a Courant Instructor at the Courant Institute of Mathematical Sciences, New York University. She received her PhD in physics from Princeton University (2013) working with Amit Singer and graduated from Trinity College, Cambridge University, with a BS and MS in physics (2008).

18:40 MLSI-406

Quantitative phase imaging and artificial intelligence: Label-free 3D imaging, classification, and inference [Presentation-Only], *Yongkeun Park[1,2]; [1]Korea Advanced Institute of Science and Technology (KAIST) and [2]Tomocube, Inc. (Republic of Korea)*

Imaging Through Scattering Medium -- Hydrodynamics Simulations

Session Chairs: Marc Klasky, Los Alamos National Laboratory (United States) and Jong Chul Ye, Korea Advanced Institute of Science and Technology (KAIST) (Republic of Korea)

19:15 – 20:15

19:15 MLSI-410

Physics-embedded deep learning for diffuser-based funduscope [Presentation-Only], *Yunzhe Li and Lei Tian, Boston University (United States)*

19:35 MLSI-411

Imaging through scattering medium with deep phase retrieval [Presentation-Only], *Mooseok Jang, Hyungjin Chung, Hyeonggeon Kim, Gookho Song, and Jong Chul Ye, Korea Advanced Institute of Science and Technology (KAIST) (Republic of Korea)*

19:55 MLSI-412

Physics based hydrodynamic learning from hydrodynamics simulations with mass constraints for density reconstruction in dynamic tomography [Presentation-Only], *Marc Klasky[1], Balu Nadiga[1], Soumi De[1], Oleg Korobkin[1], Jennie Disterhaupt[1], Trevor Wilcox[1], Maliha Hossain[1,2], and Charles A. Bouman[2]; [1]Los Alamos National Laboratory and [2]Purdue University (United States)*