Brief CV: Jinchao Xu

Basic information

- Citizenship: US citizen
- Verne M. Willaman Professor of Mathematics
- Department of Mathematics
- Penn State University
- University Park, PA 16802, USA
- Phone/Email: +1 814 865-1110, xu@multigrid.org

- Education (Mathematics): Ph.D. Cornell University, 1988; M.A. Peking University, China, 1984; B.A. Xiangtan University, China, 1982
- Work Experiences:
  - Verne M. Willaman Professor of Mathematics, Penn State University, Jan 2015–present (on leave: Fall 2022-Spring 2023)
  - Director, Center for Computational Mathematics and Applications, Penn State University, 1997 – present
  - Professor of Applied Mathematics and Computational Sciences, King Abdullah University of Science and Technology, May 2022–present
  - Francis R. and Helen M. Pentz Professor of Science, Penn State University, April 2010–December 2014
  - Distinguished Professor, Penn State University, July 2007–April 2010
  - Affiliated Faculty of the College of Information Sciences and Technology, Penn State University, May 2007–present
  - Professor, Penn State University, July 1995–present
  - Associate Professor, Penn State University, July 1991–June 1995
  - Assistant Professor, Penn State University, January 1989–June 1991
  - Visiting positions at Max-Plankt Institute, Isaac Newton Institute for Mathematical Sciences, Peking University, MSRI, Lawrence Livermore Laboratory, ETH, University of Stuttgart, University of Oslo, UCLA, ICASE, National Central University, Taiwan, Ecole Centrale de Lyon, Institute of Systems Sciences, Academia Sinica, UCSD

Research accomplishments

Pioneering contributions to computational science and engineering, especially to the development and analysis of fast multilevel methods and software.

Contributions in engineering applications

Dr. Xu is a world-renowned expert in developing fast algorithms for scientific and engineering applications. His algorithms and software packages are significantly more efficient than existing technologies in numerous applications. Through his work, he has enabled the solution of some complex scientific and engineering problems that were previously too expensive to solve using existing technologies due to their high complexity.

1. He developed an innovative Maxwell solver used in numerical simulations of magnetohydrodynamics (MHD). This solver was recognized in a 2008 report by the U.S. Department of Energy as one of the top 10 breakthroughs in computational science in recent years, highlighting the impact of fundamental mathematical research on high-performance computing. The DOE report showcases the exceptional speed of Xu's algorithm, which was found to be 25 times faster than existing algorithms for problems of size 70M unknowns. This solver has been in all the main large-scale codes at Lawrence Livermore National Laboratory (LLNL) for quite a few years now, and it has become the workhorse for all simulation involving a electric-magnetic field solver, such as in fusion energy simulations.

2. With substantial funding from the oil and gas industry, he led an international team, primarily based at Penn State, that developed fast solvers for petroleum reservoir simulation. More than 1400 sets of software that his team developed have been installed and applied in more than 100 oil and gas field blocks. Furthermore, Dr. Xu's collaborative team in China, led by his former postdoc, was awarded the first CSIAM (2021) Award for Practical Applications of Applied Mathematics in recognition of their contributions to the field.

3. He developed the Fast Auxiliary Space Preconditioning (FASP) software package, which includes the kernel part (open source) and a number of engineering applications. Building on FASP, Dr. Xu's team developed robust numerical methods and software packages for various applications, including fluid-structure interaction problems in the design of hydroelectric generators and artificial hearts, energy storage fields such as Lithium Ion Battery and fuel cell simulation, and robust methods.

4. He developed a unified model, known as MgNet, that is based on close connections that we have observed and uncovered between the convolutional neural network and multigrid methodologies. MgNet type-models are used to solve image classification, image segmentation, and time series prediction tasks from engineering fields.

Academic accomplishments

Xu's remarkable success in a wide range of engeerning applications is largely due to his deep mathematical works in the design and analysis of fast multilevel iterative methods such as multigrid and domain decomposition methods for large-scale discretized partial differential equation (PDE) systems. His fundamental contributions in this field have resulted in several well-known results that bear his name, including the Bramble-Pasciak-Xu (BPX) and Hiptmair-Xu (HX) preconditioners, Xu-Zikatanov (XZ) identity, and Morley-Wang-Xu (MWX) element.

The BPX preconditioner is one of the two fundamental multigrid algorithms for solving large-scale discretized PDEs, and the HX preconditioner, featured in 2008 by the US Department of Energy as one of the top 10 breakthroughs in computational science, is now a major solver in numerical simulation of electromagnetic problems. The XZ identity is a sharp technical tool for the Methods of Subspace Correction, a general and widely used mathematical framework that Xu established in his well-cited SIAM Review paper for the design and analysis of general iterative methods. MWX is the only known canonical construction of finite element family for any 2m-th order of elliptic and parabolic equations in any spatial-dimensions R^n.

In addition to these contributions, Xu has also made numerous other fundamental contributions with his students and collaborators, including providing the ground breaking convergence theory of multigrid methods for a variety of situations such as no-regularity PDEs and nonnested grids, and for multiplicative overlapping domain decomposition methods with multiple subdomains. He also developed the first structure-preserving discretization and efficient solvers of MHD problems, and in an invited paper in Acta Numerica, he presented a unified framework and theory that can be used to derive and analyze different algebraic multigrid (AMG) methods in a systematical manner.

Xu's research has been published in various top engineering journals, including "Computer Methods in Applied Mechanics and Engineering," (CMAME). For example, in a 2006 paper, he and his former student Lee designed new algorithms for modeling non-Newtonian flows that are immune from the well-known high Weissenberg number problem. In another paper published in 2019 with his former postdocs, Xu demonstrated both theoretically and numerically that the most popular convex-splitting schemes in phase-field modeling in engineering applications may seriously lack numerical accuracy due to time-delay caused by the splitting scheme.

Recently, Xu has been working on research that combines engineering computing and machine learning. With his student He, Xu developed MgNet, which provides a unified framework for two different research fields: multigrid methods for solving partial differential equations and convolutional neural networks for machine learning. MgNet yields a new family of convolutional neural networks that have almost identical algorithmic structure of a geometric multigrid method that is mathematically well-understood and demonstrated competitive performance in comparison with most existing CNNs and Transformer for image classification.

With his postdoc Siegel, Xu developed a comprehensive theory on the optimal approximation properties of neural network functions, especially those with ReLU and its power as activation functions. These works provide solutions to several open problems on related problems studied in approximation theory and statistical literature. Additionally, with his postdocs and students, Xu developed rigorous convergence theory and specialized training algorithms for applying neural network functions for numerical solutions of partial differential equations. The theoretical rate of convergence can be numerically realized by the special training algorithms he developed, while no other training algorithms are known to numerically demonstrate good asymptotic rate of convergence.

Examples of Research Impact

1. His algorithm HX-preconditioner was featured in a 2008 report by the U.S. Department of Energy as one of the top 10 breakthroughs in computational science http://www.multigrid.org/xu/files/top10breakthrough.pdf
2. Top 25 Highly Cited Institutions and Authors in Mathematics, 1991–2001 http://www.multigrid.org/xu/files/ScienceWatch.pdf
3. Google Scholar: citations 18346, H-index 65, i10-index 193 https://scholar.google.com/citations?user=pBHiYxcAAAAJ&hl=en&oi=ao
4. Team members (former postdoc) received the first CSIAM (2021) Award for Practical Applications of Applied Mathematics https://www.csiam.org.cn/home/article/detail/id/1521.html and an English tranlation version http://www.multigrid.org/xu/CSIAM_news.shtml
5. His former Ph.D. student Kaibo Hu was recently awarded the Royal Society University Research Fellowship (2022-2027) and the SIAM Computational Science and Engineering Early Career Prize, 2023 https://royalsociety.org/news/2022/11/URF-2022/ and https://www.maths.ox.ac.uk/node/61535

Professional Service

- Served in many panels or as a reviewer of funding agencies from many countries such as National Science Foundation, Department of Energy, European Research Council, Italian Ministry of Education, Austrian Science Fund, Einstein Foundation Berlin, Institute for Basic Science Korea, Committee of the Feng Kang Prize of Scientific Computing
- Served on more than 18 editorial boards of scientific journals, including: Numerische Mathematik, Mathematical Models and Methods in Applied Sciences, SMAI Journal of Computational Mathematics, Journal of Computational Mathematics (managing editor)
- Served in organizing and/or scientific committees for more than 100 conferences and workshops
- Supervised 23 postdoctoral fellows, 26 Ph.D students and 11 master students and numerous undergraduate students

Professional recognition, honors, awards

- Presented more than 400 invited talks in conferences (136), colloquium (233) and other talks (55)
- Fellow of the Academia Europaea, the European Academy of Sciences, the American Association for the Advancement of Science (AAAS), the American Mathematical Society (AMS), the Society for Industrial and Applied Mathematics (SIAM)
- Invited speaker at International Congress for Industrial and Applied Mathematics in 2007 and invited speaker (45 mins) at International Congress for Mathematicians in 2010
- Alexander von Humboldt Research Award for Senior US Scientists, 2005
- Research Award for National Outstanding Youth (Class B, under the age of 45), China, 2006