

# Lu Lu

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Division of Applied Mathematics, Brown University ◊ Providence, RI 02912

## EDUCATION

### Brown University

- Ph.D. in Applied Mathematics
- M.Sc. in Computer Science
- M.Sc. in Applied Mathematics
- M.Sc. in Fluids and Thermal Sciences
- GPA 3.94/4.00

8/2014–present  
Expected 12/2019

### Tsinghua University, Beijing, China

- B.Eng. in Thermal Engineering
- B.Ec. in Economics
- Minor in Computer Science
- GPA 93.8/100

8/2009–7/2013

## RESEARCH EXPERIENCE

### George Em Karniadakis' Group, Division of Applied Mathematics, Brown University

9/2014–present

- **Project:** Machine learning
  - Demonstrated numerically and theoretically that deep and narrow neural networks will converge to erroneous mean or median states of the target function depending on the loss with high probability.
  - Quantified the generalization error of neural networks for classification problems in terms of data distribution and neural network smoothness.
  - Quantified total uncertainty in physics-informed neural networks (PINNs) for solving forward and inverse stochastic problems.
  - Extended PINNs to fractional PINNs (fPINNs) to solve space-time fractional advection-diffusion equations, and demonstrated their accuracy and effectiveness in solving multi-dimensional forward and inverse problems with forcing terms whose values are only known at randomly scattered spatio-temporal coordinates.
  - Developed deep operator networks to learn operators accurately and efficiently from a relatively small dataset.
- **Project:** Computational biology
  - Developed a coarse-grained patchy particle model of sickle hemoglobin (HbS) to probe the formation process, mechanical and structural properties of HbS polymer fiber.
  - Developed a hybrid HbS fiber model by applying mesoscopic adaptive resolution scheme (MARS) which seamlessly couples the microscopic and mesoscopic HbS fiber models toward understanding of interactions between HbS fibers.
  - Developed coarse-grained models to simulate the dynamic self-assembly of two types of amyloids (amylin and amyloid  $\beta$ ) to gain a quantitative understanding of the molecular mechanisms causing different aggregated structures and biomechanical properties of amyloid fibrils.
  - Simulated the dynamics of healthy and diseased red blood cells (RBCs) traversing the interendothelial slit in the human spleen using a two-component protein-scale RBC model, which reveals that the spleen not only senses and clears RBCs with abnormal shapes and deformability but also alters the geometries of RBCs that contain protein defects arising from hereditary blood disorders.
  - Developed a kinetic model of erythrocyte sickling to examine the effectiveness of potential anti-sickling drug candidates, which provides quantitative guidelines for the discovery of intracellular processes to be targeted by sickling inhibitors.
- **Project:** Software development
  - Developed DeepXDE, a deep learning library for solving differential equations on top of TensorFlow. (<https://github.com/lululxvi/deepxde>)

- Developed OpenRBC (a fast simulator of RBCs at protein resolution) using an adaptive spatial searching algorithm based on Voronoi tessellation and  $k$ -d tree data structure, which is capable to simulate an entire RBC lipid bilayer and cytoskeleton modeled by 4 million mesoscopic particles on a single SuperVessel 4-core instance. (<https://devpost.com/software/openrbc>, <https://github.com/yhtang/OpenRBC>)

## PUBLICATIONS (\*CONTRIBUTED EQUALLY)

### Preprints

1. Lu, L., Jin, P., & Karniadakis, G. E. (2019). DeepONet: Learning Nonlinear Operators for Identifying Differential Equations based on the Universal Approximation Theorem of Operators. *arXiv preprint arXiv:1910.03193*.
2. Lu, L., Meng, X., Mao, Z., & Karniadakis, G. E. (2019). DeepXDE: A Deep Learning Library for Solving Differential Equations. *arXiv preprint arXiv:1907.04502*.
3. Jin, P., Lu, L., Tang, Y., & Karniadakis, G. E. (2019). Quantifying the Generalization Error in Deep Learning in terms of Data Distribution and Neural Network Smoothness. *arXiv preprint arXiv:1905.11427*.
4. Lu, L., Shin, Y., Su, Y., & Karniadakis, G. E. (2019). Dying ReLU and Initialization: Theory and Numerical Examples. *arXiv preprint arXiv:1903.06733*.
5. Lu, L., Su, Y., & Karniadakis, G. E. (2018). Collapse of Deep and Narrow Neural Nets. *arXiv preprint arXiv:1808.04947*.

### Journal Papers

1. Pang, G., Lu, L., & Karniadakis, G. E. (2019). fPINNs: Fractional Physics-Informed Neural Networks. *SIAM Journal on Scientific Computing*, 41(4), A2603–A2626.
2. Lu, L., Li, Z., Li, H., Li, X., Vekilov, P. G., & Karniadakis, G. E. (2019). Quantitative Prediction of Erythrocyte Sickling for the Development of Advanced Sickle Cell Therapies. *Science Advances*, 5(8), eaax3905. **(Highlighted on Science Advances homepage)**
3. Zhang, D., Lu, L., Guo, L., & Karniadakis, G. E. (2019). Quantifying Total Uncertainty in Physics-informed Neural Networks for Solving Forward and Inverse Stochastic Problems. *Journal of Computational Physics*, 397, 108850.
4. Li, H., Lu, L., Li, X., Buffet, P. A., Dao, M., Karniadakis, G. E., & Suresh, S. (2018). Mechanics of Diseased Red Blood Cells in Human Spleen and Consequences for Hereditary Blood Disorders. *Proceedings of the National Academy of Sciences*, 115(38), 9574–9579.
5. Li, H., Papageorgiou, D., Chang, H. Y., Lu, L., Yang, J., & Deng, Y. (2018). Synergistic Integration of Laboratory and Numerical Approaches in Studies of the Biomechanics of Diseased Red Blood Cells. *Biosensors*, 8(3), 76.
6. Lu, L., Deng, Y., Li, X., Li, H., & Karniadakis, G. E. (2018). Understanding the Twisted Structure of Amyloid Fibrils via Molecular Simulations. *The Journal of Physical Chemistry B*, 122(49), 11302–11310.
7. Li, H., Yang, J., Chu, T. T., Naidu, R., Lu, L., Chandramohanadas, R., ... & Karniadakis, G. E. (2018). Cytoskeleton Remodeling Induces Membrane Stiffness and Stability Changes of Maturing Reticulocytes. *Biophysical Journal*, 114(8), 2014–2023. **(Highlighted on Biophysical Journal homepage)**
8. Li, H., Chang, H. Y., Yang, J., Lu, L., Tang, Y. H., & Lykotrafitis, G. (2018). Modeling Biomembranes and Red Blood Cells by Coarse-grained Particle Methods. *Applied Mathematics and Mechanics*, 39(1), 3–20.
9. Lu, L., Li, H., Bian, X., Li, X., & Karniadakis, G. E. (2017). Mesoscopic Adaptive Resolution Scheme toward Understanding of Interactions between Sickle Cell Fibers. *Biophysical Journal*, 113(1), 48–59. **(Cover Article)**
10. Tang, Y. H., Lu, L., Li, H., Evangelinos, C., Grinberg, L., Sachdeva, V., & Karniadakis, G. E. (2017). OpenRBC: A Fast Simulator of Red Blood Cells at Protein Resolution. *Biophysical Journal*, 112(10), 2030–2037. **(Highlighted on Biophysical Journal homepage)**
11. Lu, L., Li, X., Vekilov, P. G., & Karniadakis, G. E. (2016). Probing the Twisted Structure of Sickle Hemoglobin Fibers via Particle Simulations. *Biophysical Journal*, 110(9), 2085–2093. **(Highlighted on Biophysical Journal homepage)**
12. Lu, L., Zhang, X., Yan, Y., Li, J. M., & Zhao, X. (2014). Theoretical Analysis of Natural-Gas Leakage in Urban Medium-pressure Pipelines. *Journal of Environment and Human*, 1(2), 71–86.

## PATENTS

1. Suresh, S., Lu, L., Karniadakis, G. E., & Dao, M. Machine Learning Techniques for Estimating Mechanical Properties of Solid Materials. *US Provisional Patent* filed on June 24, 2019.
2. Dong, X., Li, J. M., Yan, Y., Zhang, H., Lu, L., Wang, J., & Xiao, H. A Test Device and Method for Simulating Natural Gas Leakage in Soil. *China Invention Patent* CN103712755A, filed on June 14, 2013, and issued on April 9, 2014.

## TALKS AND PRESENTATIONS

### Invited Talks

1. Collapse of Deep and Narrow Neural Nets. *ICERM Scientific Machine Learning*, Providence, RI, Jan. 2019.

### Conference Presentations

1. DeepXDE: A Deep Learning Library for Solving Differential Equations. *Deep Learning for Science School*, Berkeley, CA, Jul. 2019. (Poster Presentation)
2. Quantitative Prediction of Erythrocyte Sickling for Anti-polymerization Activities in Sickle Cell Disease. *60<sup>th</sup> Annual Red Cell Meeting*, New Haven, CT, Oct. 2018. (Poster Presentation)
3. OpenRBC: A Fast Simulator of Red Blood Cells at Protein Resolution. *SIAM Annual Meeting*, Pittsburgh, PA, Jul. 2017. (Oral Presentation)
4. Probing the Twisted Structure of Sickle Hemoglobin Fibers via Particle Simulations. *20<sup>th</sup> Biennial Hemoglobin Switching Conference*, Pacific Grove, CA, Sept. 2016. (Poster Presentation)
5. Shock Tube Ignition Delay Time Study of RP-1/Oxygen/Argon Mixtures. *Stanford Undergraduate Visiting Research Symposium*, Stanford, CA, Aug. 2012. (Oral and Poster Presentation)
6. The Feasibility Analysis of Small-sized Commercial Ice-storage Air-conditioning System. *10<sup>th</sup> National Symposium on Refrigerators, Air Conditioners and Compressors*, Qingdao, Shandong, Aug. 2011. (Oral Presentation)

## AWARDS AND HONORS

- Associate Member, Sigma Xi, 2018.
- George Irving Hopkins Fellowship, Brown University, 2017.
- [Open Graduate Education Program](#), Brown University, 2017.
- Third Prize, [IBM OpenPOWER Developer Challenge contest](#), 2016.
- Fellowship for graduate students, Brown University, 2015.
- Provincial Outstanding Graduates, Beijing, China, 2013. (top 5% of graduating students)
- Provincial Merit Student, Beijing, China, 2013. (top 1 student in every department)
- Outstanding Graduates, Tsinghua University, 2013. (top 2% of graduating students)
- Outstanding Undergraduate Graduation Thesis, Tsinghua University, 2013. (top 5% of graduating students)
- Excellent Student Cadre, Tsinghua University, 2013.
- December Ninth Scholarship, Tsinghua University, 2012. (top 1 student in every department)
- Summer Research Scholarship, [Chinese Undergraduate Visiting Research Program](#), Stanford University, 2012.
- Outstanding Volunteer, Tsinghua University learning center, 2012.
- Member of ["Spark" Innovative Talent Cultivation Program](#), Tsinghua University, 2011. (top 36 of 3300 students)
- Tsinghua Friend-Kai Feng Fellowship, Tsinghua University, 2011. (top 10 students in every grade)
- Best Paper Award, 10<sup>th</sup> National Symposium on Refrigerators, Air Conditioners and Compressors, Shandong, China, 2011.
- Third Prize, 29<sup>th</sup> "Challenge Cup" Tsinghua University Students' Extracurricular Academic Science and Technology Works Contest, 2011.
- Three-star Volunteer, Tsinghua University, 2011. (entitled to those who devoted more than 100 hours to voluntary work)
- Tsinghua Friend-Kai Feng Fellowship, Tsinghua University, 2010. (top 10 students in every grade)
- First Prize, 27<sup>th</sup> Annual National Physics Contest for College Students, Beijing, China, 2010.
- Second Prize, 4<sup>th</sup> Intelligent Car Competition, Tsinghua University, 2010.
- First Prize, Chinese Physics Olympiad, Jiangsu, China, 2008.
- First Prize, Chinese Mathematical Olympiad, Jiangsu, China, 2008.
- Third Prize, Chinese Chemistry Olympiad, Jiangsu, China, 2008.
- Second Prize, Chinese Physics Olympiad, Jiangsu, China, 2007.

## PROFESSIONAL SERVICES

- Journal Reviewer: Journal of Computational Physics, Journal of Eye Study and Treatment, International Journal of Blood Research and Disorders
- Conference Reviewer: Conference on Neural Information Processing Systems: Machine Learning and the Physical Sciences Workshop (2019)

## TEACHING EXPERIENCE

- Teaching Assistant, Numerical Solution of Partial Differential Equations I 9/2018–12/2018
- Teaching Assistant, Operations Research: Probability Models 1/2018–5/2018
- Teaching Assistant, Computational Probability and Statistics 9/2017–12/2017
- Teaching Assistant, Advanced Fluid Mechanics 1/2015–5/2015
- Instructor, Tsinghua University National Students' Innovation Camp (instructed 24 senior high school students to complete 8 innovation projects in one week) 8/2011
- Instructor, Tsinghua University learning center (taught freshmen mathematics and physics) 3/2010–12/2011

## ACADEMIC ACTIVITIES

- **Leader** of the Tsinghua–Toshiba Innovation Development Interest Group (managed 60 students and 10 research projects on city construction and energy conservation) 6/2012–3/2013
- **President** of the Association of Students for Science and Technology, Tsinghua University (organized the science contest on energy saving and emission reduction, which 40 groups participated in) 12/2011–2/2013
- **Representative** of Tsinghua University, 6<sup>th</sup> Freescale Cup National University Students Intelligent Car Race, Shanxi, China 8/2011
- **Team leader** of an in-field study on power generating and environment protection, Daihai Power Plant, Inner Mongolia, China 8/2010
- **Volunteer** of the 33<sup>rd</sup> International Symposium on Combustion, Beijing, China 8/2010

## SKILLS

<b>Softwares</b>	LAMMPS, VMD; OpenFOAM, Gambit, Fluent, Chemkin; AutoCAD, SolidWorks; L <sup>A</sup> T <sub>E</sub> X.
<b>Programming</b>	C/C++, Python, MATLAB, Fortran, Java, SQL, x86/x86-64 Assembly; TensorFlow, OpenMP, MPI.
<b>Systems and Tools</b>	Linux/UNIX; Vim, Emacs; CMake, GDB, Valgrind; Git, SVN; MongoDB, Redis.

*Last updated: October 8, 2019*