

# Deepak Narayanan

## Curriculum Vitae

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### Education

- 2015-Present **Ph.D., Stanford University**, Computer Science  
**Advisor:** Matei Zaharia  
**Thesis title:** Resource-Efficient Execution of Deep Learning Computations  
**Research areas:** Systems for Machine Learning, Distributed Systems, Cloud Computing, Systems Performance.  
I broadly work on Systems. I design and implement software to improve the *runtime performance* and *efficiency* of emerging machine learning and data analytics workloads on modern hardware.
- 2014-2015 **Masters of Engineering, Massachusetts Institute of Technology**, GPA: 5.0/5.0, Computer Science.
- 2011-2013 **Bachelor of Science, Massachusetts Institute of Technology**, GPA: 4.9/5.0, Computer Science and Mathematics.

### Selected Honors

- 2016-2021 NSF Graduate Research Fellowship.
- 2015-2016 Stanford Graduate Fellowship.
- 2011 All India Rank 229 in IIT Joint Entrance Examination (~500,000 candidates).
- 2010-2011 International Mathematics Olympiad Training Camp Invitee, Government of India (~ 50 invitees across India).
- 2010 Kishore Vaigyanik Protsahan Yojana (KVPY) Fellowship, Government of India (~ 250/100,000 candidates across India).
- 2009 International Astronomy Olympiad (Junior) Training Camp Invitee, Government of India (~ 30 invitees across India).
- 2007 National Talent Search Examination (NTSE) Scholarship, Government of India (~ 1000 scholars across India).
- 2007 Study of Exceptional Talent (SET) Membership, Center for Talented Youth (CTY), Johns Hopkins University.

### Publications

- In-Progress **Efficient Large-Scale Language Model Training on GPU Clusters**  
Preprints Deepak Narayanan, Mohammad Shoeybi, Jared Casper, Patrick LeGresley, Mostofa Patwary, Vijay Korthikanti, Dmitri Vainbrand, Prethvi Kashinkunti, Julie Bernauer, Bryan Catanzaro, Amar Phanishayee, Matei Zaharia. *arXiv:2104.04473*.
- Allocation of Fungible Resources via a Fast, Scalable Price Discovery Method**  
Akshay Agrawal, Stephen Boyd, Deepak Narayanan, Fiodar Kazhamiaka, Matei Zaharia. *arXiv:2104.00282*.

- Memory-Efficient Pipeline-Parallel DNN Training**  
 Deepak Narayanan, Amar Phanishayee, Kaiyu Shi, Xie Chen, Matei Zaharia. *arXiv:2006.09503*.
- Conference Papers **Heterogeneity-Aware Cluster Scheduling Policies for Deep Learning Workloads**  
 Deepak Narayanan, Keshav Santhanam, Fiodar Kazhamiaka, Amar Phanishayee, Matei Zaharia. *OSDI 2020*.
- Offload Annotations: Bringing Heterogeneous Computing to Existing Libraries and Workloads**  
 Gina Yuan, Shoumik Palkar, Deepak Narayanan, Matei Zaharia. *USENIX ATC 2020*.
- Willump: A Statistically-Aware End-to-end Optimizer for Machine Learning Inference**  
 Peter Kraft, Daniel Kang, Deepak Narayanan, Shoumik Palkar, Peter Bailis, Matei Zaharia. *MLSys 2020*.
- MLPerf Training Benchmark**  
 Peter Mattson, Christine Cheng, Cody Coleman, Greg Diamos, Paulius Micikevicius, David Patterson, Hanlin Tang, Gu-Yeon Wei, Peter Bailis, Victor Bittorf, David Brooks, Dehao Chen, Debojyoti Dutta, Udit Gupta, Kim Hazelwood, Andrew Hock, Xinyuan Huang, Bill Jia, Daniel Kang, David Kanter, Naveen Kumar, Jeffery Liao, Deepak Narayanan, Tayo Oguntebi, Gennady Pekhimenko, Lillian Pentecost, Vijay Janapa Reddi, Taylor Robie, Tom St. John, Carole-Jean Wu, Lingjie Xu, Cliff Young, Matei Zaharia. *MLSys 2020*.
- PipeDream: Generalized Pipeline Parallelism for DNN Training**  
 Deepak Narayanan\*, Aaron Harlap\*, Amar Phanishayee, Vivek Seshadri, Nikhil R. Devanur, Gregory R. Ganger, Phillip B. Gibbons, Matei Zaharia. *SOSP 2019*.
- Evaluating End-to-End Optimization for Data Analytics Applications in Weld**  
 Shoumik Palkar, James Thomas, Deepak Narayanan, Pratiksha Thaker, Parimarjan Negi, Rahul Palamuttam, Anil Shanbhag, Holger Pirk, Malte Schwarzkopf, Saman Amarasinghe, Samuel Madden, Matei Zaharia. *VLDB 2018*.
- MacroBase: Prioritizing Attention in Fast Data**  
 Peter Bailis, Edward Gan, Samuel Madden, Deepak Narayanan, Kexin Rong, Sahaana Suri. *SIGMOD 2017*.
- Weld: A Common Runtime for High Performance Data Analytics**  
 Shoumik Palkar, James Thomas, Anil Shanbhag, Deepak Narayanan, Holger Pirk, Malte Schwarzkopf, Saman Amarasinghe, Matei Zaharia. *CIDR 2017*.
- Journal Papers **Analysis of DAWNBench, a Time-to-Accuracy Machine Learning Performance Benchmark**  
 Cody Coleman\*, Daniel Kang\*, Deepak Narayanan\*, Luigi Nardi, Tian Zhao, Jian Zhang, Peter Bailis, Kunle Olukotun, Chris Re, Matei Zaharia. *SIGOPS Operating Systems Review July 2019*.
- MacroBase: Prioritizing Attention in Fast Data**  
 Firas Abuzaid, Peter Bailis, Jialin Ding, Edward Gan, Samuel Madden, Deepak Narayanan, Kexin Rong, Sahaana Suri. *TODS 2018*.
- Workshop Papers **Analysis and Exploitation of Dynamic Pricing in the Public Cloud for ML Training**  
 Deepak Narayanan, Keshav Santhanam, Fiodar Kazhamiaka, Amar Phanishayee, Matei Zaharia. *DISPA 2020*.
- Accelerating Deep Learning Workloads through Efficient Multi-Model Execution**  
 Deepak Narayanan, Keshav Santhanam, Amar Phanishayee, Matei Zaharia. *NeurIPS Systems for ML Workshop 2018*.

## **Analysis of the Time-To-Accuracy Metric and Entries in the DAWNBench Deep Learning Benchmark**

Cody Coleman\*, Daniel Kang\*, Deepak Narayanan\*, Luigi Nardi, Tian Zhao, Jian Zhang, Peter Bailis, Kunle Olukotun, Chris Re, Matei Zaharia. *NeurIPS Systems for ML Workshop 2018*.

## **DAWBench: An End-to-End Deep Learning Benchmark and Competition**

Cody Coleman, Deepak Narayanan, Daniel Kang, Tian Zhao, Jian Zhang, Luigi Nardi, Peter Bailis, Kunle Olukotun, Christopher Re, Matei Zaharia. *NeurIPS Systems for ML Workshop 2017*.

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## Teaching Assistantships

- CS149 **Parallel Computing**, Stanford University, Fall 2019. Instructor: Kayvon Fatahalian, Kunle Olukotun.
- CS245 **Principles of Data-Intensive Systems**, Stanford University, Spring 2019. Instructor: Matei Zaharia.
- CS161 **Design and Analysis of Algorithms**, Stanford University, Fall 2018. Instructor: Aviad Rubinfeld.
- 6.046 **Design and Analysis of Algorithms**, Massachusetts Institute of Technology, Spring 2015, Instructors: Erik Demaine, Srini Devadas, Nancy Lynch.
- 6.006 **Introduction to Algorithms**, Massachusetts Institute of Technology, Spring 2014, Instructors: Srini Devadas, Nancy Lynch, Vinod Vaikuntanathan.

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## Experience

- Fall 2020 **Research Intern**, *NVIDIA*, Santa Clara, CA, Applied Deep Learning.  
Mentor: Patrick LeGresley and Mohammad Shoeybi  
Integrated pipeline parallelism primitives from PipeDream with tensor model parallelism used in Megatron to train large state-of-the-art language models efficiently.
- Summer 2019 **Research Intern**, *Microsoft Research*, Redmond, WA, Systems and Networking.  
Mentor: Amar Phanishayee  
Explored applying pipeline parallelism to large models that do not fit on a single worker. Also worked on heterogeneous cluster scheduling.
- Summer 2018 **Research Intern**, *Microsoft Research*, Redmond, WA, Systems and Networking.  
Mentor: Amar Phanishayee  
Generalized pipeline parallelism to modern model architectures and hardware topologies with heterogeneous communication links. Also helped build a performance debugging tool for deep learning applications.
- Summer 2016 **Research Intern**, *Microsoft Research*, Redmond, WA, Systems and Networking.  
Mentor: Amar Phanishayee  
Explored the implications of combining model and data parallelism with input pipelining for deep learning training (PipeDream).
- Summer 2015 **Research Intern**, *Microsoft Research*, Redmond, WA, Systems and Networking.  
Mentor: Amar Phanishayee  
Explored the effects of different synchronization primitives on deep model training on a multicore server.
- Summer 2014 **Software Engineering Intern**, *Microsoft*, Bellevue, WA, Bing Ads Click Prediction.  
Implemented a Machine Learning experimentation framework that allowed engineers to experiment with different click prediction indicators more efficiently.
- Summer 2013 **Software Engineering Intern**, *Pinterest*, San Francisco, CA, Data Infrastructure.  
Improved the reliability and efficiency of the company's post-hoc data analysis workflows.

Summer 2012 **Undergraduate Research Intern**, *Microsoft Research*, Bangalore, India, Multilingual Systems.  
Mentor: Raghavendra Udupa  
Designed and implemented a type-ahead email search system in C# for Microsoft Outlook that used NLP techniques to return context-sensitive, personalized suggestions to the user.

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## Selected Talks

- Nov. 2020 "PipeDream: Generalized Pipeline Parallelism for DNN Training".  
Data+AI Summit Europe. Online (due to COVID-19).
- Nov. 2020 "Resource-Efficient Execution of Deep Learning Computations".  
Stanford SystemX. Online (due to COVID-19).
- Jun. 2020 "Memory-Efficient Pipeline-Parallel DNN Training using PipeDream-2BW".  
NVIDIA. Online (due to COVID-19).
- Jun. 2020 "Heterogeneity-Aware Cluster Scheduling Policies for Deep Learning Workloads".  
DAWN Retreat. Online (due to COVID-19).
- Mar. 2018 "Accelerating Model Search with Model Batching".  
DAWN Retreat. Santa Cruz, CA.
- Nov. 2017 "Kostos: A Cost-Based Optimizer for Modern Hardware".  
Stanford SystemX. Stanford, CA.
- Mar. 2017 "Weld: A Common Runtime for Data Analytics".  
Strata + Hadoop World. San Jose, CA.

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## Service

- 2019-2020 Member, Stanford CS Faculty Search Committee (academic year 2019-2020).
- 2018-2020 Organizer, Stanford CS TGIF.
- 2018-2020 Organizer, Stanford DAWN Seminar.
- 2014-2015 Member, MIT Undergraduate Student Advisory Group in EECS (USAGE).