

Deepak Narayanan

Curriculum Vitae

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Education

2015-Present **Ph.D., Stanford University**, Computer Science.

2014-2015 **Master 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.

Relevant Coursework Convex Optimization, Operating Systems, Distributed Systems, Performance Engineering of Software Systems, Computer Systems Security, Databases, Design and Analysis of Algorithms, Machine Learning, Natural Language Processing

Research

Overview **Advisor:** Prof. Matei Zaharia

Thesis title: Resource-Efficient Execution of Deep Learning Computations

I broadly work on Systems for Machine Learning. I design and implement software to improve the *runtime performance* and *resource efficiency* of various machine learning applications on modern hardware.

Publications **Heterogeneity-Aware Cluster Scheduling Policies for Deep Learning Workloads**

Deepak Narayanan, Keshav Santhanam, Fiodar Kazhamiaka, Amar Phanishayee, Matei Zaharia. *OSDI 2020 (to appear)*.

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*.

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.

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.

Workshops **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.

Preprints **Heterogeneity-Aware Cluster Scheduling Policies for Deep Learning Workloads**

Deepak Narayanan, Keshav Santhanam, Fiodar Kazhamiaka, Amar Phanishayee, Matei Zaharia. *arXiv:2008.09213*.

Memory-Efficient Pipeline-Parallel DNN Training

Deepak Narayanan, Amar Phanishayee, Kaiyu Shi, Xie Chen, Matei Zaharia. *arXiv:2006.09503*.

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. *arXiv:1910.01500*.

Willump: A Statistically-Aware End-to-end Optimizer for Machine Learning Inference
Peter Kraft, Daniel Kang, **Deepak Narayanan**, Shoumik Palkar, Peter Bailis, Matei Zaharia. *arXiv:1906.01974*.

PipeDream: Fast and Efficient Pipeline Parallel DNN Training
Aaron Harlap, **Deepak Narayanan**, Amar Phanishayee, Vivek Seshadri, Nikhil Devanur, Greg Ganger, Phil Gibbons. *arXiv:1806.03377*.

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. *arXiv:1806.01427*.

Weld: Rethinking the Interface Between Data-Intensive Libraries

Shoumik Palkar, James Thomas, **Deepak Narayanan**, Anil Shanbhag, Holger Pirk, Malte Schwarzkopf, Saman Amarasinghe, Samuel Madden, Matei Zaharia. *arXiv:1709.06416*.

Teaching

- 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, Srinivas Devadas, Nancy Lynch
- 6.006 **Introduction to Algorithms**, Massachusetts Institute of Technology, Spring 2014, Instructors: Srinivas Devadas, Nancy Lynch, Vinod Vaikuntanathan

Experience

- Summer-Fall 2020 **Research Intern**, *NVIDIA*, Stanford, CA, Applied Deep Learning.
Mentor: Patrick LeGresley and Mohammad Shoeybi
Integrated pipeline parallelism primitives from PipeDream with intra-stage model parallelism used in Megatron.
- 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 **Master's 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.

Selected Honors

- 2016-2019 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)
- 2010 Kishore Vaigyanik Protsahan Yojana (KVPY) Fellowship, Government of India
(~ 250/100,000 candidates)
- 2007 Study of Exceptional Talent (SET) Membership, Center for Talented Youth (CTY), Johns Hopkins University

Talks

- Jun. 2020 "Memory-Efficient Pipeline-Parallel DNN Training using PipeDream-2BW".
NVIDIA. Online (due to COVID-19).
- Jun. 2020 "Memory-Efficient Pipeline-Parallel DNN Training using PipeDream-2BW".
Facebook. Online (due to COVID-19).
- Jun. 2020 "Heterogeneity-Aware Cluster Scheduling Policies for Deep Learning Workloads".
DAWN Retreat. Online (due to COVID-19).
- Nov. 2019 "PipeDream: Generalized Pipeline Parallelism for DNN Training".
Facebook. Menlo Park, CA.
- Sep. 2019 "PipeDream: Generalized Pipeline Parallelism for DNN Training".
DAWN Retreat. Menlo Park, CA.
- Mar. 2019 "A Scheduler for Efficiently Sharing GPU Clusters".
DAWN Retreat. Chaminade, CA
- Mar. 2018 "Accelerating Model Search with Model Batching".
DAWN Retreat. Santa Cruz, CA.
- Nov. 2017 "Kostos: A Cost-Based Optimizer for Modern Hardware".
SystemX Alliance Conference. Stanford, CA.
- Sep. 2017 "Kostos: Cost-Based Optimization of Data Science Workloads".
DAWN Retreat. Santa Cruz, CA.
- Mar. 2017 "Weld: A Common Runtime for Data Analytics".
Strata + Hadoop World. San Jose, CA.