Minhak Song

Undergraduate Student, **KAIST**

Personal Website | Google Scholar | Email: minhaksong@kaist.ac.kr

Research Interests

I am interested in the **foundations of modern machine learning**, including the theory of deep learning, generative models, language models, and interactive decision making, with the goal of bridging theory and practice.

My recent research focuses on understanding the **optimization dynamics in deep learning**, particularly in the pre-training and post-training of language models, leveraging the insights to design principled and efficient optimization algorithms.

Education

Korea Advanced Institute of Science and Technology (KAIST), *Daejeon, South Korea* 03/2020 – Present
B.S. in Mathematical Sciences (Minor in Industrial and Systems Engineering) (Graduation: 08/2026)
› Tuition and stipend fully covered by National Presidential Science Scholarship.
› Military leave of absence for 2 academic years (02/2023 – 11/2024).

University of Washington, *Seattle, WA* 01/2025 – 06/2025
Exchange Student
› Tuition and stipend fully covered by Korea-U.S. Student Exchange Program Scholarship.

University of California, Berkeley, *Berkeley, CA* 06/2022 – 08/2022
Summer Session
› Tuition and stipend fully covered by KAIST Presidential Fellowship.

Korea Science Academy of KAIST, *Busan, South Korea* 03/2017 – 02/2020
Science High School for Gifted Students

Research Experience

Paul G. Allen School of Computer Science & Engineering, University of Washington, *Seattle, WA* 06/2025 – Present
Visiting Student Researcher advised by **Prof. Sewoong Oh** (with Dr. Michael Muehlebach, Prof. Niao He)
› Focus: Zeroth-Order Optimization in Deep Learning

Optimization & Machine Learning Laboratory, KAIST AI, *Seoul, South Korea* 03/2022 – Present
Undergrad Research Assistant advised by **Prof. Chulhee Yun** (with Dr. Kwangjun Ahn, Prof. Suvrit Sra, Prof. Ali Jadbabaie)
› Focus: Training Dynamics of Optimization Algorithms in Deep Learning [1, 2, 3, 4, 5, 7]

Paul G. Allen School of Computer Science & Engineering, University of Washington, *Seattle, WA* 01/2025 – 06/2025
Visiting Student Researcher advised by **Prof. Simon Shaolei Du** (with Prof. Maryam Fazel)
› Focus: Theoretical Analysis of Preference Learning Algorithms (RLHF, DPO) under Model Misspecification [8]

Publications

(* denotes equal contribution)

[8] **Understanding the Performance Gap in Preference Learning: A Dichotomy of RLHF and DPO**
Ruizhe Shi*, Minhak Song*, Runlong Zhou, Zihan Zhang, Maryam Fazel, Simon S. Du [arXiv:2505.19770]
arXiv preprint **[Preprint]**

[7] **Implicit Bias of Per-Sample Adam on Separable Data: Departure from the Full-Batch Regime**
Beomhan Baek*, Minhak Song*, Chulhee Yun [arXiv:2510.26303]
International Conference on Learning Representations **[ICLR 2026]**
NeurIPS 2025 Workshop on Optimization for Machine Learning **[NeurIPSW 2025]**

[6] **Suspicious Alignment of SGD: A Fine-Grained Step Size Condition Analysis**
Shenyang Deng, Boyao Liao, Zhuoli Ouyang, Tianyu Pang, Minhak Song, Yaoqing Yang [arXiv:2601.11789]
International Conference on Algorithmic Learning Theory **[ALT 2026]**

[5] **Through the River: Understanding the Benefit of Schedule-Free Methods for Language Model Training**
Minhak Song*, Beomhan Baek*, Kwangjun Ahn, Chulhee Yun [Paper] [arXiv:2507.09846]
Conference on Neural Information Processing Systems **[NeurIPS 2025]**
ICML 2025 Workshop on High-dimensional Learning Dynamics **[ICMLW 2025]**

[4] **Understanding Sharpness Dynamics in NN Training with a Minimalist Example: The Effects of Dataset Difficulty, Depth, Stochasticity, and More**
Geonhui Yoo, Minhak Song, Chulhee Yun [Paper] [arXiv:2506.06940]
International Conference on Machine Learning **[ICML 2025]**

[3] **Does SGD really happen in tiny subspaces?**
Minhak Song, Kwangjun Ahn, Chulhee Yun [Paper] [arXiv:2405.16002]
International Conference on Learning Representations **[ICLR 2025]**
ICML 2024 Workshop on High-dimensional Learning Dynamics **[ICMLW 2024]**

[2] **Linear attention is (maybe) all you need (to understand Transformer optimization)**
Kwangjun Ahn*, Xiang Cheng*, Minhak Song*, Chulhee Yun, Ali Jadbabaie, Suvrit Sra [Paper] [arXiv:2310.01082]
International Conference on Learning Representations **[ICLR 2024]**
NeurIPS 2023 Workshop on Mathematics of Modern Machine Learning, Oral Presentation **[NeurIPSW 2023 Oral]**

[1] **Trajectory Alignment: Understanding the Edge of Stability Phenomenon via Bifurcation Theory**
Minhak Song, Chulhee Yun [Paper] [arXiv:2307.04204]
Conference on Neural Information Processing Systems **[NeurIPS 2023]**

Talks

''Through the River: Understanding the Dynamics of SGD and Schedule-Free Methods in Neural Network Training''

- Prof. Niao He's Group, ETH Zürich CS. Invited Talk (60min). *Remote*, 11/2025
- Prof. Donghwan Kim's Group, KAIST Math. Invited Talk (60min). *Daejeon, South Korea*, 11/2025

''Does SGD really happen in tiny subspaces?''

- Prof. Yaoqing Yang's Group, Dartmouth CS. Invited Talk (60min). *Remote*, 05/2025
- Prof. Sewoong Oh's Group, University of Washington CSE. Invited Talk (60min). *Seattle, WA*, 04/2025

Industry Experience

Upstage, *Seoul, South Korea* 09/2022 – 12/2022
AI Research Engineer Intern
- Designed personalized recommendation models using contextual bandit algorithms for e-commerce service.

Selected Honors and Awards

National Presidential Science Scholarship, Korea Student Aid Foundation. 2020 – 2026
KAIST Presidential Fellowship, KAIST. 2020 – 2026
KAIST Alumni Academic Scholarship, KAIST Alumni Scholarship Foundation. 2021 – 2026
Korea-U.S. Student Exchange Program Scholarship, Minister of Trade, Industry and Energy. 2025
Top Reviewer Award, NeurIPS 2025. *San Diego, CA* 2025
Travel Award, ICLR 2024. *Vienna, Austria* 2024
Travel Award, NeurIPS 2023. *New Orleans, LA* 2023
Top Student Award (Ranked #1 in the department), KAIST ISE. Spring 2021, Fall 2021, Spring 2022
Dean's List (Top 2% of the school), KAIST College of Engineering. Spring 2021, Fall 2021, Spring 2022
7th Place Prize & Merit Prize, Simon Marais Mathematics Competition. 2021
Talent Award of Korea (50 high school students in Korea), Deputy Prime Minister and Minister of Education. 2019
Hanseong Scholarship for Gifted Students, Hanseong Sonjaehan Scholarship Foundation. 2018 – 2019
Grand Prize, Korean Young Physicists' Tournament. 2018

Teaching and Academic Activities

Conference Reviewer: NeurIPS 2024–2025 (**Top Reviewer**, NeurIPS 2025), ICLR 2025–2026, ICML 2025, AISTATS 2025

Workshop Reviewer: ICML 2025 Workshop on High-dimensional Learning Dynamics

Participant, Deep Learning Theory Workshop and Summer School, Simons Institute. *Berkeley, CA* Summer 2022
- Part of ''Summer Cluster: Deep Learning Theory'' program at Simons Institute for the Theory of Computing.

Academic Tutor, KAIST. *Daejeon, South Korea* 2021
- Courses: Calculus I (Spring 2021), Calculus II (Fall 2021).