Minhak Song

Undergraduate Student, **KAIST**

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Research Interests

I am interested in the theoretical foundations of modern machine learning, with the goal of **bridging theory and practice**. My current research focuses on the **training dynamics of optimization algorithms**, particularly in the pretraining and fine-tuning of language models, leveraging these insights to design principled and efficient methods.

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) GPA: 4.19/4.3 (Graduation: 08/2026)
› Tuition and stipend fully covered by National Presidential Science Scholarship.
› Leave of absence for 2 years of mandatory alternative military service (02/2023 – 11/2024).

University of Washington (UW), *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 @ UW, *Seattle, WA* 06/2025 – Present
Undergraduate Researcher with Prof. Sewoong Oh
› Focus: Zeroth-Order Optimization for Language Model Training

Optimization & Machine Learning Laboratory @ KAIST, *Seoul, South Korea* 03/2022 – Present
Undergraduate Researcher with Prof. Chulhee Yun
› Focus: Training Dynamics of Optimization Algorithms in Deep Learning [1, 2, 3, 4, 6]

Paul G. Allen School of Computer Science & Engineering @ UW, *Seattle, WA* 01/2025 – 06/2025
Undergraduate Researcher with Prof. Simon Du
› Focus: Reinforcement Learning for Human Feedback (RLHF) from an Optimization Perspective [5]

Publications

(* denotes equal contribution)

[6] **Through the River: Understanding the Benefit of Schedule-Free Methods for Language Model Training**
Minhak Song*, Beomhan Baek*, Kwangjun Ahn, Chulhee Yun [arXiv:2507.09846]
Under Review at NeurIPS 2025 **[Preprint]**
ICML 2025 Workshop on High-dimensional Learning Dynamics **[ICMLW 2025]**

[5] **Understanding the Performance Gap in Preference Learning: A Dichotomy of RLHF and DPO**
Ruizhe Shi*, Minhak Song*, Runlong Zhou, Zihan Zhang, Maryam Fazel, Simon Du [arXiv:2505.19770]
Under Review at NeurIPS 2025 **[Preprint]**

[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

"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 @ UW CSE. Invited Talk (60min). *Seattle, WA*, 04/2025

"Trajectory Alignment: Understanding the Edge of Stability Phenomenon via Bifurcation Theory"

- Prof. Chulhee Yun's Group @ KAIST AI. Invited Talk (60min). *Seoul, South Korea*, 07/2023

Industry Experience

Upstage, *Seoul, South Korea* 09/2022 – 12/2022
AI Research Engineer Intern
- AI startup led by Prof. Sung Kim @ HKUST.
- Designed personalized recommendation models using contextual bandit algorithms for e-commerce service.

Selected Honors and Awards

National Presidential Science Scholarship (45,000 USD), Korea Student Aid Foundation. 2020 – 2026
KAIST Presidential Fellowship (30,000 USD), KAIST. 2020 – 2026
KAIST Alumni Academic Scholarship (15,000 USD), KAIST Alumni Scholarship Foundation. 2021 – 2026
Korea-U.S. Student Exchange Program Scholarship (9,000 USD), Minister of Trade, Industry and Energy. 2025
Travel Award, ICLR 2024. *Vienna, Austria* 2024
Travel Award, NeurIPS 2023. *New Orleans, LA* 2023
Top Student Award (rank #1 at department), KAIST ISE. Spring 2021, Fall 2021, Spring 2022
Dean's List (top 2% at university), KAIST. 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 (10,000 USD), Hanseong Sonjaehan Scholarship Foundation. 2018 – 2019
Grand Prize, Korean Young Physicists' Tournament. 2018

Teaching and Academic Activities

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).

Conference Reviewer: NeurIPS 2024–2025, ICML 2025, ICLR 2025, AISTATS 2025

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

Skills

Languages: Korean (native), English (fluent) — TOEFL iBT: 108 (R29/L25/S28/W26)

Computer Languages & Software: Python, LaTeX, MATLAB