

MINHAK SONG

Undergraduate Student, KAIST

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Research Interests

I am interested in the foundations of modern machine learning, spanning the theory of deep learning, language models, generative 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)	GPA: 4.19/4.3 (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: Reinforcement Learning for Human Feedback (RLHF) from an Optimization Perspective [6]	

Publications

(* denotes equal contribution)

- [7] **Implicit Bias of Per-sample Adam on Separable Data: Departure from the Full-batch Regime**
Beomhan Baek*, Minhak Song*, Chulhee Yun [\[arXiv:2510.26303\]](#)
Under Review at ICLR 2026 [Preprint]
NeurIPS 2025 Workshop on Optimization for Machine Learning [NeurIPSW 2025]
- [6] **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 [\[arXiv:2505.19770\]](#)
Under Review at ICLR 2026 [Preprint]
- [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
- › AI startup led by Prof. Sung Kim at 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
- 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 (10,000 USD)**, 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).
- Volunteering Club Member, SEED (Social Education Embracing Diversity)**, KAIST. *Daejeon, South Korea* 2021 – 2022
- › Volunteering activity focusing on educational services for multicultural families and underprivileged students.