

# 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

<b>Korea Advanced Institute of Science and Technology (KAIST), Daejeon, South Korea</b>	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).	
<b>University of Washington, Seattle, WA</b>	01/2025 – 06/2025
Exchange Student	
› Tuition and stipend fully covered by Korea-U.S. Student Exchange Program Scholarship.	
<b>University of California, Berkeley, Berkeley, CA</b>	06/2022 – 08/2022
Summer Session	
› Tuition and stipend fully covered by KAIST Presidential Fellowship.	
<b>Korea Science Academy of KAIST, Busan, South Korea</b>	03/2017 – 02/2020
Science High School for Gifted Students	

## Research Experience

<b>Paul G. Allen School of Computer Science &amp; Engineering, University of Washington, Seattle, WA</b>	06/2025 – Present
Visiting Student Researcher advised by <a href="#">Prof. Sewoong Oh</a> (with Dr. Michael Muehlebach, Prof. Niao He)	
› Focus: Zeroth-Order Optimization in Deep Learning	
<b>Optimization &amp; Machine Learning Laboratory, KAIST AI, Seoul, South Korea</b>	03/2022 – Present
Undergrad Research Assistant advised by <a href="#">Prof. Chulhee Yun</a> (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]	
<b>Paul G. Allen School of Computer Science &amp; Engineering, University of Washington, Seattle, WA</b>	01/2025 – 06/2025
Visiting Student Researcher advised by <a href="#">Prof. Simon Shaolei Du</a> (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 [\[arXiv:2510.26303\]](#) [\[Preprint\]](#) [\[NeurIPS 2025\]](#)  
*Under Review at ICLR 2026*  
*NeurIPS 2025 Workshop on Optimization for Machine Learning*
- [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 [\[arXiv:2505.19770\]](#) [\[Preprint\]](#)  
*Under Review at ICLR 2026*
- [5] **Through the River: Understanding the Benefit of Schedule-Free Methods for Language Model Training** Minhak Song\*, Beomhan Baek\*, Kwangjun Ahn, Chulhee Yun [\[Paper\]](#) [\[arXiv:2507.09846\]](#) [\[NeurIPS 2025\]](#) [\[ICMLW 2025\]](#)  
*Conference on Neural Information Processing Systems*  
*ICML 2025 Workshop on High-dimensional Learning Dynamics*
- [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 [\[Paper\]](#) [\[arXiv:2506.06940\]](#) [\[ICML 2025\]](#)  
*International Conference on Machine Learning*

- [3] **Does SGD really happen in tiny subspaces?**  
 Minhak Song, Kwangjun Ahn, Chulhee Yun  
*International Conference on Learning Representations*  
*ICML 2024 Workshop on High-dimensional Learning Dynamics* [Paper] [arXiv:2405.16002] [ICLR 2025] [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  
*International Conference on Learning Representations*  
*NeurIPS 2023 Workshop on Mathematics of Modern Machine Learning, Oral Presentation* [Paper] [arXiv:2310.01082] [ICLR 2024] [NeurIPS 2023 Oral]
- [1] **Trajectory Alignment: Understanding the Edge of Stability Phenomenon via Bifurcation Theory**  
 Minhak Song, Chulhee Yun  
*Conference on Neural Information Processing Systems* [Paper] [arXiv:2307.04204] [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

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|--|-------------------------------------|
| <b>National Presidential Science Scholarship (45,000 USD)</b> , Korea Student Aid Foundation.                      | 2020 – 2026                         |
| <b>KAIST Presidential Fellowship (30,000 USD)</b> , KAIST.   | 2020 – 2026                         |
| <b>KAIST Alumni Academic Scholarship (15,000 USD)</b> , KAIST Alumni Scholarship Foundation.                       | 2021 – 2026                         |
| <b>Korea-U.S. Student Exchange Program Scholarship (9,000 USD)</b> , Minister of Trade, Industry and Energy.       | 2025                                |
| <b>Top Reviewer Award</b> , NeurIPS 2025. <i>San Diego, CA</i>   | 2025                                |
| <b>Travel Award</b> , ICLR 2024. <i>Vienna, Austria</i>  | 2024                                |
| <b>Travel Award</b> , NeurIPS 2023. <i>New Orleans, LA</i>   | 2023                                |
| <b>Top Student Award (Ranked #1 in the department)</b> , KAIST ISE.  | Spring 2021, Fall 2021, Spring 2022 |
| <b>Dean’s List (Top 2% of the school)</b> , KAIST College of Engineering.  | Spring 2021, Fall 2021, Spring 2022 |
| <b>7th Place Prize &amp; Merit Prize</b> , Simon Marais Mathematics Competition.                                   | 2021                                |
| <b>Talent Award of Korea (50 high school students in Korea)</b> , Deputy Prime Minister and Minister of Education. | 2019                                |
| <b>Hanseong Scholarship for Gifted Students (10,000 USD)</b> , Hanseong Sonjaehan Scholarship Foundation.          | 2018 – 2019                         |
| <b>Grand Prize</b> , 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.