

# Minhak Song

Undergraduate Student, KAIST

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## Research Interests

Theoretical Foundations of Modern Machine Learning, Optimization, Statistics

## Education

- Korea Advanced Institute of Science and Technology (KAIST)**, Daejeon, South Korea 03/2020 – Present  
B.S. in Industrial and Systems Engineering & Mathematical Sciences (double major) GPA: 4.19/4.3  
> Tuition and stipend fully covered by National Presidential Science Scholarship.  
> Completed 2 years of mandatory alternative military service (02/2023 – 11/2024).
- University of Washington (UW)**, Seattle, WA (Expected) 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  
Exchange Student  
> 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 (Expected) 01/2025 – 06/2025  
Undergraduate Researcher with [Prof. Simon Du](#)  
> Focus: Reinforcement Learning Theory.
- Optimization & Machine Learning Laboratory @ KAIST**, Seoul, South Korea 03/2022 – 12/2024  
Undergraduate Researcher with [Prof. Chulhee Yun](#)  
> Focus: Deep Learning Theory and Optimization.

## Publications

(\* denotes equal contribution)

- [3] **Does SGD really happen in tiny subspaces?**  
[Minhak Song](#), Kwangjun Ahn, Chulhee Yun [\[arXiv:2405.16002\]](#)  
*ICML 2024 Workshop on High-dimensional Learning Dynamics: The Emergence of Structure and Reasoning* [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]
- [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]

## Research Projects

- Effectiveness of Schedule-Free AdamW in LLM pre-training** [Ongoing] 09/2024 – Present  
with [Dr. Kwangjun Ahn](#), Beomhan Baek, [Prof. Chulhee Yun](#) Microsoft Research, KAIST  
> Co-leading research on the advantages of Schedule-Free AdamW for language model pre-training.  
> Theoretically analyzing performance compared to modern learning rate schedulers (e.g., Warmup-Stable-Decay) based on loss landscape properties.
- Implicit bias of stochastic Adam on separable data** [Ongoing] 09/2024 – Present  
with Beomhan Baek, [Prof. Chulhee Yun](#) KAIST  
> Co-leading project to study the implicit bias of stochastic Adam in linear logistic regression.  
> Discovered that the implicit bias of Adam heavily depends on the choice of batch size and training data.

SGD dynamics along Hessian eigenspaces in deep learning [3]  
with Dr. Kwangjun Ahn, Prof. Chulhee Yun  
10/2023 – 05/2024  
Microsoft Research, KAIST

> Led research investigating whether SGD can be trained in the tiny subspace spanned by top eigenvectors of the Hessian.  
> Proved that SGD fails to decrease training loss when constrained to this tiny subspace.  
> Extended our findings to the Edge of Stability regime, Sharpness-Aware Minimization (SAM), and Adam.  
> Proposed the hypothesis of ill-conditioned valley loss landscapes to explain this phenomenon.

Optimization characteristics of linear Transformers [2]  
with Dr. Kwangjun Ahn, Prof. Xiang Cheng, Prof. Ali Jadbabaie, Prof. Suvrit Sra, Prof. Chulhee Yun  
08/2023 – 03/2024  
MIT, KAIST

> Co-led a project to develop a simplified abstraction of the Transformer from an optimization perspective.  
> Demonstrated that a simplified shallow linear Transformer replicates key aspects of training dynamics of Transformer, including Adam’s superior performance over SGD.

Understanding progressive sharpening and Edge of Stability phenomena [1]  
with Prof. Chulhee Yun  
01/2023 – 10/2023  
KAIST

> Led a project to analyze progressive sharpening and Edge of Stability phenomena in deep learning optimization.  
> Discovered and rigorously proved the novel phenomenon of trajectory alignment, which enables precise characterization of gradient descent trajectories in the Edge of Stability regime.

Industry Experience

Upstage, Seoul, South Korea  
AI Research Engineer Intern  
09/2022 – 12/2022

> 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, Austria2024  
Travel Award, NeurIPS 2023. New Orleans, LA2023  
Top Student Award (rank #1 at department), KAIST ISE.Spring 2021, Fall 2021, Spring 2022  
Dean’s List (top 2%), KAIST.Spring 2021, Fall 2021, Spring 2022  
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, CASummer 2022  
> Part of “Summer Cluster: Deep Learning Theory” program at Simons Institute for the Theory of Computing.

Academic Tutor, KAIST. Daejeon, South Korea2021  
> Courses: Calculus I (Spring 2021), Calculus II (Fall 2021).

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

Skills

Languages: Korean (native), English (fluent) — TOEFL iBT: 108/120

Computer Languages & Software: Python,  $\LaTeX$ , MATLAB