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 Mathematical Sciences (Minor in Industrial and Systems Engineering) 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* 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* 01/2025 – 06/2025
Undergraduate Researcher with Prof. Simon Du
› Focus: Reinforcement Learning Theory and Language Model Alignment.

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 [Paper] [arXiv:2405.16002]
International Conference on Learning Representations **[ICLR 2025]**

[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

Theory of online Direct Policy Optimization from optimization perspective [Ongoing] 01/2025 – Present
with Prof. Simon Du, Ruizhe Shi, Dr. Zihan Zhang, Runlong Zhou University of Washington
› Co-leading research on analyzing/improving convergence of online DPO under function approximation setting.

Understanding Schedule-Free learning 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] 10/2023 – 05/2024
with Dr. Kwangjun Ahn, Prof. Chulhee Yun 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 (EoS) regime, Sharpness-Aware Minimization (SAM), and Adam.

Optimization characteristics of linear Transformers [2] 08/2023 – 03/2024
with Dr. Kwangjun Ahn, Prof. Xiang Cheng, Prof. Ali Jadbabaie, Prof. Suvrit Sra, Prof. Chulhee Yun 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] 01/2023 – 10/2023
with Prof. Chulhee Yun 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* 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%), 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, 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

Skills

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

Computer Languages & Software: Python, LaTeX, MATLAB