# Kaiwen Hu

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## EDUCATION

**School of EECS, Peking University** Beijing, China

*Bachelor of Science in Computer Science* *Sep. 2021 - July 2025 (Expected)*

- GPA: **3.73/4.00**

- TOEFL: Reading 30 Listening 28 Speaking 27 Writing 29 Total 114

- Highlighted Courses: Mathematical Analysis I, II (94, 87), Advanced Algebra I, II (87, 91.5), Practice of Programming in C&C++ (91), Introduction to Artificial Intelligence (91), Probability Theory and Statistics(A) (88), Set Theory and Graph Theory (89), Algebraic Structure and Combinatorial Mathematics (96), Mathematical Logic (96), Quantum Computing (86), Operating System (89), Computer Architectures (88)

## RESEARCH INTERESTS

- Representation Learning: Revisiting the existing deep learning (e.g., self-supervised learning) paradigms and uncovering their underlying mechanisms theoretically.

- Reinforcement Learning: Improving the sample efficiency of multiple settings with guarantees of robustness.

## PUBLICATIONS AND PREPRINTS

* indicates equal contributions

- **Understanding the Role of Equivariance in Self-supervised Learning**
  Yifei Wang*, **Kaiwen Hu\***, Sharut Gupta, Ziyu Ye, Yisen Wang, Stefanie Jegelka
  The 38th Annual Conference on Neural Information Processing Systems (**NeurIPS**), 2024, Acceptance Rate 25.8%.

- **Projection Head is Secretly an Information Bottleneck**
  Zhuo Ouyang*, **Kaiwen Hu\***, Qi Zhang, Yifei Wang, Yisen Wang
  Under review.

## RESEARCH EXPERIENCES

**Equivariant Self-supervised Learning Theory (Accepted at NeurIPS 2024)** Oct. 2023-May 2024

*Supervised by* **Prof. Yisen Wang (School of Artificial Intelligence, Peking University)**

- **Summary:** In this work, we seek to establish a theoretical explanation for the principle of equivariant self-supervised learning (E-SSL) using the information theory. We utilize the explaining-away effect to analyze the mutual information between augmentation and class information, which indicates that E-SSL can indeed encourage the model to extract class-relevant features from data and benefit downstream tasks. We also propose three principles for the design of E-SSL and explain how advanced E-SSL designs echo with our theory.

  **Contributions:**

- Use a toy model to investigate how to maximize the mutual information between the augmentation information and the class information when given the encoder feature.

- Discover that a balanced mixture of augmentation information and class information makes a good feature and that a larger action space is preferable for learning a better feature.

- Verify that acquiring class information can help E-SSL by explicitly injecting and eliminating class information during pretraining.

- Verify that aggressive base transformations can effectively prune shortcuts like learning from colors in E-SSL, encouraging the model to rely more on extracting class information during pretraining.

- Compare the performance of a regular network and an equivariant one and discover that the latter improves feature equivariance and achieves much higher downstream accuracy across different datasets and base transformations.

**Contrastive Learning Theory (Under review at ICLR 2025 with positive scores)** June 2024-Oct. 2024

*Supervised by* **Prof. Yisen Wang (School of Artificial Intelligence, Peking University)**

- **Summary:** In this work, we aim to investigate the role of the projection head in contrastive learning from an information theory perspective. We establish theoretical lower and upper bounds for the downstream performance, suggesting that the projection head should act as an information bottleneck. In addition, we optimize the design of the projection head by means of training and structural regularization, which improves downstream performance.

  **Contributions:**
- Establish the theoretical lower and upper bounds on downstream performance and propose that the key point is to control the mutual information between the encoder and projector features.
- Add the matrix mutual information between the encoder and projector features as a regularization term to the contrastive loss, which increases downstream task accuracy and aligns well with theory.
- Discover that discretizing the projector feature improves downstream performance across different datasets and propose a brief theoretical explanation for this method.
- Finetune the classifier to verify that the bottleneck of downstream performance is not the capability of the classifier but the mutual information between encoder and projector features.

**Low-rank MDPs in the Constrained Setting (Plan to submit to ICML 2025)**      June 2024-Present

*Supervised by* **Prof. Lin Yang (Electrical and Computer Engineering Department, UCLA)**

- **Summary:** In this work, we aim to investigate low-rank MDPs in the constrained setting. Our goal is to figure out the sample complexity in the constrained setting for both relaxed feasibility (i.e., small violation is allowed) and strict feasibility (i.e., the constraint must be strictly satisfied). We leverage the primal-dual approach and a specially designed bonus term to achieve our goal. Our analysis is currently based on the offline setting and we plan to extend to the online setting and improve our current results in the following two months.

  **Contributions:**
- Adopt the MLE guarantee and the specially designed bonus term from previous works to bound the distance between the value functions derived from the ground truth and the estimated transition models.
- Use the primal-dual approach to obtain an approximately optimal reward value while satisfying the constraint.
- Solve the sample complexity of the relaxed feasibility, proving that it is the same with that of the unconstrained setting.
- Solve the sample complexity of the strict feasibility obtained by considering a linear combination of the dual regrets of the ground truth optimal policies for the primal and constraint reward values.

**Multimodal Behavior-regularized Reinforcement Learning**      Nov. 2024-Present

*Supervised by* **Prof. Amy Zhang (Electrical and Computer Engineering Department, UT Austin)**

- **Summary:** While KL divergence is often used as a regularization term in various RL settings, previous works compute it assuming that the policy follows a single-modal Gaussian distribution. In this work, our aim is to propose a method to compute it with the policy under multimodal distributions to allow more complex fitting distributions and enhance performance.

  **Idea:**
- Set the initial distribution of the SVGD sampler to the behavior distribution, and then utilize the SVGD update rule to obtain our policy after sufficient iterations.
- KL divergence is dependent on the initial particles sampled from the behavior policy alone, and thus can be computed without explicit computation of the behavior policy in every iteration.
- Samples of the behavior policy can be collected from a diffusion model in the offline setting.

## SKILLS

- Programming Languages: C, C++, Python (Pytorch).
- Tools: VS code, Visual Studio, Github, Latex, Notions, Markdown.

## HONORS AND AWARDS

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| Third Prize in the Peking University Programming Contest | 2023 |
| Peking University Excellent Study Award | 2022 |
| First Prize in the National High School Mathematics Competition (Shanghai Provincial) | 2019, 2020 |