http://leegilwoo.com

GILWOO LEE

gilwoo301@gmail.com

Robotics / Machine Learning Research Scientist

My primary research interest is to enable robots to acquire a diverse set of skills in autonomous navigation and manipulation. Such skill acquisition requires a large amount of data and entails risks of damaging robots as well as the surrounding environments. I have shown that Bayesian reinforcement learning can expedite the learning process and result in robust and risk-sensitive skill acquisition. In addition, I am interested in human-robot interaction for people with disabilities. I have built an autonomous robot which feeds people with upper-extremity mobility impairments. I believe that robots can be empowering tools for humans when equipped to safely interact with and around humans.

EDUCATION

2017 - 2020 **Ph.D., Computer Science and Engineering, University of Washington, Seattle, WA**

Advisor Siddhartha S. Srinivasa (Boeing Endowed Professor)

Thesis Scalable Bayesian Reinforcement Learning (Tentative)

Committee Siddhartha S. Srinivasa, Byron Boots, Debadeepta Dey, Sam A. Burden

2015-2017 **Master of Science in Robotics Institute, Carnegie Mellon University, Pittsburgh, PA**

Advisors Matthew T. Mason, Siddhartha S. Srinivasa

Thesis GP-ILQG: Data-driven Robust Optimal Control for Uncertain Nonlinear Dynamical Systems

Committee Matthew T. Mason, Siddhartha S. Srinivasa, Geoffrey J. Gordon

2014-2015 **Master of Engineering in Computer Science, Massachusetts Institute of Technology, Cambridge, MA**

Advisors Leslie P. Kaelbling, Tomás Lozano-Peréz

Thesis Hierarchical planning for multi-contact non-prehensile manipulation

2006-2010 **Bachelor of Science in Computer Science and Mathematics, Massachusetts Institute of Technology, Cambridge, MA**

Advisors Leslie P. Kaelbling (Computer Science), Richard P. Stanley (Math)

AWARDS & HONORS

2015-2020 **Kwanjeong Educational Foundation Fellowship**
5-year scholarship for PhD students, 125K USD

2016-2017 **Presidential Fellowship, CMU School of Computer Science**

2015 **Best Conference Paper Finalist**, IEEE/RSJ International Conference on Intelligent Robots and Systems
For the paper titled "Hierarchical planning for multi-contact non-prehensile manipulation"

2006-2010 **Samsung Scholarship**, one of ten undergraduate awardees
4-year scholarship, 200K USD

RESEARCH EXPERIENCES

2018-Present **Research Associate, University of Washington**
The Curious Minded Machine: Developing intelligent robots with a sense of "curiosity" can enable robots to proactively expand their knowledge and capabilities by themselves through information-generation. I have proposed Bayesian reinforcement learning (BRL) framework as a principled method to model and integrate curiosity into unsupervised learning. Further, I have empirically demonstrated that BRL yields naturally curious behaviors that diversify acquired manipulation and navigation skills. This project is an ongoing collaboration among University of Washington, CMU, University of Pennsylvania, MIT, and Honda Research Institute USA.

Publications See [3], [6], [10], [11], [12] in the publications list. Invited talks at RSS'19 and AAAI Fall Symposium'19.

2020 **Scalable, Adaptive, and Resilient Autonomy (SARA)**: SARA is a research collaboration with U.S. Army Research Laboratory's Combat Capabilities Development Command (CCDC). We work on increasing the operational tempo and mobility of autonomous ground systems to traverse complex off-road environments. I coordinate the UW team and work on the development and off-road testing of a new motion planning algorithm and the integration of perception, planning, and control. Our team will participate in a two-week experimentation event in Oct 2020, at Base Camp Lejeune in North Carolina.

Off-Road Autonomous Maneuver of a Combat Vehicle

2017-Present **Food Manipulation for Assistive Feeding**: Eating free-form food is one of the most intricate manipulation tasks we perform everyday, demanding robust non-prehensile manipulation of a deformable hard-to-model target. Through this project, we develop algorithms and technologies towards a robotic system that can autonomously feed people with upper-extremity mobility limitations. I have developed the perception and motion planning components, and have designed manipulation strategies for picking up food from the plate.

The assistive robot, ADA, delivers honeydew to the person sitting on the wheelchair.

Media Appearance "Robots that feed people who can't feed themselves are here," FastCompany, Mar. 13, 2019.
"Assistive robot learns to feed," U.S. National Institutes of Health, April 10, 2019.
(Others: BBC News, BBC World News, Reuters, GeekWire, Futurism, labroots,, New Atlas, Wonderful Engineering, Interesting Engineering, Digital Trends, Science Daily, Futurity, UW News)

Publications See [1], [5], [13], [14], [15], [16] in the publications list.

2018-2020 **Manipulation in Cluttered Spaces**: This project is supported by US Army Research Laboratory (ARL)'s Robotics Collaborative Technology Alliance (RCTA), which aims to "address research and development required to enable the deployment of future military unmanned ground vehicle systems ranging in size from man-portables to ground combat vehicles." Four key technology areas are identified as the key to the development of future autonomous systems: Perception, Intelligence, Human-Robot Interaction, and Dexterous Manipulation and Unique Mobility (DMUM). Our team has been in charge of DMUM and the integration of all four components. The goal for this robot is to clear a pile of heavy debris autonomously. I have developed AIKIDO, the backbone software which integrates perception, planning, and control.

ROMAN picks up a piece of wooden branch from cluttered debris.

This project is a collaboration among ARL, CMU, Florida State University, General Dynamics Land Systems, Jet Propulsion Laboratory, MIT, QinetiQ North America, University of Central Florida, and UPenn.

Media Appearance: My role in the RCTA project was interviewed and the video clip was shown in the RCTA Capstone Meeting held in Pittsburgh, PA in Nov 2019.

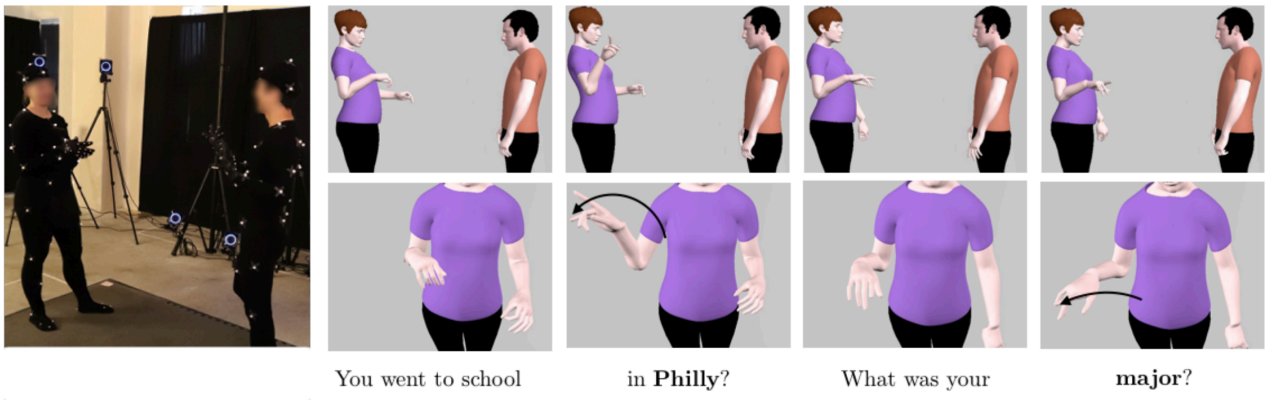
Publications: See [3] in the publications list.

2017-2018 **Human-Robot Handover**: Human-robot collaboration can enable humans to work on safe and less physically demanding tasks while robots take care of risky and heavy-payload tasks. In order for humans and robots to collaborate safely and swiftly, robots need to understand human intentions and act in a way that is predictable and legible from human perspective. We have proposed a unified generative model of human reaching motion that allows the robot to infer human intent and plan legible motions. Our study on human reaching motion reveals that elliptical motion model yields a good fit to empirical data. I have analyzed the collected user study data and implemented legible robot motions.

Human-to-robot handover in a shared-workspace collaboration

Publications: See [6] in the publications list.

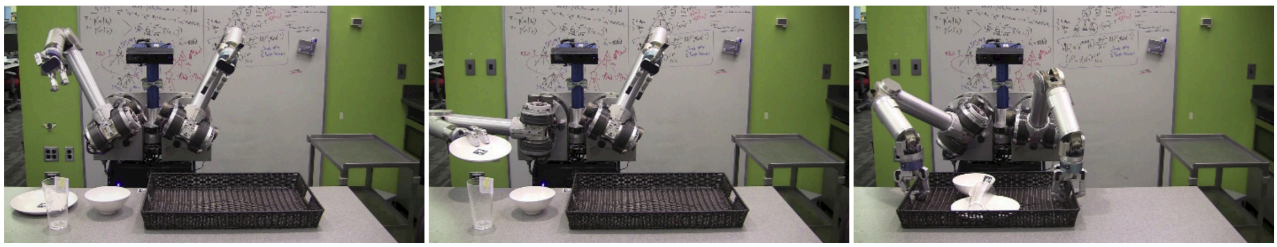
2017-2019 **Ph.D. Research Intern & Part-time Research Consultant, Facebook Reality Lab**
Learning Human Gestures and Synthesizing Real-time Finger Motions: To work with humans, robots must understand how humans behave and communicate. Human behavior involves the highly structured, multi-channel coordination of gaze, gesture, verbal and facial movements. To address the challenge of interpreting human gestures, we have collected a multimodal, wholistic dataset of people having social interaction captured with a motion capture system, which amounts to 16.2M frames. This is the largest dataset available. The statistical analysis verifies strong intraperson and interperson covariance of arm, hand, and speech features, potentially enabling new directions on data-driven social behavior analysis, prediction, and synthesis. We utilize the dataset to train a real-time motion synthesis deep neural network to synthesize finger motions aligned with speech. I have been the lead developer and research scientist on this project.



The dataset collected on social interaction (left) has been used to generate real-time finger motions (right).

Publications See [4] in the publications list.

2015-2017 **Research Associate, Carnegie Mellon University**
Multi-step Mobile Manipulation with Error-recovery: Household manipulation presents a challenge to robots because it requires perceiving a variety of objects, planning multi-step motions, and recovering from failure. In collaboration with Toyota Motor Engineering & Manufacturing North America, we have worked on practical techniques that improve performance in these areas. We validate these techniques on a table-clearing task that involves loading objects into a tray and transporting it. These techniques improve success rate and task completion time by incorporating expected real-world performance into the system design.
I was in charge of error detection and recovery and empirical evaluation of the system.



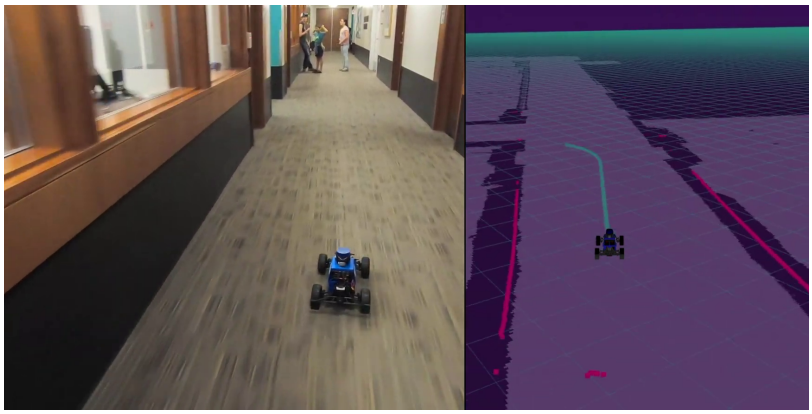
HERB clearing the table via sequential motion planning

Publications See [8] in the publications list. Invited talks in SIMPAR 2016 and RSS 2016.

Robotics Projects

2017-Present **AIKIDO**: AIKIDO is an open-source C++ library, complete with Python bindings, for solving robotic motion planning and decision making problems. This library is tightly integrated with an open-source physics simulator (DART) and an open-source motion planning library (OMPL). AIKIDO optionally integrates with ROS for execution on real robots. AIKIDO is currently being used across multiple labs and projects including University of Washington, Carnegie Mellon University, University of Southern California, and Robotics Collaborative Technology Alliance (RCTA, sponsored by US Army Research Laboratory).
I am one of the lead developer of the library.

2018-Present **MuSHR**: Our goal is to democratize robotics with MuSHR, the Multi-agent System for non-Holonomic Racing. MuSHR is a low-cost racecar platform with open-source software, tutorials, and class assignments. We want anyone from high school students to Ph.D. researchers to be able to learn about and perform research in robotics. Each MuSHR racecar is fitted with a full-suspension base, IMU, NVIDIA Jetson TX2, YDLIDAR laser scanner, and Intel RealSense RGBD camera. We have over 20 racecars in our fleet.
I have developed motion planners to be used in undergraduate coursework, designed and built an optical motion capture system for real-time state estimation, and developed a simulation pipeline for reinforcement learning.

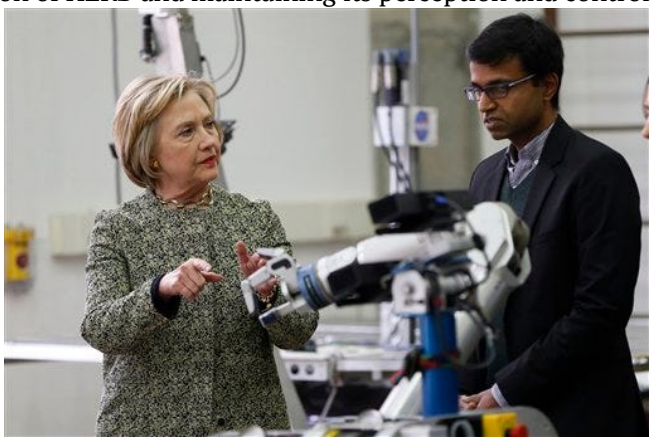


MuSHR navigating through corridors with real-time motion planning and collision detection

2017-Present **ADA**: ADA, the Assistive Dextrous Arm, mimics equipment used in real homes by people with mobility impairments. It consists of a Kinova JACO robotic arm mounted on a powered ROVI Mobility wheelchair. It is the main platform for our research thrust on robot-assisted feeding for people with upper-extremity impairments. The arm has 2 fingers, a custom tactile sensor, and Intel RealSense D415 to wirelessly transmit RGBD video. I have developed the motion planning and perception components and advised undergraduate and master's students on this project.

ADA's feeding system is being tested by users with mobility impairments

2015-Present **HERB**: HERB, the Home Exploring Robot Butler, serves as the realistic testbed for all of our algorithms and as a focal point of our industry and academic collaborations. It is a bimanual mobile manipulator comprised of two Barrett WAM arms on a Neobotix base. It is equipped with a suite of image and range sensors, including the Carnegie Robotics MultiSense SL and Intel RealSense. I have been mainly in charge of designing the 3rd generation of HERB and maintaining its perception and control pipelines.



Hillary Clinton talks with Prof. Srinivasa as he describes HERB during a tour of a Robotics Lab at Carnegie Mellon University on April 6, 2016, in Pittsburgh. (AP Photo/Keith Srakocic)

2015-2017 **PrPy**: PrPy is a Python library developed and maintained by the Personal Robotics Laboratory. This library includes robot-agnostic utilities, including a high-level planning pipeline, helper functions, and visualization tools. This library has been used in multiple labs in various academic institutions. I am one of the main developers.

Teaching

Winter 2020 **Autonomous Robotics, University of Washington, Seattle, WA**
Assisted in designing and instructing an undergraduate course on autonomous robots. Students covered a range of topics in perception, planning and control as well as implemented algorithms on MuSHR, a fleet of 1/10th sized rally cars.

Spring 2019 **Mobile Robots, University of Washington, Seattle, WA**
Assisted in designing and instructing an undergraduate course on mobile robots (MuSHR). Taught recitation classes, mentored group projects, designed and graded assignments.

Spring 2017 **Robot Autonomy, Carnegie Mellon University, Pittsburgh, PA**
Graduate-level course in motion planning and control. Mentored group projects and led recitations.

Spring 2014, Fall 2014, Spring 2015 **Elements of Software Construction, Massachusetts Institute of Technology, Cambridge, MA**
One of the largest undergraduate courses for computer science majors. Led recitations, mentored group projects, and managed assignments for over 200 students each semester.

Advising

2018-Present Nansong Yi (MS, University of Washington), Ryan Feng (PhD, University of Michigan), Kyle Zhang (Undergraduate, University of Washington), Rishabh Madan (Undergraduate, India Institute of Technology)

2014-2015 **Undergraduate Student Advisory Group (USAGE) in MIT EECS**
USAGE provides critical student input to the department leadership group, helping guide curriculum development; develops a role for undergraduate students in faculty search; and shapes IAP activities.

Service

Organizer RSS 2017 Workshop on (Empirically) Data-Driven Manipulation

Reviewer The International Journal of Robotics Research (IJRR)
The IEEE Robotics and Automation Letters (IEEE RA-L)
The IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)
The IEEE International Conference on Robotics and Automation (ICRA)
Robotics: Science and Systems (RSS)
The International Symposium on Experimental Robotics (ISER)
The IEEE International Conference on Simulation, Modeling, and Programming for Autonomous Robots (SIMPAR)

Invited Talks

2019 **Bayesian Reinforcement Learning for Sim2Real**
Robotics: Systems and Science Conference (RSS) 2019
Workshop on Closing the Reality Gap in Sim2real Transfer for Robotic Manipulation

2019 **Bayesian Reinforcement Learning**
Robotics: Systems and Science Conference (RSS) 2019
Workshop on Scalable Learning for Integrated Perception and Planning

2019 **Scalable Bayesian Reinforcement Learning with Experts**
Robotics: Systems and Science Conference (RSS) 2019
Workshop on Combining Learning and Reasoning – Towards Human-Level Robot Intelligence

2018 **Reinforcement Learning under Uncertainty**
Amazon Research Awards Fall Symposium 2018

2017 **Challenges in Non-Prehensile Manipulation**
IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS) 2017
Workshop on Development of Benchmarking Protocols for Robot Manipulation

2016 **GP-ILQG: Data-driven Robust Optimal Control for Sim-to-Real Challenges**
IEEE International Conference on Simulation, Modeling, and Programming for Autonomous Robots (SIMPAR) 2016
Workshop on Sim2Real Challenges

Publications

M.S. Thesis **GP-ILQG: Data-driven Robust Optimal Control for Uncertain Nonlinear Dynamical Systems**
Carnegie Mellon University, 2017.

M.Eng Thesis **Hierarchical planning for multi-contact non-prehensile manipulation**
Massachusetts Institute of Technology, 2019.

Journal Publications [1] **Towards Robotic Feeding: Role of Haptics in Fork-Based Food Manipulation**
Tapomayukh Bhattacharjee, Gilwoo Lee, Hanjun Song and Siddhartha. S. Srinivasa
In IEEE Robotics and Automation Letters, vol. 4, no. 2, pp. 1485-1492, April 2019.
(Citation: 17)

Conference Publications [2] **Imitation Learning as f-Divergence Minimization**
Liyiming Ke, Sanjiban Choudhury, Matt Barnes, Wen Sun, Gilwoo Lee, and Siddhartha S. Srinivasa
To appear in Workshop on the Algorithmic Foundations of Robotics (WAFR). 2020.

[3] **Posterior Sampling for Anytime Motion Planning on Graphs with Expensive-to-Evaluate Edges**
Brian Hou, Sanjiban Choudhury, Gilwoo Lee, Aditya Mandalika, Siddhartha S. Srinivasa
To appear in International Conference on Robotics and Automation (ICRA). 2020.

[4] **Talking With Hands 16.2M: A Large-Scale Dataset of Synchronized Body-Finger Motion and Audio for Conversational Motion Analysis and Synthesis**
Gilwoo Lee, Zhiwei Deng, Shugao Ma, Takaaki Shiratori, Siddhartha S. Srinivasa, Yaser Sheikh
International Conference on Computer Vision (ICCV). 2019.
(25% acceptance rate)

[5] **Robot-Assisted Feeding: Generalizing Skewering Strategies across Food Items on a Plate**
Gilwoo Lee, Ryan Feng, Youngsun Kim, Ethan K. Gordon, Matt Schmittle, Shivaum Kumar, Tapomayukh Bhattacharjee, Siddhartha S. Srinivasa
International Symposium on Robotics Research (ISRR). 2019.
(Citation: 3)

[6] **Bayesian Policy Optimization for Model Uncertainty**
Gilwoo Lee, Brian Hou, Aditya Vamsikrishna, Jeongseok Lee, Sanjiban Choudhury, Siddhartha S. Srinivasa
International Conference on Learning Representations (ICLR). 2019.
(31.4% acceptance Rate, Citation: 10)

[7] **A Study of Reaching Motions for Collaborative Human-Robot Interaction**
Sara Sheikholeslami, Gilwoo Lee, Justin W. Hart, Siddhartha Srinivasa, Elizabeth A. Croft
In International Symposium on Experimental Robotics (ISER). 2018.

[8] **A System for Multi-Step Mobile Manipulation: Architecture, Algorithms, and Experiments**
Siddhartha S. Srinivasa, Aaron M. Johnson, Gilwoo Lee, Michael C. Koval, et. al.
International Symposium on Experimental Robotics (ISER). 2016.
(Citation: 4)

[9] **Hierarchical planning for multi-contact non-prehensile manipulation**
Gilwoo Lee, Tomas Lozano-Pérez and Leslie P. Kaelbling
IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), Hamburg, 2015, pp. 264-271.
(46% acceptance rate, Finalist for Best Conference Paper Award, Citation: 29

Workshop Publications

[10] **Bayesian Residual Policy Optimization: Scalable Bayesian Reinforcement Learning with Clairvoyant Experts**
Gilwoo Lee, Brian Hou, Sanjiban Choudhury, Siddhartha S. Srinivasa
Workshop on Interactive Robot Learning
IEEE International Conference on Robotics and Automation (ICRA) 2020.

[11] **Towards Effective Human-AI Teams: The Case of Collaborative Packing**
Gilwoo Lee, Christoforos Mavrogiannis, Siddhartha S. Srinivasa
Symposium on Artificial Intelligence for Human-Robot Interaction, 2019 AAAI Fall Symposium Series.

[12] **Residual Bayesian Q-Learning for Meta-Reinforcement Learning with Experts**
Gilwoo Lee, Sanjiban Choudhury, Brian Hou, Siddhartha S. Srinivasa
Workshop on Combining Learning and Reasoning – Towards Human-Level Robot Intelligence
Robotics: Systems and Science, 2019.
(Selected for Contributed Talk)

[13] **Bite Acquisition of Soft Food Items via Reconfiguration**
Gilwoo Lee, Tapomayukh Bhattacharjee, Siddhartha S. Srinivasa
Workshop on Task-Informed Grasping (TIG-II): From Perception to Physical Interaction
Robotics: Systems and Science, 2019.

[14] **GP-ILQG: Data-driven Robust Optimal Control for Uncertain Nonlinear Dynamical Systems**
Gilwoo Lee, Siddhartha S. Srinivasa, Matthew T. Mason
Workshop on (Empirically) Data-Driven Manipulation.
Robotics: Systems and Science, 2017.
(Citation: 12)

Dataset

[15] **A Dataset of Bite Acquisition Attempts on Solid Food Using Different Manipulation Strategies**
Ethan K. Gordon, Gilwoo Lee, Ryan Feng, Youngsun Kim, Matt Schmittle, Shivaum Kumar, Tapomayukh Bhattacharjee, Siddhartha S. Srinivasa,
https://doi.org/10.7910/DVN/8A1XO3, Harvard Dataverse, 2019.
(13,628 downloads)

[16] **A Dataset of Food Manipulation Strategies**
Tapomayukh Bhattacharjee, Gilwoo Lee, Hanjun Song, Siddhartha S. Srinivasa,
https://doi.org/10.7910/DVN/8TTXZ7, Harvard Dataverse, 2018.
(36,853 downloads)