COMPUTER ENGINEERING, COMPUTER SCIENCE & APPLIED MATHEMATICS GOLDWATER RECIPIENT:

2022-2023 APPLICATION

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PROFILE INFORMATION

PERSONAL DETAILS

First Name	Mason
Last Name	Blackwell

CAREER/PROFESSIONAL ASPIRATIONS

What is the highest degree you plan to obtain?	Ph.D.
In 1-2 sentences, describe your career goals and professional aspirations. It will be used in publications if you are selected as a scholar	I plan to pursue a Ph.D. in Robotics, and research how robots can plan and operate to perform valuable tasks. I'll enjoy transferring my research to industry, teaching, and presenting my research.

What are your career goals and aspirtations? Indicate which area(s) of mathematics, science, or engineering, you are considering pursuing and specify how your current academic program and your overall educational plans will assist you in achieving your career goals and professional aspirations

I believe intelligent robotics can create a society of abundance, by reducing the cost of meeting and exceeding everyone's needs. I'm happy to be one of many devoting their lives to such a cause. I aspire to lead a research lab focused on applying manipulation to valuable tasks such as construction and food preparation, to help build out big data infrastructure for manipulation, mimicking the readily available datasets in other fields, and continue improving robotics research with novel robotics hardware.

To give myself a wide base, I'm studying for a B.S. with a triple major in computer engineering, applied mathematics, and computer science. Through computer engineering, I've learned a lot about the lower levels of robotics. I'm taught to build embedded systems, and I can create new hardware for manipulation, or novel robotics. In such a physically integrated field, being confined to only the computational elements can limit what ideas you can explore. In addition, having much more knowledge of the underlying systems will help me develop more effective algorithms. Applied math provides me a foundation for formal expression, and experience in much of the math underlying modern learning algorithms. Computer science is where much of the work being done in manipulation is, and I've been able to take graduate courses in the area, covering critical areas such as motion planning, computer vision, foundational robotics, explainable deep learning, and deep learning systems.

I'm a part of two labs on campus, a microrobotics laboratory where I get to work on multi-robot systems and novel robotics, and a robotic manipulation laboratory where I can help advance the state of the art in manipulation, and learn about the field in our weekly reading group, as well as through sharing and reading papers with my peers. I love collaborating on research work with others, learning new fields, techniques, and developing my own scientific thinking.

Once I graduate, I plan to pursue a Ph.D. in Computer Science focusing on robotic manipulation. I want to expand my knowledge of the field, fill in gaps in my knowledge, and be able to skillfully find, articulate and scope research projects. By the time I finish, I hope I'll have made an impact on the field, created readily available algorithms and datasets, and pushed the boundaries of how robots are capable of helping those who need it.

Describe an activity or experience that has been important in helping shape or reinforce your desire to pursue a research career in STEM.

When I worked as a counter in an Amazon warehouse, I had a lot of time to think. Since it was around the height of COVID-19, I had plenty of time to focus on tinkering with electronics. I'd spend all day thinking about how my job, counting objects for ten hours with the hum of machines in the background, could be automated. I'd go home, and I started to try and build that machine I'd imagined. Turns out that's a big project for someone with no experience, and not a lot of money to spend on it.

I found scrap metal, bearings, and got an Arduino CNC kit, started tinkering with computer vision, and had my brother help me weld a frame, and built my own linear rail system. My plan started to break down as I found the motors to be too small, the computer vision too out of my depth, and I moved to college, leaving the frame behind.

I started to better research previous efforts at similar automation, and felt shocked at how much time, effort, and skill had been put in. I found so many inspiring projects, with ambitious goals and so much collaboration. Talking to my professors about it, they could see I wanted to do that kind of research focused work.

While I still love to have my own fun personal robotics projects, (like the 6 degree of freedom robotic arm I built with professional features like force control and ROS integration) I think the robotics that really shapes the world will come from the collective effort, resources, and sharing of ideas that is only found in research.

In what way did COVID-19 or other hardships over the past couple years affect your research career plans and did those events alter your ability to pursue those plans? If you have had to make changes, in what way(s) did you adapt to the situation? If COVID-19 did not influence your plans, simply state there was no impact.

Not significantly impacted

Optional Question: Goldwater Scholars will be representative of the diverse economic, ethnic and occupational backgrounds of families in the United States. Describe any social and/or economic impacts you have encountered that influenced your education - either positively or negatively - and how you have dealt with them.

I'm so grateful for my mom. She went for 11 years without health insurance, living with her parents and working part time as a teacher so she could spend time raising her children. My mom has sacrificed a lot for us, but I knew I'd have to get myself through college. In high school, I worked hard to get perfect grades, and spent months practicing for standardized tests.

I've had to continue working throughout college, and it's made for a very busy life. I've worked part time in one to two jobs each semester, so my time is stretched pretty thin. I've had to learn to efficiently schedule out time, and make sure I'm completing work as fast as I can. Because of this, I'm well aware of the cost of getting an education, and I'm making the most of my classes, and learning as much as I can.

Getting into research was pretty difficult, even though I knew it was what I wanted to do. I was able to get a start doing programming work for a logic optimization lab, but getting to work in robotics took longer. It's tough to balance financing school with learning about the field I'm passionate about. I saved carefully, and worked hard to get scholarships. Once I'd saved enough I was able to start spending my time helping out in a couple robotics labs, and have even been able to get scholarship and REU funding to keep researching!

RESEARCH PROJECTS AND SKILLS

RESEARCH PROJECT #1

Manipulation with Graph Neural Network Relational Classifiers

Dates	12/2021-ongoing
Average Hrs/Wk	10 (academic year); 20 (summer)
Name of Project Mentor	Tucker Hermans
Position and Affliation of Project Mentor	Associate Professor of Computer Science, Senior Research Scientist, University of Utah, NVIDIA
Where the research was performed	University of Utah
Do you have paper/publications/presentations related to this project?	No

Description of research, including your involvement in AND contribution to the project

Research is extending a paper on using graph neural networks to represent scenes, and planning actions by predicting an action's changes to inter-object relationships. I was involved after the initial publication, to help extend the work by encoding the environment into the model, and to help build infrastructure to improve experiments.

Research Skills: Briefly describe any research skill(s) you developed while working on this project that will be important going forward in your research

I gained a lot of knowledge about the field, through regular paper reading, discussion, and constantly asking my mentor questions.

RESEARCH PROJECT #2

Continuum Microrobotics

Dates	08/2022-ongoing
Average Hrs/Wk	10 (academic year)
Name of Project Mentor	Daniel Drew; Alan Kuntz
Position and Affliation of Project Mentor	Assistant Professor of Electrical and Computer Engineering; Assistant Professor of Computer Science; University of Utah
Where the research was performed	University of Utah
Do you have paper/publications/presentations related to this project?	Yes; 1 publication

Description of research, including your involvement in AND contribution to the project

This research is on tendon driven continuum micro-robots. Some eye surgeries have severe constraints on movement, and most current approaches have very little capacity for flexibility. State of the art approaches are limited to small bends in needles.

Our approach uses micro scale flexible robotics driven by tendons to solve this problem. I wrote the code to drive our robot, reliably recording the data we'd need for publication. I helped plan and co-ordinate experiments, as well as helped conduct them.

I've also written code for data analysis, and measured all of the data we'll be using in our publication.

Our publication will be submitted on December 1st.

Research Skills: Briefly describe any research skill(s) you developed while working on this project that will be important going forward in your research

I learned a lot about the practical aspects of research, generating figures, creating reliable programs, and co-ordinating experiments. In my future career, I hope to continue doing collaborative research.

RESEARCH PROJECT #3

Learning to Select and Sequence Skills from Partial View Point Clouds

Dates	10/2022-ongoing
Average Hrs/Wk	15 (academic year)
Name of Project Mentor	Tucker Hermans
Position and Affliation of Project Mentor	Associate Professor of Computer Science, Senior Research Scientist, University of Utah, NVIDIA
Where the research was performed	University of Utah
Do you have paper/publications/presentations related to this project?	No

Description of research, including your involvement in AND contribution to the project

Most robotic planning algorithms plan in the domain of object state. However, planning algorithms that use 3d position and orientation for a known object often struggle in unstructured environments, like a home.

My advisor and I proposed a planning algorithm, using precondition prediction, simple rigid transformations as action effects, and parameterized action primitives. Our skills, all operating on point sets, could then predict when our actions will be successful, what the effects are, and how to complete the action.

I built infrastructure for the project. I implemented scenarios for testing, implemented hand simulation, and created environments.

I programmed the algorithm, and associated components. I designed the precondition predictor, collected data on action success, and trained them, and demonstrated the algorithm creating successful plans.

We're planning to submit this work for publication in February, after completing more experiments, and comparisons.

Research Skills: Briefly describe any research skill(s) you developed while working on this project that will be important going forward in your research

I learned a lot about planning in robotic manipulation, diving deep into many papers. I've learned a lot about making a contribution, and taking an idea from conception to demonstration. I also know much better now how to formulate research questions, and show improvement over past methods.

MENTOR RECOGNITION

LETTER WRITER INFORMATION

OTHER ACTIVITIES/ ACCOMPLISHMENTS

Activity/ Accomplishment	President of the Residence Hall Association
Organization/Scope of Activity	University of Utah/College/University
Role/ Involvement	I've been the president of RHA. I help plan events for students, facilitate student governance, represent students within the administration, and manage a $300k budget. I help to improve life for students by advocating for those who need it most.
Position/Length of Involvement	President/Academic Year

Activity/ Accomplishment	Presidential Intern
Organization/Scope of Activity	University of Utah/Community
Role/ Involvement	I was selected as a presidential intern, to represent students within the administration, and help work on improving our school. I'm passionate about improving teaching methods, and worked on an experiential learning degree requirement.
Position/Length of Involvement	Academic Year

Activity/ Accomplishment	Social Justice Advocate
Organization/Scope of Activity	University of Utah/College/University
Role/ Involvement	I worked as a social justice advocate, helping educate students about important social issues, and providing support for students who needed it.
Position/Length of Involvement	More than 1 academic year

RECOGNITIONS

Recognition/Type	National Merit Scholar/National
Year	2020
Description	I was selected as a National Merit Scholar, among a nationally competitive pool of applicants!

Recognition/Type	Wesley H. Ford & Joseph H. Merrill Engineering Scholarship/College/University
Year	2021
Description	Was selected for scholarship as one of the top students in the department of Engineering.

Recognition/Type	Undergraduate Research Opportunities Program (UROP) Scholar/College/University
Year	2022
Description	Was selected for funding to pursue the research I proposed as one of many competitive applicants within my university.

Recognition/Type	Undergraduate Math Competition 2nd Place/College/University
Year	2021
Description	One second place in the undergraduate math competition, a series of problems posed to prep students for the Putnam. I successfully completed all problems, and was awarded extra points for writing the best answer to one of three.

RESEARCH CAREER INTEREST/DIRECTION

Major Field of Study	Computer and Information Science and Engineering (CISE)
CISE Areas of Sepcialiation	Robotics & Computer Vision
Is the research you intend to do in a multidisciplinary area?	Yes
What disciplinary background would be most appropriate for someone reviewing your application?	Computer Science

CURRENT COLLEGE/UNIVERSITY

GPA	3.96
Graduation Year	Spring 2024

COURSEWORK

RESEARCH ESSAY

Learning to Select and Sequence Skills for Autonomous Manipulation from Partial Views

Introduction and Motivation

An at-home robot tasked with unpacking groceries, or tidying up a living room will have to contend with complex scenes, unknown objects, and imperfect knowledge of object state. Often, robots have access only to one or few color and depth cameras. The scope of what the robot might need to do is huge, and programming skills for each possible goal is not possible.

A traditional approach, Task and Motion Planning (TAMP) algorithms, uses desired changes in object state to compute fully specified motion plans [1]. However these fail in real environments, requiring full state knowledge to function (e.g. where every object is located), and few objects to be computed reasonably fast. Planning using sub-skills, or skill primitives is a common approach to manipulation tasks, promising complex behavior emergent from sequencing simple skills. Many still require full object state knowledge [2][3][4], limiting their real world use.

I advocate for an alternative approach: to use common-sense primitive skills that operate on the point sets the robot perceives. In collaboration with Prof. Hermans, I helped to propose an approach to plan and sequence skill primitives, using affordance prediction, and simple rigid transformation skill effects models all operating on partial view point clouds.

My work consists of designing and implementing an algorithm that creates a plan to get to a desired point cloud by exploring possible skills, and sampling across their parameters to find predicted successful actions. For successful actions, we use their associated common sense point cloud transformation to plan the next step in the sequence, ensuring feasibility. With this new approach, we hope to demonstrate a way to create robots that can solve a broad range of tasks in unstructured environments.

Methodology

To demonstrate this algorithm, I designed a book rearrangement task that requires the robot to sequence skills for a long horizon goal. For this experiment, I wanted to show that this method can accomplish complex goals with inter-task dependencies reliably.

To start, I created the task environment in simulation, as well as the task primitives. This required more from the rigid-fingered analog for our real robot hand, and I implemented state of the art research on hand simulation [5] into our lab's shared infrastructure.

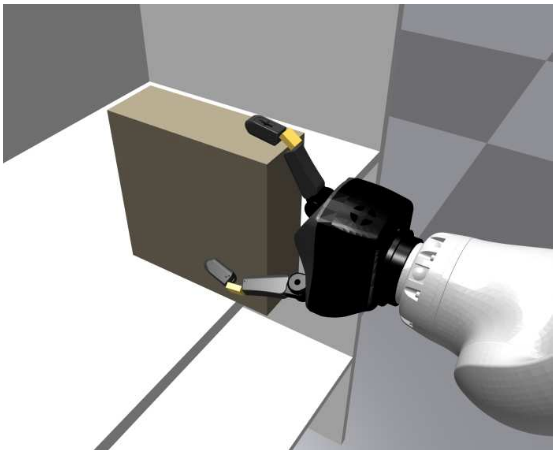

Figure 1: A view of the advanced ReFlex hand simulation, on a simulated KUKA iiwa robot.

I then collected attempts at succeeding at the task primitives, and designed and created the model used to predict action success. The model embeds each object and the environment's point sets into a latent space shared between tasks, and then each task has a model that learns to predict task success using the point cloud embedding, and primitive skill's parameters. We call this our precondition predictor (preconditions are the set of conditions that must be true for an action to succeed).

After, I extended the lab's infrastructure for online planning to enable planning on point clouds, and implemented the planning algorithm.

Results

So far, the method has demonstrated some success. In the bookshelf manipulation environment, the algorithm has been able to plan simple re-arrangements. Though currently limited in success rates, I'll be comparing various model structures, as well as different sets of data to improve the success.

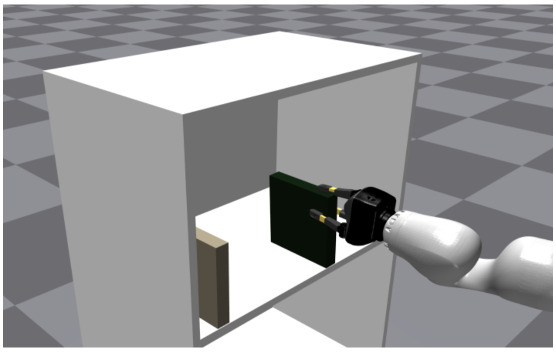

Figure 2: Grasping the object using only point set information.

In the bookshelf manipulation experiment, I demonstrate that precondition prediction functions can be used to create these plans. The algorithm samples from the precondition functions, and explores possible future states to match a given desired point cloud. Using this I've shown successful demonstration of this planning algorithm, showing precondition learning on point sets can transfer knowledge from full state planning, and that primitives trained in isolation can be combined to perform some complex behaviors, and that these simple transforms can be used to create some complex, useful, actions.

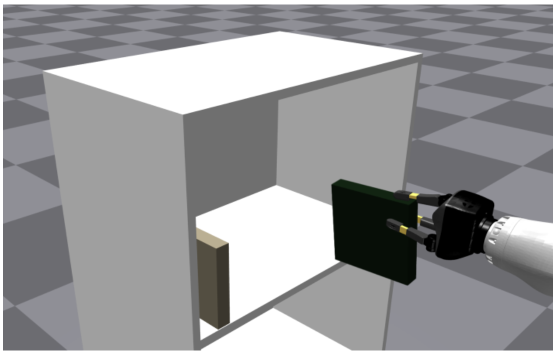

Figure 3: Successfully pulling from the shelf.

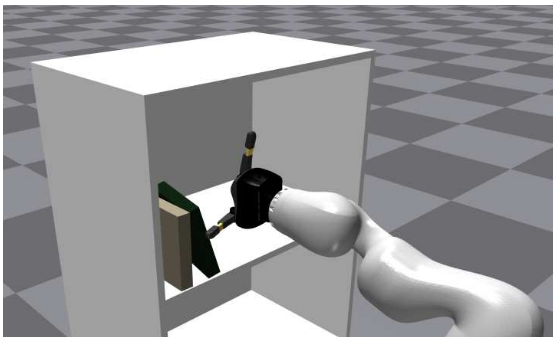

Figure 4: Placing the book in it's new position, closer to the goal point cloud.

Future Work

Before submission in March 2023, I plan to conduct more experiments. I hope to demonstrate more behaviors, exhibiting longer horizons, effective use of a wider base of primitives, and planning across a variety of domains. My current work is expanding this planning framework to demonstrate putting groceries away onto a shelf to accomplish this. In addition, I'll be doing experiments transferring the learning to the real robot in our lab.

In Huang, Conkey, and Hermans [6], a planning approach is proposed based on predicting how relationships change (or relational dynamics) encoded by a graph neural network. In a yet unpublished work, I helped extend this skill effects model by incorporating the environment, and helped build out the ability to generate random numbers of random objects in stable positions on random environments using a CEM sampling approach. One advantage that could be incorporated into this planning algorithm is framing goals in terms of relations between objects. This method could be extended by specifying goals in terms of relations, so that we don't have to simulate a goal state before reaching it.

Another direction I plan to investigate, is to explore context selection. I think using a self-attention mechanism in a precondition predictor for context selection could greatly effectiveness. For example, looking at what objects the network is paying attention to and using that to create a subset of objects to operate on.

I expect to improve the algorithm by implementing a form of constraint relaxation planning. I could create plans while relaxing some constraints on the planning, and then use objects in the environment as tools to make up for the relaxed constraints, as shown in Levihn and Christensen's work [7].

We plan to show that this method will be able to sequence skills to create long-horizon plans and complex behavior in a variety of scenarios, while generalizing to unseen objects. We will recreate, then compare to methods with full state knowledge, and expect to achieve comparable performance.

References

[1] Caelan Reed Garrett et al. "Integrated Task and Motion Planning". In: *Annual Review of Control, Robotics, and Autonomous Systems* 4.1 (2021), pp. 265–293. DOI: 10.1146/annurev-control-091420-084139. eprint: https://doi.org/10.1146/annurev-control-091420-084139. URL: https://doi.org/10.1146/annurev-control-091420-084139.

[2] Jacky Liang et al. "Search-Based Task Planning with Learned Skill Effect Models for Lifelong Robotic Manipulation". In: *Proceedings of (ICRA) International Conference on Robotics and Automation*. May 2022.

[3] Brian Ichter, Pierre Sermanet, and Corey Lynch. *Broadly-Exploring, Local-Policy Trees for Long-Horizon Task Planning*. 2020. DOI: 10.48550/ARXIV.2010.06491. URL: https://arxiv.org/abs/2010.06491.

[4] Christopher Agia et al. "TAPS: Task-Agnostic Policy Sequencing". In: *arXiv preprint arXiv:2210.12250* (2022).

[5] Alexander Koenig et al. "The Role of Tactile Sensing in Learning and Deploying Grasp Refinement Algorithms". In: *IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS), 2022*. 2022.

[6] Yixuan Huang, Adam Conkey, and Tucker Hermans. *Planning for Multi-Object Manipulation with Graph Neural Network Relational Classifiers*. 2022. DOI: 10.48550/ARXIV.2209.11943. URL: https://arxiv.org/abs/2209.11943.

[7] Martin Levihn and Henrik Christensen. "Using environment objects as tools in unknown environments". In: *2015 IEEE-RAS 15th International Conference on Humanoid Robots (Humanoids)*. Nov. 2015, pp. 160–165. DOI: 10.1109/HUMANOIDS.2015.7363530.