Project 46: A reinforcement learning approach to robotic suturing

Group 20
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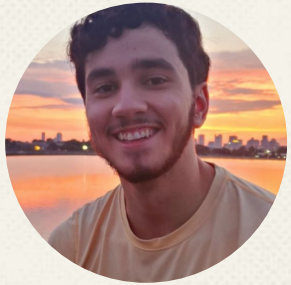
Mentors: Dr. Anqi Liu, Dr. Adnan Munawar, Dr. Manish Sahu, Dr. Peter Kazanzides

THE TEAM!



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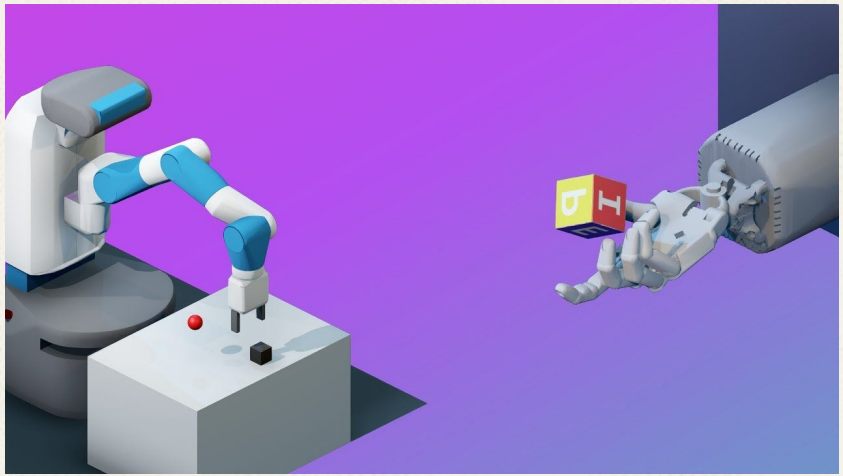
OVERVIEW

Reinforcement Learning (RL)

RL techniques have seen significant progress in the robotics domain; however, there exist a lack of platforms which offer environments conducive to medical robotics.

OpenAI Gym

OpenAI Gym is an open-source RL framework that offer realistic simulation environments with easy integration.



Surgical Robotics Challenge (SRC)

A simulation platform to develop algorithms to address various questions in surgical robotics automation with:

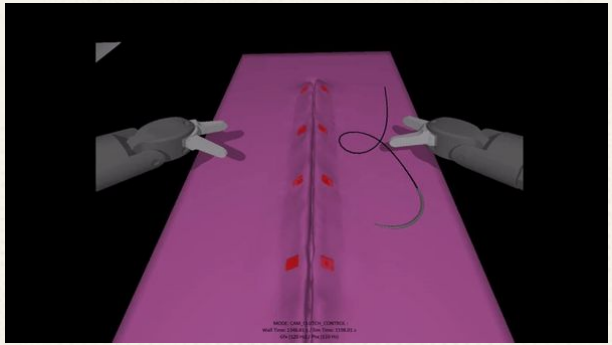
- Two 7-DOF instrument arms based on the da Vinci Surgical System large needle driver
- Controllable camera based on the da Vinci Endoscopic Camera Manipulator
- Suturing phantom
- Needle with a suture

Asynchronous Multibody Framework (AMBF)

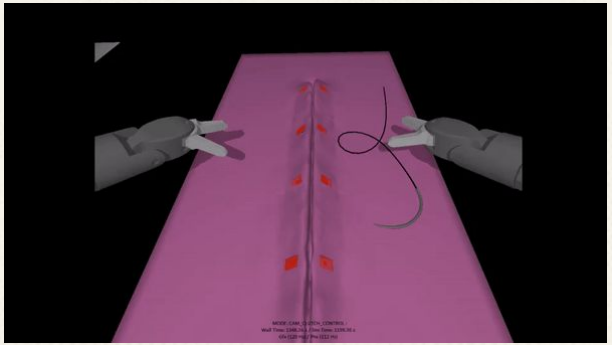
A real time dynamics simulator that serves as the backbone for the Surgical Robotics Challenge environment

BACKGROUND

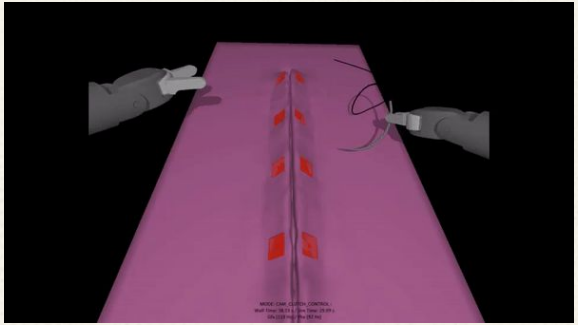
Challenge 1: Find the needle

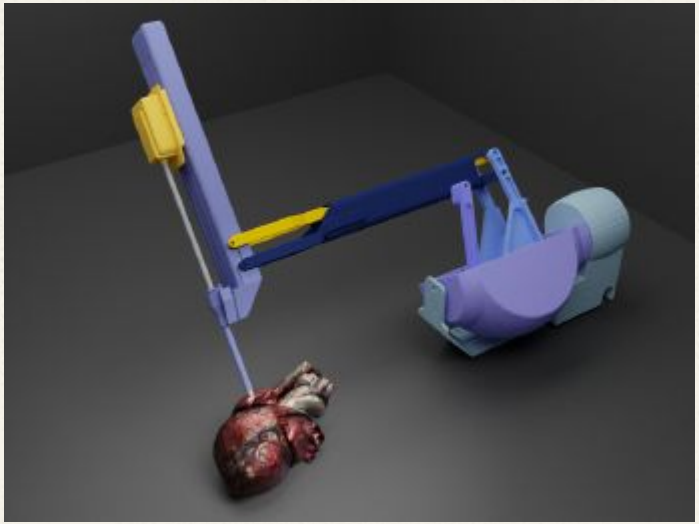


Challenge 2: Grasp needle and drive through tissue



Challenge 3: Suture the phantom





AMBF-RL

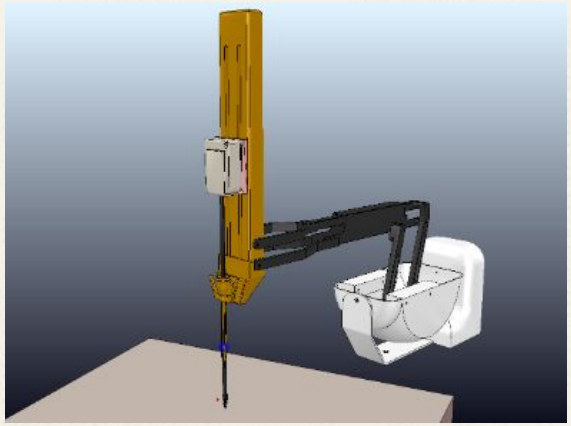
Toolkit to assist in designing control algorithms for medical robotics in AMBF environment

- Demonstrated use of RL for debris removal on dVRK Patient Side Manipulator (PSM)
  - Deep Deterministic Policy Gradient (DDPG)
  - Hindsight Experience Replay (HER)

dVRL

First open-sourced RL environments for surgical robots

- Prototyped and implemented SOTA RL algorithms on surgical robotics automation
- Functionally equivalent to OpenAI Gym
- Based simulation off of dVRK
- However, dVRL does not provide a dynamics simulation, only kinematic



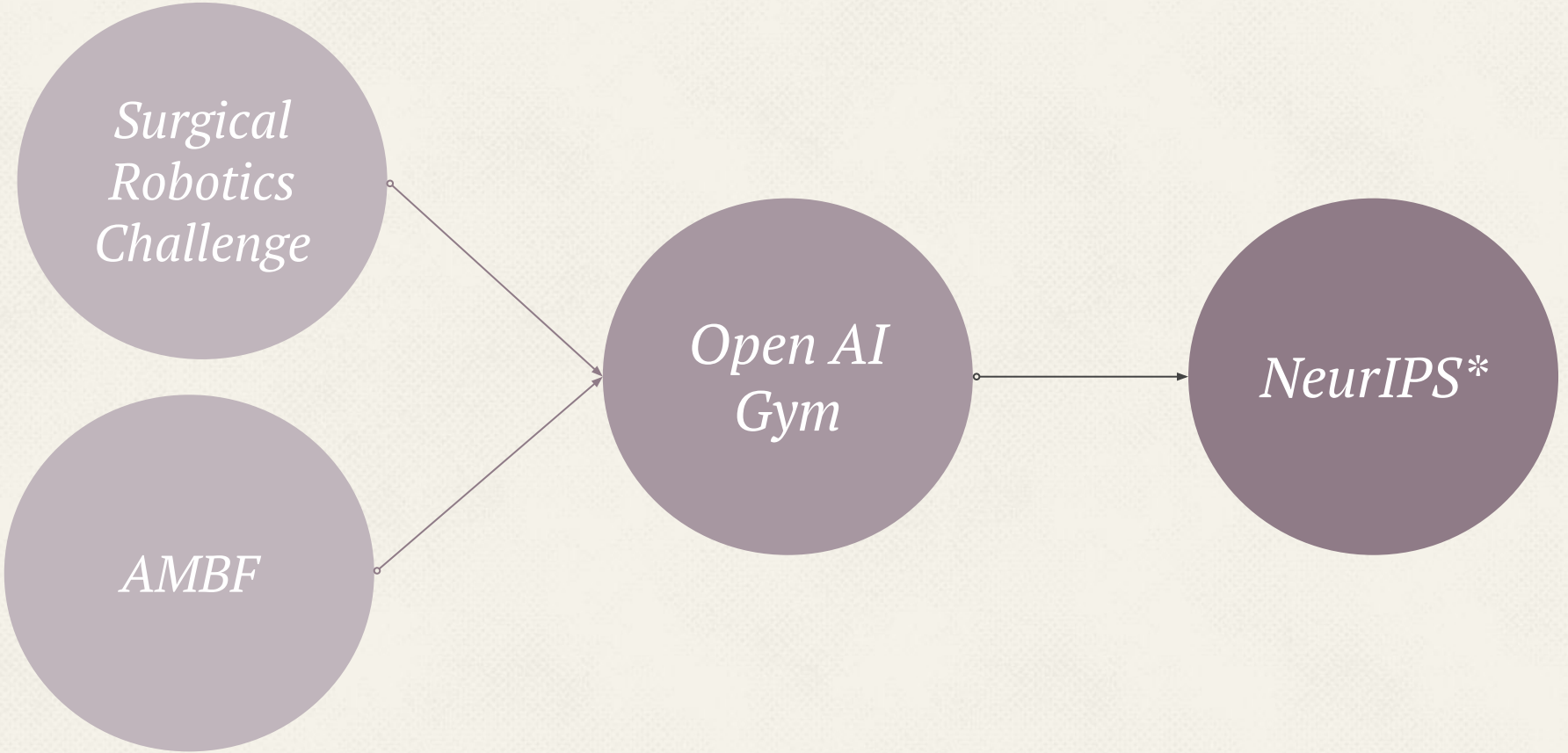
GOALS

Goal: Develop an OpenAI Gym compatible interface for the surgical robotics challenge environment with efficient, accurate RL algorithms

- Wide applicability and paves way for future surgical automation
  - Open-source environment to the masses
  - Provide baseline RL algorithms for comparison

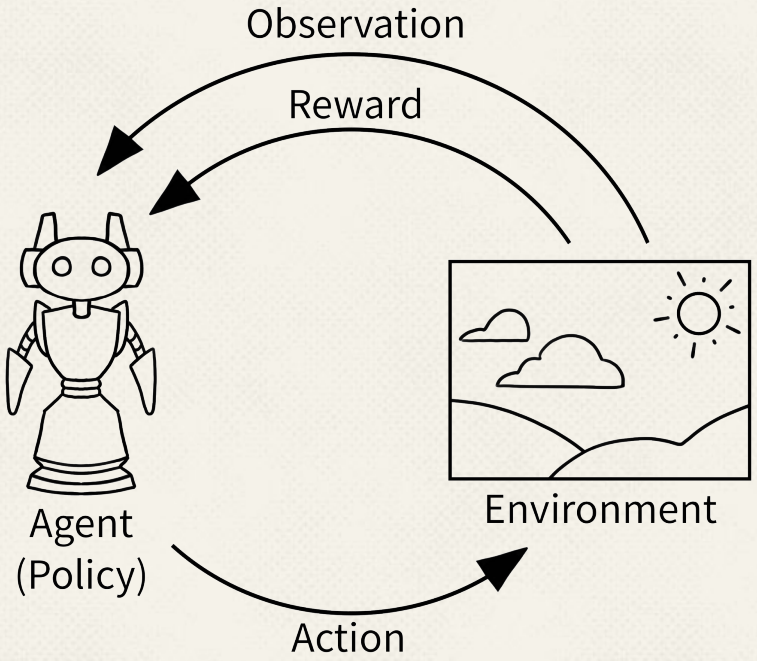
TECHNICAL COMPONENTS

TECHNICAL SUMMARY OF APPROACH

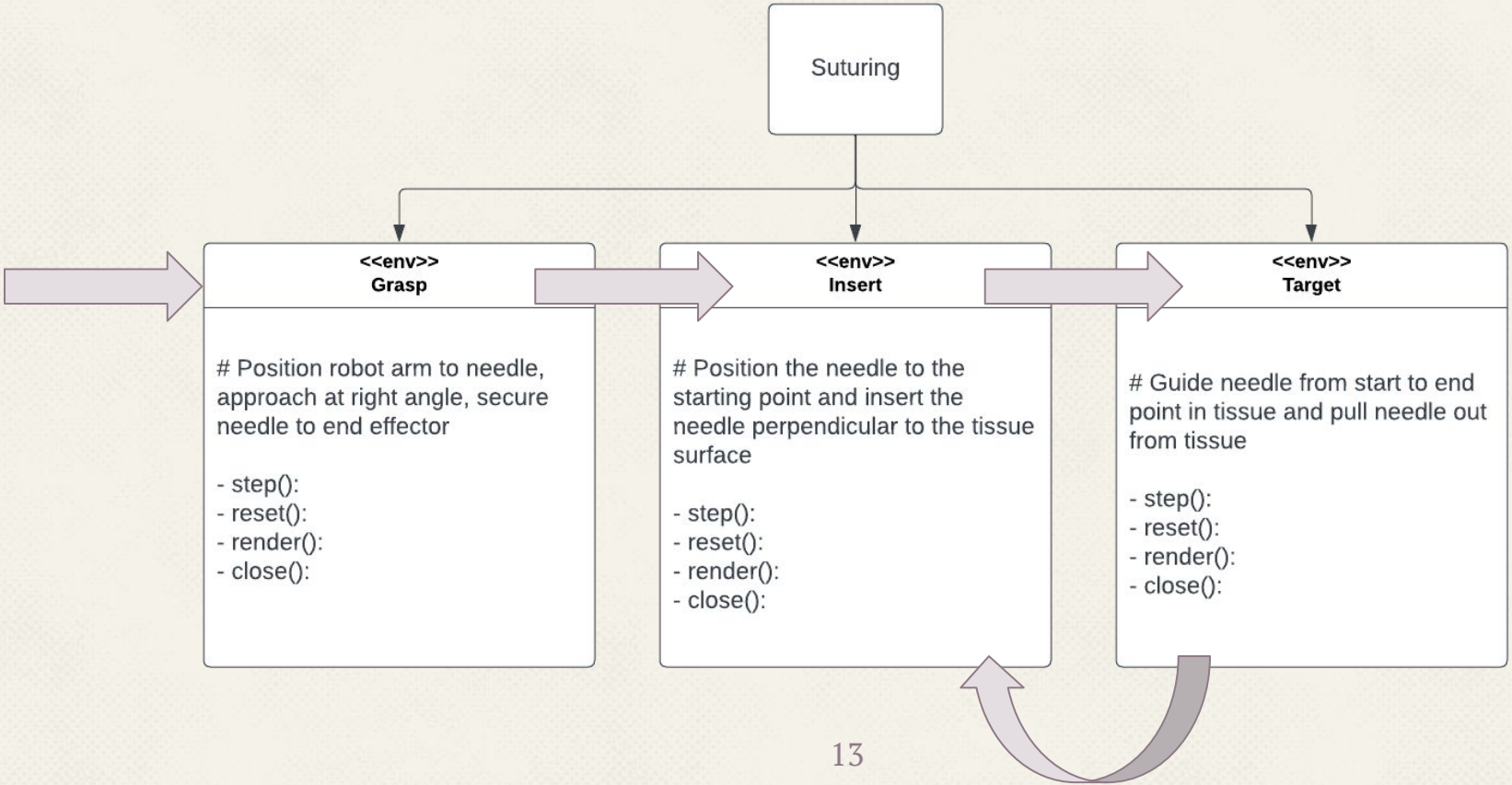


*For more information about NeurIPS conference: https://nips.cc/

OPENAI GYM / RL ARCHITECTURE



OPENAI GYM ARCHITECTURE



DELIVERABLES

Minimal: Open-source OpenAI Gym environment to train RL algorithms

- Transfer of SRC to OpenAI Gym environment (sandbox env)
- Core functionality for OpenAI Gym: `make(), reset(), step(), render()`
- Environments built to accomplish SRC Challenge #2: grasp needle and drive through tissue [4]
- Documentation of our work through entire development pipeline
- Compatibility with dVRK in the LCSR lab

Expected: Benchmarked performances of the SOTA RL algorithms

- Literature review of state-of-the-art (SOTA) RL Algorithms
- RL algorithm training for automated suturing task (SRC #2)
- Performance evaluation (accuracy and efficiency) of RL algorithms & 2021-2022 SRC winners

Maximum: Submission as NeurIPS (Datasets and Benchmark track), additional SRC tasks

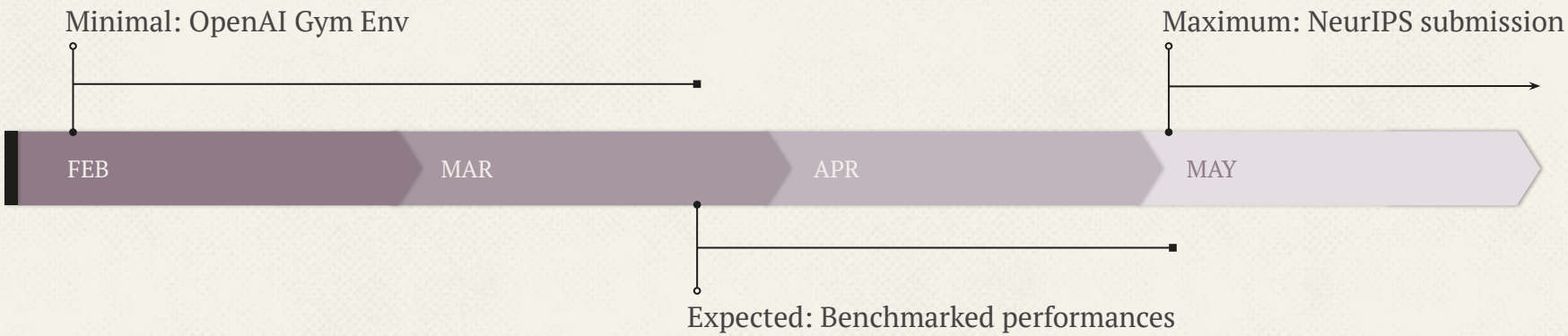
- Paper for NeurIPS conference (database and benchmarking track), deadline TBA [6]
- Additional SRC challenges [4]:
  - Challenge 1: Find the needle
  - Challenge 3: Suture phantom

TECHNICAL DEPENDENCIES

Dependency	Need	Source	Date Needed	Status	Contingency Plan
Swipe access to Robotarium, LCSR	Env Development	Dr. Adnan Munawar	3/1/2023	In-progress	**N/A**
Access to dVRK systems at the Robotarium, LCSR	Test simulation environment	Dr. Adnan Munawar	3/15/2023	In-progress	**Linux Virtual Machine w/ AMBF + ROS**
Rockfish GPU Access	Benchmarking	Dr. Anqi Liu	4/1/2023	In-progress	**Google cloud**
SRC Winning Algorithms	Benchmarking	Dr. Adnan Munawar	4/1/2023	In-progress	**N/A**

MANAGEMENT PLAN

TIMELINE


Minimal: OpenAI Gym Env
Maximum: NeurIPS submission
FEB
MAR
APR
MAY
Expected: Benchmarked performances

TIMELINE: MILESTONES + DEADLINES

Milestone	Output	Start Date	Soft End Date	Hard End Date
Transfer SRC Environment to OpenAI Gym	GitHub Repo w/ MVP of environment	2/23/23	3/1/2023	3/6/2023
Reward functions: Challenge #2 • Reward functions for needle grasp, insert, target • Test reward functions exhaustively	Tested code	3/6/2023	3/13/2023	3/17/2023
Benchmarking: Challenge #2 • Trained RL algorithm for Challenge #2 • Evaluate RL performance w/ SRC 2022 winners	Model results Evaluation spreadsheet	3/27/2023	4/21/2023	4/28/2023
Env Dev + Benchmarking: Challenge #1 • CV algorithm for needle finding • Evaluate algorithm w/ SRC 2022 winners	Tested code Model results Evaluation spreadsheet	5/1/2023	5/10/2023	5/12/2023
Env Dev + Benchmarking: Challenge #3 • Reward functions for suturing • Benchmark RL algorithm for suturing • Evaluate performance	Tested code Model results Evaluation spreadsheet	5/15/2023	5/26/2023	5/31/2023
NeurIPS • Paper submission for Dataset and Benchmark track	Submitted paper	5/29/2023	TBD	TBD

TIMELINE: GANTT CHART

	Member	February				March				April				May	
		1	2	3	4	1	2	3	4	1	2	3	4	1	2
Preliminary Research															
Set up OpenAI Gym, ROS, AMBF	All														
Lit review of SRC, AMBF	All														
RL online course	All														
Env Dev: Challenge 2															
Code Documentation	All														
Transfer SRC env to OpenAI Gym	All														
Develop grasp reward function	Jihoon														
Develop insert reward function	Walee														
Develop target reward function	Jocelyn														
Test reward functionality & train RL algorithm	All														
Benchmarking: Challenge 2															
Lit review on SOTA RL models	All														
Evaluate RL algorithm	All														

TIMELINE: GANTT CHART

	Member	March				April				May				June	
		1	2	3	4	1	2	3	4	1	2	3	4	1	2
Env Dev + Benchmark: Challenge 1															
Develop needle finding CV algorithm	Jihoon														
Test functionality	Jihoon														
Evaluate algorithm w/ SRC 2022	Jihoon														
Env Dev + Benchmark: Challenge 3															
Develop suture reward function	Jocelyn + Walee														
Test reward functionality	Jocelyn + Walee														
Benchmark RL algorithm on Challenge 3	Jocelyn + Walee														
Compare RL w/ SRC 2022															
NeurIPS															
Write paper	All														
Code cleanup for NeurIPS submission	All														

MEETINGS

- Undergraduate meetings:
  - Weekly, Mondays & Fridays 11AM
- Team meetings:
  - Weekly, Wednesdays 9AM (w/ Dr. Liu, Dr. Munawar, Dr. Sahu)
- Communication
  - Microsoft Teams, JHU email (mentors + students)
  - Discord (students)

READING LIST

- Richter, F., Orosco, R. K., & Yip, M. C. (2019). Open-sourced reinforcement learning environments for surgical robotics. arXiv preprint arXiv:1903.02090.
- Introduction to reinforcement learning with David Silver. DeepMind. (n.d.). Retrieved February 19, 2023, from https://www.deepmind.com/learning-resources/introduction-to-reinforcement-learning-with-david-silver
- V. M. Varier, D. K. Rajamani, F. Tavakkolmoghaddam, A. Munawar and G. S. Fischer, "AMBF-RL: A real-time simulation based Reinforcement Learning toolkit for Medical Robotics," 2022 International Symposium on Medical Robotics (ISMR), GA, USA, 2022, pp. 1-8, doi: 10.1109/ISMR48347.2022.9807609.
- Medical Open Network for Artificial Intelligence. MONAI. (n.d.). Retrieved February 19, 2023, from https://monai.io/index.html

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[1] Introduction to reinforcement learning with David Silver. DeepMind. (n.d.). Retrieved February 19, 2023, from https://www.deepmind.com/learning-resources/introduction-to-reinforcement-learning-with-david-silver

[2] Richter, F., Orosco, R. K., & Yip, M. C. (2019). Open-sourced reinforcement learning environments for surgical robotics. arXiv preprint arXiv:1903.02090.

[3] Medical Open Network for Artificial Intelligence. MONAI. (n.d.). Retrieved February 19, 2023, from https://monai.io/index.html

[4] 2021-2022 AccelNet Surgical Robotics Challenge (online). Collaborative Robotics Toolkit (CRTK). Retrieved February 19, 2023, from https://collaborative-robotics.github.io/surgical-robotics-challenge/challenge-2021.html

[5] Gymnasium documentation. Basic Usage. (n.d.). Retrieved February 19, 2023, from https://gymnasium.farama.org/content/basic_usage/

[6] NeurIPS 2023. Neural Information Processing Systems Foundation. (n.d.). Retrieved February 19, 2023, from https://nips.cc/Conferences/2023