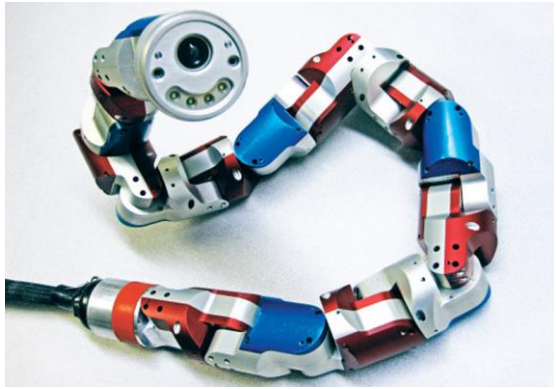
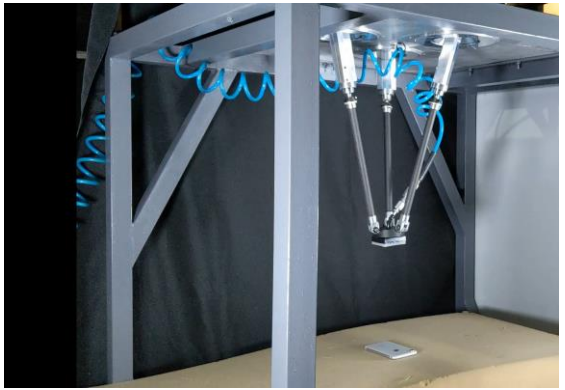
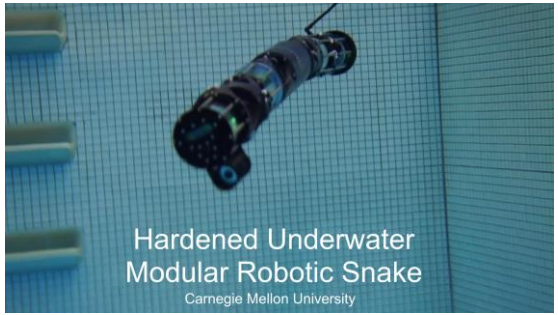
BioRobotics Lab
Travers and Choset







Theoretical Themes Biorobotics Lab

Dimension Reduction

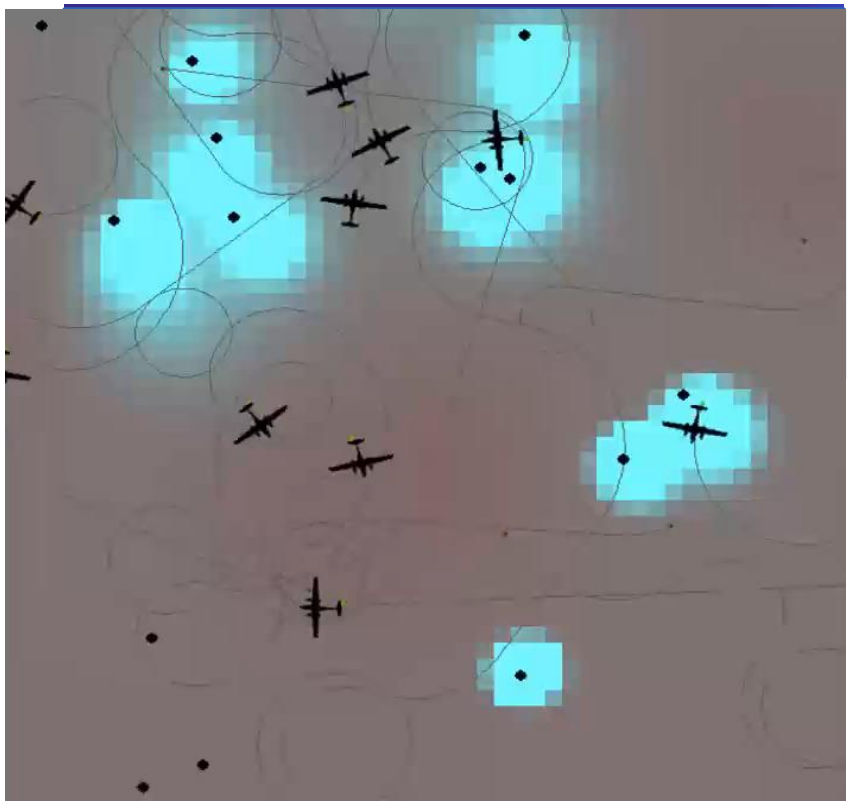
Run the Pipeline

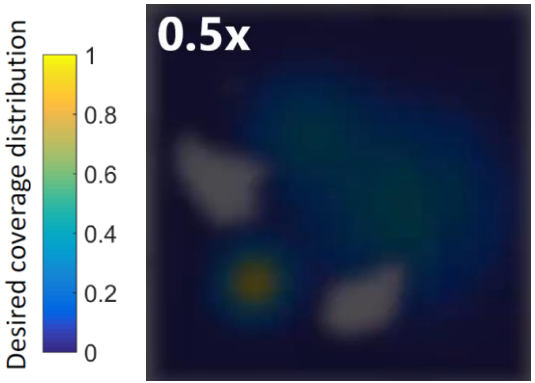
Geometry

Force / Compliance


Ad-hoc Network
Text Messages to humans
Where do we tell people in this area to go?
Fixed Wing Surveillance Drone
Are there acoustic signs of life in here?
Delivery Drone
Amphibious UGV
Scan this area for people in the water
Streetlight with vision
Robot/Robot Coordination
Edge Compute
Robot/Human Coordination
Low Altitude Drone
Security, Deception
Person spotted in the water here. Keep track of them
Portable Cloudlet
Is someone trapped here?
Power
Command Center
Social Media
Perception through haze, water, smoke, around corners

Multi-agent Heterogeneous Ergodic Search





Agents should spend time in regions in proportion to their expected amount of information.

Map is updated, say via a Gaussian Process, as information is acquired

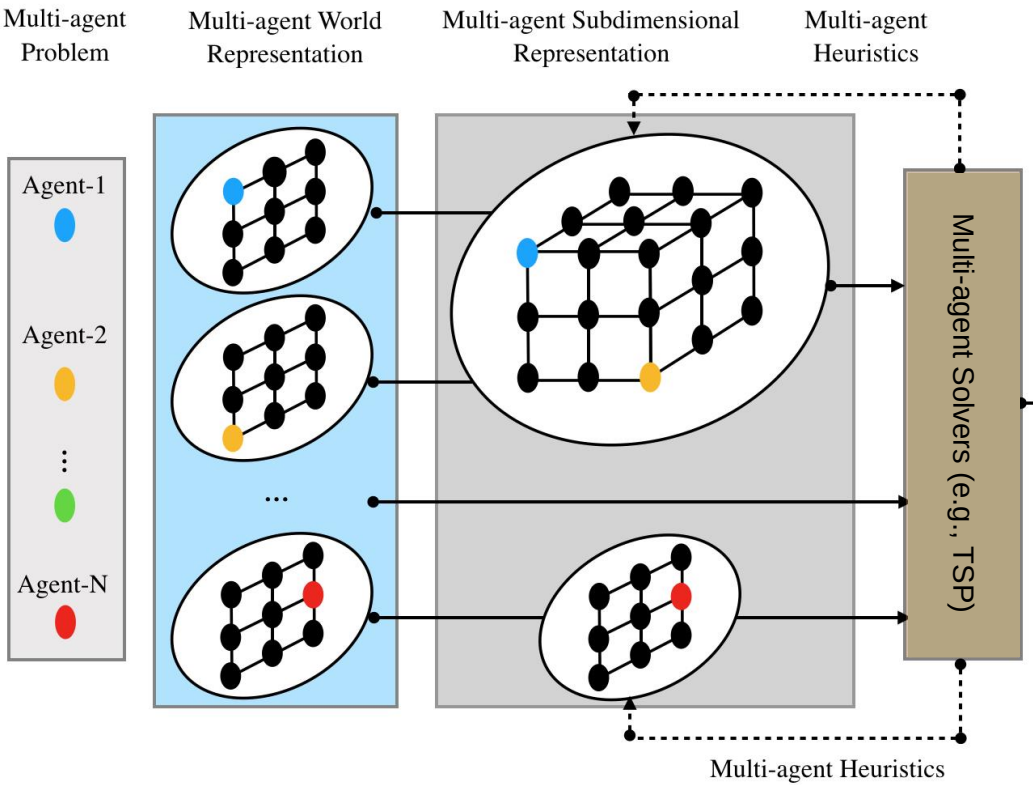
$$\phi(t) = \sum_{k=0}^{K} \Lambda_k |\Gamma_k(t) - \xi_k|^2$$

Fourier coefficients

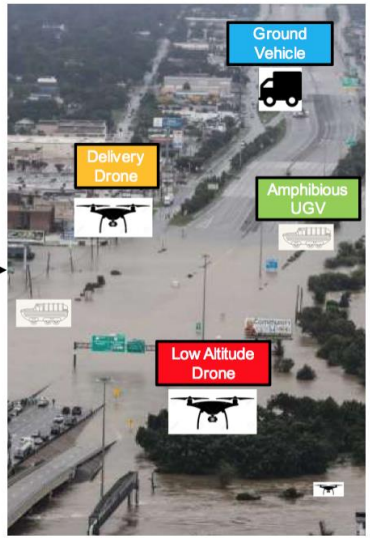
Spectral coefficients for heterogeneous search

$$D_{KL}(\Gamma^t, \xi) = \int_X \Gamma^t(\boldsymbol{x}) \, \boldsymbol{log} \left(\frac{\Gamma^t(\boldsymbol{x})}{\xi(\boldsymbol{x})} \right) d\boldsymbol{x}$$

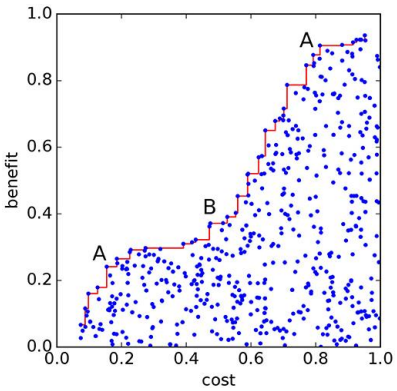
Multi-Agent Systems: Bypass the Curse of Dimensionality



Multi-agent Solutions



Multi-Agent Multi-objective Search



Pareto Optimal Front

Decentralized Multi-agent Start-goal Planning

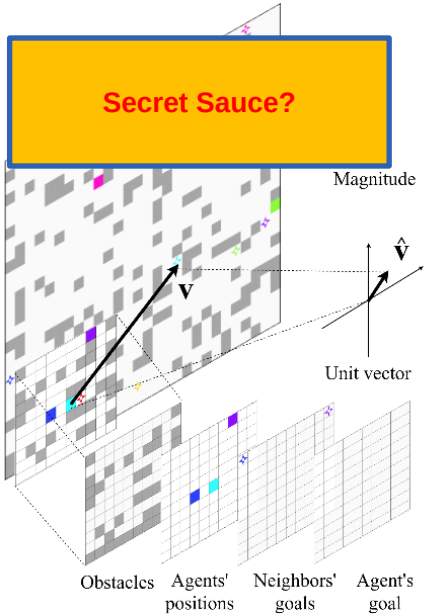
Distributed imitation/reinforcement learning approach

70% of episodes solved via RL. Goal: maximize cumulative rewards

Result: agents get to their goal as fast as possible and rest on it

30% of episodes solved using centralized planner (ODrM*)

Behavior cloning to mimic demonstrations.

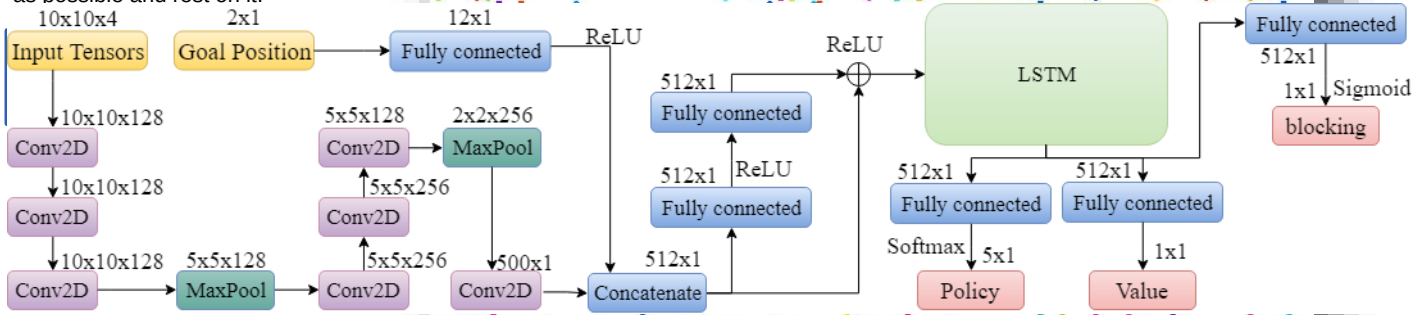


Completely Centralized Learning

Stay on goal, r = + 0

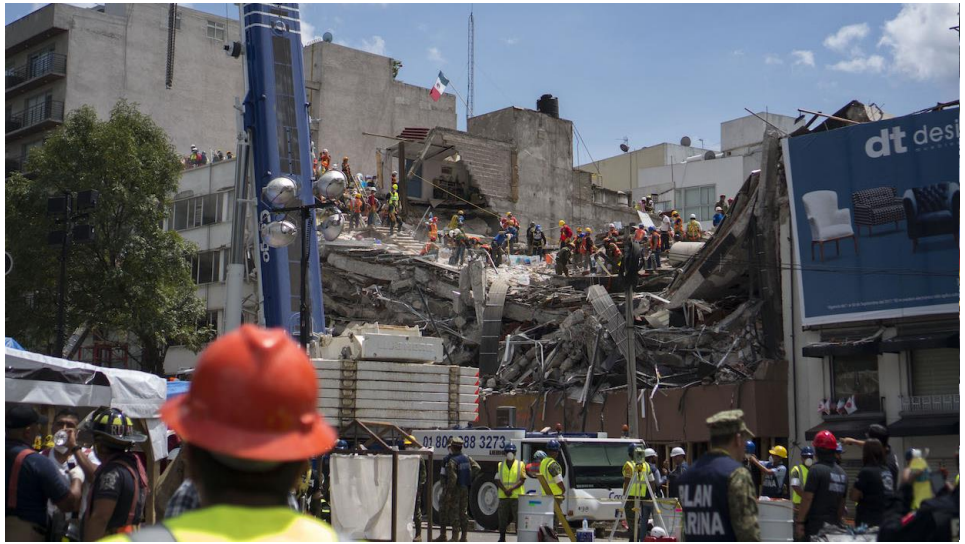
Finish episode (all agents on goal), r =

Completely Decentralized Execution



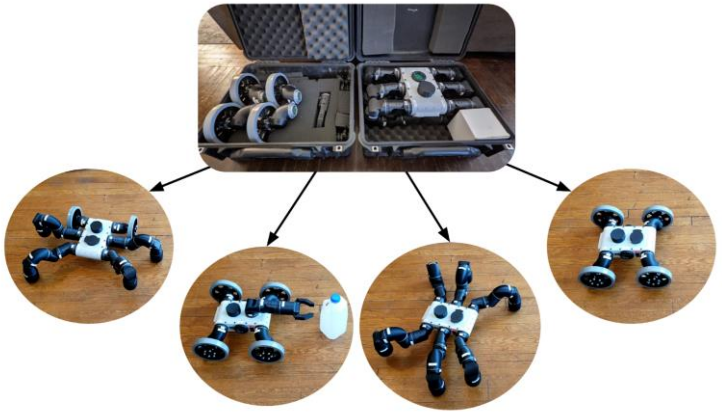
Mexico City Earthquake

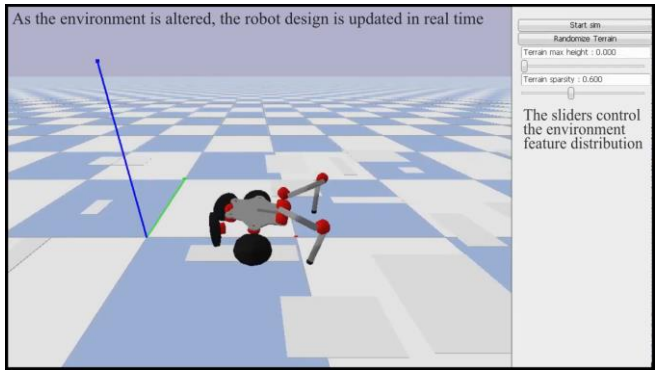
Hundreds Missing in Mexico City Days After Earthquake, WSJ, Sept 21, 2017

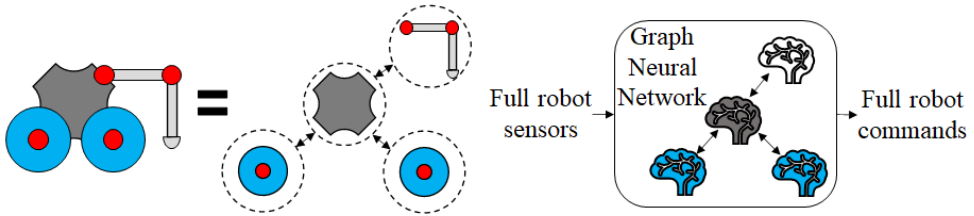


Travers, Whitman, Zavallos

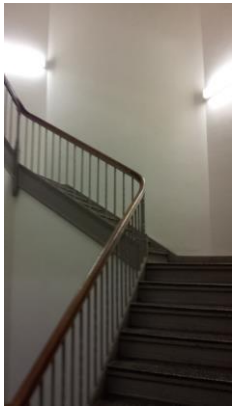
Science and Engineering of Modularity







Modularity Gradients / Stair Climbing



Rapidly load, transport and unload a heavy payload up N flights of stairs in a single trip

Predicted increase

Predicted decrease

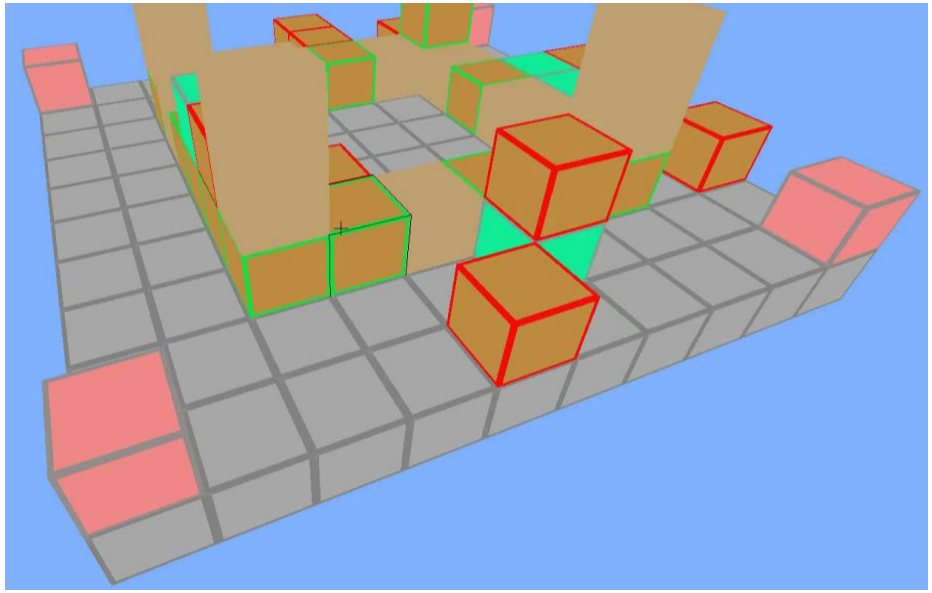
TBD

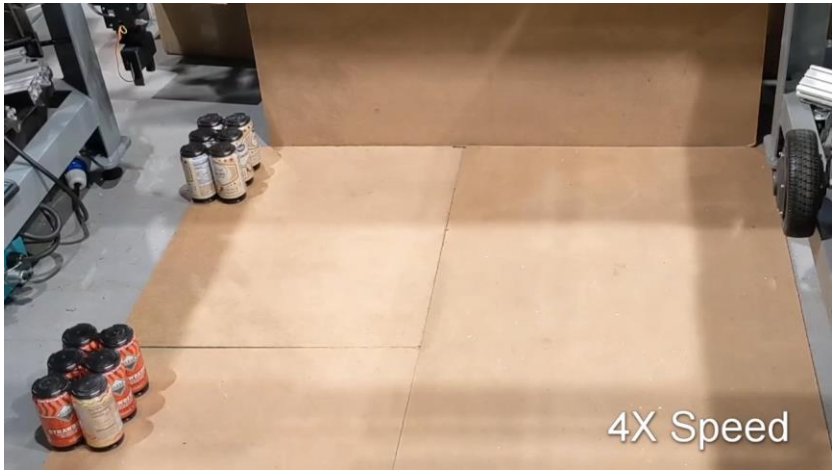
\+

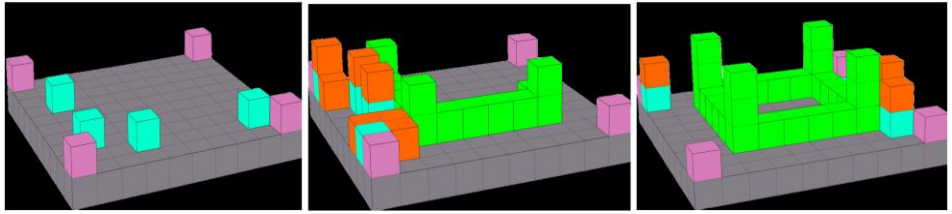
Mechanism Design

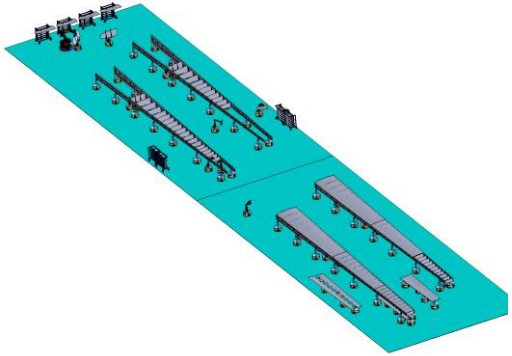
	Max carrying capacity	Max carrying time	Max distance traveled	Max flight of stairs	Max traversable terrain complexity	Time to complete tasks	Battery capacity	Price	Time spent with Logistics
# robots	Does an increase in robots increase the maximum carrying capacity of the system?	Does an increase in robots increase the maximum amount of time the sytsem can carry a payload	Does an increase in the # of robots increase the maximum distance traveled with a payload?		Does an increase in the number of robots increase the maximum traversable terrain complexity?			Does an increase of the number of robots increase the pricing (both to order and maintenance) of the system	Does an increase in the number of robots increase the time spent dealing with logistics?
# human assistants	How does an increase in the number of human assistance effect the maximum carrying capability of the system?	How does the # of human assistance effect the maximum carrying time of the system during transport?	How does an increase in the number of human assistance effect the maximum carrying capability of the system?	How does an increase in the number of human assistance effect the maximum flight of stairs the system can traverse?	How does the change in the number of human assistance effect the maximum traversable terrain complexity?	How does an increase in the number of human assistance effect the time to complete individual tasks (load, transport, unload) of the sytsem?	How does an increase in the number of human assistance effect the required battery capacity of the system?	How does an increase in the number of human assistance effect the price of the system (also consider engineering time for software development)?	How does an increase in the number of human assistance effect the time spent dealing with logistics of the sytsem i.e., startup time, setting up interfaces, charging, tranport etc?
Robot weight	How does the change in the weight of the robot change the maximum carry capacity of the system?	How does the change in the weight of the robot change the maximum carrying time of the system with a payload to transport?	How does the change in the weight of the robot change the maximum distance the system can travel with a payload?	How does the change in the weight of the robot change the maximum flights of stairs the robot can travel with a payload?	How does the change weight of the robot effect the maximum traversable terrain complexity?	How does the change in the weight of the robot change the time to complete a task with a payload?	How does the change in the weight of the robot change the necessary battery capacity of the robot?	How does the change in the weight of the robot change the price robot?	How does the change in the weight of the robot change the time spent dealing with logistics?
Battery capacity	How does the battery capacity change the maximum carrying capacity of a robot?	How does the battery capacity change the maximum carrying time of a robot with a payload?	How does the battery capacity change the maximum distance a robot can travel with a payload?	How does the battery capacity change the maximum flight of stairs the robot can go up with a payload?	How does the change in the battery capacity the maximum traversable terrain complexity?	How does the battery capacity change the time for the robot to complete individual tasks (load, transport, unload)?		How does the battery capacity change the price of a robot?	How does the battery capacity change the time spent dealing with logistics?
Max motor stall torque	How does the change in the max motor stall torque of the robot change the maximum carry capacity of the system?	How does the change in the max motor stall torque of the robot change the maximum carrying time of the system with a payload to transport?	How does the change in the max motor stall torque of the robot change the maximum distance the system can travel with a payload?	How does the change in the max motor stall torque of the robot change the maximum flights of stairs the robot can travel with a payload?	How does the change max motor stall torque of the robot effect the maximum traversable terrain complexity?	How does the change in the max motor stall torque of the robot change the time to complete a task with a payload?	How does the change in the max motor stall torque of the robot change the necessary battery capacity of the robot?	How does the change in the max motor stall torque of the robot change the price robot?	How does the change in the max motor stall torque of the robot change the time spent dealing with logistics?
Max force output	How does the change in the max force output of the robot change the maximum carry capacity of the system?	How does the change in the max force output of the robot change the maximum carrying time of the system with a payload to transport?	How does the change in the max force output of the robot change the maximum distance the system can travel with a payload?	How does the change in the max force output of the robot change the maximum flights of stairs the robot can travel with a payload?	How does the change max force output of the robot effect the maximum traversable terrain complexity?	How does the change in the max force output of the robot change the time to complete a task with a payload?	How does the change in the max force output of the robot change the necessary battery capacity of the robot?	How does the change in the max force output of the robot change the price robot?	How does the change in the max force output of the robot change the time spent dealing with logistics?
# actuators	How does the change in the # of actuaors of the robot change the maximum carry capacity of the system?	How does the change in the # of actuaors of the robot change the maximum carrying time of the system with a payload to transport?	How does the change in the # of actuaors of the robot change the maximum distance the system can travel with a payload?	How does the change in the # of actuaors of the robot change the maximum flights of stairs the robot can travel with a payload?	How does the change # of actuaors of the robot effect the maximum traversable terrain complexity?	How does the change in the # of actuaors of the robot change the time to complete a task with a payload?	How does the change in the # of actuaors of the robot change the necessary battery capacity of the robot?	How does the change in the max force output of the robot change the price robot?	How does the change in the # of actuaors of the robot change the time spent dealing with logistics?
Payload weight		How does the change in the payload weight change the maximum carrying time of the system with a payload to transport?	How does the change in the payload weight change the maximum distance the system can travel with a payload?	How does the change in the payload weight change the maximum flights of stairs the robot can travel with a payload?	How does the change payload weight effect the maximum traversable terrain complexity?	How does the change in the payload weight change the time to complete a task with a payload?	How does the change in the payload weight change the necessary battery capacity of the robot?	How does the change in the payload weight change the price robot?	How does the change in the payload weight change the time spent dealing with logistics?

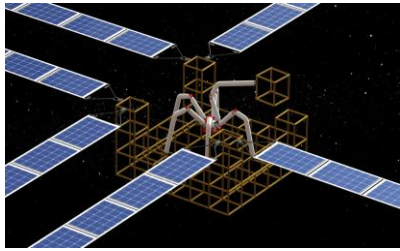
Decentralized Construction: Reinforcement Learning



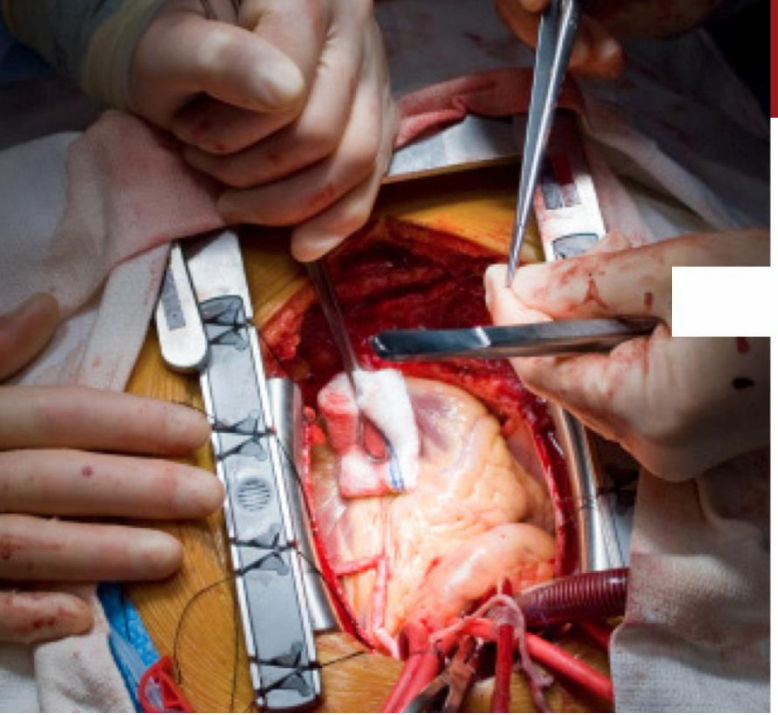








Minimally Invasive Surgery



Reduce post-operative discomfort

Decrease costs

Disseminate **care**

Operate on Humans

CEO Catches Stranger After Hours, Prompting Espionage Charges, WSJ, Sept 19 2017

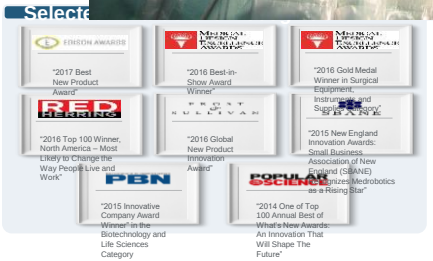
FDA Clearances

Transoral	Laryngeal	Transanal	Transabdominal
(July 2015)	(July 2015)	(May 2017)	(Est. 4Q 2018)

Not a Surgeon

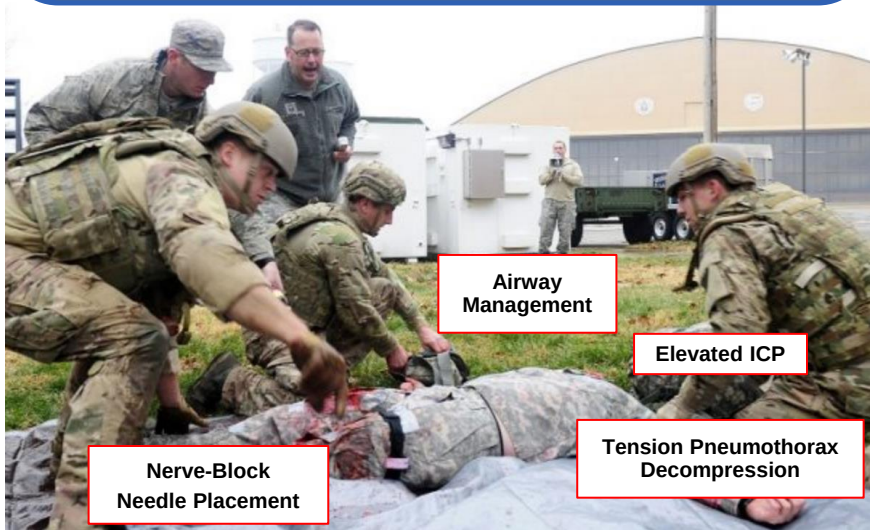
First [illegible] be clea[illegible]hat has the [illegible]s indi[illegible]

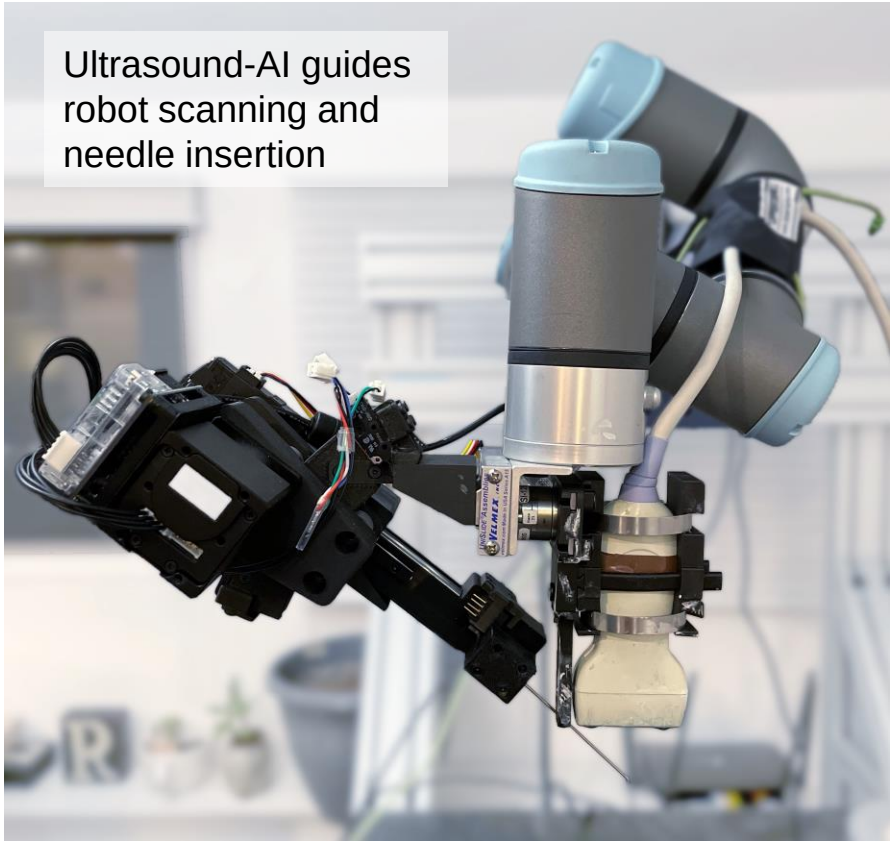
4 c[illegible]
in 1[illegible]



Ultrasound Guided Medical Robots: Advancing AI and Saving Lives

New AI that:
- Trains with limited, noisy data
- Generalizes to the unexpected
- Explains Itself

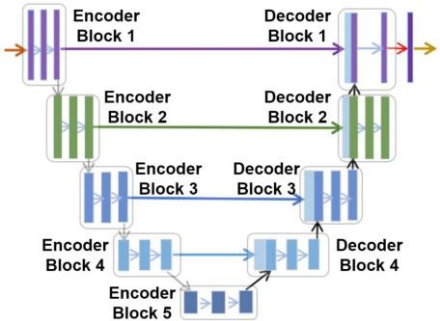


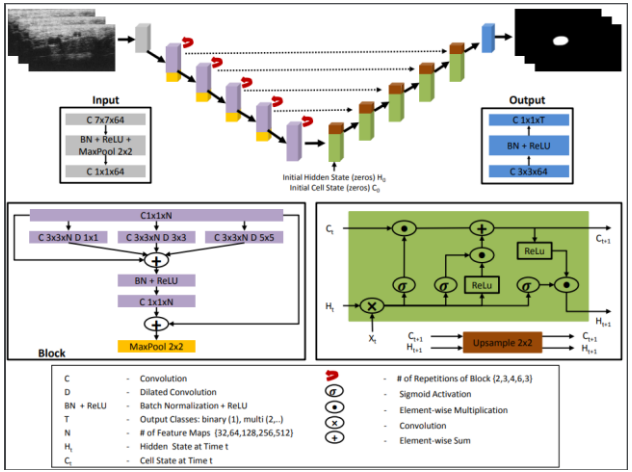


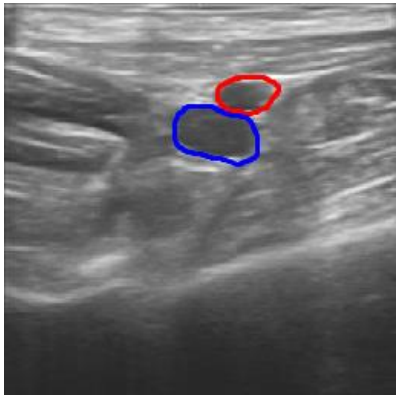
Deep Learning Architectures

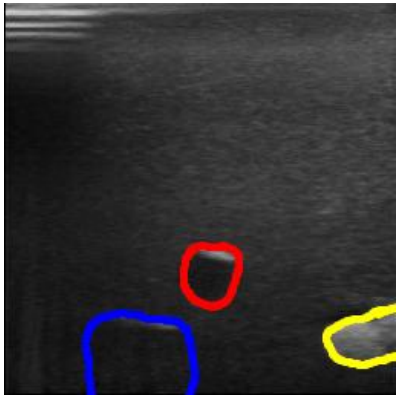
Domain Generalization:

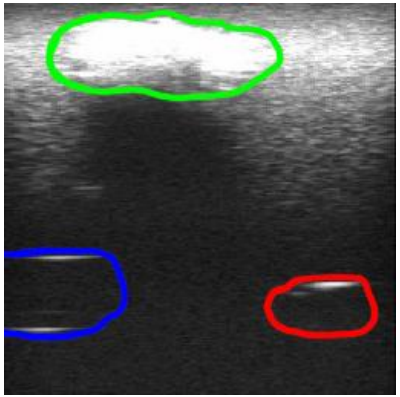
- Transfer Learning
- Data Augmentation
- Bayesian Modelling

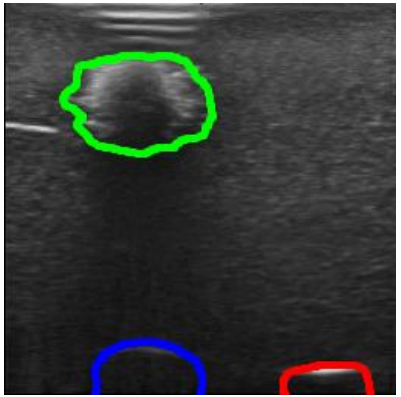










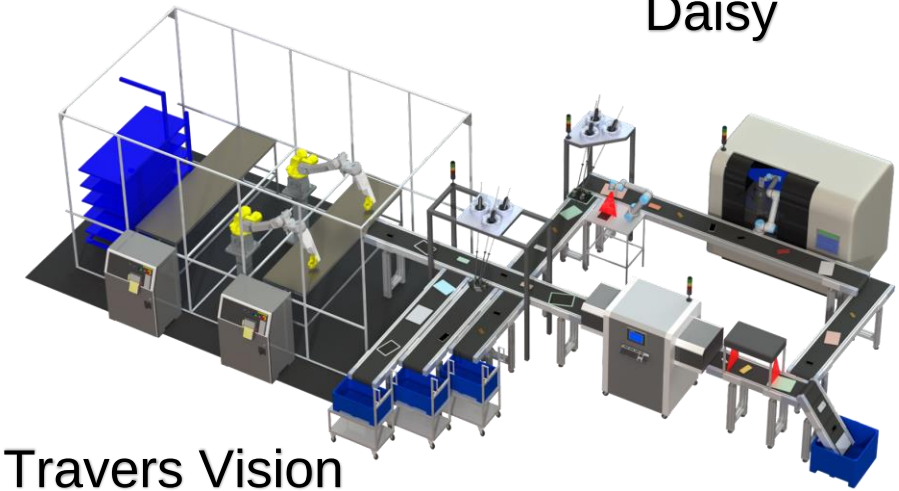


Mathai T.S., Gorantla V., Galeotti J., "Segmentation of Vessels in Ultra High Frequency Ultrasound Sequences using Contextual Memory". Medical Image Computing and Computer Assisted Intervention. MICCAI 2019.

E-waste recycling

E-waste is a tremendous problem

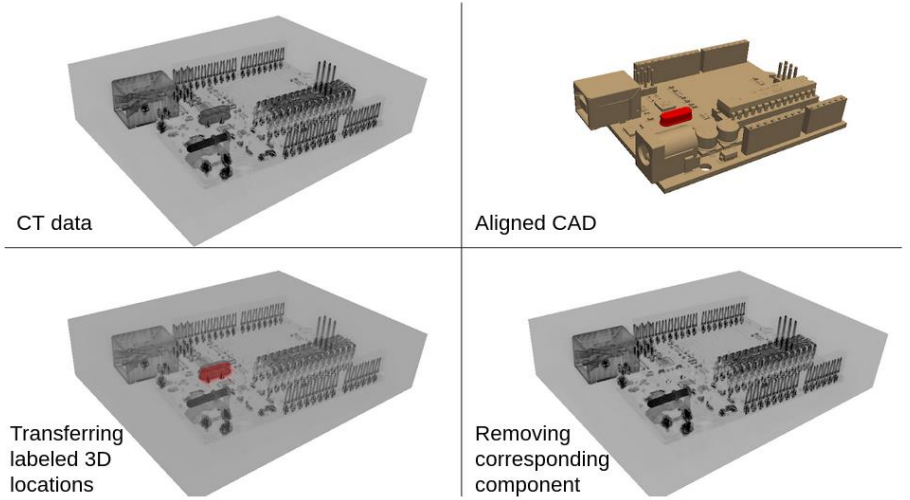
Daisy



Travers Vision

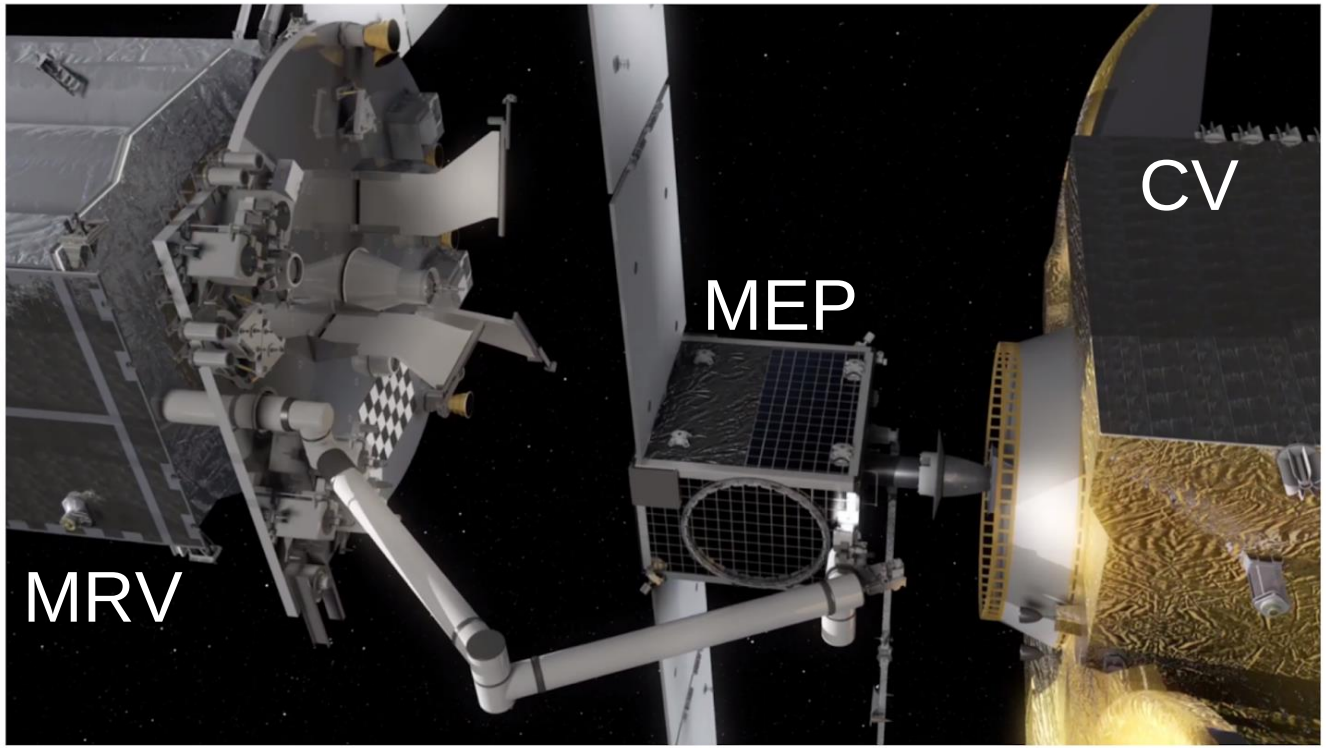
E-waste recycling

E-waste is a tremendous problem



Generate different 2-D images under different conditions

Recycling in Space

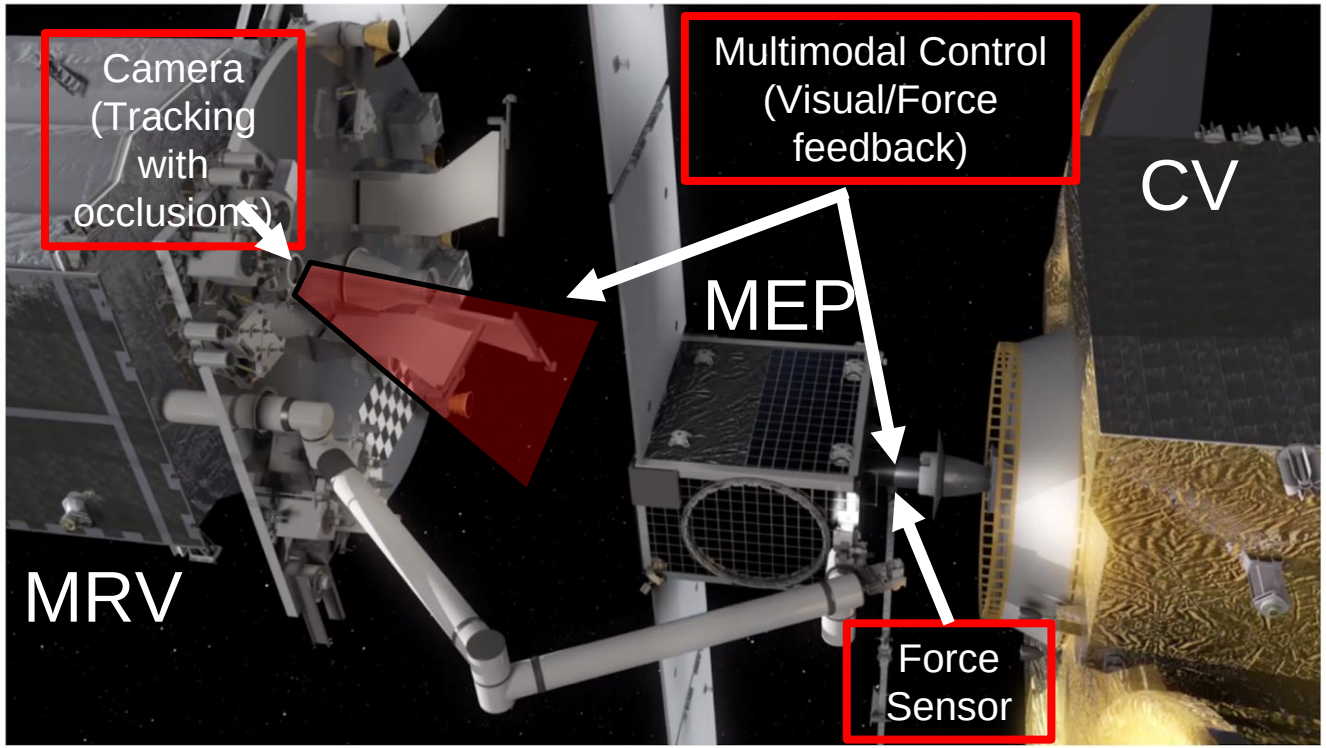


MRV – Mission Robotic Vehicle

MEP – Mission Extension Payload

CV – Client Vehicle

Challenges



MRV – Mission Robotic Vehicle

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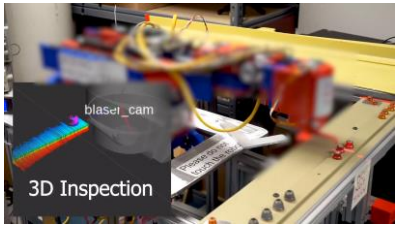
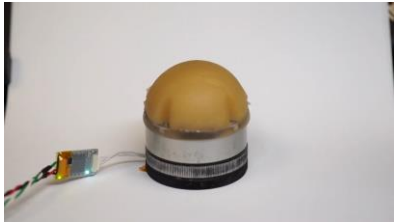




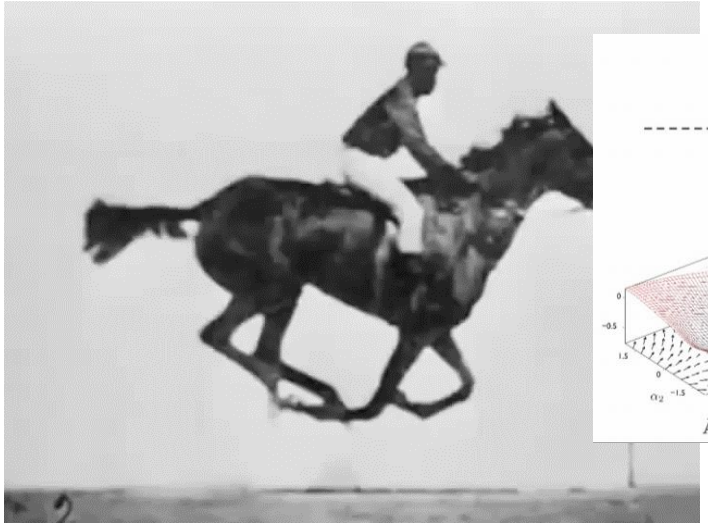
Geometric Mechanics +Gaits

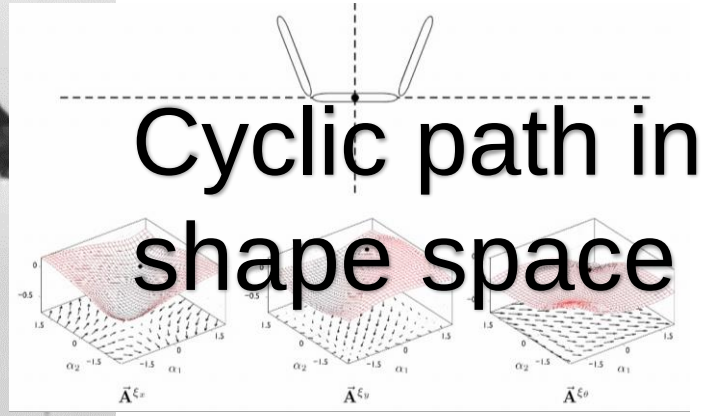
Body Velocity

Shape Velocity

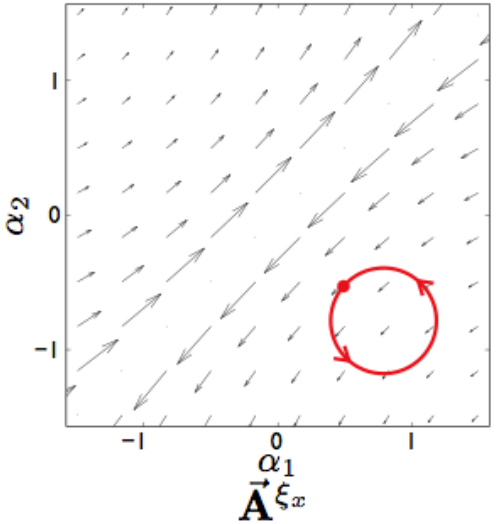
$$\oint \xi \mathrm{d}t = \mathbf{A}(\alpha)\mathrm{d}\alpha$$

Connection

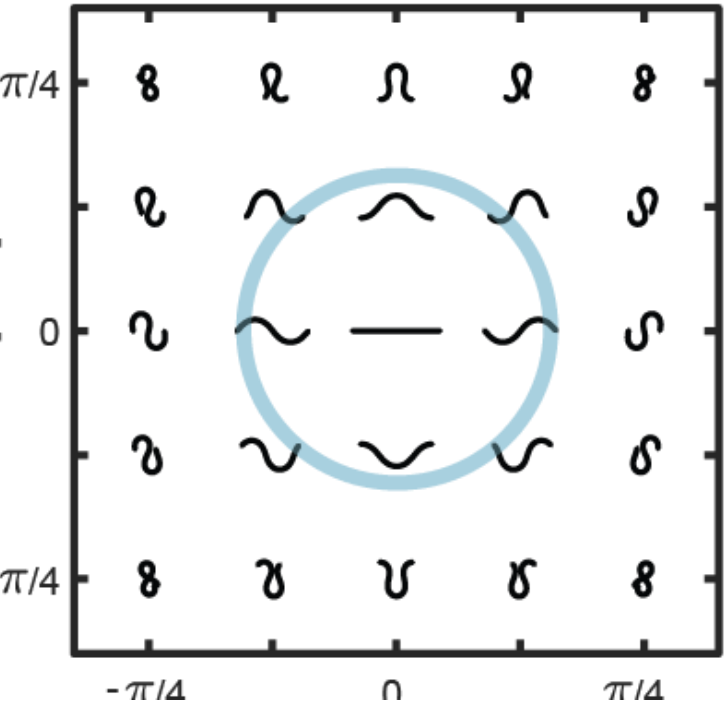


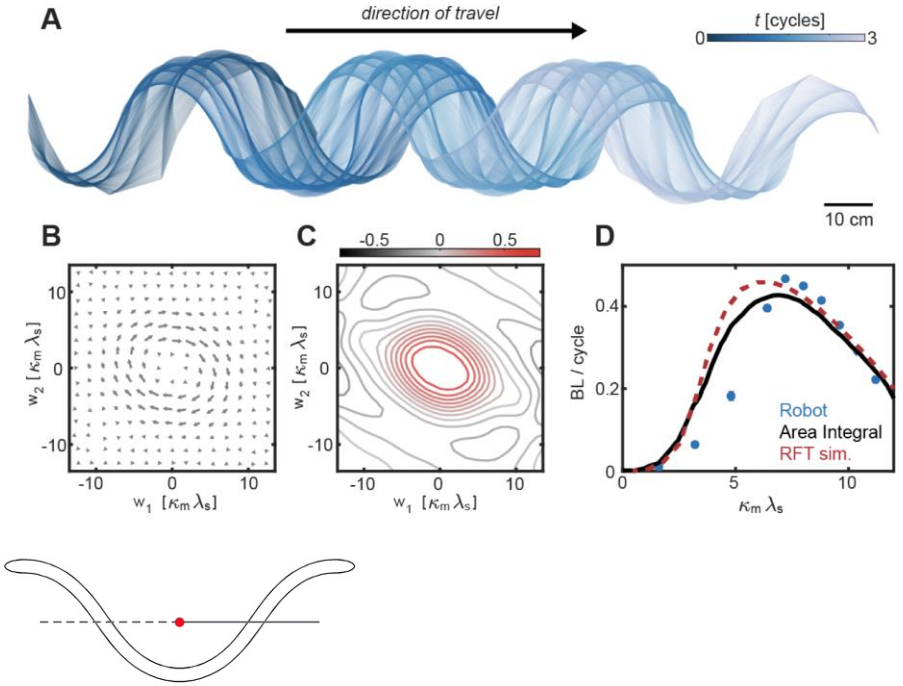


Cyclic path in shape space

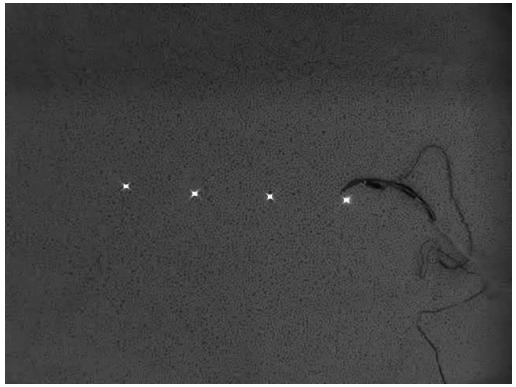


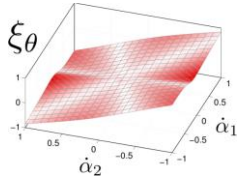
Basis Functions / Shape Template

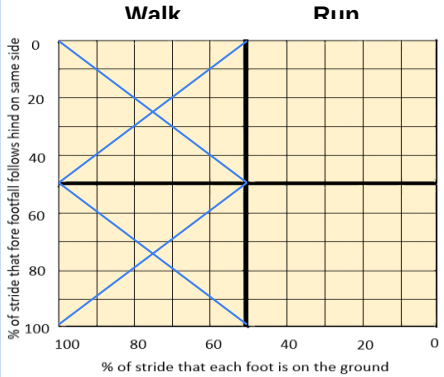


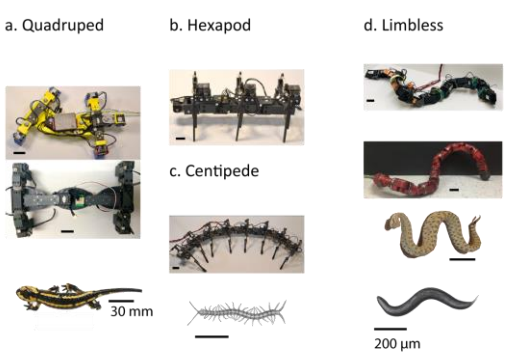


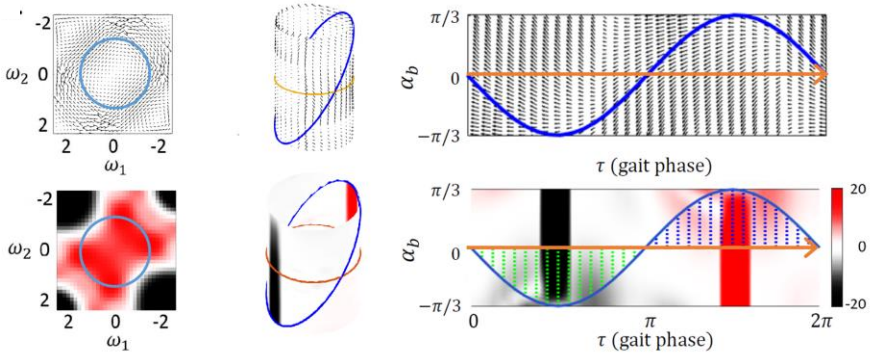
Contact (Dan Goldman)

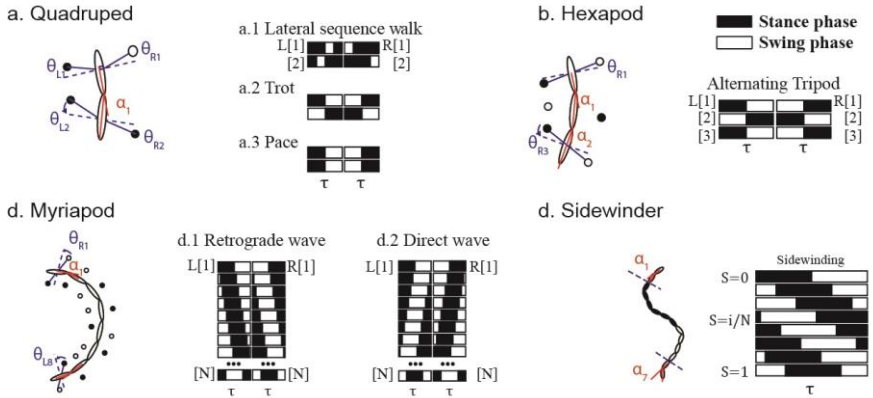












Adaptable

With position control only, must rely on
- difficult computational models
- lots of sensed data, high resolution
- High bandwidth information
- Limitations on size and speed of robot

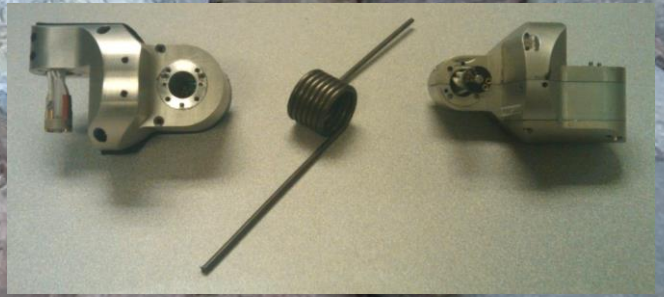
Animals
- Reactive control / decentralized
- Low resolution sensors
- Low bandwidth information
- Highly dynamic at a variety of scales

$$m\ddot{\theta}_d + b\dot{\theta}_d + k(\theta_d - \theta_0) = \tau_d$$

$$\theta_d = \kappa \sin(\eta s - \omega t)$$

$$m'\ddot{\kappa} + b'\dot{\kappa} + k'(\kappa - \kappa_0) = \tau'_d$$

Shape-Based Admittance Control



Shape-Based Admittance Control

Capabilities of Biorobotics Lab

Snake Robots (Land and Sea)	Novel Mechanisms	Modular Robots	Confined Space Robotics
Multi-Agent Planning	Force-based Control	Reinforcement Learning	Imitation Learning
Mapping	Registration	Miniaturization	Medical Robotics