
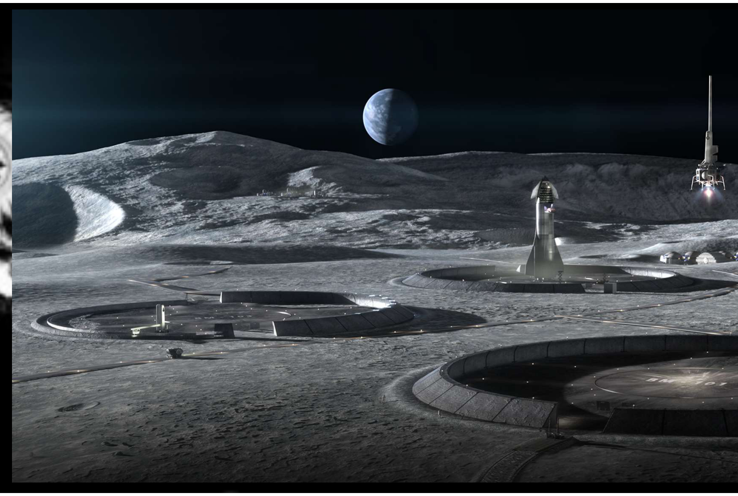


First Steps Towards Lunar Settlements: Small Multirobot Chains For Landing Pad Construction

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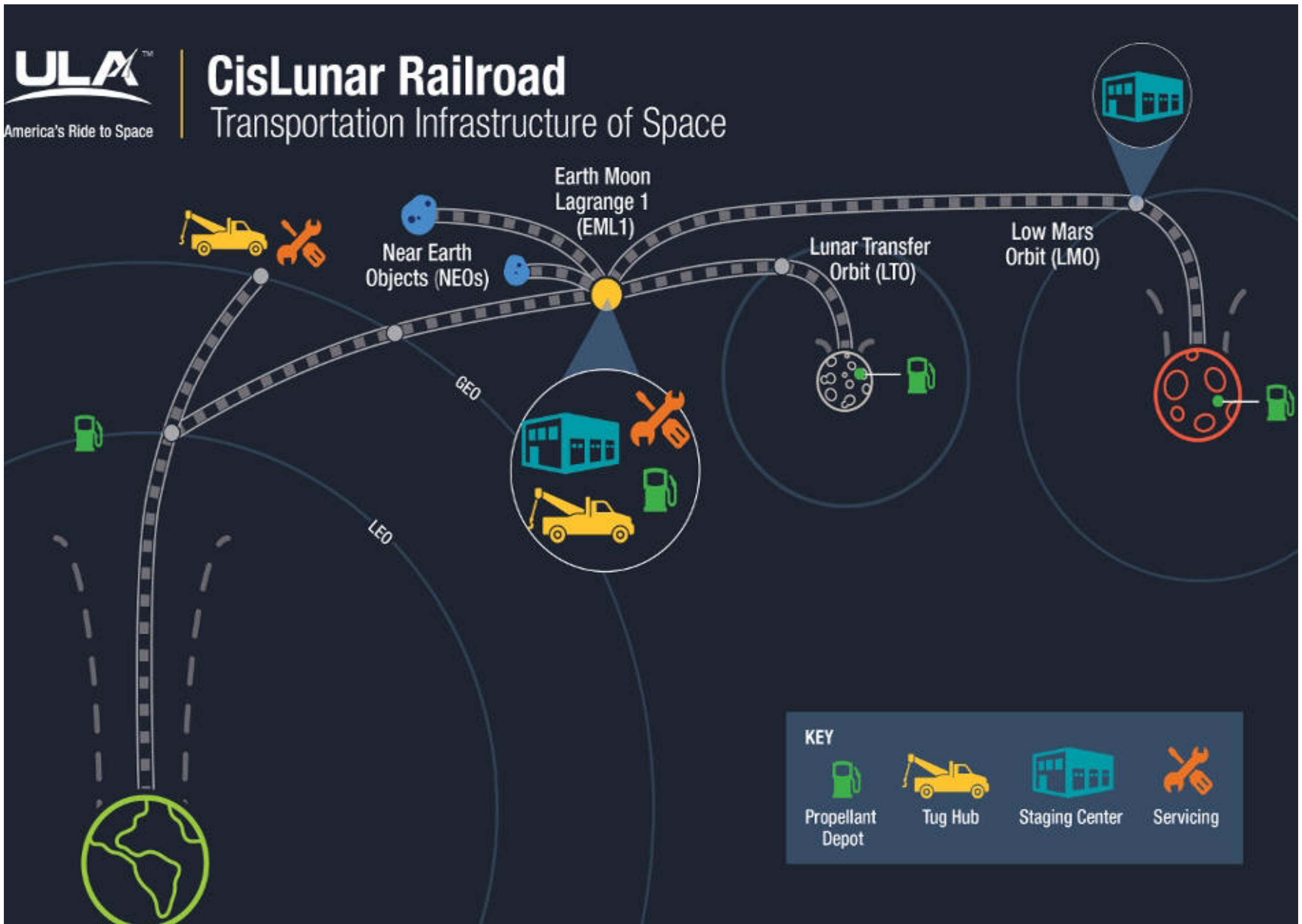
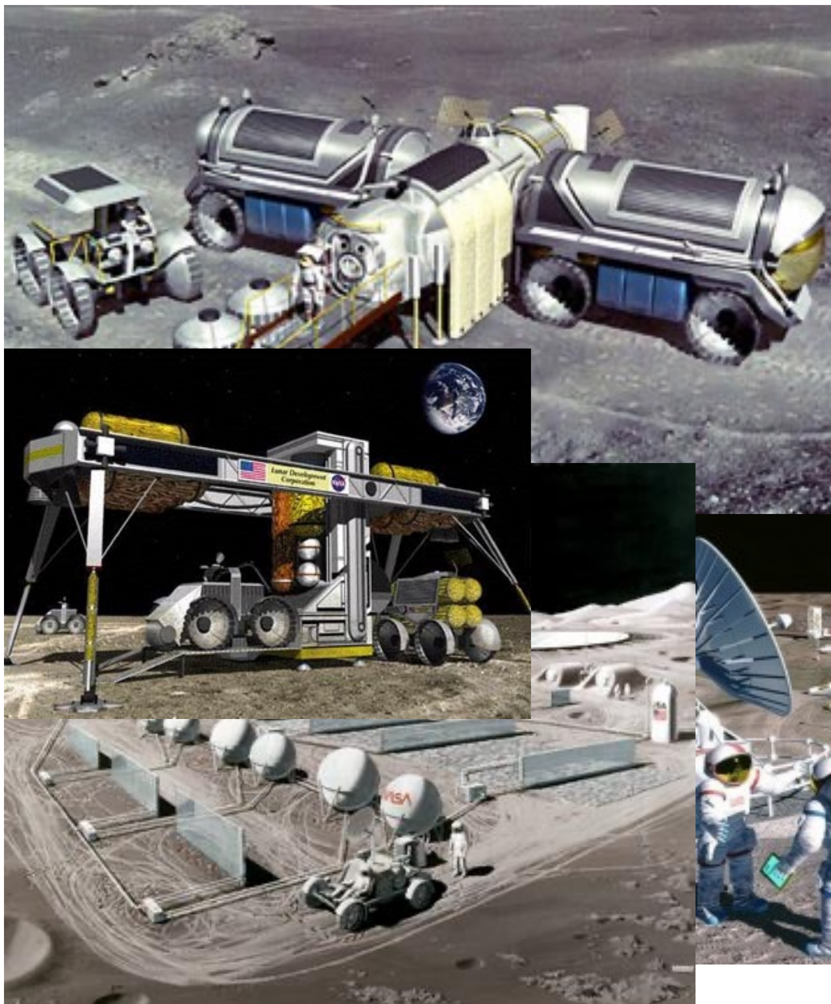
Outline

- Motivation
- Launch and Landing Pads
- Challenges
- Objectives
- Approach
- Results
- Summary
- Future Work

Motivation


ULA
America's Ride to Space
CisLunar Railroad
Transportation Infrastructure of Space
Earth Moon Lagrange 1 (EML1)
Near Earth Objects (NEOs)
Lunar Transfer Orbit (LTO)
Low Mars Orbit (LMO)
GEO
LEO
KEY
Propellant Depot
Tug Hub
Staging Center
Servicing

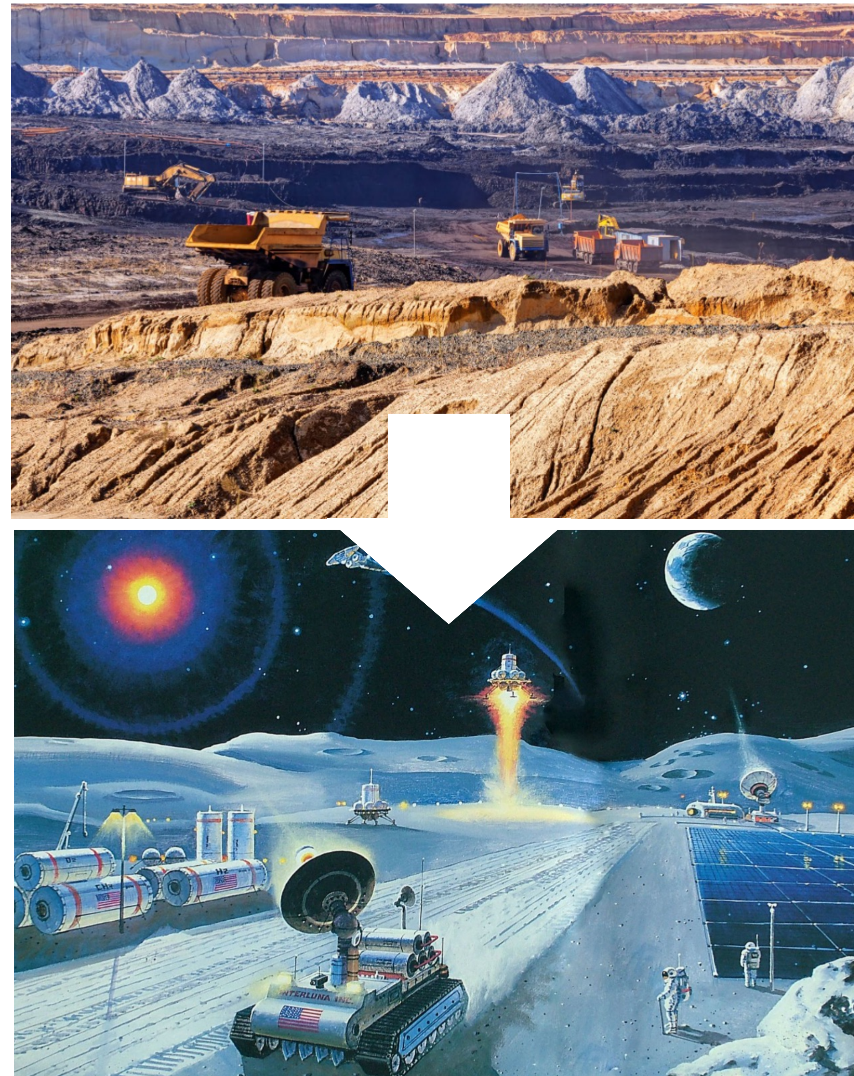
Motivation



- Refueling base at various locations in cis Lunar space
- Water electrolyzed to produce H_2 and O_2
- Fuel and raw material for transport, construction and manufacturing

Motivation

- How to practically extract resources at large scale
  - Full automation
  - Self-encapsulated
  - Extensible
  - Minimal functionality
- Can we seek out exemplars from the bio-world ?
  - What can we mimic ?
  - What do we discard ?



Importance of Launch and Landing Pads

- **Quick means of transport of goods, services, astronauts to mining sites and outposts will be critical.**
- **Launch and landing pads will be the main gateway into the base and needs to be in excellent condition.**

- Withstand high demand use
- Handle heavy and uneven loading/unloading.

Challenges

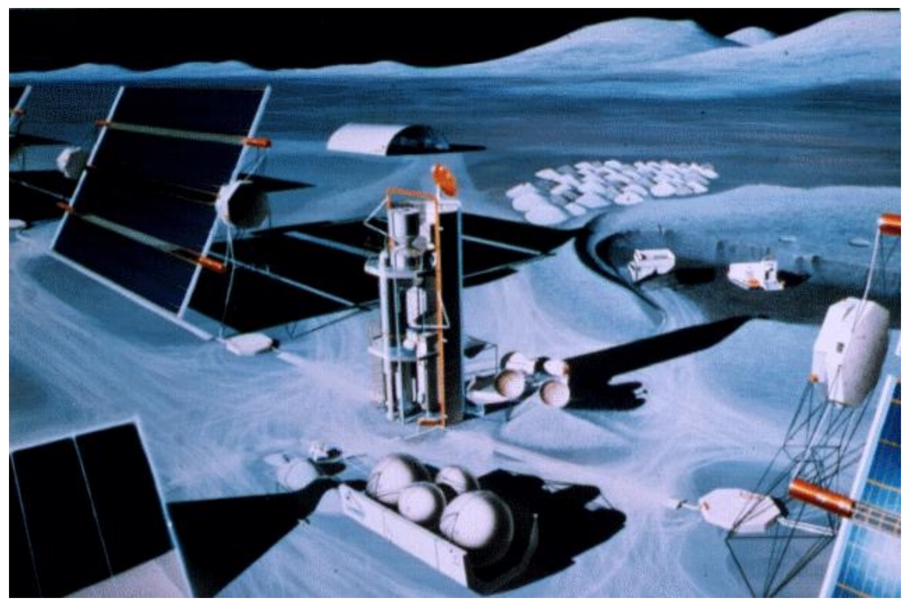
- Low gravity – low traction → low speeds
- Low cohesion sand/dust → increased wear and tear

Rutting

Windrows

Keys to Lunar Base Robotics

- Autonomous Control
  - Unstructured environments
  - Minimal supervision and task decomposition
  - In-situ adaptation
- Multiple robots
  - Cooperation
  - Specialization
  - Redundancy
  - <u>Ability to improvise</u>
- Control development
  - Adaptive, robust, little or no onsite support



From Excavation to Construction

- **Papers being presented at Earth and Space, 2022**

Objective

- Develop an autonomous robotic system to construct Lunar Landing Pads (LLP).

- Thrusts: What are the interaction behaviors needed to attain a desired global behavior for a given number of robots ?
  - Effective templates
  - Effective stigmergy (communication mediated via environment)
  - Minimal human input
  - How to deal with *antagonism ?* - negative interaction with too many robots
  - Scalable autonomy

Approach

- Biologically inspired ideas suited for design of space robotic systems

- Model of natural selection:
  - Evolutionary Algorithms [Rechenberg, 1971], [Holland, 1975]

Approach

- **Biologically inspired ideas suited for design of space robotic systems**

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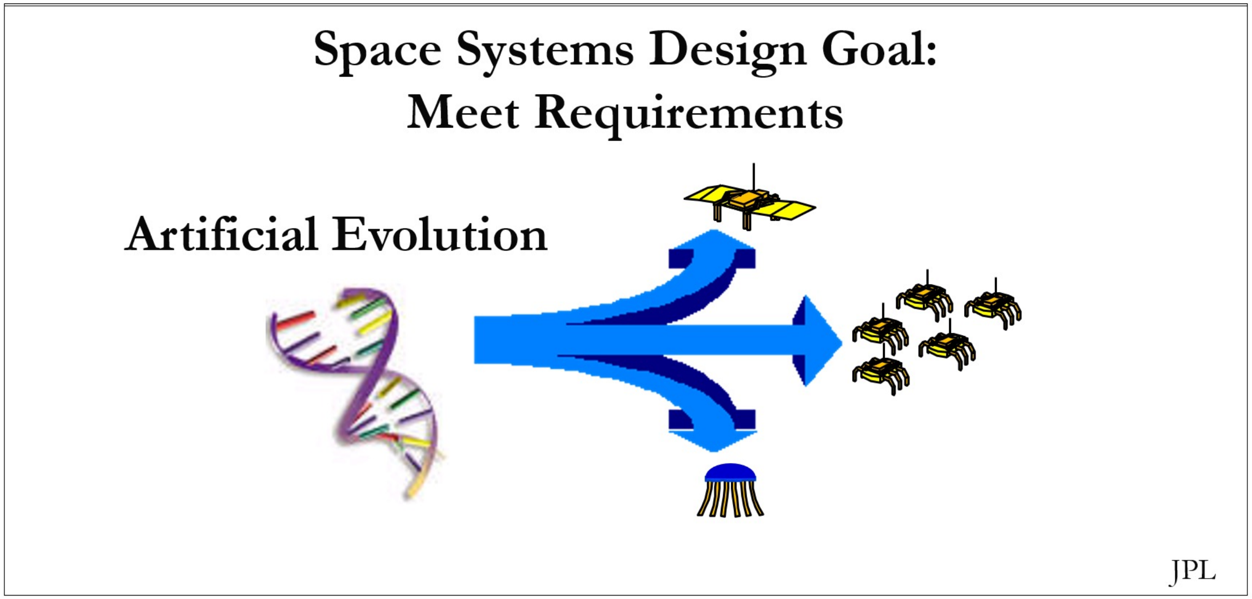


The Engineering Model: Social Insects

- "Whole greater than the sum of the parts" -Koffka
- Solve a complex task using many individuals.
- Individuals are simple, low-cost, disposable.
- They have survived for 400+ million years through 2 major extinction events.


The Engineering Model: Social Insects

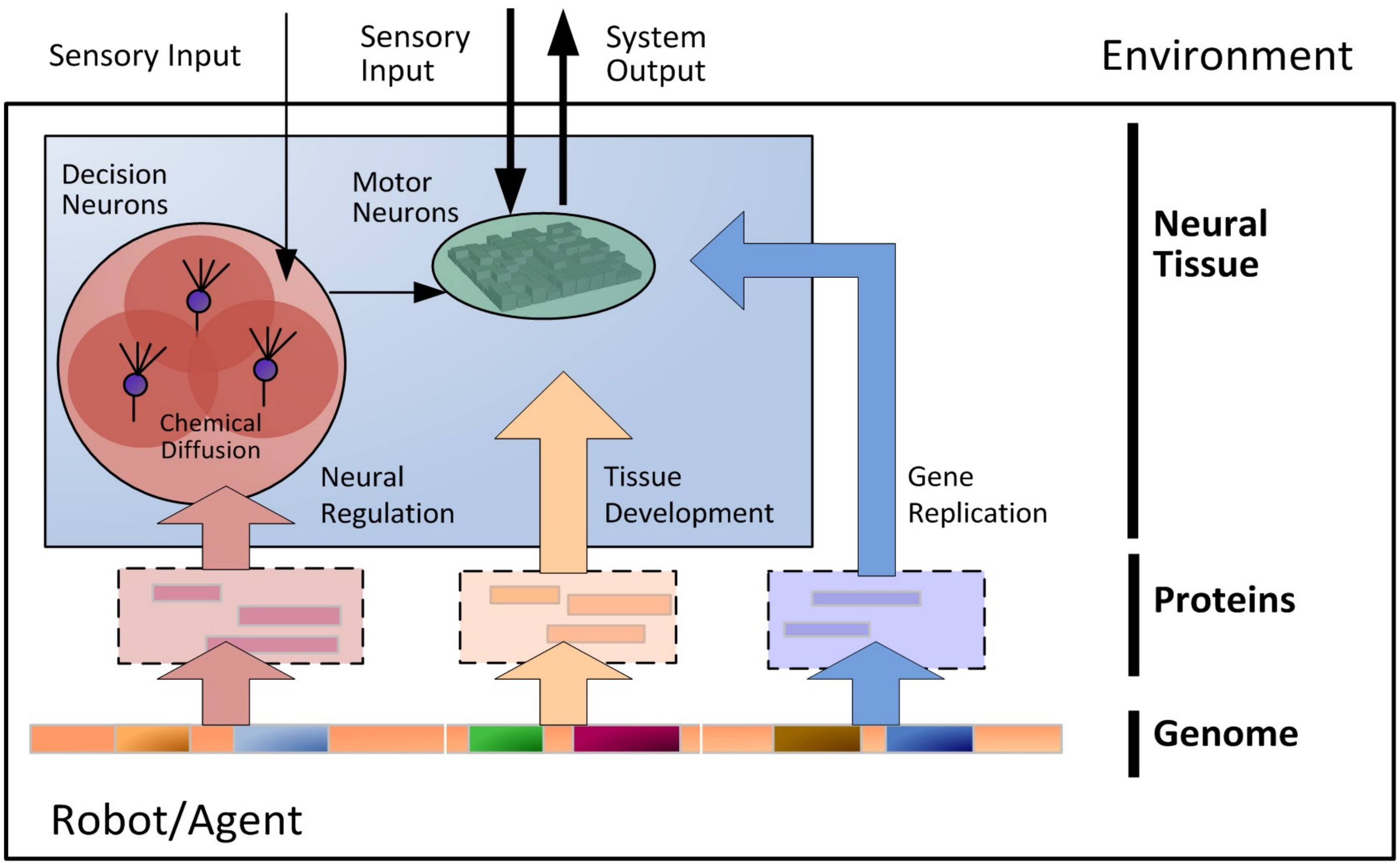
- Stigmergy
- Templates
- Self-organization


Computation Intelligence for Constructing LLPs

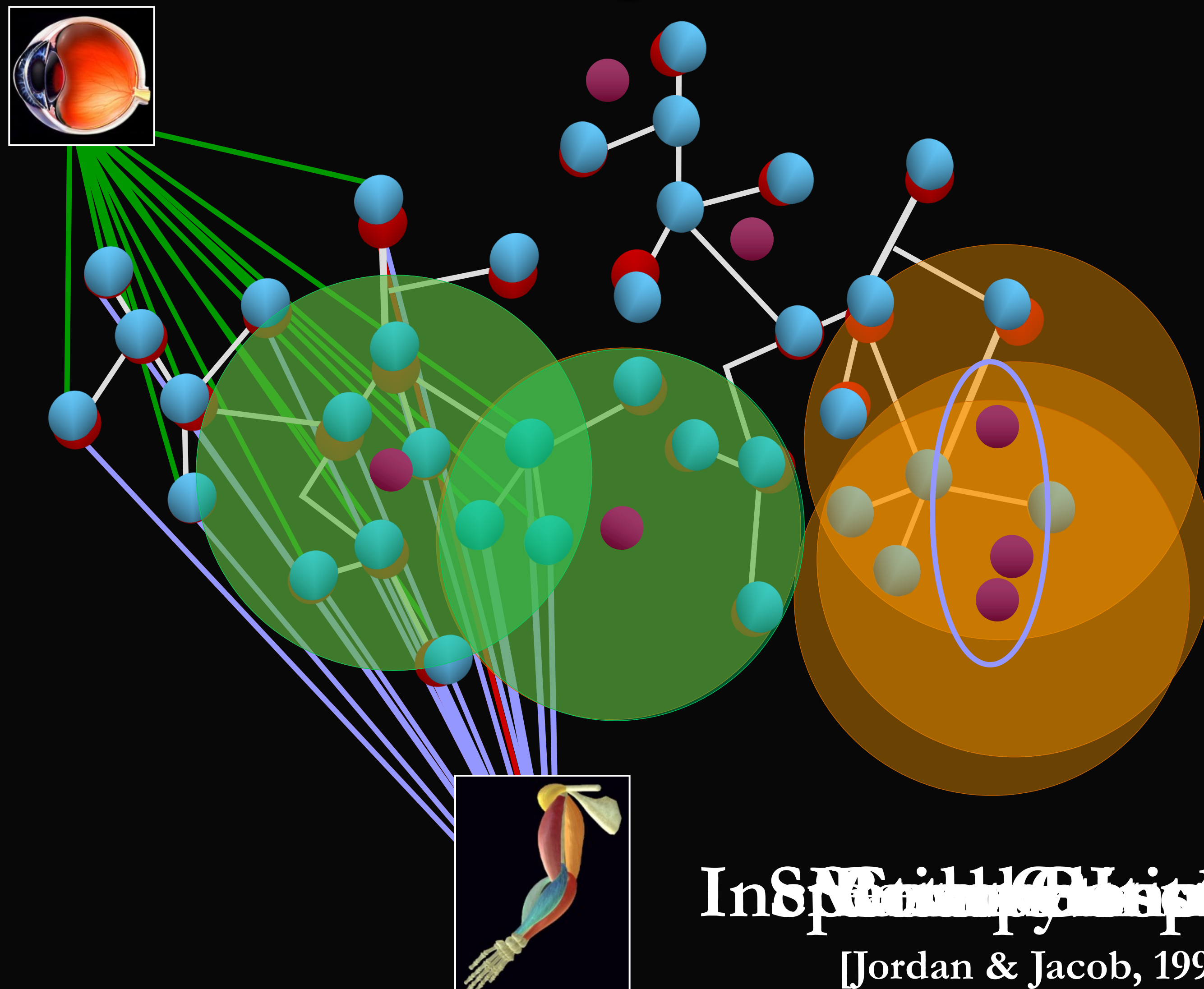
- Effective task decomposition
  - Task allocation – multiple robots
- Find solutions where little task domain knowledge available
  - Plastic
  - Creative
  - Extensible
  - Robust, scalable, multiplatform

Artificial Neural Tissues

[Thangavelautham & D'Eleuterio, 2005]

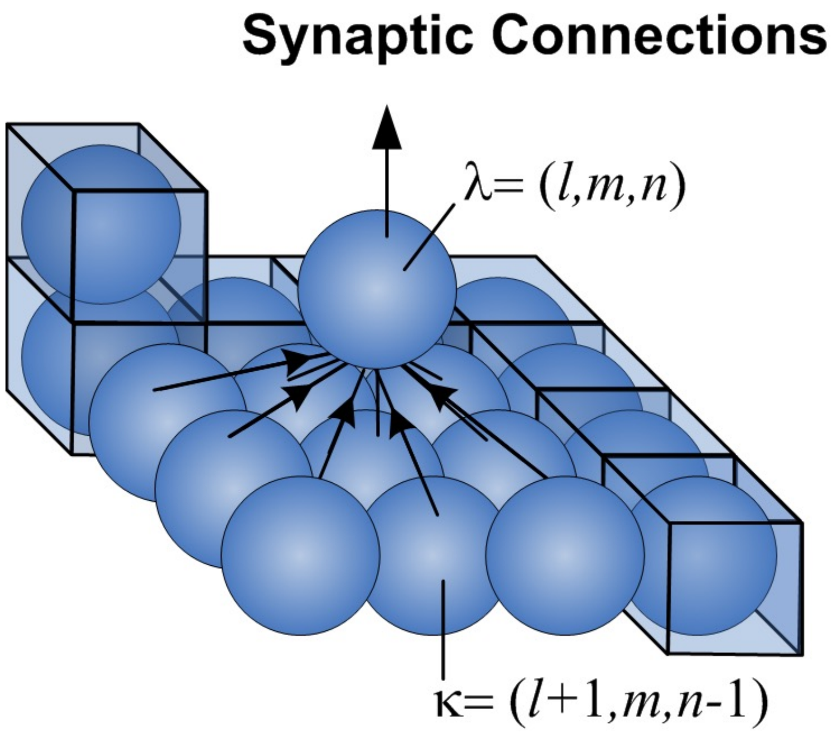


Neural Regulation

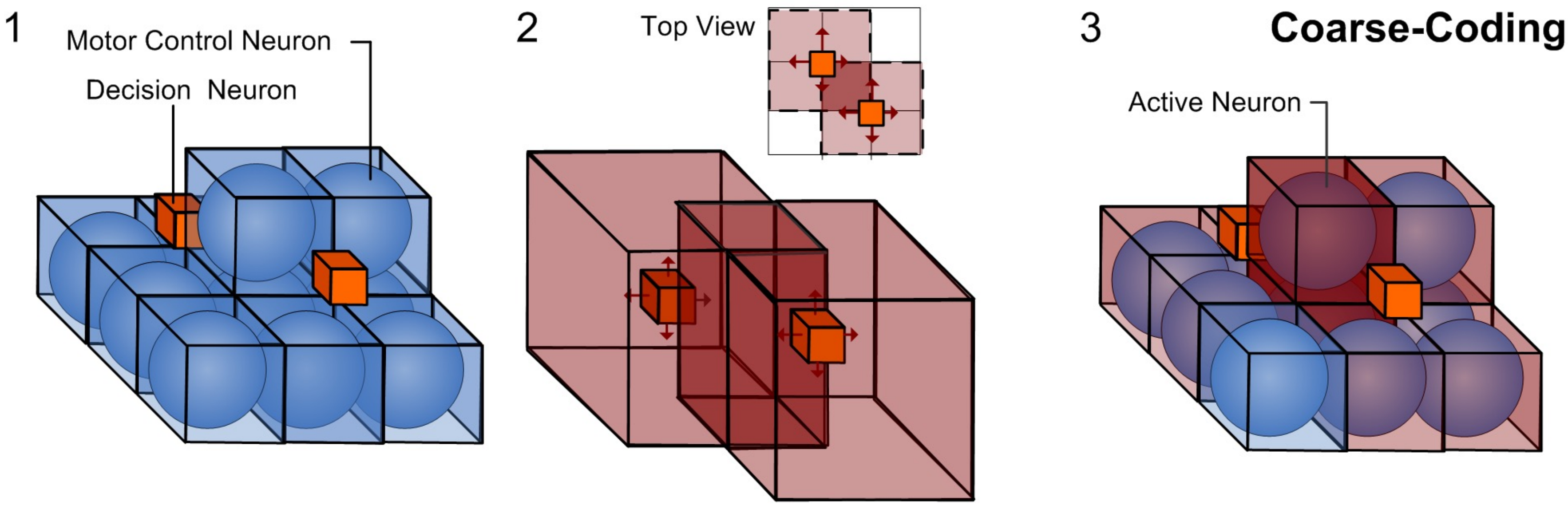


[Jordan & Jacob, 1991]

ANT Topology



Neural Regulation within ANT



Tissue Topology

Overlapping Concentration Fields
(Decision Neurons Diffuse Neurotransmitter)

Network Activation/Inhibition
(MC Neurons with Highest Concentration Activated)

Partner

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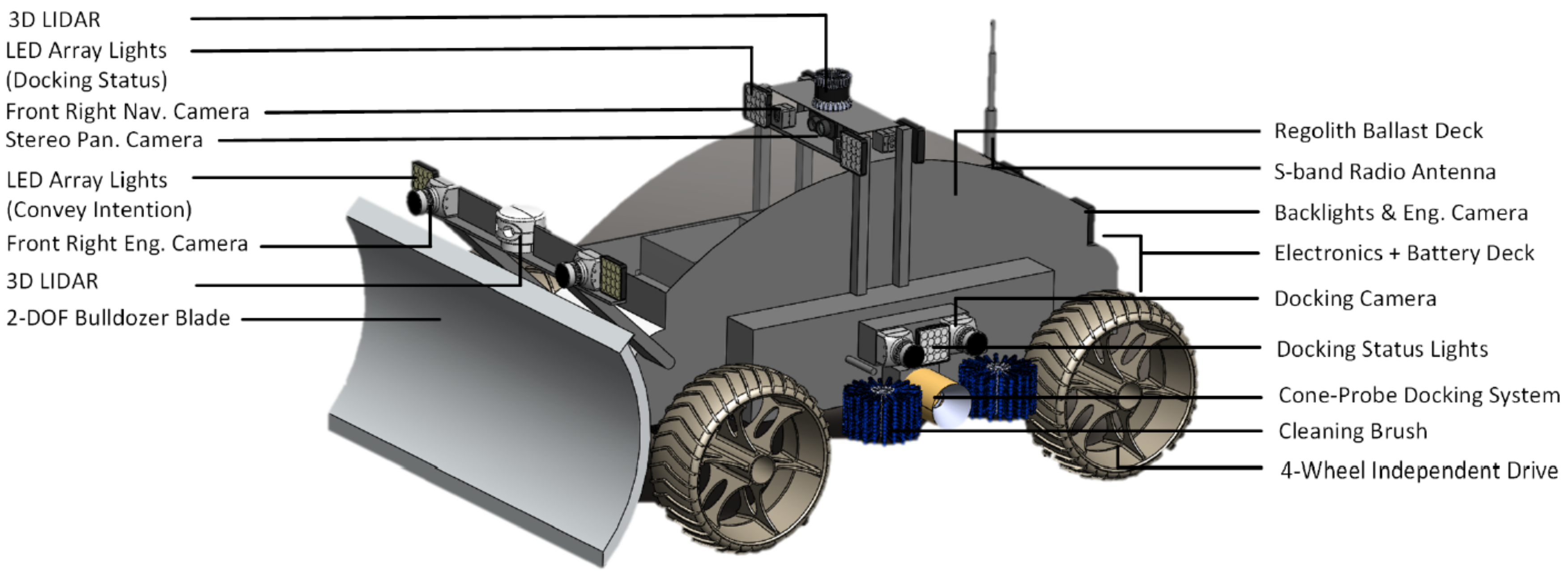
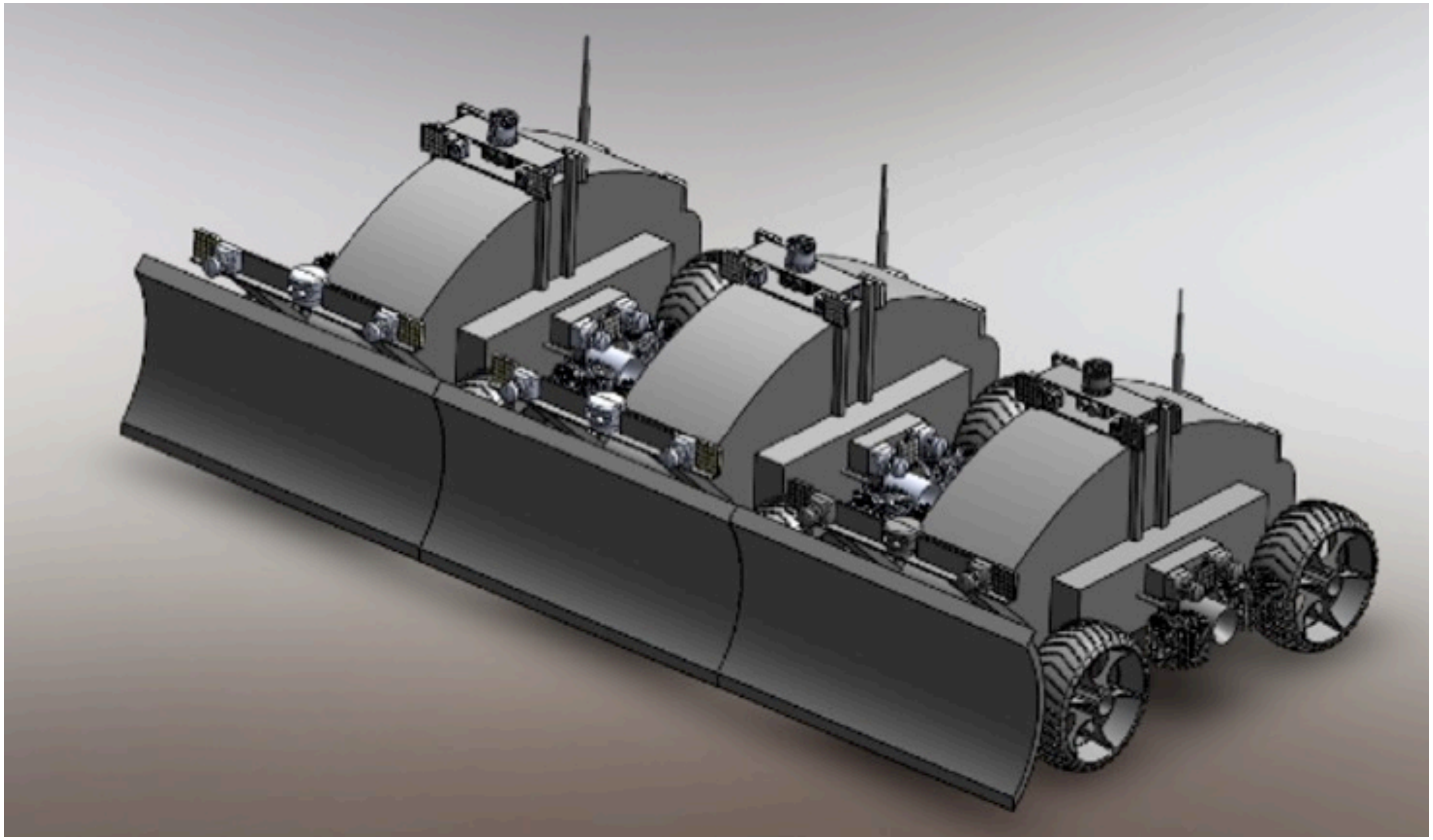
Landing Pad Construction Robot



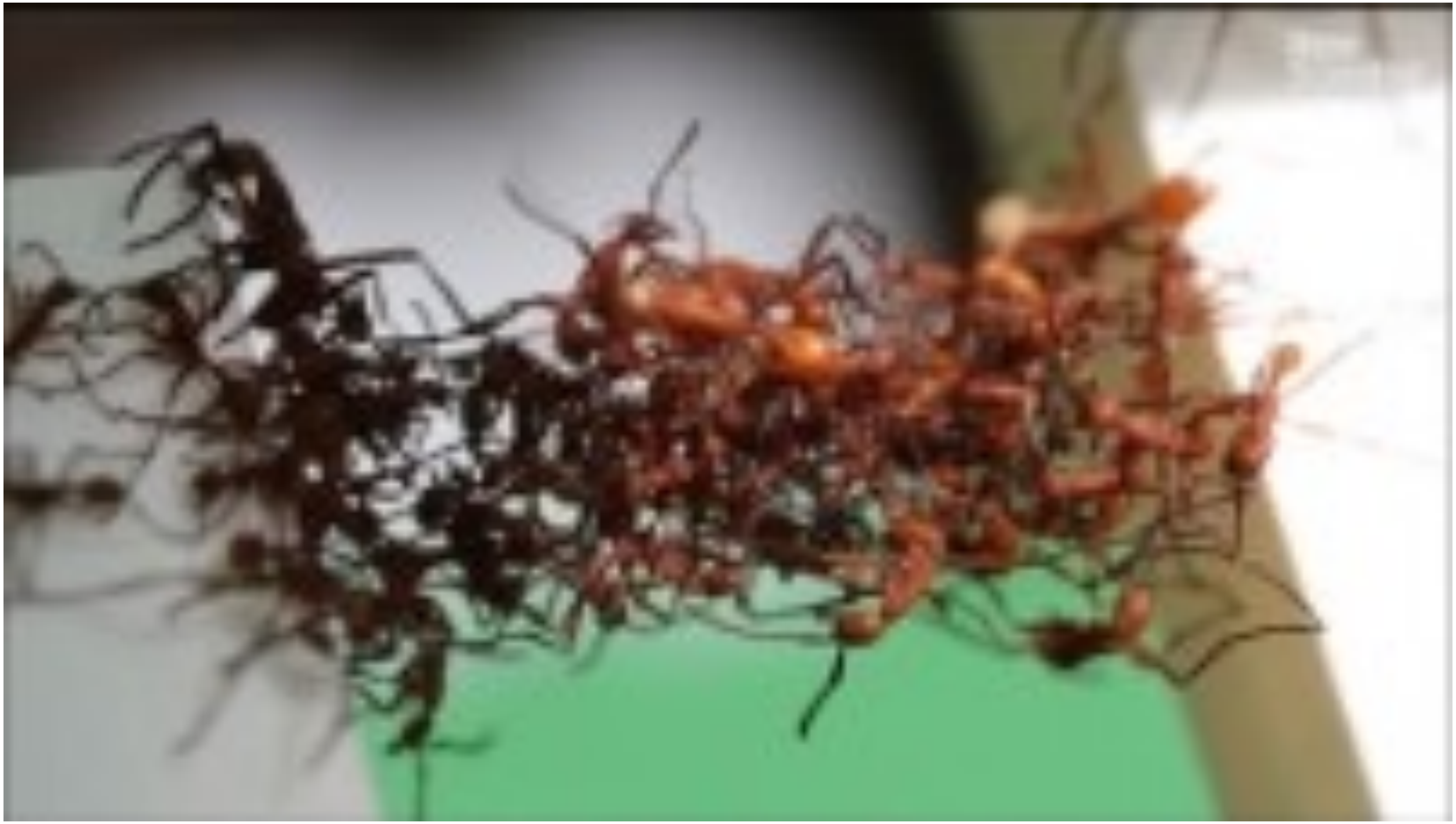
Chaining



Why Chaining and Aggregation ?

- Chaining is form of an aggregation strategy
- Requires close coordination but provides x advantage
- Ancient Romans used Turtle Formations with great success in battle.
- Ants use it as bridges, transport of large objects and a general defensive strategy against a larger threat.

Ant Chaining Behavior

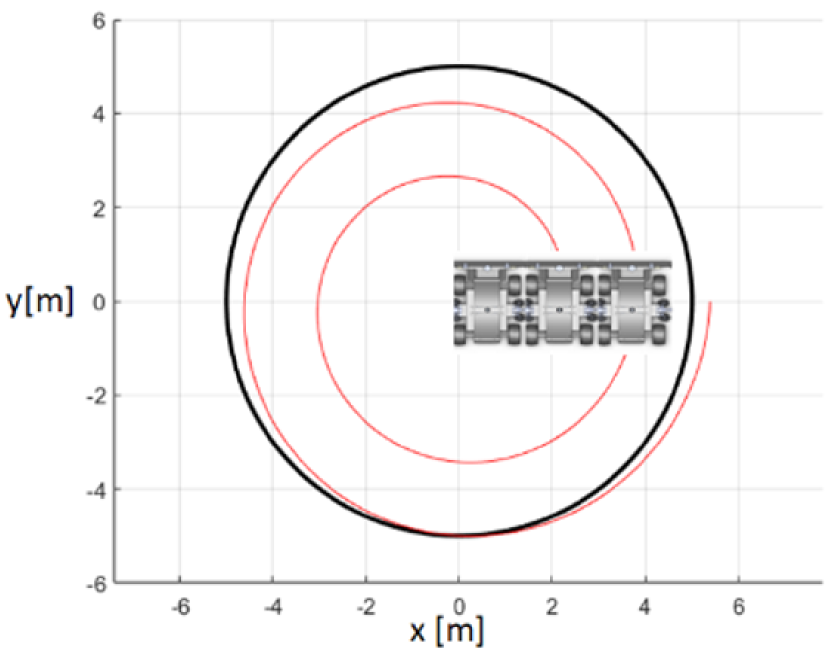


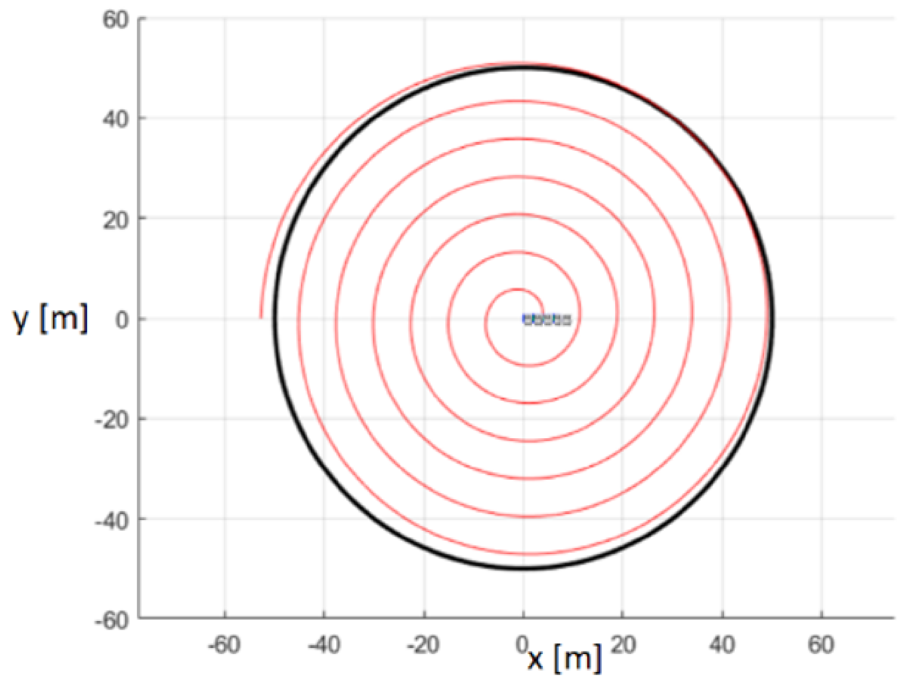
Why Chaining ?

- The robots can work cooperatively to clear the landing pad space – avoid antagonism
- Exploit the advantage of parallelism
- Load evenly distributed.
- Reduced windrows per unit area.

- Challenge:
- How to coordinate the robots
- How physically place them next to each other.

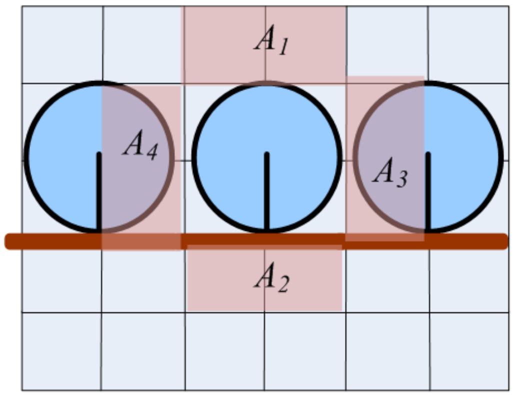
Landing Pad Construction Strategy



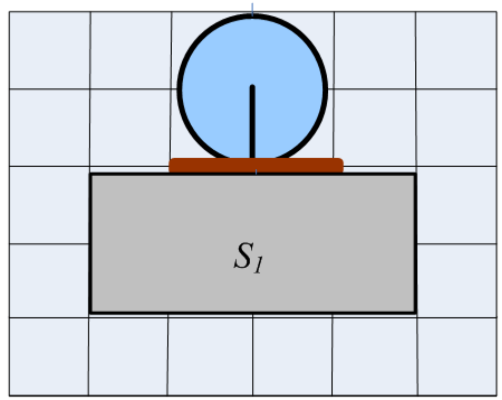


Sensor Inputs

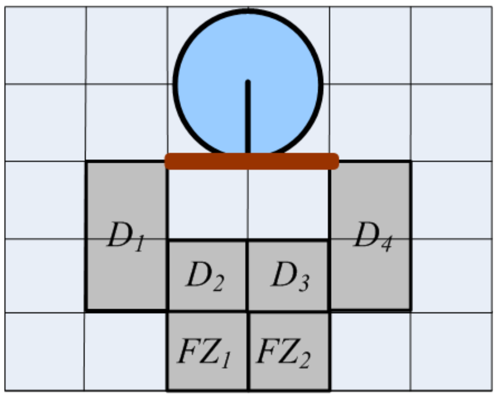
Robot Alignment



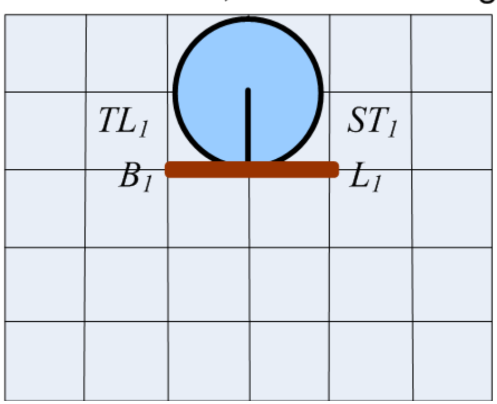
Obstacle Avoidance



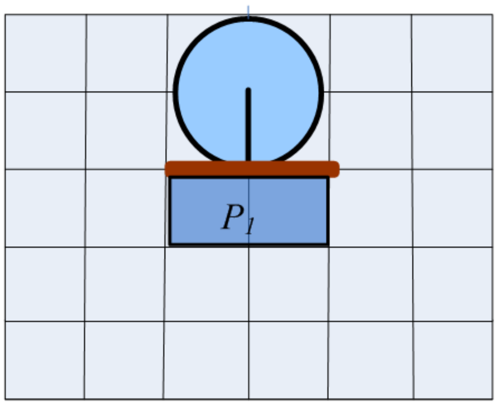
Depth Sensing



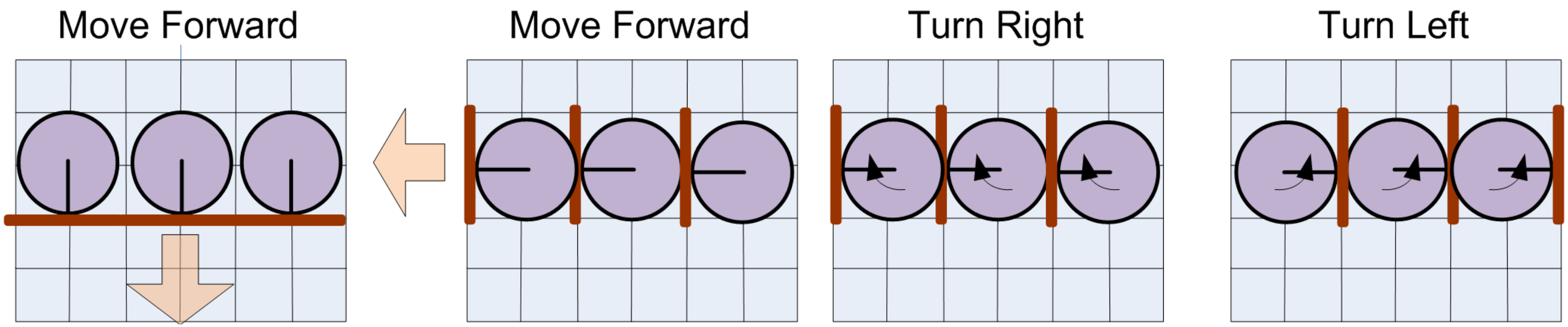
Blade Position, Motion Sensing



Place Memory



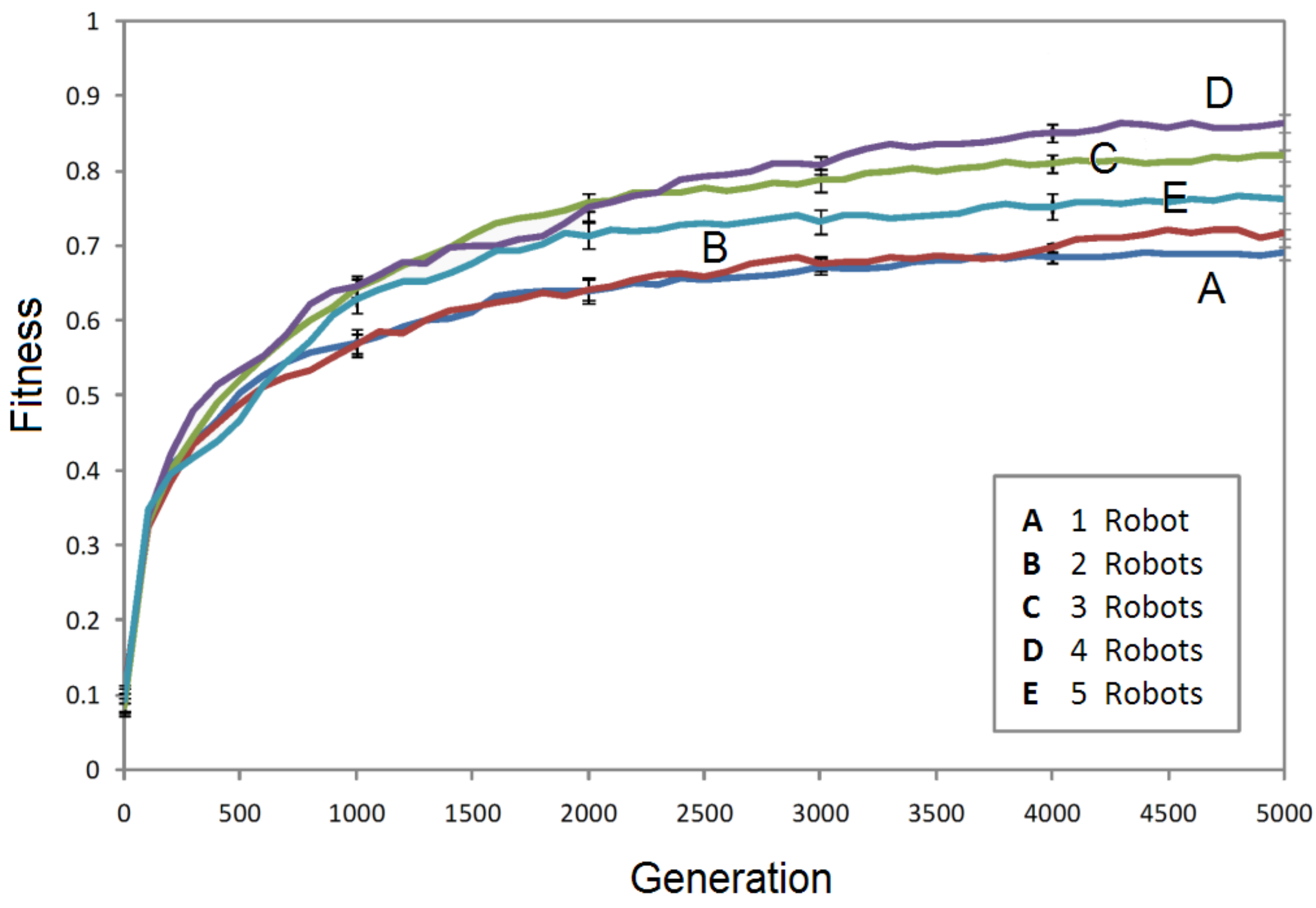
Chained Movement



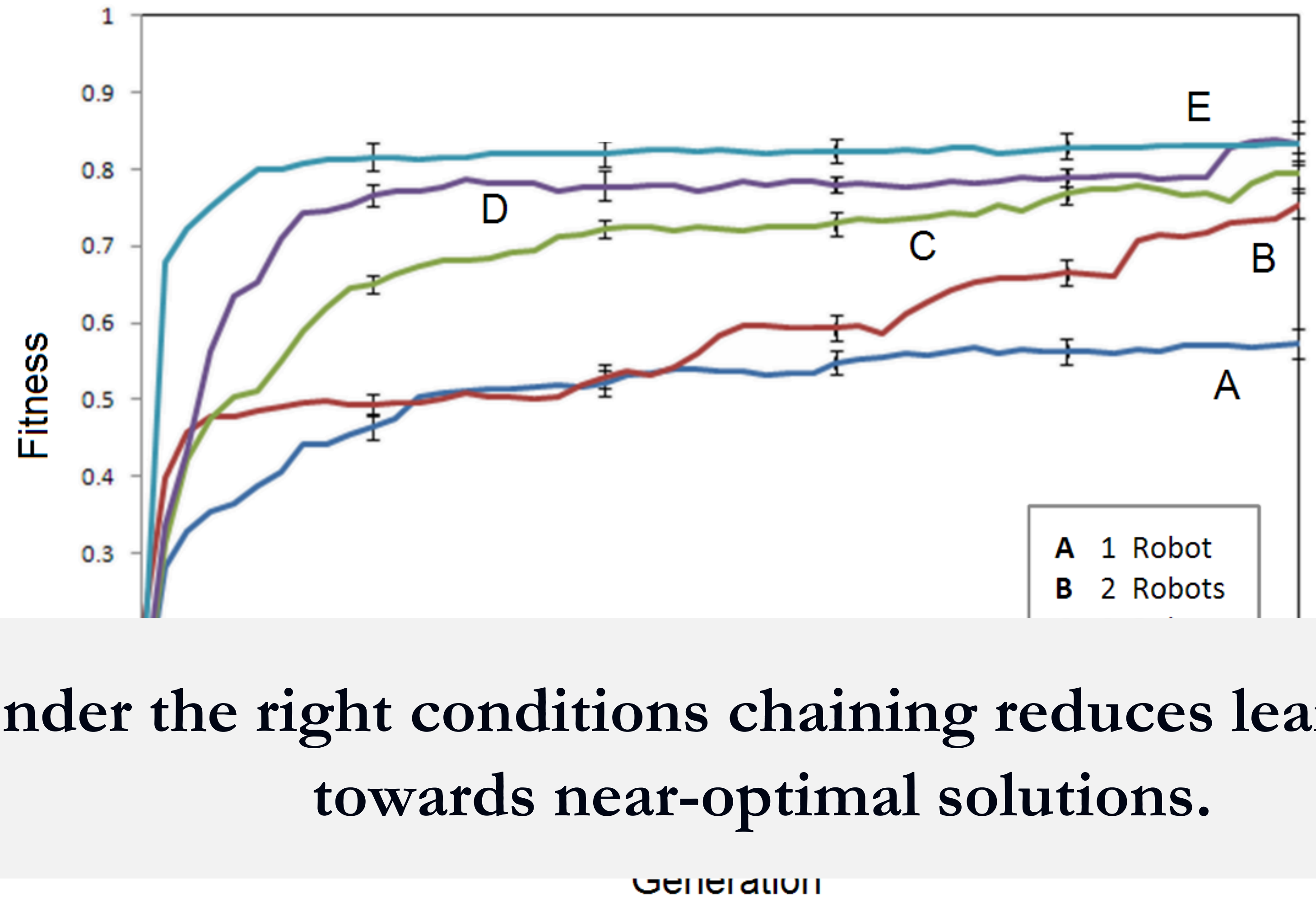
Task Specification

- Robots given blueprint of site to excavate/clear. Also includes site for dumping regolith.
- Blueprint specifies depth, grade, and don't care areas.
- The task is time limited.
- Evolutionary training involves evaluation of 100+ scenarios.
- Robots cannot collide.
- Robots cannot get buried in regolith.

Evolution – No Chaining

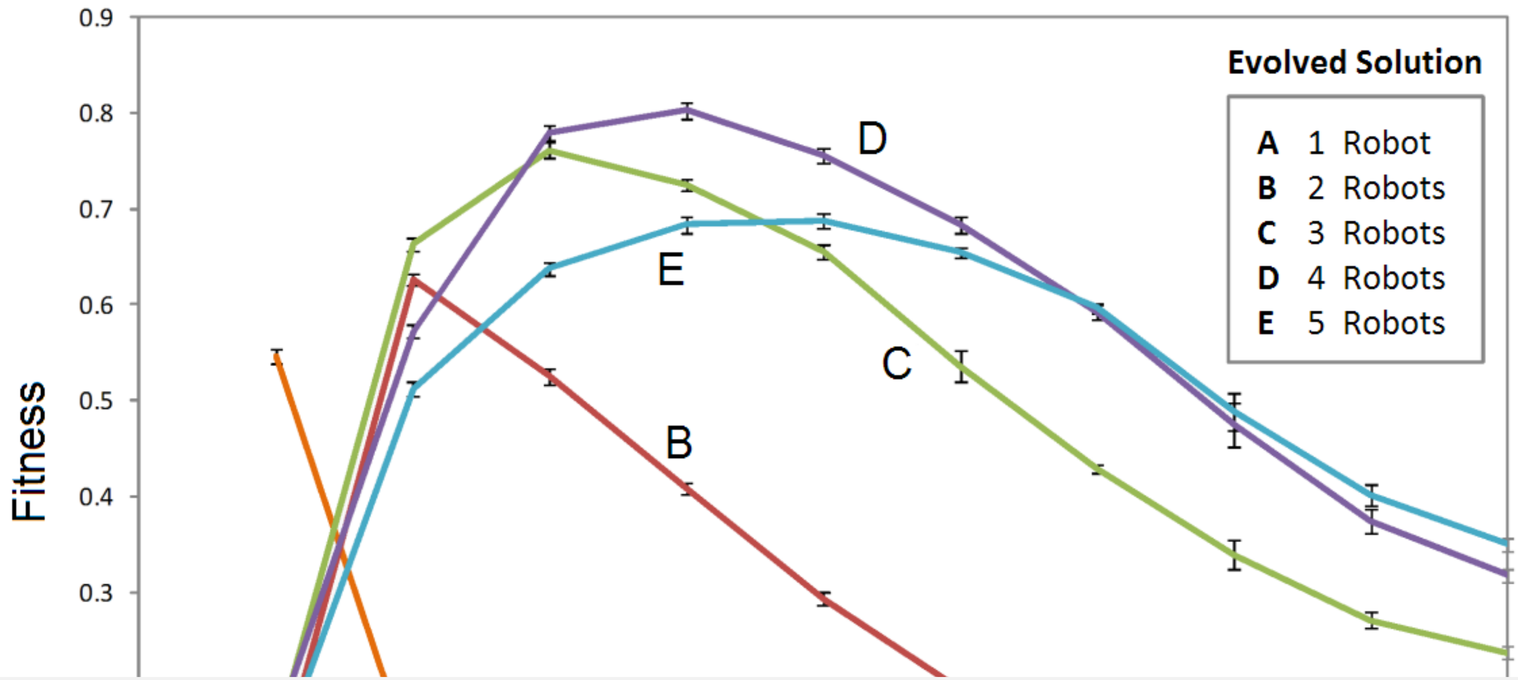


Evolution - Chaining



Under the right conditions chaining reduces learning time towards near-optimal solutions.

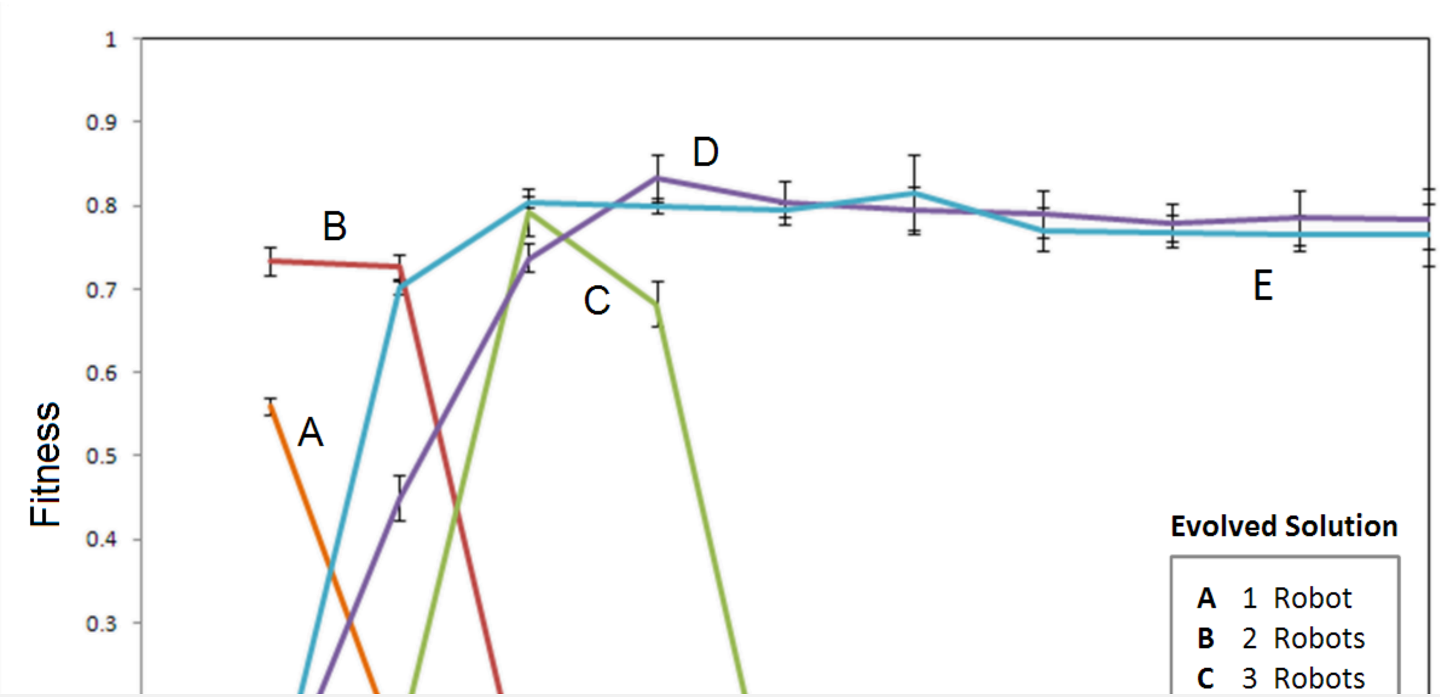
Scalability – No Chaining



Reduced performance with too few robots due to insufficient labor. Too many robots and we have antagonism.

Robots (Rescaled)

Scalability – Chaining

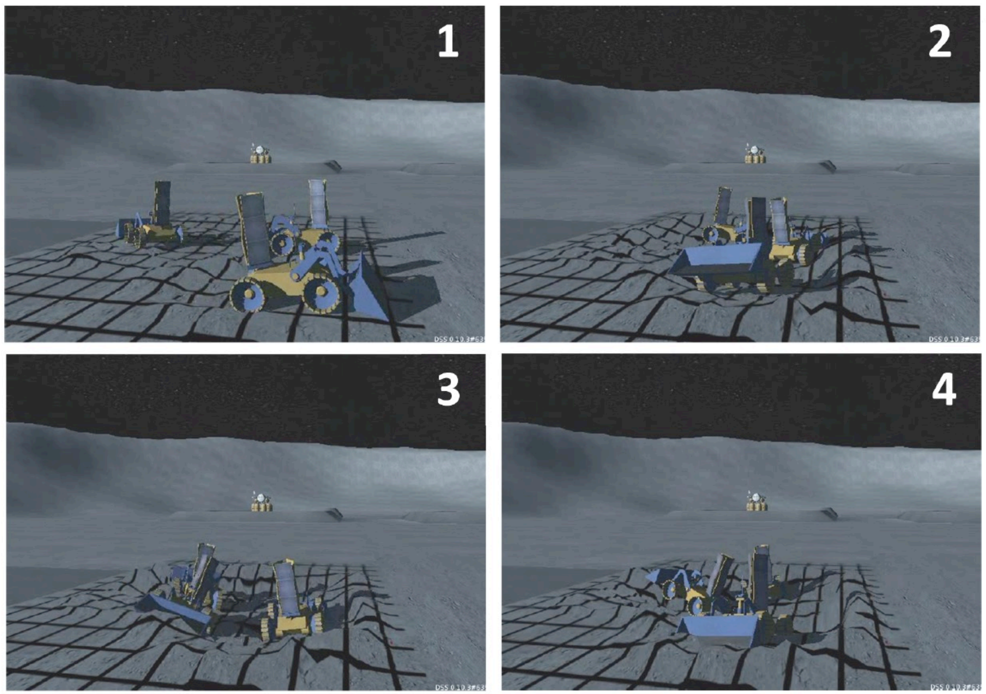


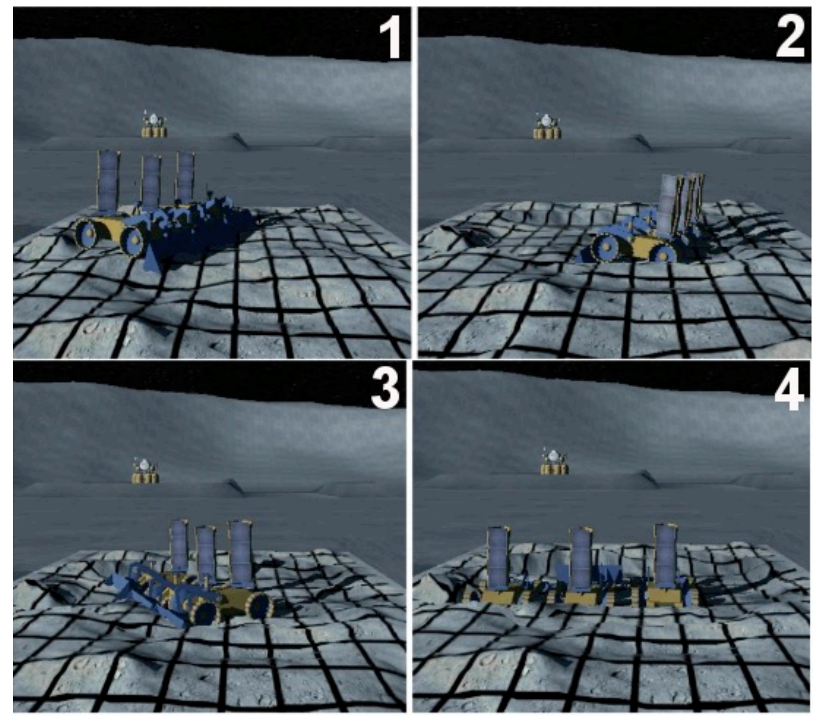
Antagonism can be significantly reduced and chaining is an advantage over a decentralized approach.

Lab Experiment Comparison

- Chaining approach effective at clearing windrows.
- Unlikely to get stuck in closed loop that limits area coverage.

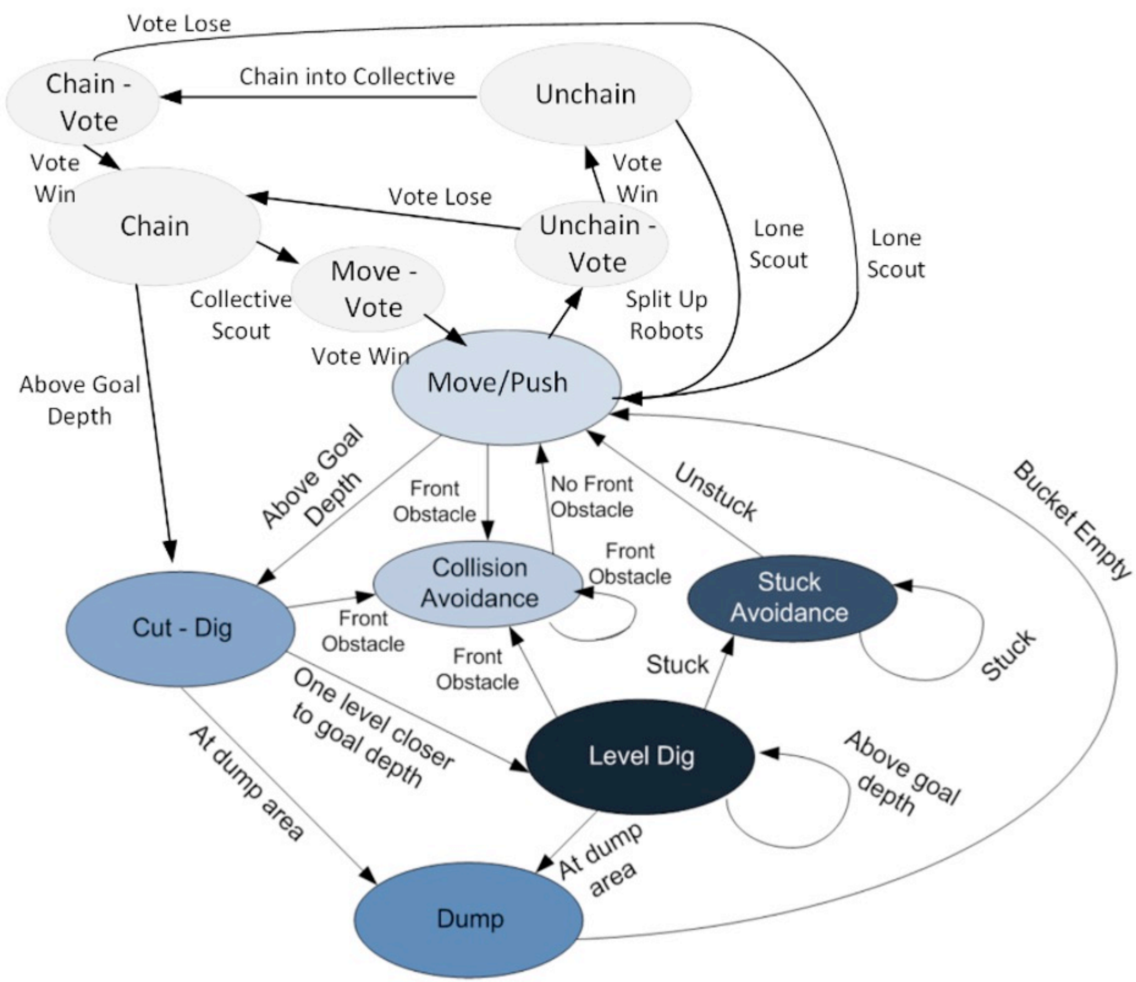
High Fidelity Simulations





- Chaining approach shows increased quality (flatness, contiguous) and requires reduced time for clearing an area.

Finite State Machine Controller Derived from ANT

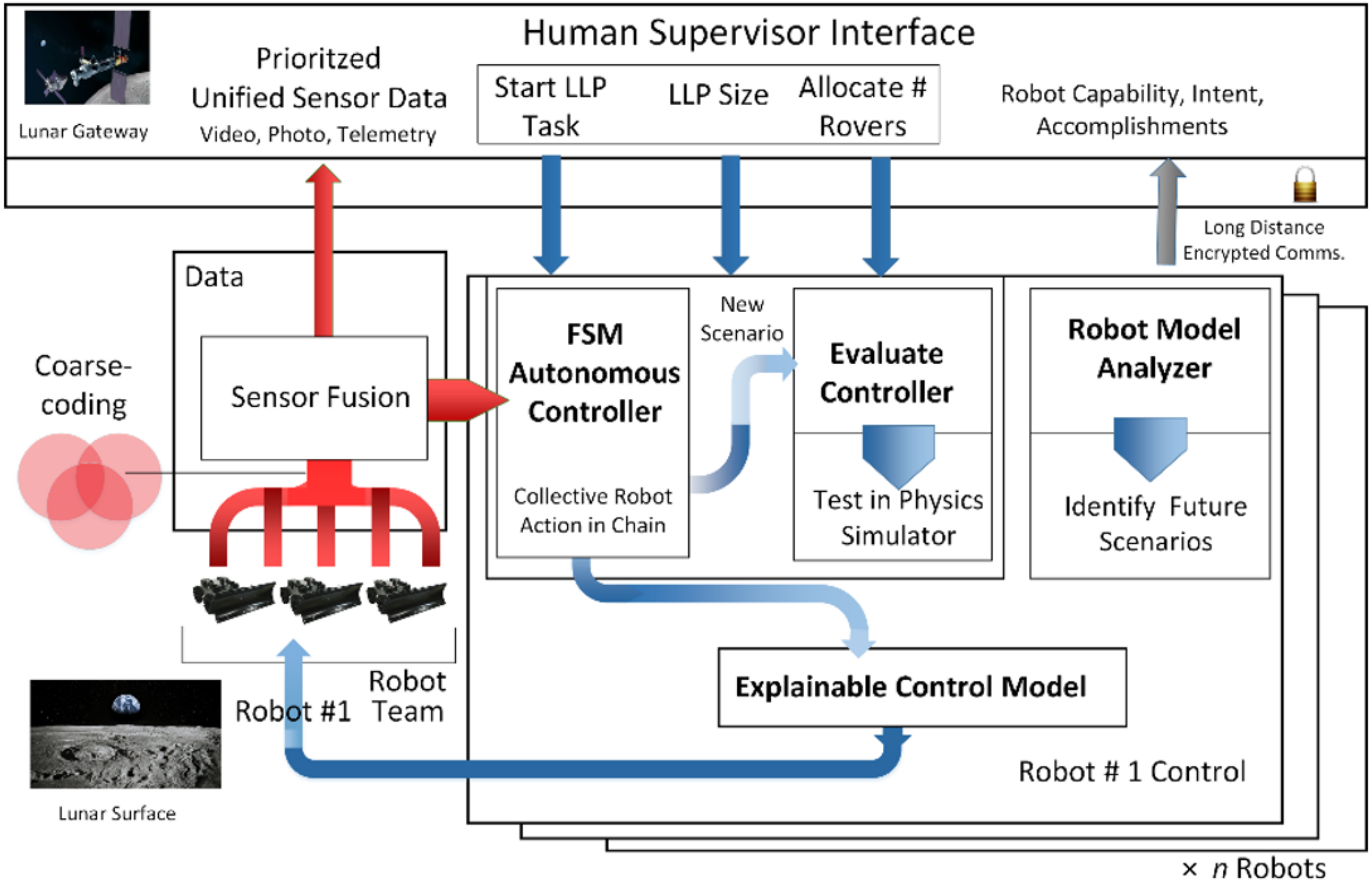


- Captures key behaviors
- FSM easy to understand
- Easy to port.
- Helps with prediction

Partner

SpaceTREx

Implementation on a Mission



Discussion

- Chaining/aggregation approach shows promising results for area clearing tasks.
  - Increased quality, reduced time due to increased efficiency.
  - Avoids antagonism
- Experiments have shown it clear windrows. It has the potential to reduce rutting. More experiments needed.
- Challenge is how to implement on real robots without substantial increase in complexity.
  - Deal with large obstacles that may require unchaining (?)

Future Work

- Physical comparison of several candidate chaining methods including using docking.
- Evaluation of robots performing chaining, dispersal and chaining.
- Construction of half or third scale rover team for the landing pad construction task.


SpaceTREx
Adventure Awaits

Thank You!

Questions ?

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LABORATORY

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