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Department of Informatics

Intelligent Gait Adaptation in Malfunctioning Robots

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Technical Aspects of Multimodal Systems

19. November 2018

doobybrain.com

What does it mean to intelligently adapt the gait of a malfunctioning robot?

- **Gait**: repetitive forward walking motion at a particular speed.
- **Malfunctioning Robot**: e.g. a damaged joint.
- **Adaptation**: change behavior in response to abnormal conditions.
- **Intelligence**: the application of machine learning algorithms.

Outline

1. Getting to know the problem
2. Classical solutions
3. Intelligent solutions
4. Intelligent Trial & Error algorithm
5. Reset Free Trial & Error algorithm
6. Comparing solutions
7. Summary

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Problem Scenarios

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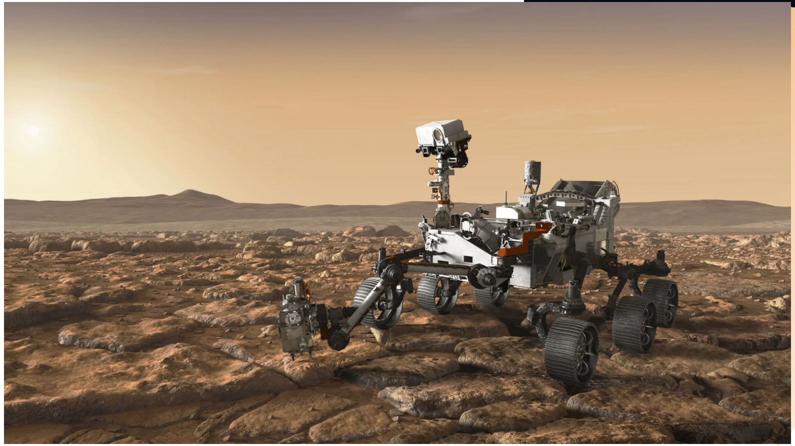

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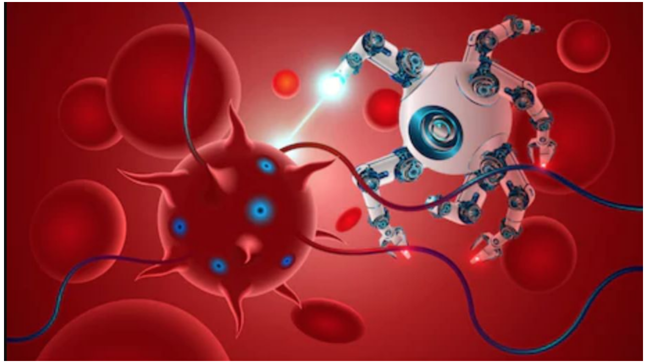
Space Exploration

Problem Scenarios



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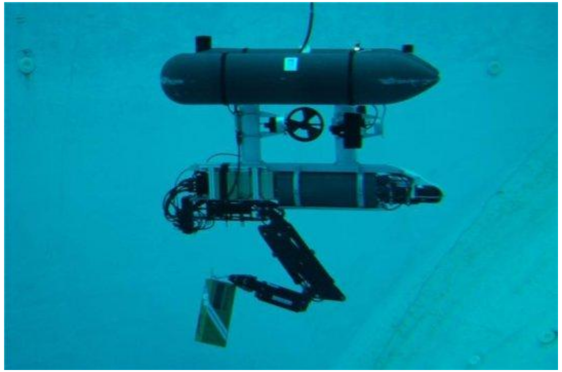
Health Care



Sciencedaily.com

Deep Sea Exploration

army.mil

Search & Rescue

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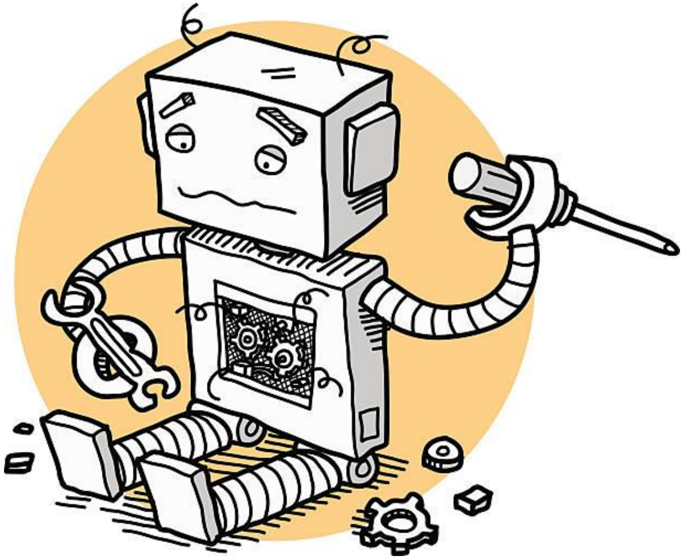
Classical Solutions



1. Robot programmed to achieve an objective
2. Robot aware of the possible ways it could malfunction
3. Robot aware of possible ways to compensate for each malfunction
4. Robot malfunctions
5. Robot uses sensors to diagnose the malfunction
6. Robot resets itself
7. Robot reprograms itself to compensate for the malfunction
8. Robot proceeds with objective

Problems with Classical Solutions

- Not scalable:
  - More complex robots → more possible ways to malfunction
  - More solutions to store → state space grows exponentially

- Expensive to build:
  - More malfunctions to diagnose → more sensors required
  - More state to keep track of → large and expensive storage system

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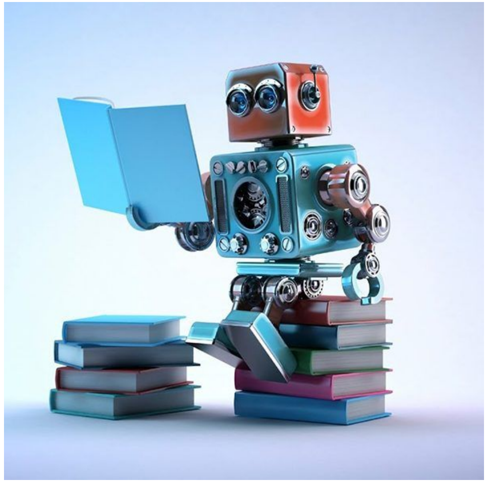
Intelligent Solutions

Goal: Overcome problems that face classical solutions:
- Avoid the diagnostic step completely
- Learn to compensate dynamically

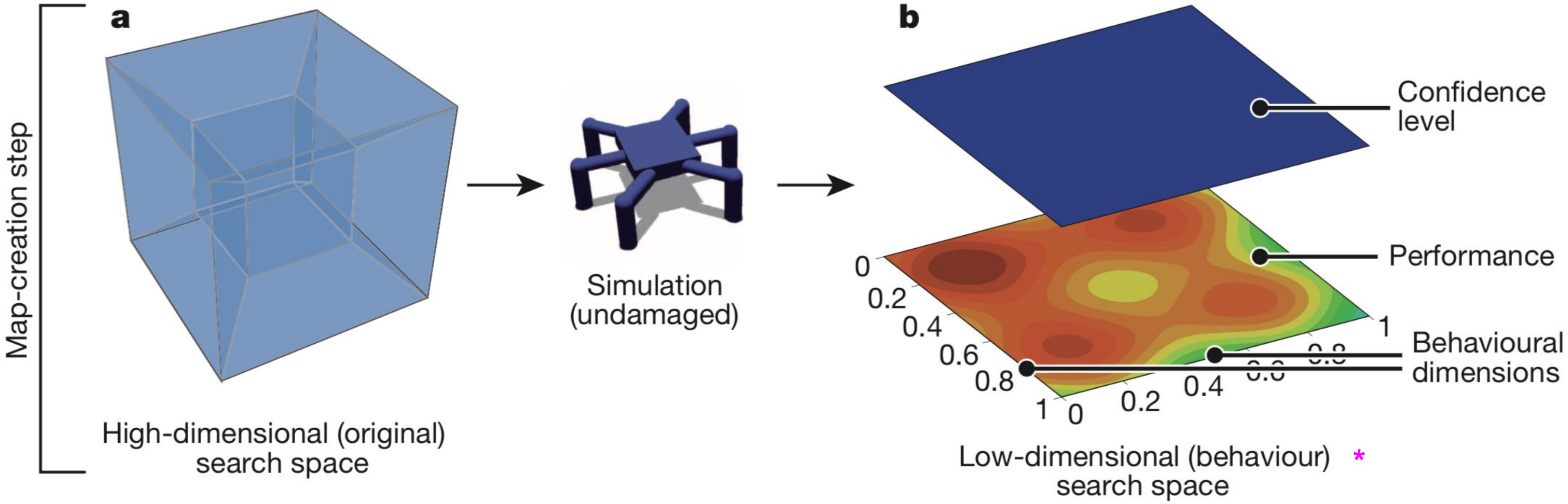
Often use machine learning algorithms to accomplish this:
- Reinforcement learning
- Policy search (direct, model-based, episodic, etc.)
- …

Intelligent solutions typically consist of two phases:
- Offline: Simulation & map building
- Online: Real-world application & adaptation



jinnovations.ca

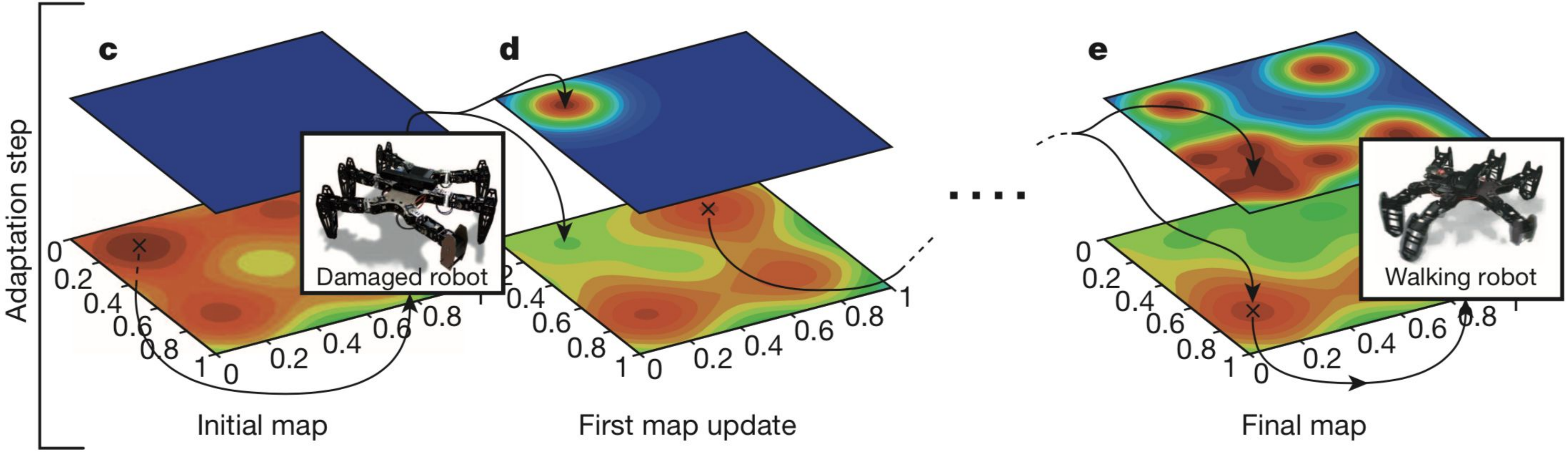
Simulation & Map Building



Cully, Antoine et al. “Robots That Can Adapt Like Animals.” Nature 521.7553 (2015): 503–507.

Real-world Application & Adaptation *

Detect → Look Up → Try → Repeat



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Intelligent Solutions

[Video Demonstration]

Clips are taken from:
https://www.youtube.com/watch?v=UZXSSHZtLFc

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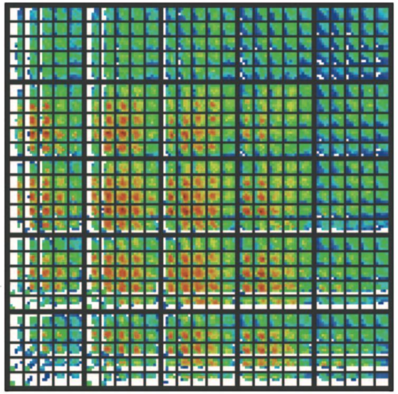
Intelligent Trial & Error Algorithm

Introduces two new algorithms:

- Simulation → MAP-Elites
- Adaptation → Map-Based Bayesian Optimization (M-BOA)

MAP-Elites

Input: High-dimensional search space
Output: Behavior-performance map



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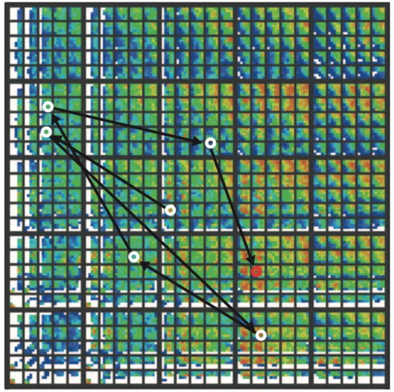
- Create an empty behavior-performance map.
- Each location in the map represents the performance of a possible solution.
- Seed Phase:
  → generate a set of random candidate solutions.
  → evaluate each solution and record its performance in the map.
- Mutation Phase:
  → pick an existing solution at random from the map.
  → randomly mutate a copy of that solution.
  → evaluate that mutated solution and record its performance in the map.
  → repeat until a stopping procedure is met (e.g. time, # iterations).

Map-Based Bayesian Optimization

Input: Behavior-performance map & live sensor data
Output: A high performing solution to compensate for a malfunction



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- Triggered by a dip in the robot's performance.
- Measures the current behavior of the robot using live sensor data.
- Looks up a solution from the behavior map.
- Tries the solution and measures its performance.
- If this solution does not perform well enough…
    - Updates the behavior map with the observed performance.
    - Continues to try **similar** solutions until a high performing solution is found.
    - Bayesian optimization is used to search for these similar solutions.

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Reset Free Trial & Error Algorithm

Reset-Free Trial-and-Error Learning for Robot Damage Recovery

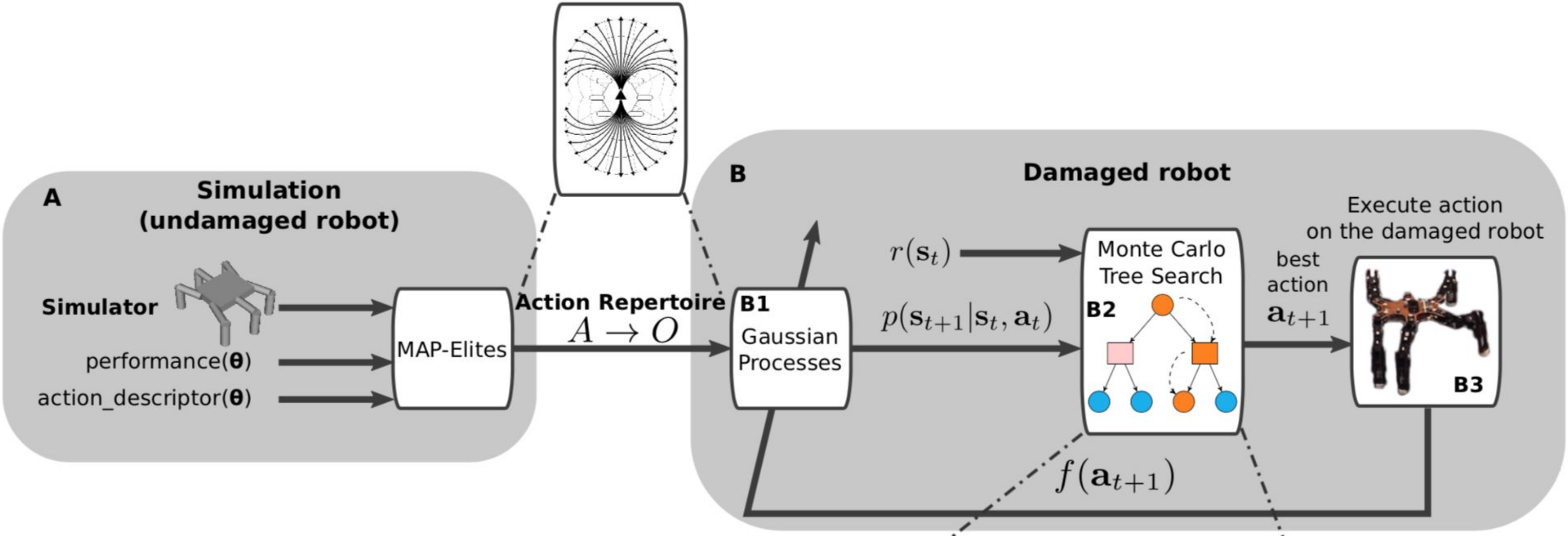
Konstantinos Chatzilygeroudis, Vassilis Vassiliades, and Jean-Baptiste Mouret

1 Inria Nancy - Grand Est, France
2 CNRS, France
3 Université de Lorraine, France

Elsevier B.V., 2017

- Simulation → Reuses MAP-Elites
- Adaptation → Replaces M-BOA with Monte Carlo Tree Search (MCTS)

Reset Free Trial & Error Algorithm



Chatzilygeroudis, et al. "Reset-Free Trial-and-Error Learning for Robot Damage Recovery." Robotics and Autonomous Systems 100 (2018): 236–250.

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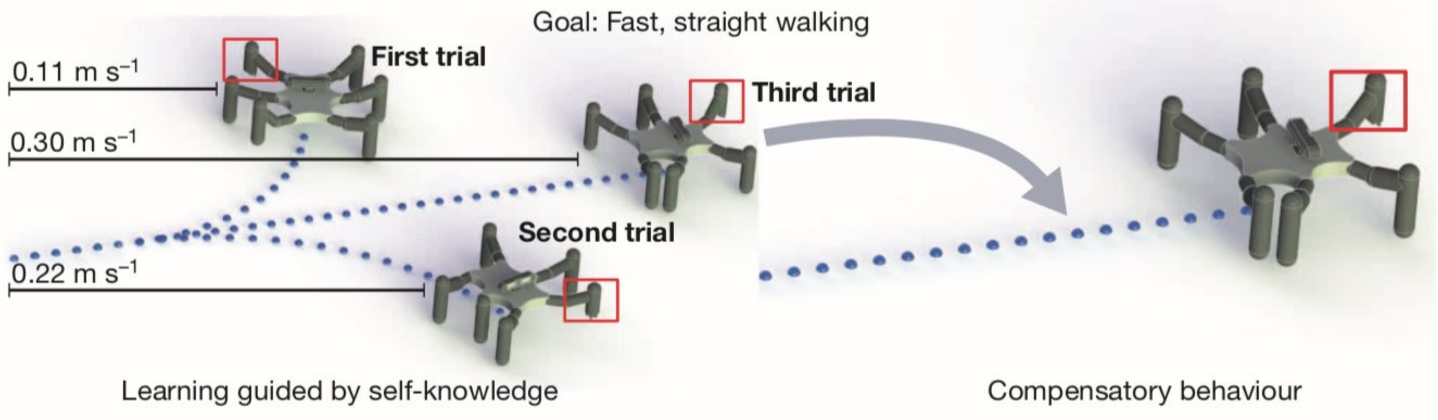
Comparing Solutions

Problem: Classical solutions suffer from the "curse of dimensionality".
Solution: IT&E performs offline simulations to generate a behavior map with fewer dimensions.

Problem: The more complex the robot, the more expensive the classical solution costs.
Solution: IT&E does not require extra sensors to diagnose a malfunction.

Experiment Objective: Move forward as fast as possible.



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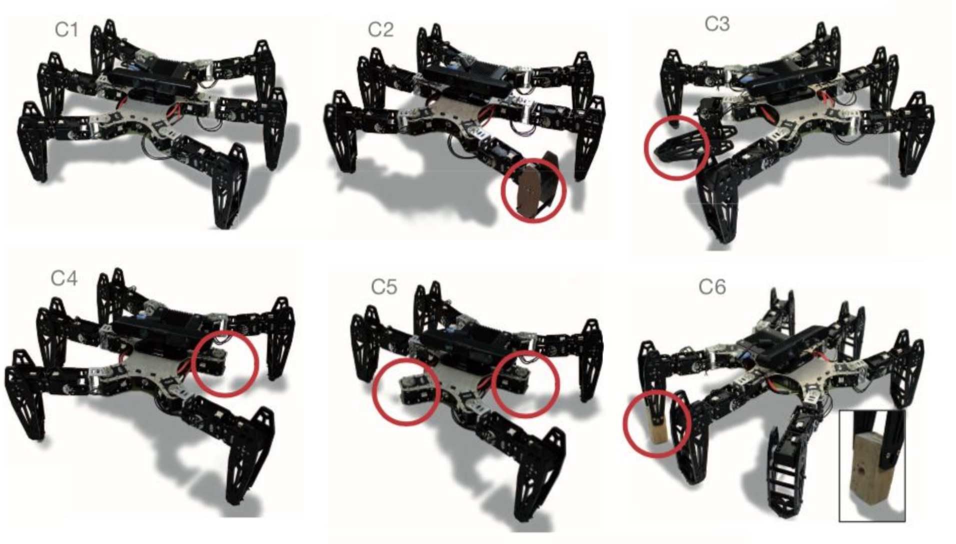
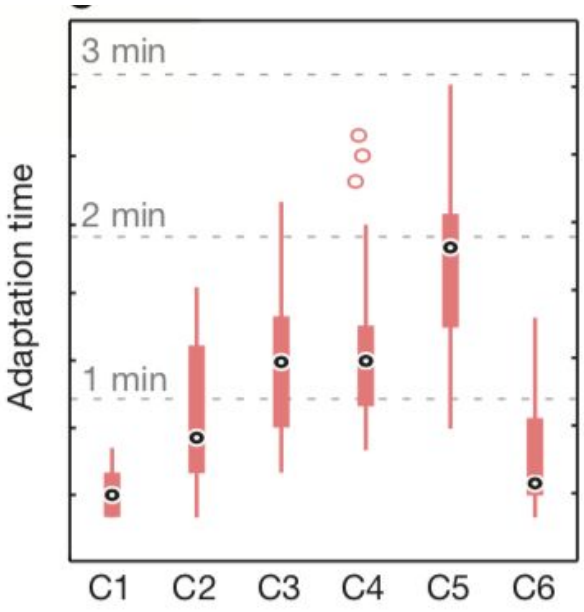
Comparing Solutions





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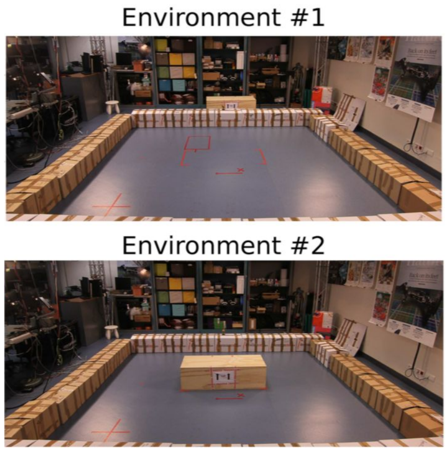
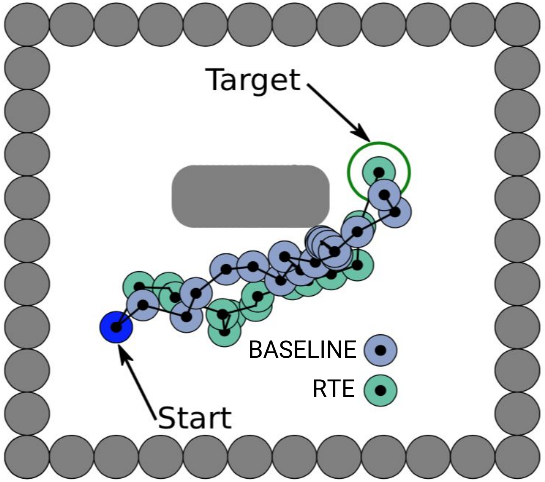
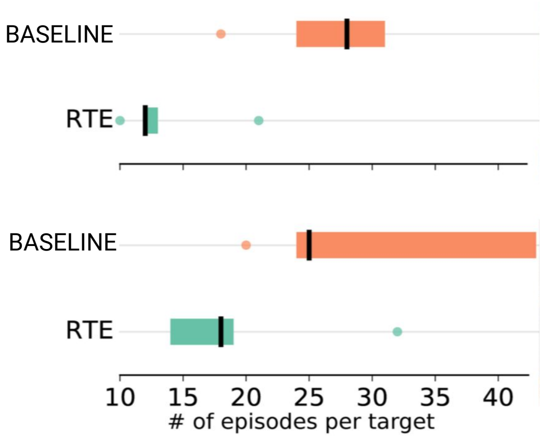
Comparing Solutions

Problem: IT&E does not take into consideration the physical environment and obstacles.
Solution: RT&E uses MCTS to leverage knowledge of the physical environment when searching for a solution.

Experiment Objective: Reach a specified target as fast as possible.







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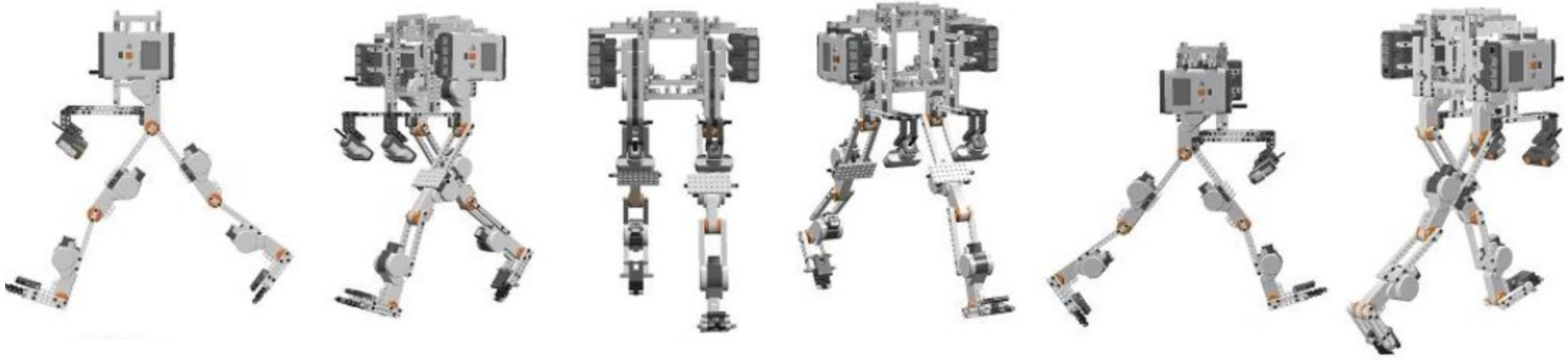
Comparing Solutions

Problem: RT&E can be slow when learning with Gaussian processes.
Solutions: (1) Rewrite to reduce the query time of the Gaussian processes.
(2) Replace the Gaussian process with a neural network.

Future ideas: Use IT&E and RT&E to train legged robots to walk in the first place.



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Summary

- There is a need for robust solutions for adapting malfunctioning robots.
- Classical solutions encounter scale and cost problems.
- Two new intelligent approaches:
  - Intelligent Trial & Error (IT&E)
  - Reset Free Trial & Error (RT&E)
- Intelligent approaches outperform classical approaches without the same scale and cost problems.
- This is an ongoing area of exciting research!

Thank you for your attention.

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Questions?