

GECCO



Genetic and Evolutionary Computation Conference

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Novelty Search for Soft Robotic Space Exploration

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SOFT ROBOTIC SPACE EXPLORATION

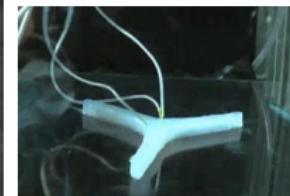
Exploration of extraterrestrial bodies

- ▶ One challenge: mobility
- ▶ Find ideas inspired by biology
- ▶ Locomotion strategy and morphology rarely connected

Soft Robots

- ▶ Inspired by nature
- ▶ Gravity-independent
- ▶ No restriction in locomotion strategy

Soft Robots can have passive or active actuation



SOFT ROBOTS IN SIMULATION



VoxCad Simulator¹

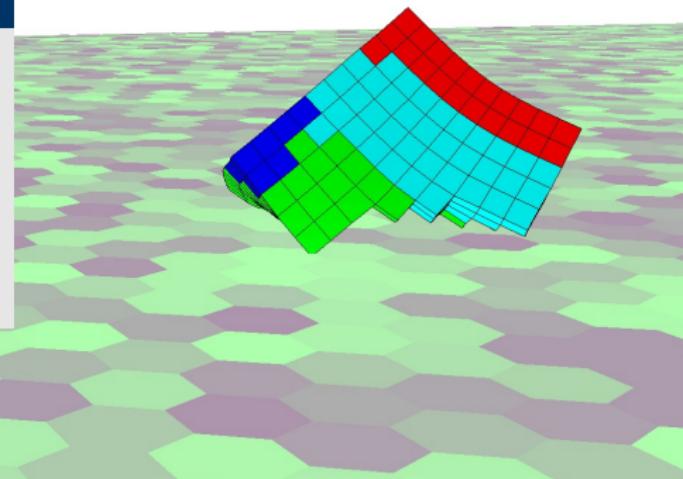
- ▶ Voxel modeling and analyzing software
- ▶ Physics engine extracted and used for the simulations

Simulation

- ▶ 3-D Grid, Voxels, Materials, Temperature

Possible solution space:

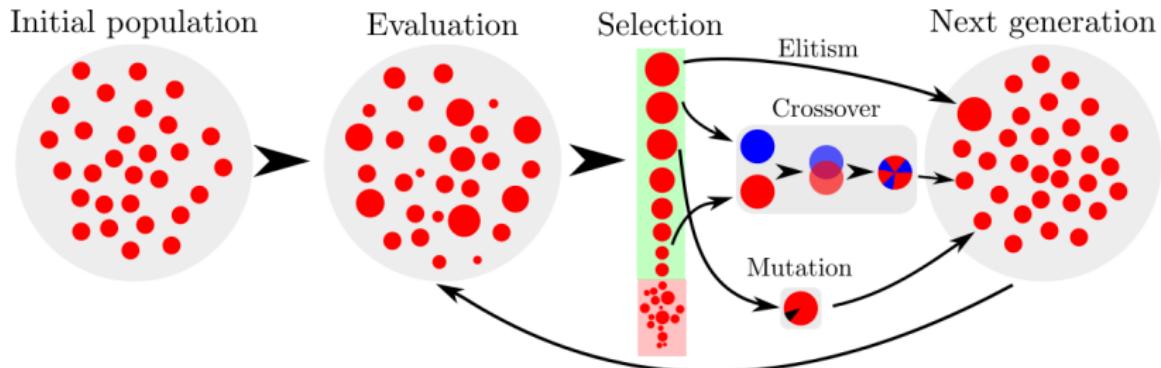
- ▶ for size 10^3 : **9.3×10^{698}**



¹ hiller2012dynamic.

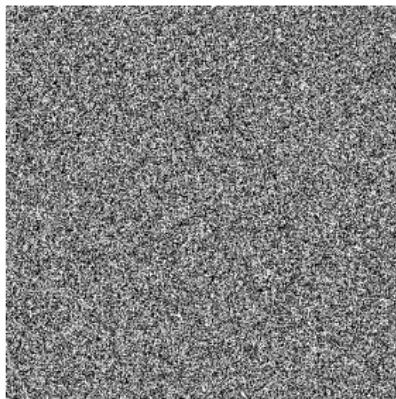
EVOLUTION OF SOFT ROBOTS

Evolutionary algorithms

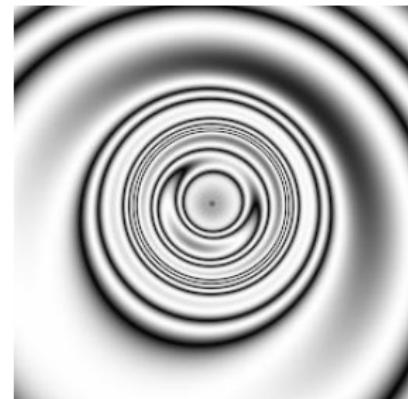


ENCODING SCHEMES

Direct



Generative



010101...111101

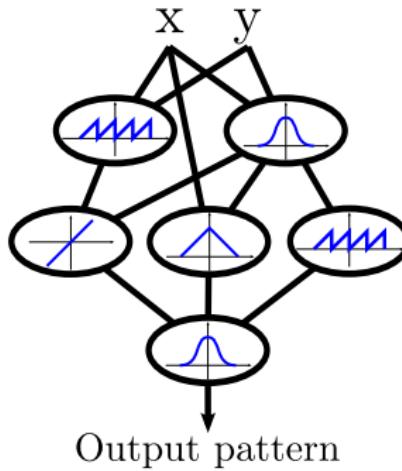
number of pixels

$f(\underbrace{x, y}) = \text{pixel value}$

coords.

COMPOSITIONAL PATTERN-PRODUCING NETWORK²

- ▶ Similar to artificial neural networks
- ▶ Large set of canonical activation functions



- ▶ Produce symmetrical and repetitive patterns
- ▶ Appropriate for problems with geometrical structure

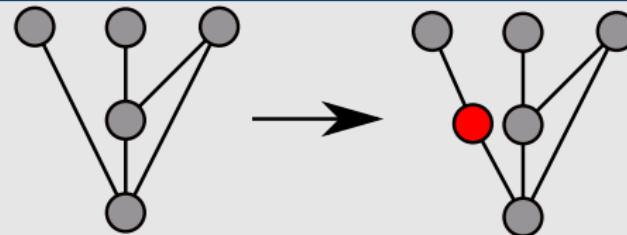
²stanley2007compositional

NEUROEVOLUTION OF AUGMENTED TOPOLOGIES³

Key points:

- ▶ Evolving neural network topologies along with weights
- ▶ Crossover between different topologies
- ▶ Structural innovation through speciation

Genetic Operations in NEAT:



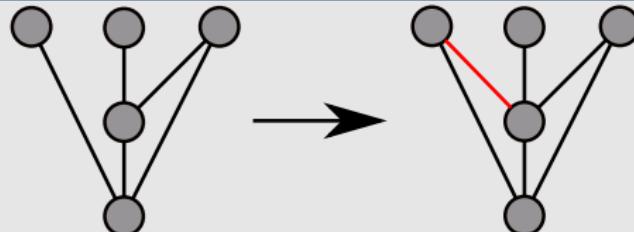
³ stanley2002evolving.

NEUROEVOLUTION OF AUGMENTED TOPOLOGIES

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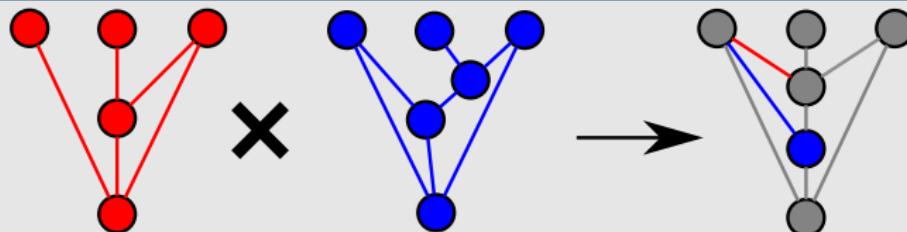


NEUROEVOLUTION OF AUGMENTED TOPOLOGIES

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Genetic Operations in NEAT:



EVOLUTION OF SOFT ROBOTS BY NOVELTY SEARCH⁴

What is novelty search?

- ▶ Traditionally fitness measures how good an individual is.
- ▶ Objective function can prevent evolution reaching the target.
- ▶ Abandon the objective
- ▶ Define a behavior metric
- ▶ Try finding novelty in behavior space

Sparsity

$$s(x) = \frac{1}{k} \sum_{i=0}^k dist(x, b_i)$$

⁴lehman2011abandoning.

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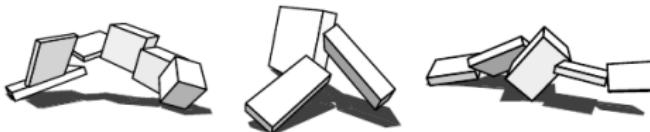
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RELATED WORK

*Evolving virtual creatures*⁵

- ▶ Rigid body parts, joints
- ▶ Evolution of the morphology and the control



*Evolving a diversity of virtual creatures through novelty search and local competition*⁶

- ▶ Novelty < Fitness
- ▶ Novelty search with global fitness competition > Fitness

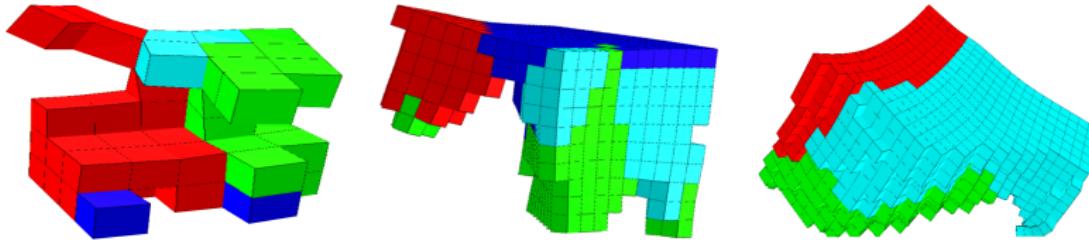
⁵sims1994evolving.

⁶lehman2011evolving.

RELATED WORK

Evolving soft robots with multiple materials and a powerful generative encoding⁷

- ▶ Generative encoding, Compositional pattern-producing network, CPPN
- ▶ Neuroevolution of augmenting topologies, NEAT



⁷ cheney2013unshackling.

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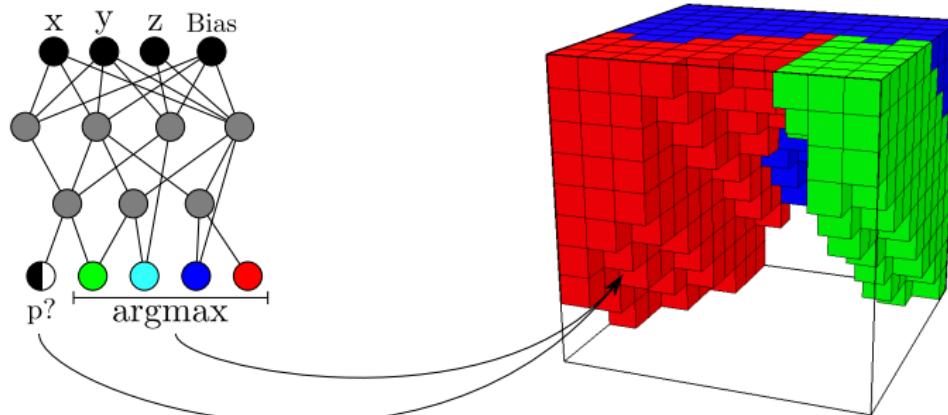
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CPPN-NEAT

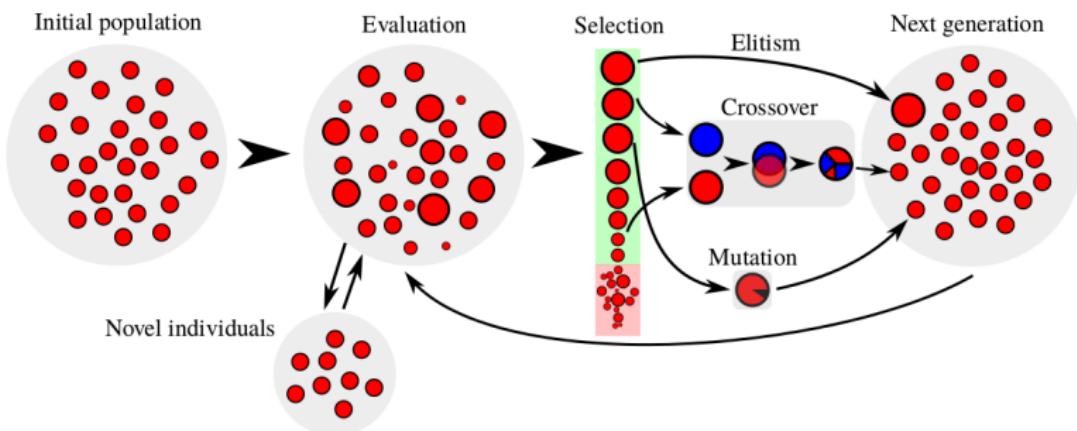
Evolving CPPNs with NEAT

- ▶ Each genome is represented by a CPPN
- ▶ This CPPN is queried for each input coordinate to output the existence and the type of the material.
- ▶ NEAT evolves these CPPNs



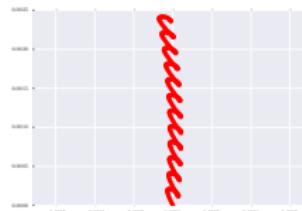
EXTENDING CPPN-NEAT WITH NOVELTY SEARCH

- ▶ Novelty takes the place of fitness
- ▶ Novel individuals stored in a list
- ▶ For each new individual in the population, check its novelty in respect to the stored novel individuals.

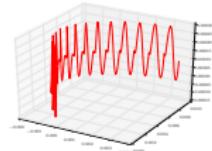


BEHAVIORS

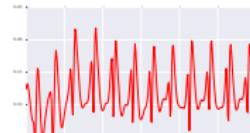
2D-traj.



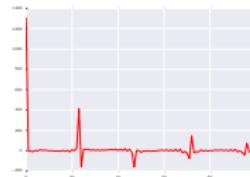
3D-traj.



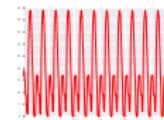
Pace



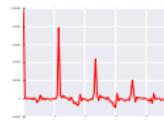
DFT-Pace



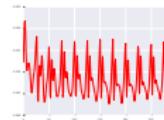
VTG



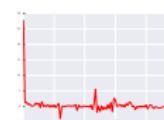
DFT-VTG



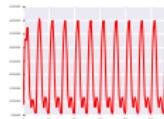
Pr



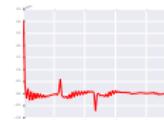
DFT-Pr



KE



DFT-KE



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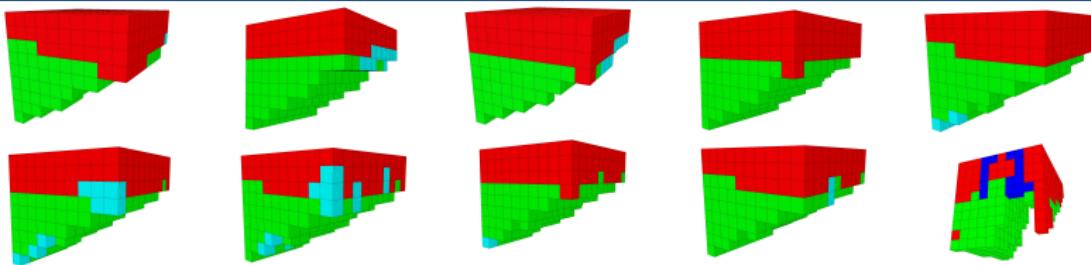
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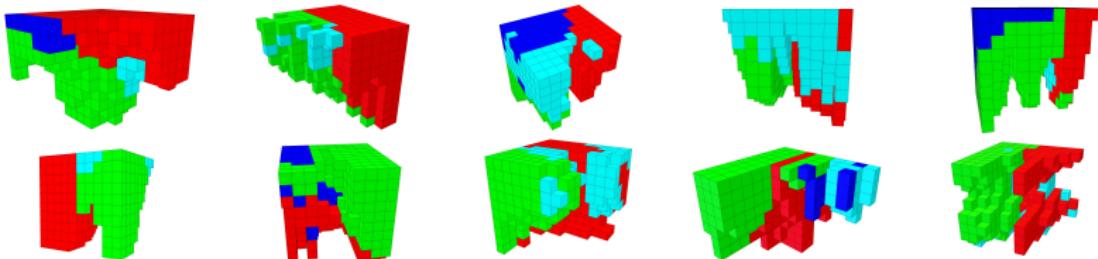
Conclusion

INCREASED DIVERSITY

Fitness-based Search - Champions every 100 generations:

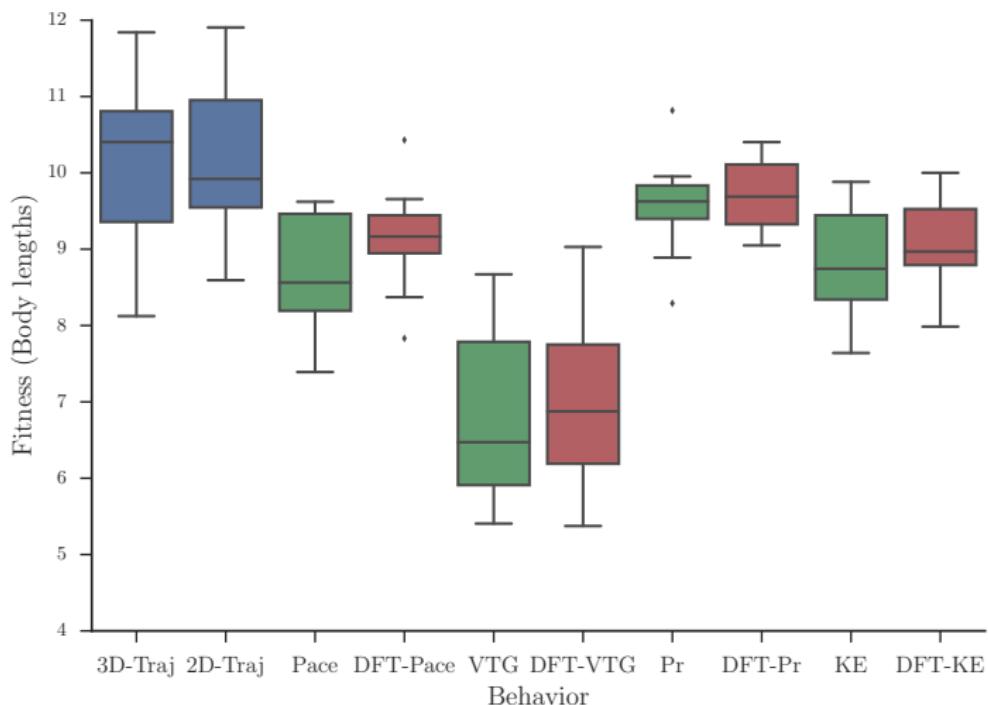


Novelty Search - Champions every 100 generations:



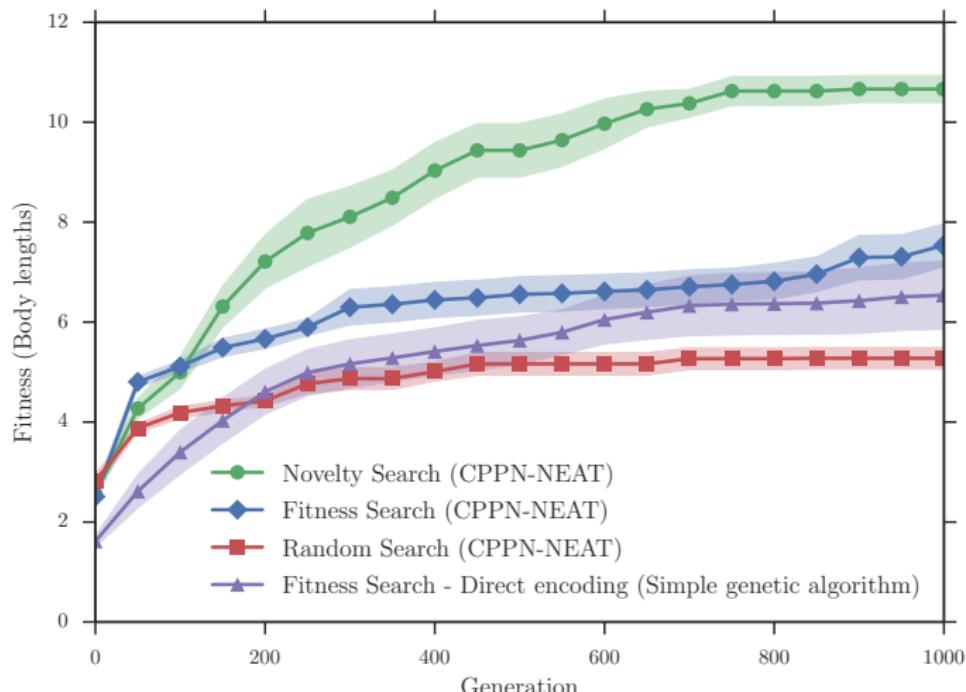
BEHAVIOR SELECTION

Novelty search, 10 different behavior metrics



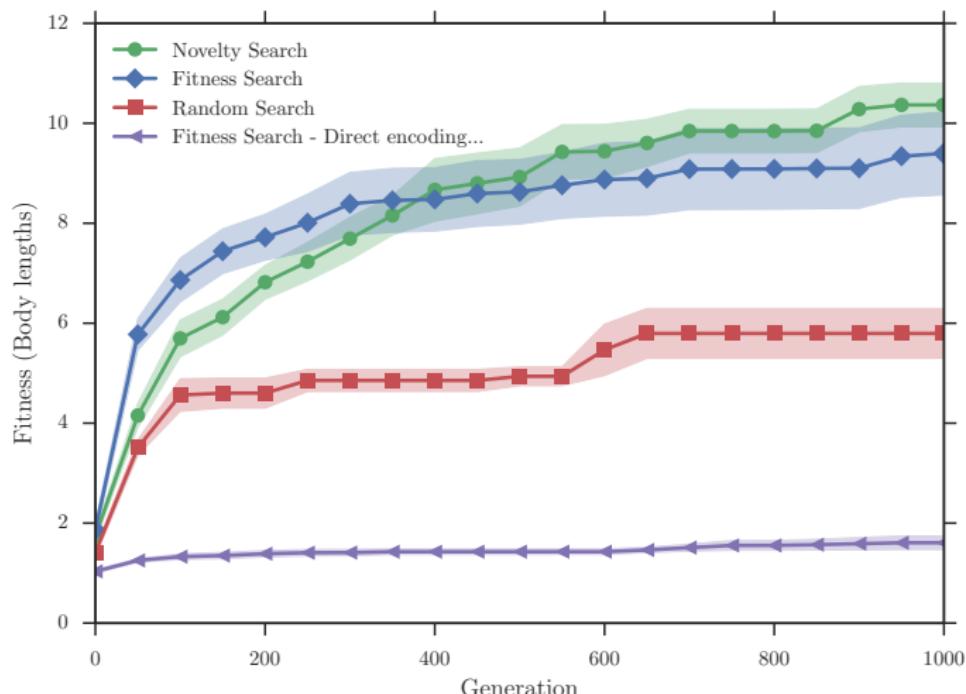
INCREASED PERFORMANCE

Best fitness so far, low-resolution

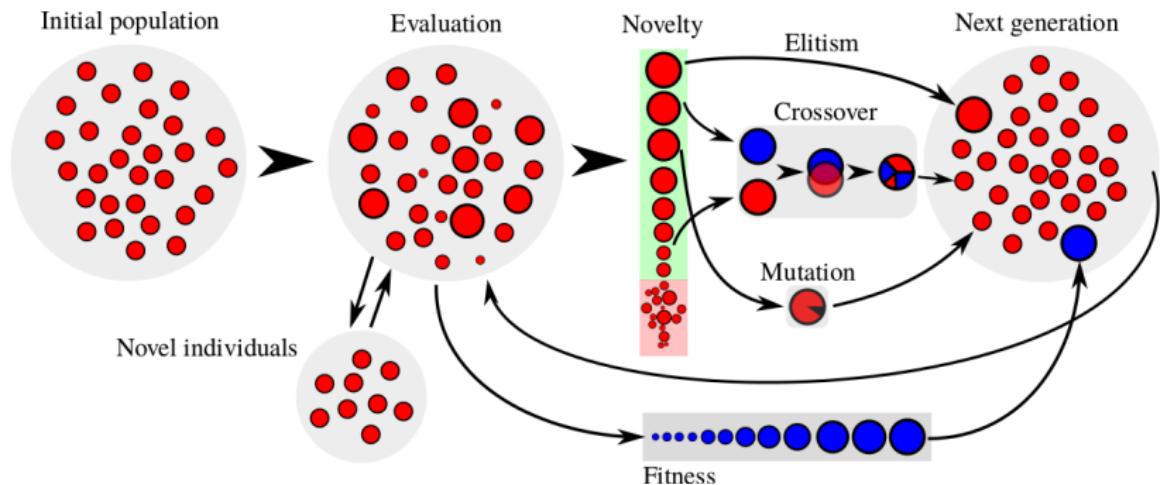


INCREASED PERFORMANCE

Best fitness so far, high-resolution

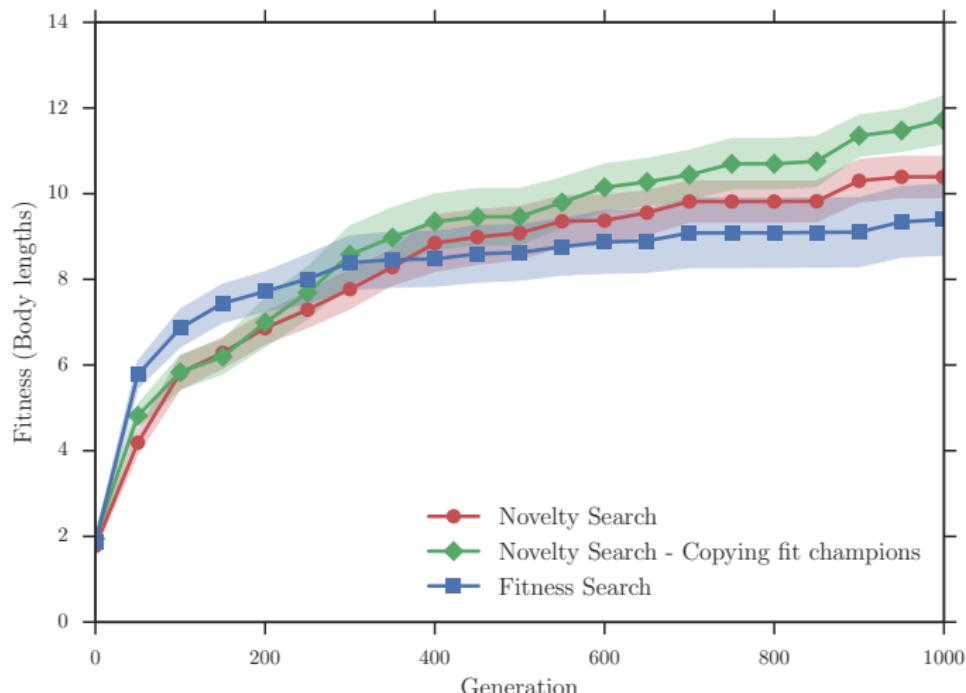


INCORPORATING FITNESS INTO NOVELTY SEARCH



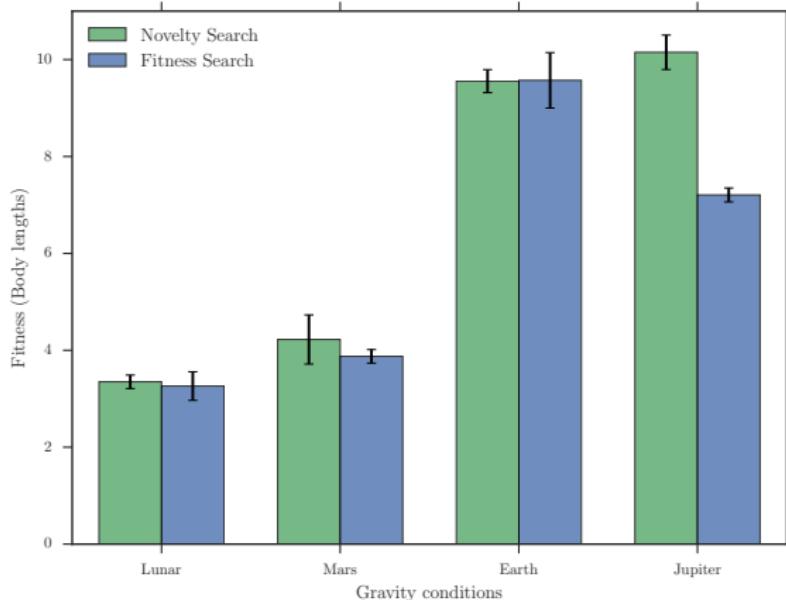
FITNESS ELITISM IN NOVELTY SEARCH

Best fitness so far, high-resolution



EVOLVING SOFT-ROBOTS FOR OUTER SPACE

Displacement achieved in variant gravity levels



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CONCLUSION

- ▶ Novelty search performs better in respect to fitness
 - ▶ Increased performance on different settings
 - ▶ Performance is not much affected by the behavior metric
 - ▶ Fitness elitism further improves performance
-
- + Co-evolution of materials alongside morphology
 - + Develop methods to combine both searches
 - + Combinatorial behavior metrics

CWI



Thank you!

