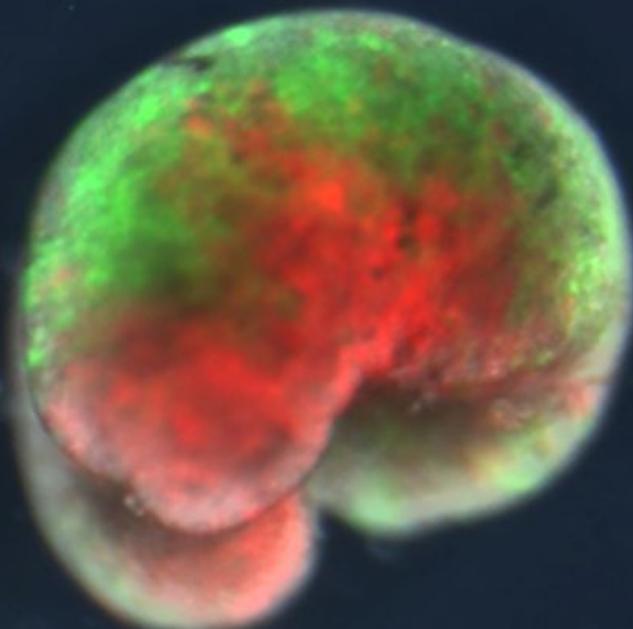


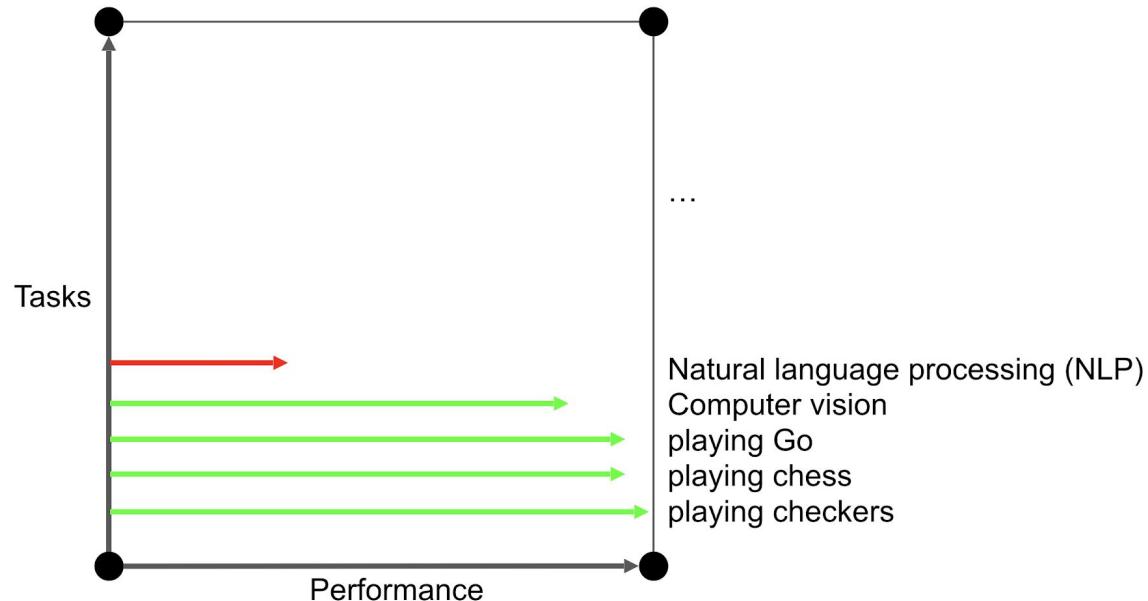
Computer-designed organisms

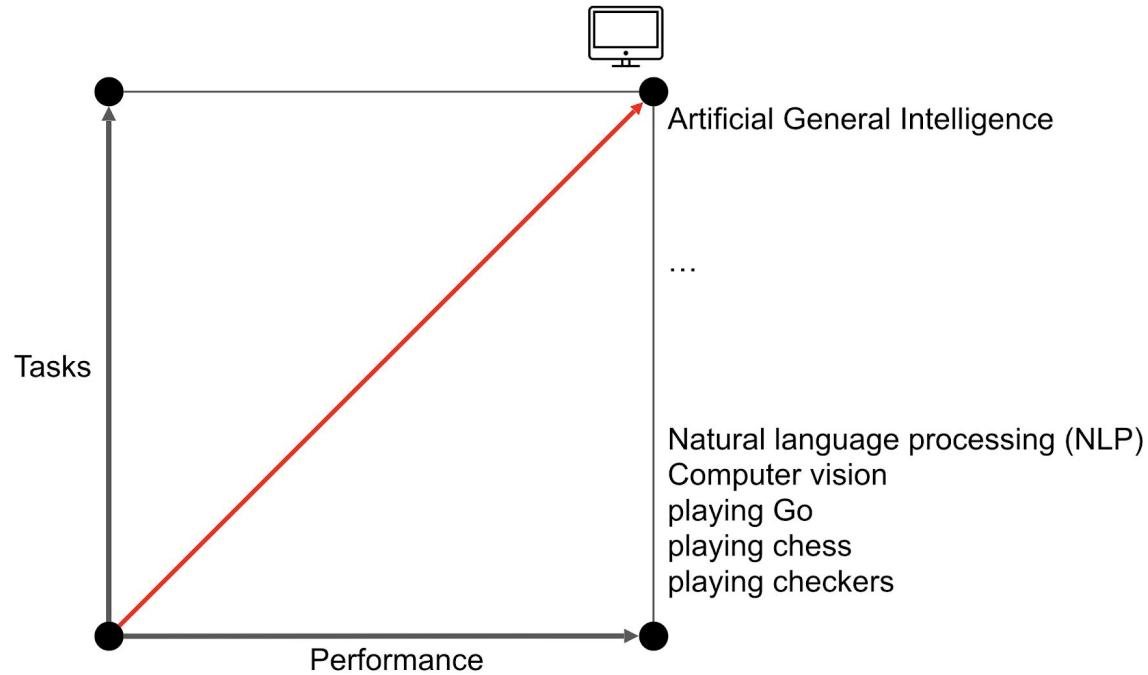


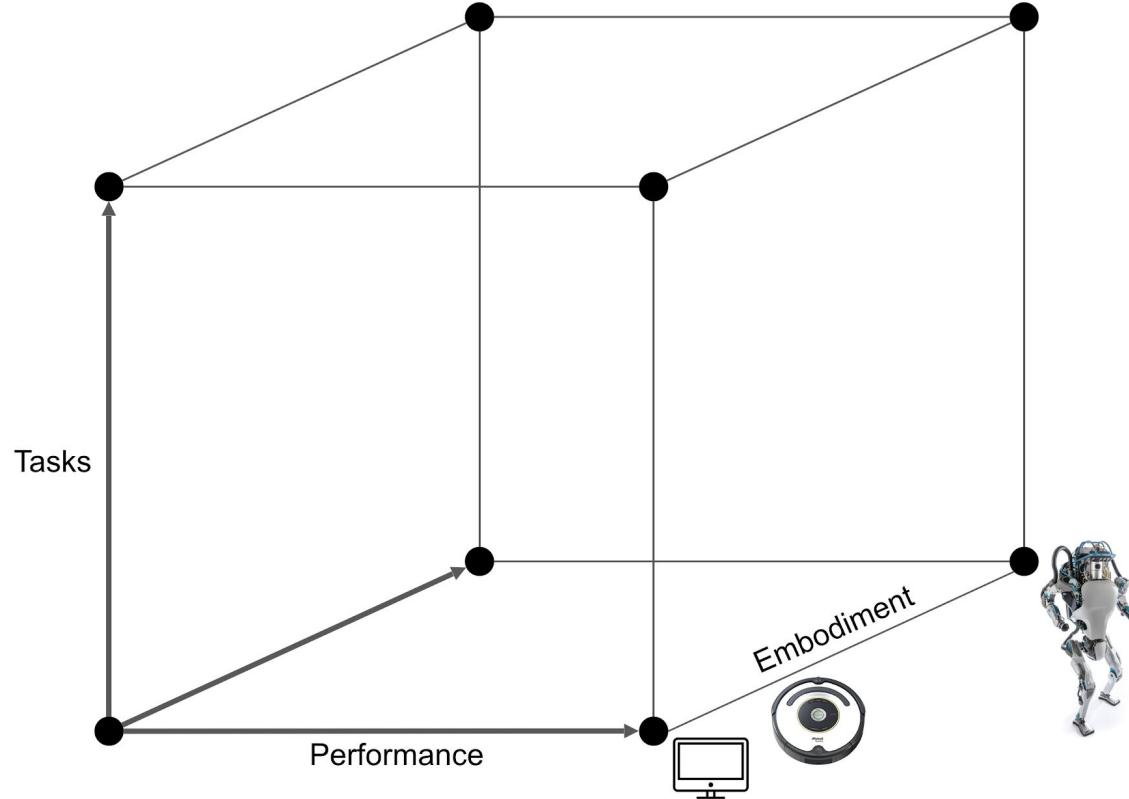
Josh Bongard, University of Vermont

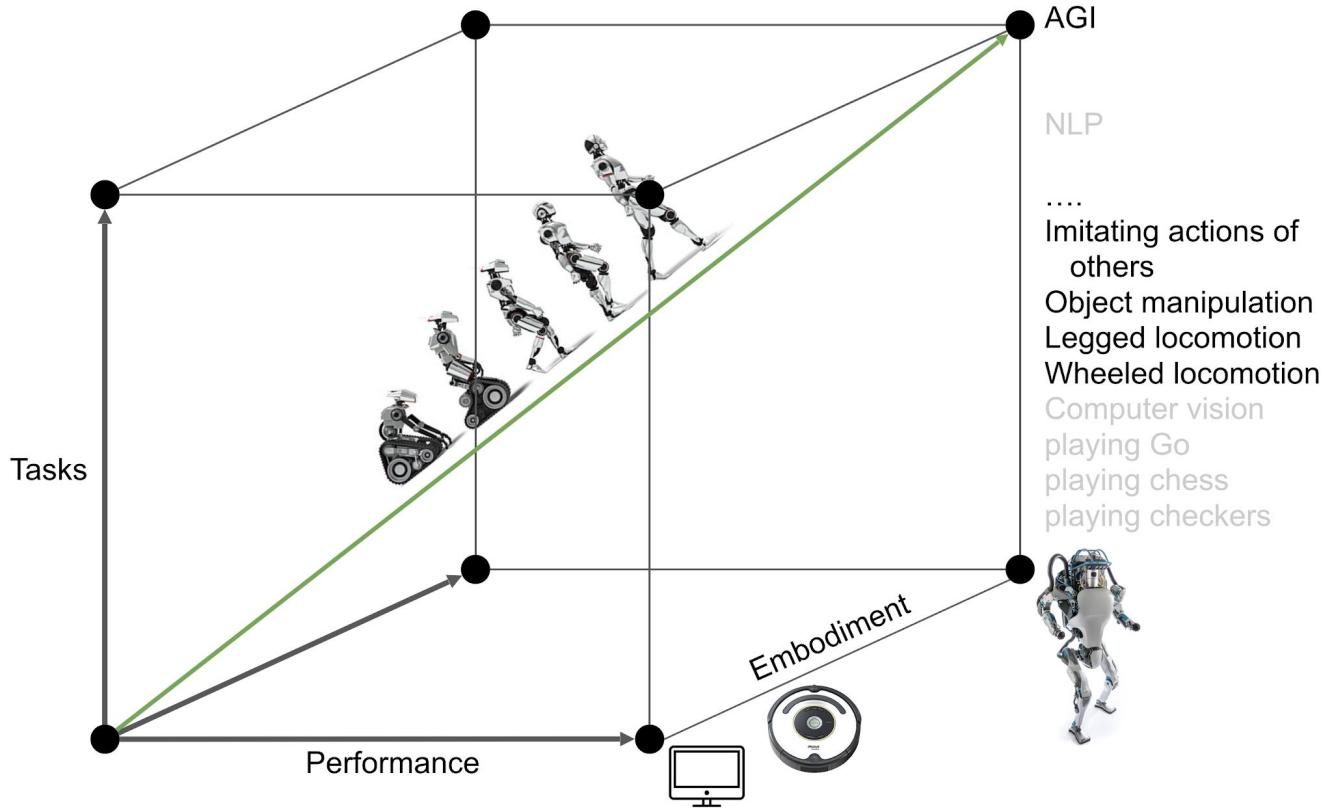
(work w/ Sam Kriegman, UVM; Doug Blackiston & Michael Levin, Tufts)











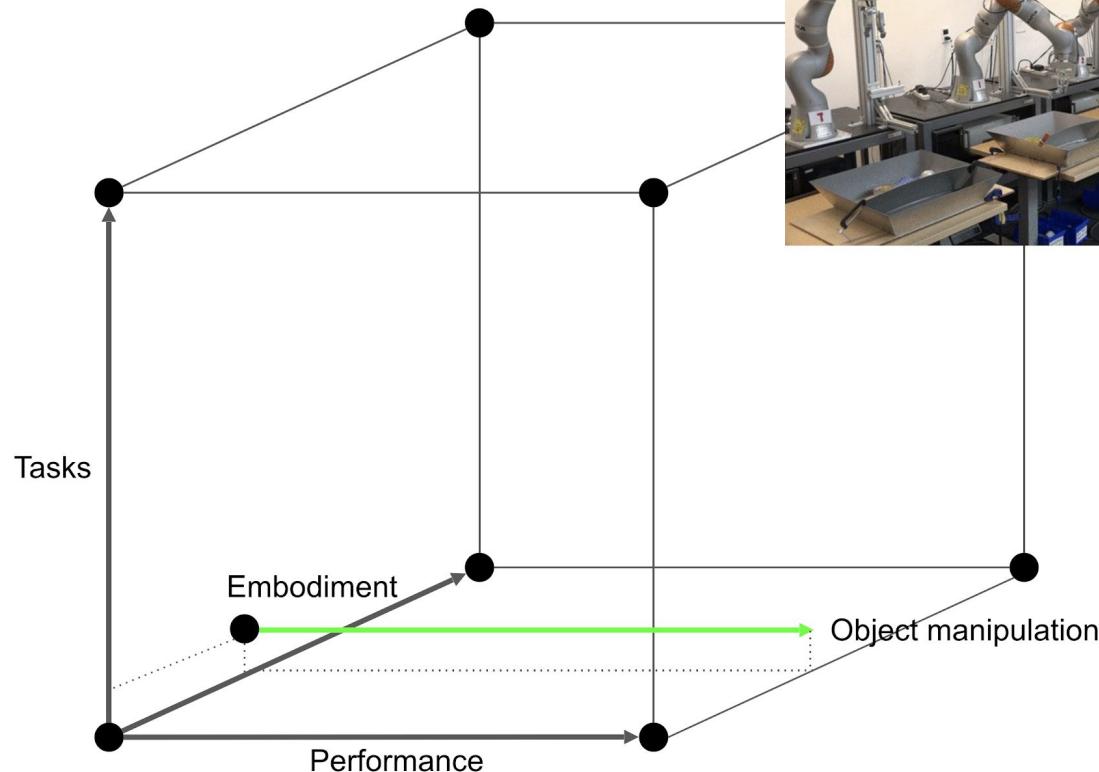
Andrej Karpathy ✨ @karpathy · Jun 30 2018



Scalable Deep Reinforcement Learning for Robotic Manipulation

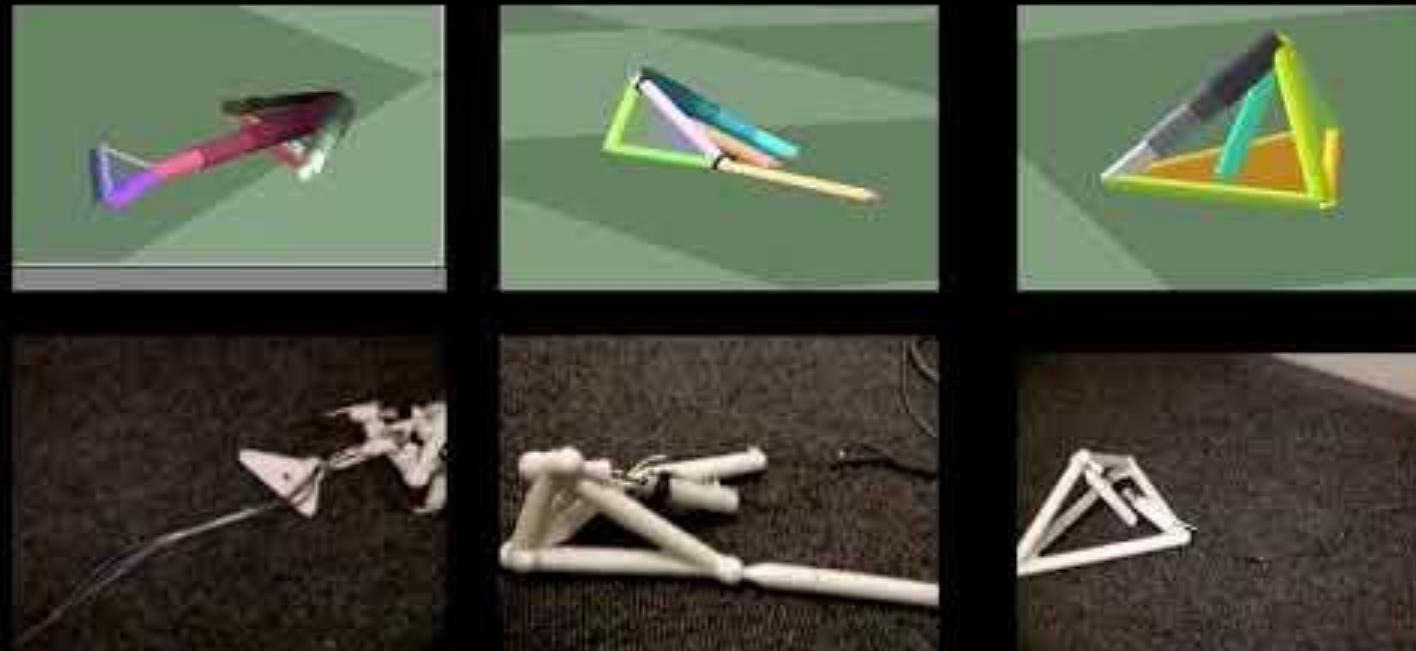
ai.googleblog.com/2018/06/scalab... hand-designed init -> 580k grasp attempts
on 7 **robot** arms over 4 months (raw monocular RGB camera input) -> 1.2M
param net -> **96%** successful test set grasps



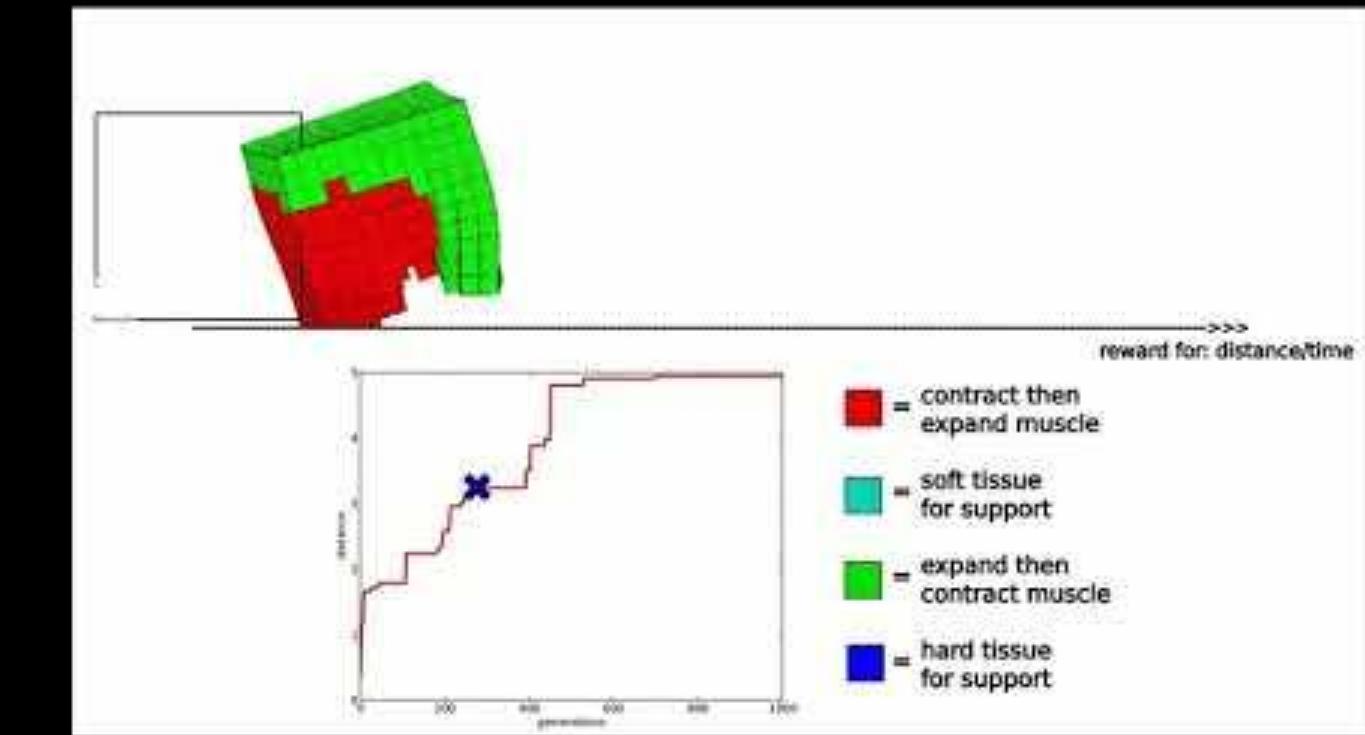




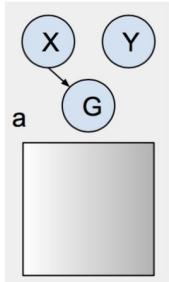
K. Sims (1994).
Procs of Artificial Life II.



Lipson & Pollack (2000)
Nature



Cheney, N., MacCurdy, R., Clune, J.,
& Lipson, H. (2014).
Procs of GECCO, 7(1), 11-23.

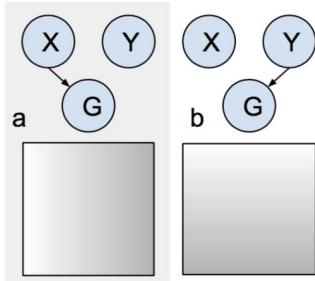


Stanley (2007).

Compositional pattern producing networks:

A novel abstraction of development.

Procs. of the GECCO Conf.

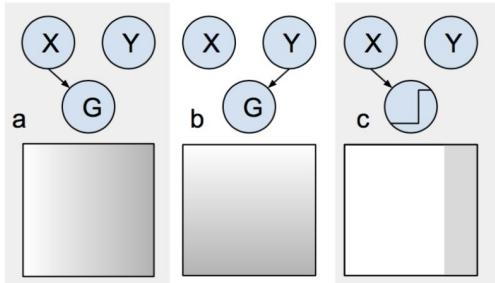


Stanley (2007).

Compositional pattern producing networks:

A novel abstraction of development.

Procs. of the GECCO Conf.

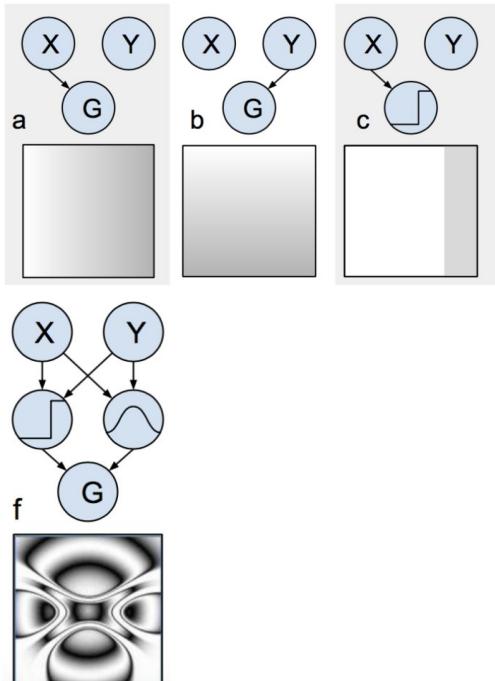


Stanley (2007).

Compositional pattern producing networks:

A novel abstraction of development.

Procs. of the GECCO Conf.

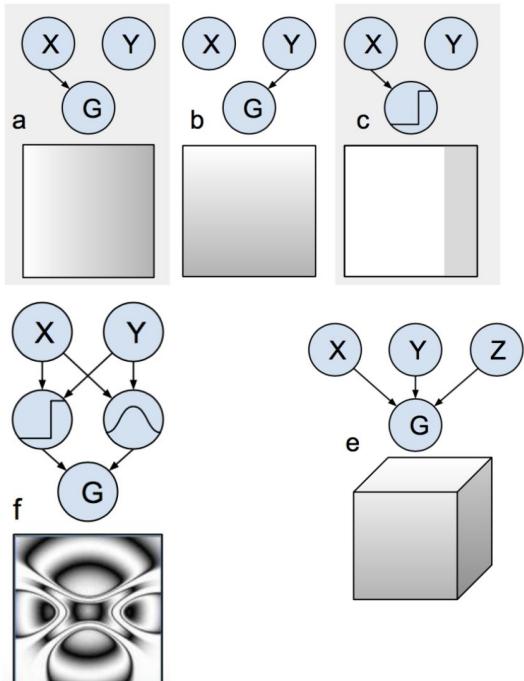


Stanley (2007).

Compositional pattern producing networks:

A novel abstraction of development.

Procs. of the GECCO Conf.

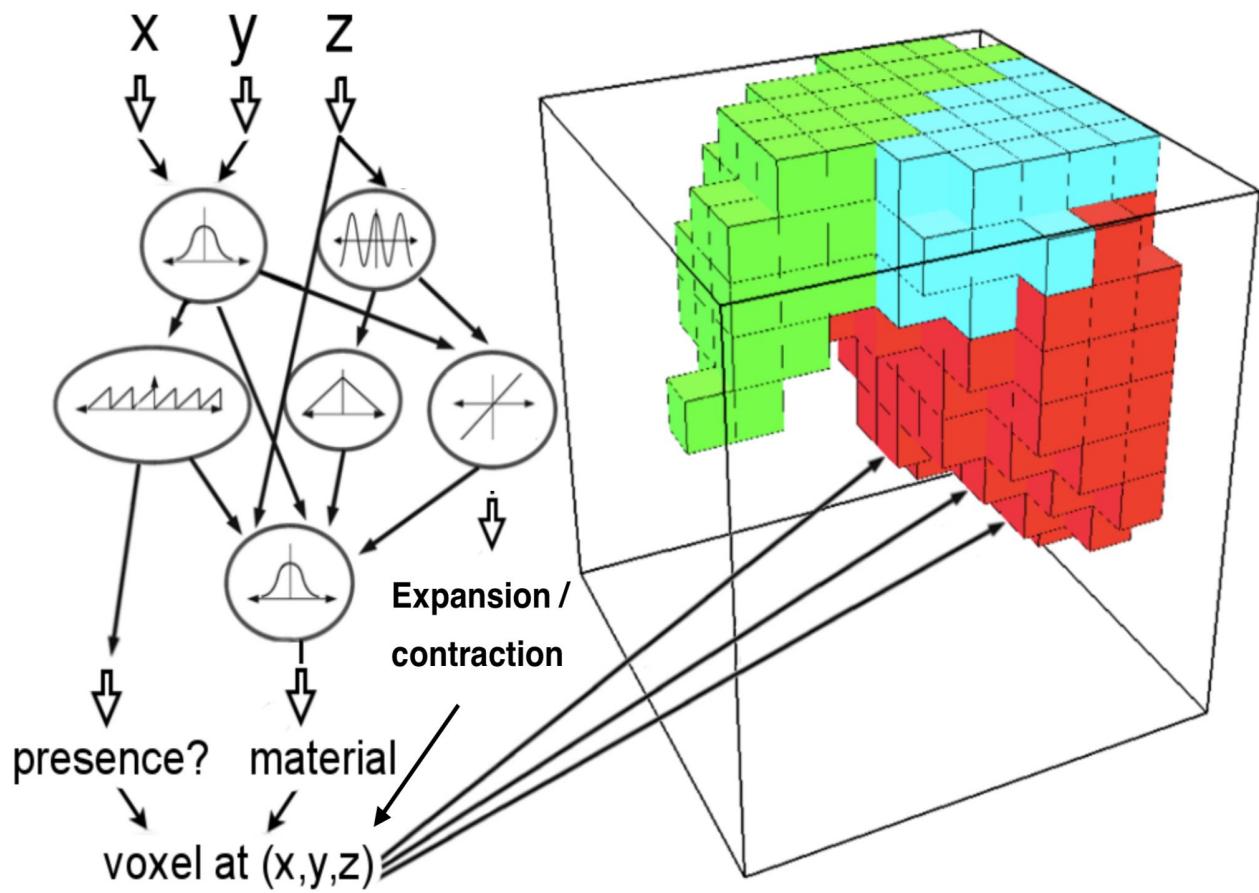


Stanley (2007).

Compositional pattern producing networks:

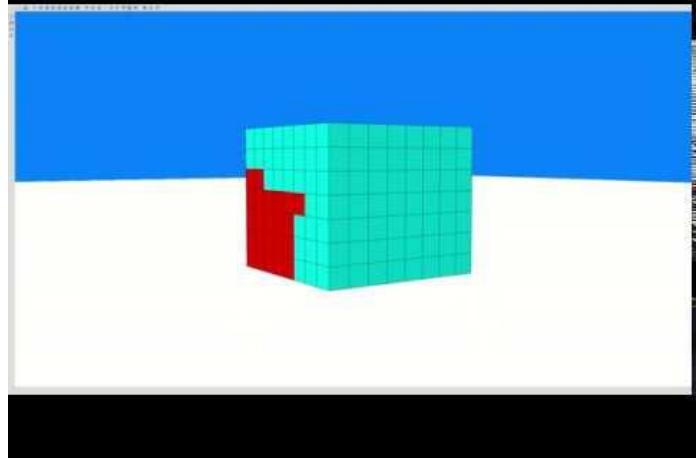
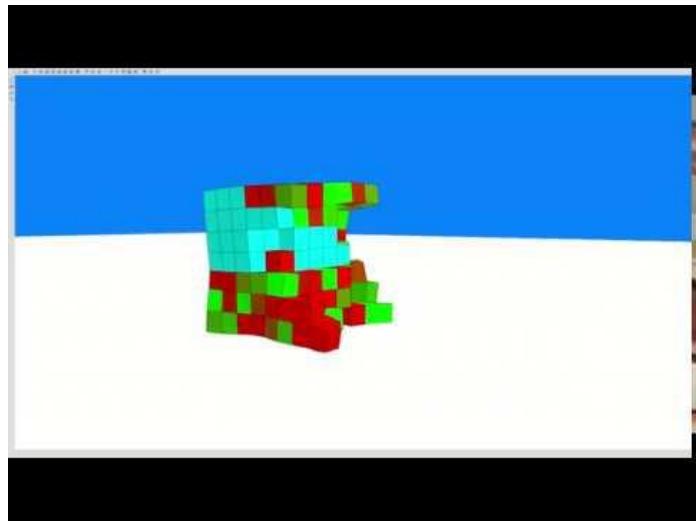
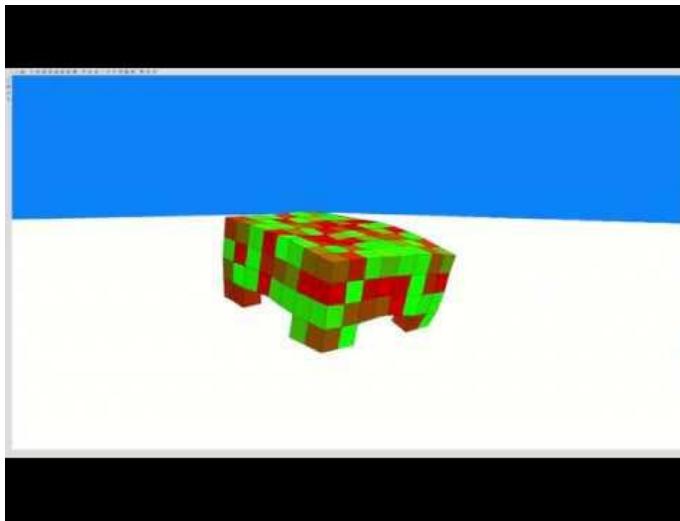
A novel abstraction of development.

Procs. of the GECCO Conf.

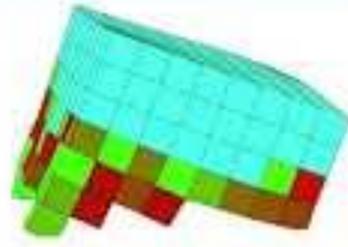


Cheney, N., MacCurdy, R., Clune, J., & Lipson, H. (2014).
Procs of GECCO, 7(1), 11-23.

Kriegman, S., Blackiston,
D., Levin, M., & Bongard,
J. (2020). *PNAS*.

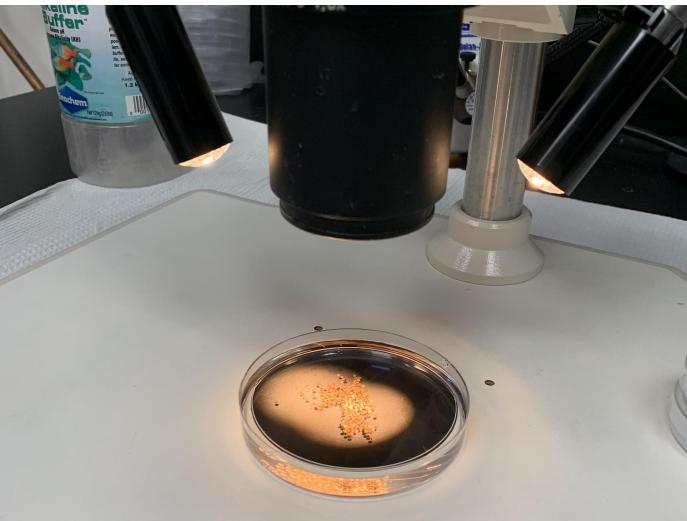


in silico

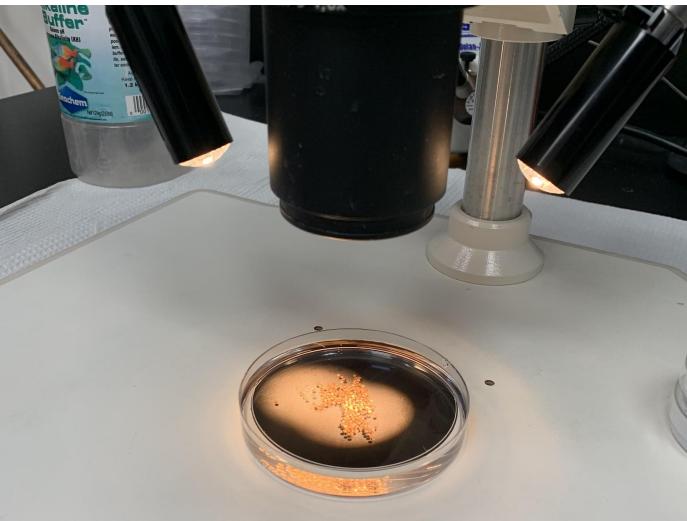


Kriegman, S., Blackiston,
D., Levin, M., & Bongard,
J. (2020). **PNAS**.

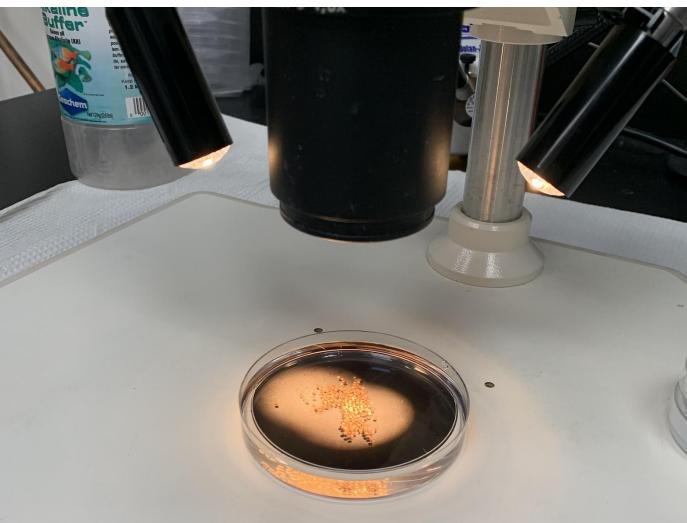
(1/10) Injecting Fertilized Embryos to Determine Cell Type



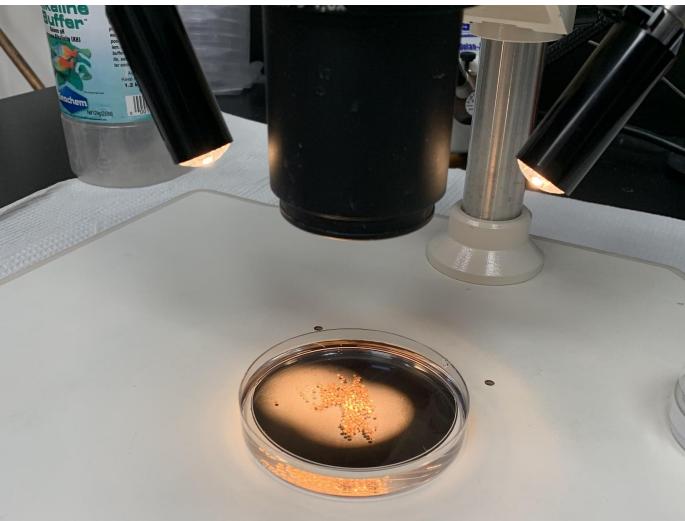
(2/10) Removing Vitelline Membrane



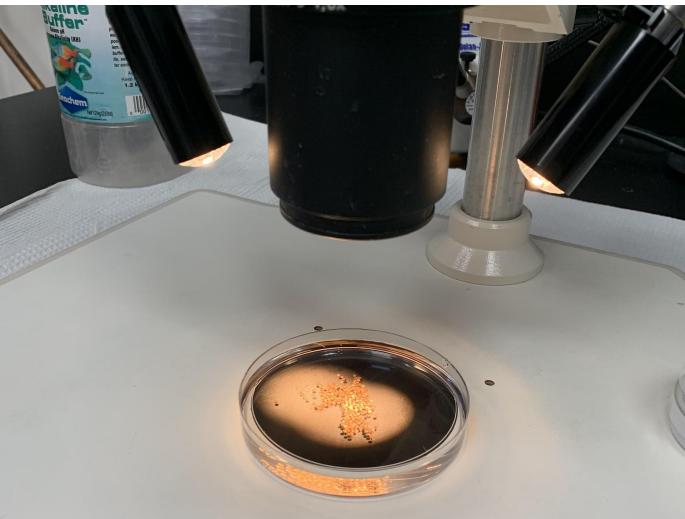
(3/10) Removing animal caps



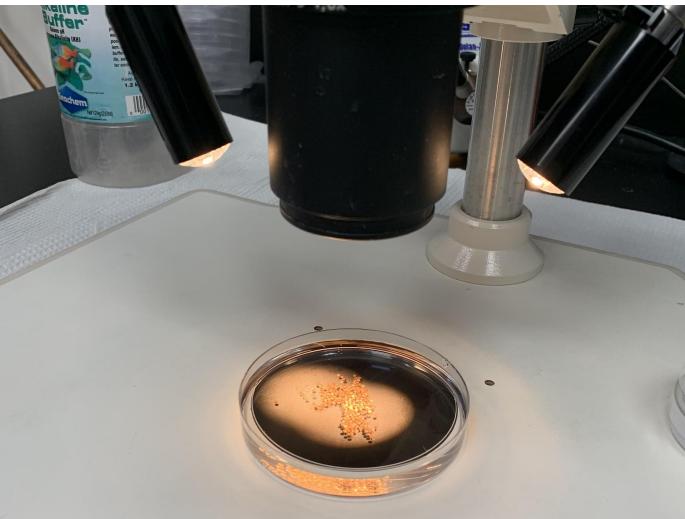
(4/10) Separating Ectoderm From Dissociated Inner Cells



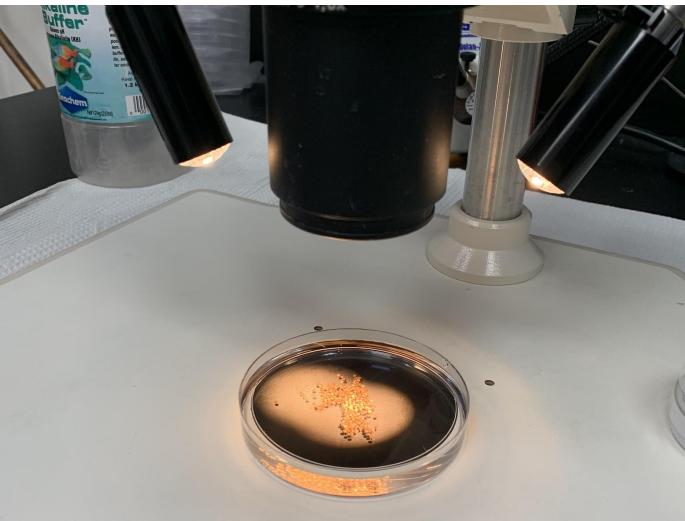
(5/10) Pooling Cells



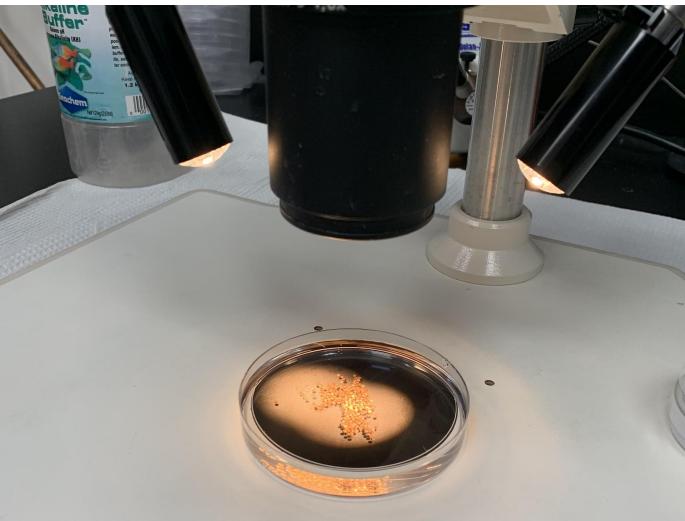
(6/10) Transferring Cells to Wells



(7/10) Pooled Cells Re-adhere



(8/10) Reaggregated Cells Develop



(9/10) Cauterize and Sculpt Rough Shape

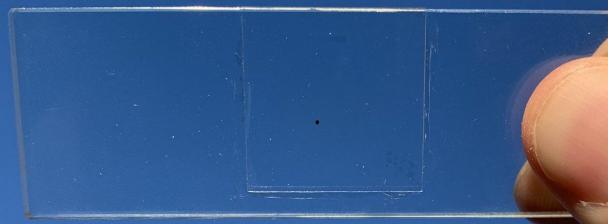
Target shape.



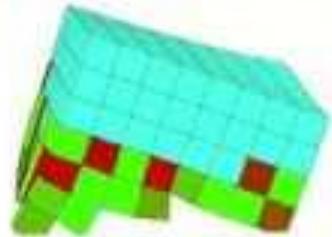
(10/10) Sculpt Final Features

Target shape.





in silico



in vivo

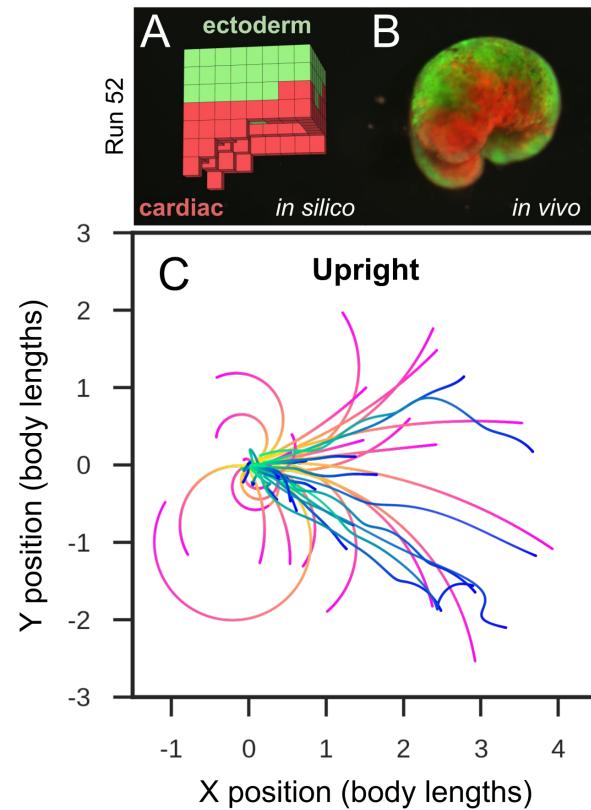
4x speed



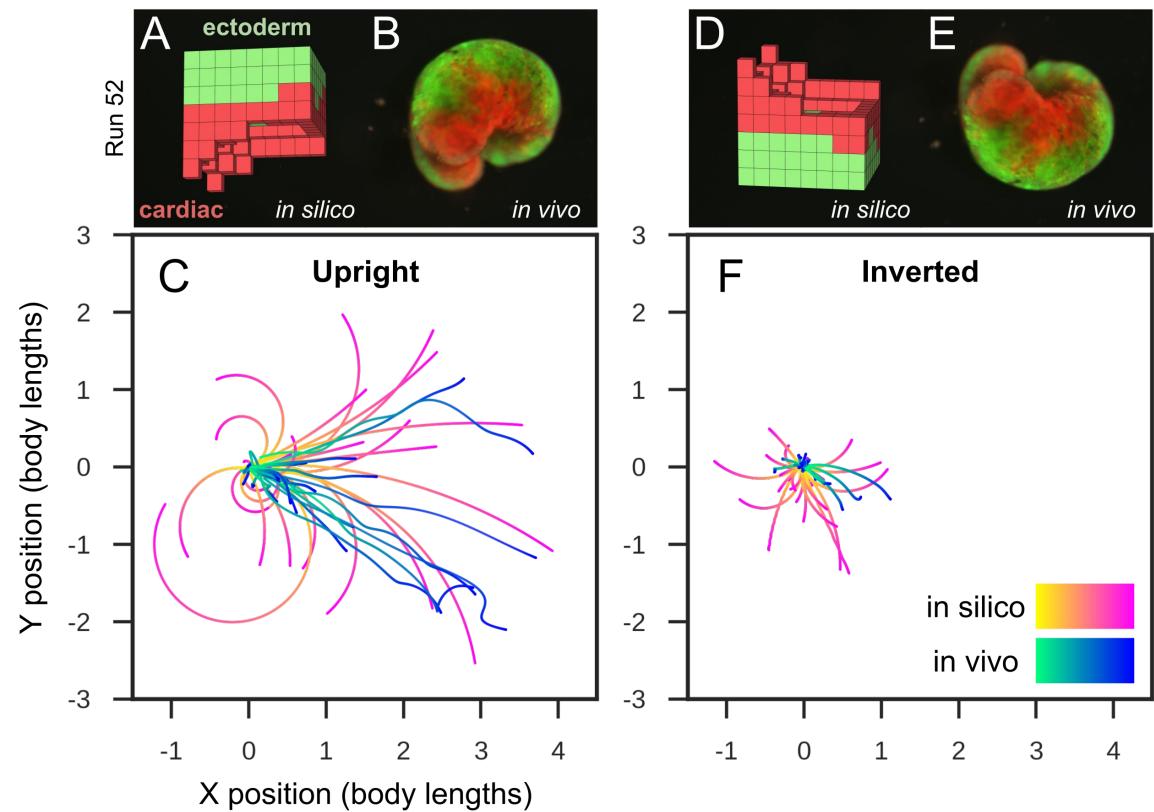
(aerial view)

Kriegman, S., Blackiston,
D., Levin, M., & Bongard,
J. (2020). **PNAS**.

Kriegman, S., Blackiston,
D., Levin, M., & Bongard,
J. (2020). ***PNAS***.



Kriegman, S., Blackiston,
D., Levin, M., & Bongard,
J. (2020). ***PNAS***.



Collective behavior

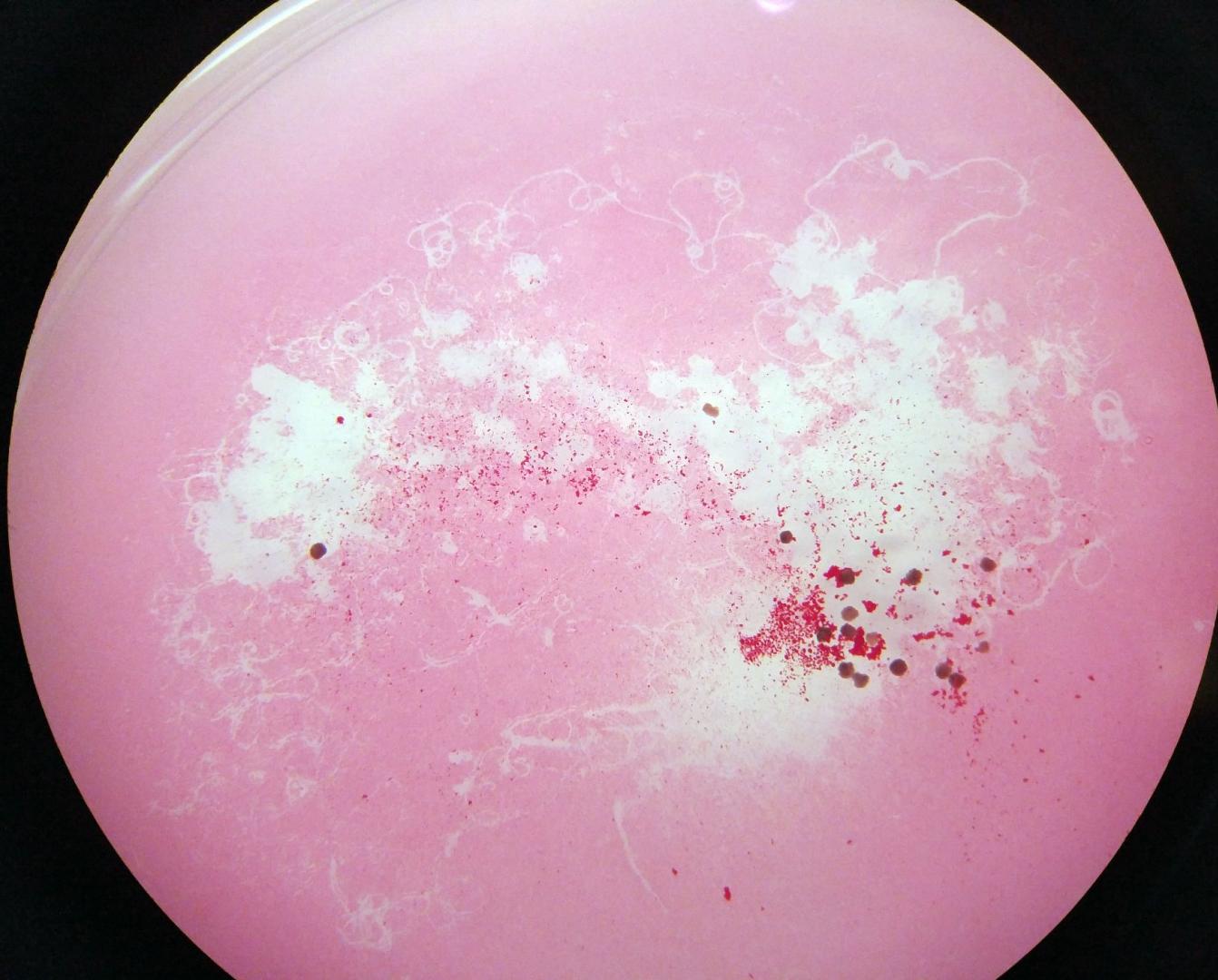


in silico

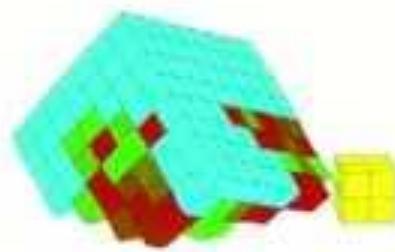


in vivo

Kriegman, S., Blackiston,
D., Levin, M., & Bongard,
J. (2020). *PNAS*.



Object manipulation



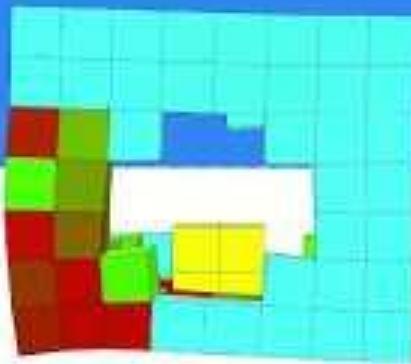
in silico



in vivo

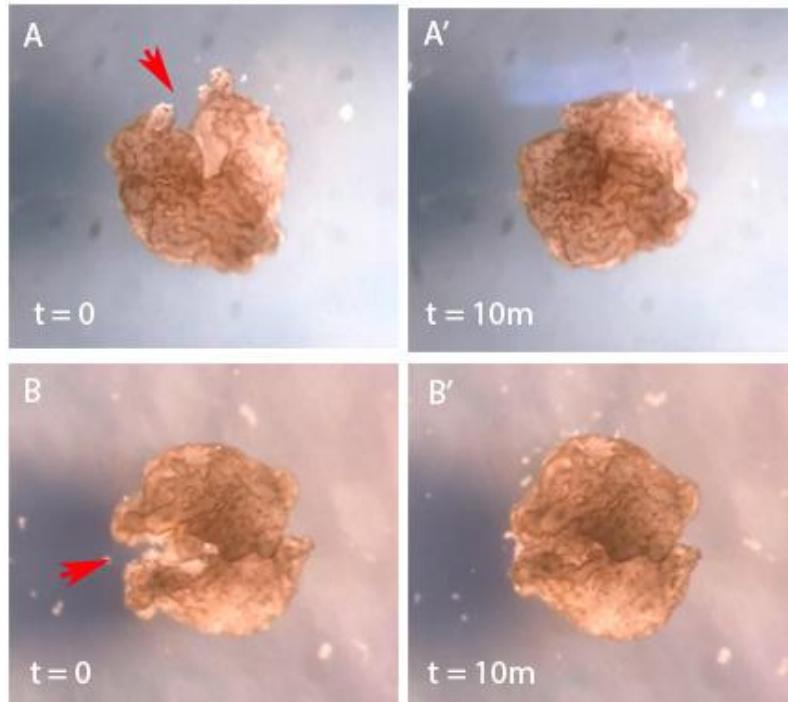
Kriegman, S., Blackiston,
D., Levin, M., & Bongard,
J. (2020). *PNAS*.

Object transport



Kriegman, S., Blackiston,
D., Levin, M., & Bongard,
J. (2020). *PNAS*.

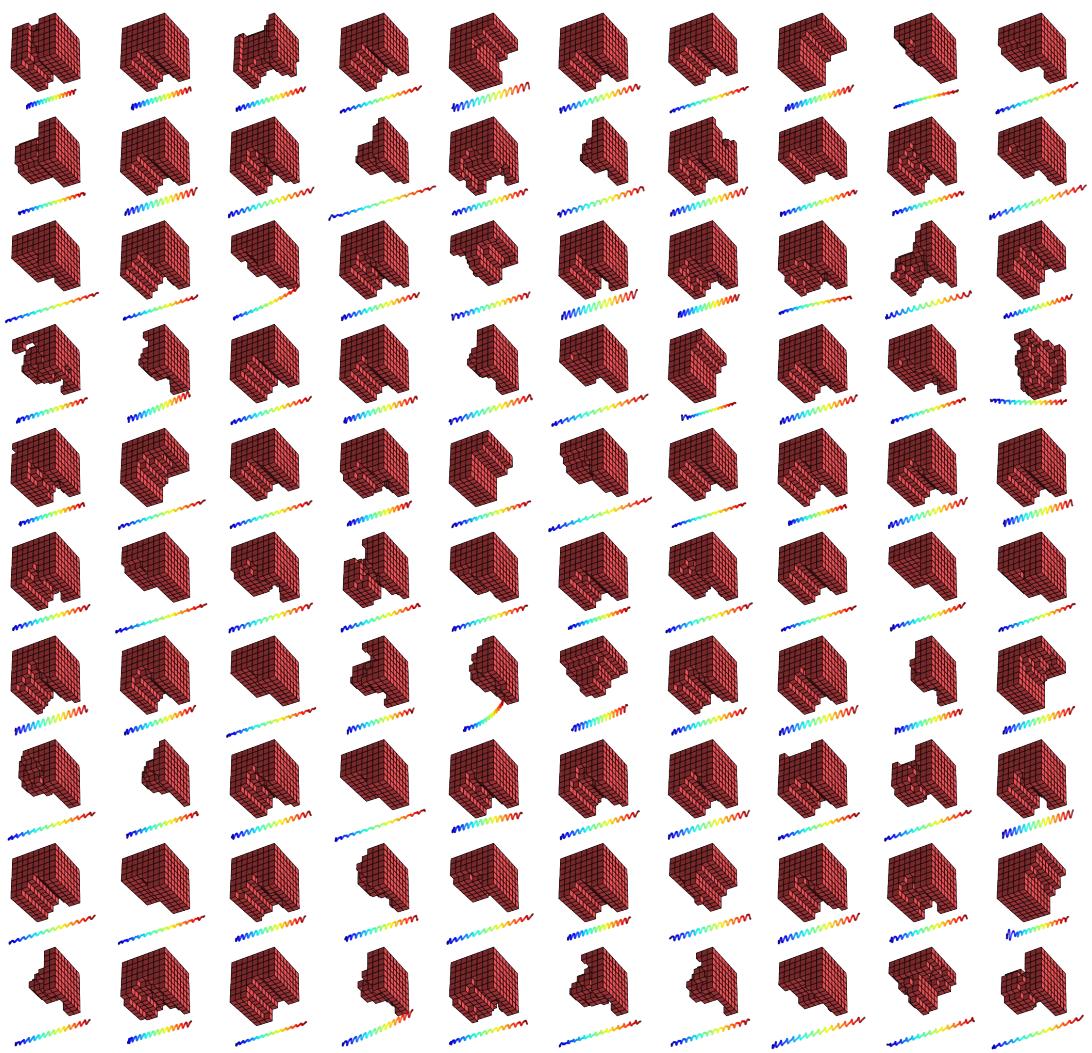
Self repair

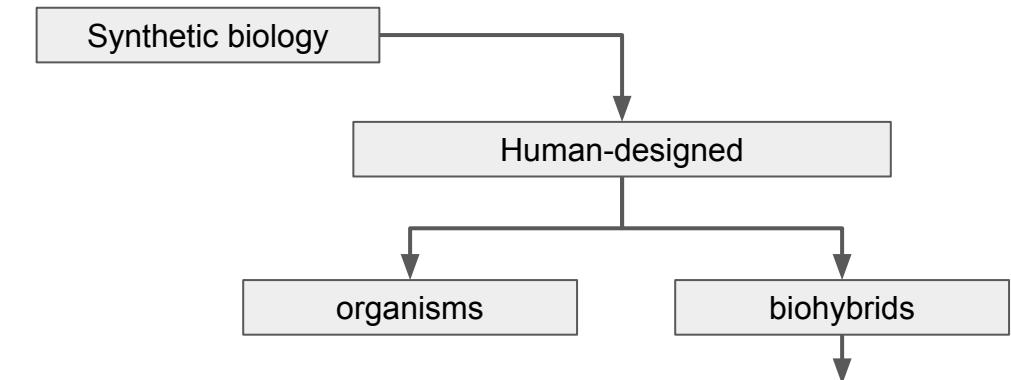


Kriegman, S., Blackiston, D., Levin,
M., & Bongard, J. (2020). *PNAS*.

Kriegman, S., Blackiston,
D., Levin, M., & Bongard,
J. (2020). *PNAS*.

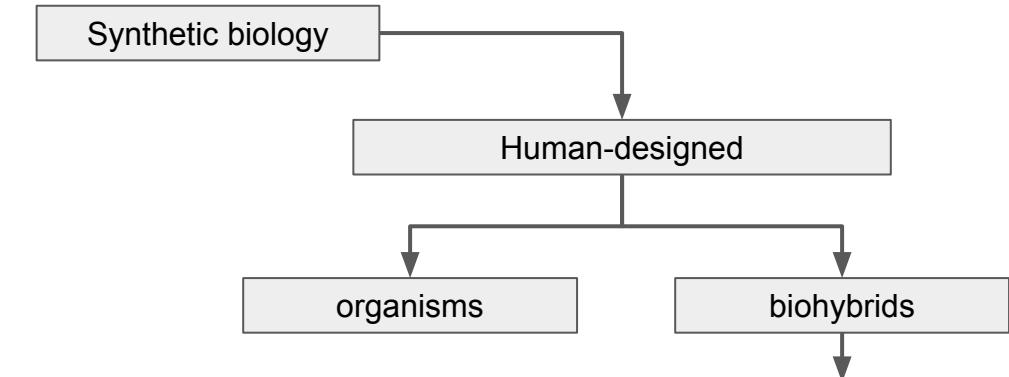
cdorgs.github.io



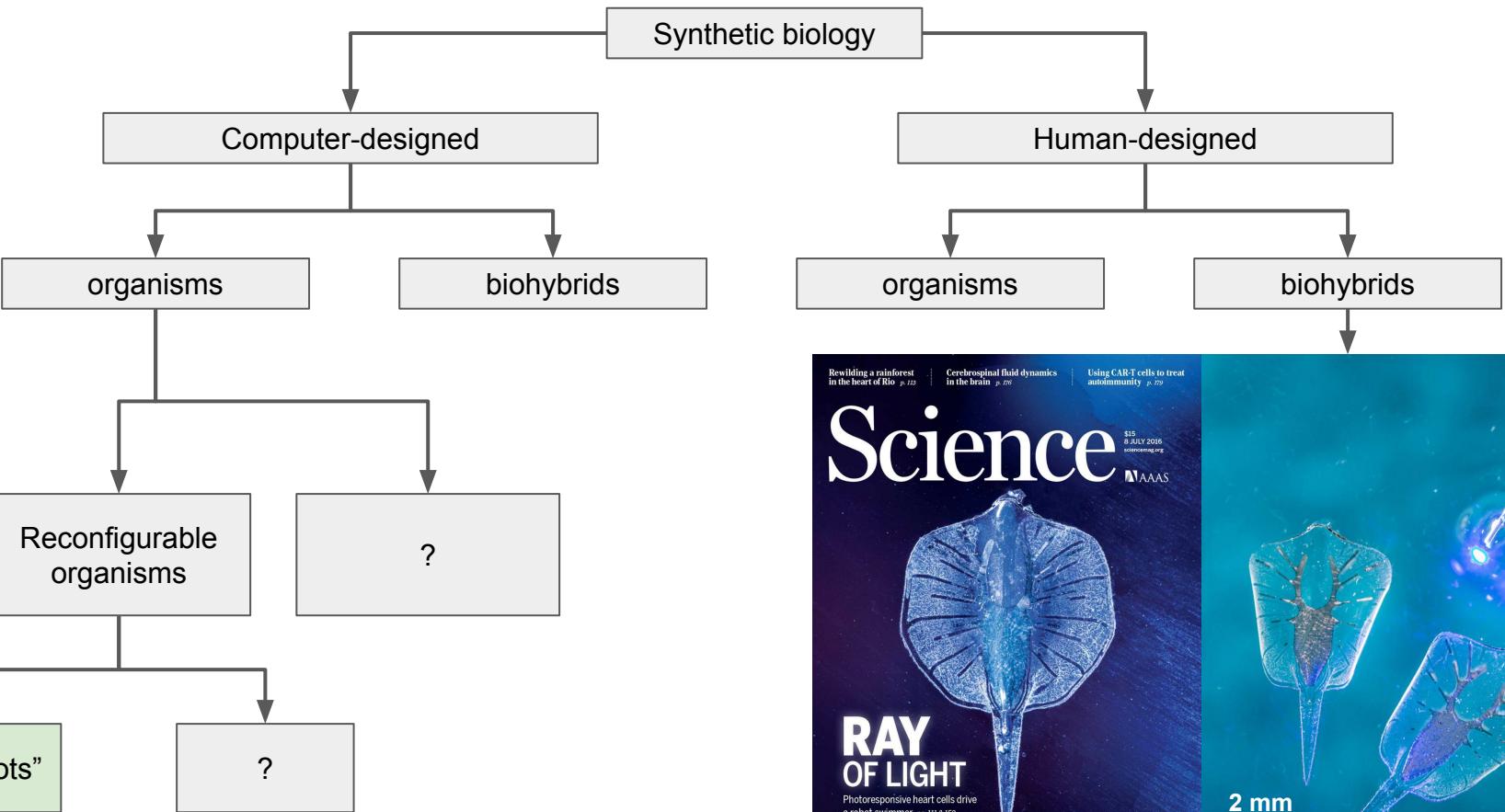


Heart cells embedded in silicone jellyfish.

J. Nawroth et al. *Nature biotechnology* (2012).



Optogenetically controlled heart muscle stingray.
S. Park et al. *Science* (2016).



Optogenetically controlled heart muscle stingray.
S. Park et al. *Science* (2016).

Computer-designed organisms:

Evolutionary algorithm discovers novel forms with desired function, then manually manufactured.
cdorgs.github.io

Future Work

Automating manufacture.

Gain control of spontaneously-appearing useful function.

Adding new

tissue types

sense organs

“Actuators”

Nervous tissue

Cells from other species

Automated improvement of “sim2life” transferal.

“Cracking the bioelectric code”

Finding new collaborators

Acknowledgements

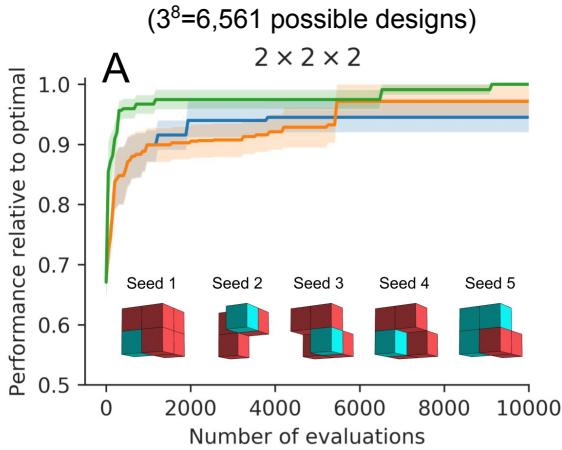
Sam Kriegman (UVM)

Doug Blackiston (Tufts)

Mike Levin (Tufts)



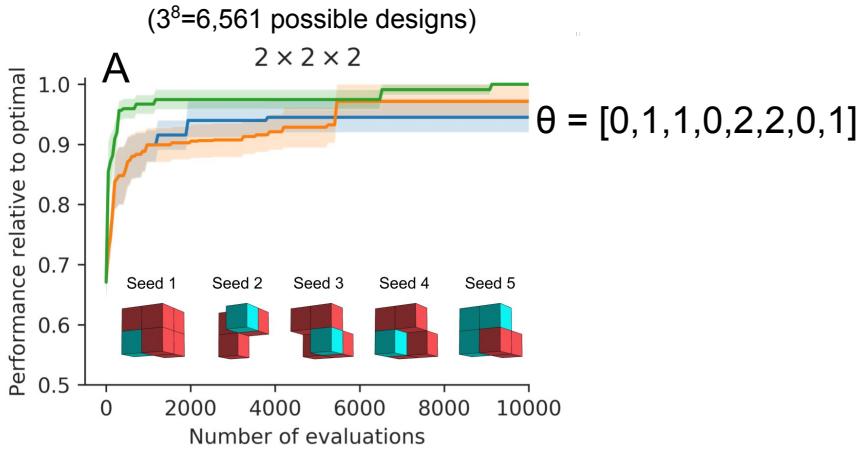
DARPA Lifelong Learning Machines (L2M) program



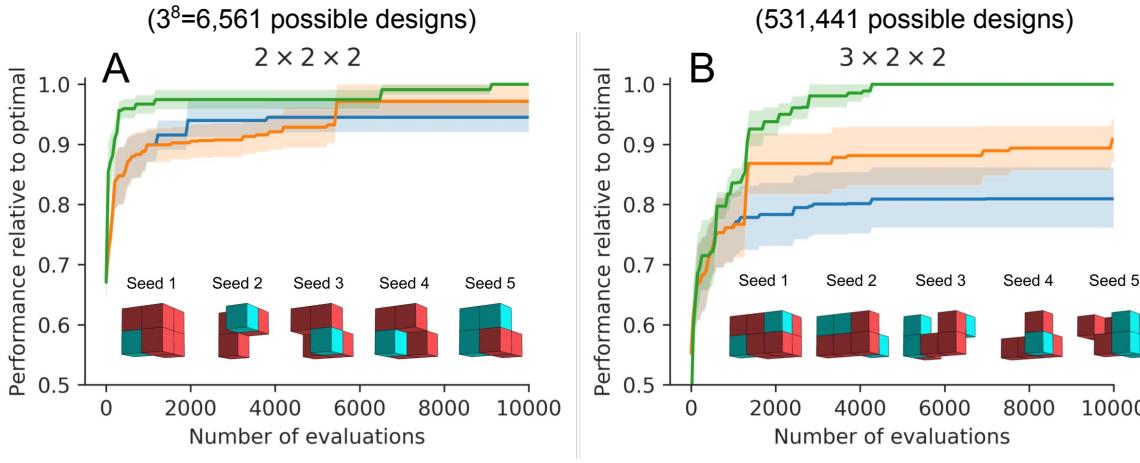
EA = Age Fitness Pareto Optimization (Schmidt & Lipson, 2011)

SGD = Parameter-exploring policy gradients (Senkhe et al., 2010)

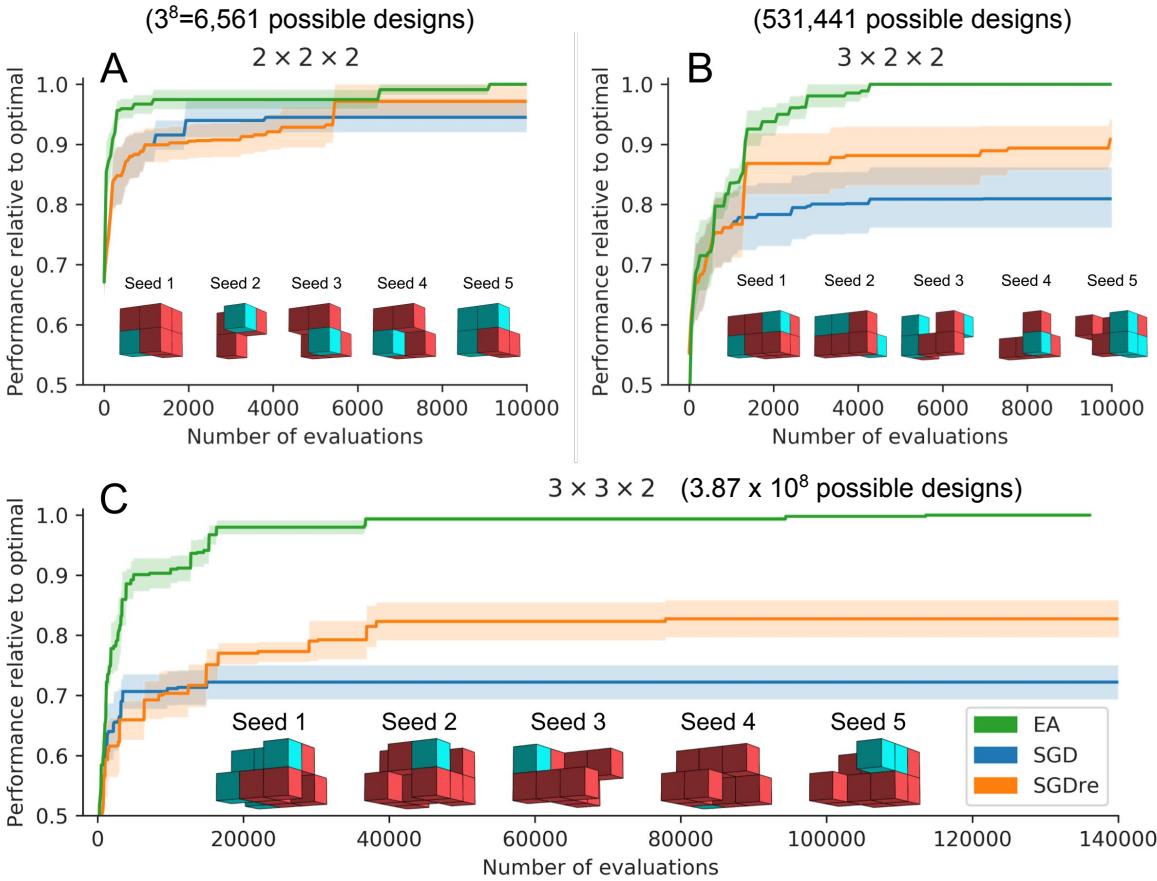
SGDre = PEPG with restarts



EA = Age Fitness Pareto Optimization (Schmidt & Lipson, 2011)
SGD = Parameter-exploring policy gradients (Senkhe et al., 2010)
SGDre = PEPG with restarts



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SGDre = PEPG with restarts