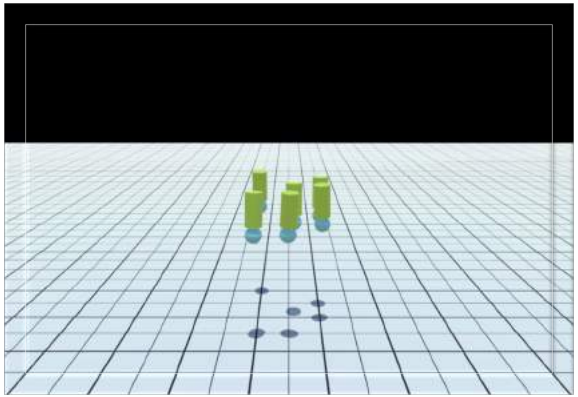
# SELF-ASSEMBLING MORPHOLOGIES

## GENERALIZATION VIA MODULARITY



Deepak Pathak*, Chris Lu*, Trevor Darrell, Philipp Isola, Alexei A. Efros

UC Berkeley

* equal contribution

BAIR
BERKELEY ARTIFICIAL INTELLIGENCE RESEARCH

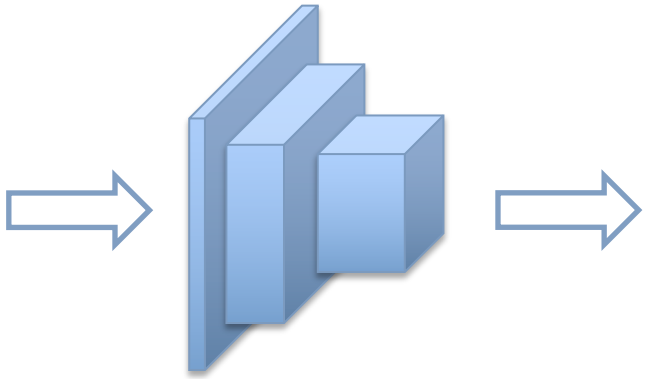
Berkeley
UNIVERSITY OF CALIFORNIA

# Supervised Learning

ImageNet Test Set ~ 80%

YouTube Video ~ 25%


Input $x$



Model $f_\theta(\,)$

"Cobra (Snake)"

Output

$y = f_\theta(\,x\,)$

[Output of ResNet-50][Also see "The Elephant in the Room", Rosenfeld et.al. 2018]

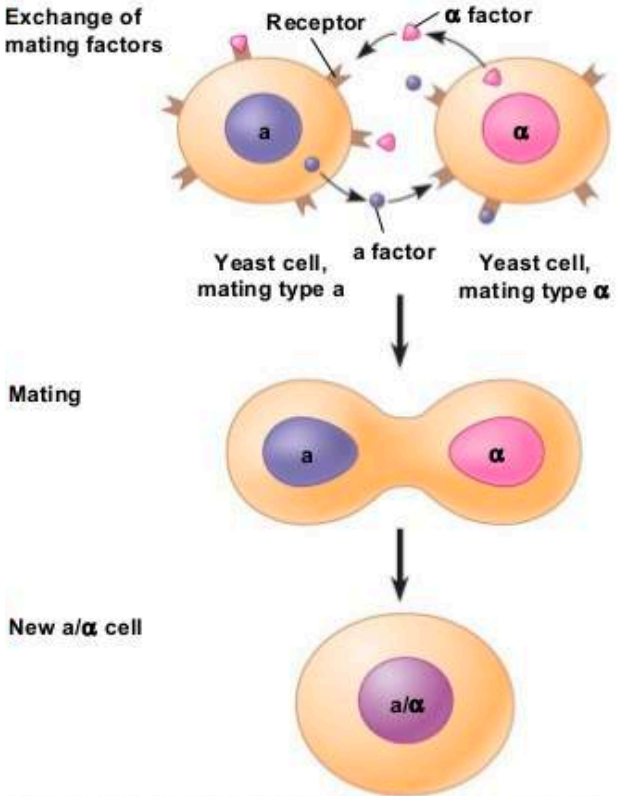
# Toward Generalist Machines

## “Nature vs. Nurture”

# Toward Generalist Machines

## “Nature vs. Nurture”

# Unicellular to Multicellular Evolution




Investigate “Modularity”

Reusability

+

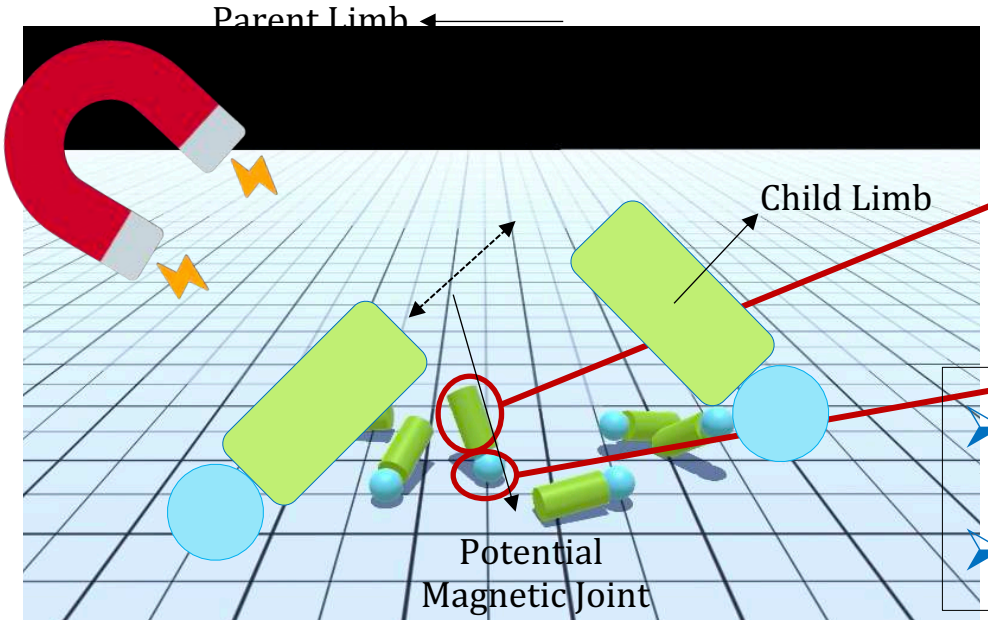
Compositionality

# **Modular Co-evolution** of Control and Morphology

*a collection of primitive agents learns to self-assemble to jointly solve control tasks.*

**Pathak***, Lu*, Darrell, Isola, Efros. NeurIPS 2019 (Spotlight).

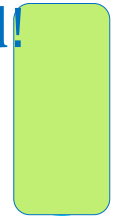
# **Modular Co-evolution** of Control and Morphology




Acts as single agent upon joining

Rewards are shared!

Cylindrical Limb

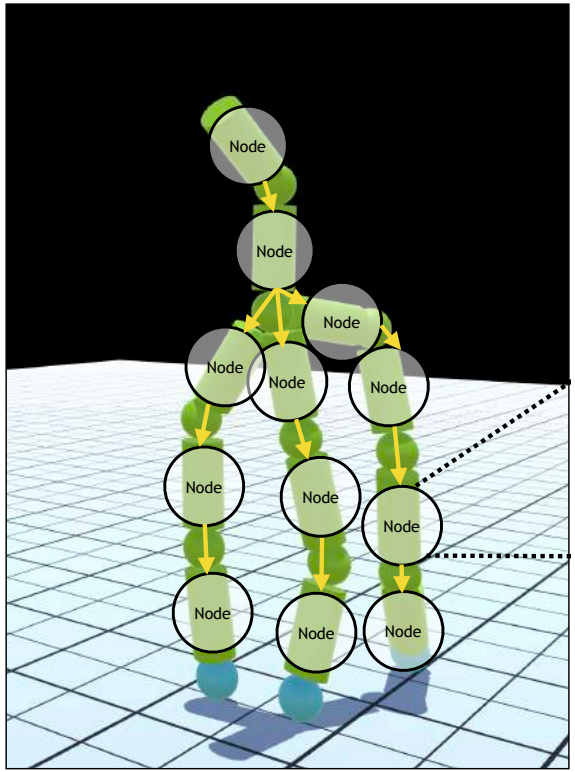


Configurable Motor Joint

- Input = *Local* Sensory State
- Output = Torques, Link, Unlink

**Pathak***, Lu*, Darrell, Isola, Efros. NeurIPS 2019 (Spotlight).

# “Modular” Self-assembling Morphologies

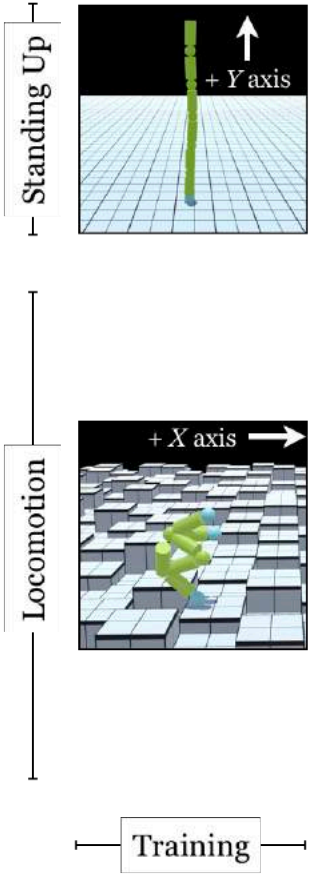


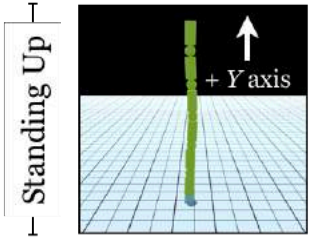

$$\max_{\theta} \sum_{i=\{1,2\ldots,n\}} \mathbb{E}_{\vec{a}^i \sim \pi_\theta^i}[\Sigma_t r_t^i]$$

Dynamic Graph Networks

**Pathak***, Lu*, Darrell, Isola, Efros. NeurIPS 2019 (Spotlight).

# Environments



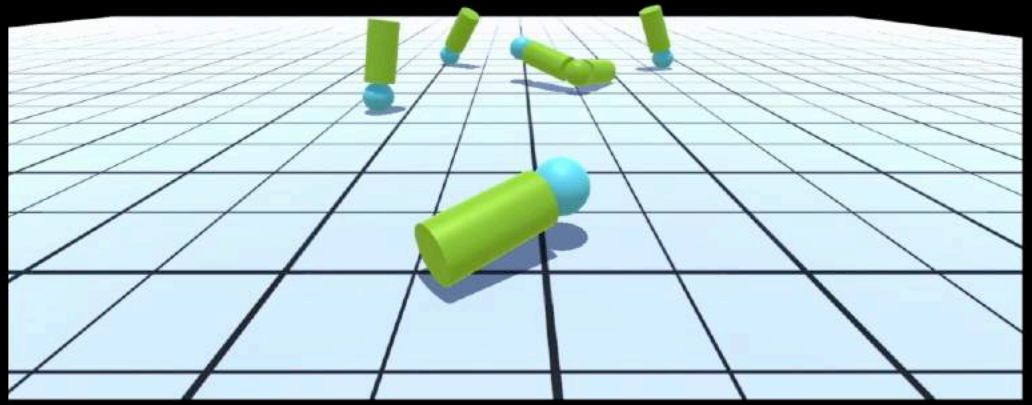



# How well Vanilla RL work?

# Vanilla Reinforcement Learning

**Pathak***, Lu*, Darrell, Isola, Efros. NeurIPS 2019 (Spotlight).

# Instead, we start with primitive limbs and allow them to self-assemble

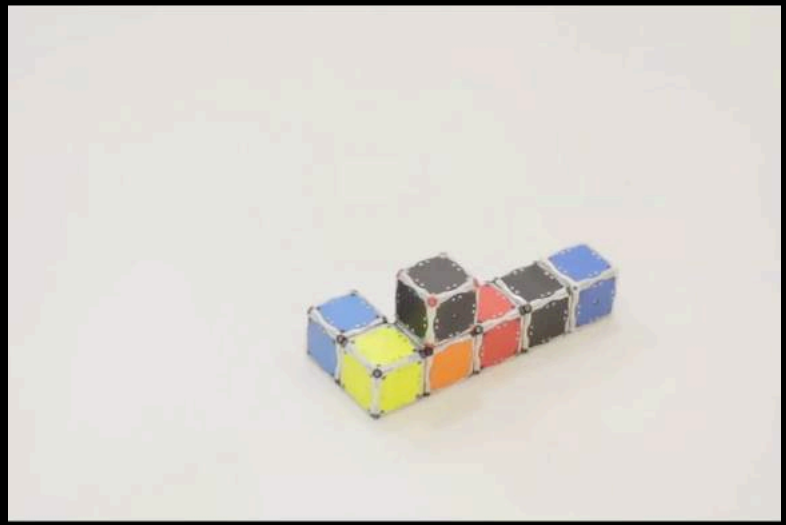


**Pathak***, Lu*, Darrell, Isola, Efros. NeurIPS 2019 (Spotlight).

a bit crazy… even possible in real world?

# Self-Assembling Robots in the Real World


[Mark Yim's Lab at UPenn]



[Daniela Rus's Lab at MIT]

Also: [Modular Snake Robot – Howie Choset's Lab at CMU]

https://people.eecs.berkeley.edu/~pathak/

# Thank You!

**Pathak***, Lu*, Darrell, Isola, Efros.
Learning to control self-assembling agents:
A study of generalization via modularity.
NeurIPS 2019.