Approaching Artificial Intelligence as an Embodied Developmental Process

LEFT: Chicken neural crest migration, MIDDLE: Axolotl developing nervous system,
RIGHT: elongation of Zebrafish notochord.

**Bradly Alicea, Rishabh Chakrabarty, Akshara Gopi, Anson Lim,
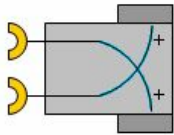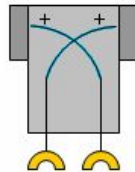Furkan Özçelik, and Jesse Parent**
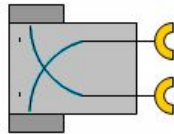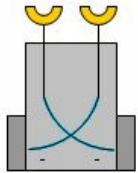
Braitenberg Vehicles

First-order stimulus-response mapping:

- observe empirical world, hard-wired to elicit response.

- vehicle types yield taxis, or reflexive behavior.

Very simple neural networks that are embodied agents (effects of body are explicit).

2a

2b
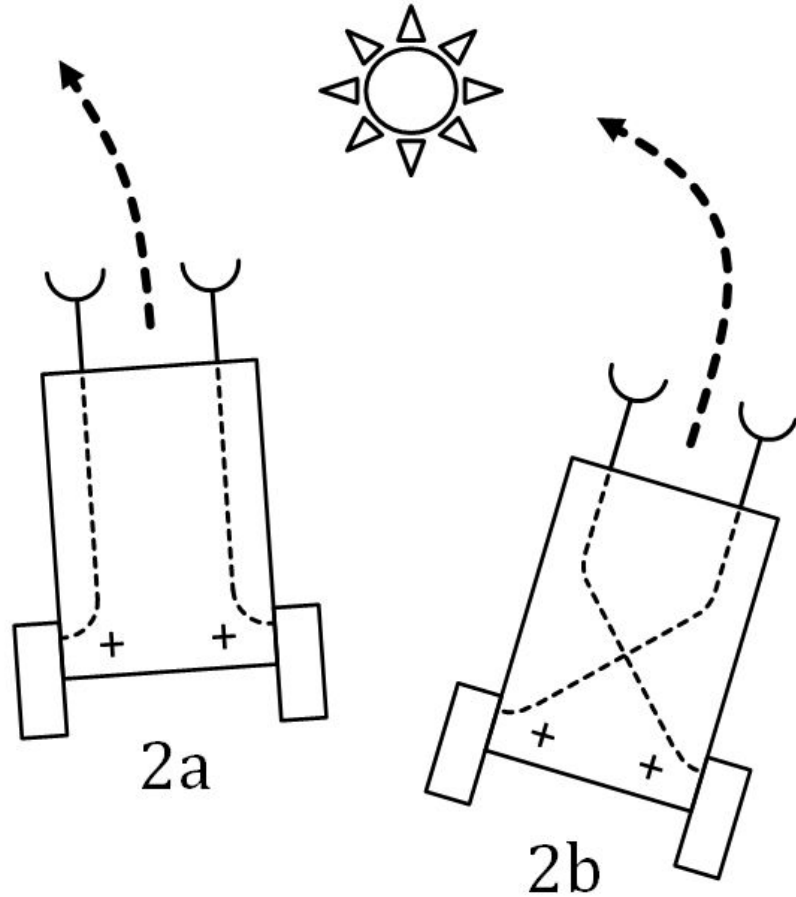
Developmental Braitenberg Vehicles (dBVs)
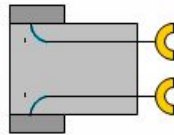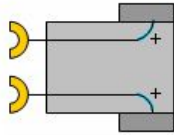
Embodied nervous system, neural network develops inside of a simple phenotype.

Development: network morphogenesis

- initial condition: a mapping between sensor and effector

- complex network of interneurons that attenuate the initial feedforward signal.
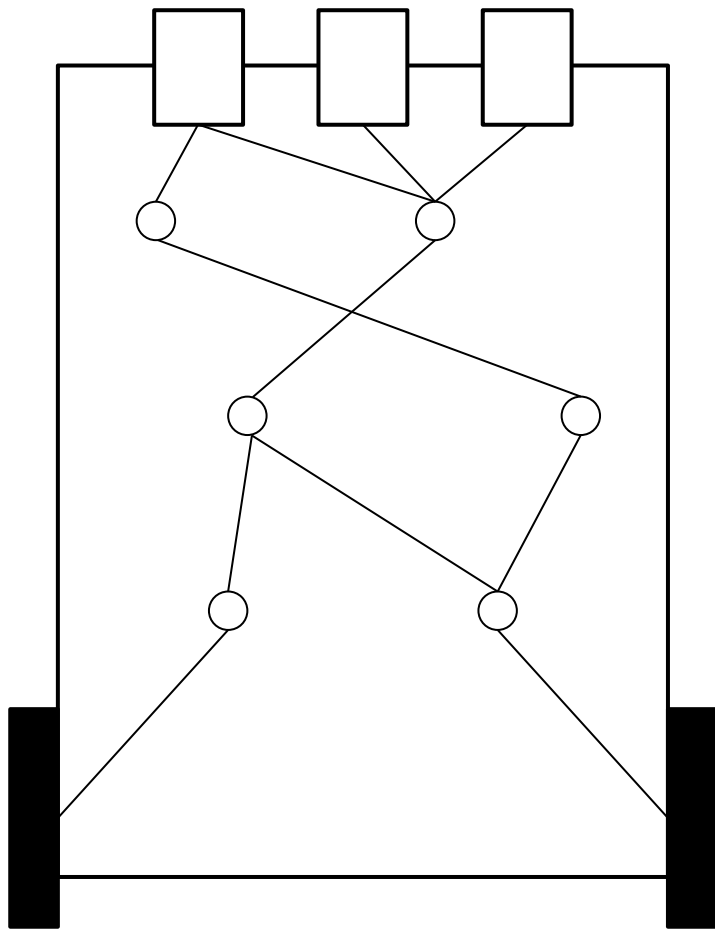
Sensor Nodes

Simple mapping between sensors and effectors modified over time by intermediate (internal) nodes.

Internal Nodes

Internal node mediate between sensor and effector, combine sensory signals.

CGS kernel embedded among the internal nodes, transforms signals into fuzzy combinations (probabilistic signals).

Effector Nodes

Sensor
Nodes

Internal
Nodes

Effector
Nodes

Chromotaxis

Example of behavior generated by Meta-brain Model that utilizes a dBV.
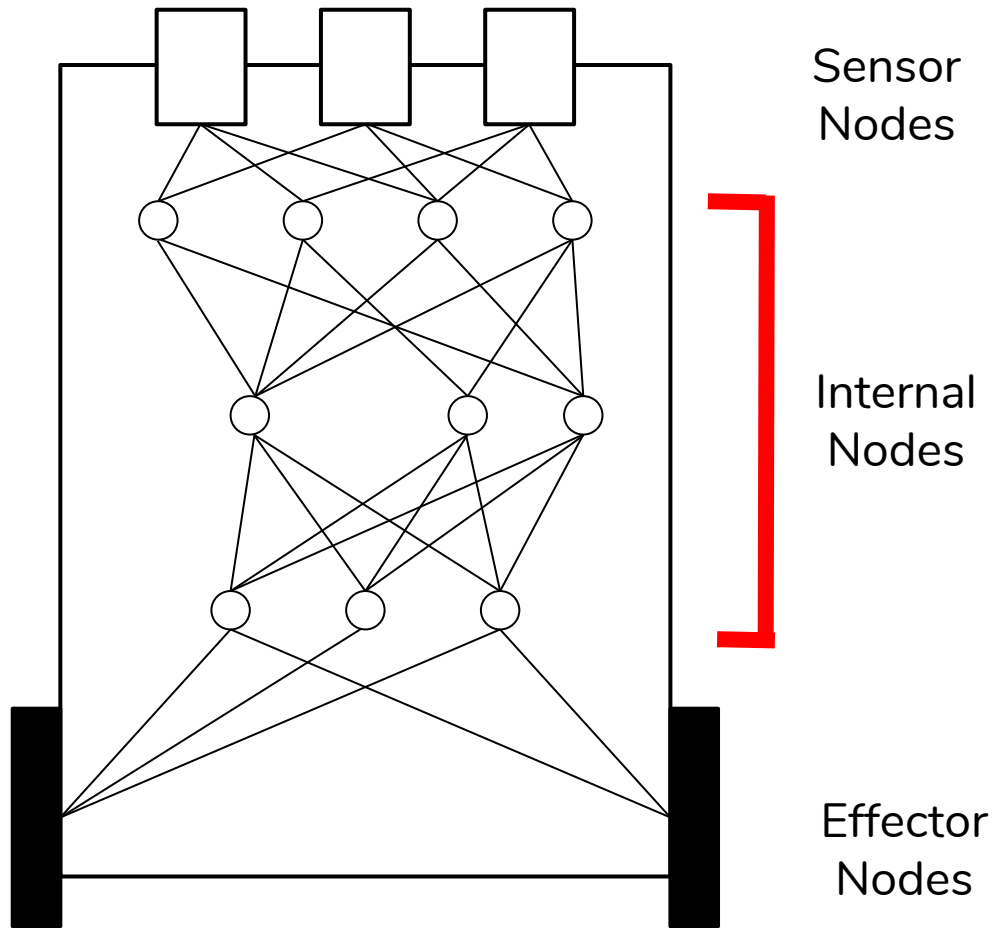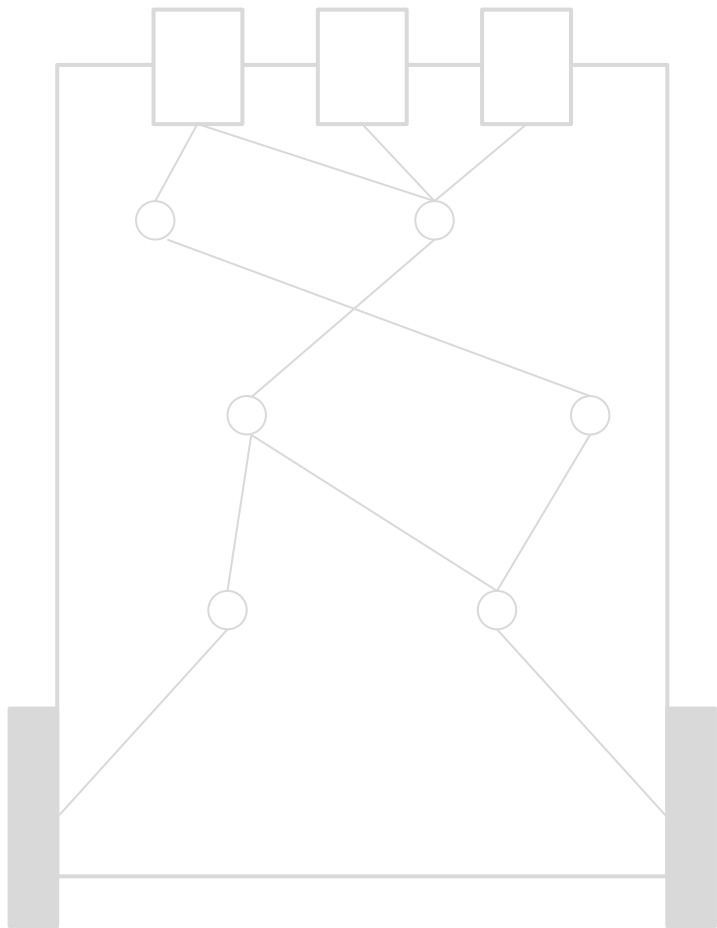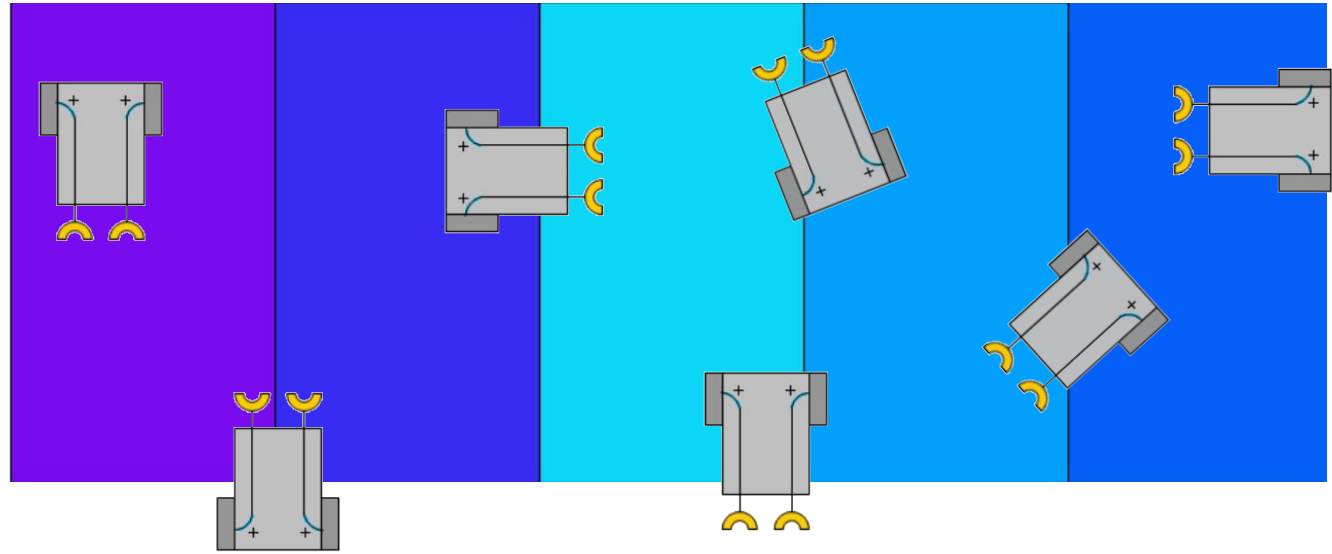
Meta-brain Model: Developmental Embodied Agents as Meta-brain Models. *Developmental Neural Networks Workshop*, Artificial Life 2020.

DevoNN

As a phototaxis, simple attraction/repulsion

As a preference, a separate continuum of emotional valence.

Difference between congruent stimuli (color, shape) enables Generalized Hebbian learning (GHA).

Differentiation between incongruous colors enables spatial learning (assembly via genetic algorithm -- BraGenBrain).

W$_{ij}$

Connectivity Activation Encoding

	SL	SM	SR	IN	WL	WR
SL	0	0	0	1	1	0
SM	0	0	0	1	1	0
SR	0	0	0	0	0	1
IN	1	1	0	0	1	1
WL	1	1	0	1	0	0
WR	0	0	1	1	0	0

$$W_{ij}$$

Each developmental time point produces a connectivity matrix W_{ij}.

Each matrix has a corresponding determinant $|A|$

$$W_{ij} = |A_n|$$

$$W_{ij}$$

What is W_{ij}? A summary of connections among a network of size k. In development, the number of neurons (k) can grow and synapses (connections i,j) can fluctuate in terms of their strength and efficacy. So W_{ij} is scaled by parameter k.

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Universality and individuality in neural dynamics across large populations of recurrent networks. *Advances in Neural Information Processing Systems*, 32, 15629–15641.

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Reductionist representation: add all components of a biological neural network (synaptic signaling, glia, astrocytes, protein expression, intercellular matrix).

What do we need to add to W_{ij} to make this model more "biological"? Or can we add biological realism without finding universal features or making model more descriptive?

$$W_{ij} = |A_1|$$

$$W_{ij} = |A_2|$$
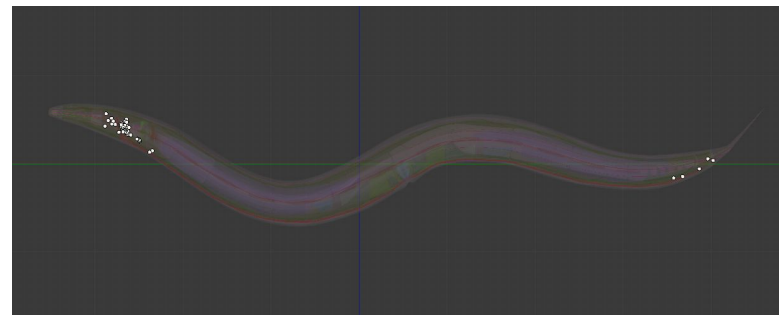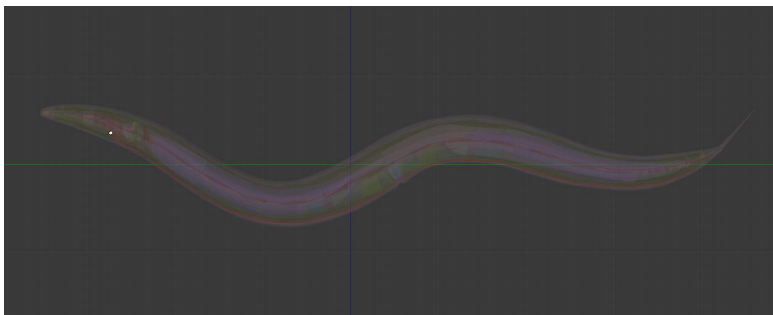
$$W_{ij} = |A_3|$$

Birth of neuronal cells (white) in *C. elegans* embryo at 265, 280, 300 minutes post-fertilization.
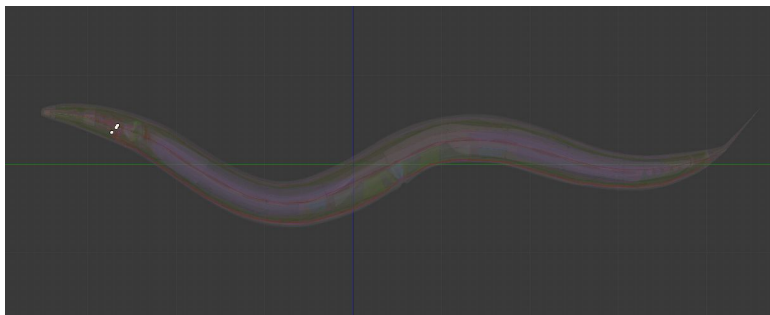
C. elegans embryonic connectome: *Biosystems*, 173, 247-255 (2018).

Critical Periods

Critical period: window of developmental time that features an enhanced ability to learn.

- associated with physiological reorganization.

- critical period window can have variable width, shifted earlier or later in development.
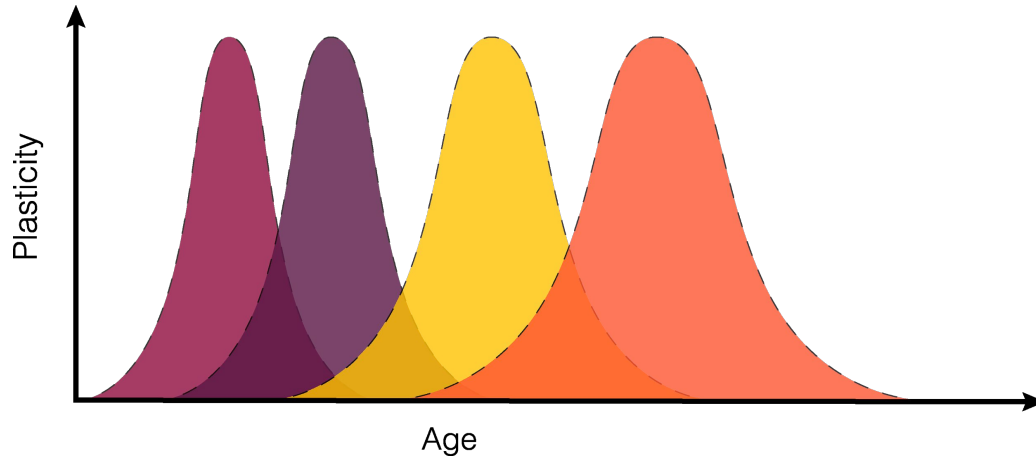
Critical Periods

Morphogenesis

Defined by slow growth before critical period, fast growth during.
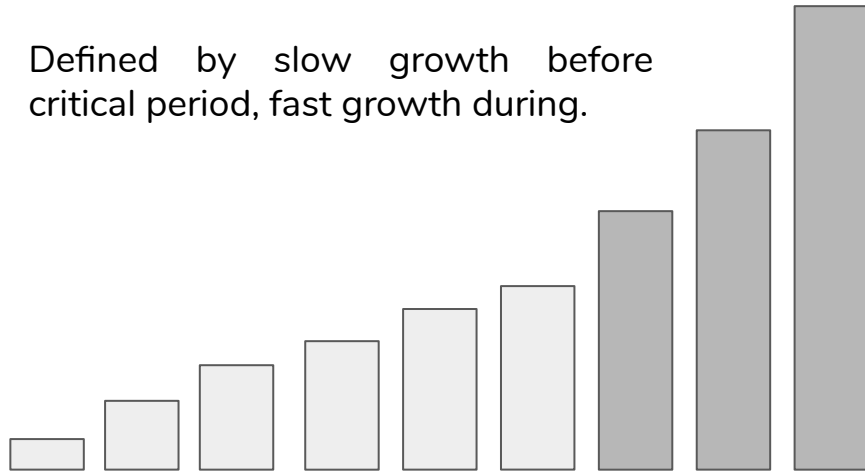
Critical Period
(dark gray)

Critical Periods

Morphogenesis
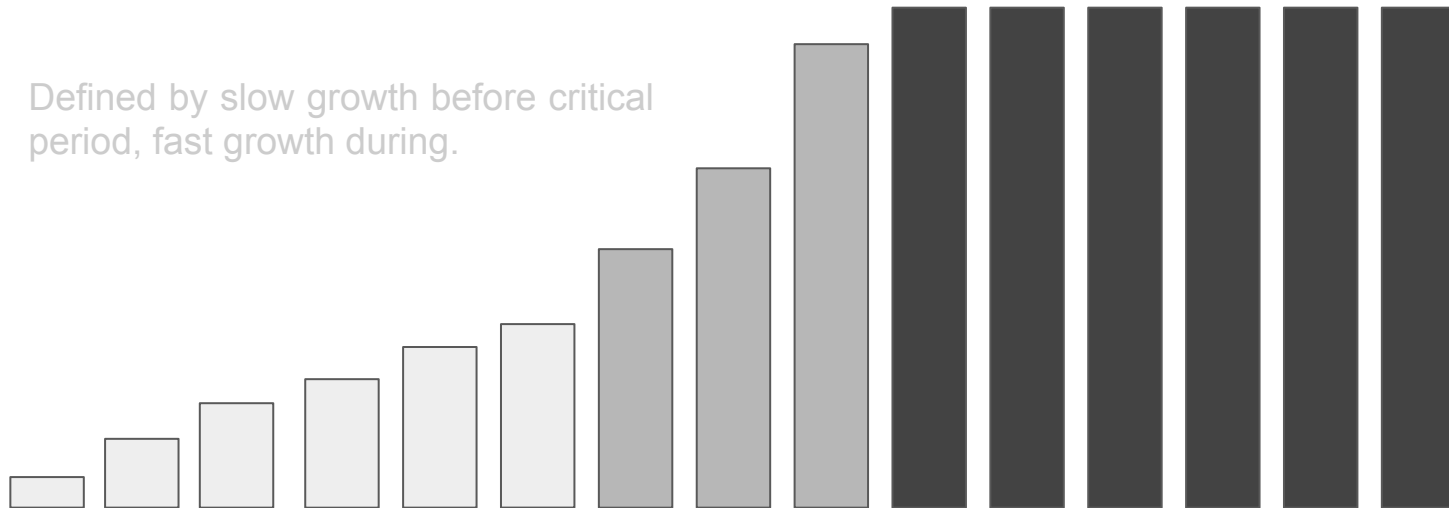
Defined by no growth in size of matrix and relative stability among connections. Enables **developmental freedom**, or ability to learn on a stable network.

Defined by slow growth before critical period, fast growth during.

Developmental Learning

	EARLY	**LATE**
CRITICAL PERIOD	Adult neural network: tends to be more homogeneous, Less time for preliminary or auxiliary nervous system or behavioral traits to develop Fewer varieties of experience prior to maturity.	
DEVELOPMENT FREEDOM		

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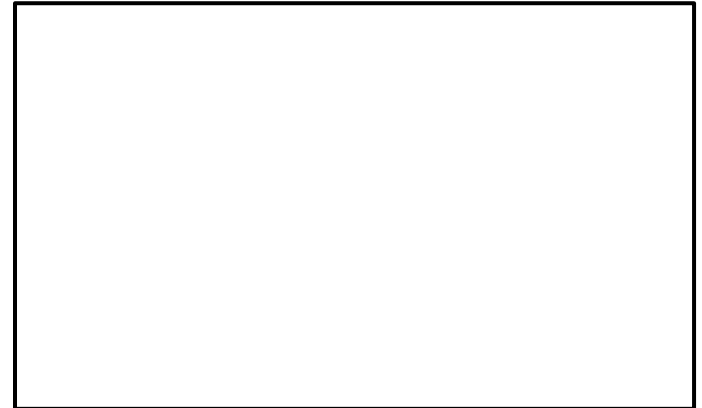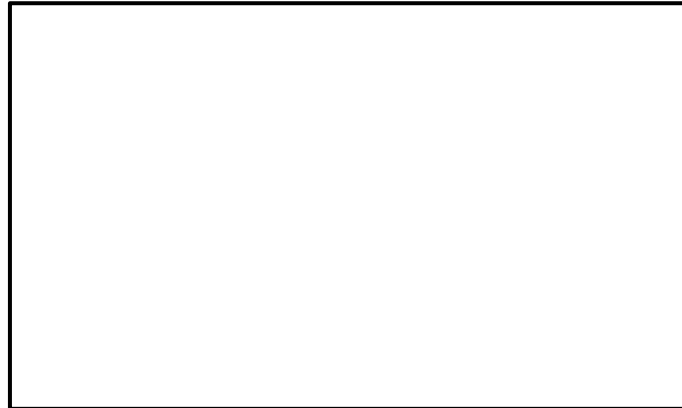|	**EARLY**	**LATE**
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DEVELOPMENT FREEDOM	Low degree of overall developmental freedom. Early critical period allows for faster ascendance to a fully mature suite of behaviors suite and capabilities.	High degree of overall developmental freedom. Later critical period allows for a slower ascendance to adult behaviors and capabilities.

Gibsonian Information
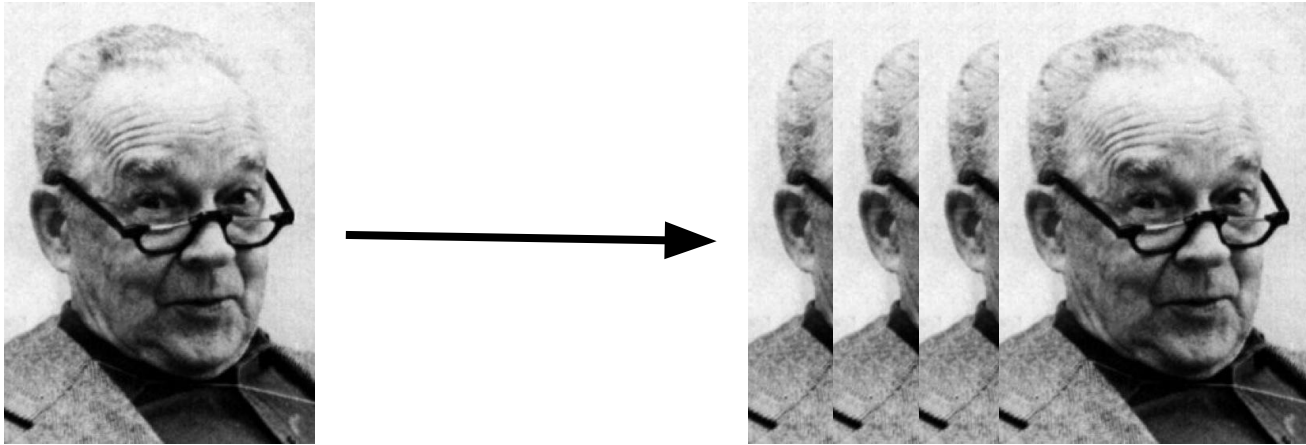
Motion provides information!

Optical flow, relative motion between object and observer, structure from motion

1) **Flow, motion, and contrast.**

2) Disjoint distribution (moving vs. stationary pixels).

3) Time-series structure (temporal-dependence).

4) Maximum vs. minimum coherent movement.

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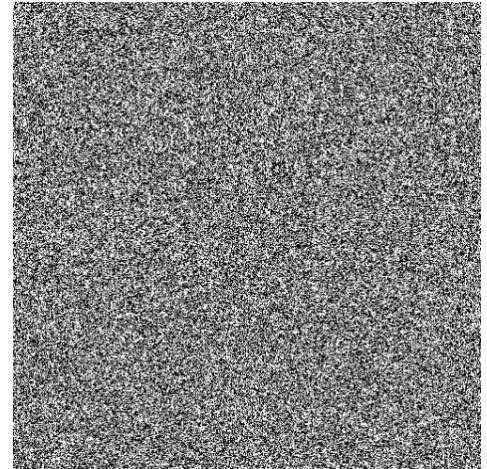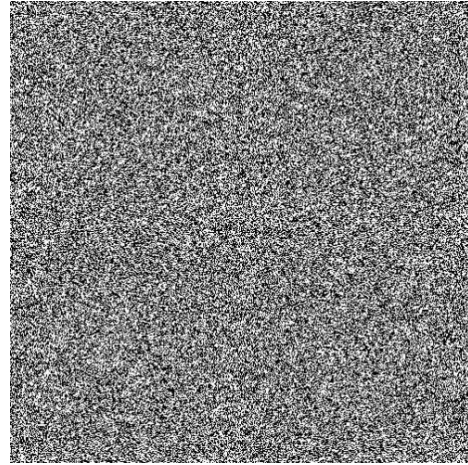
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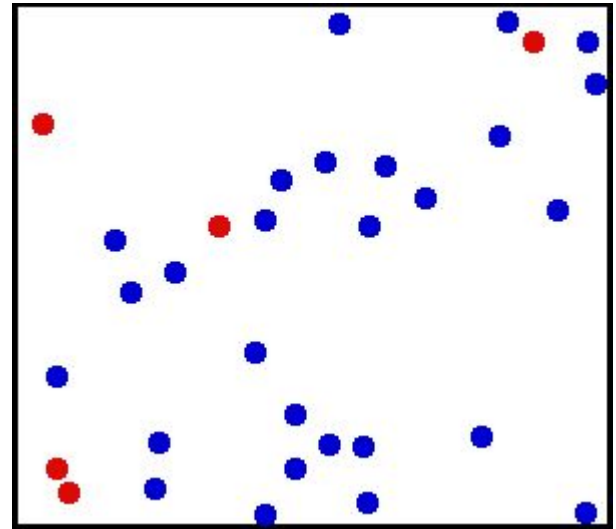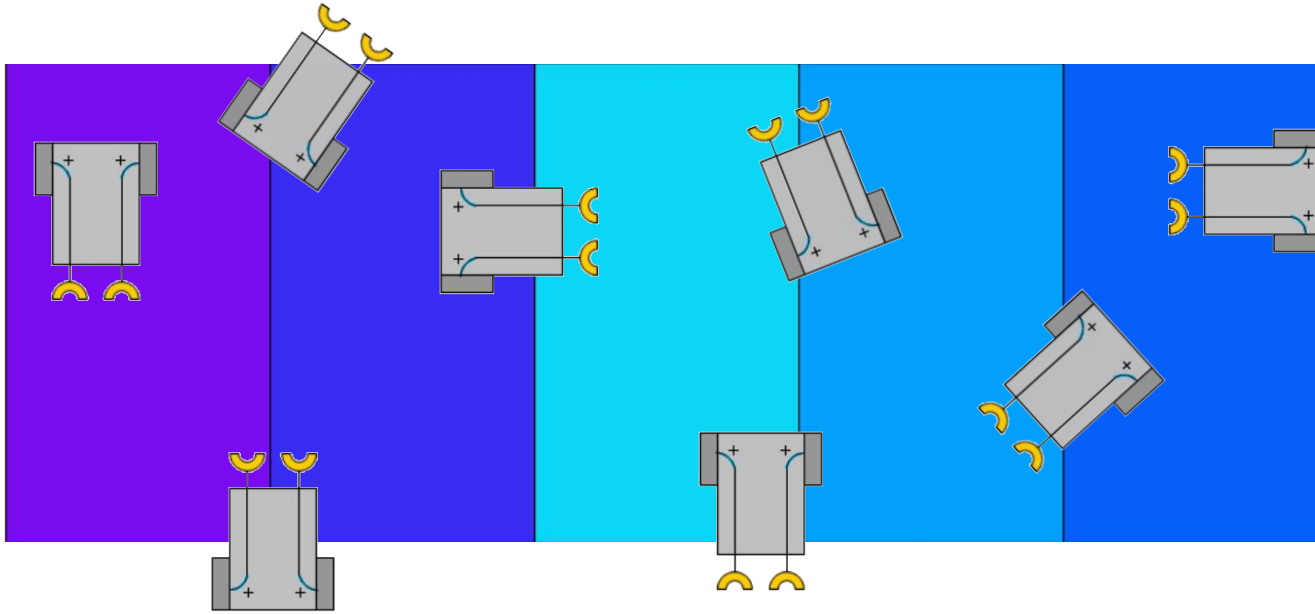
Towards a Developmental Reinforcement Learning (dRL) approach:

- development of discrete layers will help agents learn better policies.

- growth of nervous system counters potentially large, continuous action space.

- curriculum learning (easy examples, then harder examples over time).

t

1-*D* developmental
possibility space

Contingency in Development

Interpreting scenarios A-D
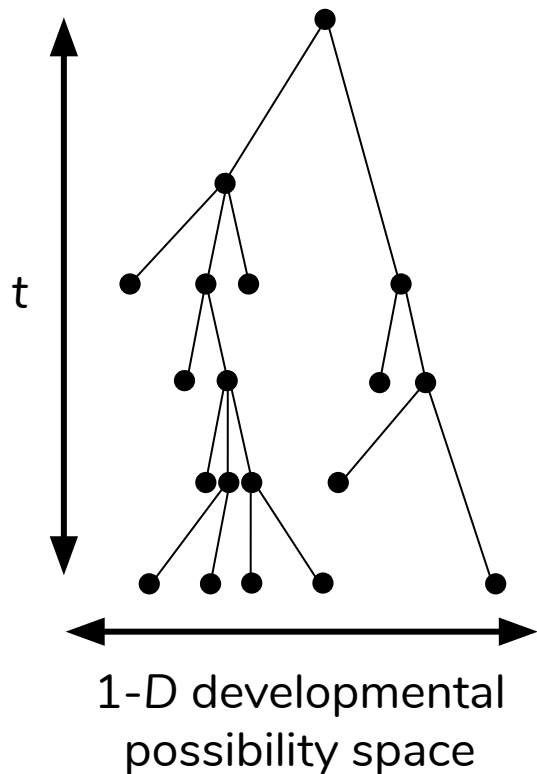
Each node is a developmental event, branches
are possible developmental pathways.

Morphogenetic events (growth of matrix W_{ij}) actually
restricts: earliest branches (higher in the tree) restrict
developmental system in possibility space.

More changes occur during critical period, but results in a
network restricted to an increasingly smaller number of
possible outcomes over time.

Developmental freedom may allow for limited convergent
evolution of development (evo-devo). Brain vs. mind?
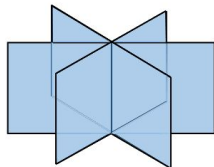
Thanks for Your Attention!

Acknowledgements

Developmental Braitenberg Vehicles

Stefan Dvoretskii
Ziyi Gong
Ankit Gupta

Read our preprint on ResearchGate!

http://tiny.cc/q651tz

Visit our lab website and Github!
https://orthogonal-research.weebly.com/
https://github.com/Orthogonal-Research-Lab

REPRESENTATIONAL BRAINS AND PHENOTYPES

Thanks to the Saturday Morning NeuroSim group

Theme 8: Neural Excitability, Synapses, and Glia

The Psychophysics of Non-neuronal Cognition

Non-neuronal cognition can be used to explain what appear to be neural behaviors in cellular-level systems. Examples include cellular decision-making (Perkins and Swain, 2009), information processing in regenerative processes (Baluska and Levin, 2016), and active perception among filopodia (Aspalter et al,

a corresponding degree of output. From these input/output curves, we can derive just-noticeable differences and signal detection measurements. To model the movements that lead to statistical

Room 8, Thursday, 12:30pm UTC