

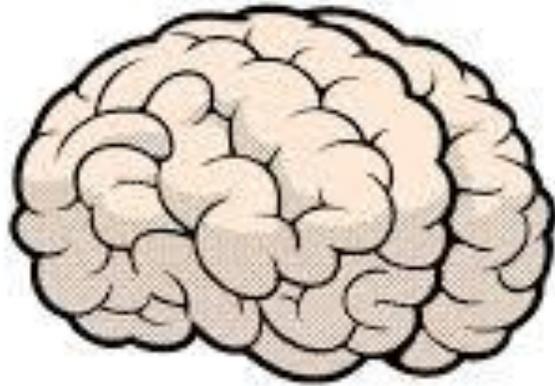
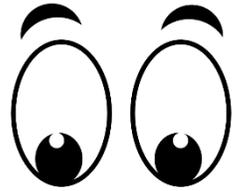
Morphogenesis: the shape of knowledge in space and time

Thomas E. Portegys

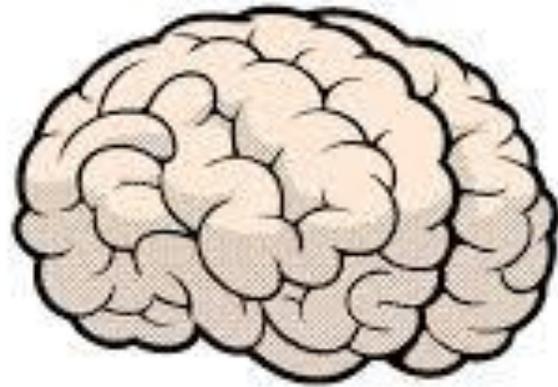
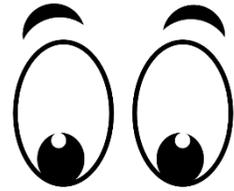
tom.portegys@ey.com, Ernst & Young

The elevator pitch

**The brain is intelligent.
Therefore we look at the
brain to learn about
intelligence.**

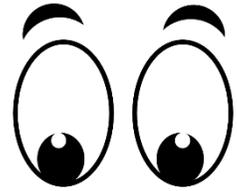


The elevator pitch

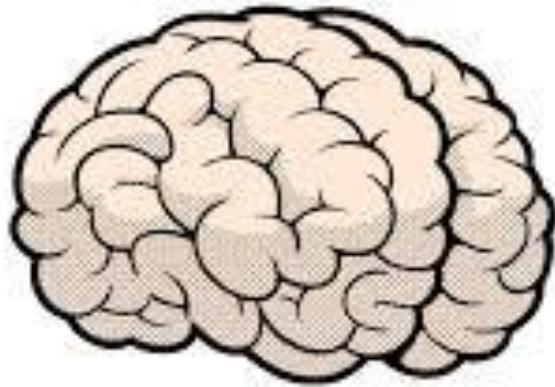


**But the brain is a solution
to a problem: its
environment.**

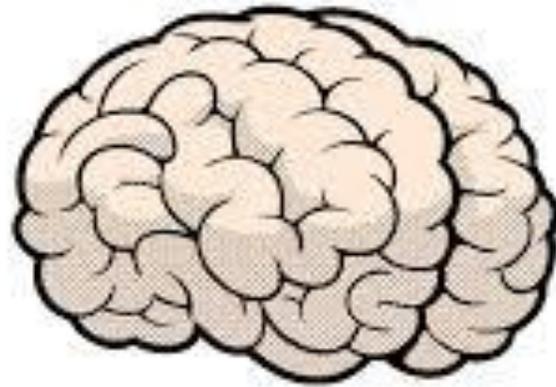
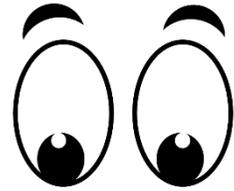
The elevator pitch



**So instead of looking only
at the brain...**



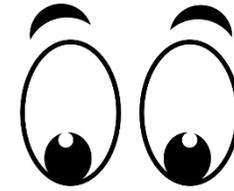
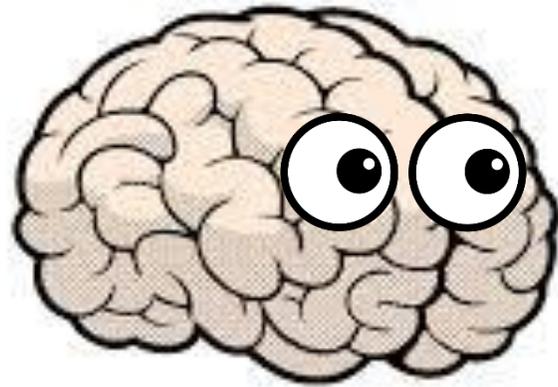
The elevator pitch



**Notoriously hard to
reverse engineer...**

The elevator pitch

We should also look at what the brain is looking at!



What is “out there” for the brain to sense?

- We may be constrained by evolution to be unable to directly sense the “real” world.
 - Only sense stimuli that are ancestrally needed for survival and reproduction.
 - The rest is irrelevant resource-consuming baggage, like color vision for night dwelling mammals.

What is “out there” for the brain to sense?

- Philosophers and physicists are not settled on what is reality and the physical world:
 - Epistemology, e.g. solipsism, nihilism, etc.
 - Multi-dimensional string theory and multiple worlds.
 - Nature as a giant graph or automaton.
 - Holographic projections and simulation.
 - Quantum wave collapses.

A simple model works

- Space and time are universal experiences.

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- Even if there is a different underlying reality, the model is effective.

A simple model works

- Space and time are universal experiences.
- Even if there is a different underlying substructure, the model is effective.
- Higher intelligence can be understood as the ability to process information arising from a larger extent of space-time.

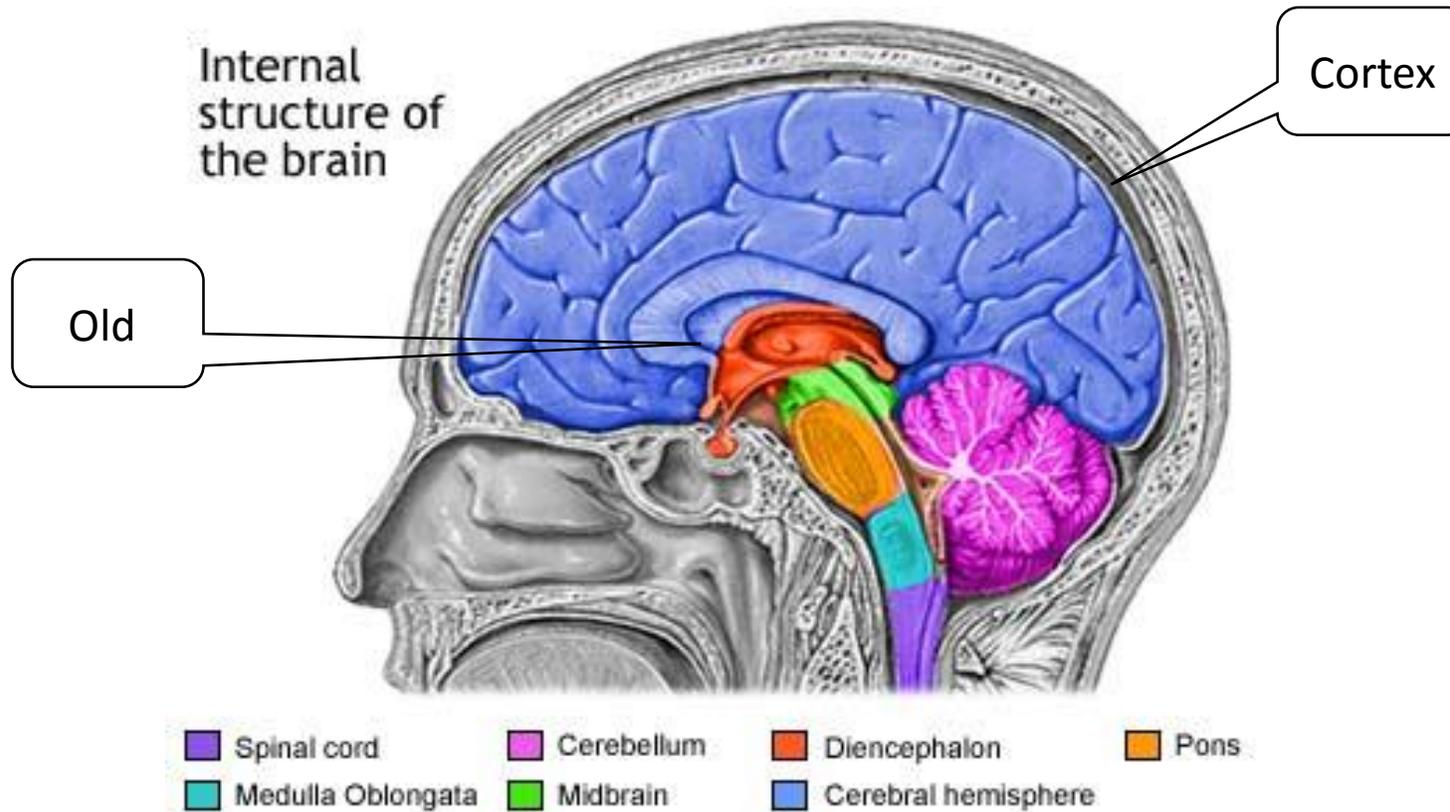
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A simple model works

- Space and time are universal experiences.
- Even if there is a different underlying substructure, the model is effective.
- Higher intelligence can be understood as the ability to process information arising from a larger extent of space-time.
- The mammalian brain has structures for dealing with spatial geometry.
- In keeping with nature's penchant for extending rather than replacing, the purpose of the mammalian neocortex might then be to record events from distant reaches of space and time and render them, as though yet near and present, to the older, deeper brain whose instinctual roles have changed little over eons.

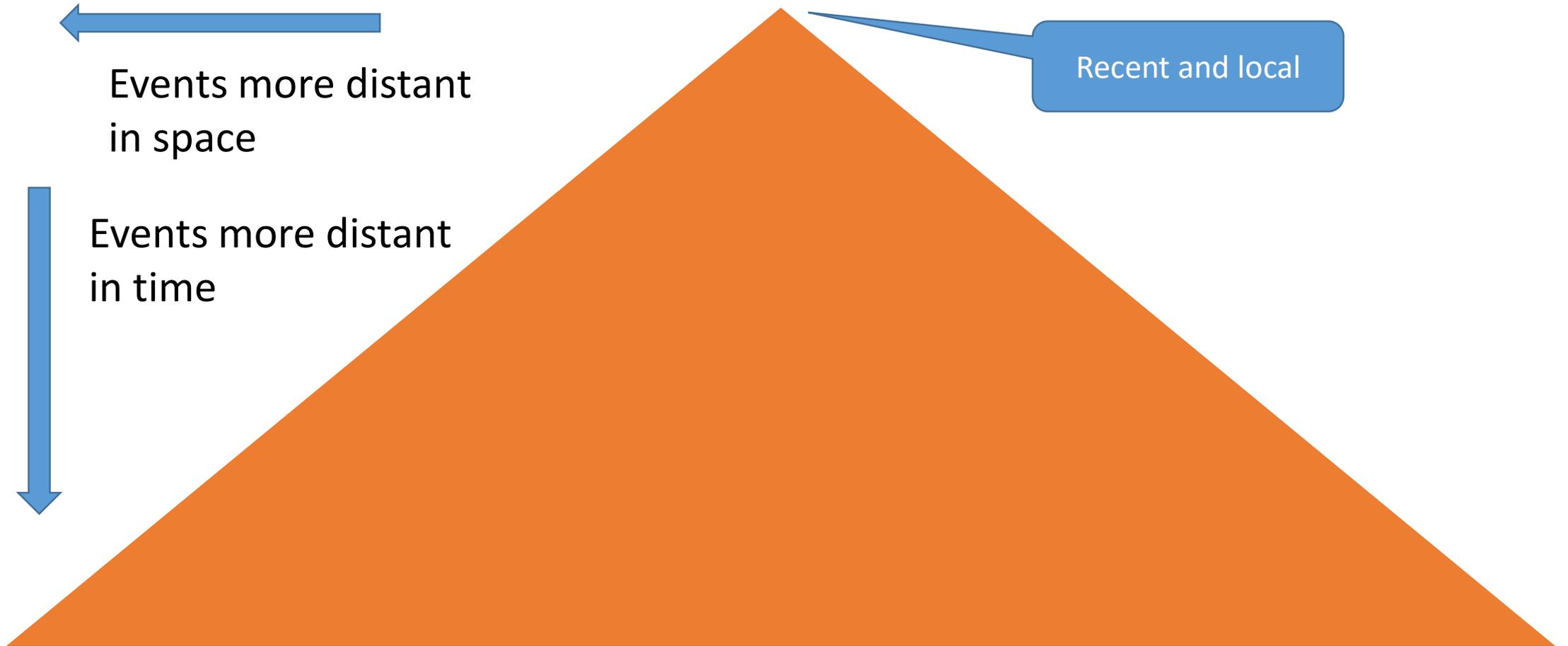
Is the cerebral cortex a ~~virtual~~ reality helmet for the “old brain”?



Synopsis

- Building an internal spatial and temporal model of the environment allows an organism to navigate and manipulate the environment.
- Introduces a model called *morphognosis* (*morpho* = shape and *gnosis* = knowledge).
- Its basic structure is a pyramid of event recordings called a *morphognostic*. At the apex of the pyramid are the most recent and nearby events. Receding from the apex are less recent and possibly more distant events.

Morphognostic pyramid



Mox food foraging in a 2D cellular world



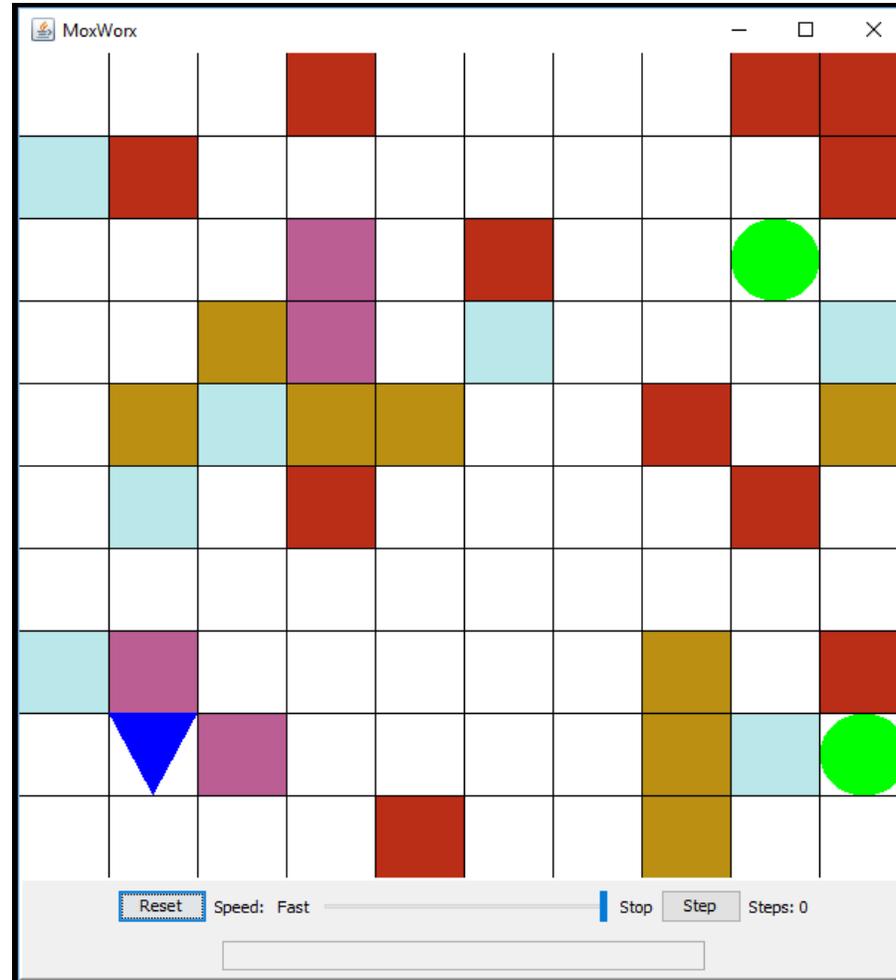
mox



food



obstacles



Mox orientation:
north, south, east, west

Mox responses:
forward
turn right/left
eat

Mox demo

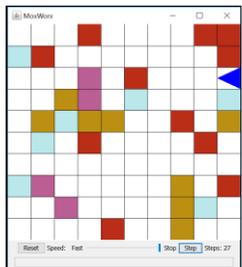
Pyramid of obstacle type densities arranged as hierarchy of 3x3 cell neighborhoods



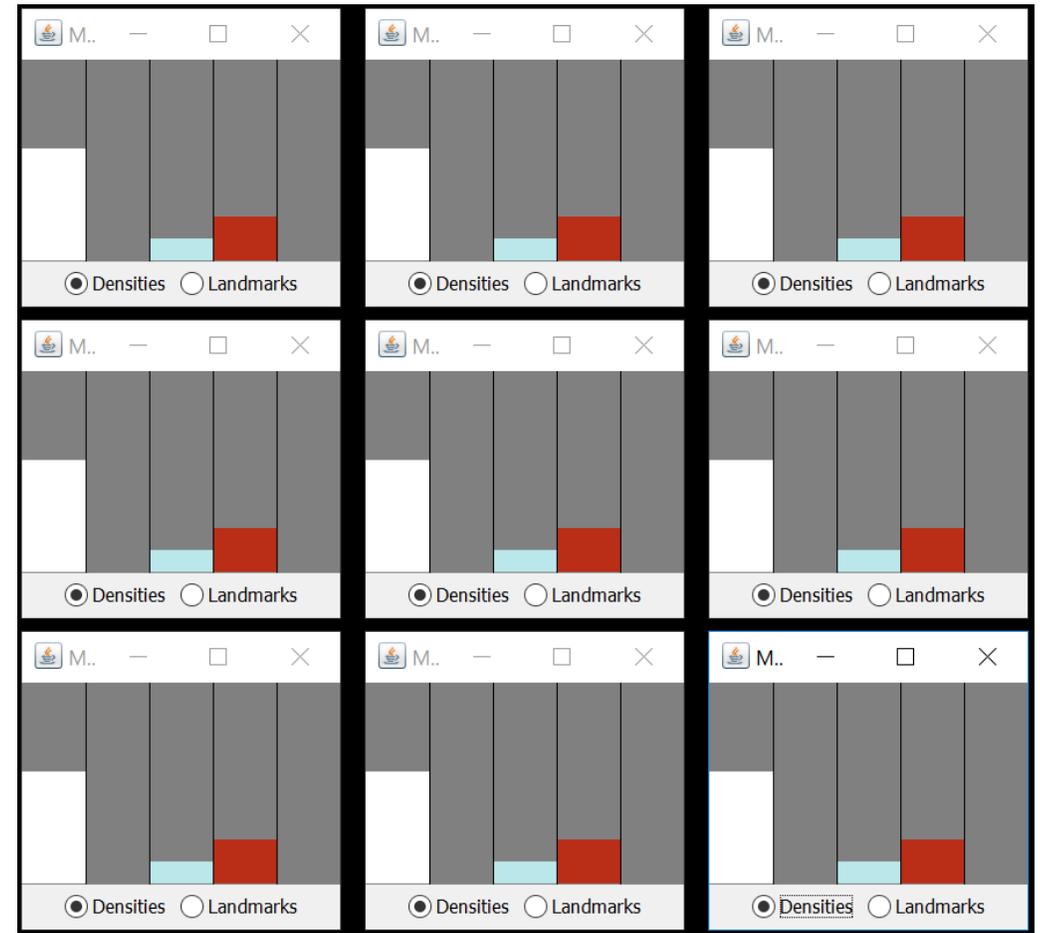
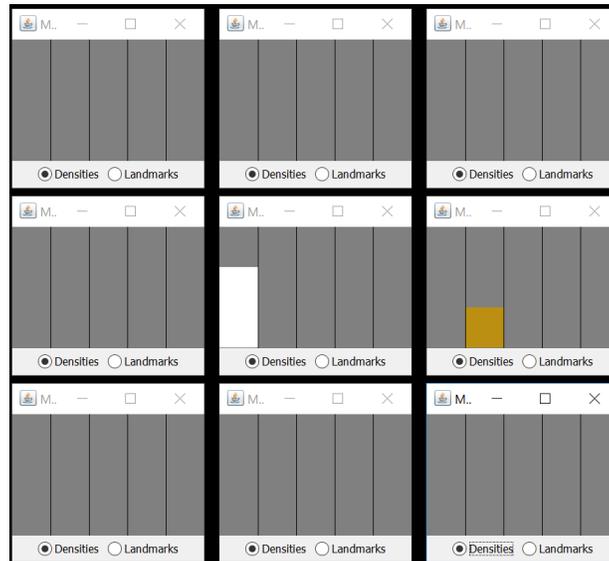
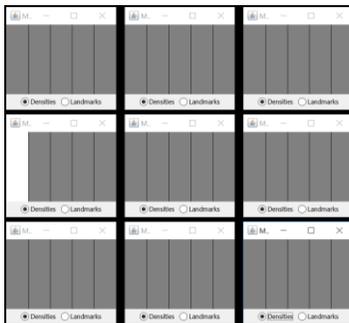
Less recent and more distant

$$(3 \times 3) \times (3 \times 3) = 9 \times 9$$

$$(9 \times 9) \times (9 \times 9) = 27 \times 27$$



3x3



Morphognostic spatial neighborhoods

- A cell defines an elementary neighborhood:

$$\textit{neighborhood}_0 = \textit{cell}$$

- A non-elementary neighborhood consists of an $N \times N$ set of *sectors* surrounding a lower level neighborhood:

$$\textit{neighborhood}_i = N \times N(\textit{neighborhood}_{i-1})$$

where N is an odd positive number.

Morphognostic (cont.)

The value of a sector is a vector representing a histogram of the cell type densities contained within it:

value(sector) = (density(cell-type₀), density(cell-type₁), ... density(cell-type_n))

The number of cells contributing to the density histogram of a sector of neighborhood_{*i*} = $N^{i-1} \times N^{i-1}$

Morphognostic temporal neighborhoods

- A neighborhood contains events that occur between time *epoch* and *epoch + duration*:

$$t1_0 = 0$$

$$t2_0 = 1$$

$$t1_i = t2_{i-1}$$

$$t2_i = (t2_{i-1} * 3) + 1$$

$$epoch_i = t1_i$$

$$duration_i = t2_i - t1_i$$

Why use cell type densities?

- Storing individual cell values does not scale as hierarchy grows.
- Storing type densities allows linear growth of information.
- Could be some other aggregation function or significant events.

Metamorphs

- A *metamorph* embodies a morphognostic→response rule.
- A set of metamorphs can be learned from a manual or programmed sequence of responses within a world.
- Important duality:
 - Learned morphognostics shape responses.
 - Responses shape the learning of morphognostics.

Metamorphs

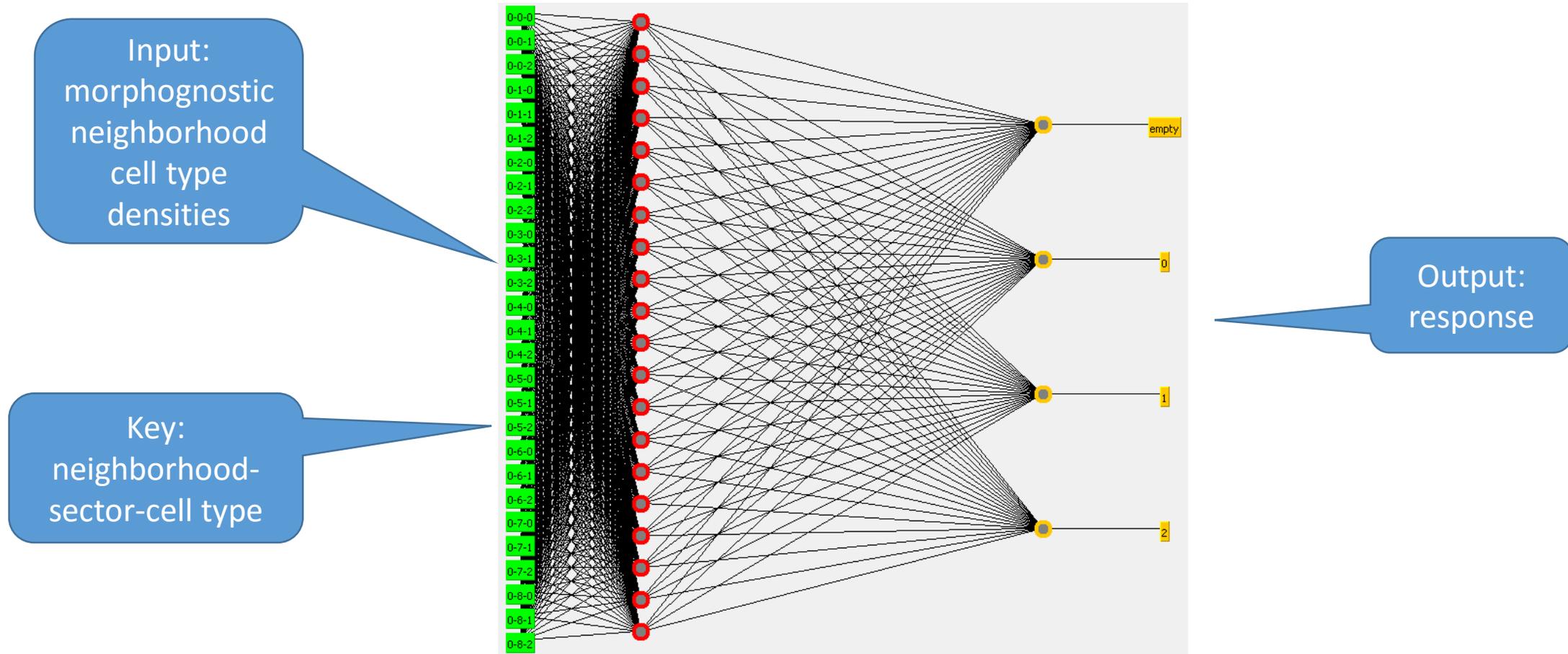
- Metamorph “execution” consists generating a morphognostic for the current mox position and orientation then finding the closest morphognostic contained in the learned metamorph set, where:

$$\text{distance}(\text{metamorph}_i, \text{metamorph}_j) = \sum_x^{\text{neighborhoods}} \sum_y^{\text{sectors}} \sum_z^{\text{cell types}} \text{abs}(\text{cell type density}_{i,x,y,z} - \text{cell type density}_{j,x,y,z})$$

Metamorph artificial neural network implementation

- Alternatively, instead of searching a database of metamorphs, the morphognostic can be input to an artificial neural network (ANN) that has been trained with generated metamorphs to map morphognostic inputs to responses:
 - Faster.
 - More compact.
 - More noise tolerant.

Metamorph artificial neural network



Foraging results in 10x10 worlds

More obstacles tend to improve performance.

Larger neighborhoods also improve performance.

Neighborhoods	Obstacle types	Obstacles	Food
1	1	10	0.1
1	1	20	0.2
1	2	10	0
1	2	20	0
1	4	10	0
1	4	20	0
2	1	10	0.3
2	1	20	0.4
2	2	10	0.2
2	2	20	0.6
2	4	10	0.2
2	4	20	0.6
3	1	10	1
3	1	20	0.9
3	2	10	1
3	2	20	1
3	4	10	1
3	4	20	1

Foraging with noise

Before each training run, cell types were probabilistically modified.

Therefore the test run must rely on a composite of multiple training runs.

Increasing the number of training runs improved performance even in the presence of heavy noise.

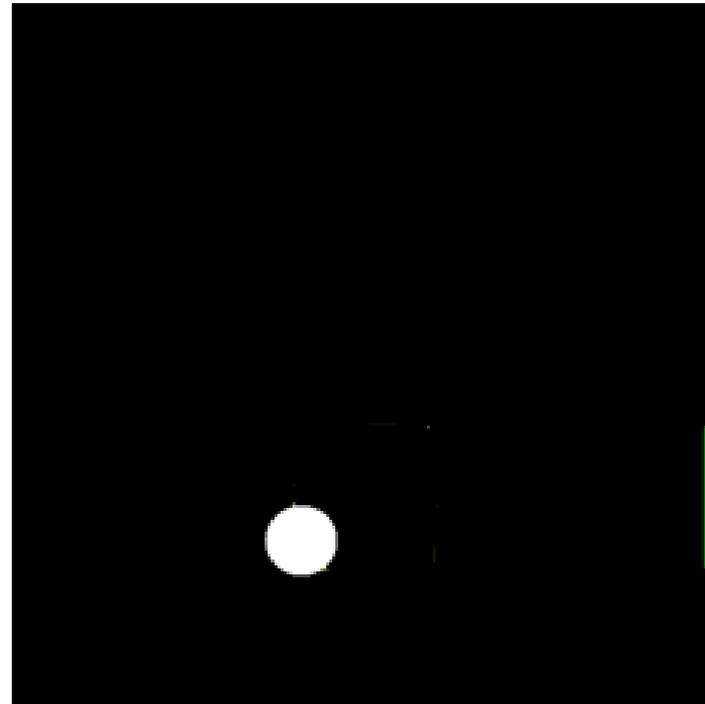
Noise	#Train	Food
0.1	1	1
0.1	5	1
0.1	10	1
0.25	1	0.9
0.25	5	1
0.25	10	1
0.5	1	0.6
0.5	5	0.8
0.5	10	0.9

Learning the game of Pong

The goal of the game is to vertically move a paddle to prevent a bouncing ball from striking the right wall.

Much of the world is nondeterministic, taking the form of unpredictable or probabilistic events that must be acted upon. If AIs are to engage such phenomena, then they must be able to learn how to deal with nondeterminism.

Here the game of Pong poses a nondeterministic environment. The learner is given an incomplete view of the game state and underlying deterministic physics, resulting in a nondeterministic game.



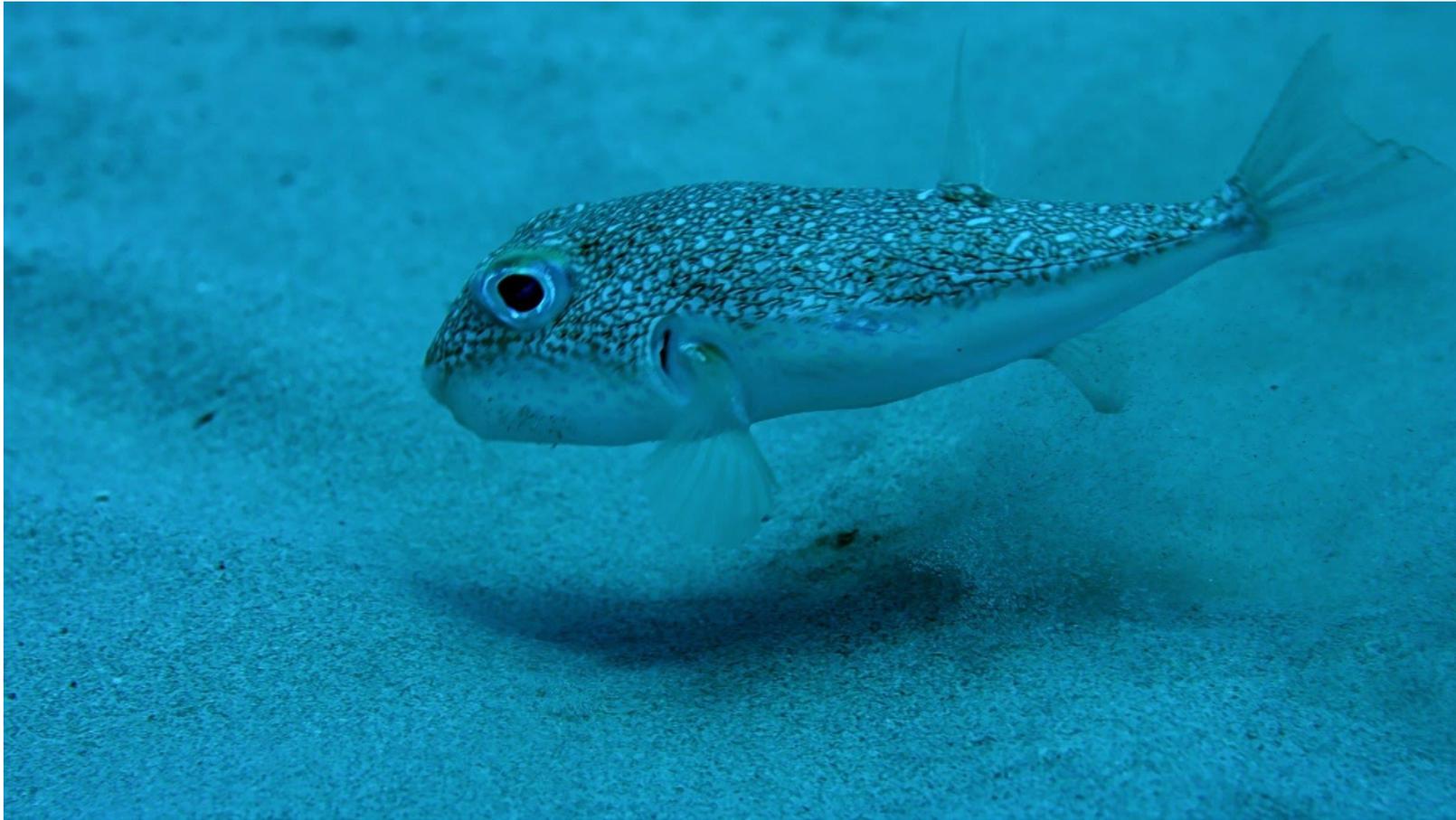
Game details

- Ball and paddle move in a cellular grid.
 - Unseen deterministic physics moves ball in grid.
- Cell state: (ball state, paddle state)
 - Ball state: (empty, present, moving left/right/up/down)
 - Paddle state: (true | false)
- Learner orientation: (north, south, east, west)
- Responses: (wait, forward, turn right/left)
 - If paddle present and orientation north or south, then forward response moved paddle also.

Procedure and results

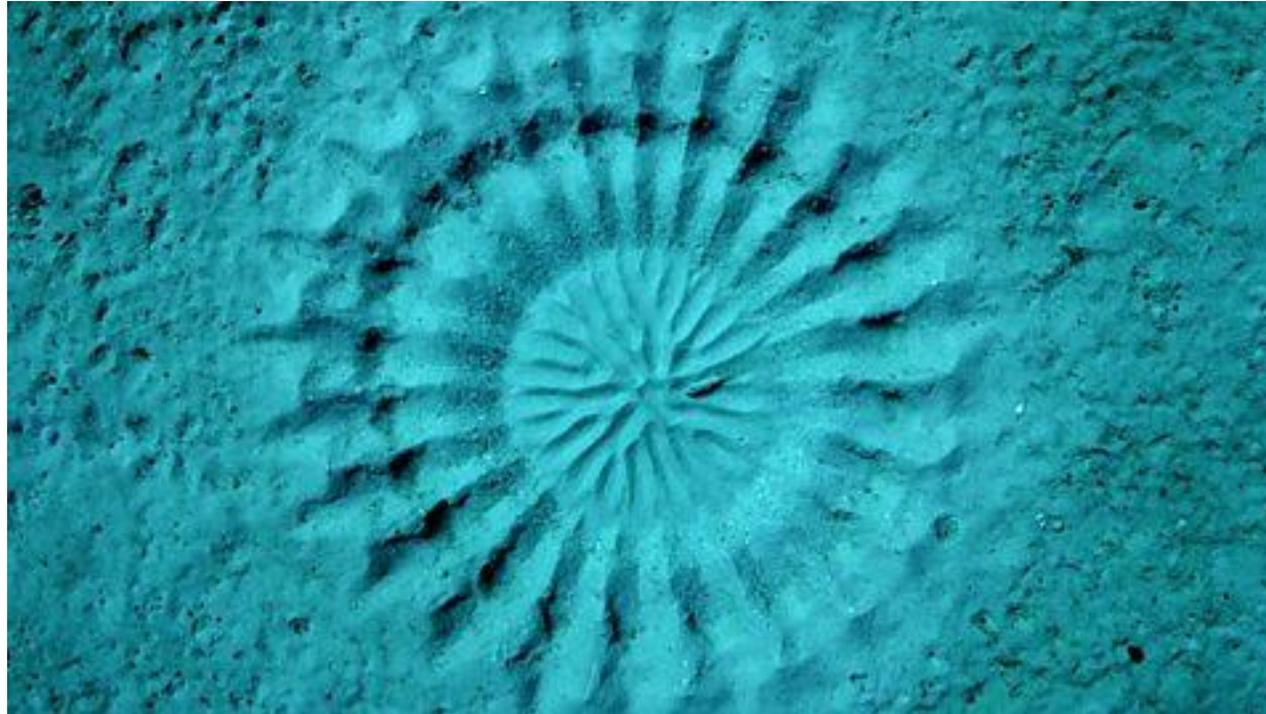
- Learner was trained with multiple randomly generated initial ball velocities.
- When the ball moved left and right, the learner moved with the ball.
- When the ball moved up or down, the learner moved to the paddle and moved it up or down.
 - This was the challenge: remembering ball state while traversing empty cells to the paddle so as to move it correctly, then to turn and return to ball for next input.
- Testing on different random game: 100% successful.

Next up: the Japanese pufferfish builds...



<http://www.livescience.com/40132-underwater-mystery-circles.html/>

...these displays on the seafloor to attract a mate.



Can an artificial morphognosis-based pufferfish do the same?

<https://aigrant.org/>