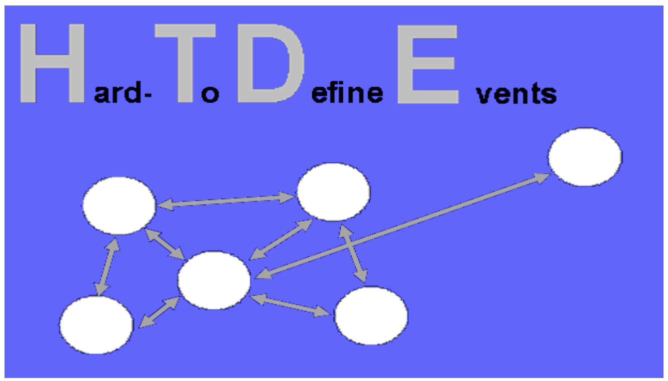
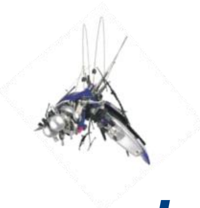
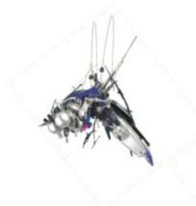
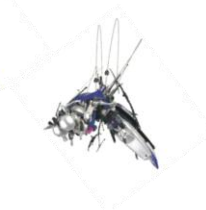
Toward Robotic Intelligence: Evolution of Memory Use in Digital Organisms

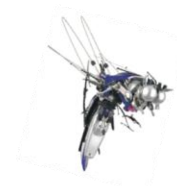


Presented at the HTDE (Hard-to-Define Events) Workshop 2012,
Artificial Life XIII, East Lansing, MI USA

Laura Grabowski
University of Texas Pan-American (UTPA)
http://faculty.utpa.edu/grabowskilm/

Toward Robotic Intelligence: Evolution of Memory Use in Digital Organisms




Laura M. Grabowski, Ph.D.

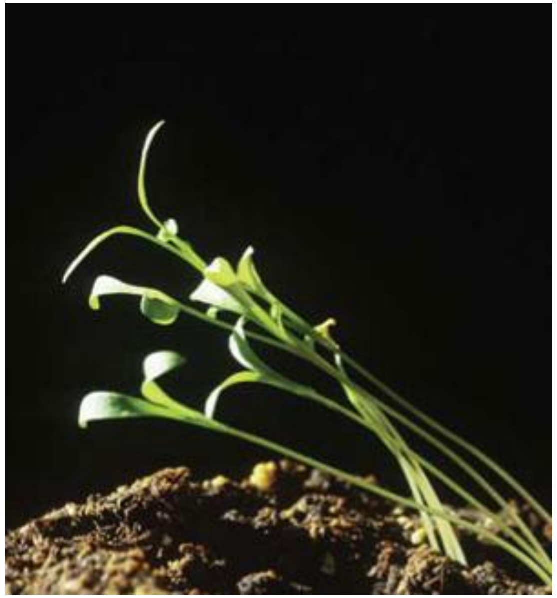

Department of Computer Science
The University of Texas-Pan American

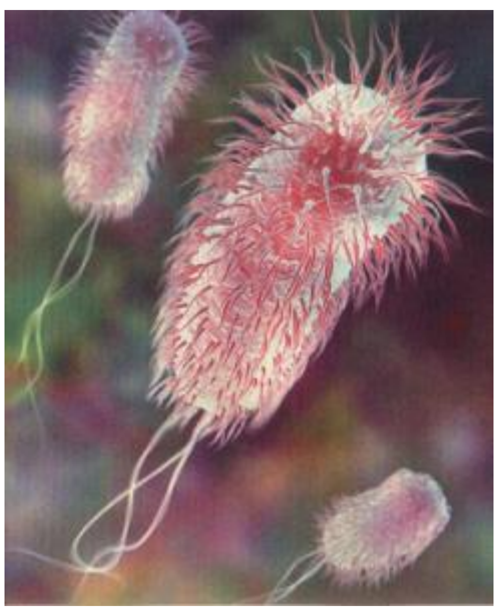
UTPA

Evolving Behavior

- Central Question: *How can we study evolving behavior?*
- Application goal: Behavioral flexibility
- “Intelligence” is not one big ability, but many smaller ones
    - What are the building blocks?

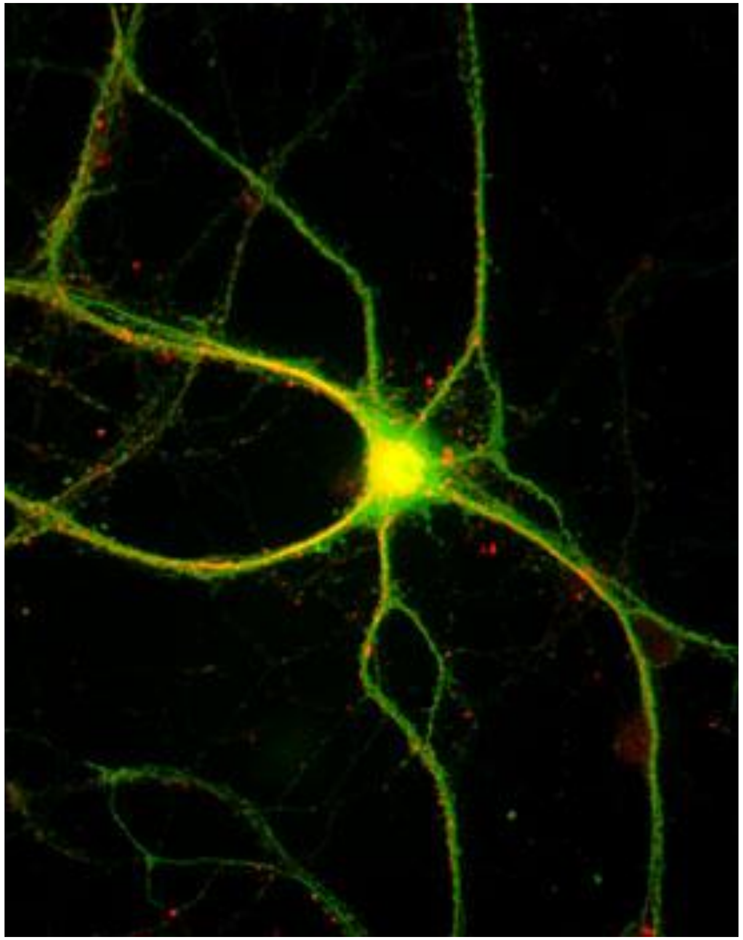
Building Blocks of Intelligent Behavior





- Requires such capabilities as
  - Sensing
  - Memory
  - Decision-making
- Common threads
  - Differential behavior based on current environment
  - Using past experience

Memory: Critical Component of Intelligence



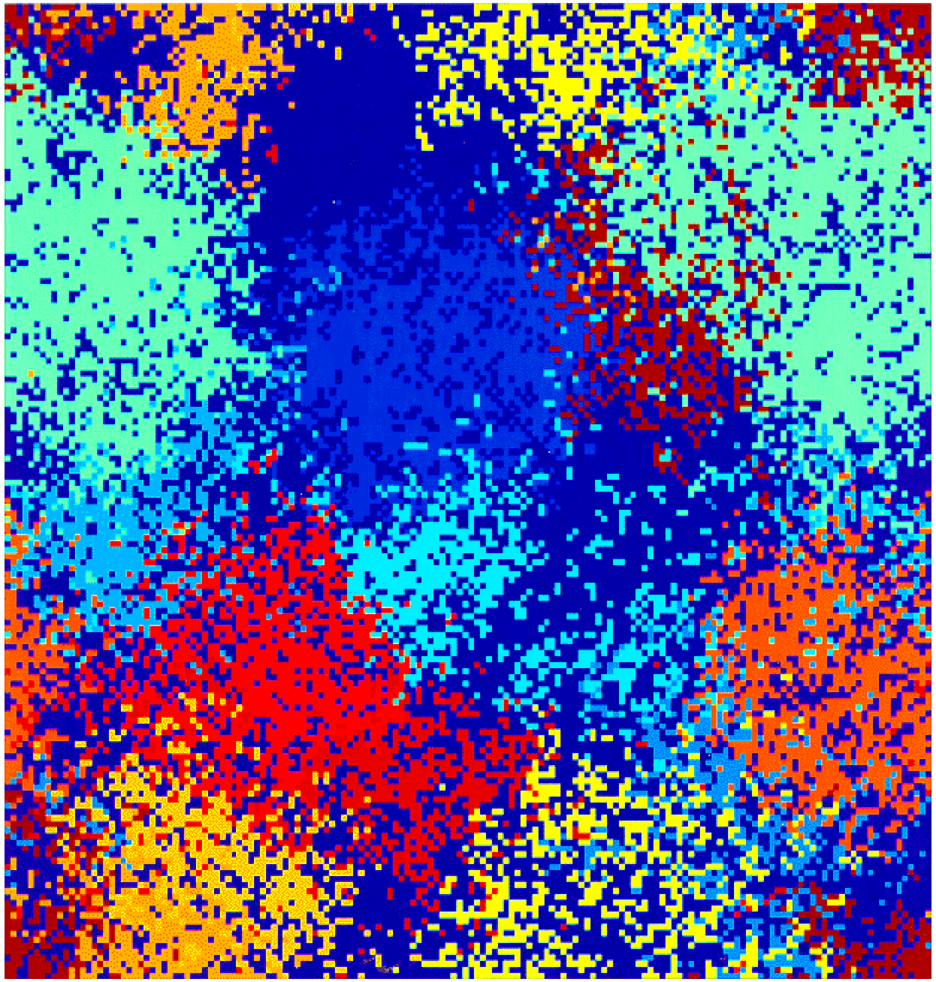
Primary hippocampal neuron
Image source: http://www.unm.edu/~neurohsc/ZhaoLab/links/index.html

- Actually interested in learning

BUT

- Memory underpins learning

Digital Evolution



- Population of self-replicating programs, “digital organisms”
- Organisms replicate, mutate, compete

The Avida* Digital Evolution Platform

- Virtual environment (“virtual Petri dish”), but **real evolution****
- One advantage: Detailed analysis of evolved programs

* C. Ofria and C. O. Wilke. (2004). Avida: a software platform for research in computational evolutionary biology. In *Artificial Life 10,* 191-229.

** Pennock, R.T. (2007). Models, simulations, instantiations, and evidence: the case of digital evolution. *Journal of Experimental and Theoretical Artificial Intelligence*, 19(1):29-42.

Quick Avida Overview

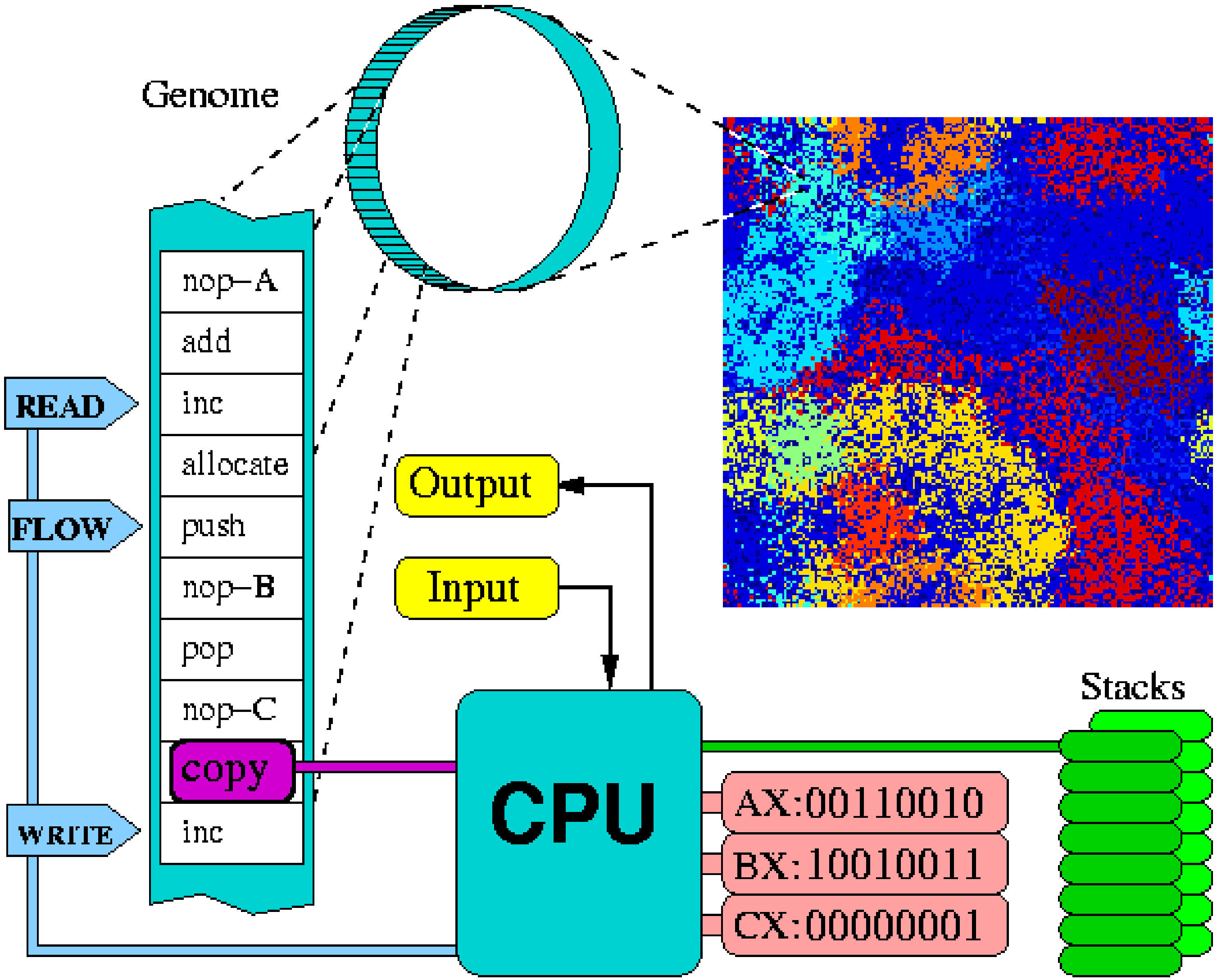
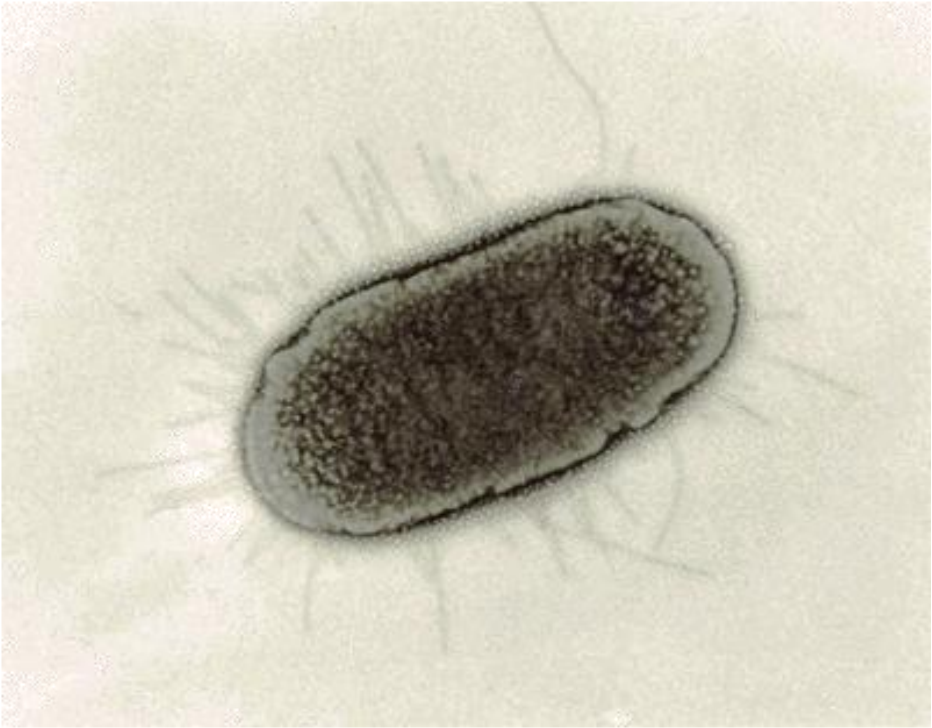


Figure from:
“A Guided Tour of an Ancestor and its Hardware,” Avida documentation.
http://avida.devosoft.org/wiki/documentation/general-information/a-guided-tour-of-the-ancestor-and-its-hardware/

Evolving Tactic Behavior Using Avida

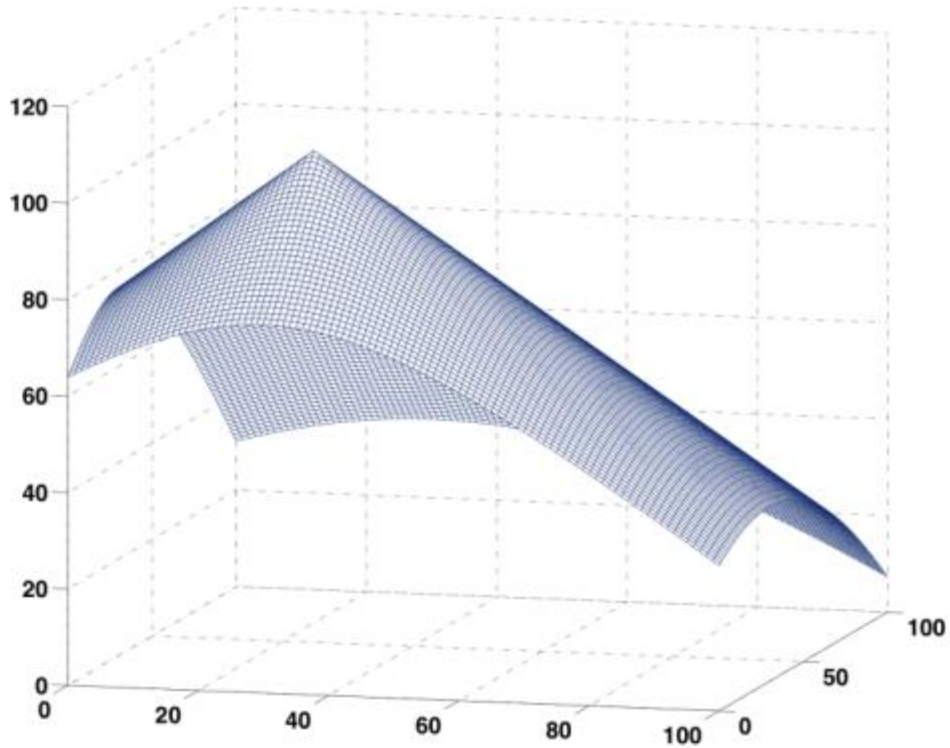


- Inspired by chemical gradient-following behavior of *E. coli*
- Evolution of chemotaxis-like response*

*Grabowski, L.M., Elsberry, W.R., Ofria, C., and Pennock, R.T. (2008). On the evolution of motility and intelligent tactic response. *GECCO '08: Proceedings of the 10th Annual Conference on Genetic and Evolutionary Computation,* pp. 209-216.

Purpose: Proof-of-concept, evolving simple navigation

Experimental Environment

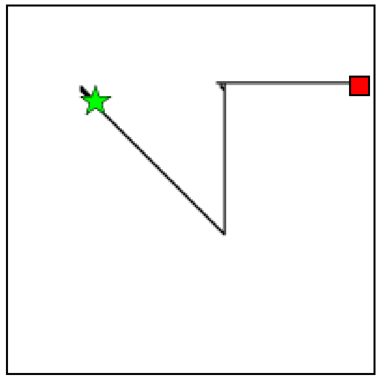


- Organisms evolved to traverse idealized gradient
- Two treatments
  - Implicit memory: provided prior information
  - Without implicit memory: did not provide prior information

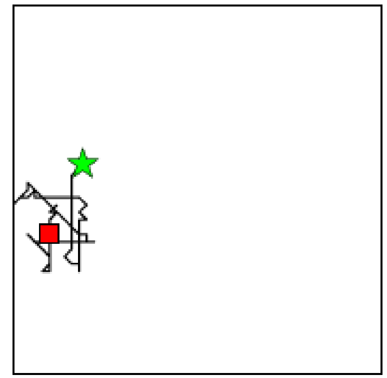
Representative Trajectory Plots of Evolved Organisms

Implicit Memory
26/100 replicate populations*

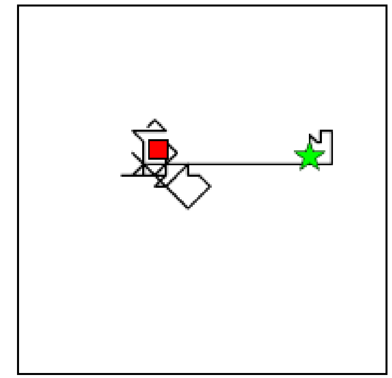
Example Organism 1



Example Organism 2

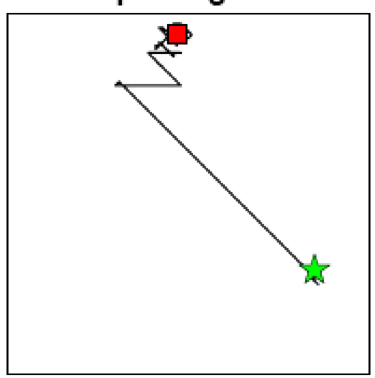


Example Organism 3

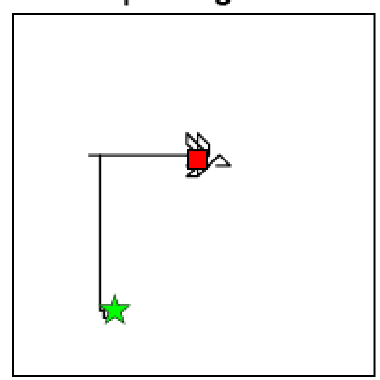


Evolved Memory
7/100 replicate populations*

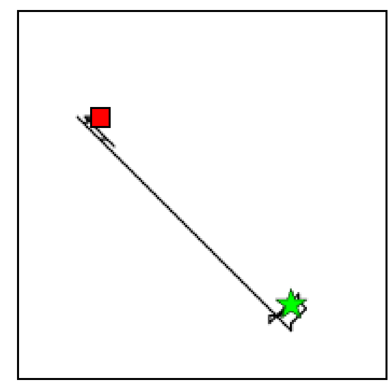
Example Organism 1



Example Organism 2



Example Organism 3



*Closest approach within 10% of initial distance to peak

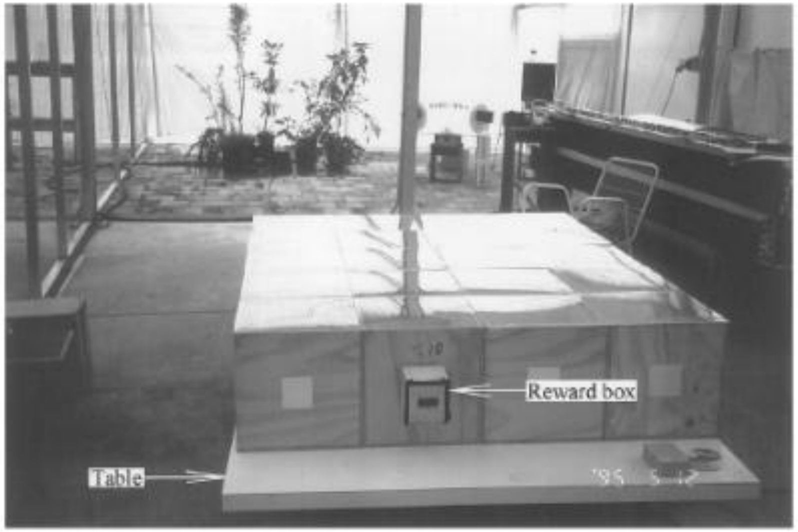
Conclusions

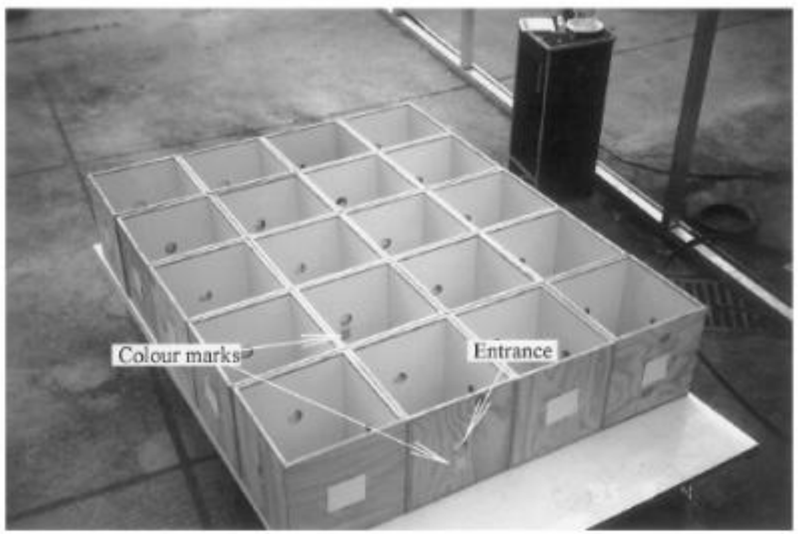
- Proof-of-concept for motility in Avida
- Evolution of fundamental navigation
- Tactic behavior easier to evolve when memory is provided

Key result: Memory is a hurdle to evolving intelligent behavior

UTPA

Focus on Evolving Memory Use

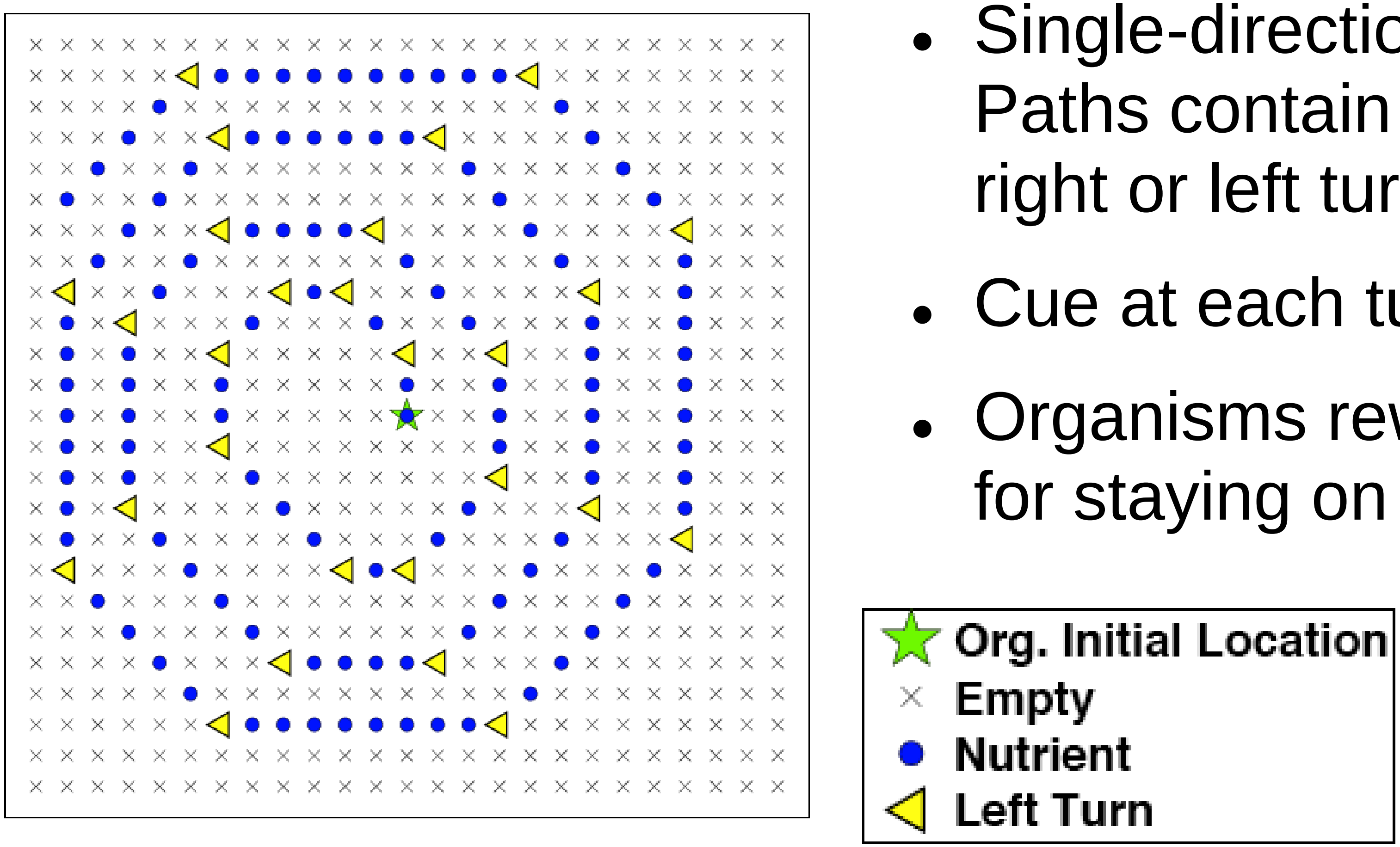




- Path-following experiments with honey bees*
- Similar path environment in Avida
- Different types of paths using several environmental cues

* Zhang, S.W., Bartsch, K. & Srinivasan, M. V. (1996). Maze learning by honeybees. Neurobiology of Learning and Memory, 66:267-282.

Single-direction Paths Experiments

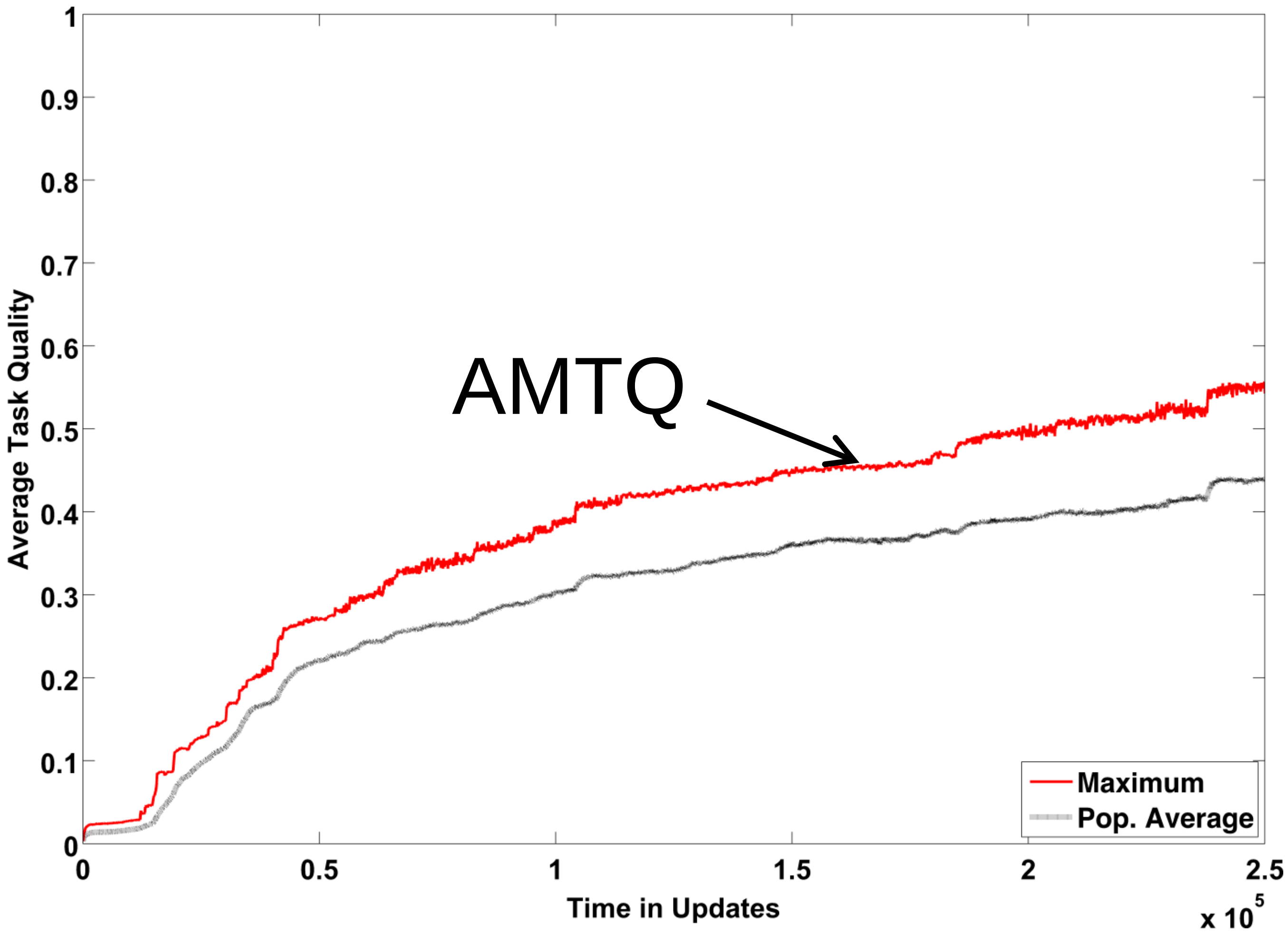


- Single-direction paths: Paths contain only right or left turns
- Cue at each turn point
- Organisms rewarded for staying on path

Purpose: Evolve reflexive reactions to environmental cues

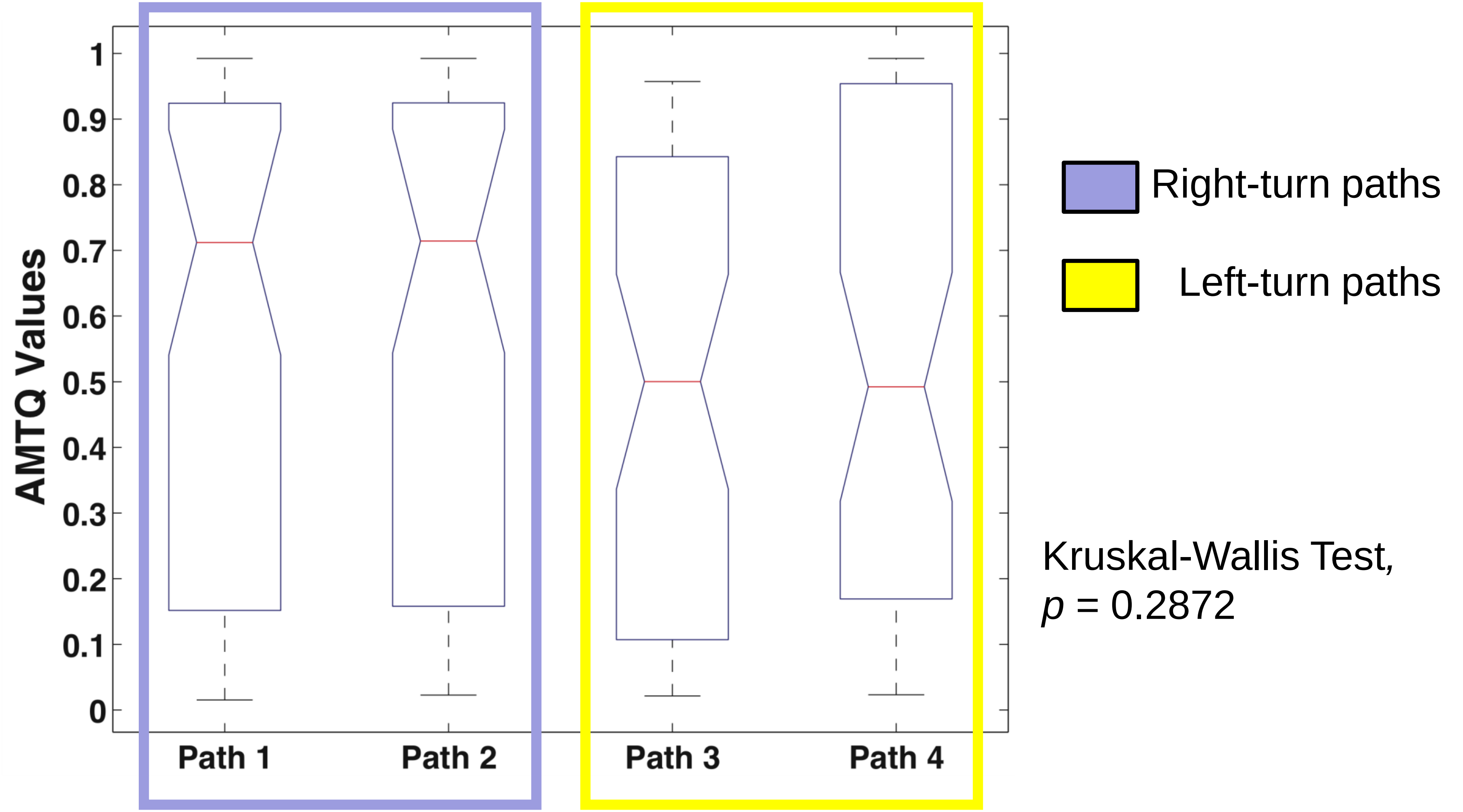
UTPA

Results: Single-direction Paths



- Metric: Average Maximum Task Quality (**AMTQ**)
- Direct quantitative measure of correct path traversal

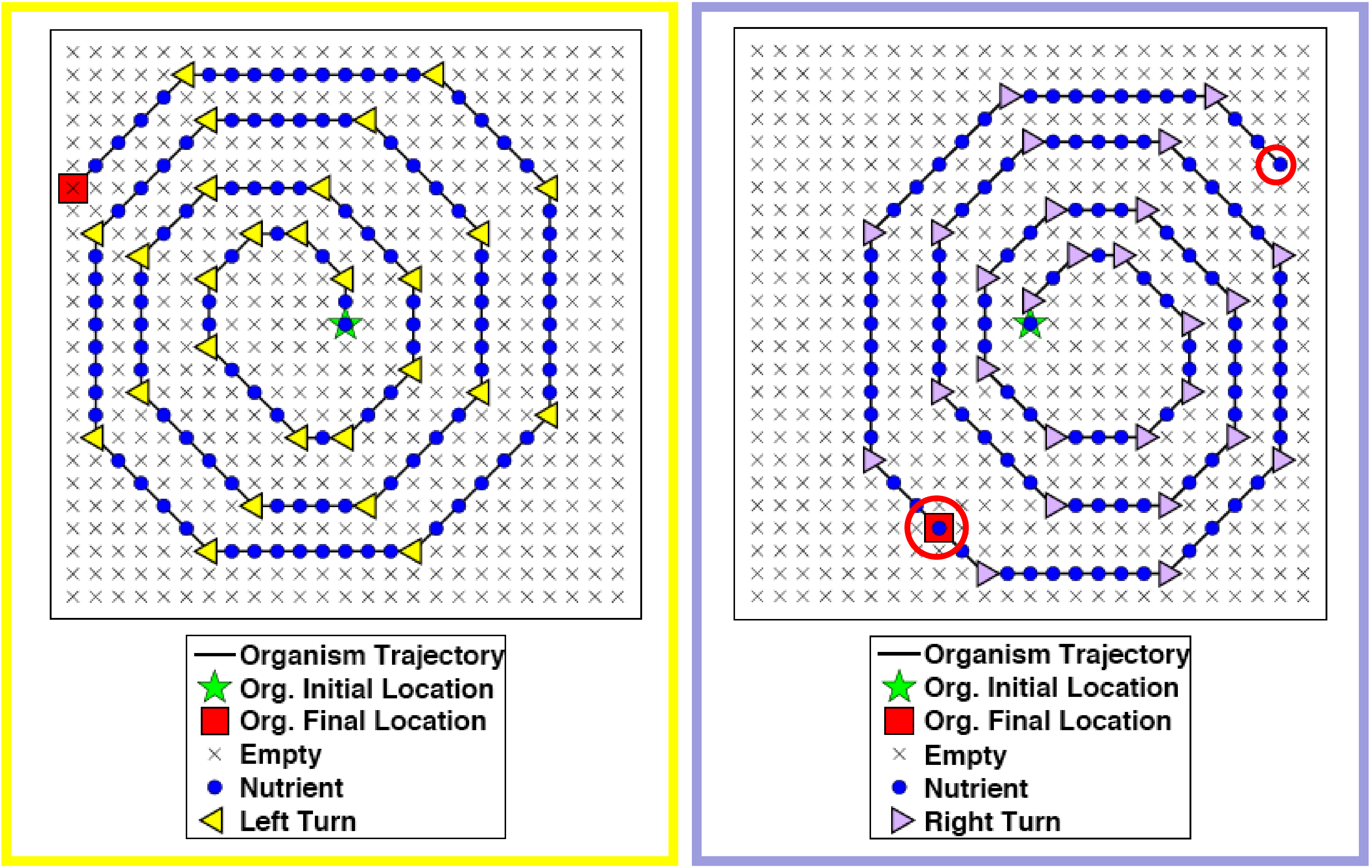
AMTQ Values, Individual Paths



Kruskal-Wallis Test,
$p = 0.2872$

Grabowski. L. M., Bryson, D. M., Dyer, F. C., Ofria, C., & Pennock, R. T. (2010). Early evolution of memory usage in digital organisms. In *Artificial Life XII: Proceedings of the Twelfth International Conference on the Synthesis and Simulation of Living Systems,* pages 224–231, Cambridge, MA.MIT Press.

Example Evolved Organism Trajectories



Grabowski *et al.* (2010)

Analyzing the Step-Counter Organism

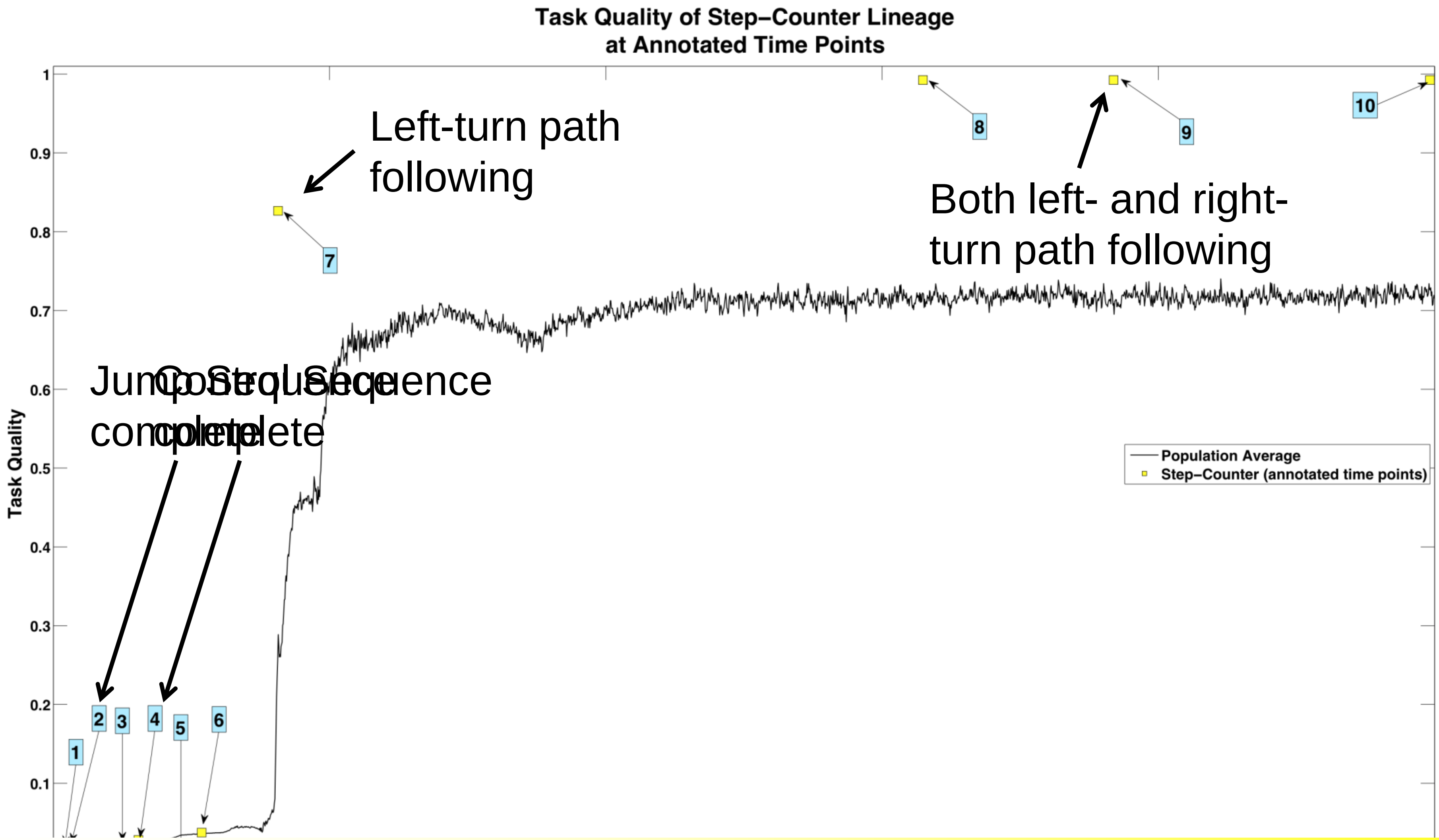
Site	Instruction	Instruction Functionality
117	h-search	Marks the start of counting module.
118	sg-rotate-r	Turn right 45°
119 120	if-grt-0 nop-C	CX register contents > 0? This comparison is TRUE when on a right-turn path.
121	h-copy	Copy (executes only when on a right-turn path).
122	h-copy	Copy (always executes).
123 124	sg-sense nop-C	Put current sense input into CX register.
125	jmp-head	Move the IP the number of instructions designated by the value in CX register. If sense input was nutrient, CX = 0; IP does not change. If sense input was right, CX = 2; IP skips 126-127 and moves to site 128. If sense input was left, CX = 4; IP skips 126-129 and moves to site 130.
126	sg-rotate-l	Executes only when sense input is nutrient (*i.e.*, CX = 0). When executed, undoes right turn at top of loop (site 118).
127	if-equ-X	BX register contents = 1? This comparison is TRUE on a right-turn path.
128	get-head	Put the current value of IP into CX (*i.e.*, CX = 128). Executes only when on a right-turn path.
129	sg-move	Take a step. Does not execute on a left-turn path.
130	inc	Increment value in BX (*i.e.*, BX = BX + 1).
131	if-n-equ	If contents of BX are not equal to contents of CX, execute the next instruction. Instruction tests for loop exit conditions.
132	mov-head	Exit on right-turn path after taking 127 steps, then incrementing BX to 128. Exit on left-turn path after turning 180° (4 1/8 turns) without taking any steps.

“Jump” sequence

“Control” sequence

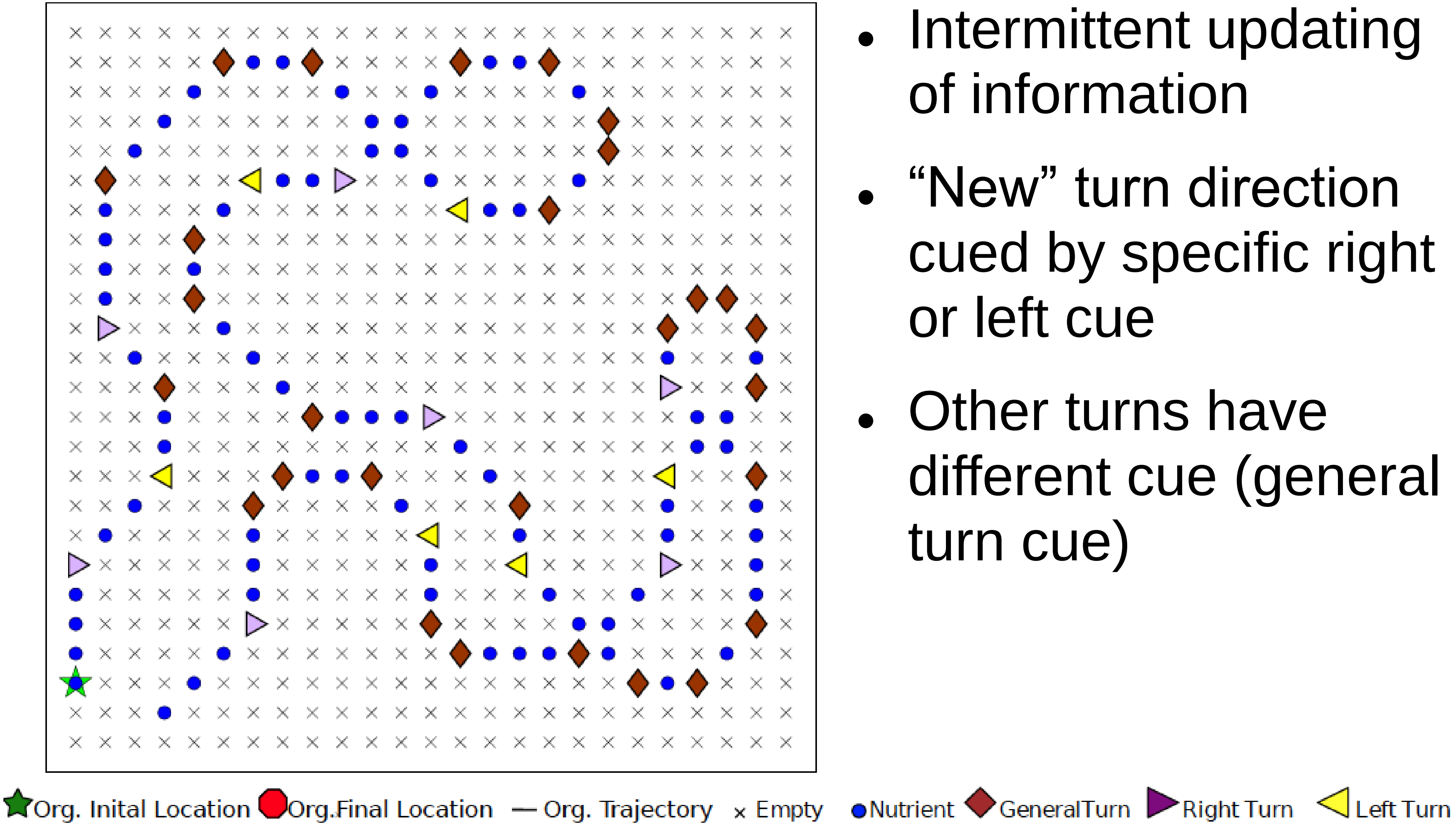
Grabowski. L. M., Bryson, D. M., Dyer, F. C., Pennock, R. T., & Ofria, C. (2012). An analysis of the *de novo* evolution of a complex odometric behavior. In *Artificial Life XIII: Proceedings of the 13th International Conference on the Synthesis and Simulation of Living Systems.* Cambridge, MA.MIT Press.

Analyzing the Step-Counter Organism



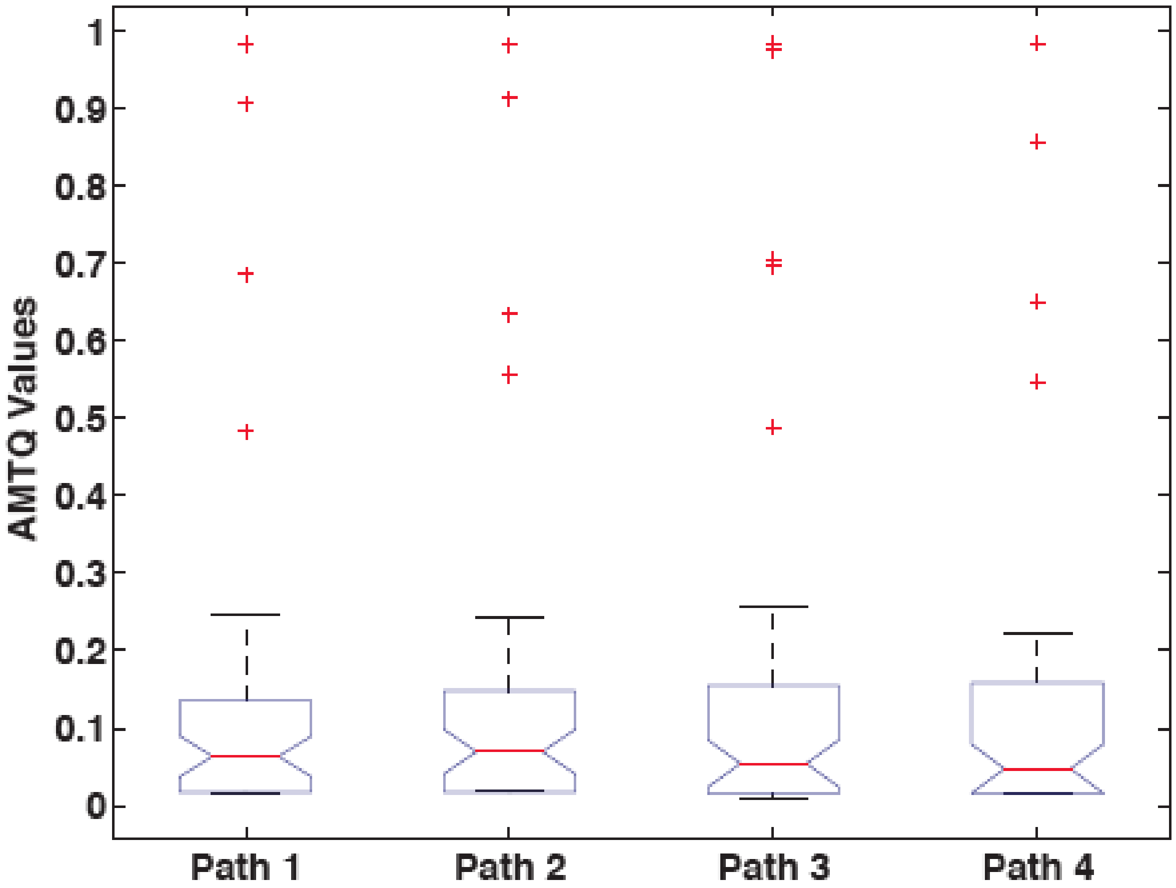
Key Result: Example of process of evolving complexity

Evolving Short-Term Memory



- Intermittent updating of information
- “New” turn direction cued by specific right or left cue
- Other turns have different cue (general turn cue)

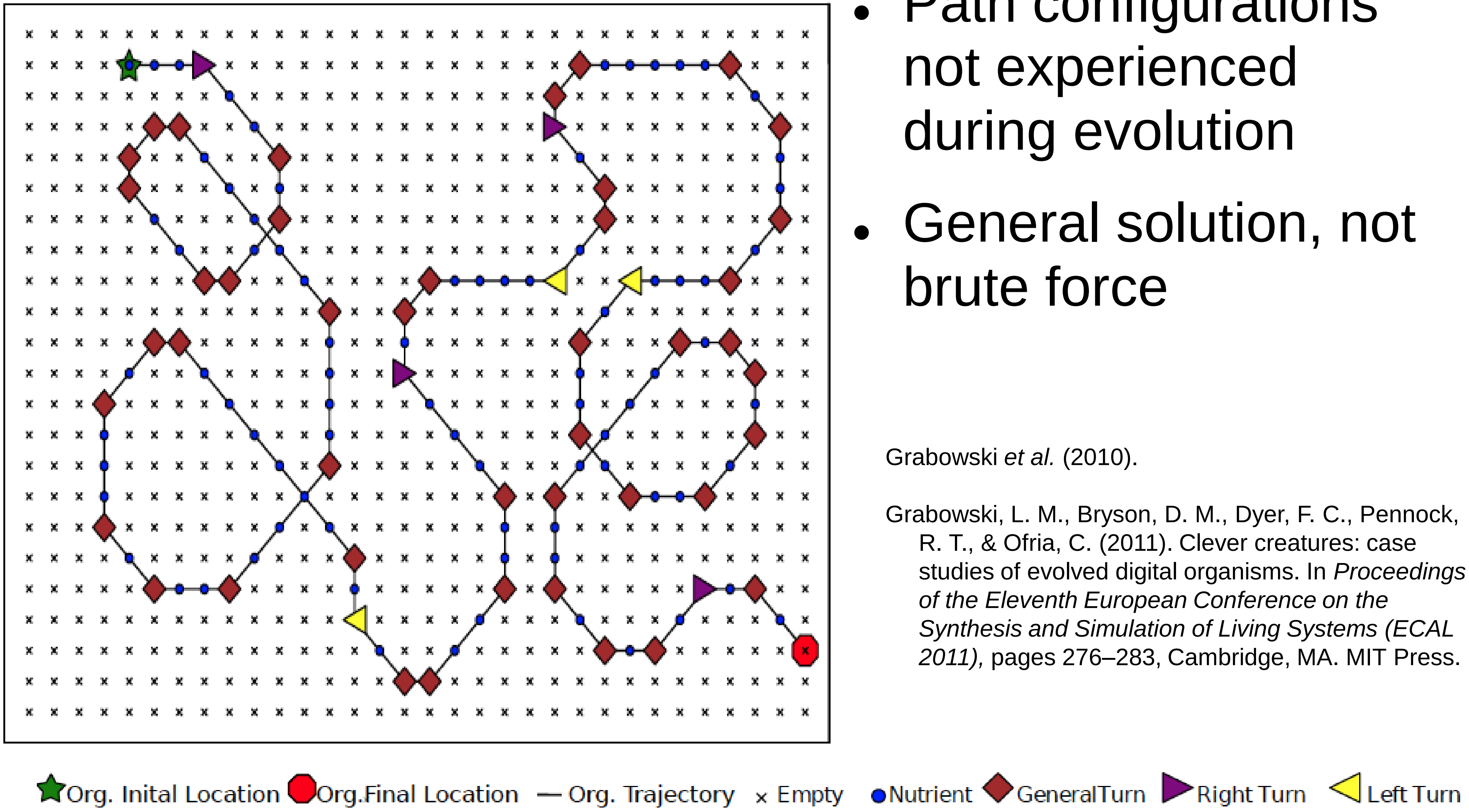
Results: Environment of Evolution



- Challenging problem for Avidians
- A handful of populations evolved a highly successful strategy (~5 of 50 populations with AMTQ ≈ 0.8)

Grabowski *et al.* (2010).

Results: Unfamiliar Path



- Path configurations not experienced during evolution
- General solution, not brute force

Grabowski *et al.* (2010).

Grabowski, L. M., Bryson, D. M., Dyer, F. C., Pennock, R. T., & Ofria, C. (2011). Clever creatures: case studies of evolved digital organisms. In *Proceedings of the Eleventh European Conference on the Synthesis and Simulation of Living Systems (ECAL 2011),* pages 276–283, Cambridge, MA. MIT Press.

Conclusions

- Memory use is difficult/costly to evolve, and may emerge only rarely in open-ended evolution.
- Rare events may provide interesting insights into how behavior evolves.

Current Directions

- Evolving navigation behavior
- Cost of evolving memory
- Evolution of complexity
- Transfer from Avida to robotic platforms

Thank you!

For more information:

Laura M. Grabowski’s Homepage
http://faculty.utpa.edu/grabowskilm/

Avida Digital Life Platform
http://avida.devosoft.org/