

Computational Models of Natural Complexity

Craig Reynolds
Matterport

Reflections | Projections
University of Illinois, Urbana-Champaign
October 1-4, 2015

Who I am

Somewhere between:
a researcher gone horribly astray
and
a Silicon Valley software engineer who dabbles in research.



- University of California Berkeley
- Stanford University
- University of California Santa Cruz
- Facebook
- Google
- Matterport





And now a word from our sponsor...



3D Showcase

INTERESTS

- Since childhood:
 - complex motion: collective motion, fluid flow
 - animal behavior
 - evolutionary design / optimization
- closing the loop of graphics and vision

BIO by PLACES

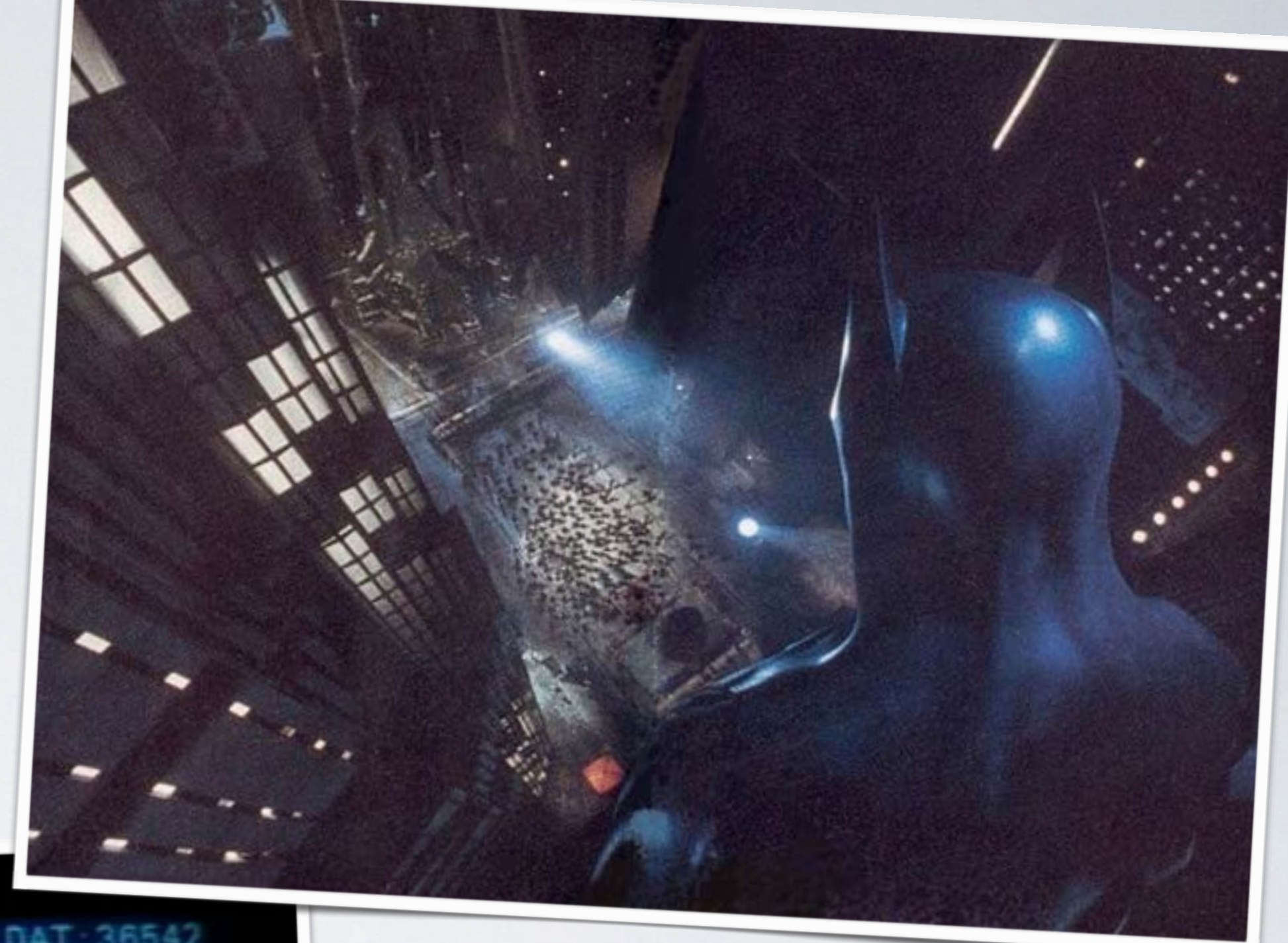
- MIT–Architecture Machine Group
- Ramtek
- ComputerVision
- triple-I
- Symbolics
- Electronic Arts
- SGI
- Dreamworks
- Sony Playstation R&D
- UC Santa Cruz–Games and Playable Media
- Staples SparX
- Matterport

BIO by TOPICS

- procedural animation
- feature films (CGI/SFX)
- behavioral animation
- collective behavior
- mesh/cloud algorithms
- games / game AI
- genetic algorithms
- stigmergy /
collective construction
- texture synthesis
- camouflage
- graphics/vision duality



TRON, 1982,
Walt Disney Studios



Batman Returns, 1992,
Warner Brothers



Looker, 1981,
The Ladd Company



Cliffhanger, 1993, Carolco Pictures

BOIDS

AGENT-BASED FLOCKING

- Questions I wondered about as an undergraduate:
 - How do bird flocks work?
 - Can we simulate them?
 - Can we base this model on individual birds?
 - Can a flock *emerge* from local bird behavior?

Thought experiments based on personal experience



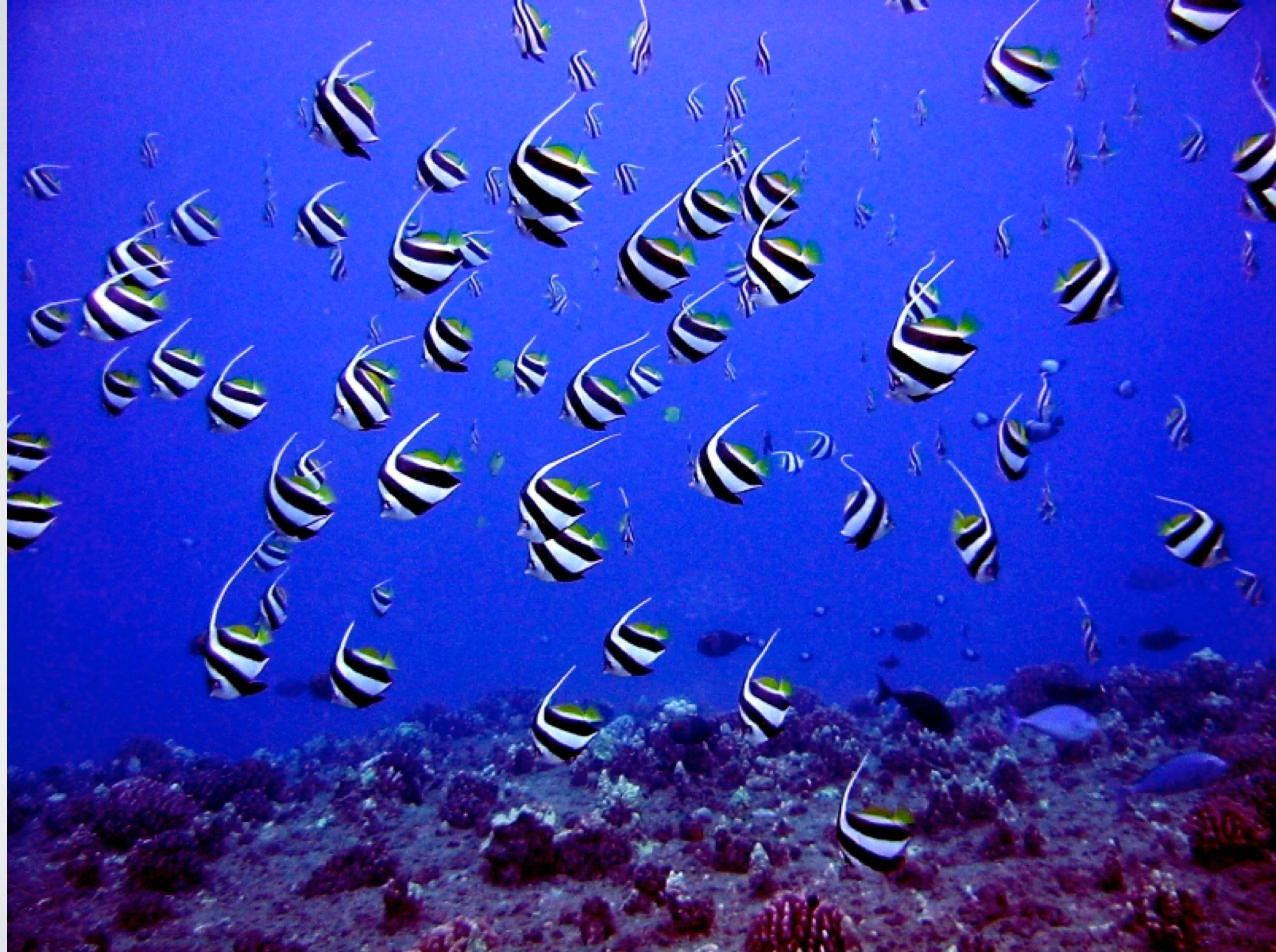






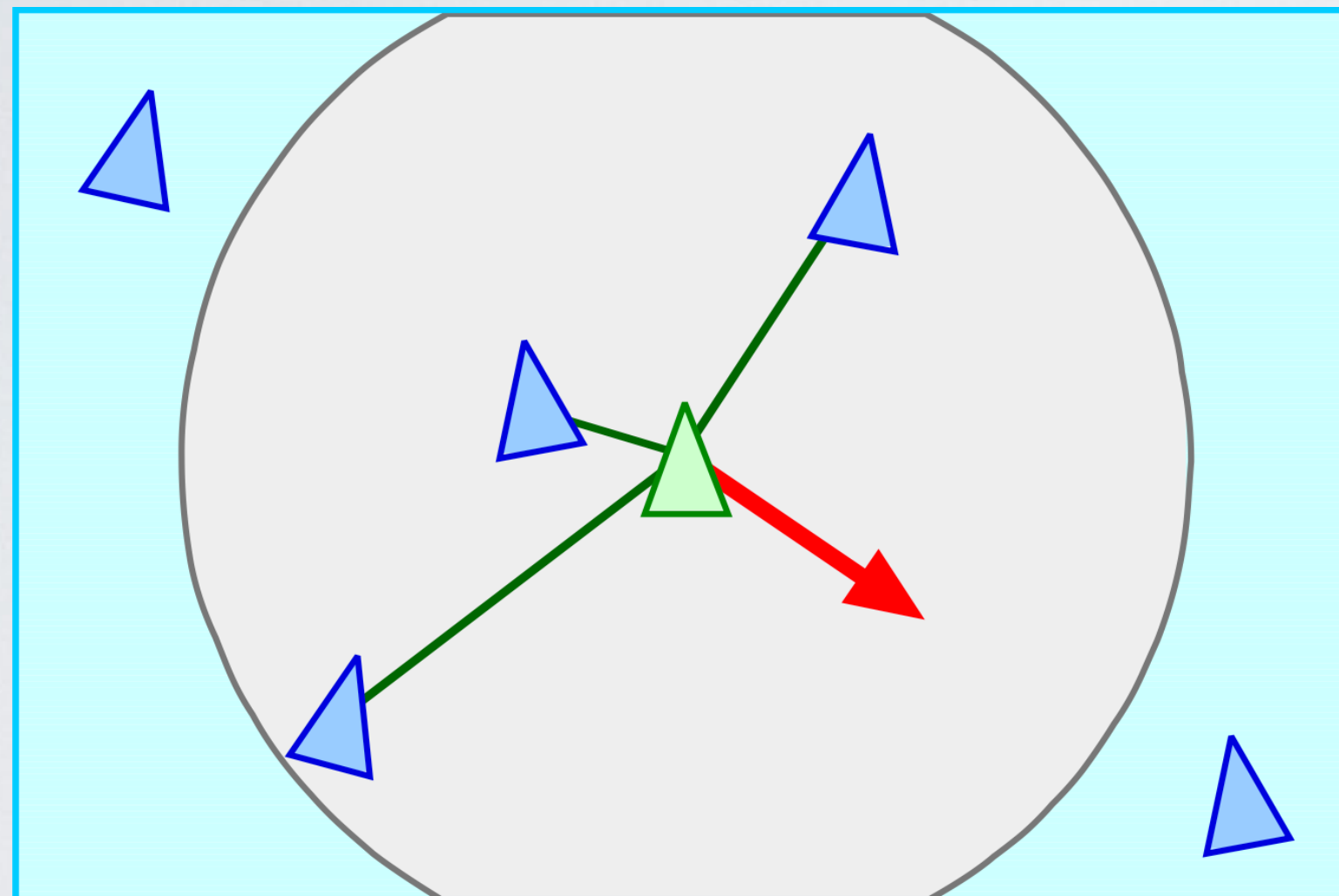




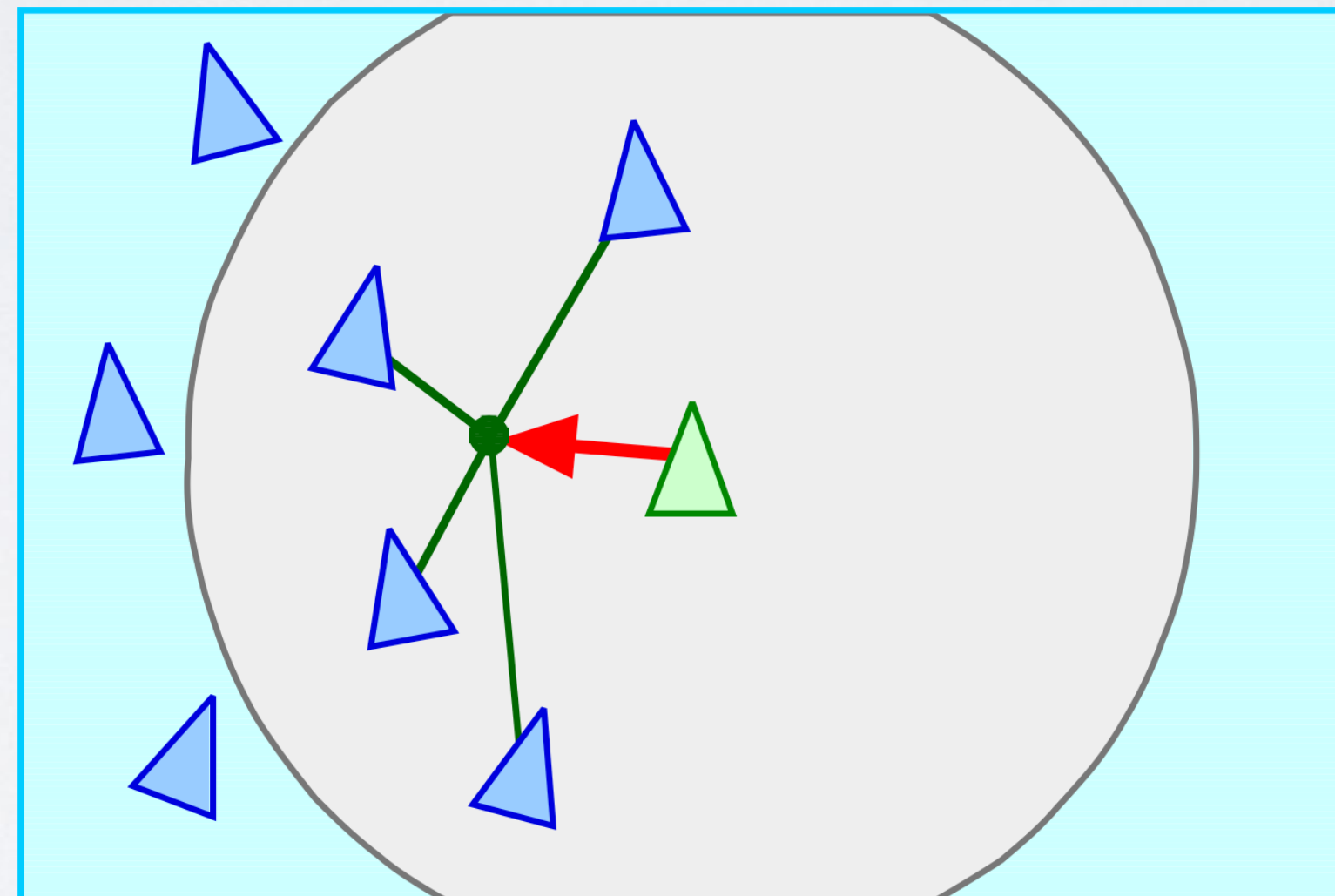




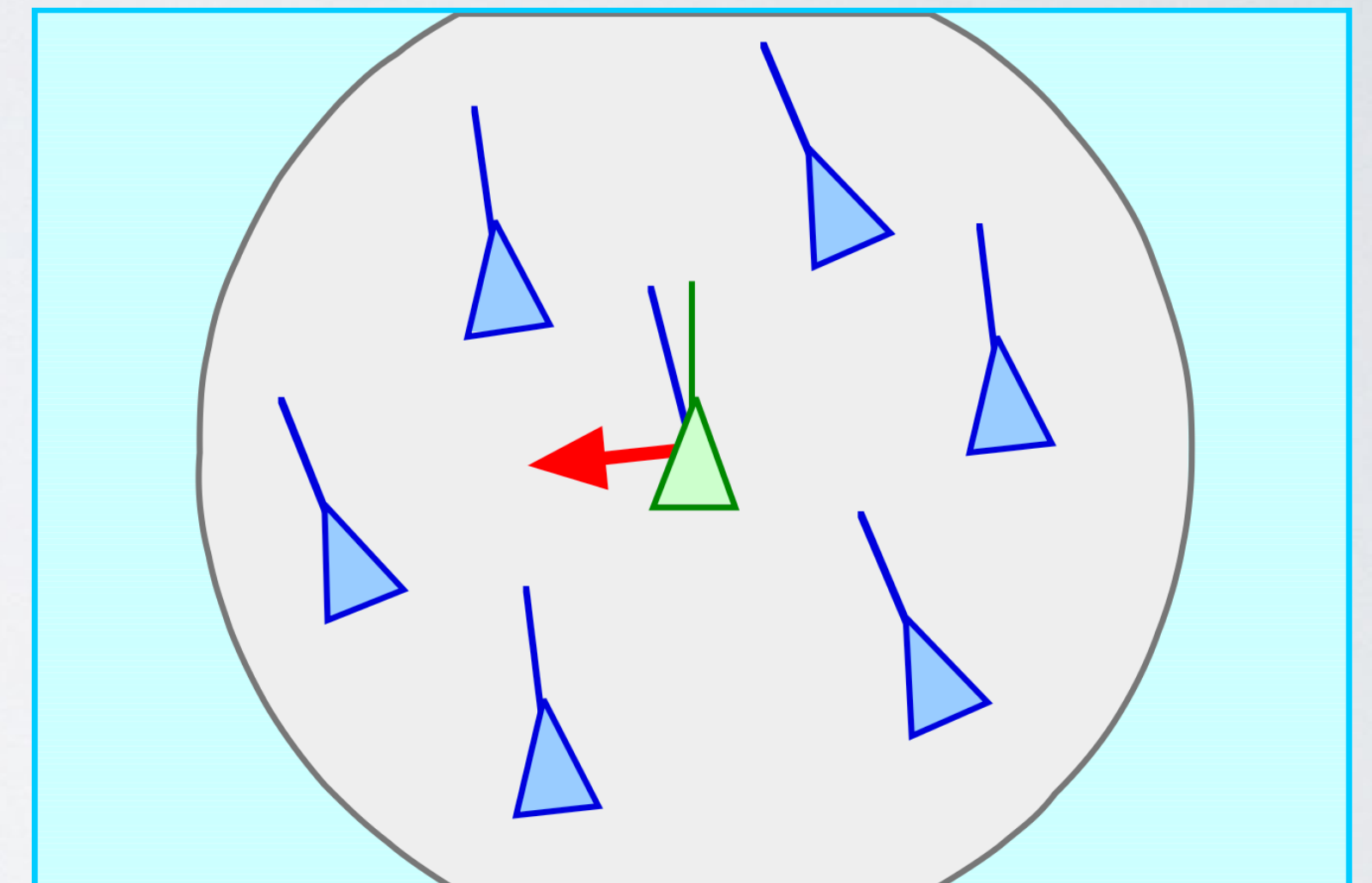
Three basic behaviors seemed necessary,
but where they sufficient?



separation



cohesion



alignment

Formal analysis may have been applicable.

But as software geek “there is only one way to be sure.”

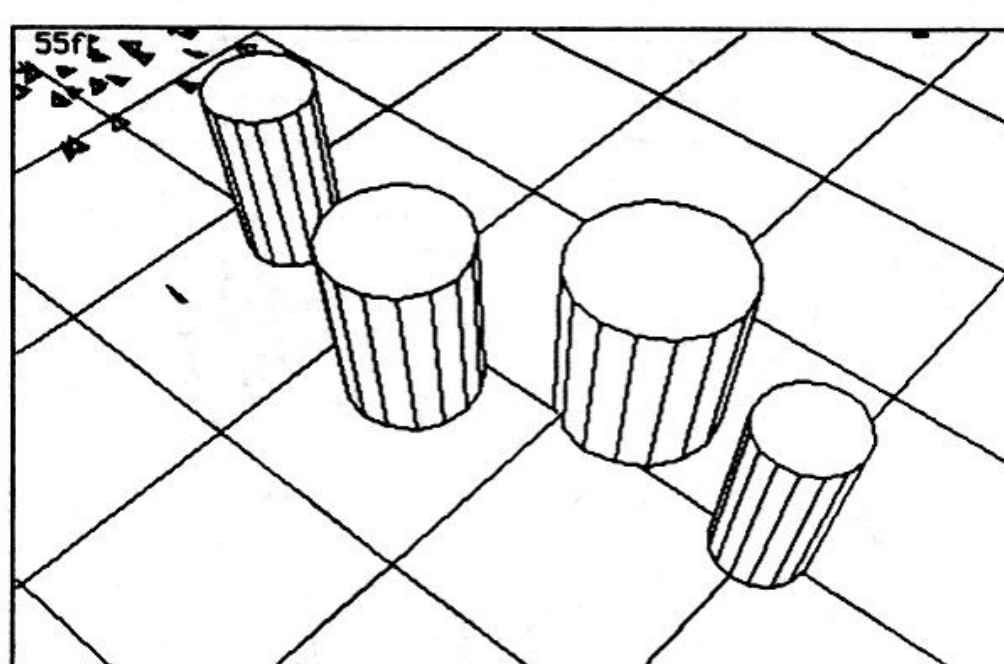
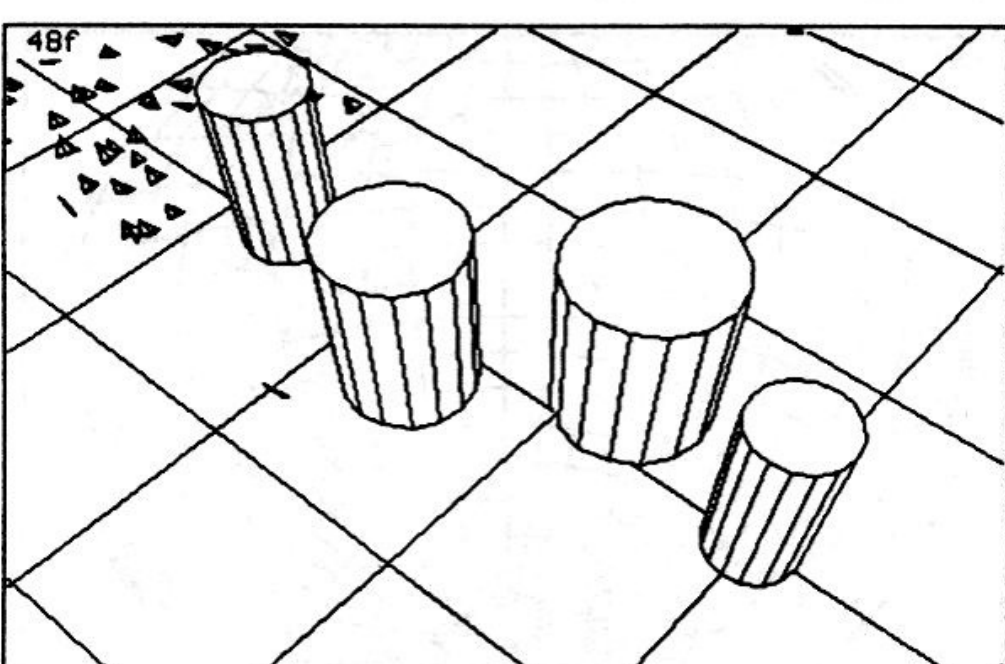
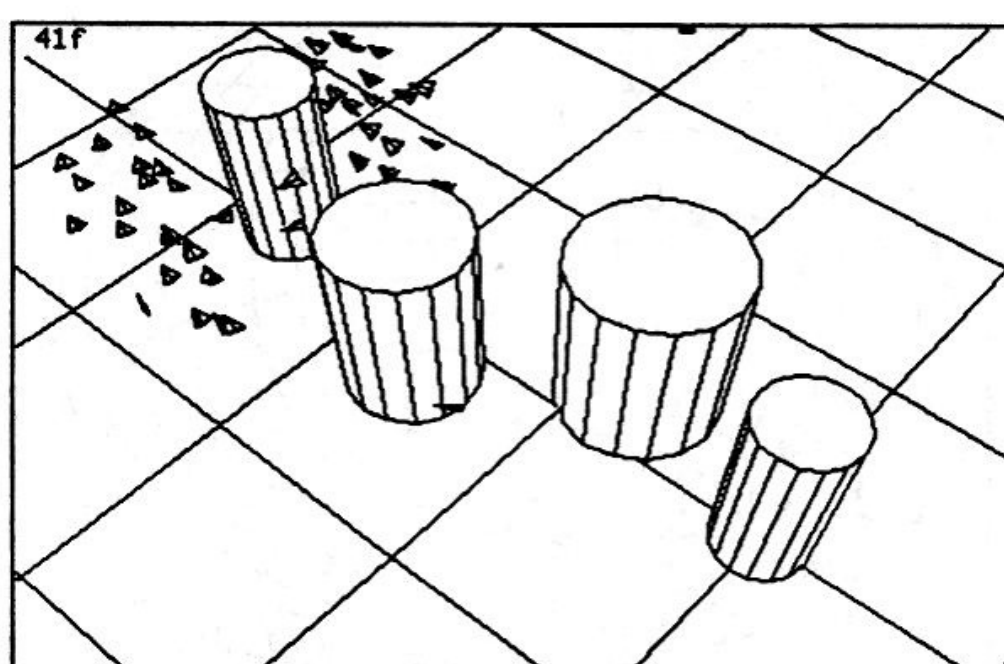
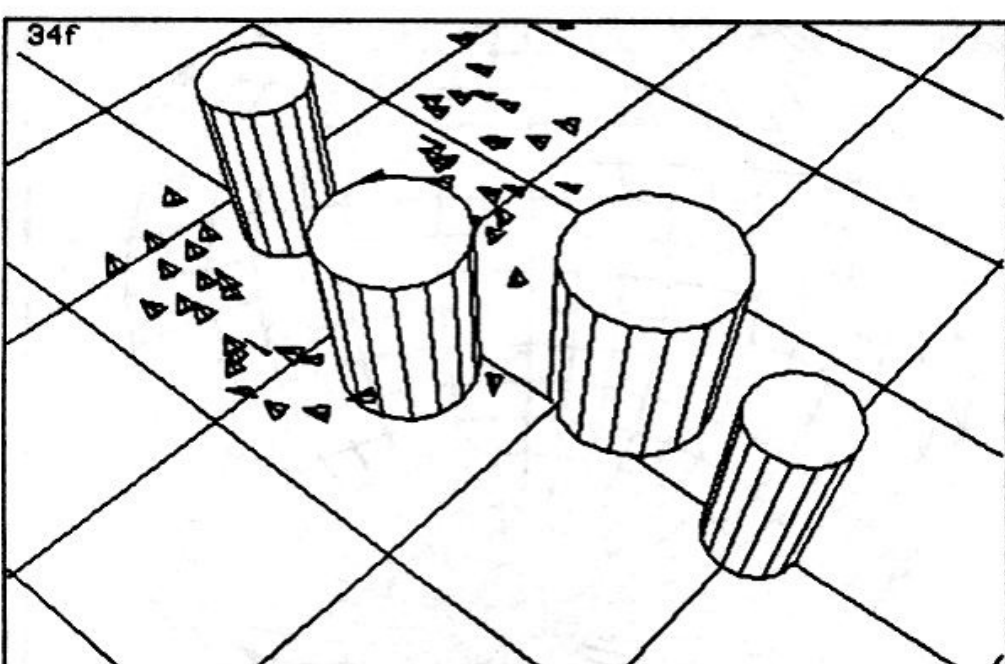
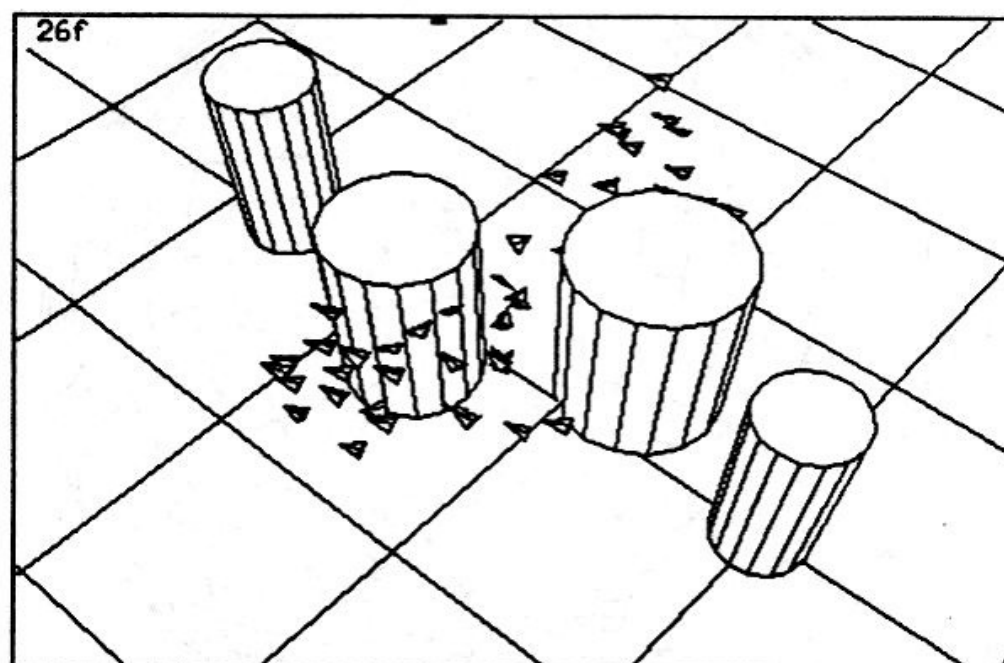
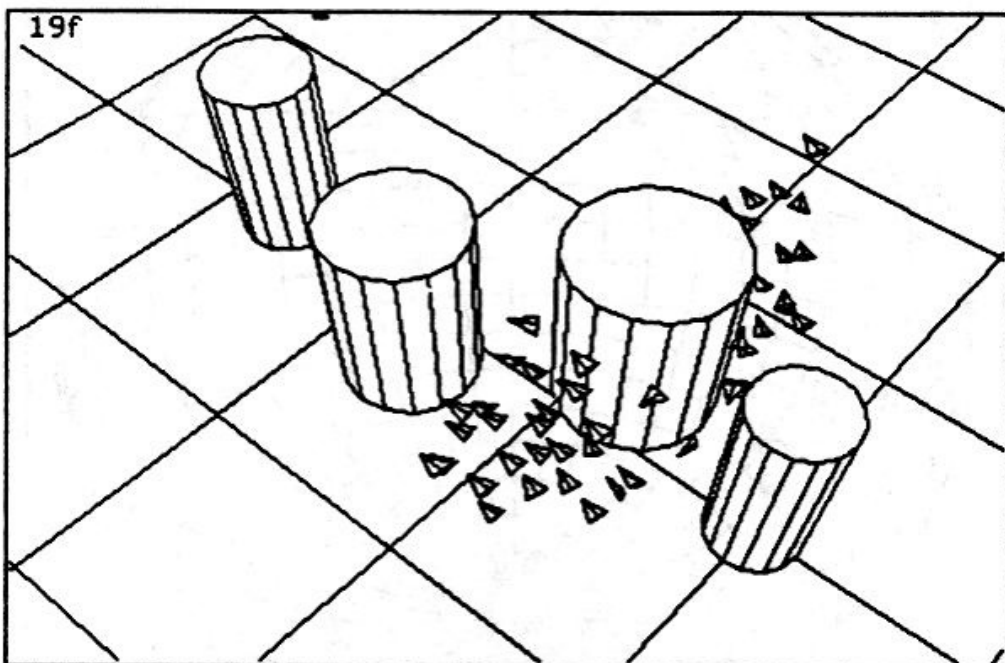
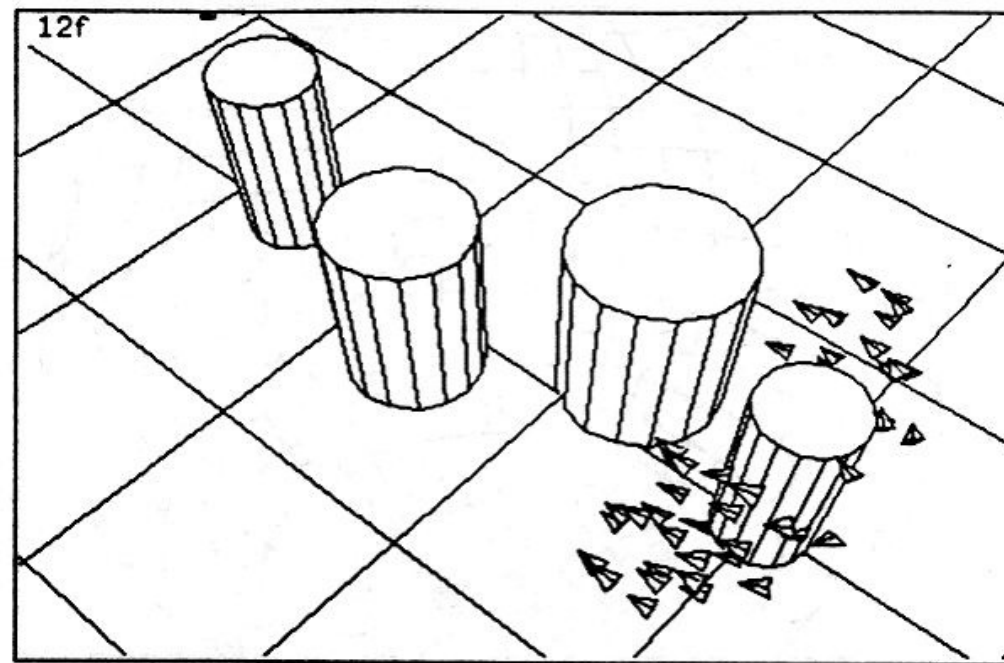
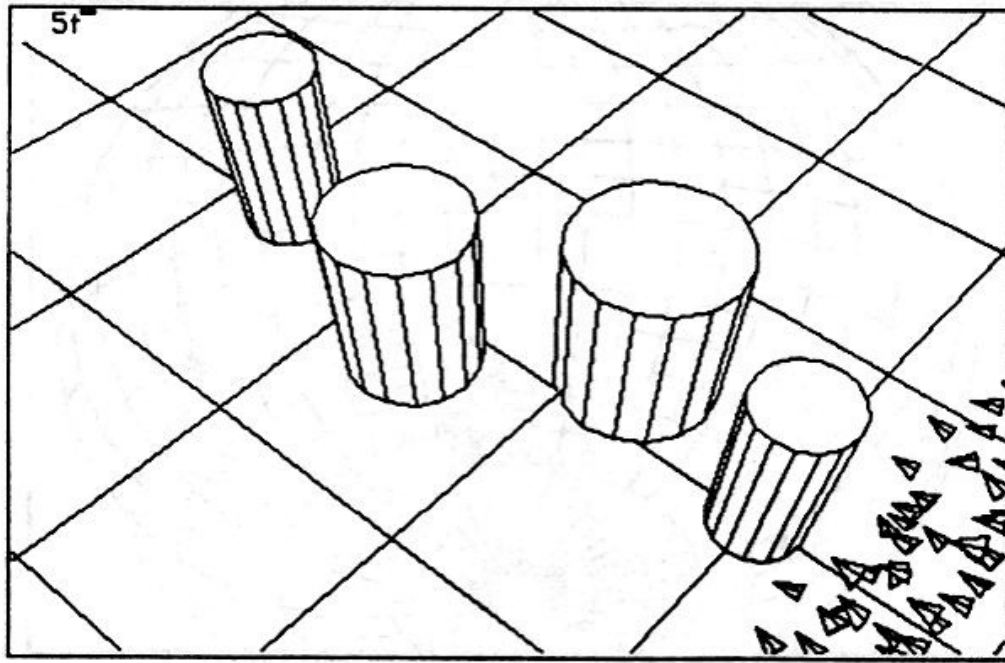
I needed an empirical demonstration, in the form of an animated graphical simulation.

Portion of original boids implementation, in Lisp, on a Symbolics Lisp Machine:

```
(defmethod (:AVOIDANCE-FOR-FLOCKMATE BOID-BRAIN) (flockmate)
  (if (eq flockmate self)
      (values 0 0 0)
      (vlet* ((its-center (send flockmate :global-center))
               (my-center (send self :global-center))
               (seperation (3d-vector-sub my-center its-center))
               :scaler
               (threshold (send self :flockmate-avoidance-threshold))
               (exponent (send self :flockmate-avoidance-exponent))
               (distance-squared (magnitude-squared seperation)))
            (if (> distance-squared
                  (* threshold threshold))
                (values 0 0 0)
                (vlet* ((local-seperation (localize-direction seperation self))
                         :scaler
                         (distance (3d:fast-sqrt distance-squared))
                         (relative-distance (/ distance threshold))
                         (repulsion (expt-non-neg (- 1 relative-distance) exponent))
                         (strength (send self :flockmate-avoidance-strength))
                         (factor (* strength (/ repulsion distance))))
                      (if (zerop distance)
                          (values 0 0 0)
                          (3d-vector-scale factor local-seperation))))))))

(defmethod (:VELOCITY-MATCHING BOID-BRAIN) ()
  (vlet* ((target-global (send self :nearby-velocity))
          (target-local (localize-direction target-global self))
          (current-local (send self :local-velocity))
          (difference (3d-vector-sub target-local current-local))
          (trimmed-goal (truncate-magnitude difference)))
    ;;
    ;; This might want to be done in :choose-course. A value of 1.0 was very unstable, the
    ;; boids would just flutter around erratically, while a value of 0.1 had very little effect. A
    ;; value between 0.2 and 0.3 seems to do the right thing. It is interesting that the performance
    ;; is so non-linear.
    ;;
    (let ((strength (send self :velocity-matching-strength)))
      (3d-vector-scale strength trimmed-goal))))

(defmethod (:NEARBY-VELOCITY BOID-BRAIN) (&optional (objects (send self :nearby-flockmates)))
  ;;
  ;; Note this this currently uses uniform weighting. It should be center/forward weighted.
  ;;
  (let ((threshold (send self :velocity-matching-threshold)))
    (flet ((velocity (object) (send object :global-velocity))
            (nearby-p (object) (send self :nearby-p object threshold)))
      (average-3d-vector-values objects #'velocity #'nearby-p))))
```

1986 boids motion test, as screen grabs from a Symbolics Lisp Machine. Includes additional behaviors:

- flocking
 - separation
 - alignment
 - cohesion
- seek
- obstacle avoidance





Stanley and Stella in Breaking the Ice

1987

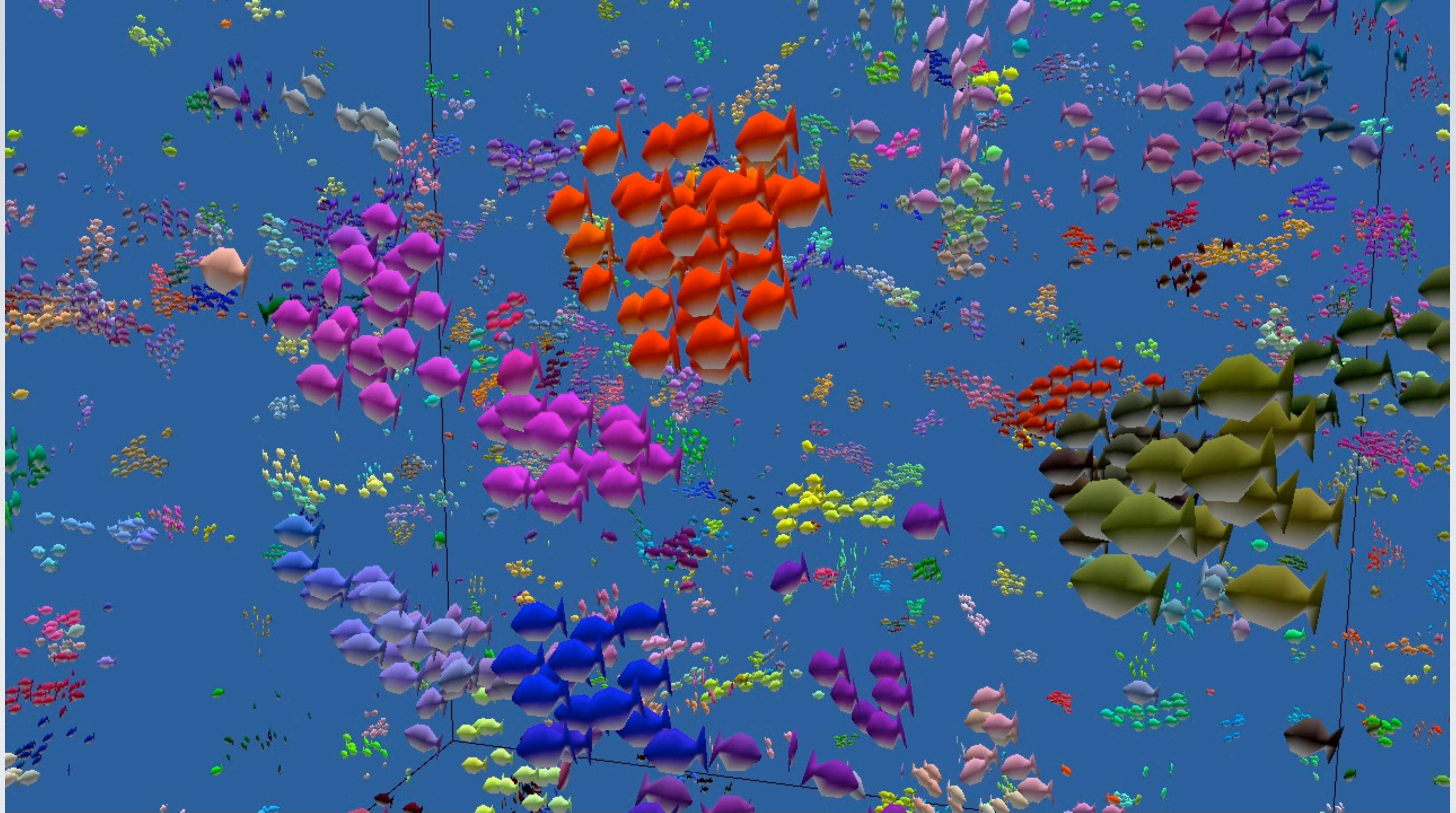
Symbolics, Inc.

in association with

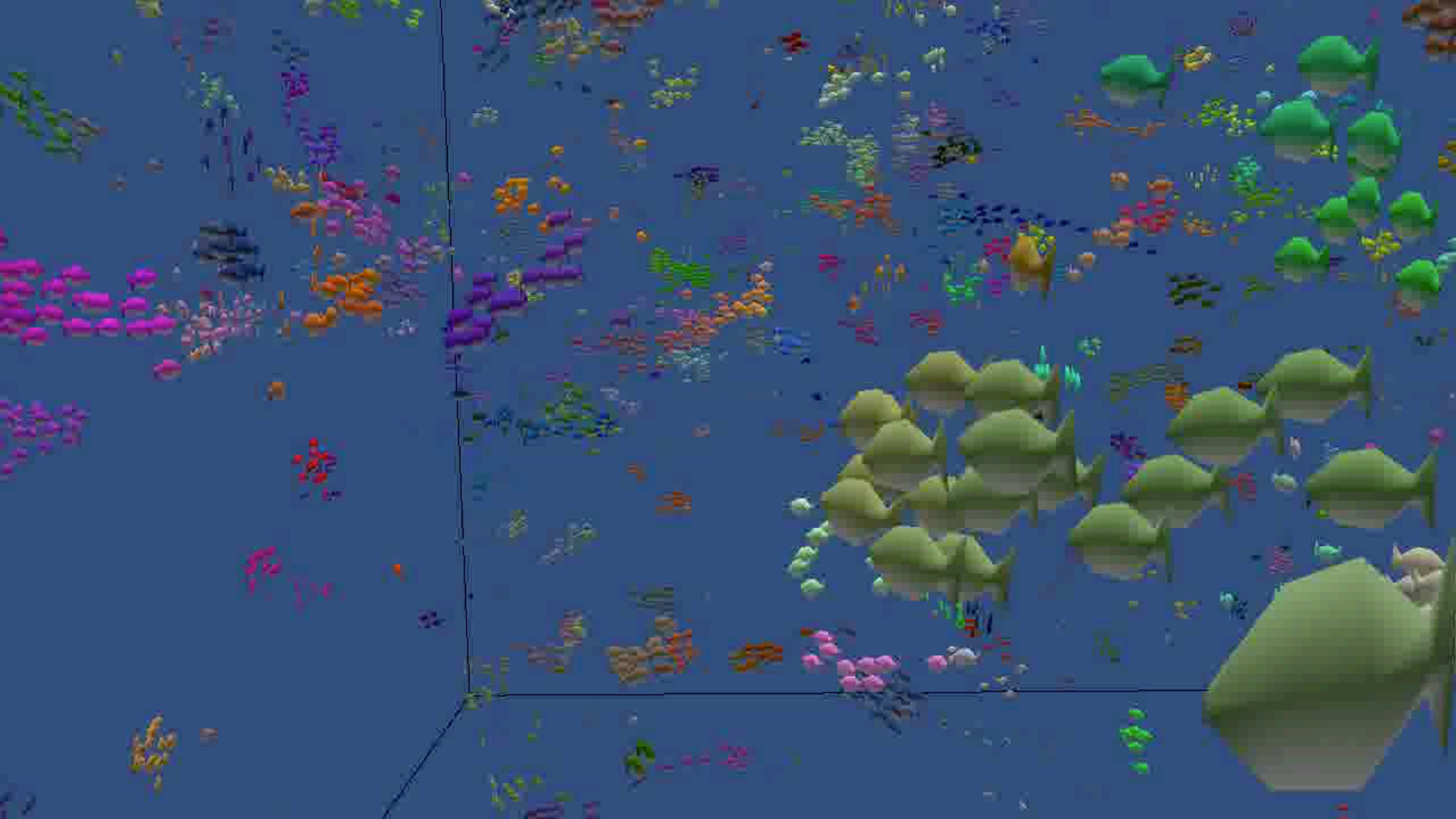
Whitney / Demos Productions

[BtI on YouTube](#)

SYMBOLICS
GRAPHICS DIVISION

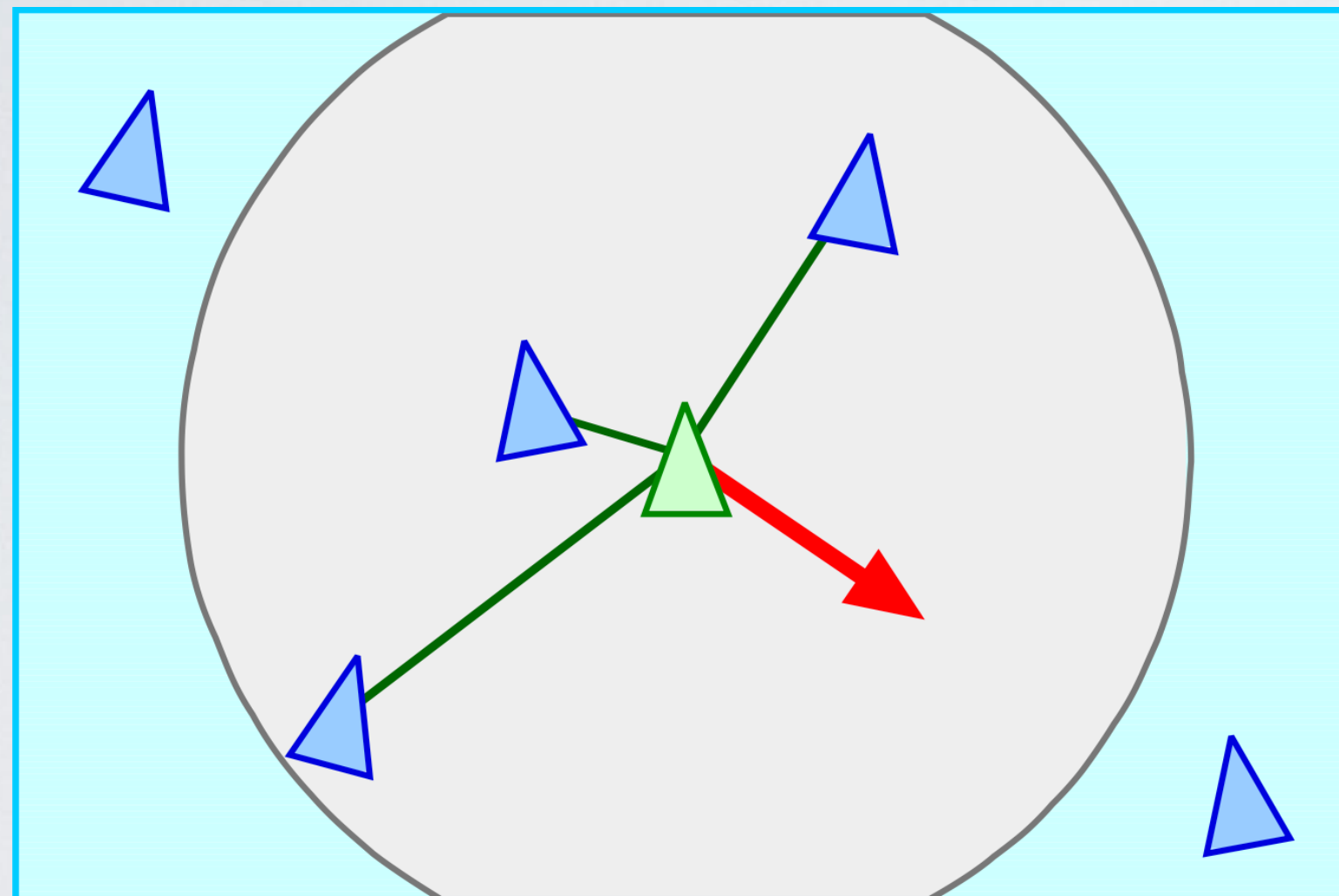


Real time boids on Playstation3 — about 10,000 at 60Hz — PSCrowd, 2006

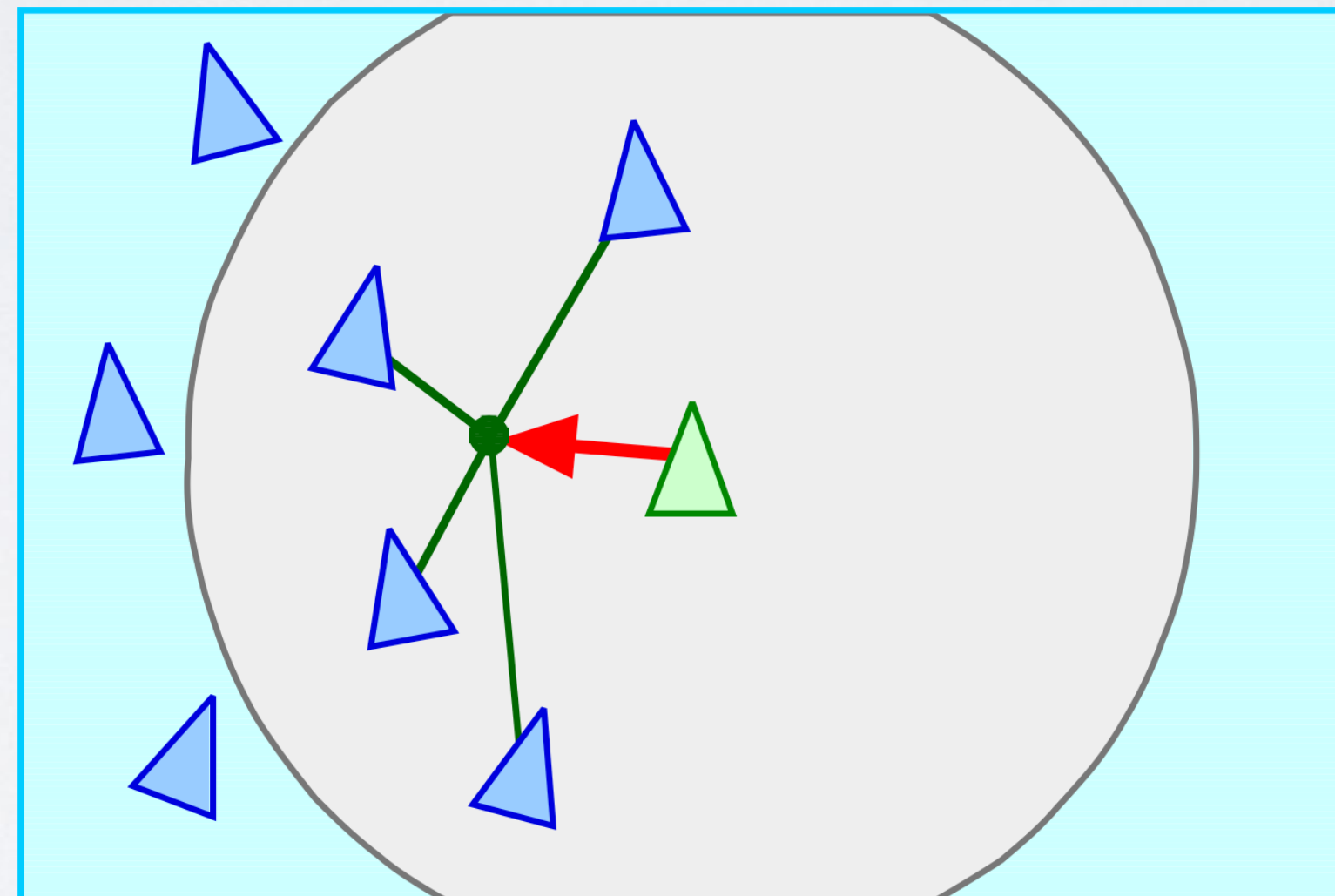




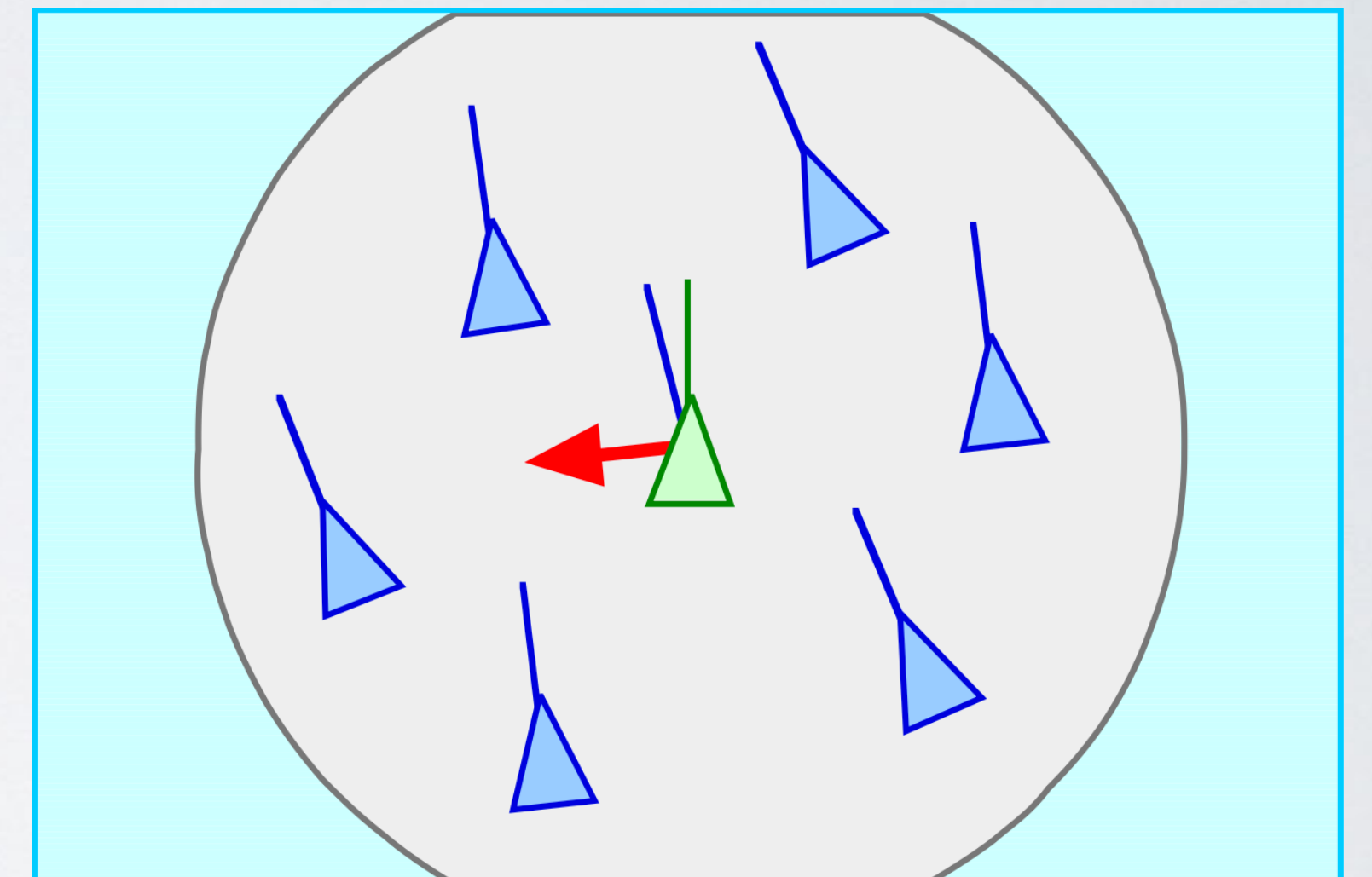
Returning to that key concept of neighborhood...



separation

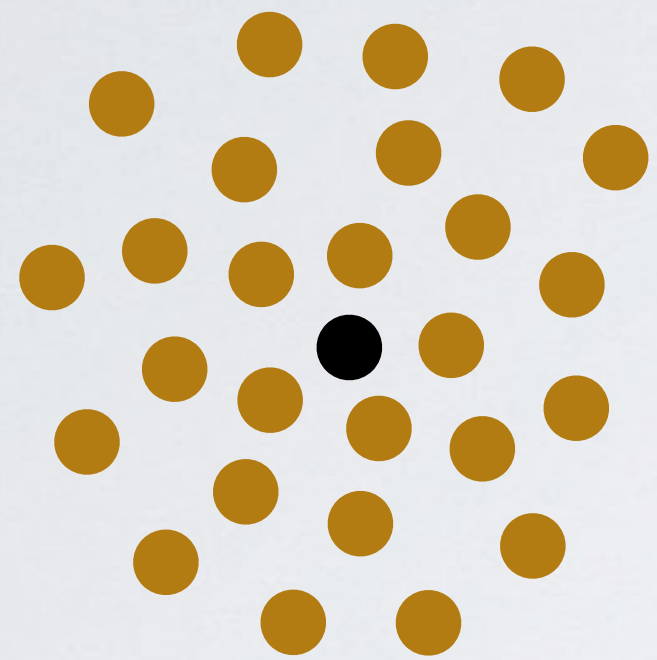


cohesion

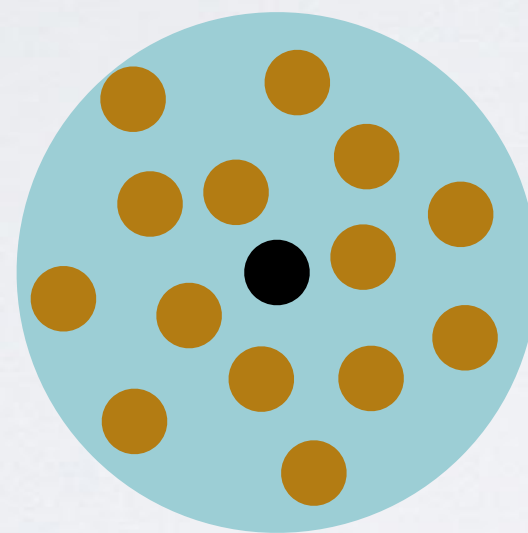


alignment

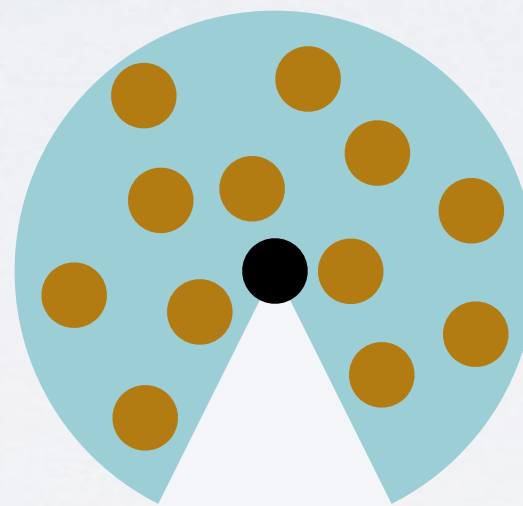
Evolution of neighborhood definition in flocking models



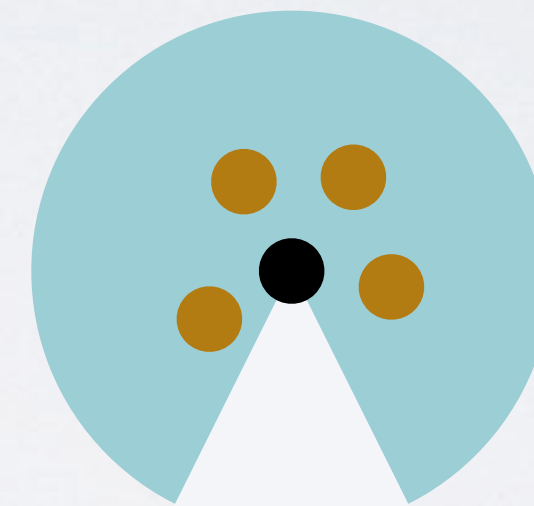
entire flock



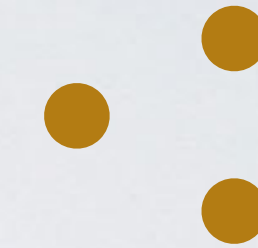
sphere



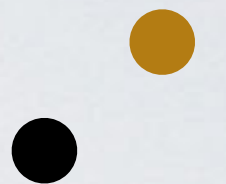
sphere - cone
spherical sector



kNN
in sector



kNN
($k=4$)



kNN
($k=1$)

1986



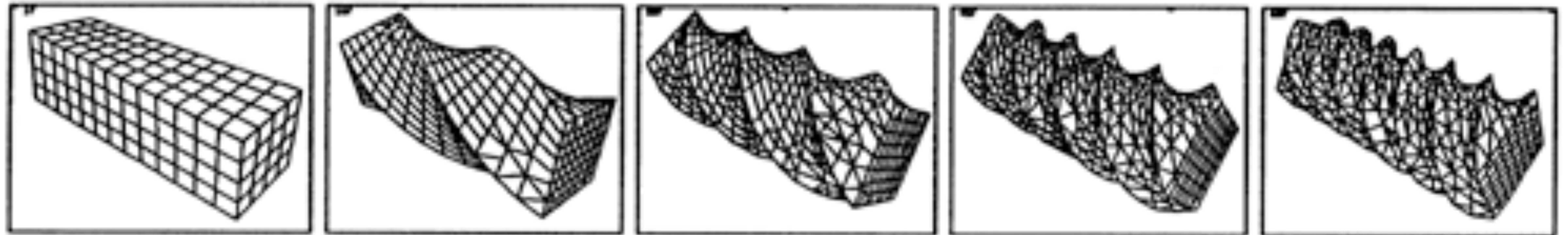
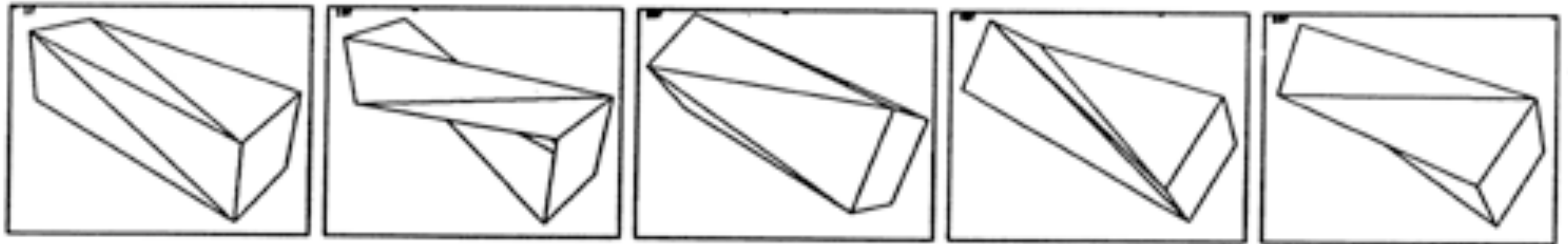
2014

DUCTILE FLOW

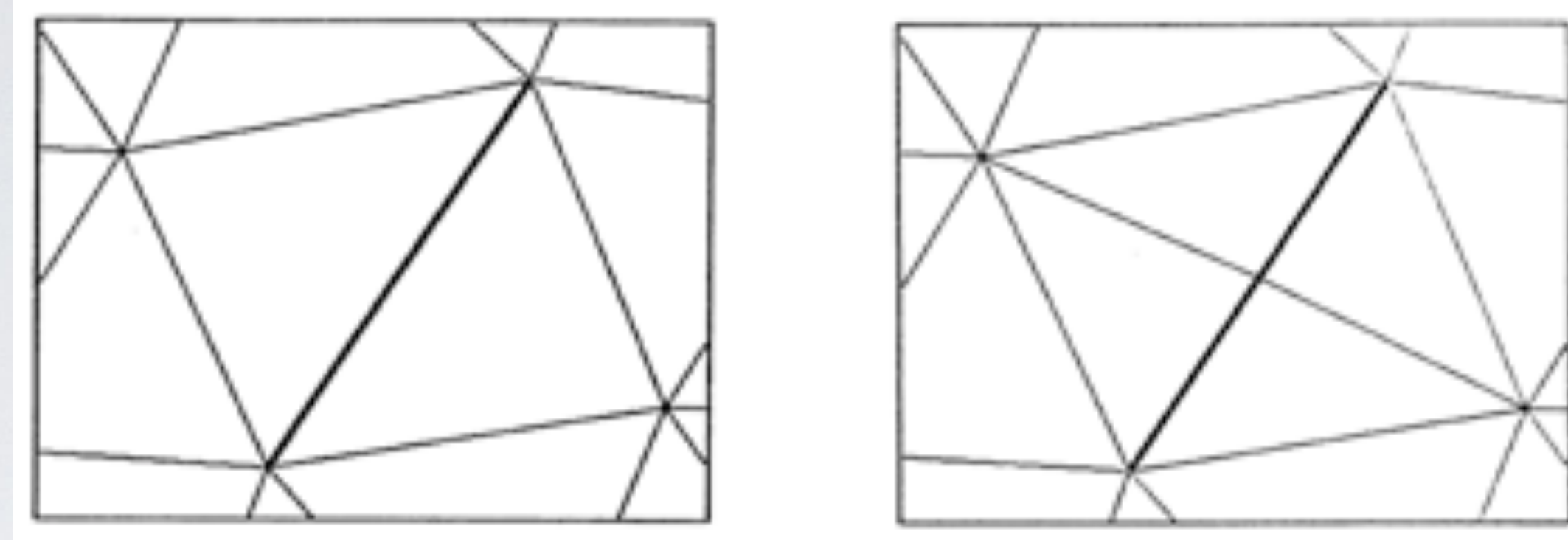
Adaptive Polyhedral Resampling for Vertex Flow Animation

- Allow 3d geometric models to advect in flow fields
- Adjusts vertex density to keep consistent sampling
- 1991 paper rejected by SIGGRAPH, draft on web
- Now cited by two subsequent SIGGRAPH papers!

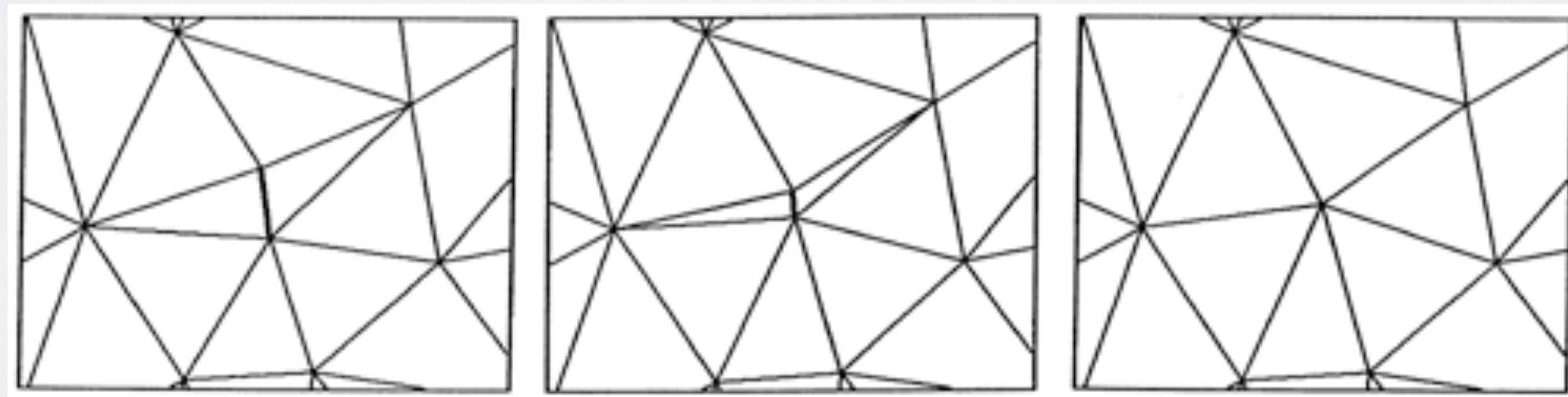
fixed geometry



adaptive subdivision

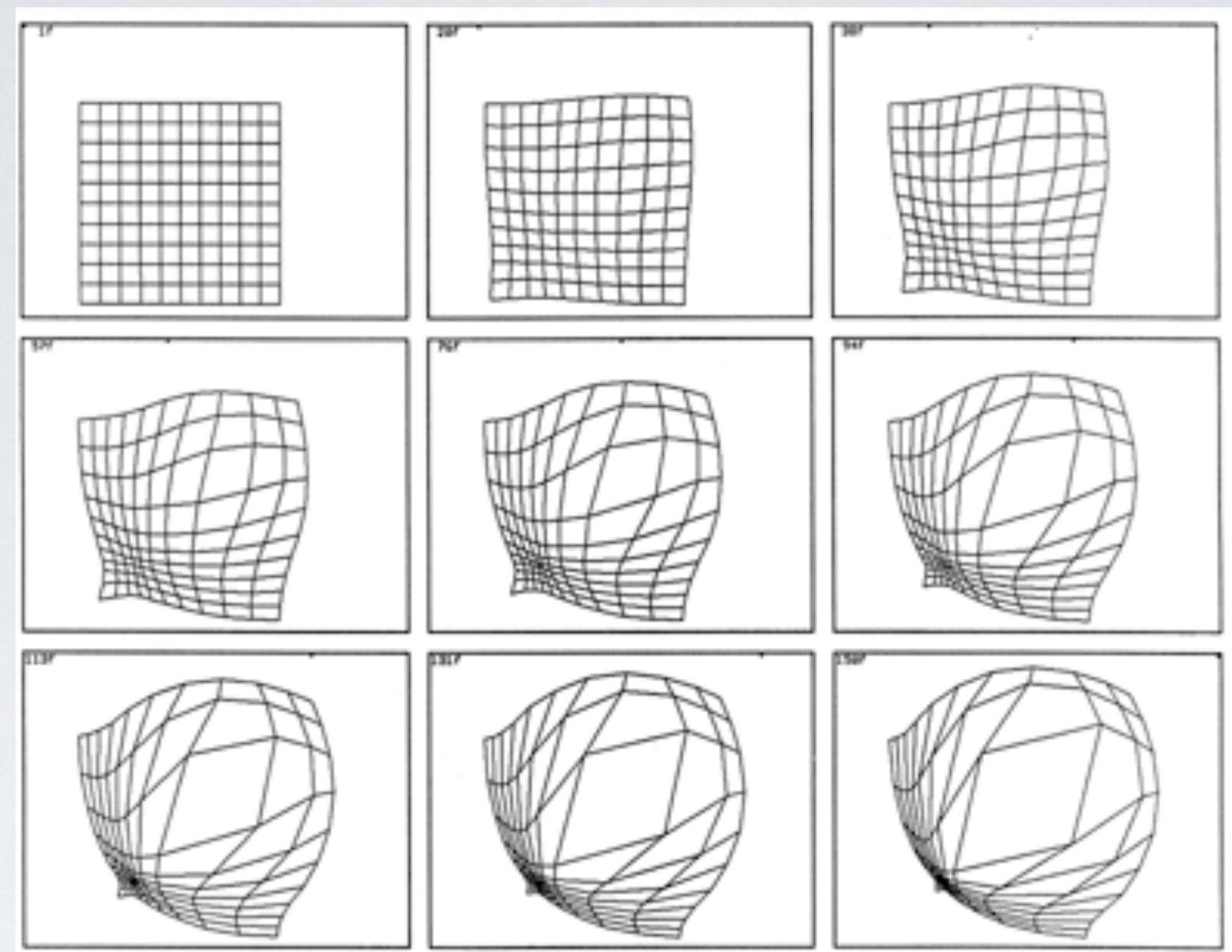


splitting a long edge and its two adjacent triangular faces



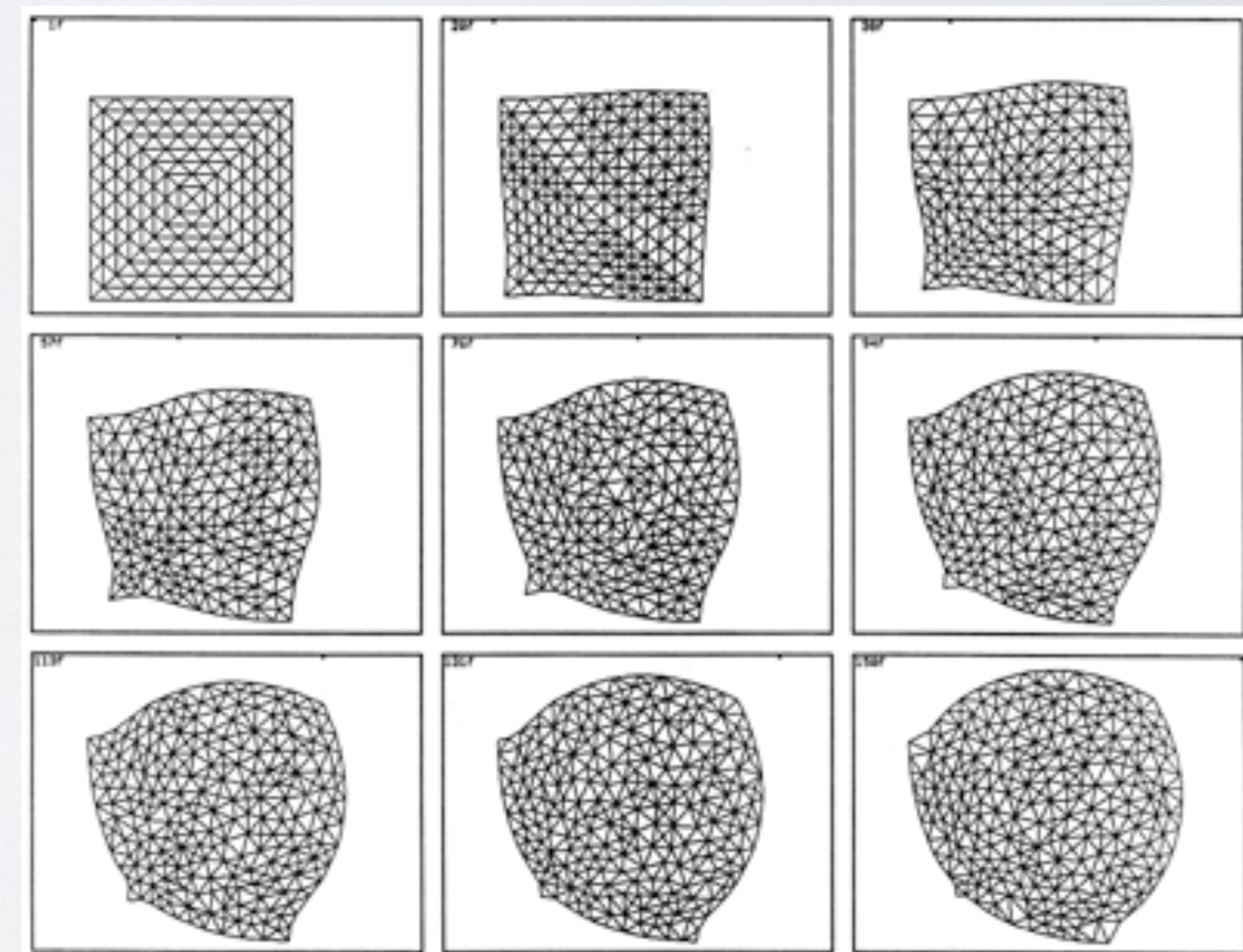
“unsubdivision” — collapsing a short edge

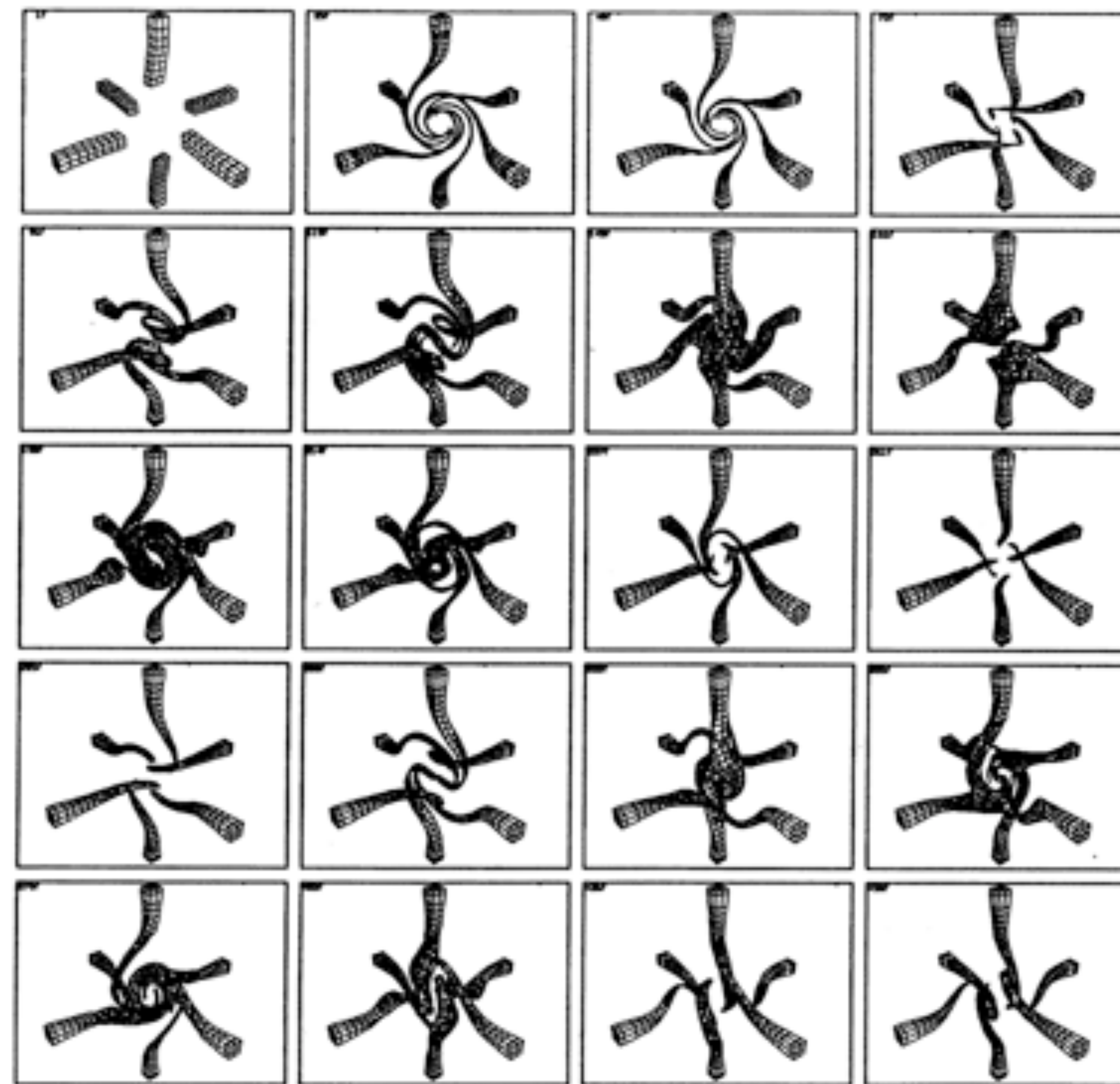
polygons



without adaptive subdivision

triangles





motion test of “flow sculpture”
from Matt Elson’s *Virtually Yours*



Still from Ductile Flow
(full video on my web site if you are interested)

STIGMERGY: COLLECTIVE CONSTRUCTION

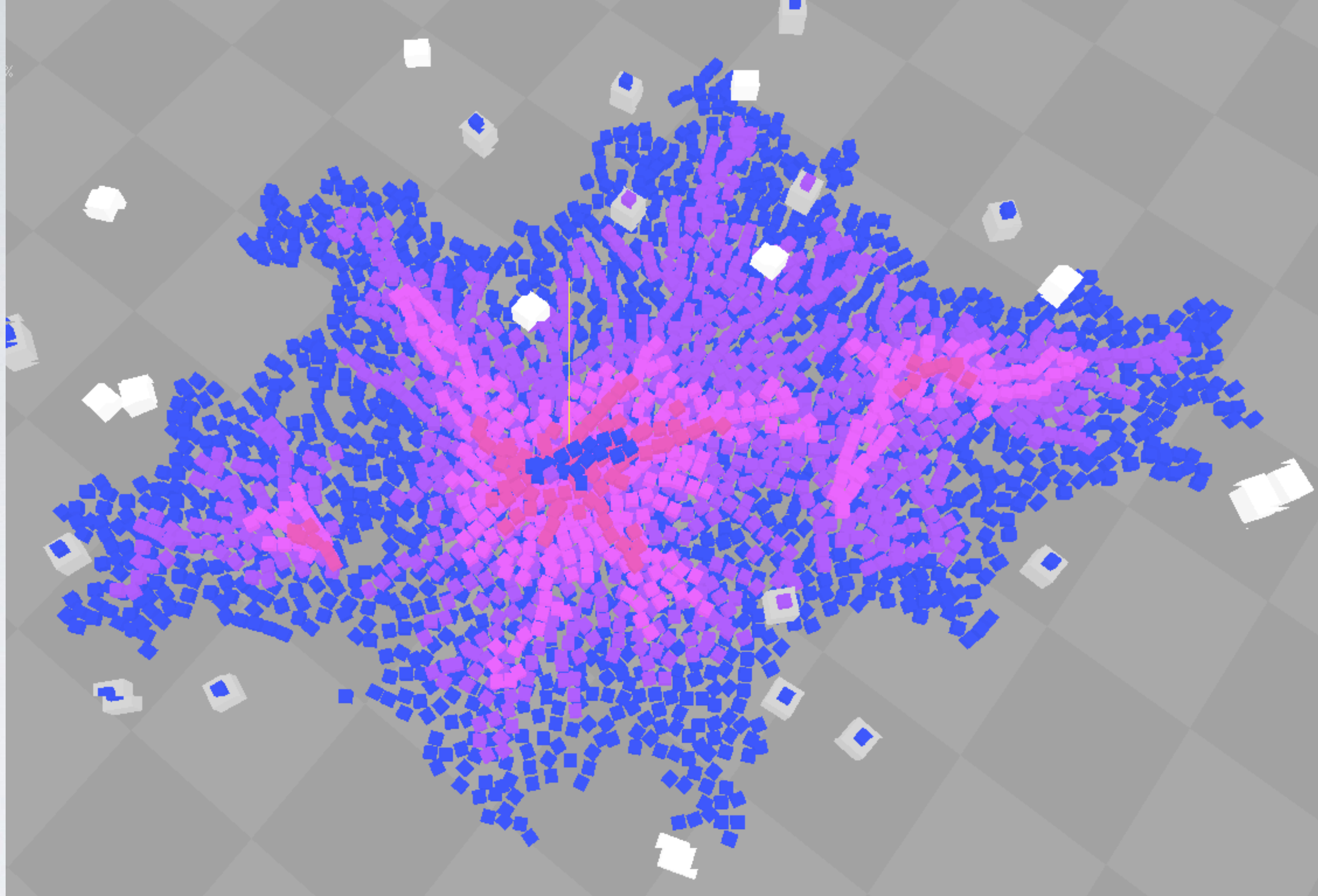
STIGMERGY

- Unpublished work 2009-2010
- Inspired by stigmergy in social insects
- Crowd model based on emergent teamwork
- Create large global structures with simple local rules

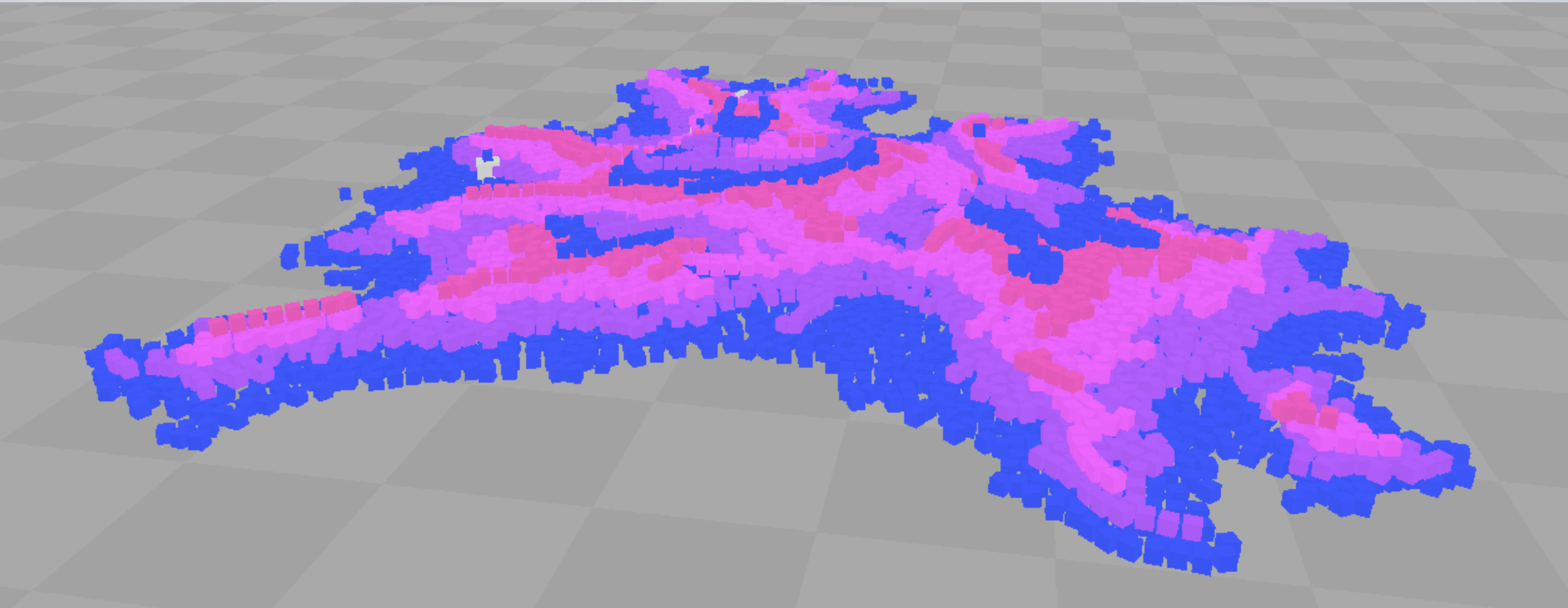


two termite cathedral mounds in the Northern Territory of Australia

CC 2005 Ray Norris via Wikimedia

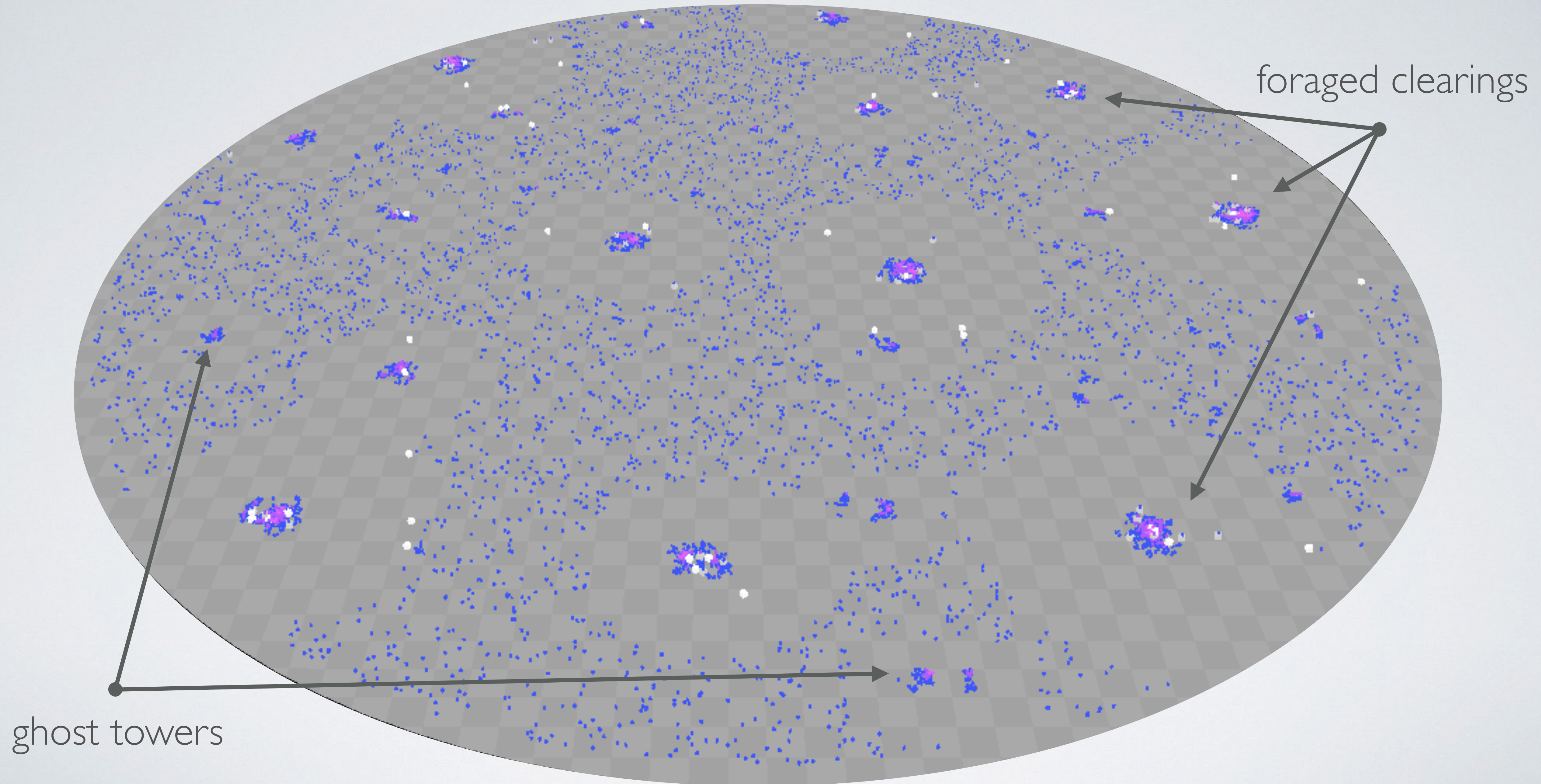


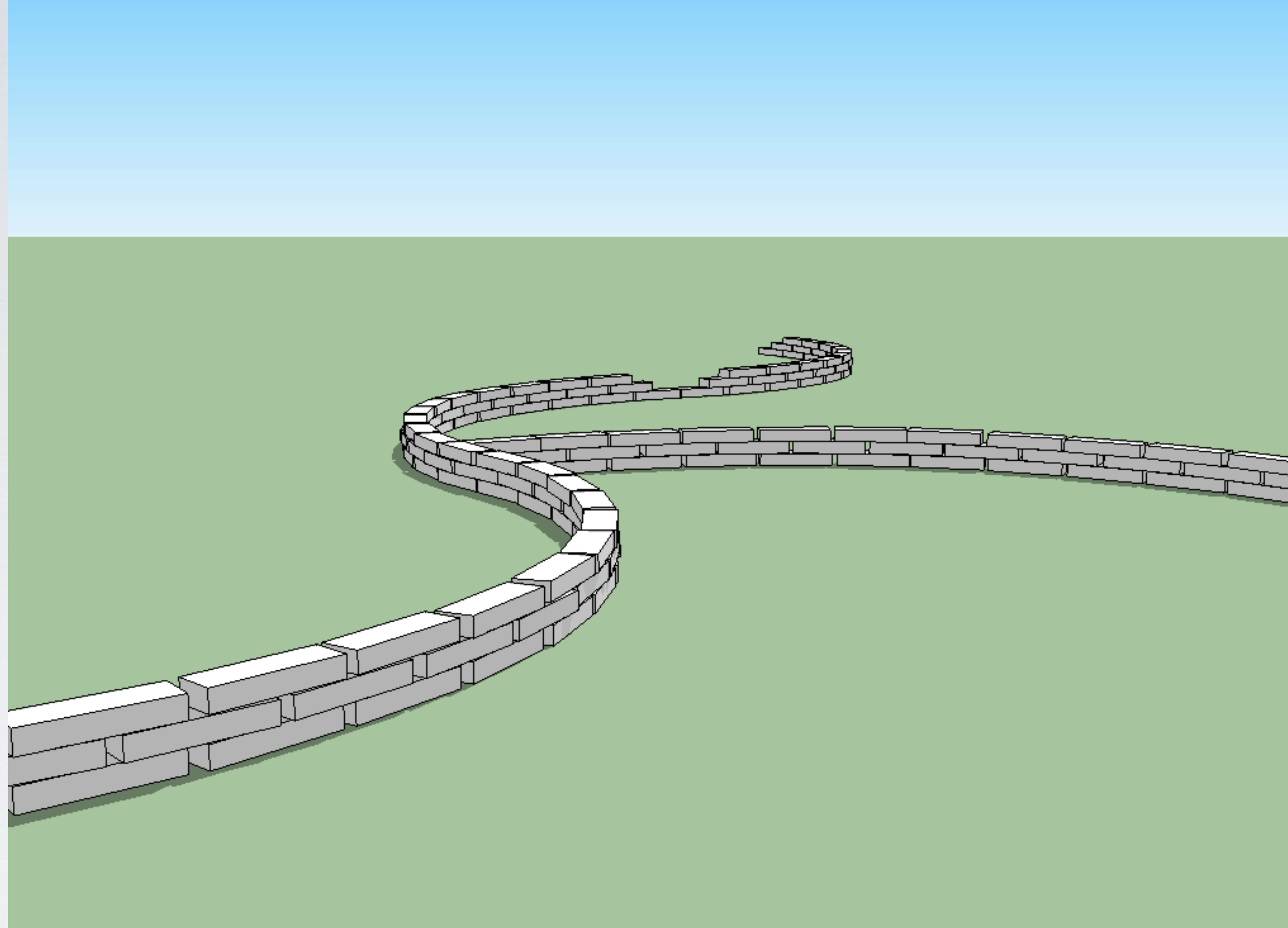
2008 stigmergic multi-agent mound-building simulation



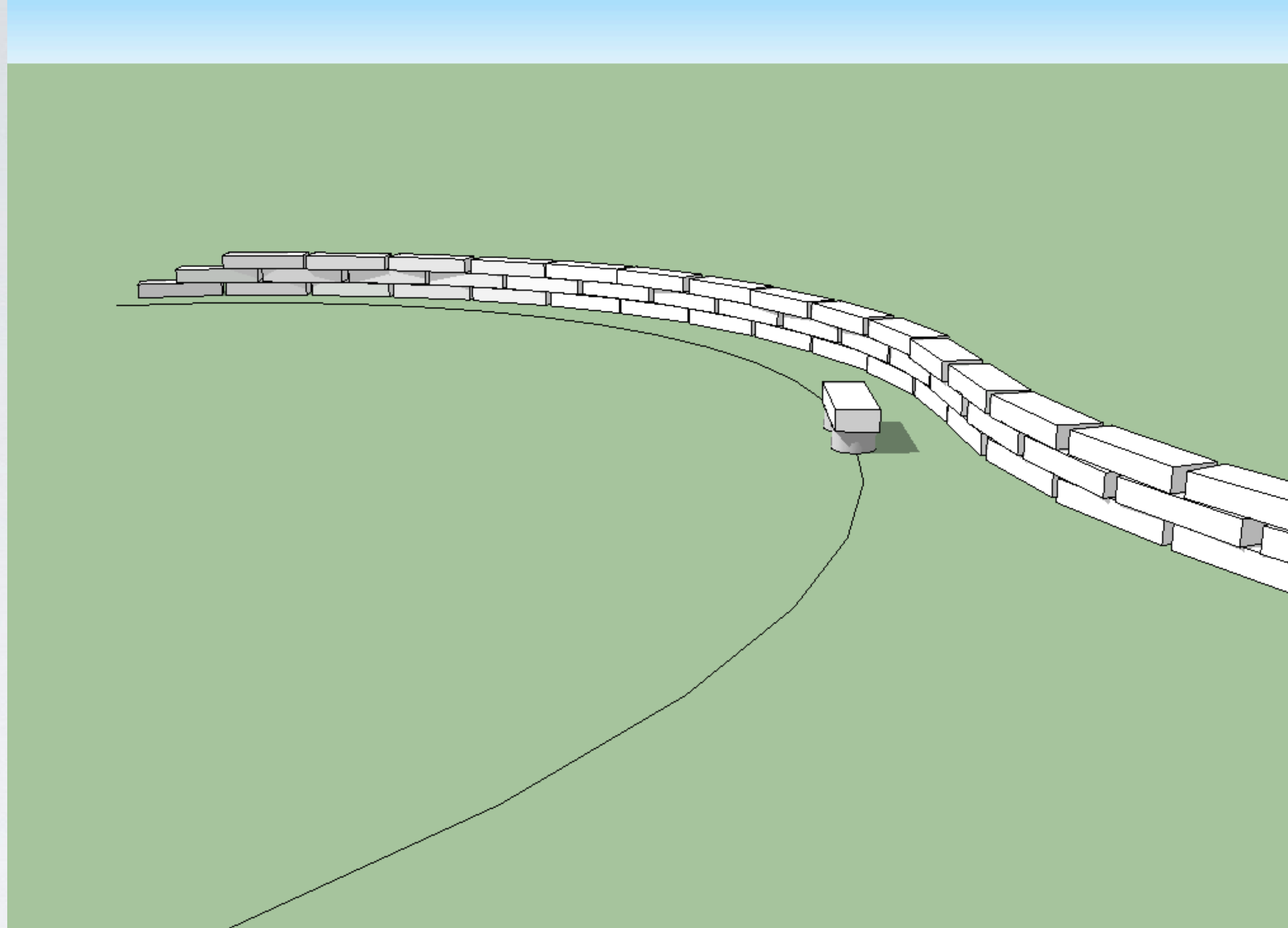
2008 stigmergic multi-agent mound-building simulation

Emergent teamwork: tower construction

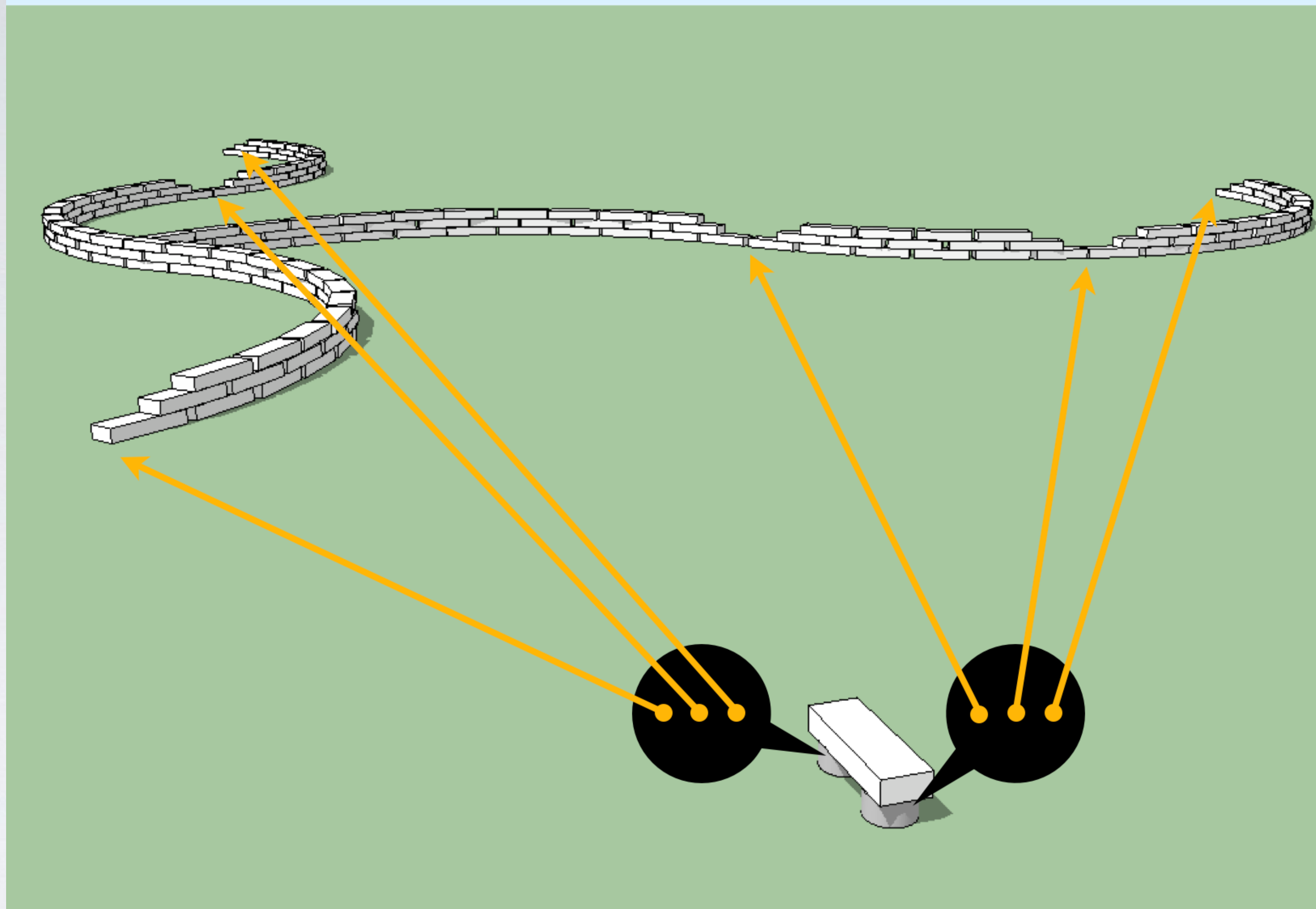




Proposed stigmergic wall-building scenario.



Proposed stigmergic wall-building scenario:
wall following to construction site.



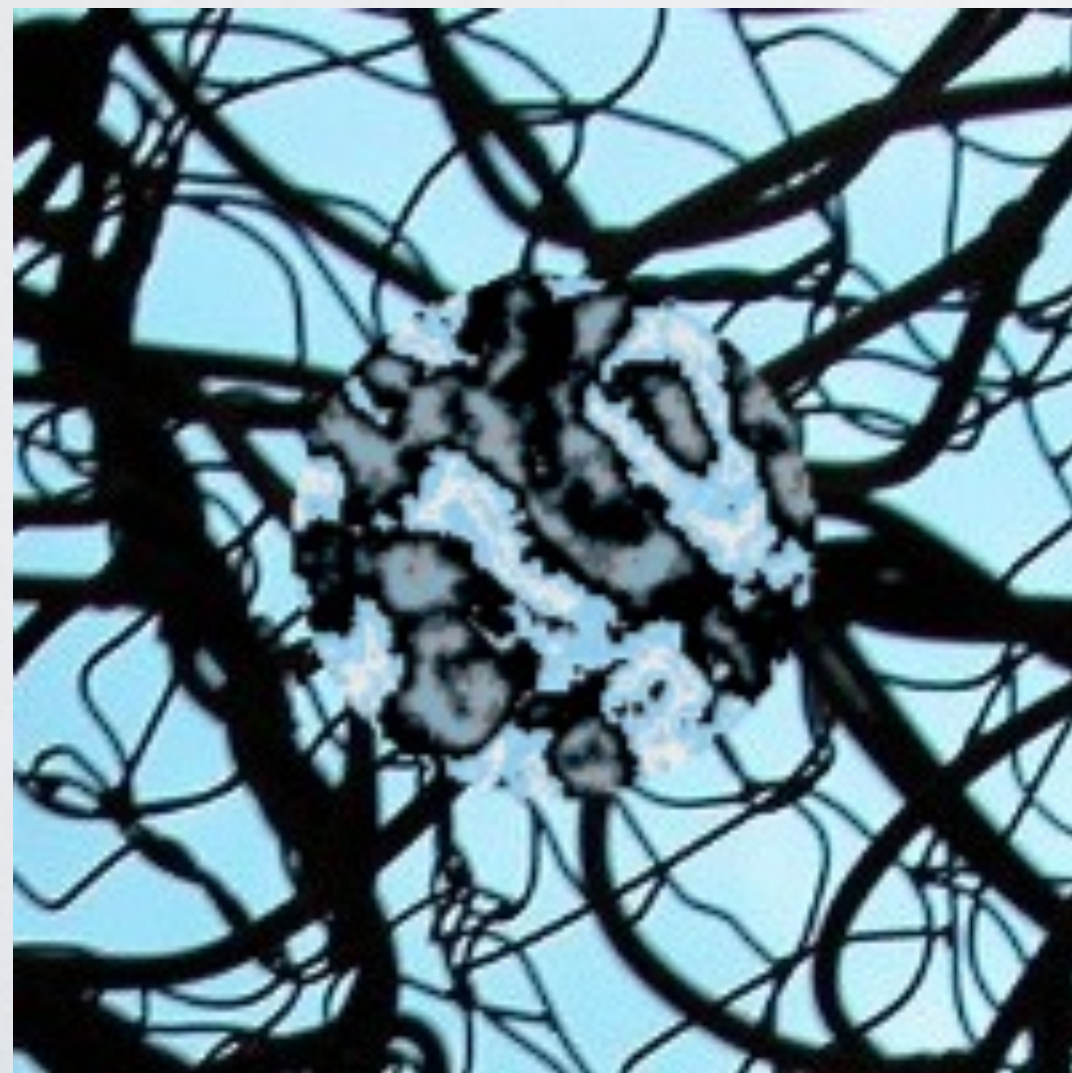
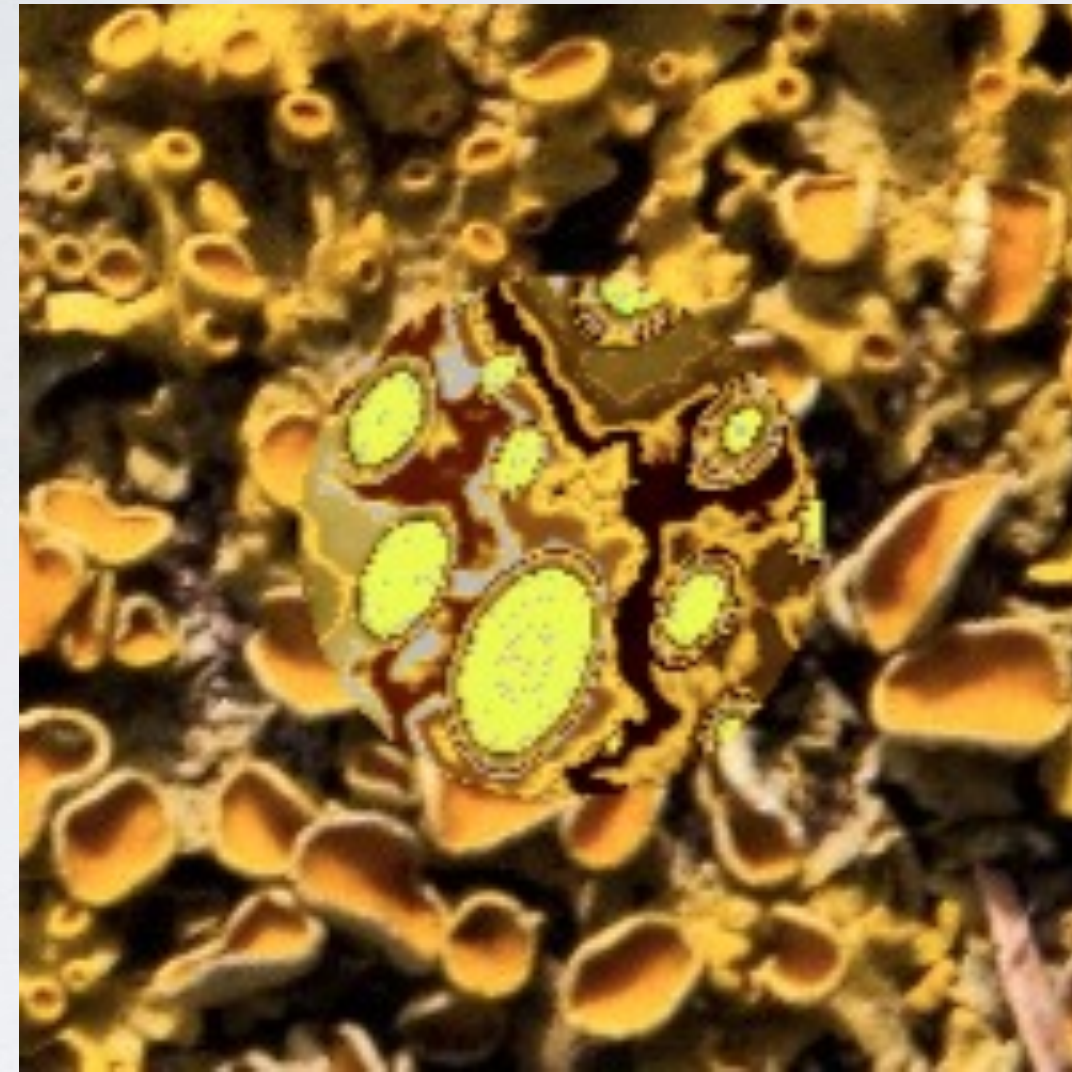
Proposed stigmergic wall-building scenario:
two robots carry a brick, recalling recent work sites

INTERACTIVE EVOLUTION OF CAMOUFLAGE

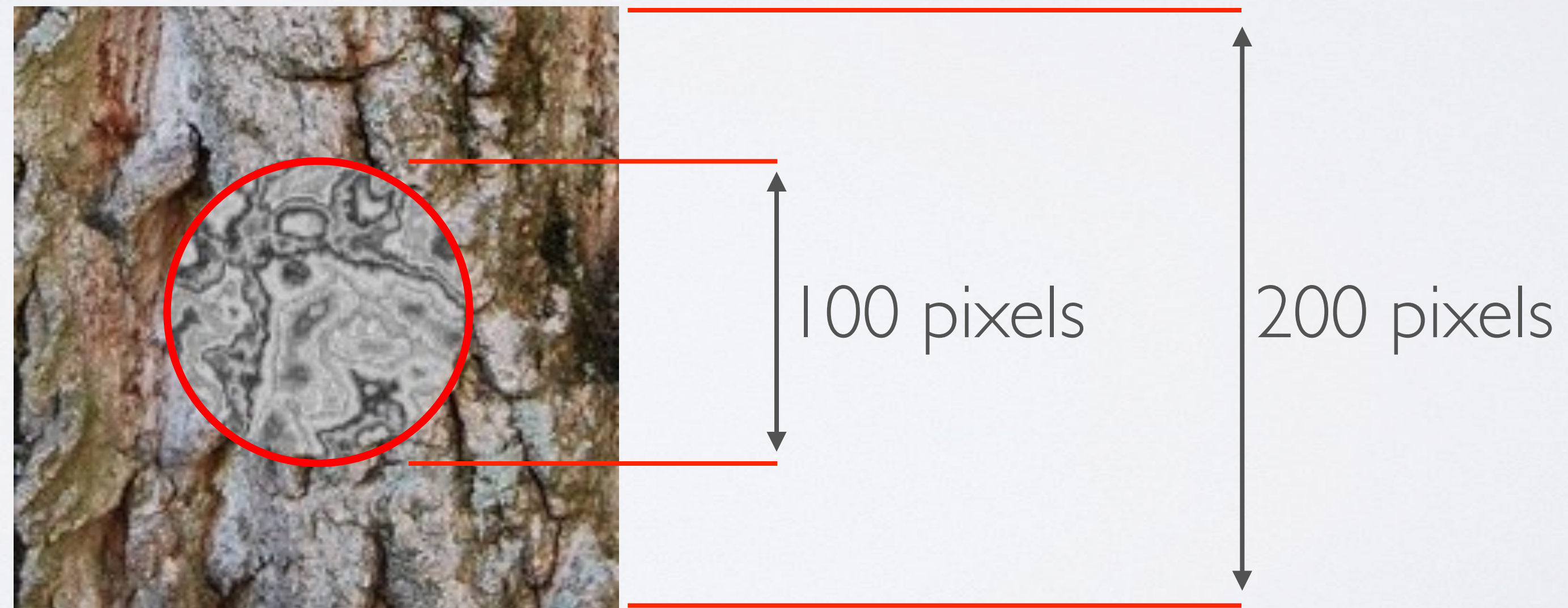
Interactive Evolution of Camouflage

- Abstract model of camouflage evolution in nature.
- evolutionary computation: genetic programming
- computer graphics: procedural texture synthesis
- hybrid system: human vision “in the loop”

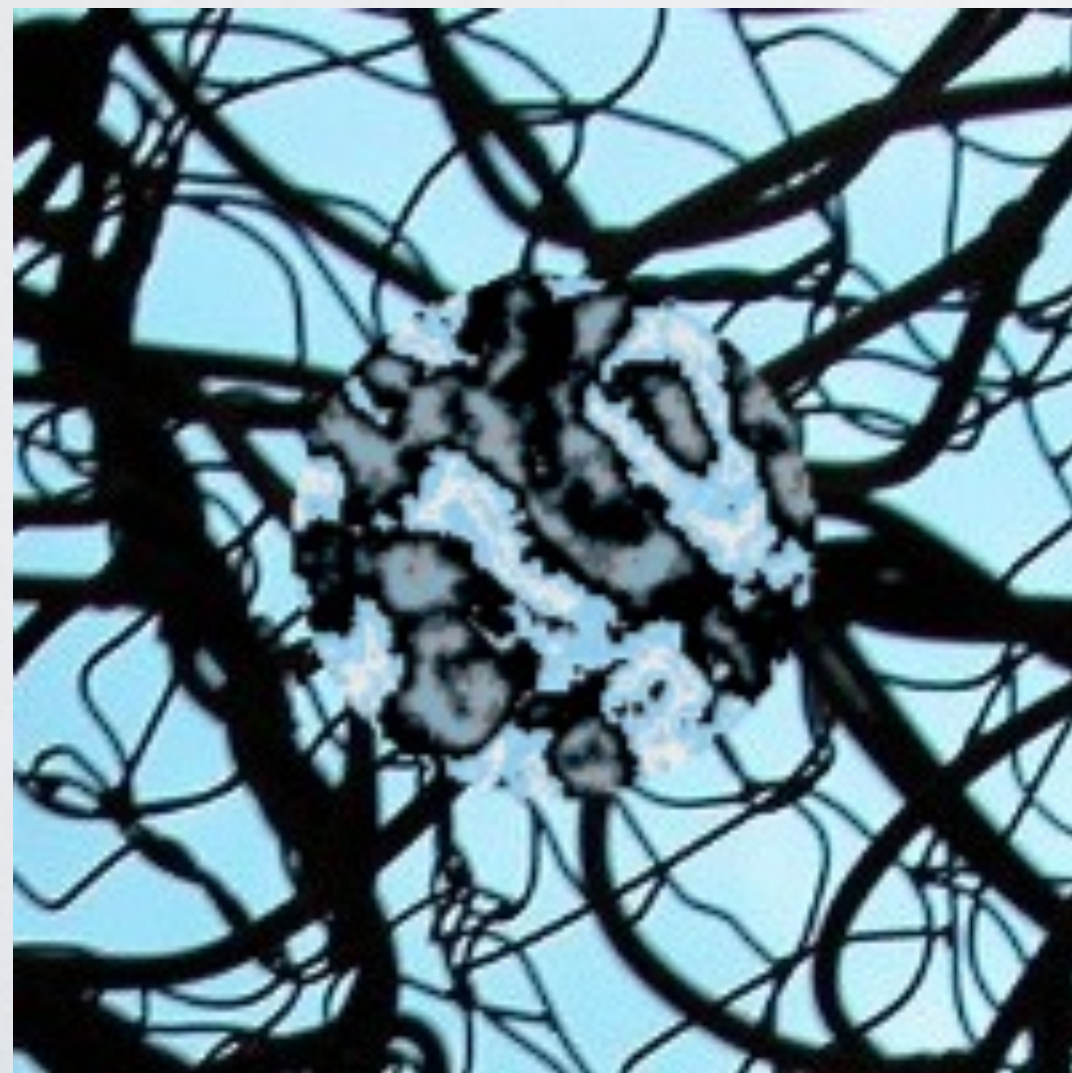
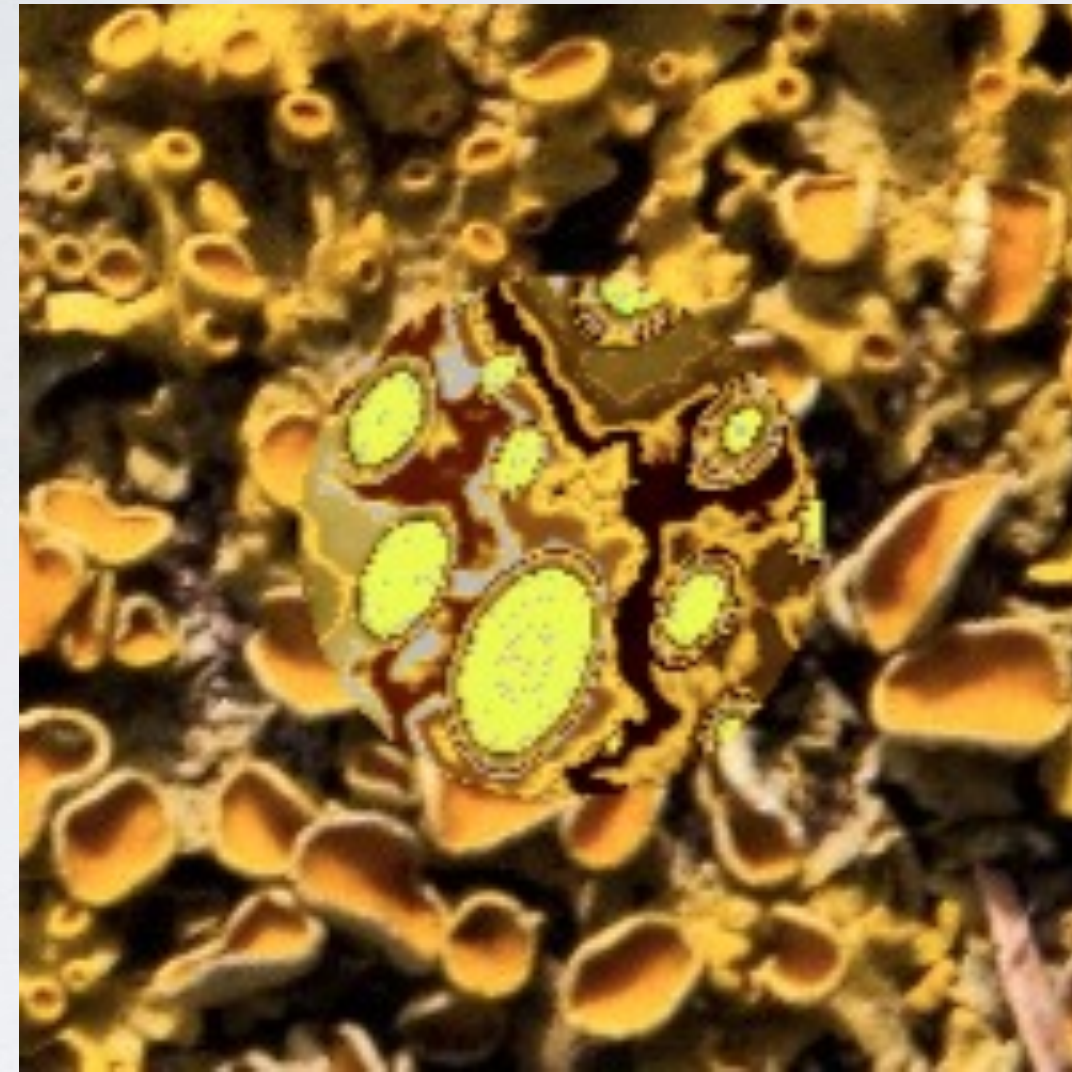
Evolved camouflage

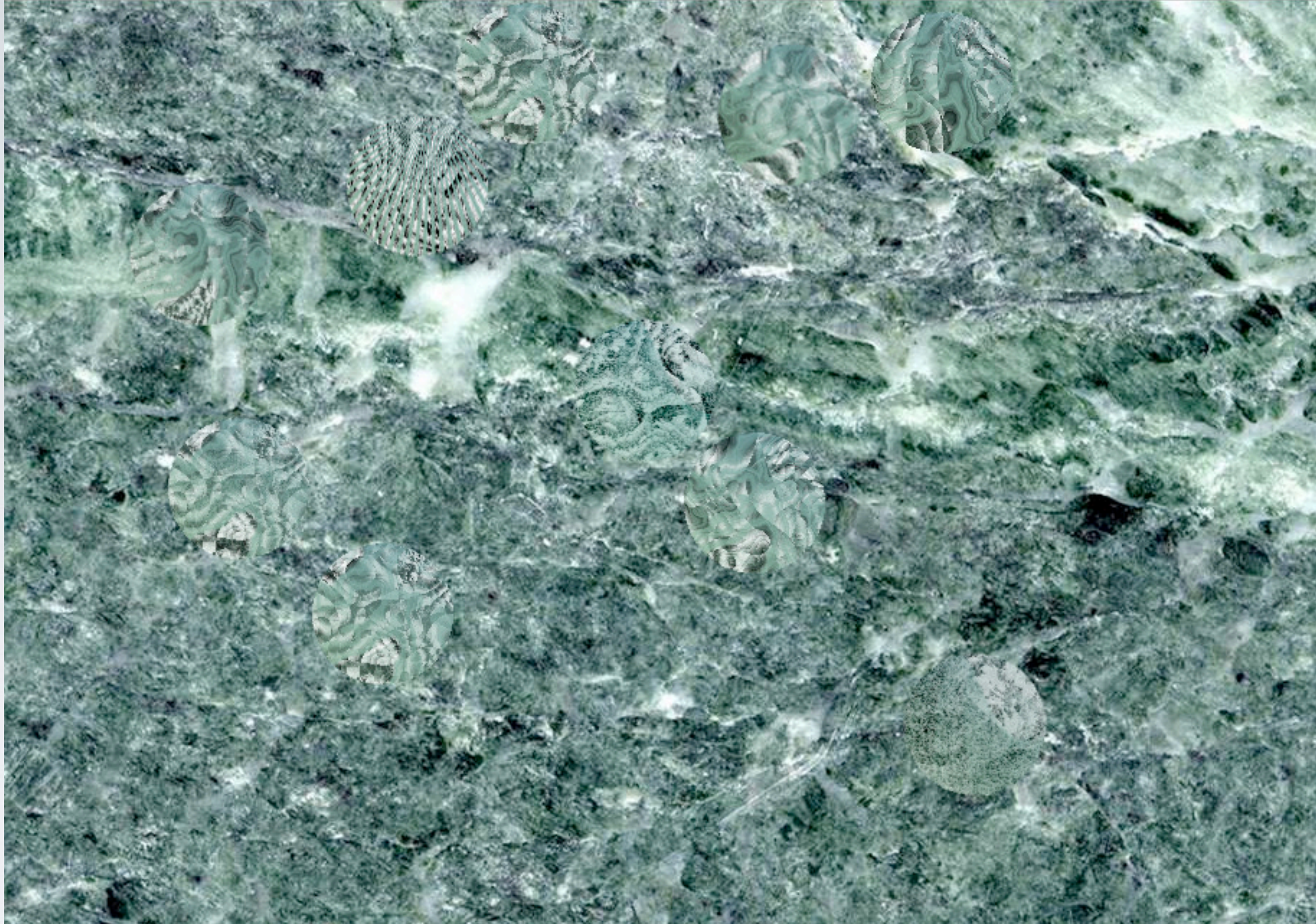


Evolved camouflage



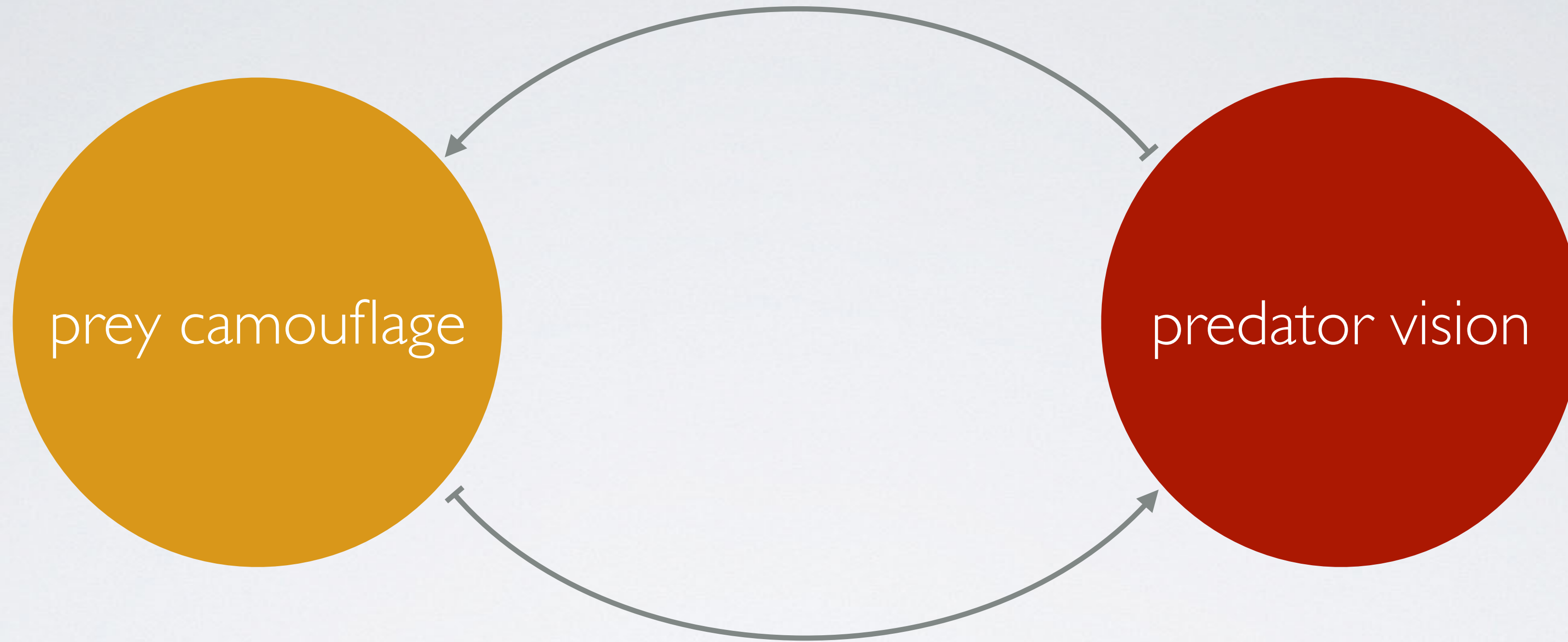
Evolved camouflage



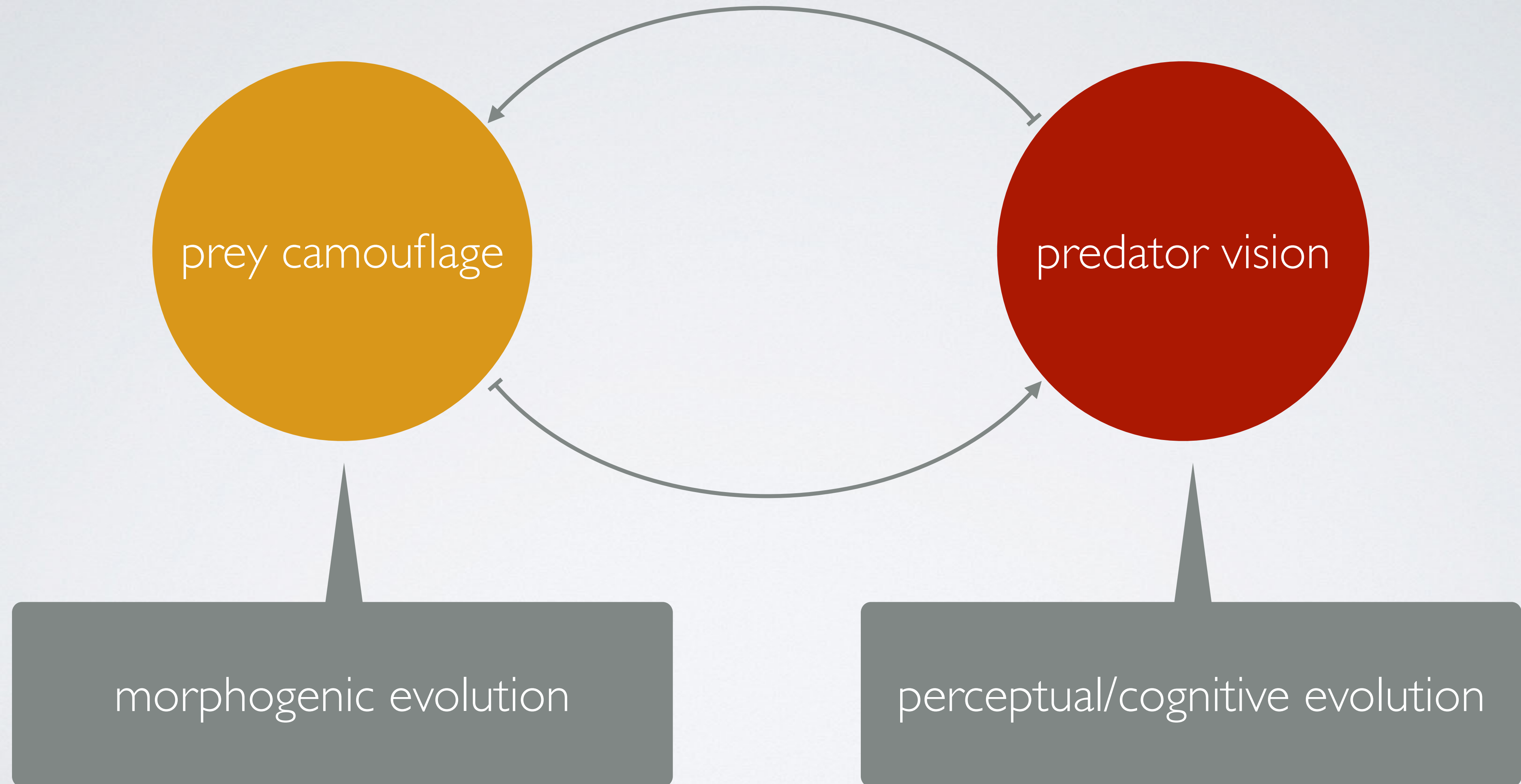


Cohort of ten prey with evolved camouflage over a photographic background of natural texture. In this case: polished serpentine stone.

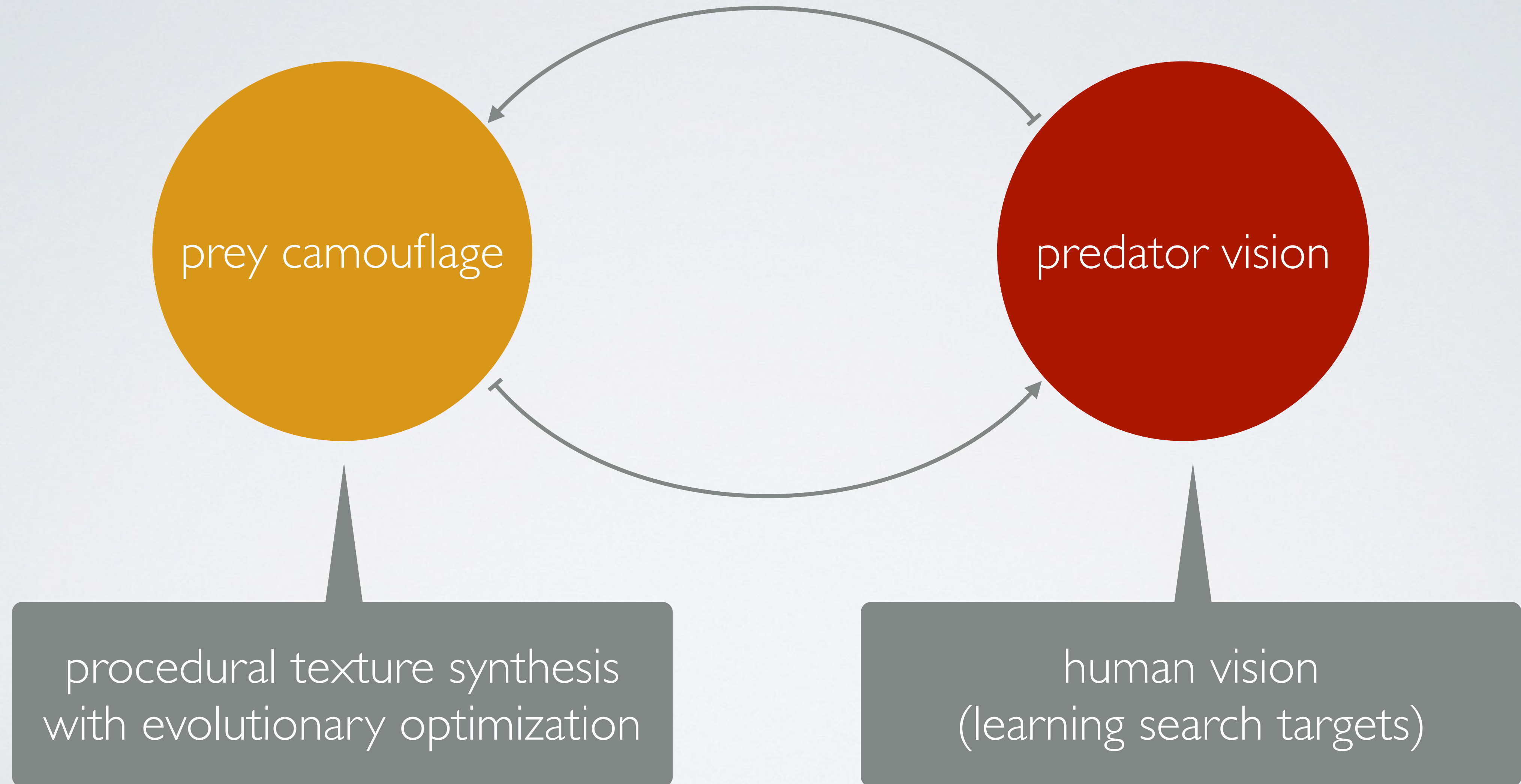
Coevolutionary System:



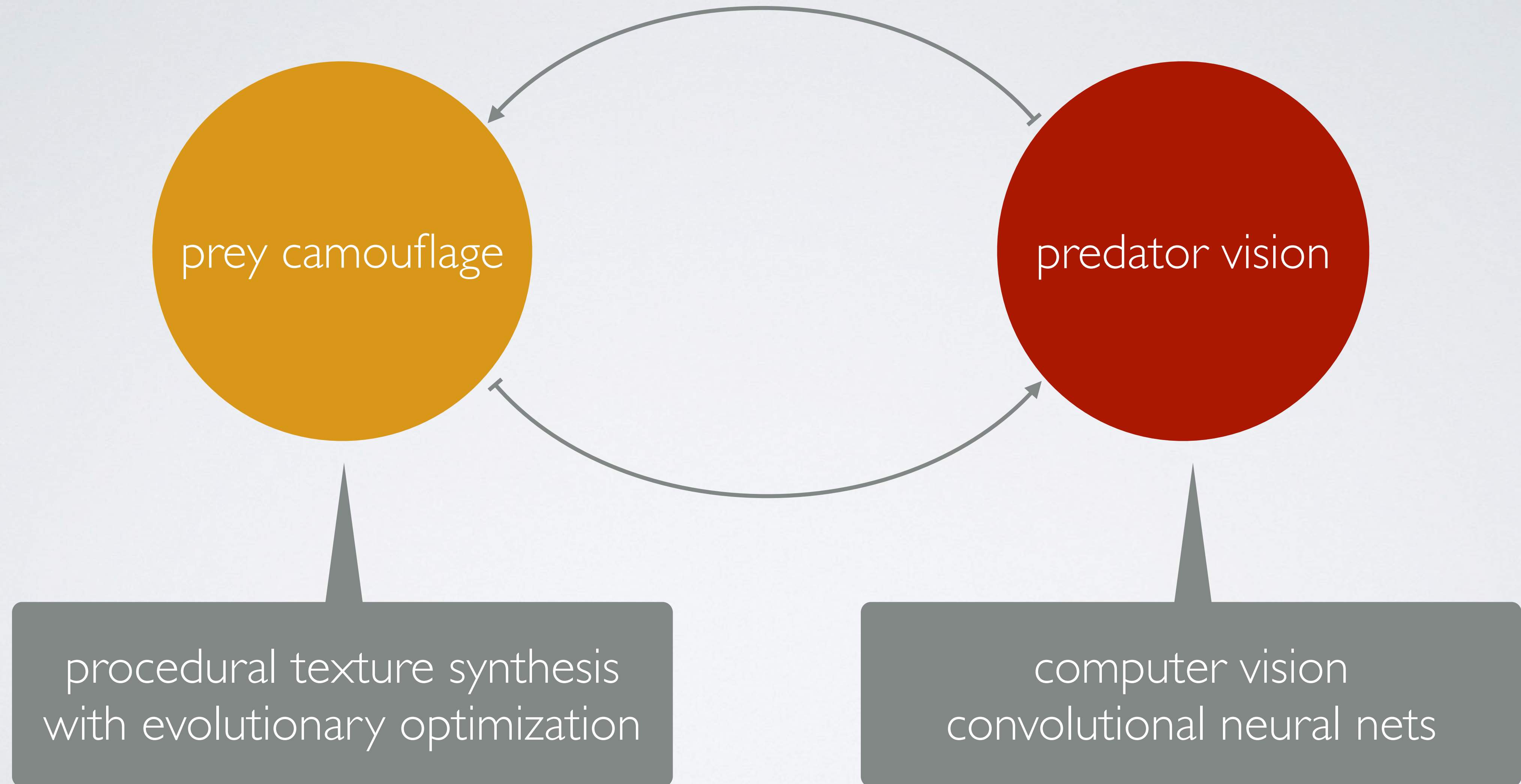
In nature:



Current version, hybrid of procedural and interactive:



Eventual goal, a fully procedural simulation:



Camouflage in Nature



Malagasy Lanternfly, forest canopy, Madagascar
©2009 Danté B Fenolio, used with permission



Caterpillar of
Common Baron
butterfly (*Euthalia
aconthea*), Malaysia

(cc) 2009 Conny
Sandland, used
with permission



Bark bug, Peruvian Amazon

©2008 Dr. Arthur Anker,
used with permission

© Steven Trainoff 2007



Juvenile C-O sole
(*Pleuronichthys coenosus*)

©2007 Steven Trainoff
Ph.D., used with
permission



Tawny frogmouth
owls (*Podargus
strigoides*)

©2005 C. Coverdale
via Wikimedia
Commons



Northern leopard frog (*Rana pipiens*),
Michigan USA — (cc)2008 Kenneth
Walny, used with permission



Southern leopard frog (*Rana sphenocephala*),
Florida USA — (cc)2009 Gabriel Kamener,
used with permission



Leaf-tailed Gecko (*Uroplatus fimbriatus*), Madagascar

©2009 Diana Bradshaw, used with permission



Acacia tree and giraffe (*Giraffa camelopardalis*)
©2007 Martin Heigan, used with permission

Camouflage: evolutionary computation

- Genetic Programming
 - texture synthesis library
 - *Open BEAGLE* (to be replaced by: *Lazy Predator*)
- Steady-state population — individual based model
 - high elitism
 - not generations / moments in individual's life
 - remain in population until “eaten” by predator
- Interactive cohort-based fitness

GP Crossover

a (b (5), c (2, d (12, 4)))

x (y (w (6, 2), 3), z (9))

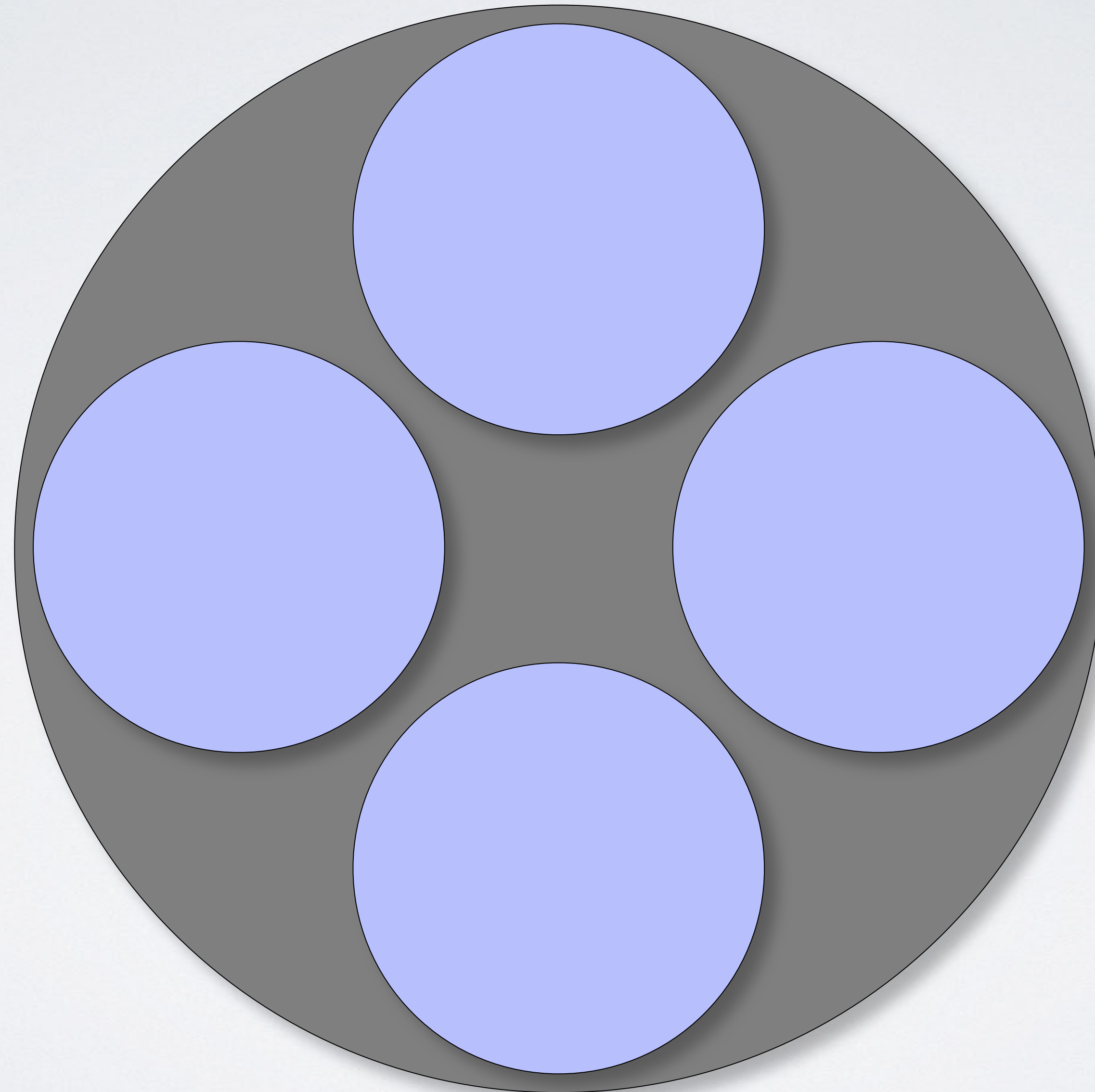
a (b (5), c (2, d (12, 4)))

x (y (w (6, 2), 3), z (9))

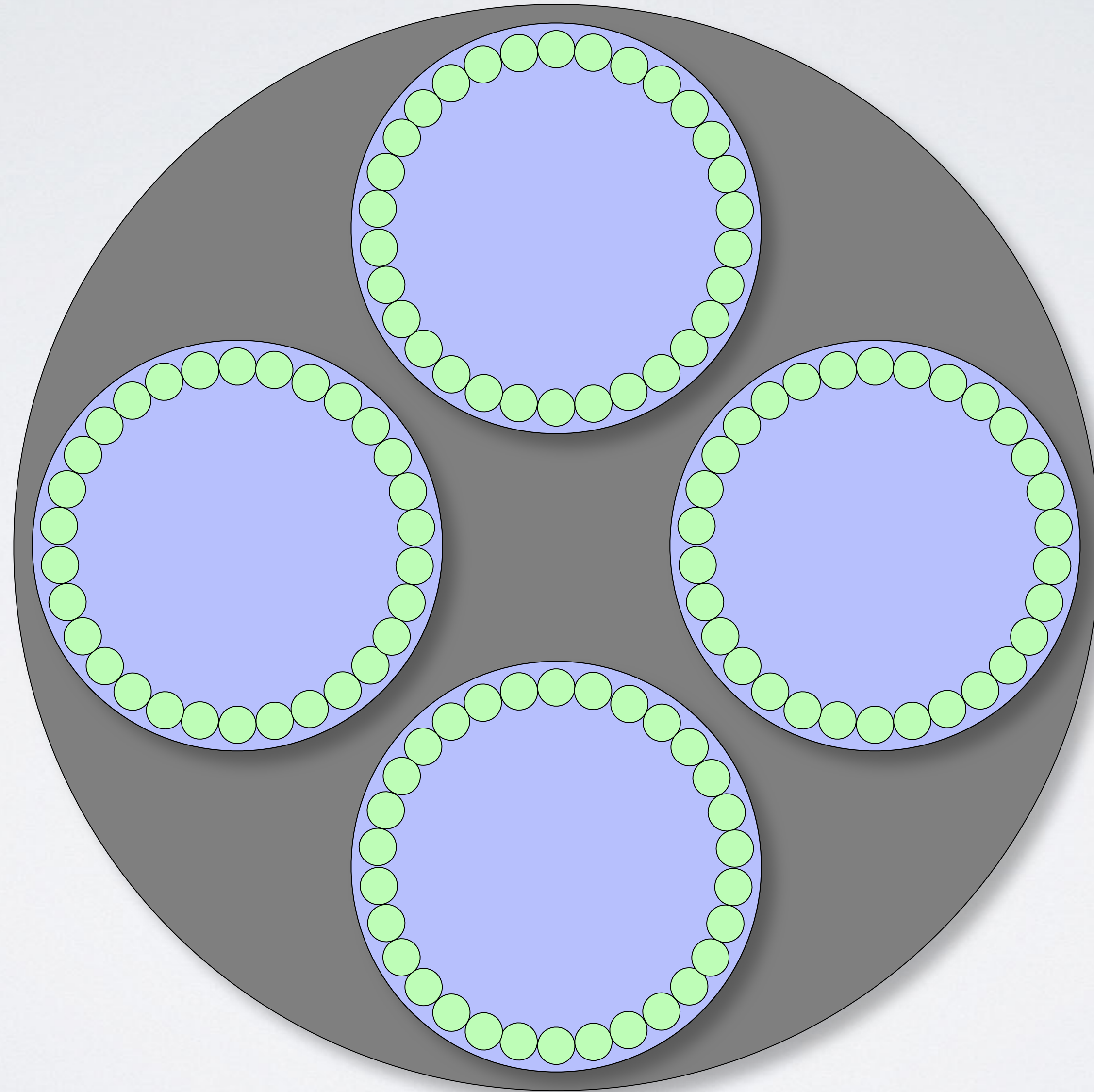
a (b (5), c (2, y (w (6, 2), 3)))



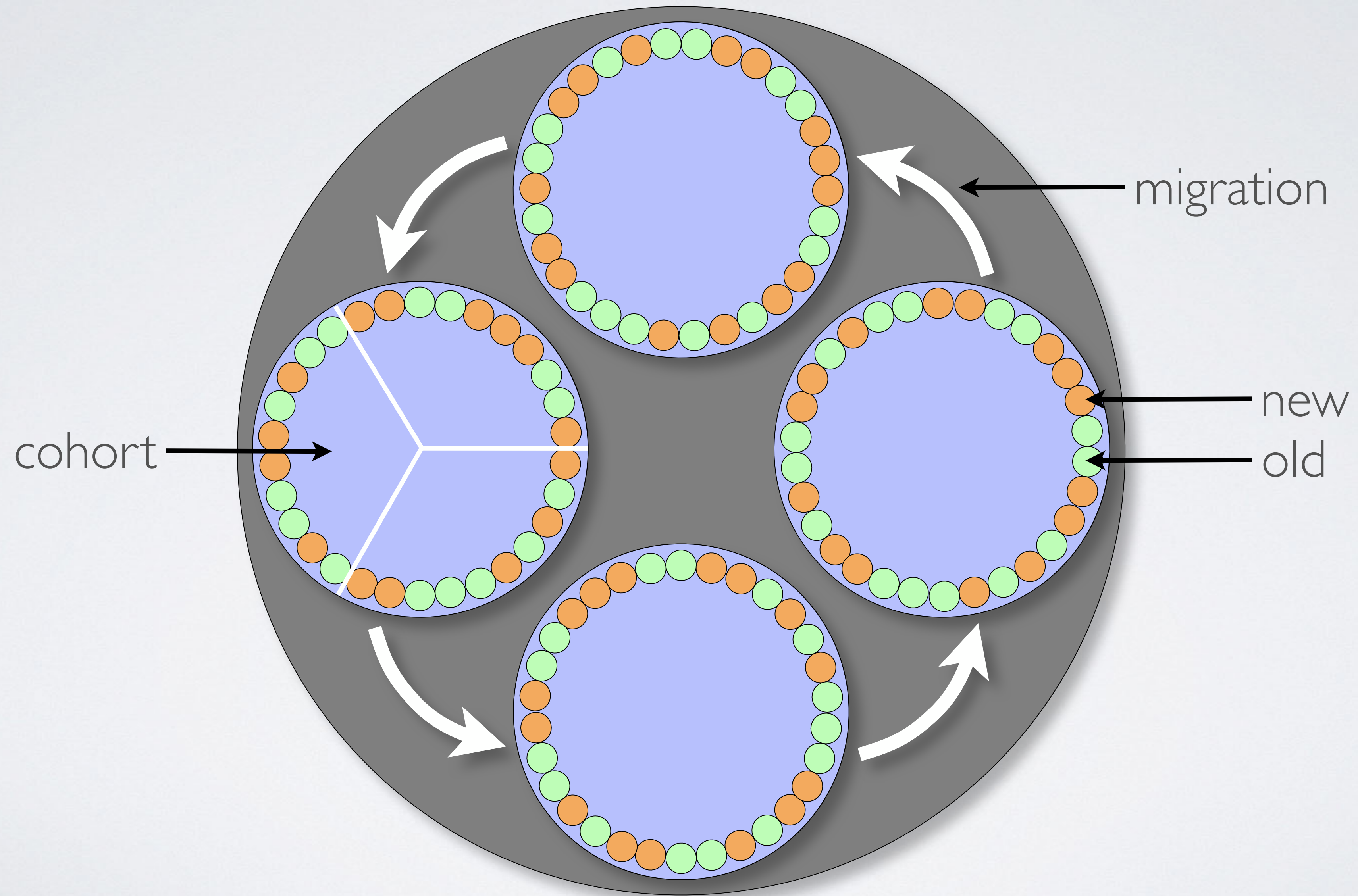
Population divided into 4 demes



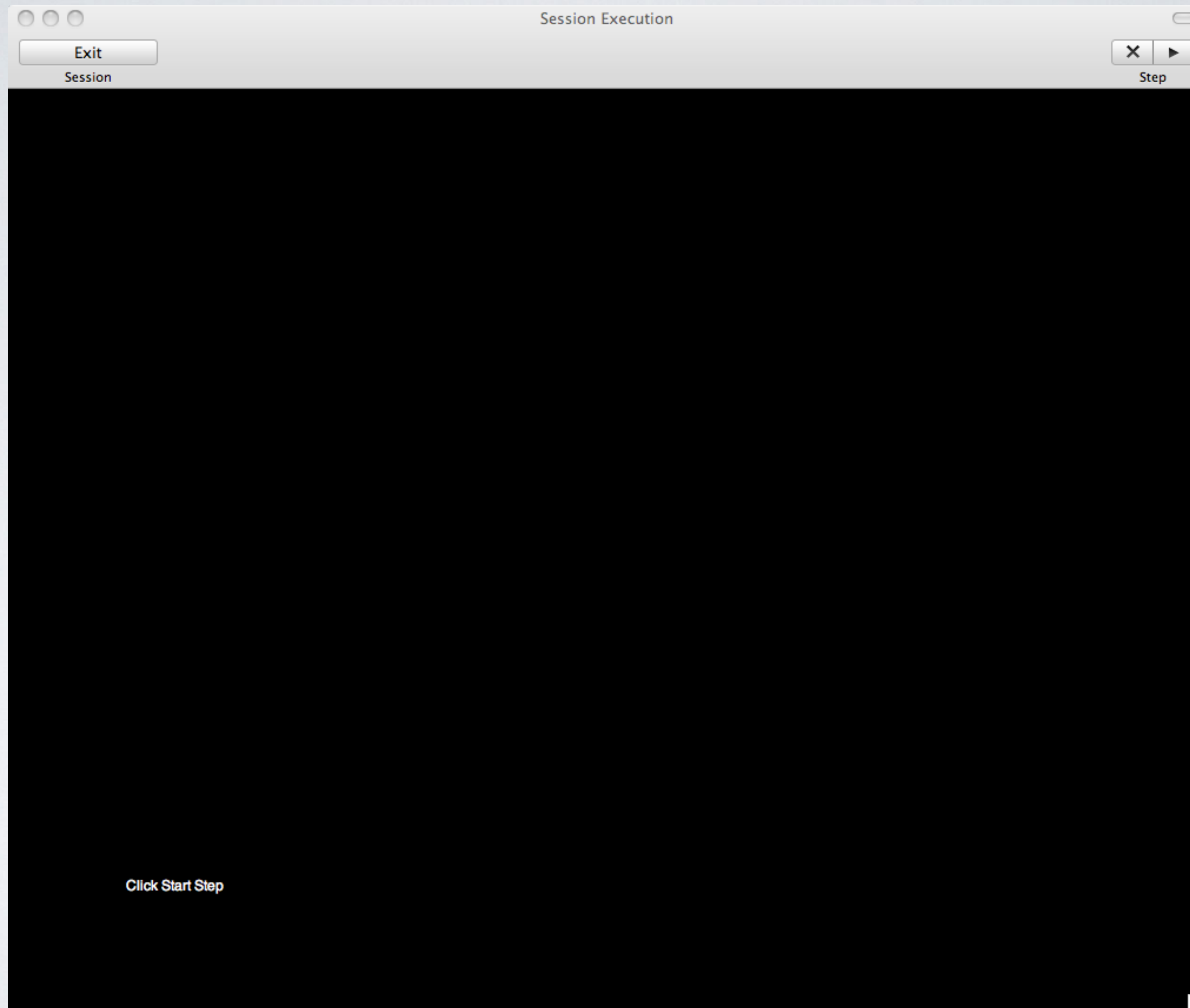
4 demes of 30 individuals



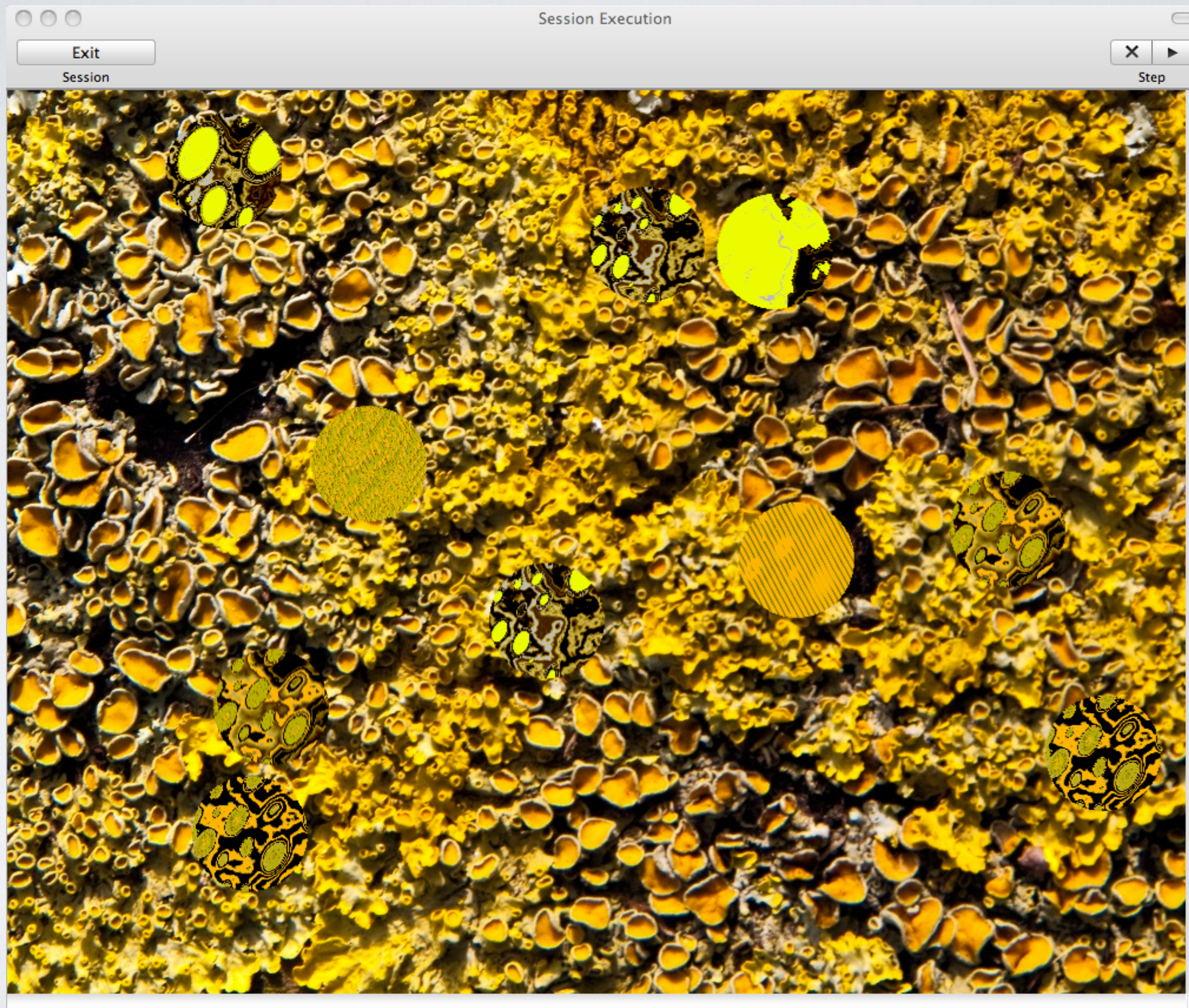
cohorts, migration, elitism



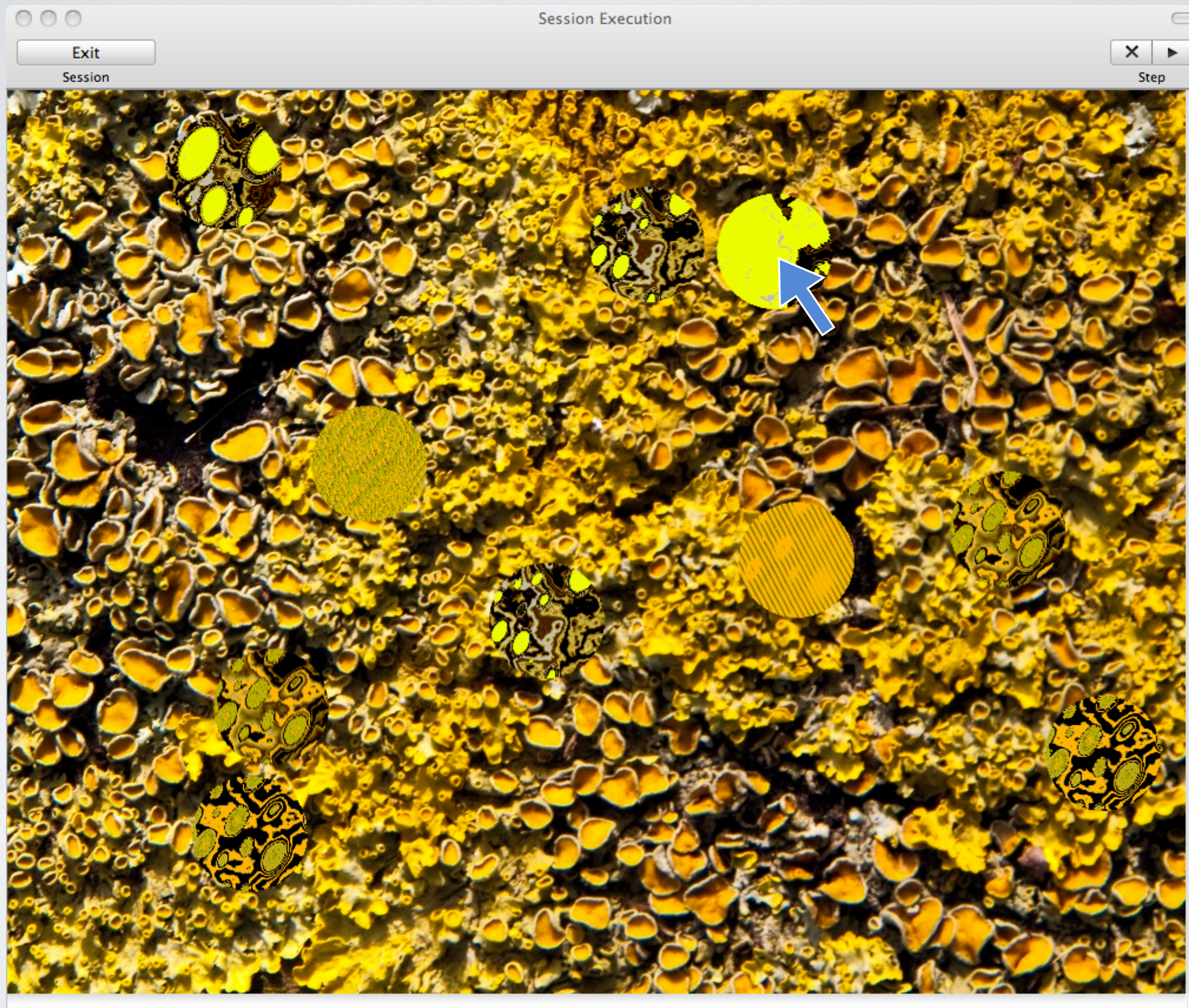
Camouflage: user interaction and GUI



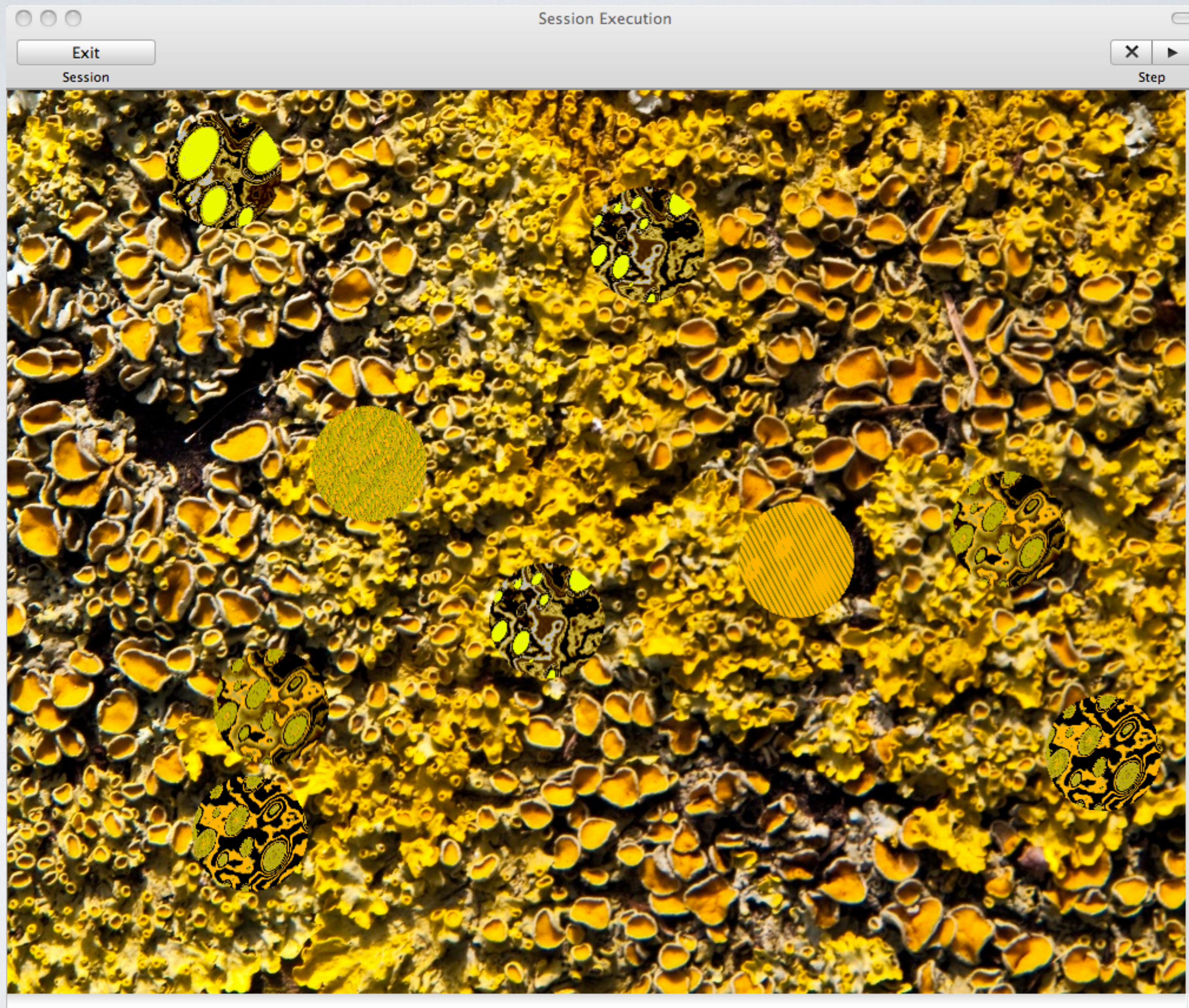
Start of
“camouflage
game” for one
cohort of 10
evolved prey.



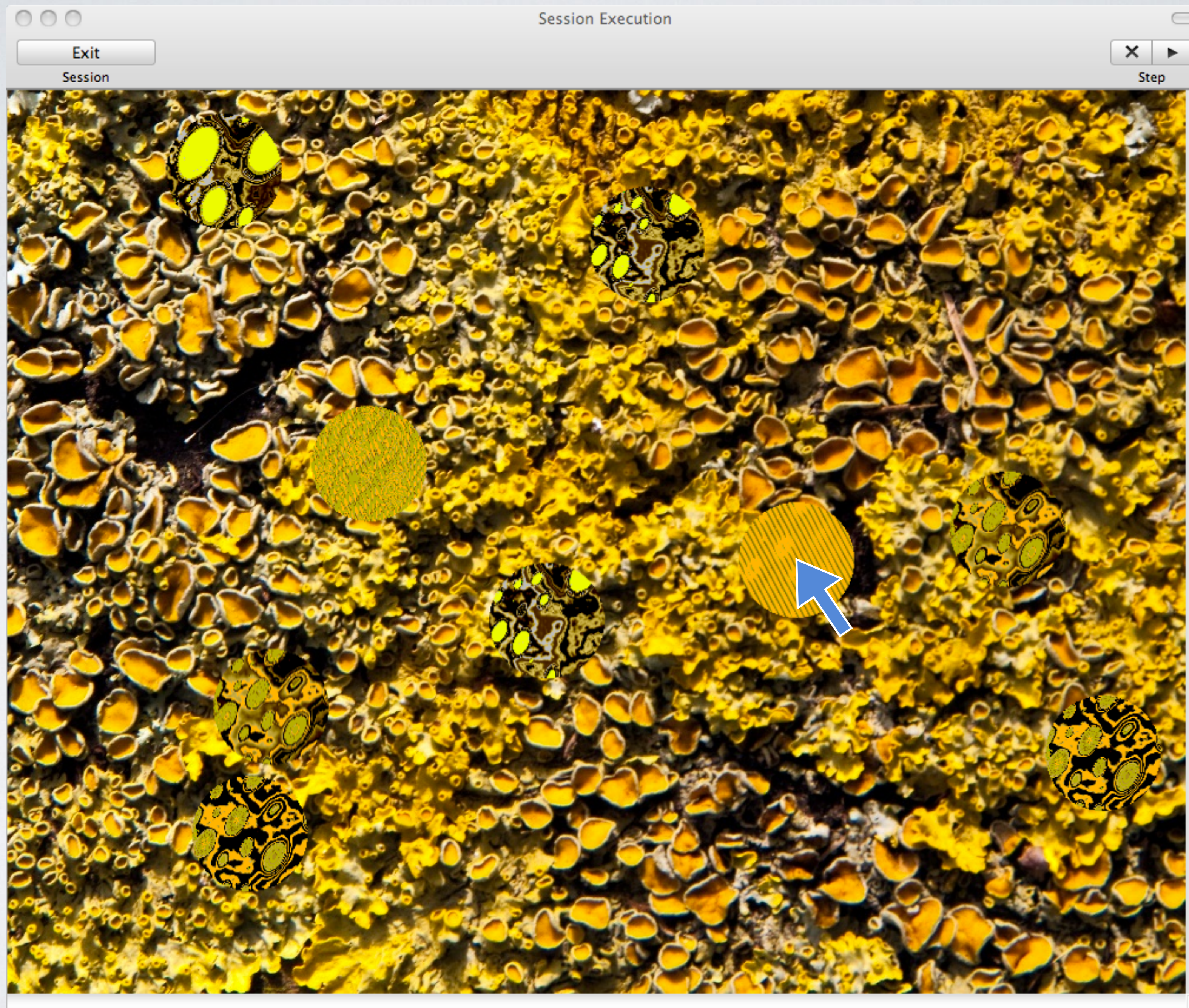
10 prey



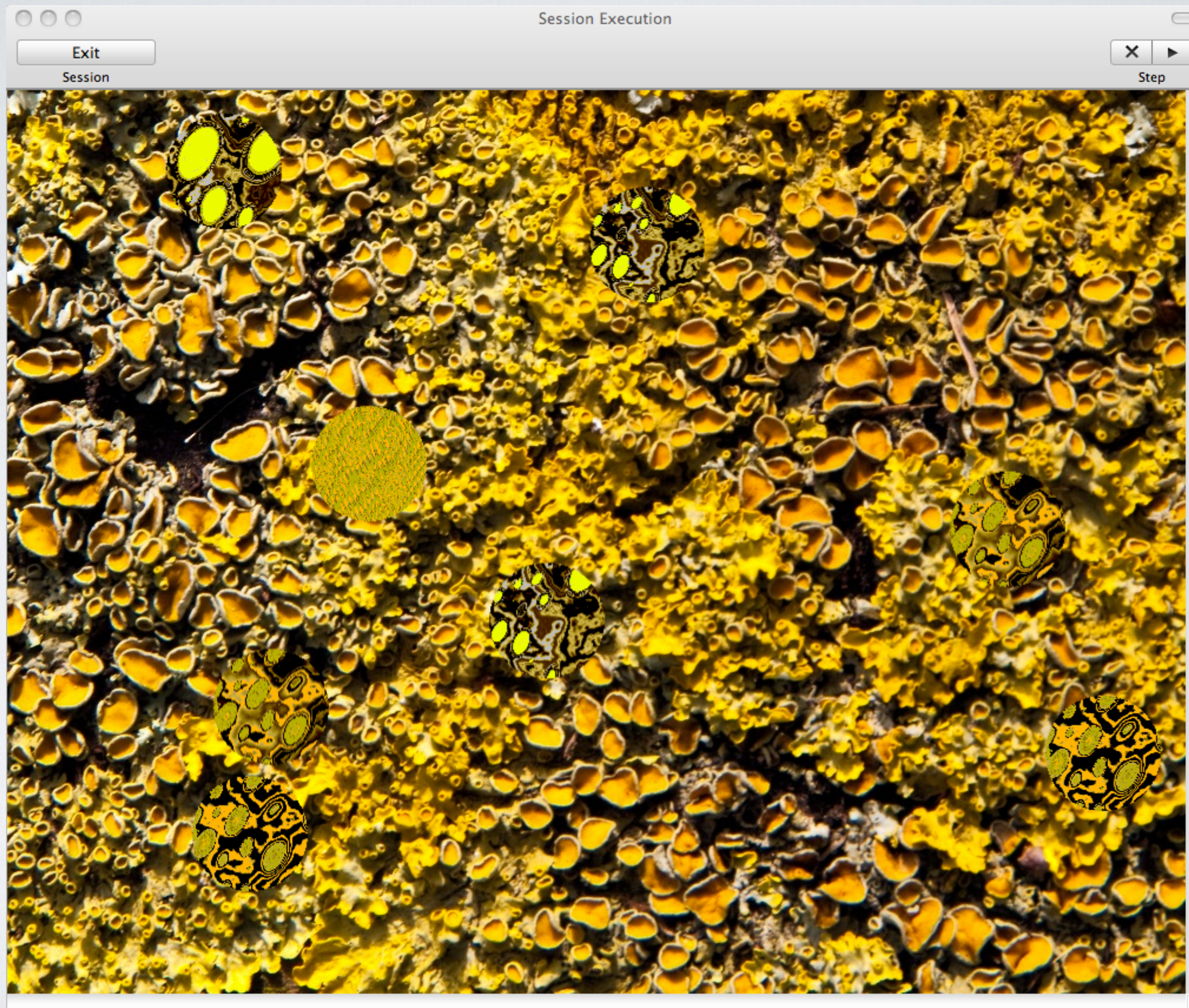
Predator
selects prey 1.



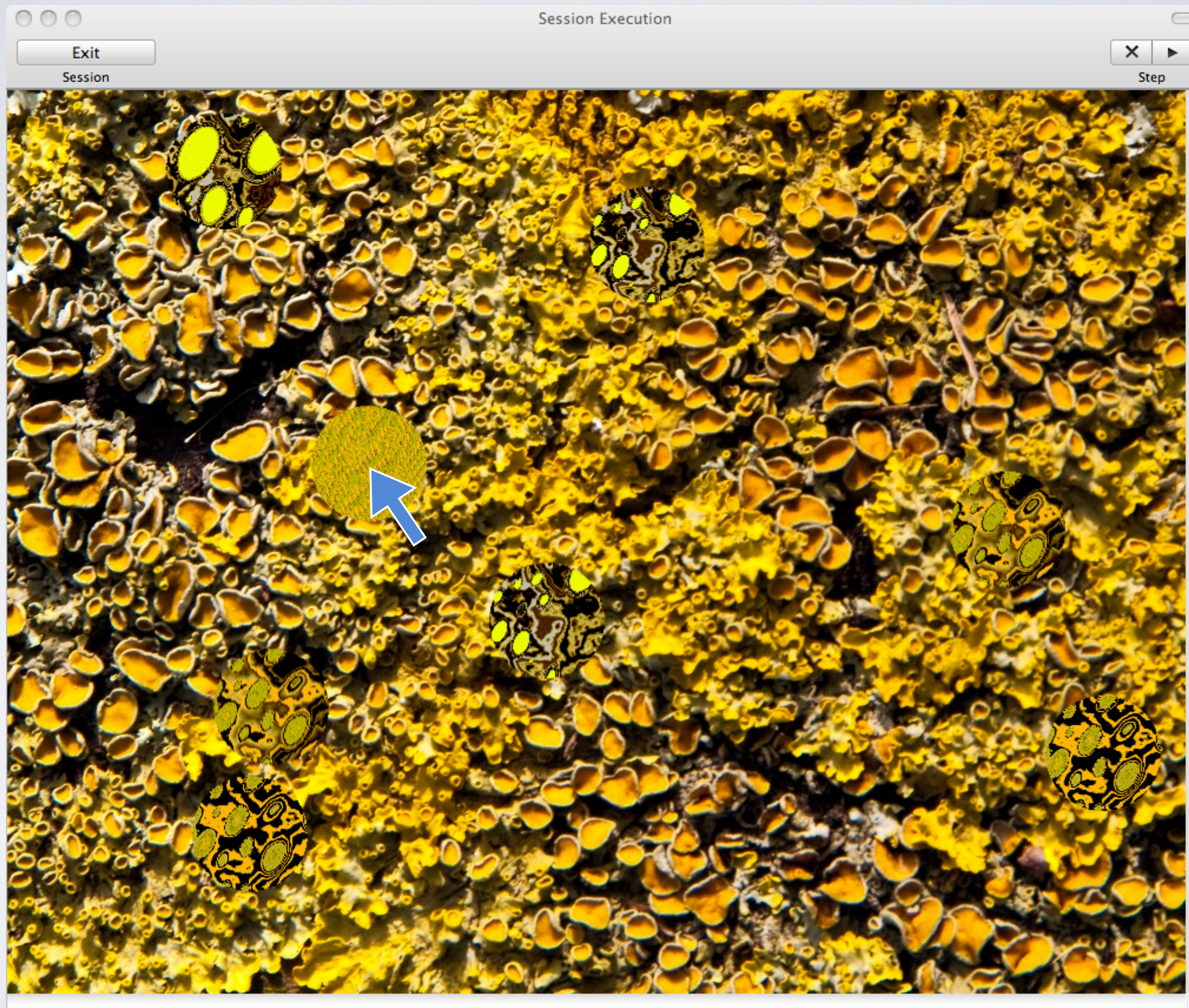
9 prey remain.



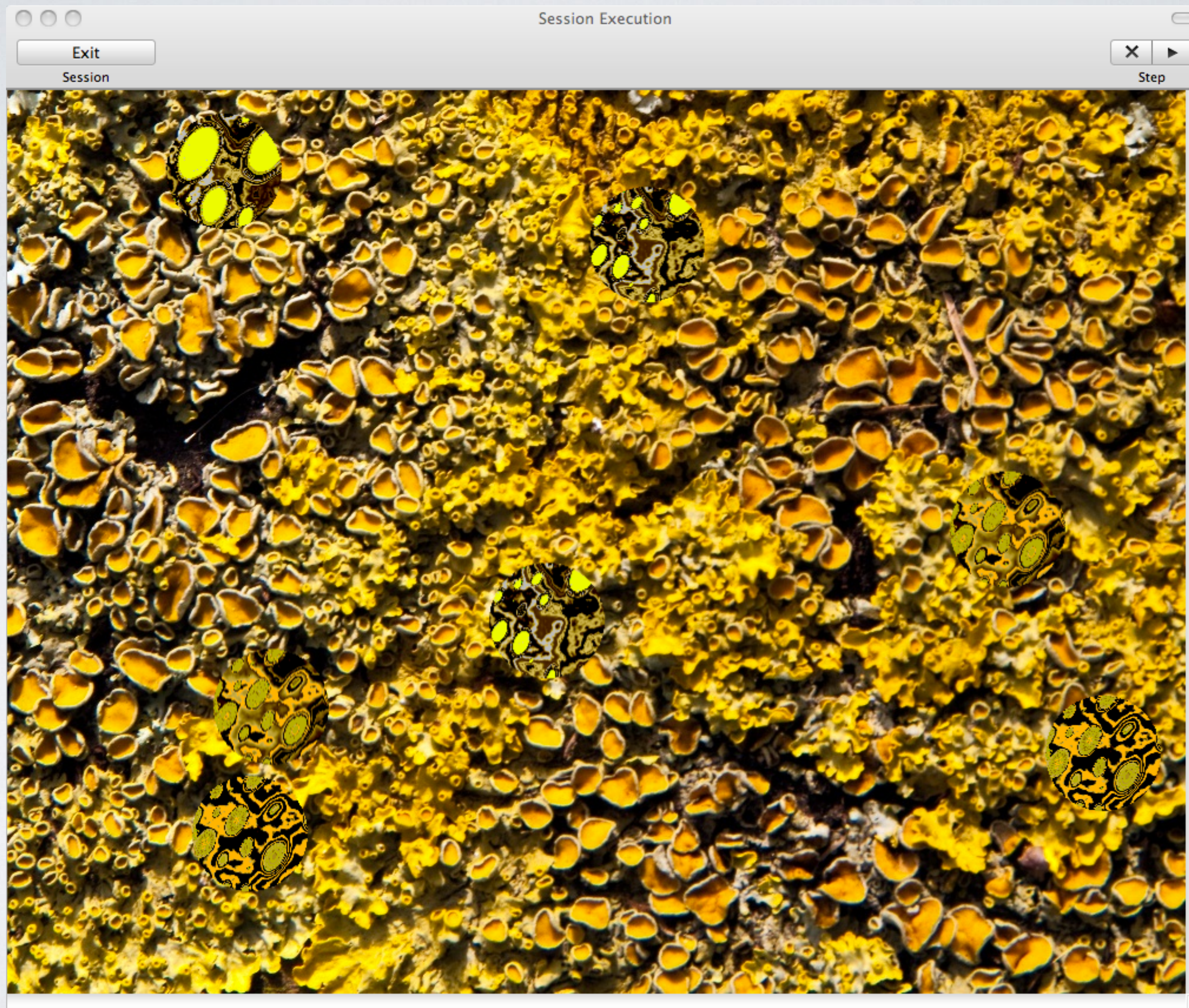
Predator
selects prey 2.



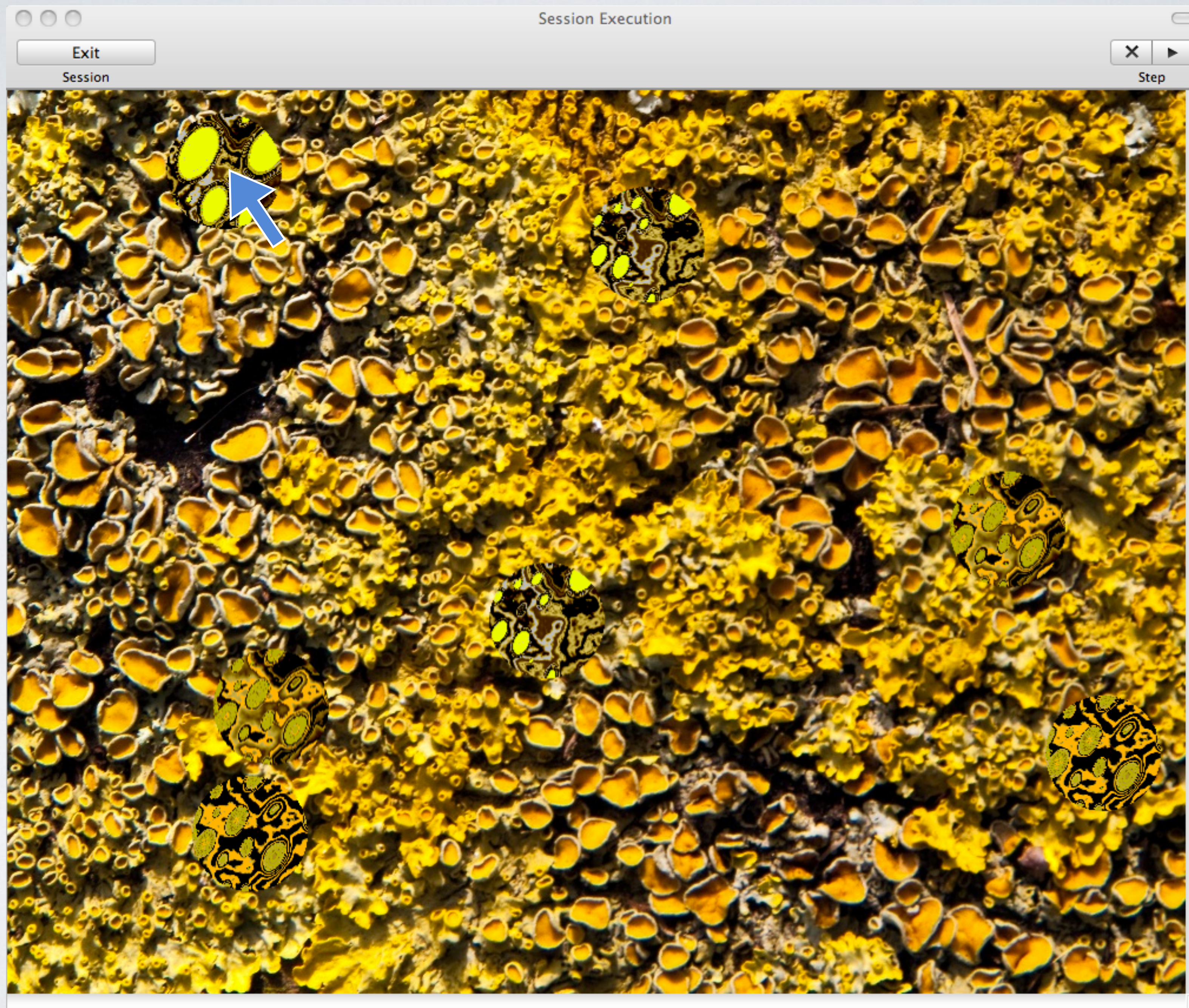
8 prey remain.



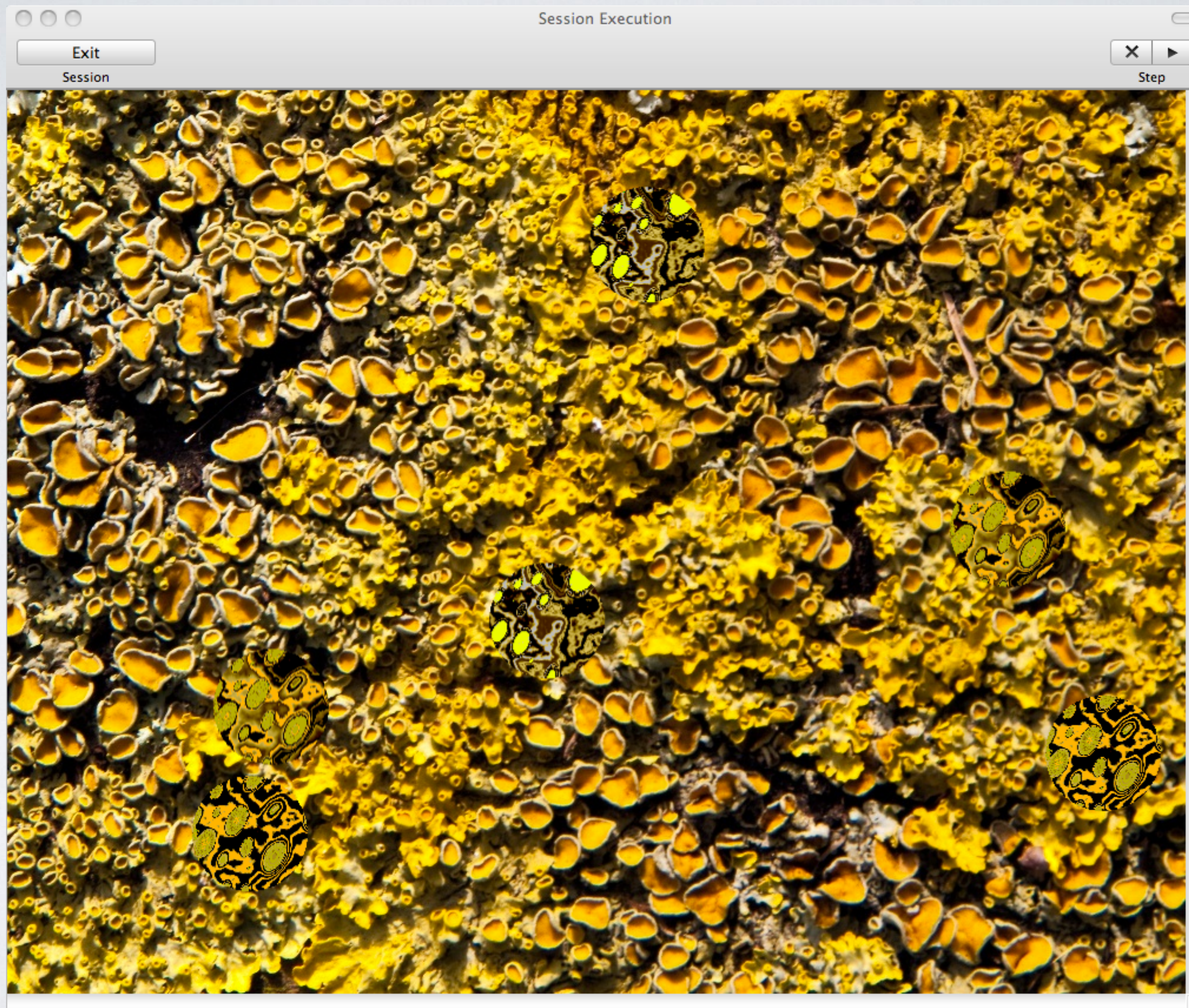
Predator
selects prey 3.



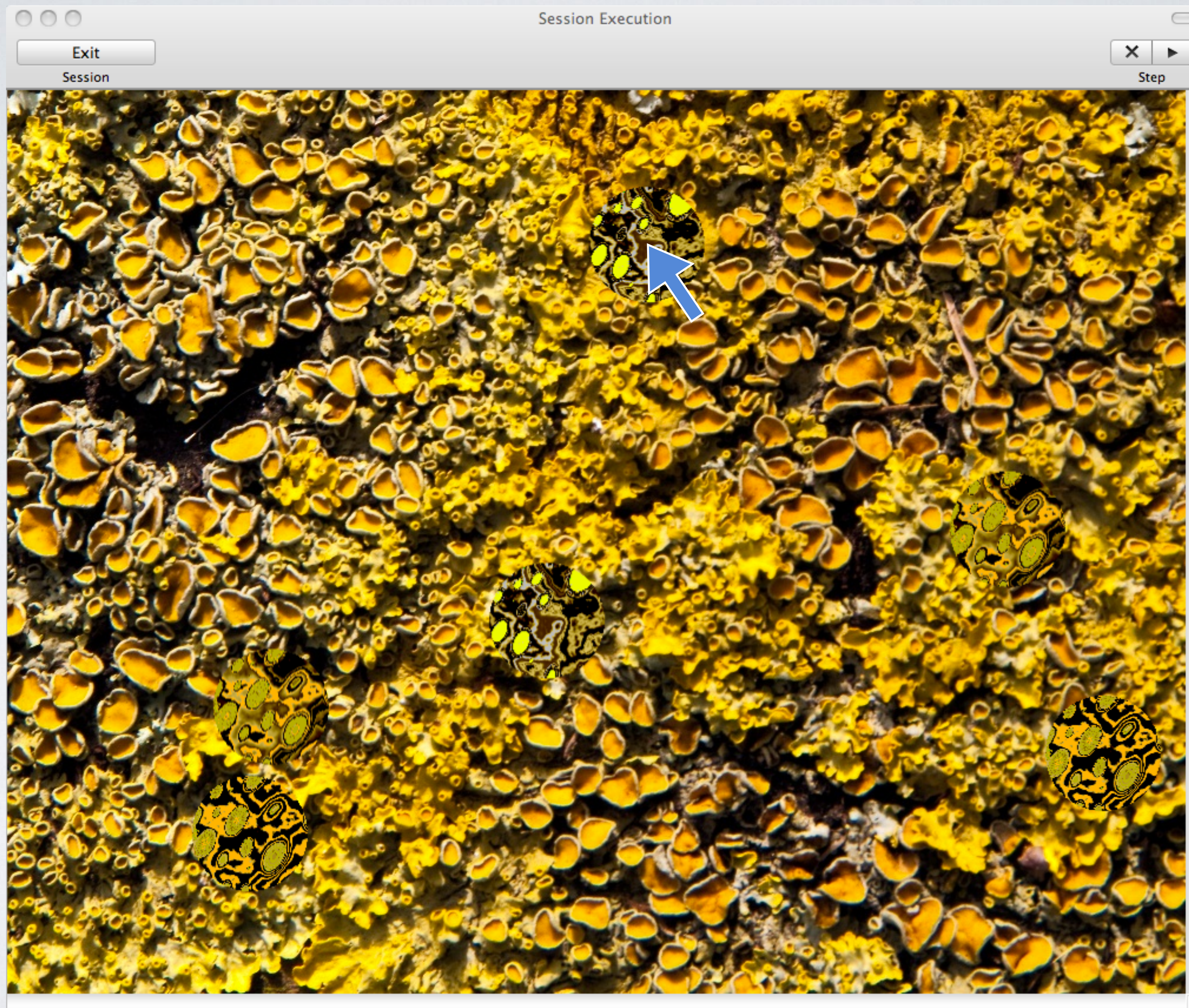
7 prey remain.



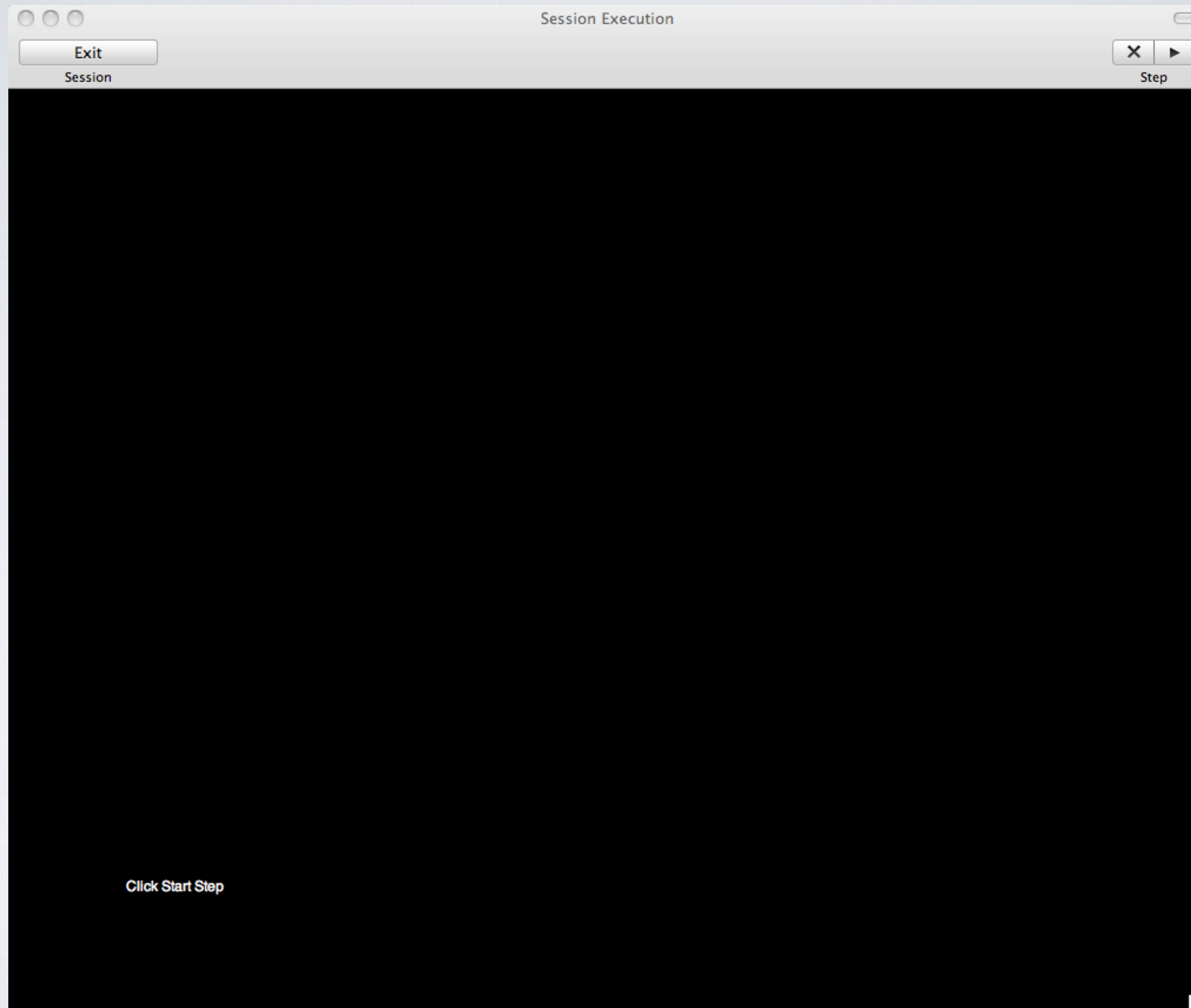
Predator
selects prey 4.



6 prey remain.



Predator
selects prey 5.



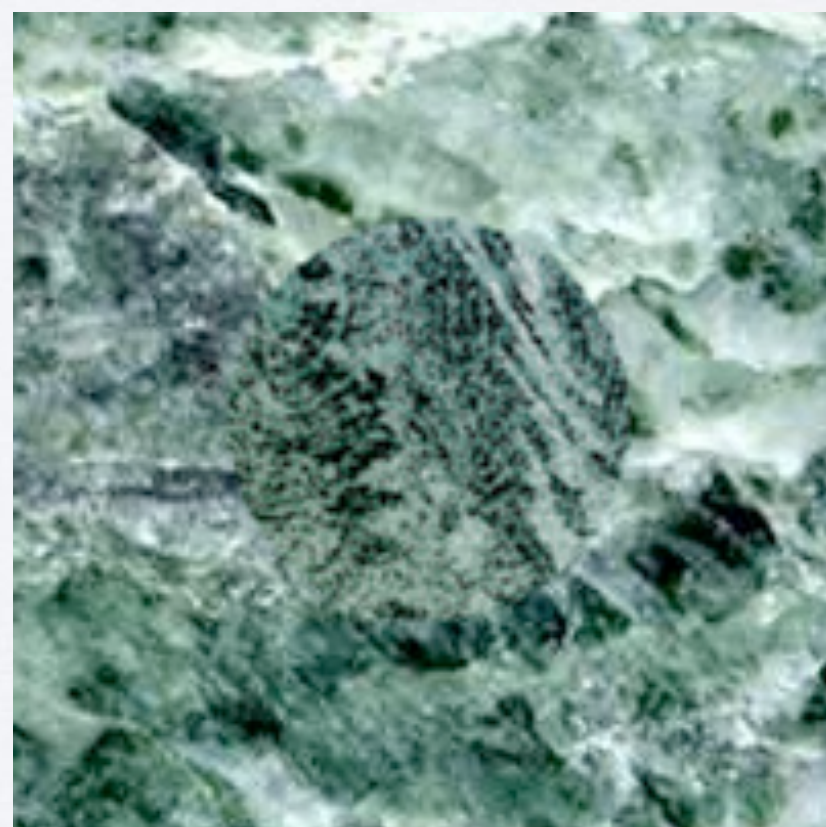
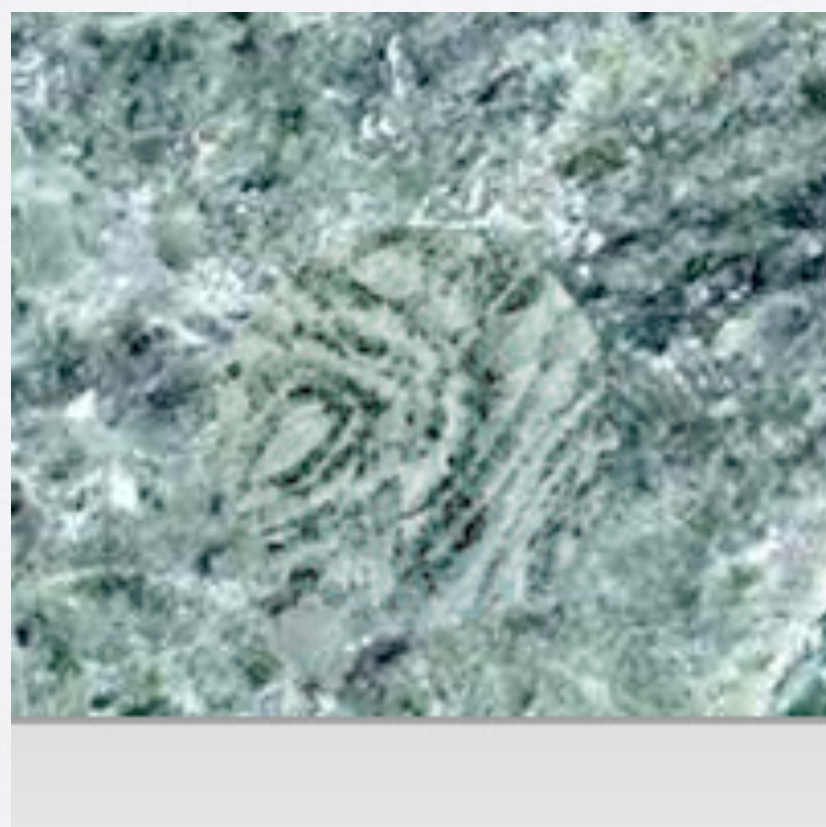
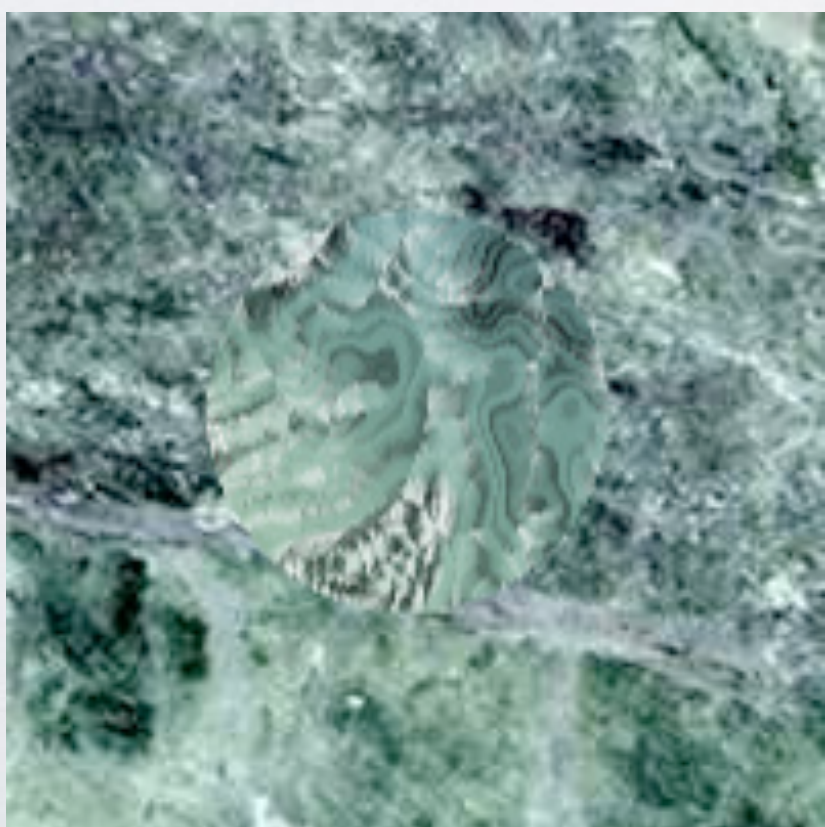
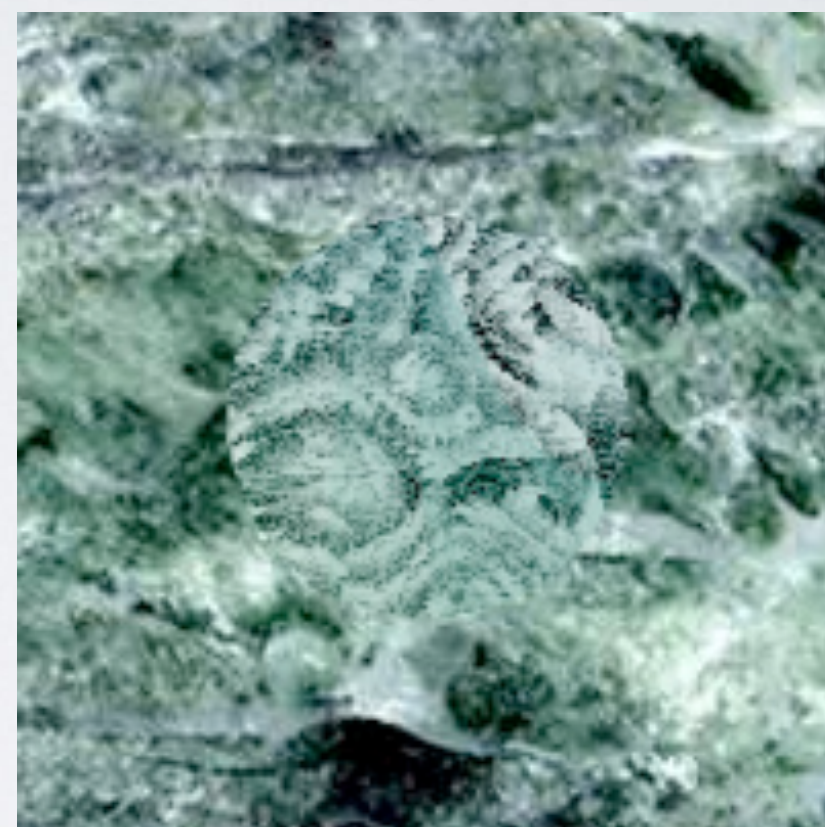
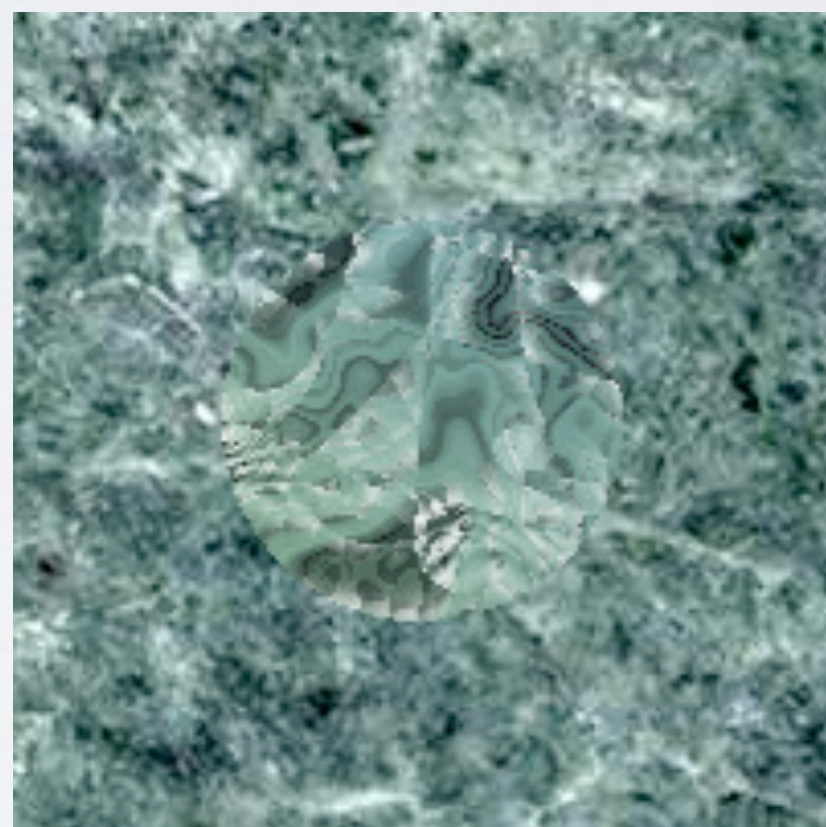
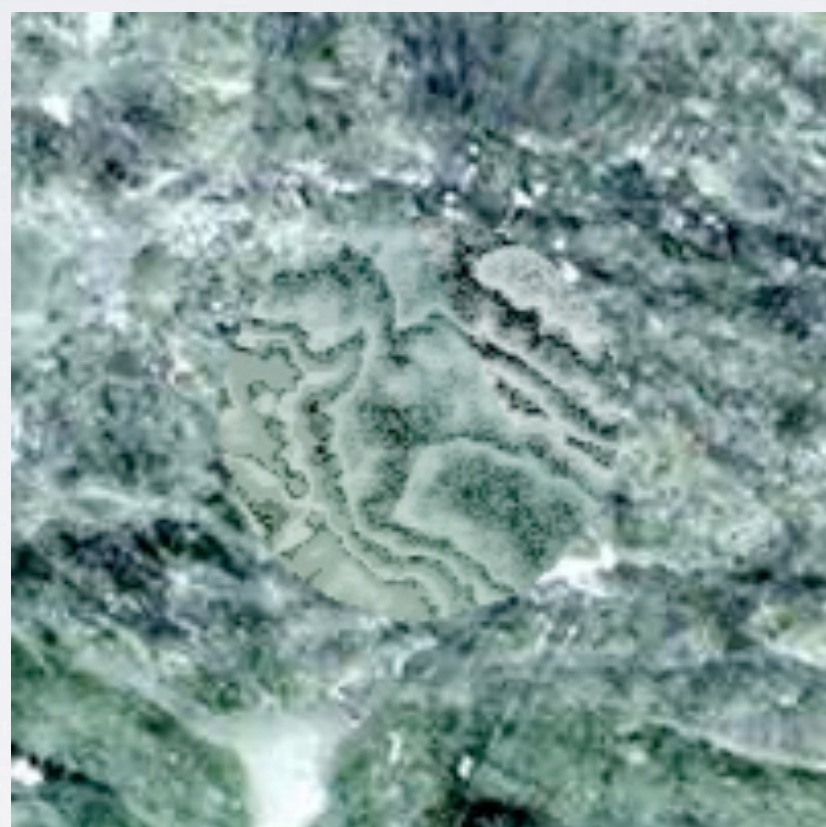
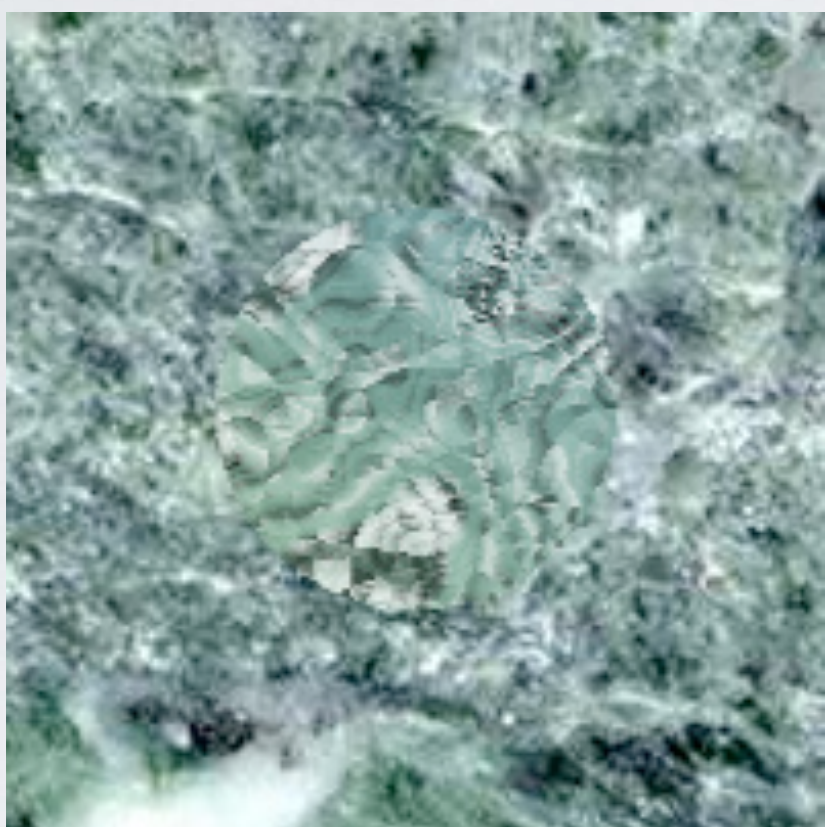
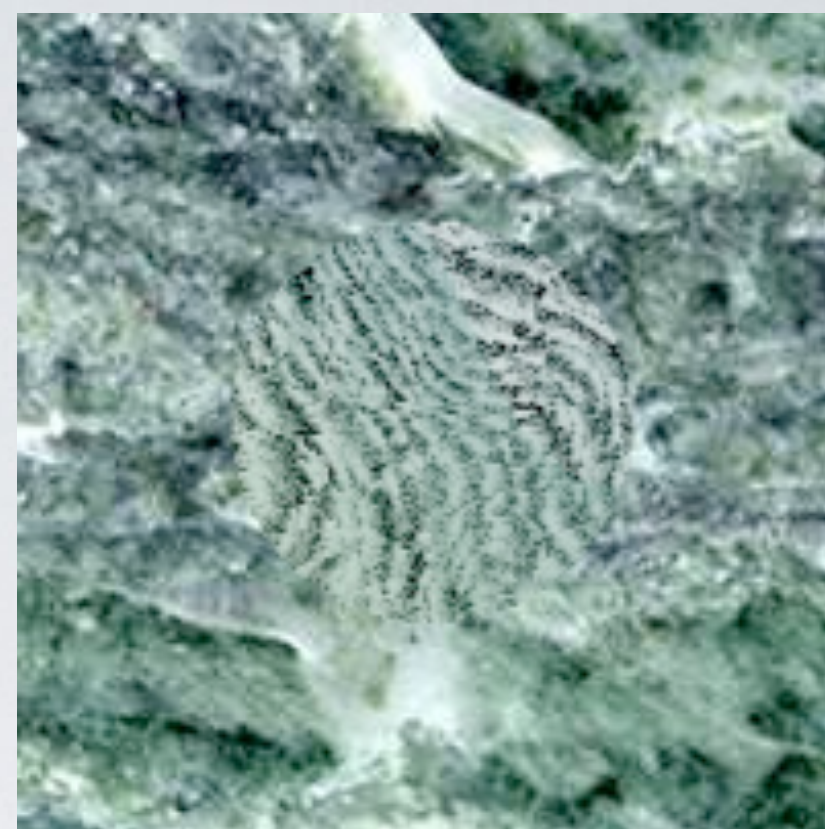
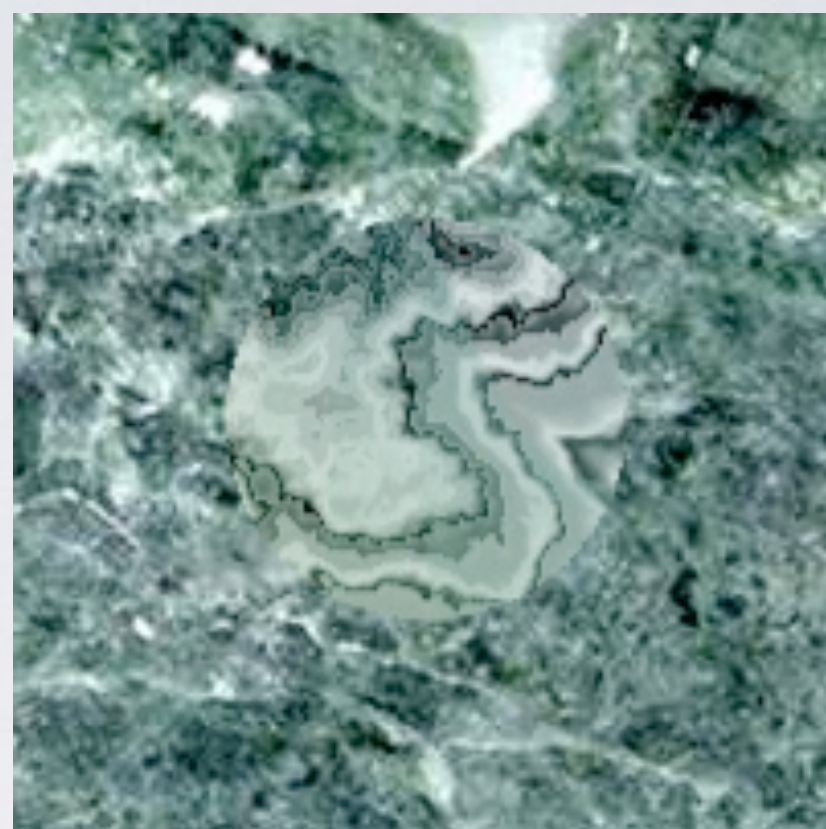
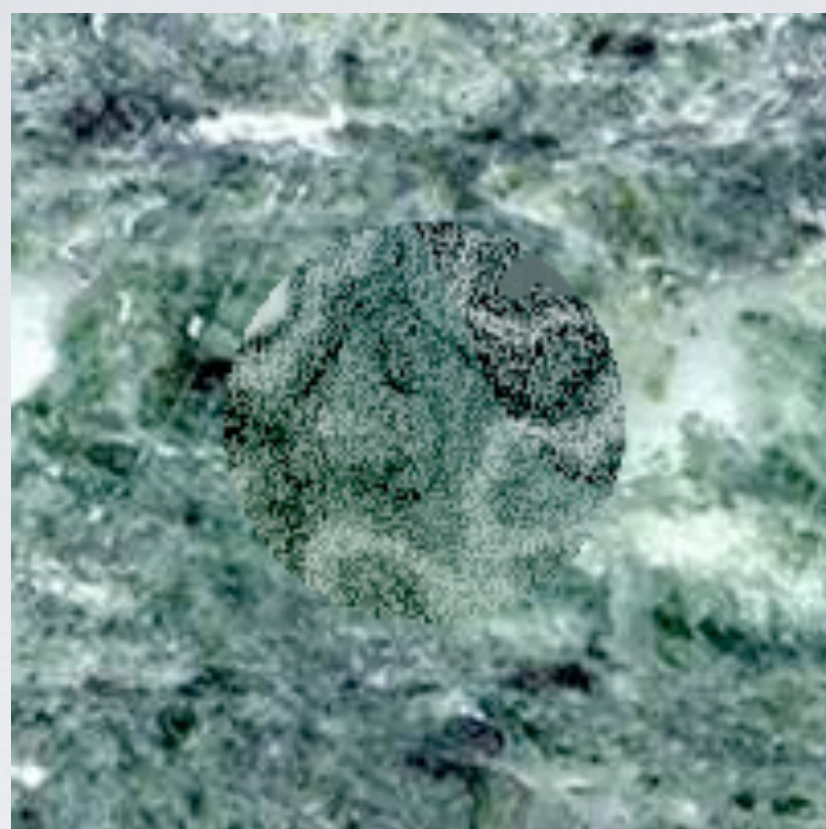
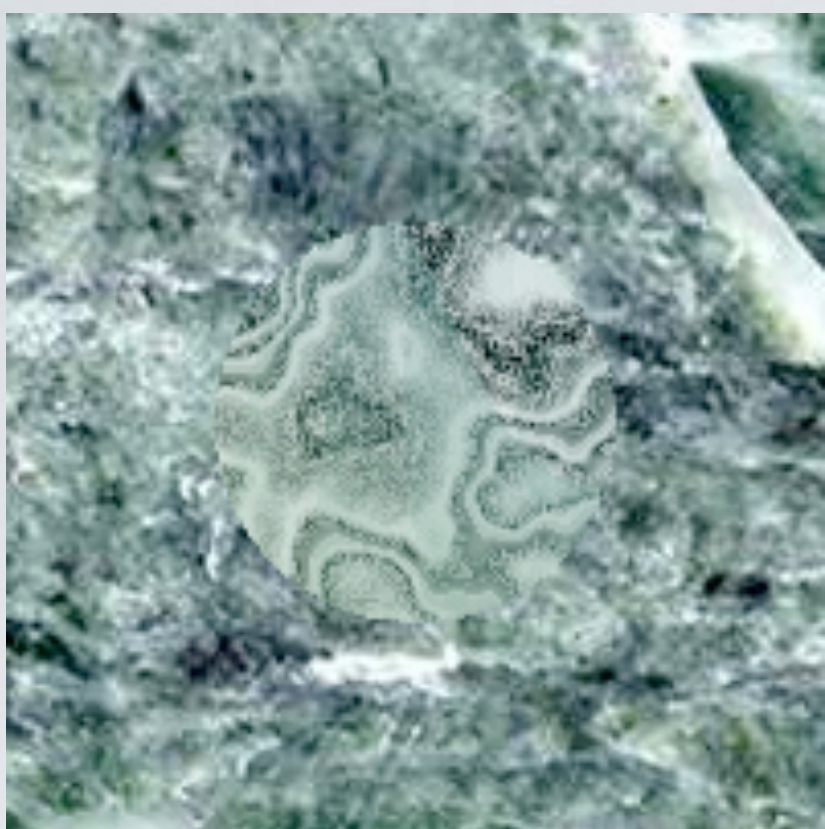
End of
“camouflage
game” for one
cohort of 10
evolved prey.
5 prey have
been eaten,
and 5 survive.

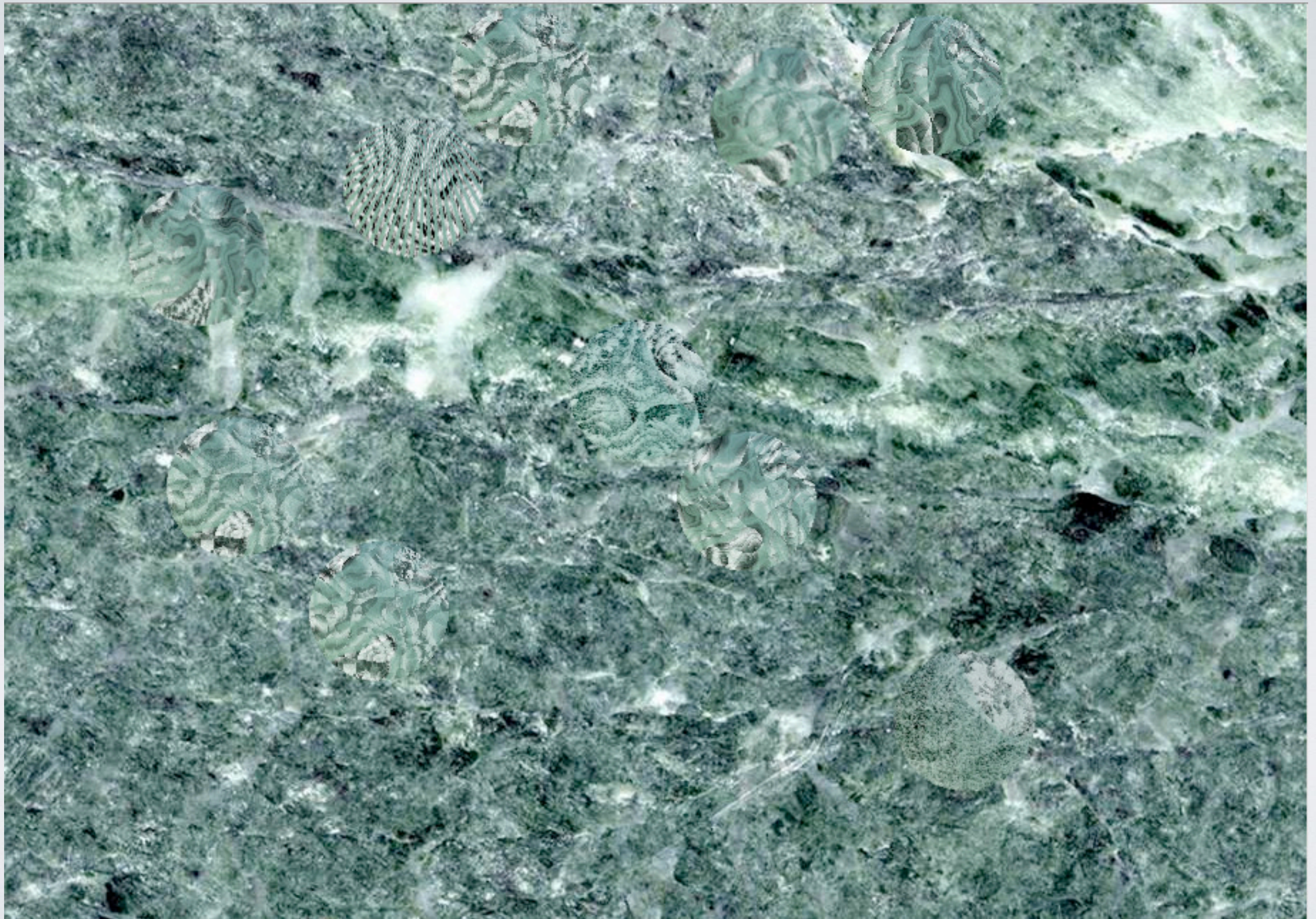
TYPICAL RUN

- 1000 cohorts—sometimes 2000 or more
- 10,000 individuals fitness tested
- 83 “generations” in traditional GA/GP (pop=120)
- **5000** mouse clicks by human predator
- 3 hours of steady work—spread over several days

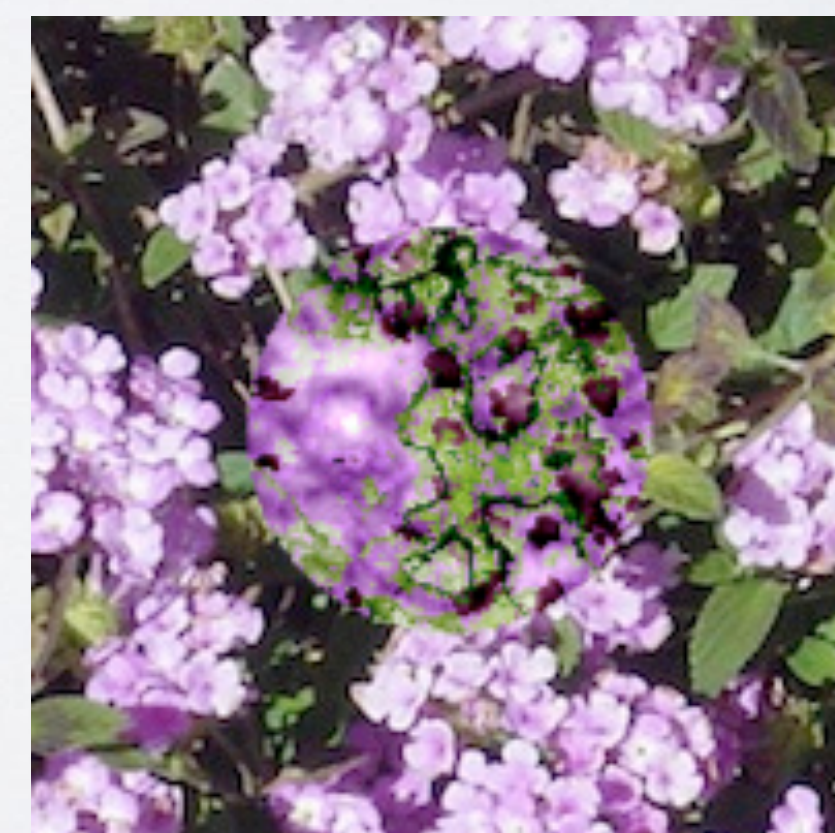
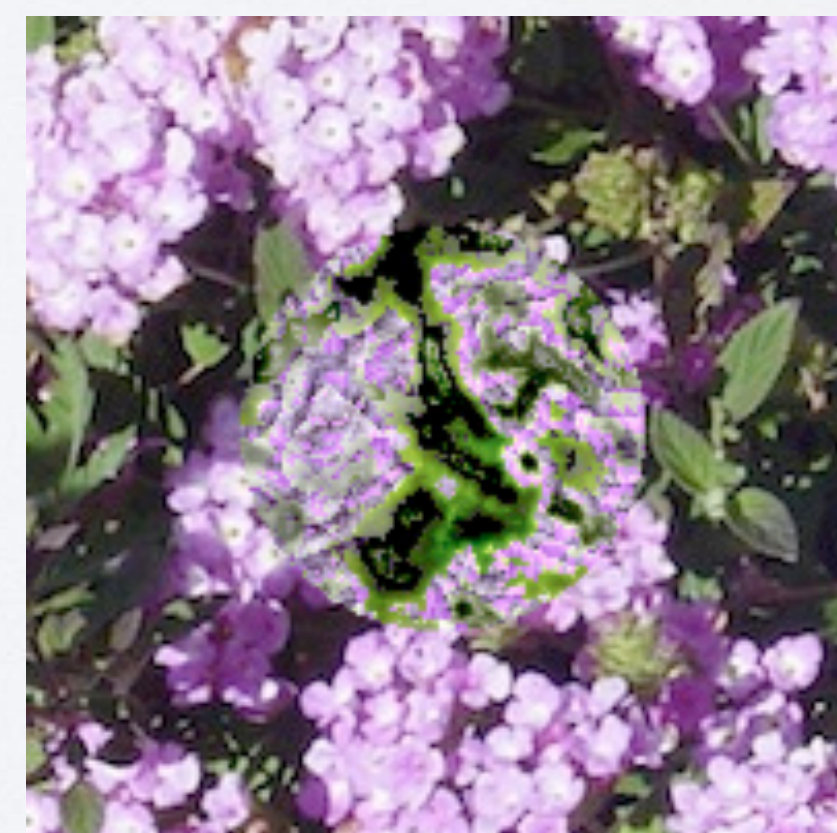
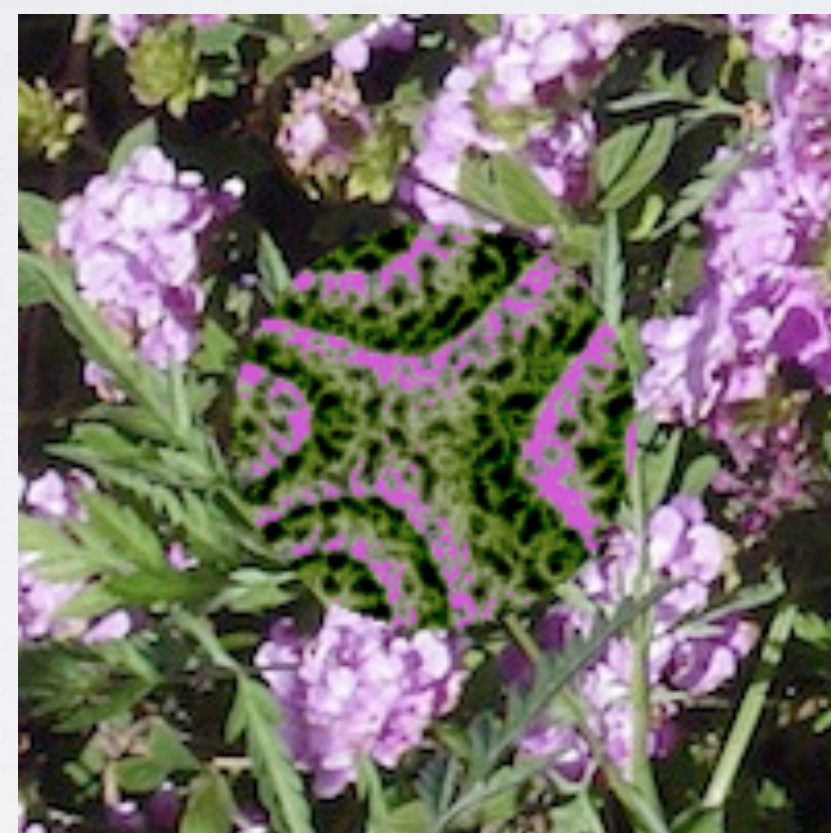
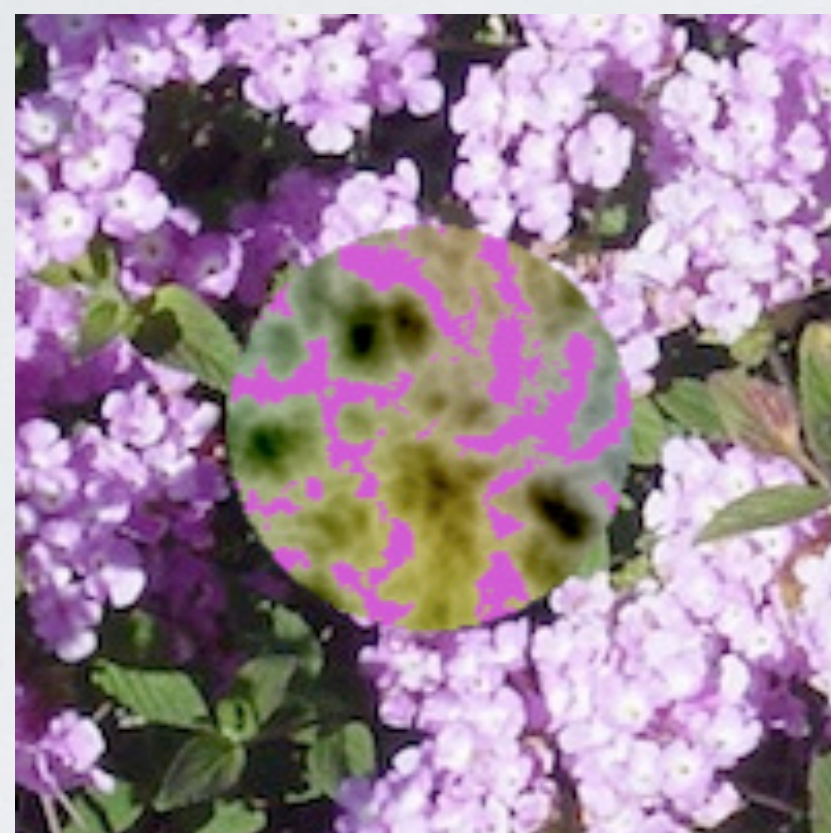
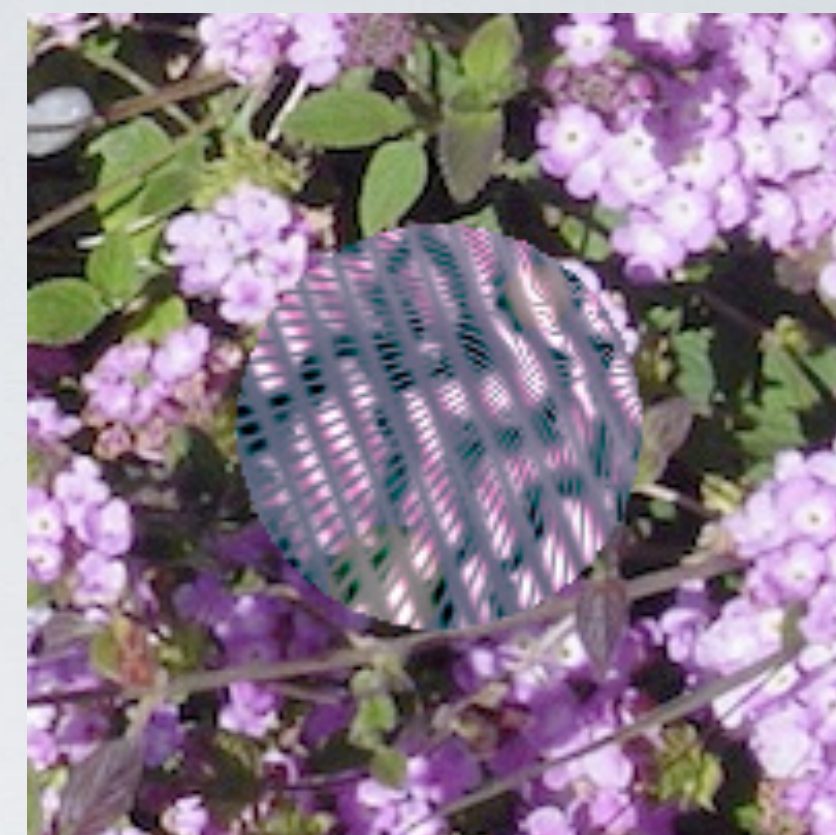
Camouflage: results

Serpentine
(polished stone)



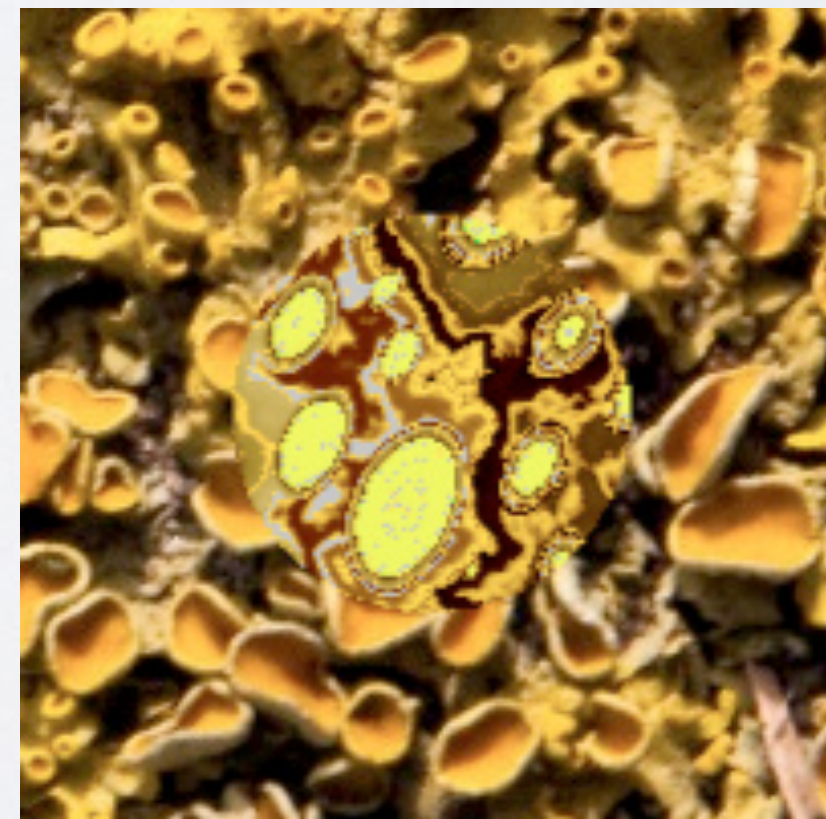
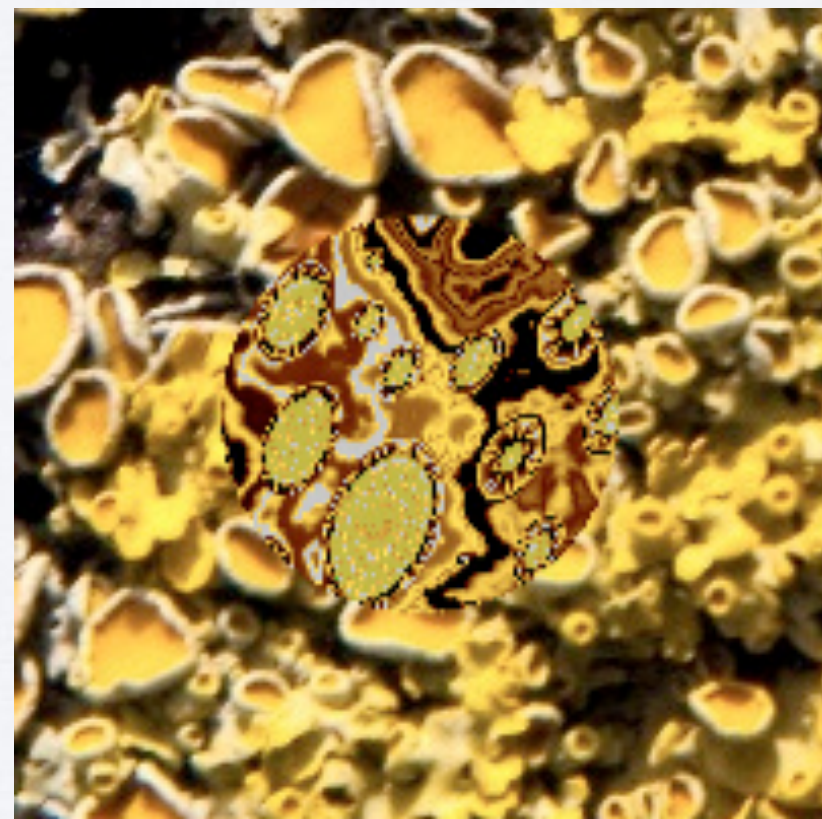
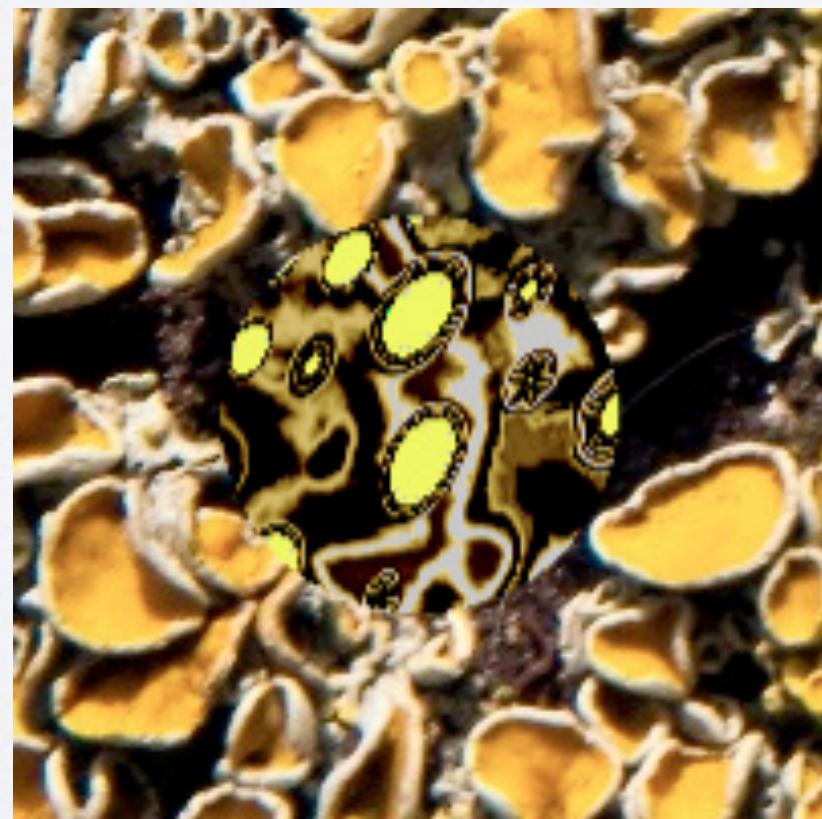
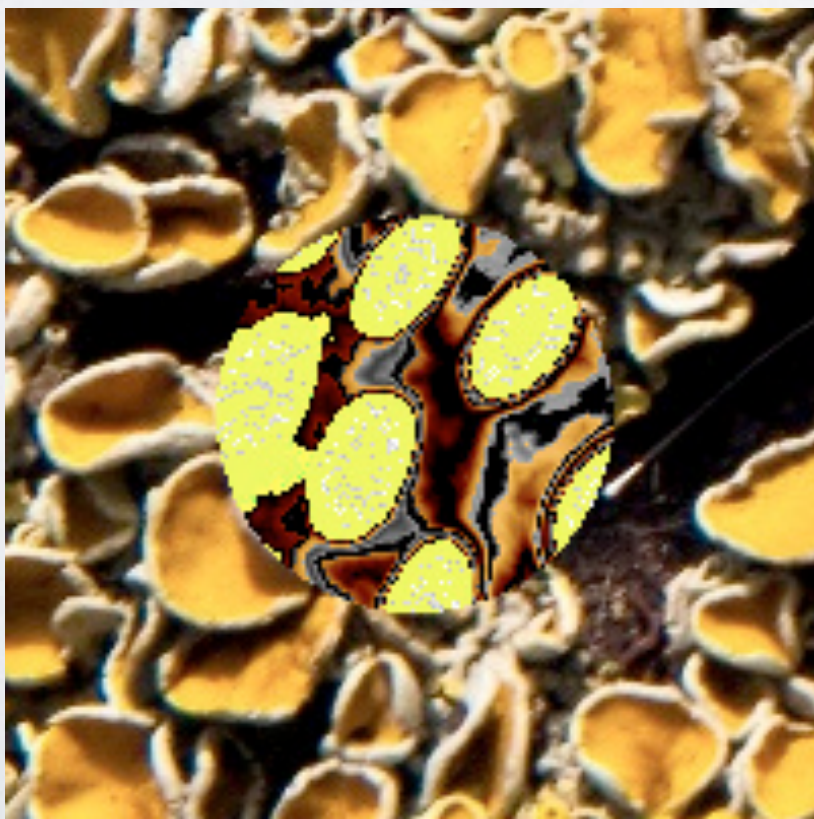
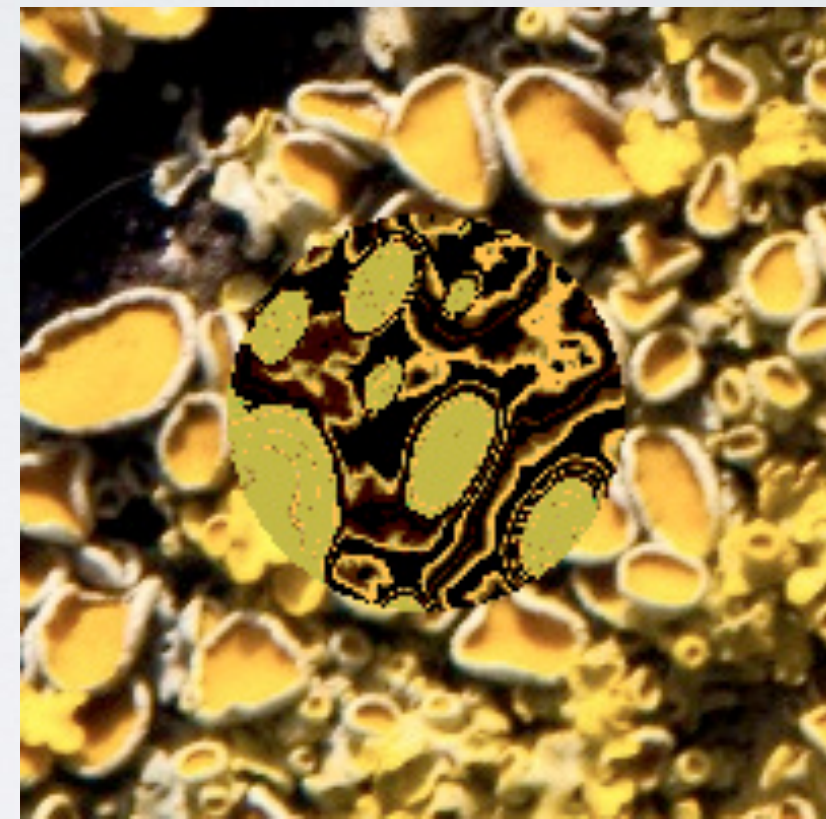
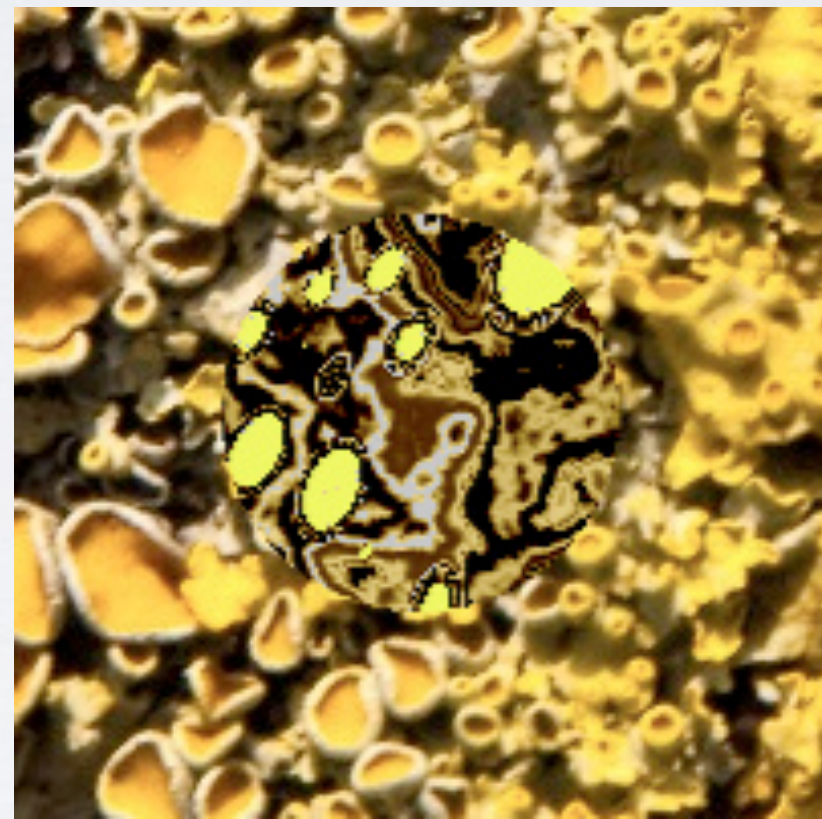
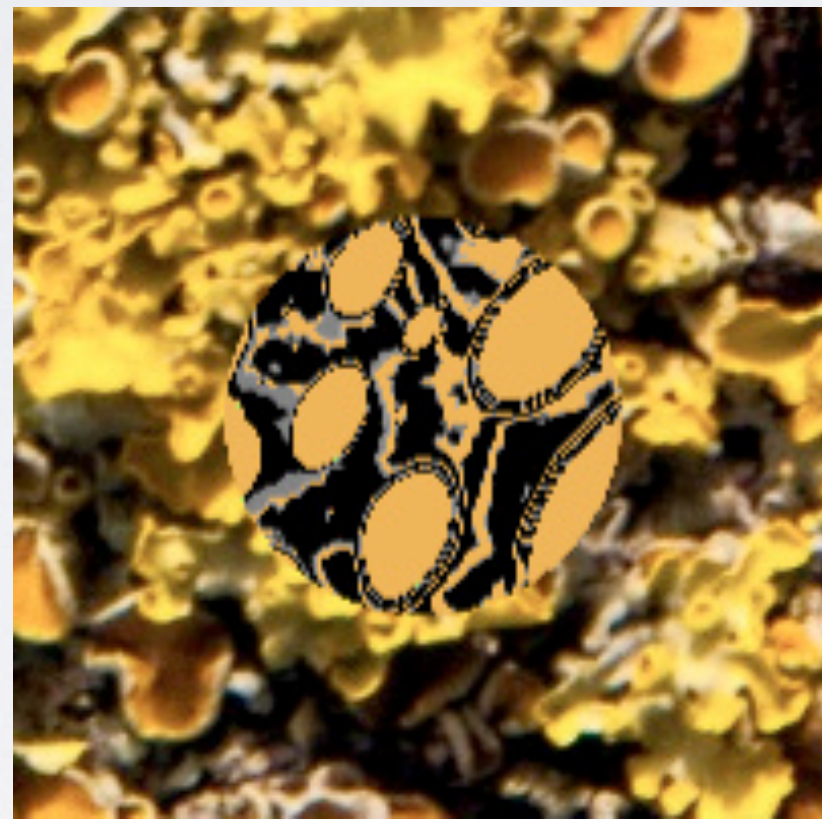
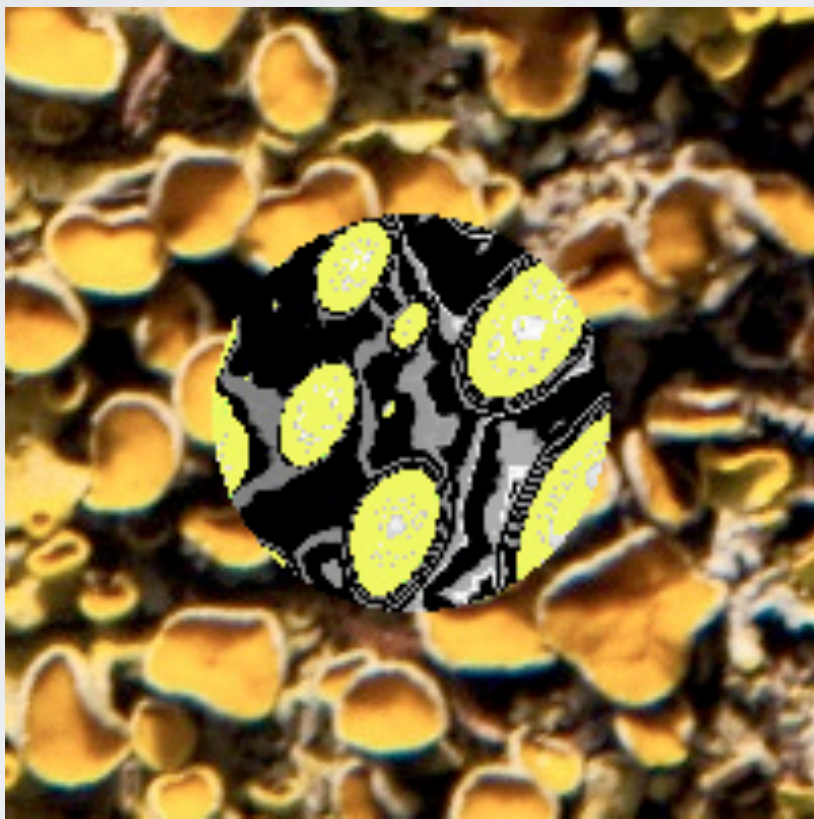
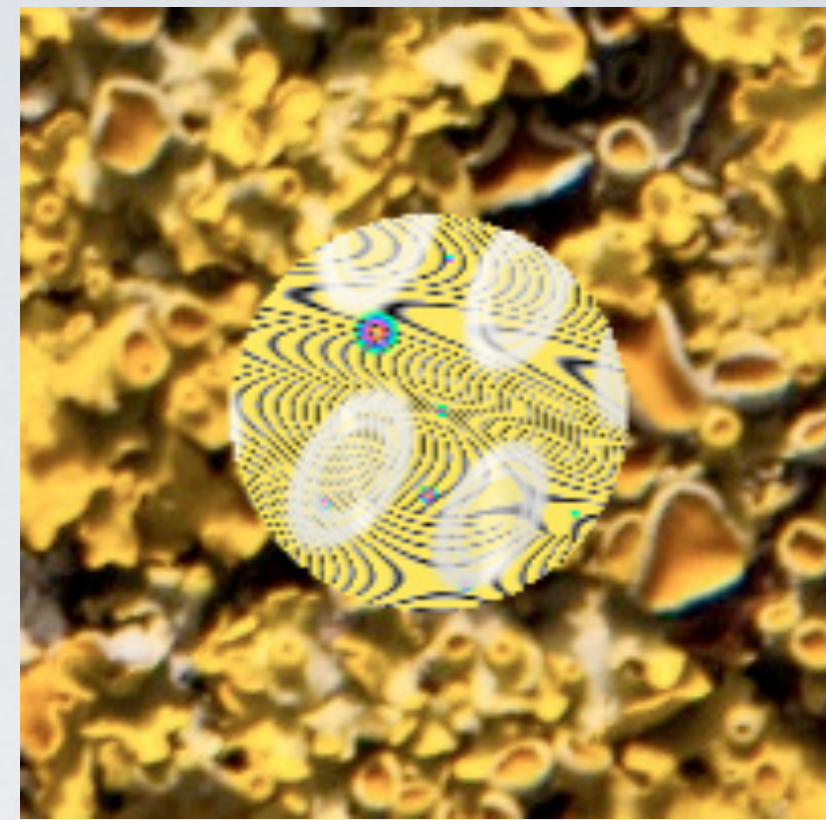
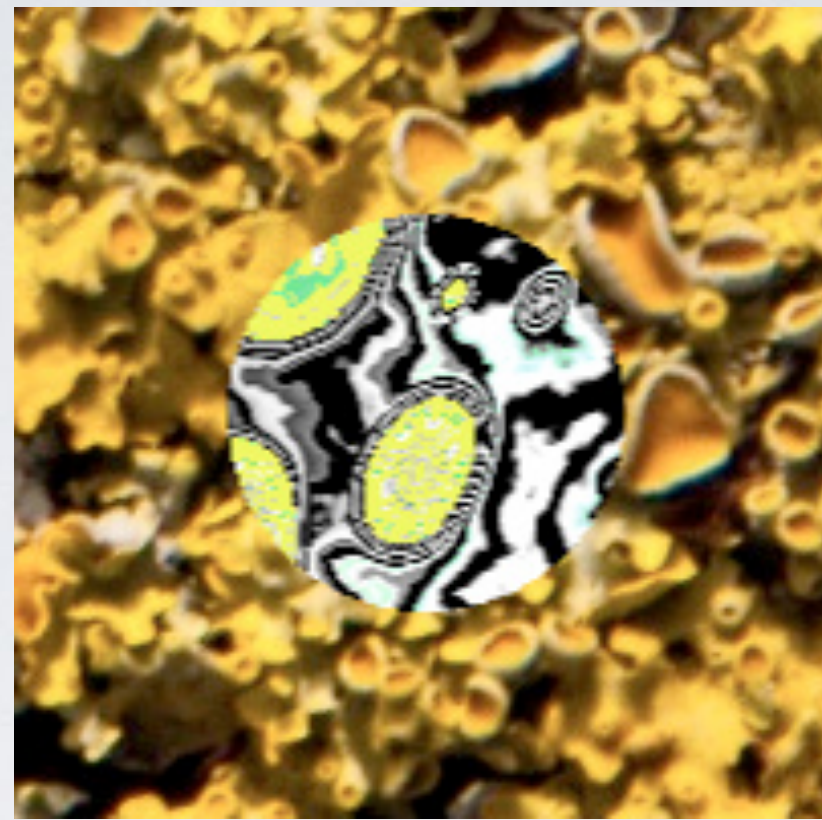
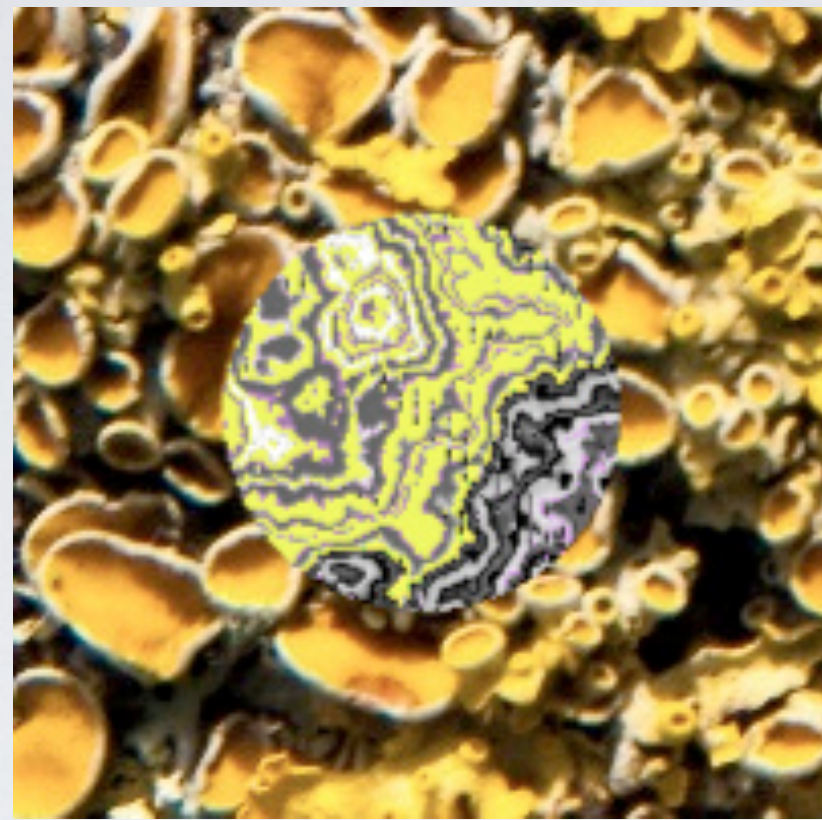
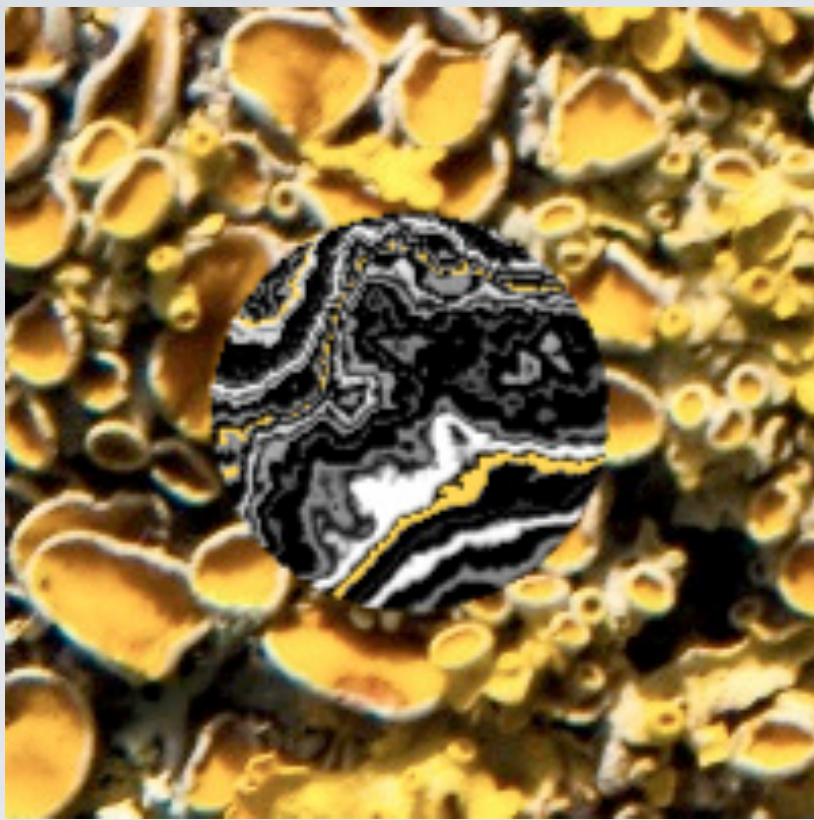


Flowers and leaves
(*lantana montevidensis* in my backyard)



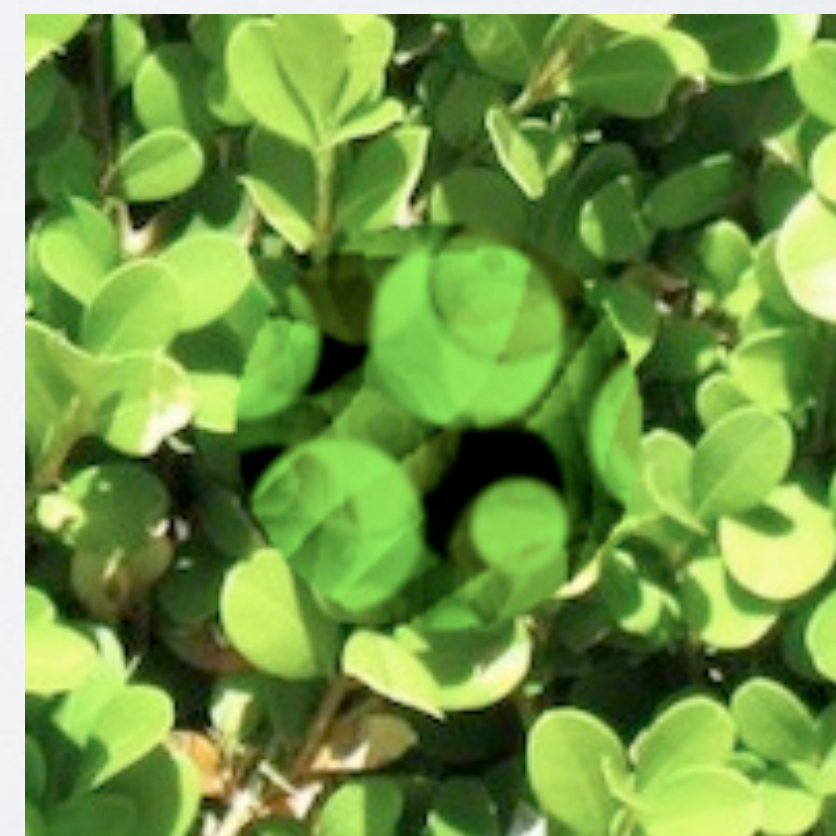
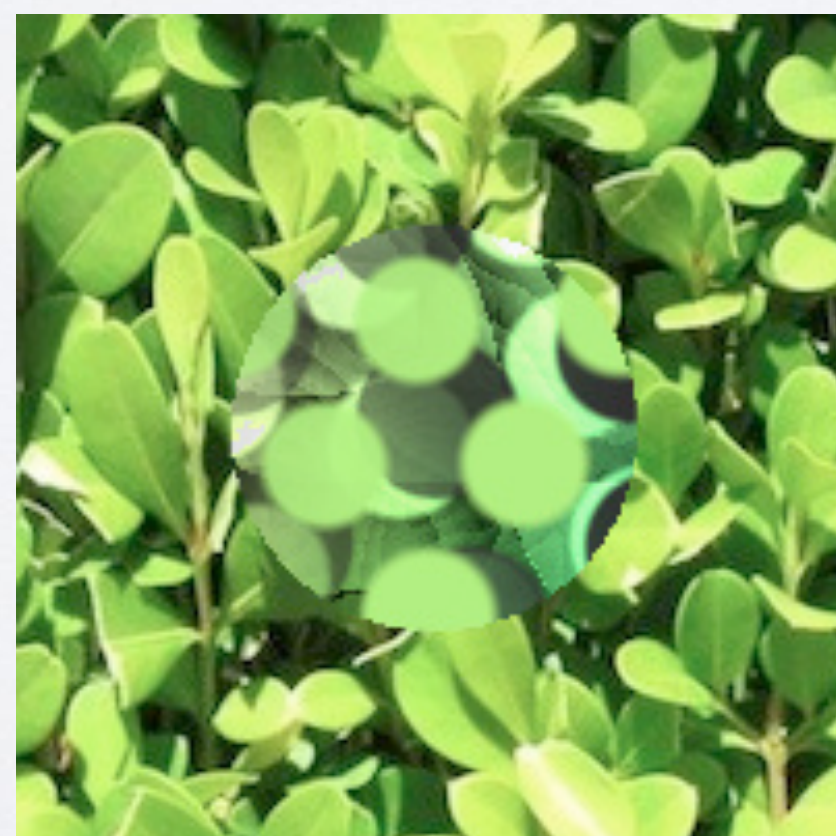
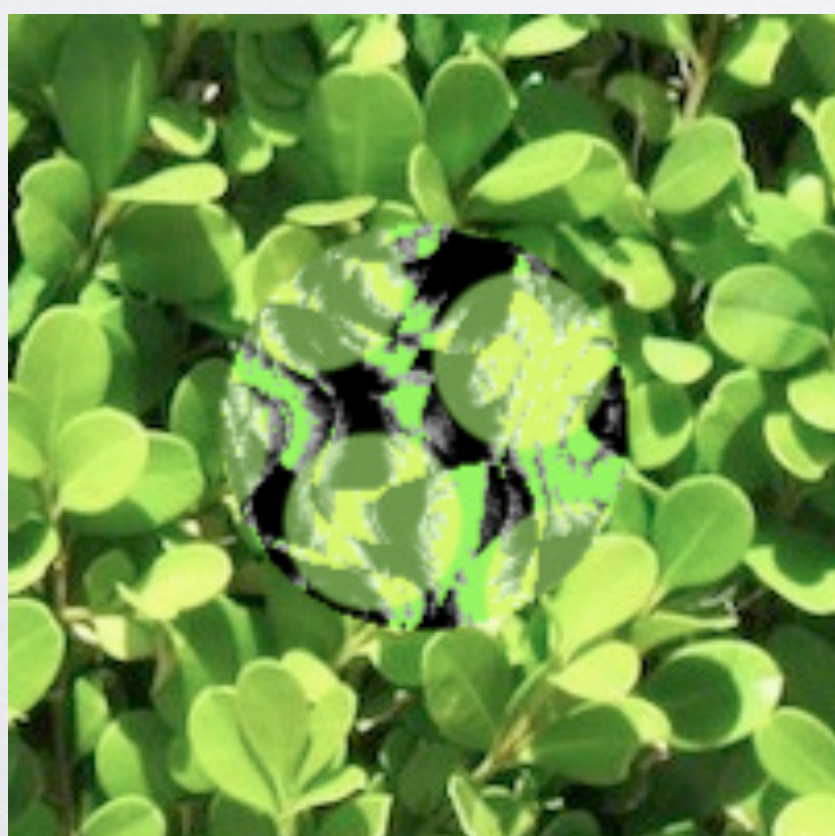
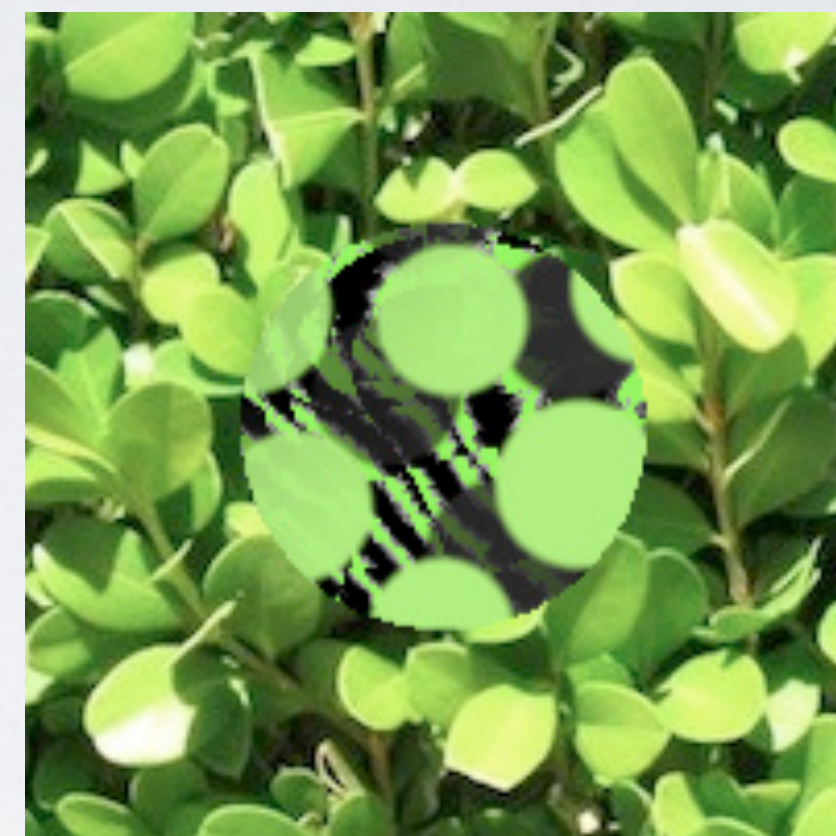
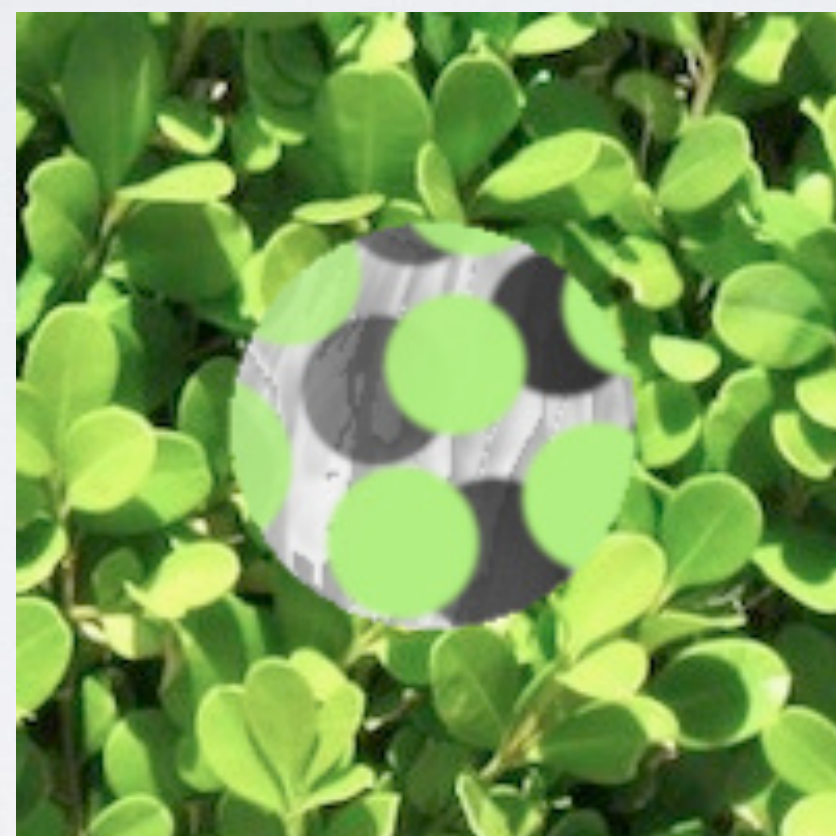
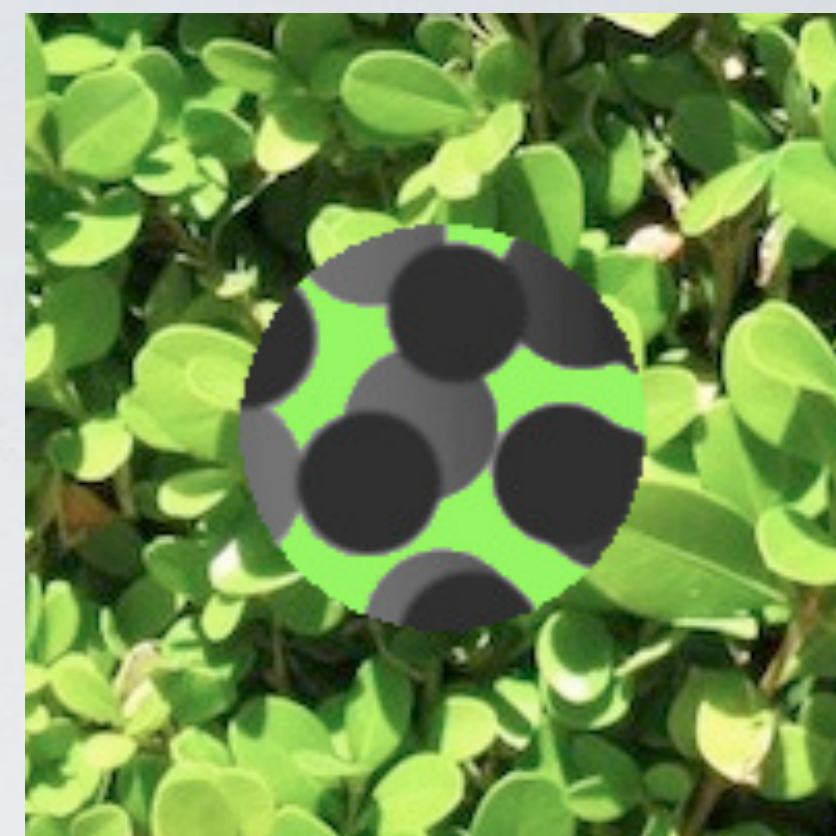
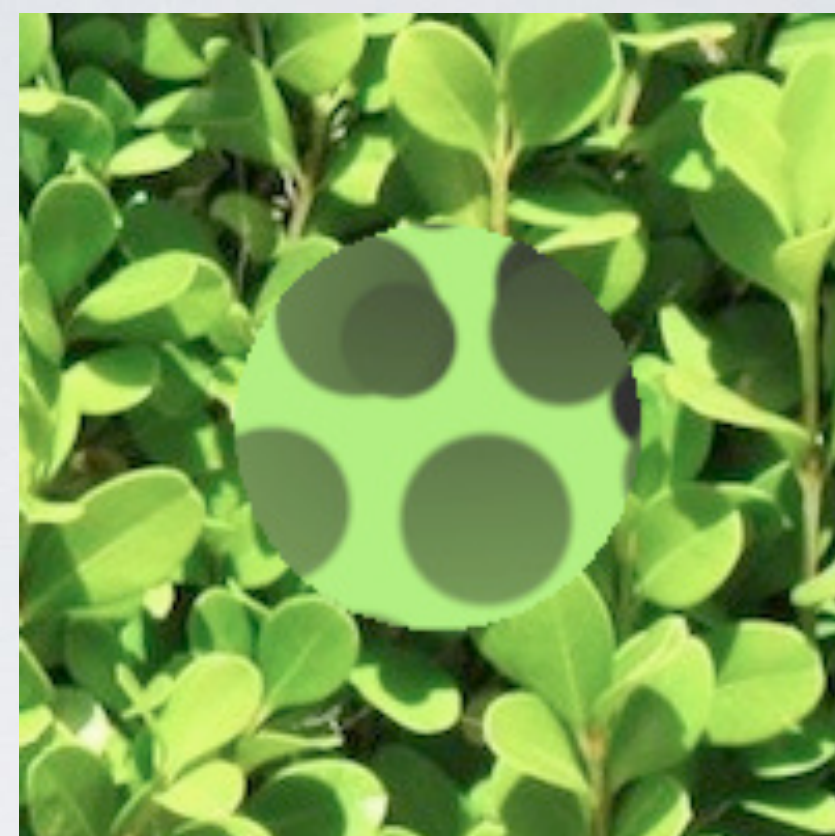


Lichen



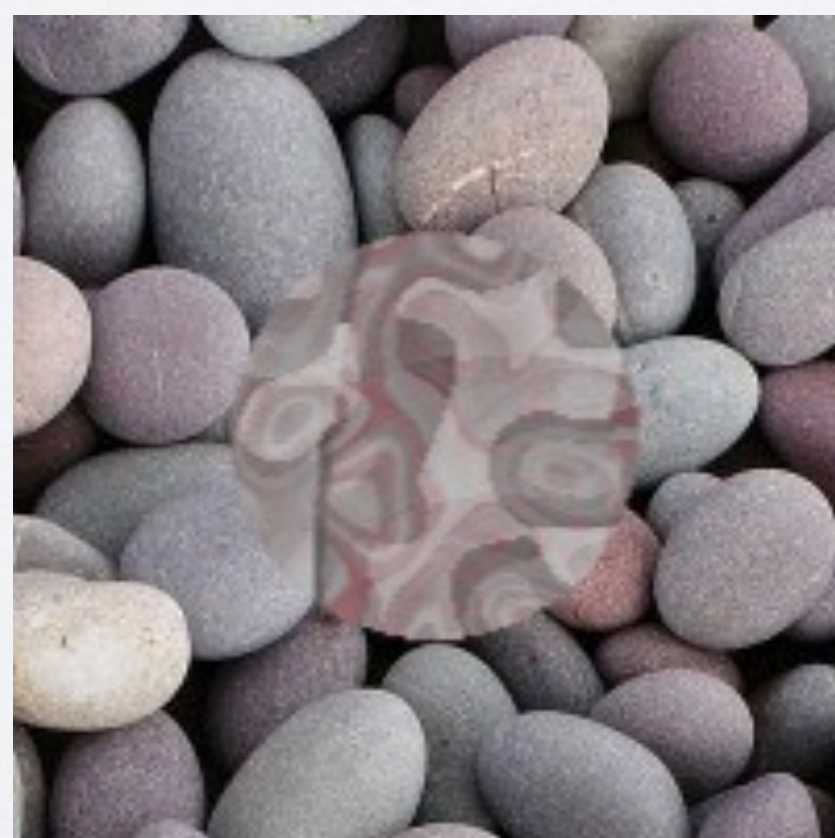


My neighbor's hedge





Beach Pebbles





Thank You!

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<http://www.red3d.com/cwr/>