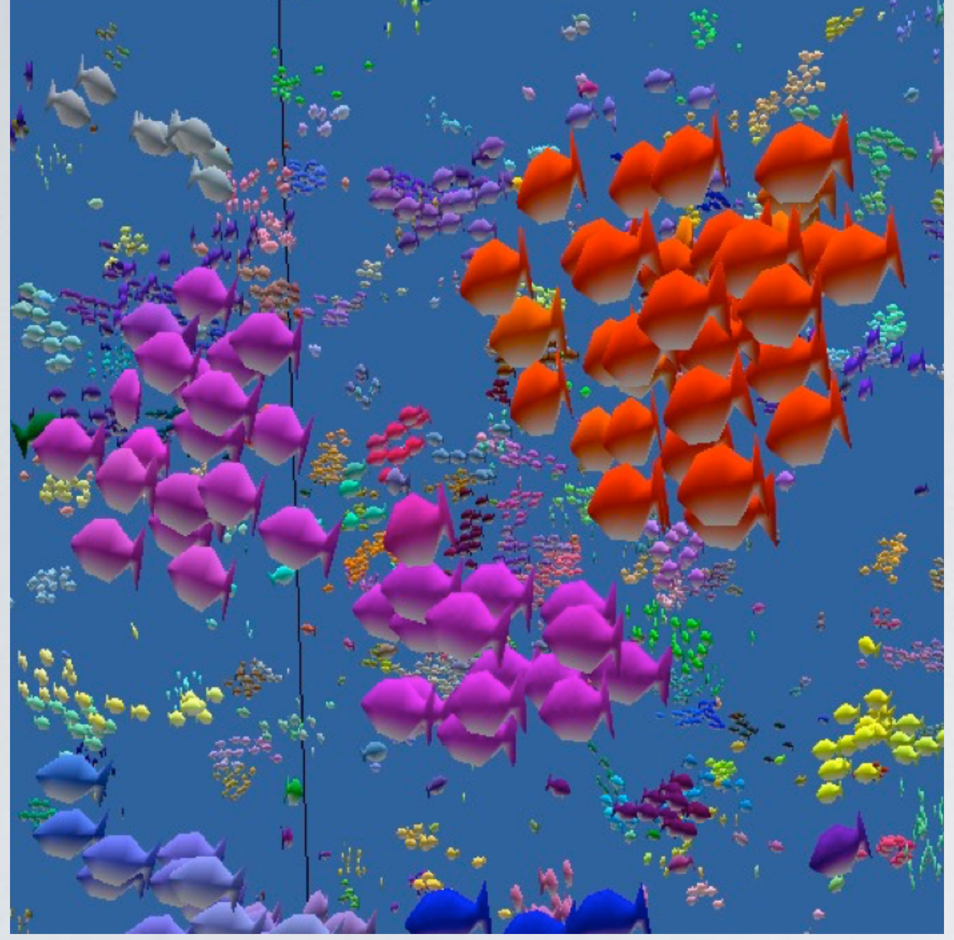
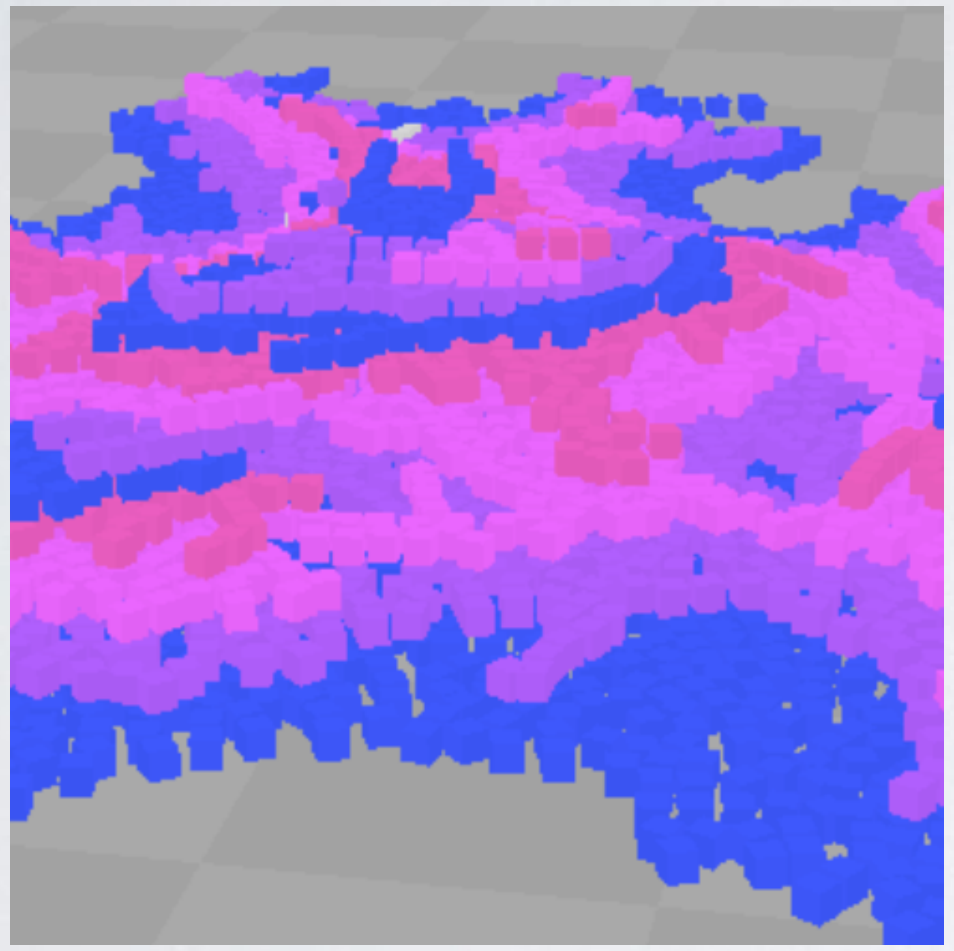




Computational Models of Natural Complexity

Craig Reynolds
Matterport

5th Student Conference on Complexity Science
Granada, Andalusia, Spain
September 9-11, 2015

Modified Oct 11, 2015: un-include video data

Who I am

Somewhere between:

a researcher gone horribly astray

and

a Silicon Valley software engineer who dabbles in research.

The organizers requested I talk a bit about that.
I will return to it at the end of my presentation.

- University of California Berkeley
- Stanford University
- University of California Santa Cruz

- Facebook
- Google
- Matterport

And now a word from our sponsor…

matterport®

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

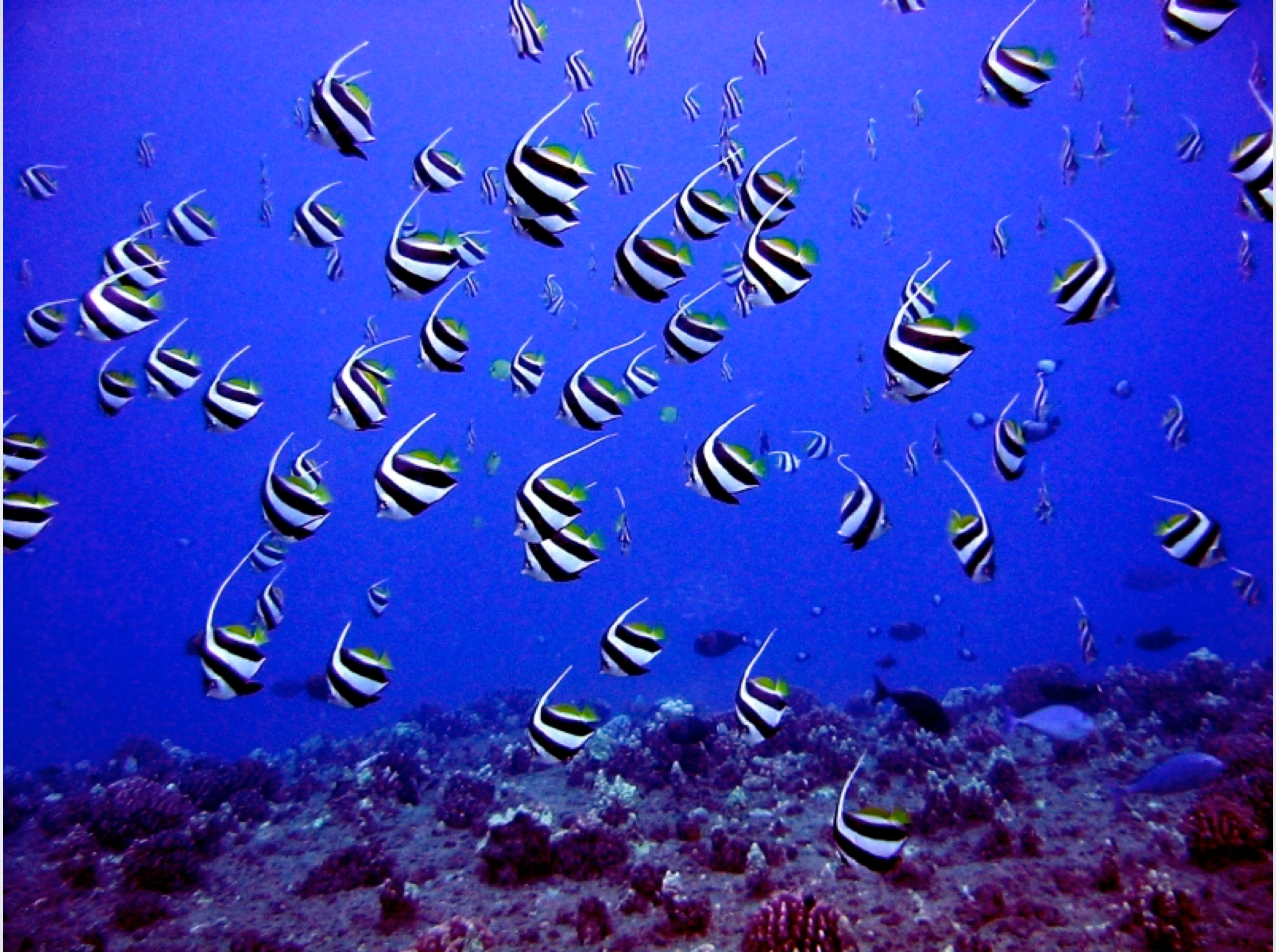
Cliffhanger, 1993, Carolco Pictures

BOIDS

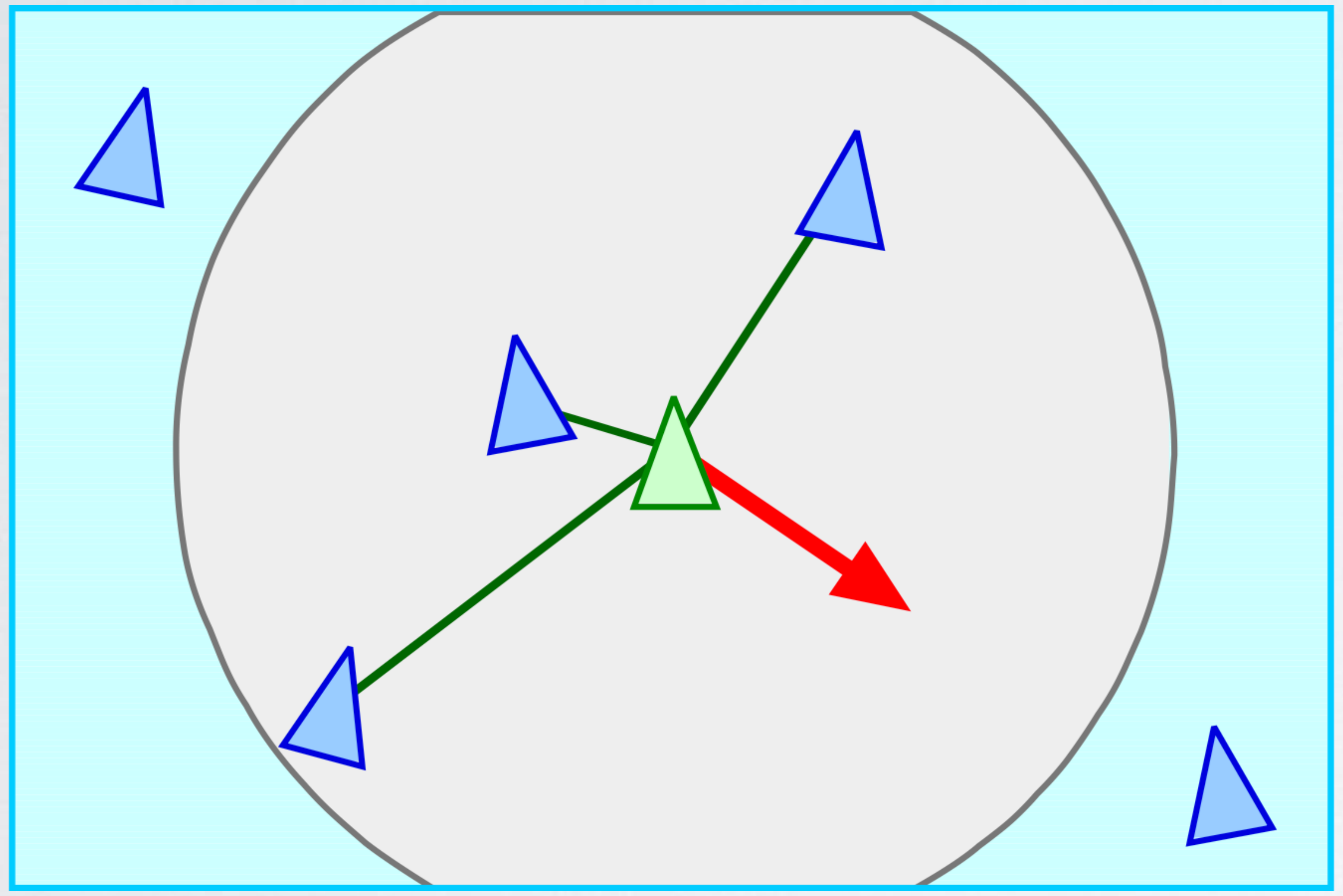
AGENT-BASED FLOCKING

- 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?

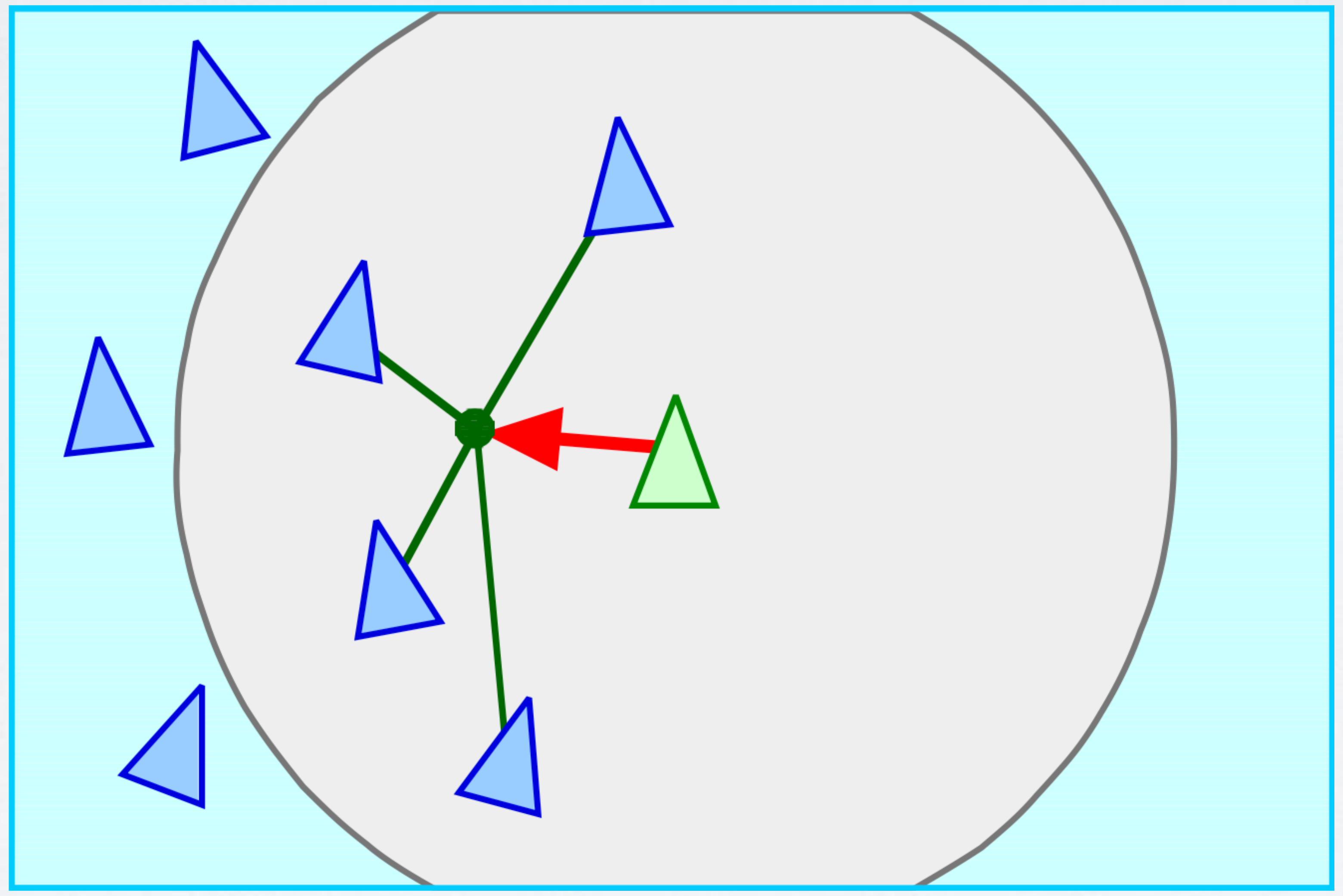
Thought experiments based on personal experience



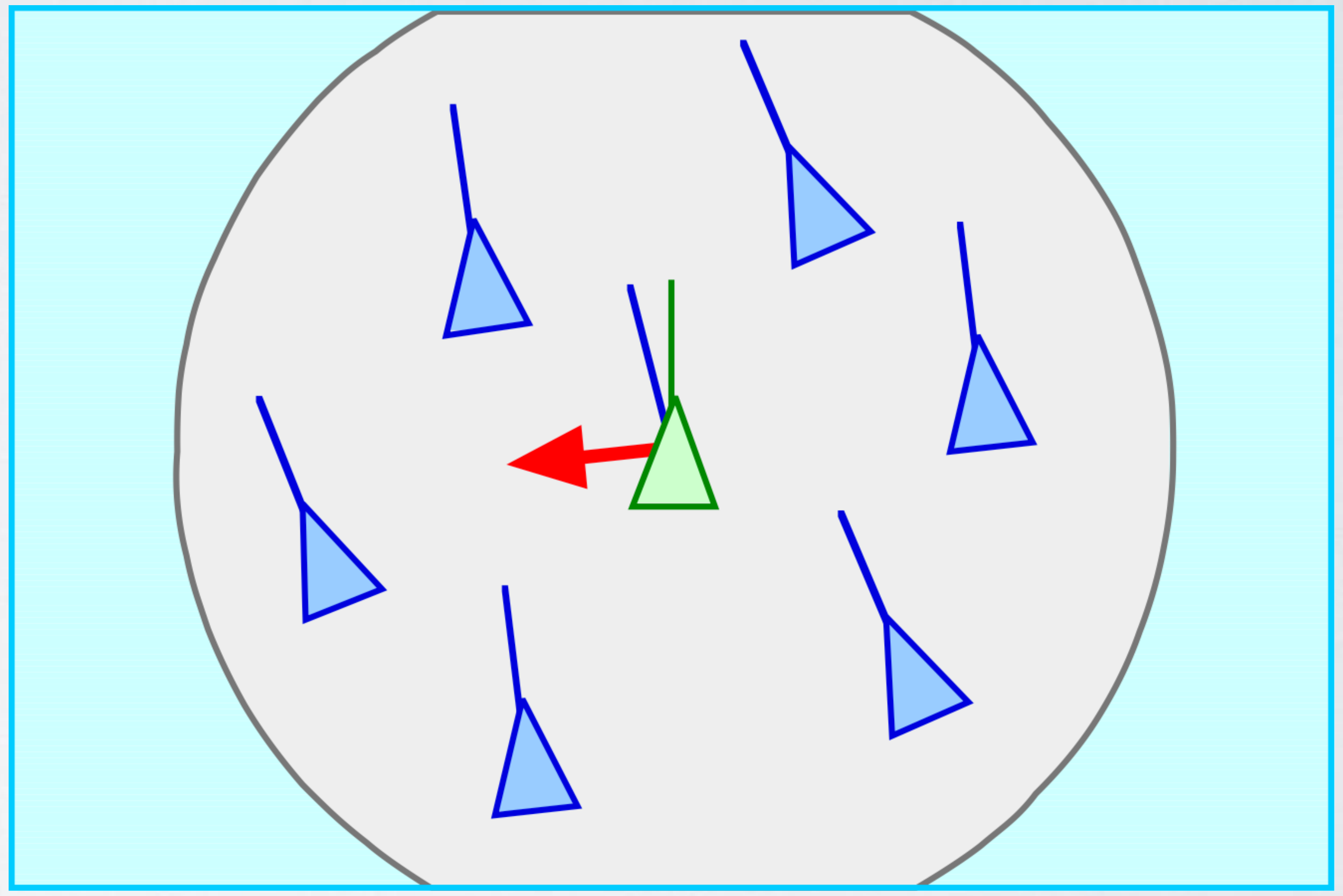
Three basic behaviors seemed necessary, but where they sufficient?



separation



cohesion



alignment

Formal analysis may have been applicable.

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

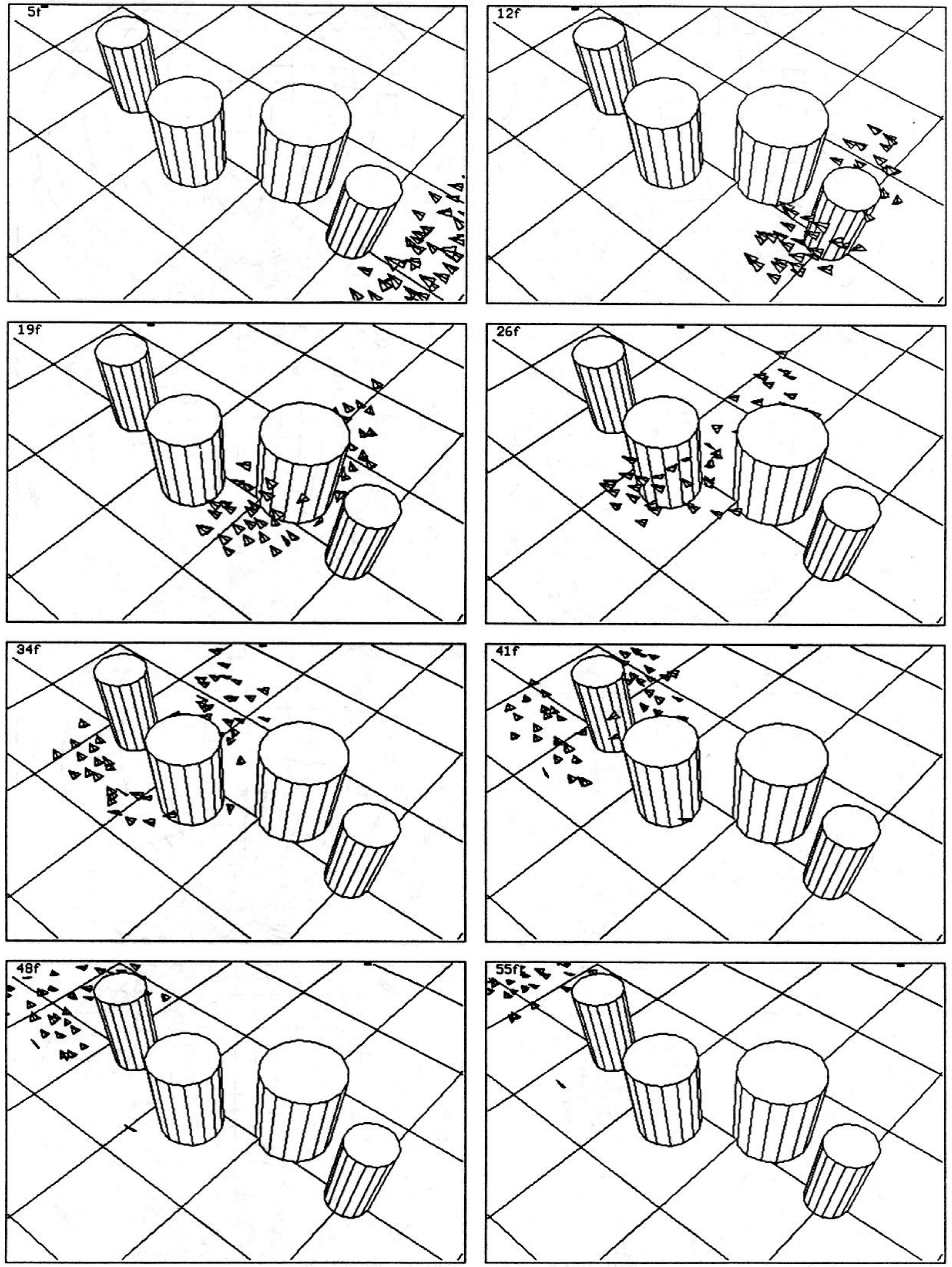
I needed an empirical demonstration, in the form of an animated graphical simulation.

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

[Boids B on YouTube]

Stanley and Stella in Breaking the Ice

1987

Symbolics, Inc.

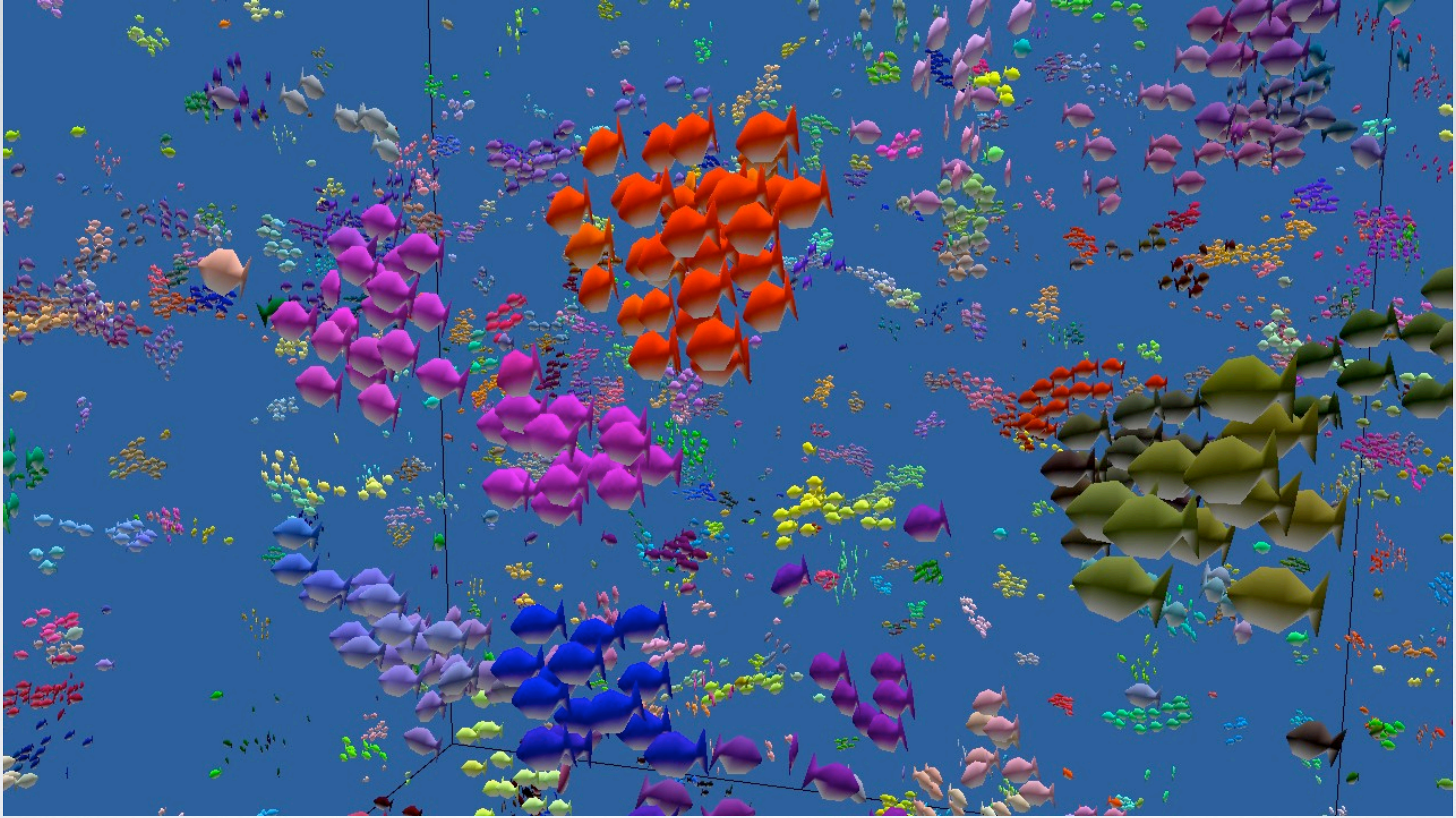
in association with

Whitney / Demos Productions

BtI on YouTube

SYMBOLICS

GRAPHICS DIVISION

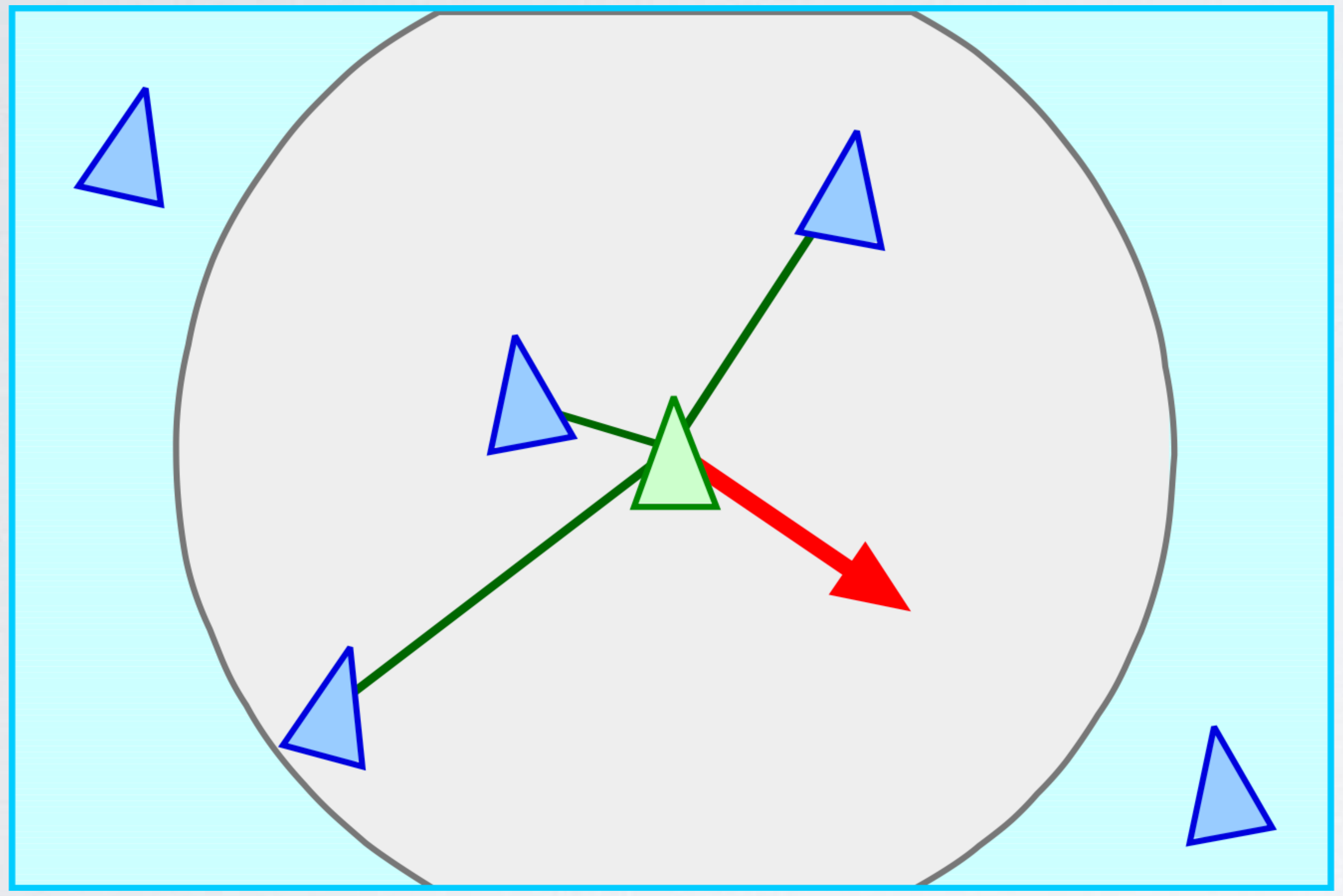


Real time boids on Playstation3 — about 10,000 at 60Hz — PSCrowd, 2006

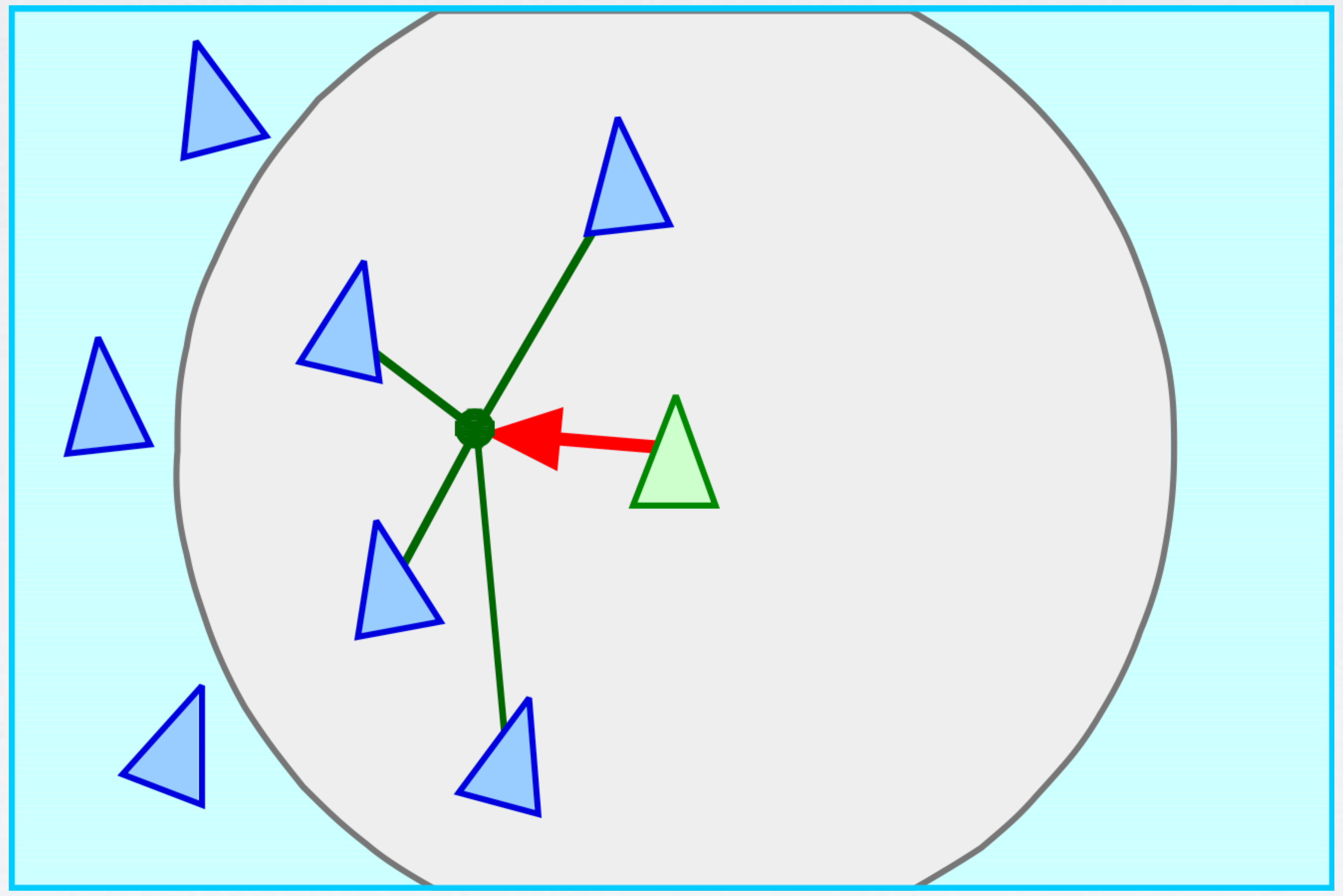
chameleon test on youtube

final 12k fish on youtube

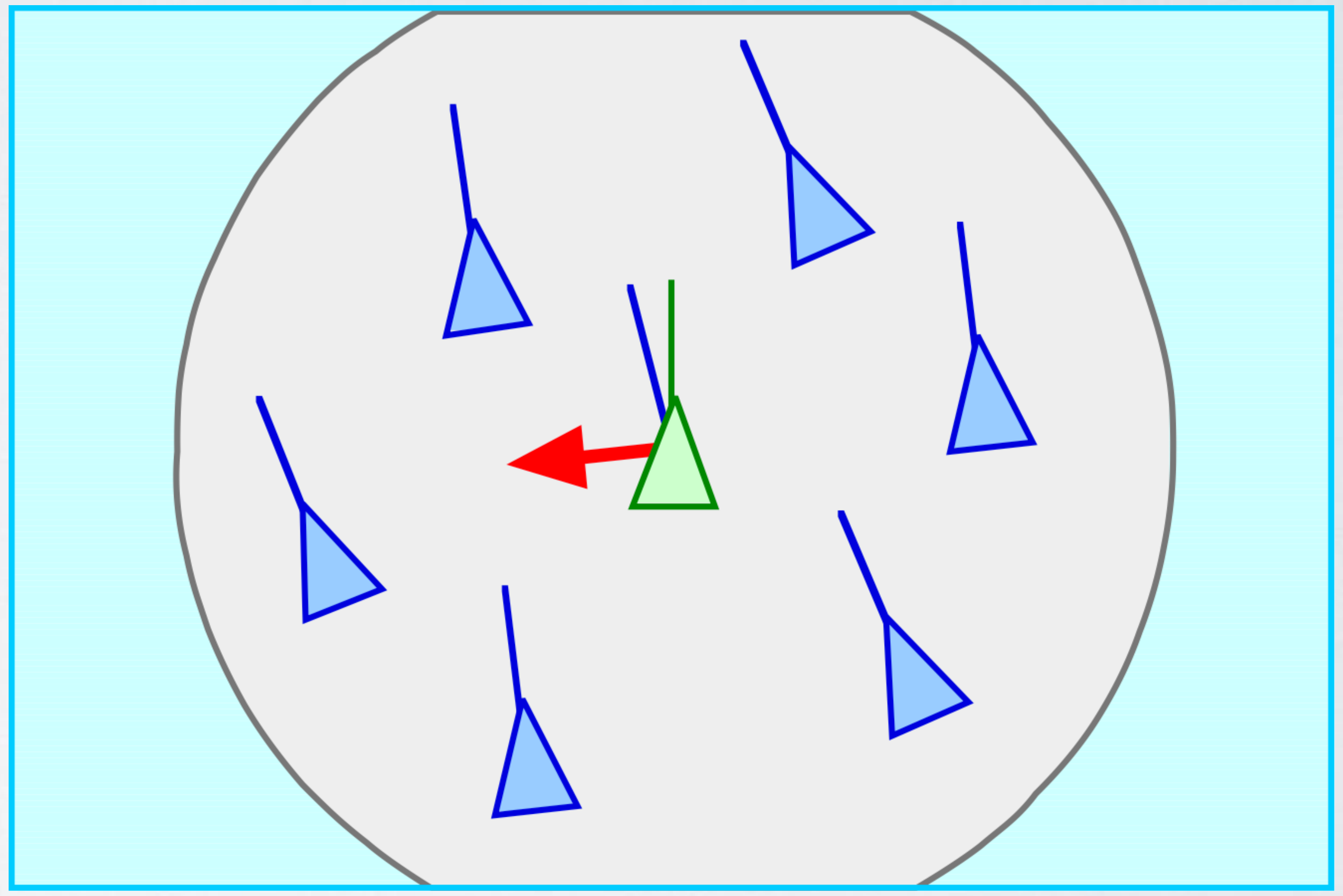
Returning to that key concept of neighborhood…



separation

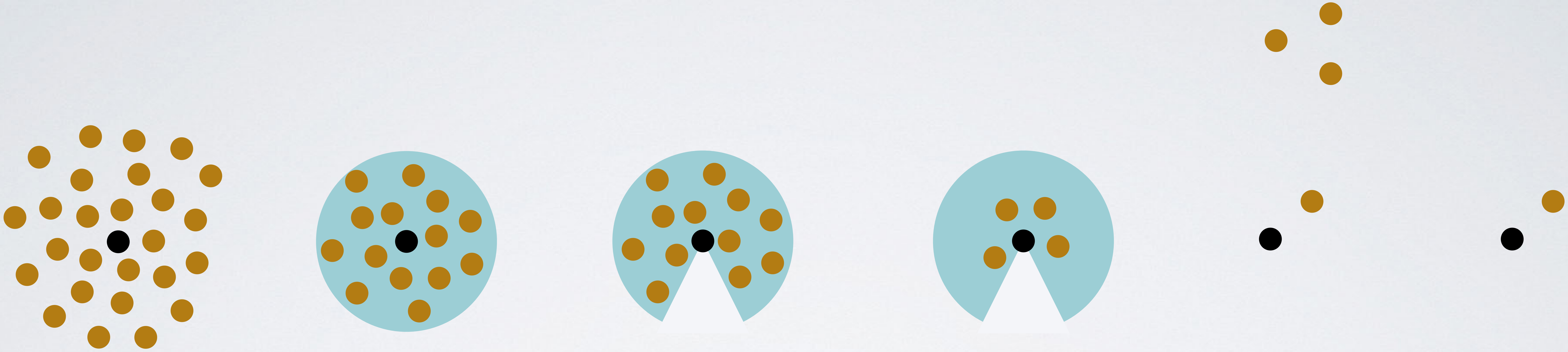


cohesion



alignment

Evolution of neighborhood definition in flocking models



entire flock	sphere	sphere - cone spherical sector	kNN in sector	kNN (k=4)	kNN (k=1)

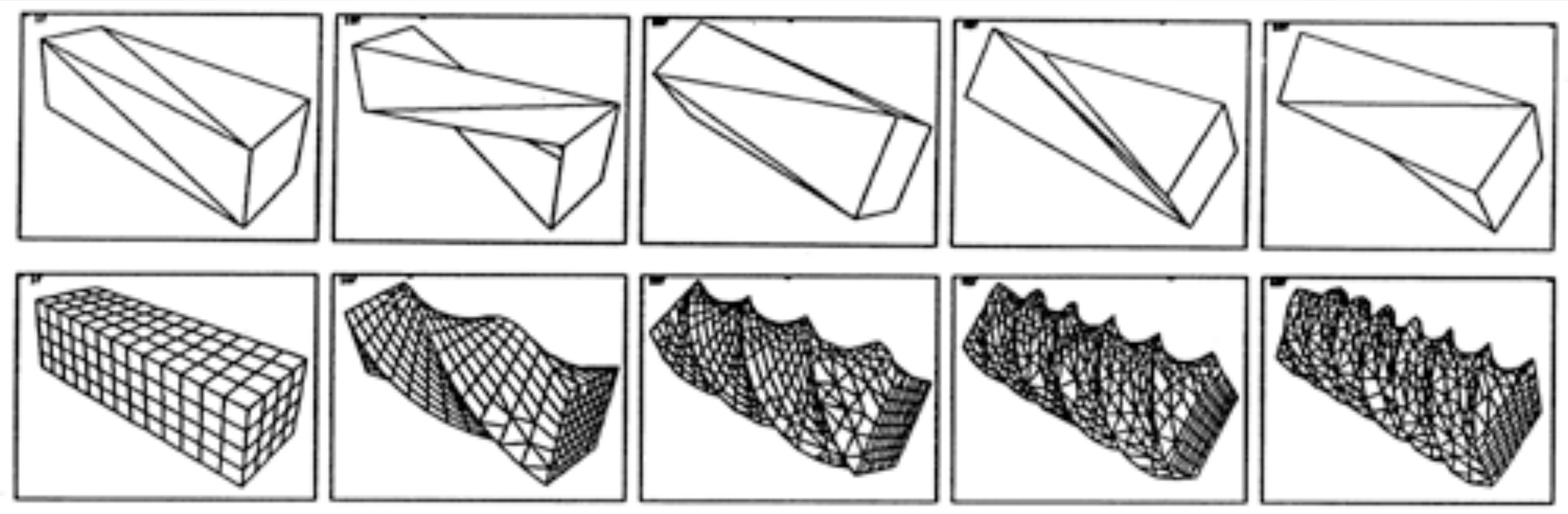
1986 → 2014

DUCTILE FLOW

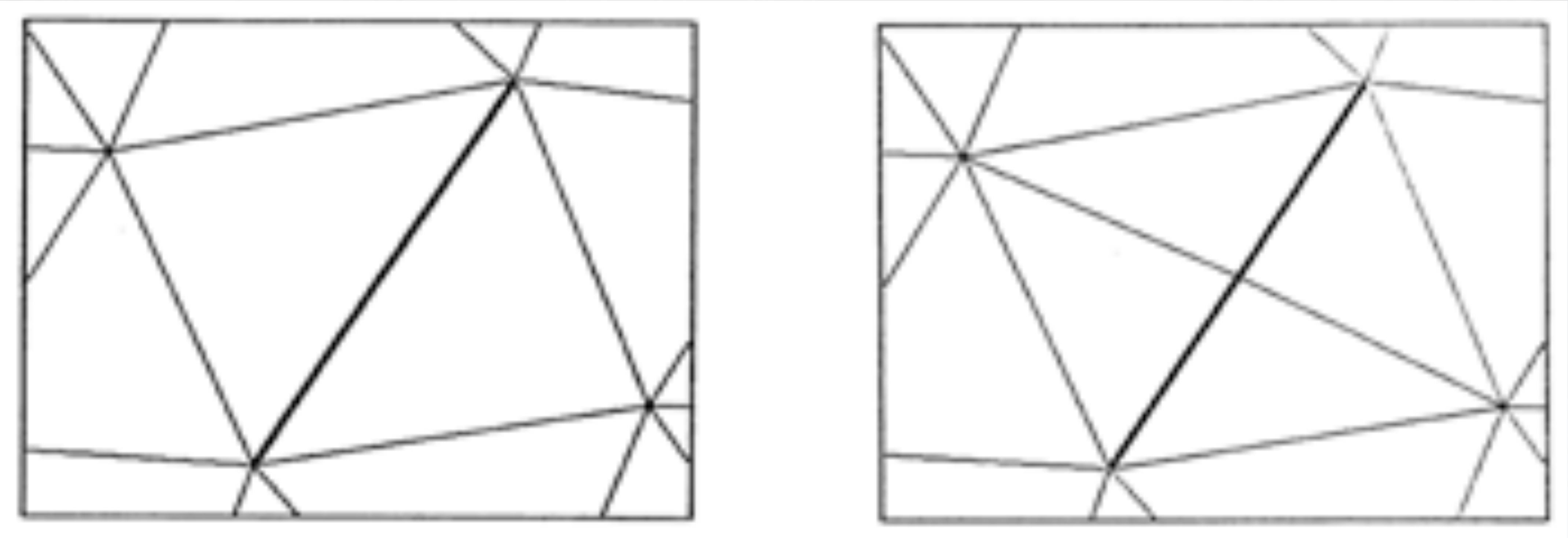
Adaptive Polyhedral Resampling for Vertex Flow Animation

- 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!

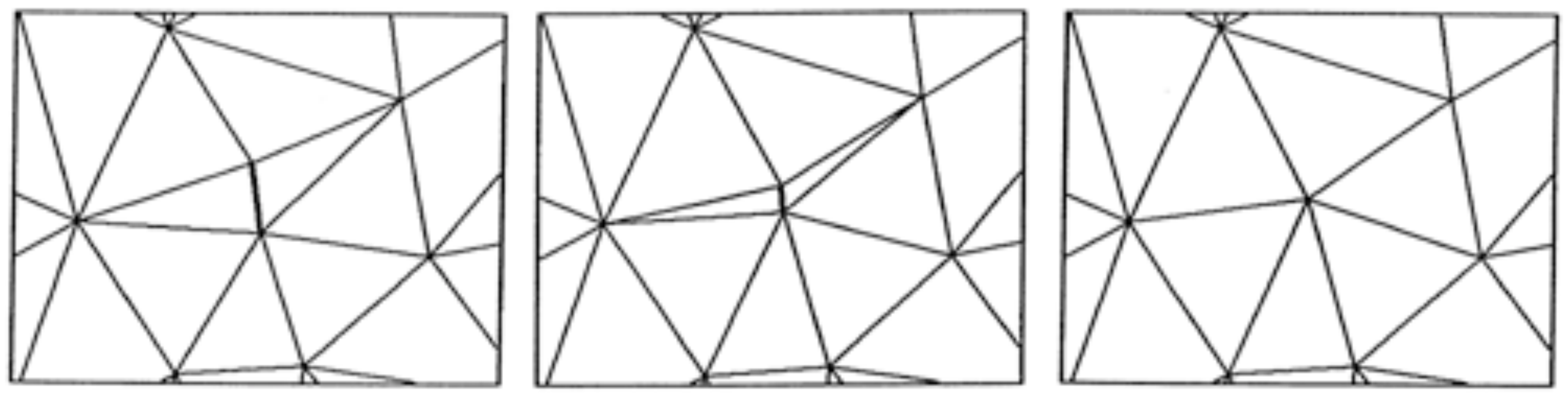
fixed geometry



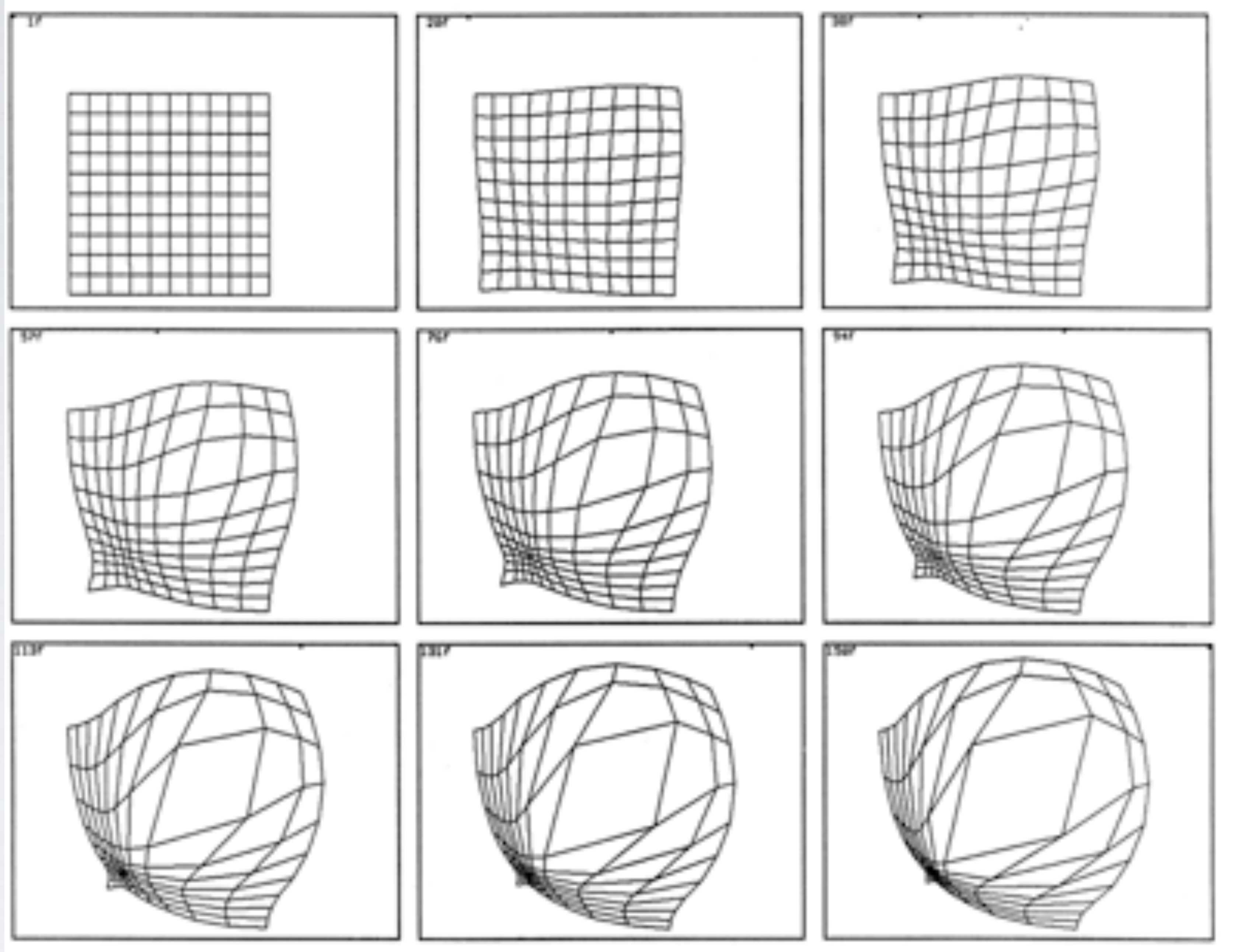
adaptive subdivision



splitting a long edge and its two adjacent triangular faces

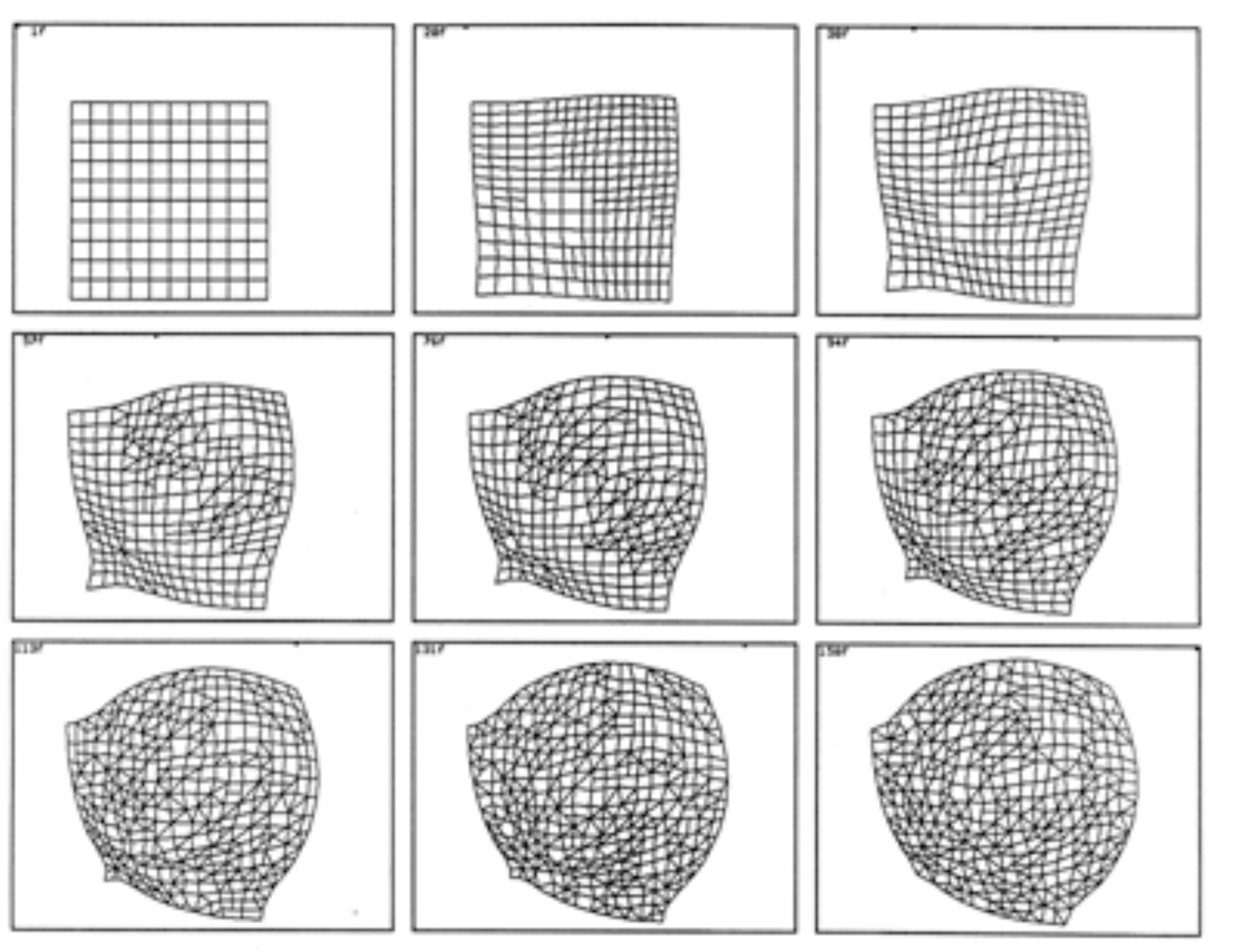


“unsubdivision” — collapsing a short edge

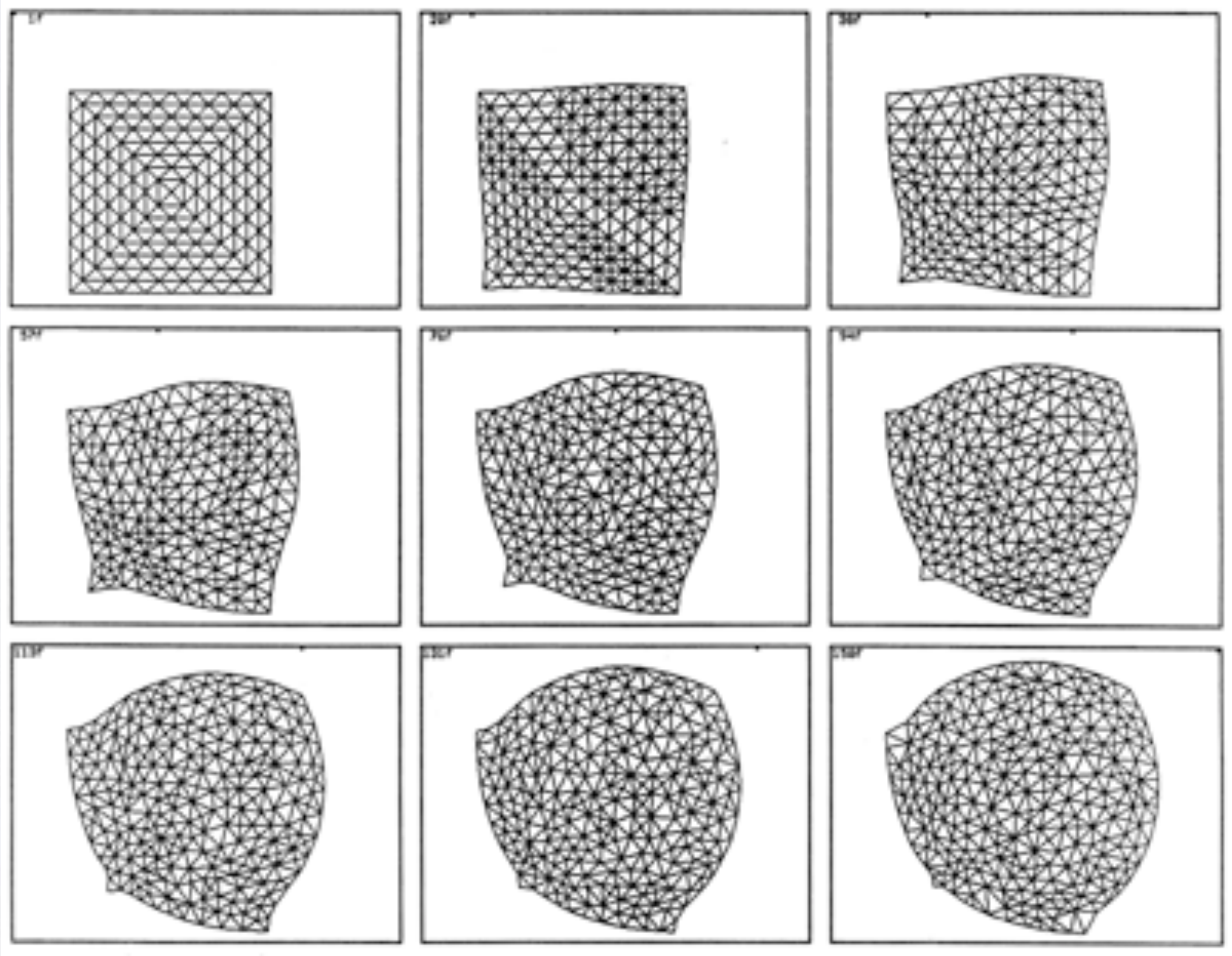


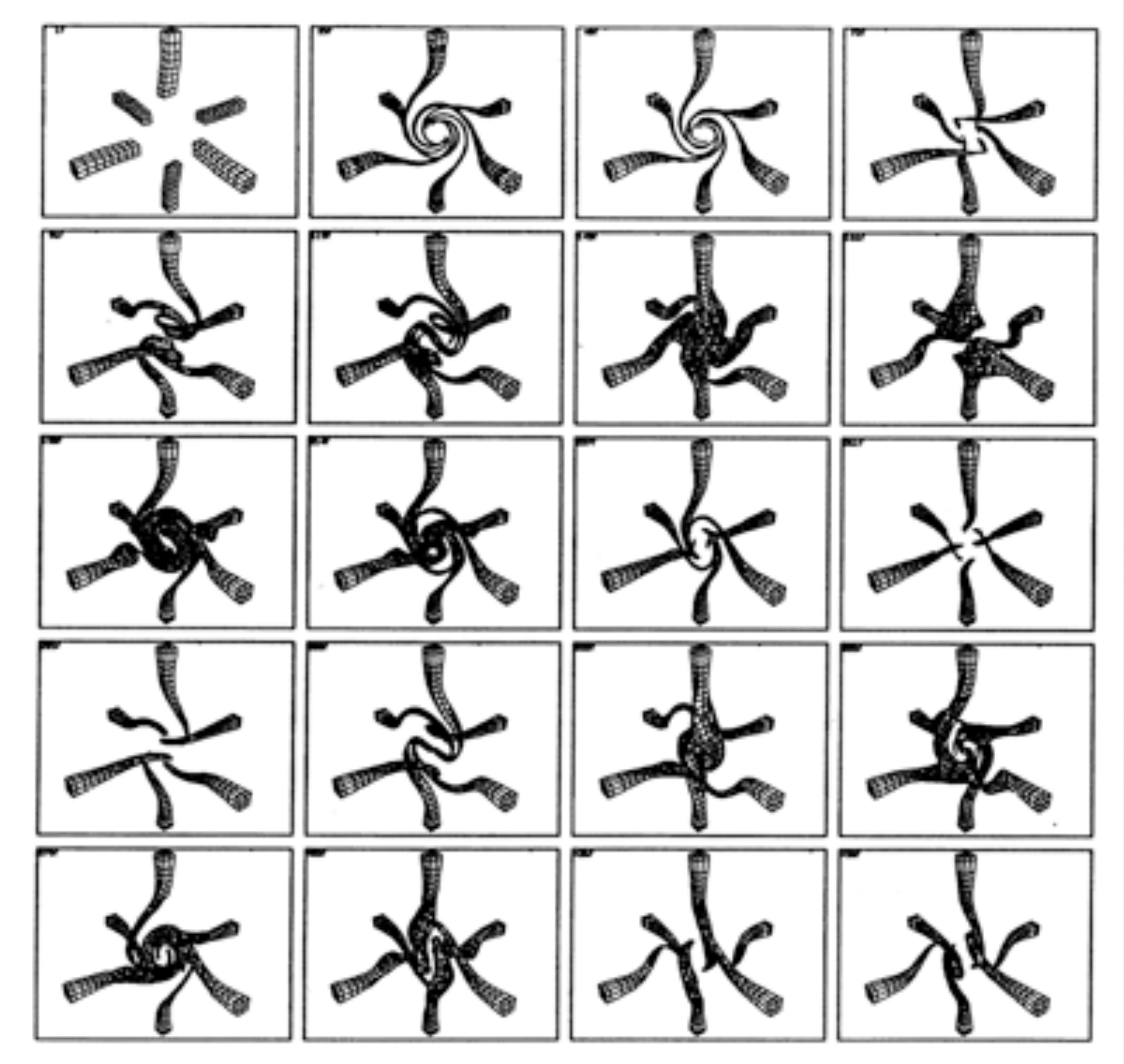
without adaptive subdivision

polygons

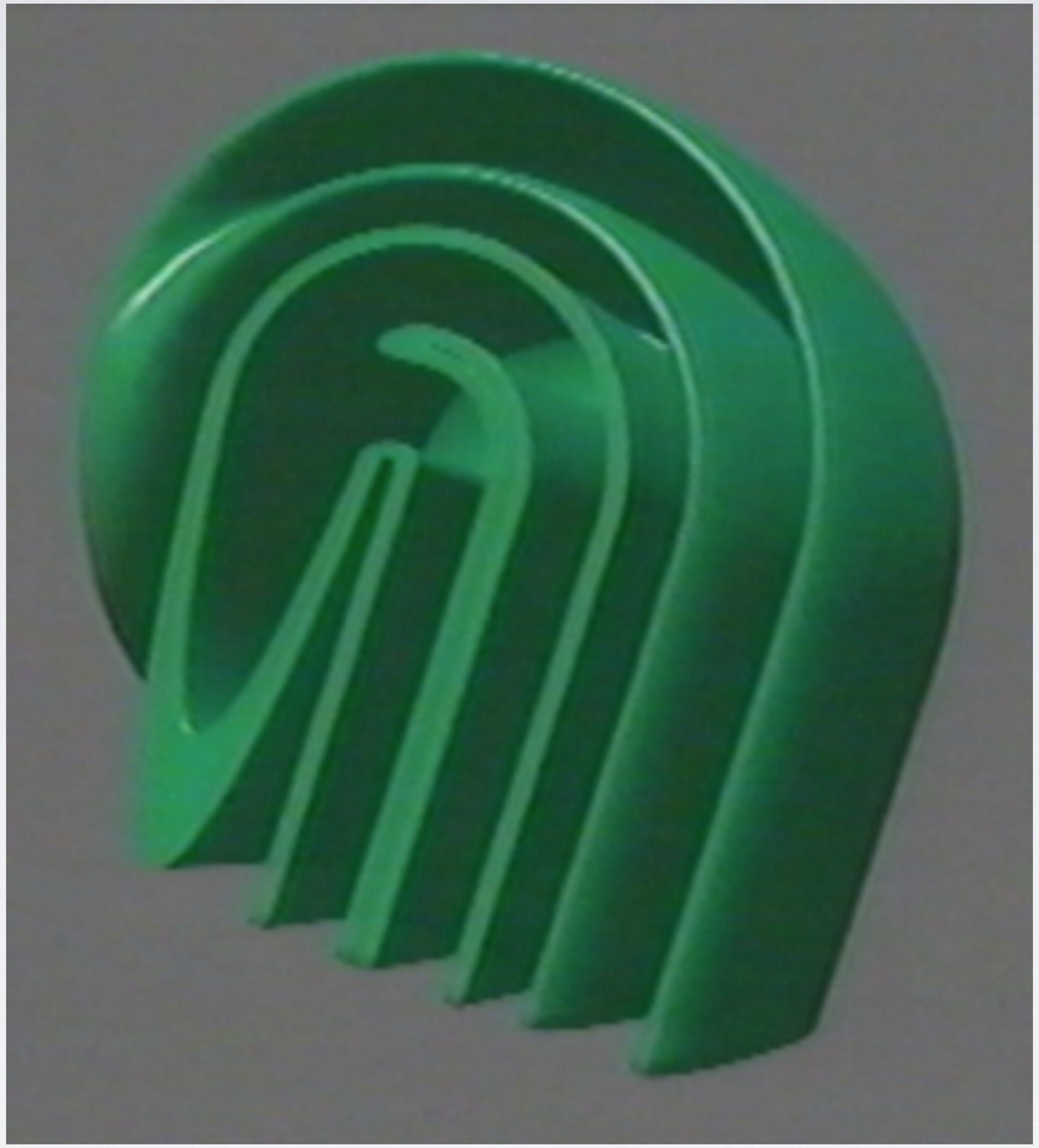


triangles





motion test of "flow sculpture"
from Matt Elson's *Virtually Yours*



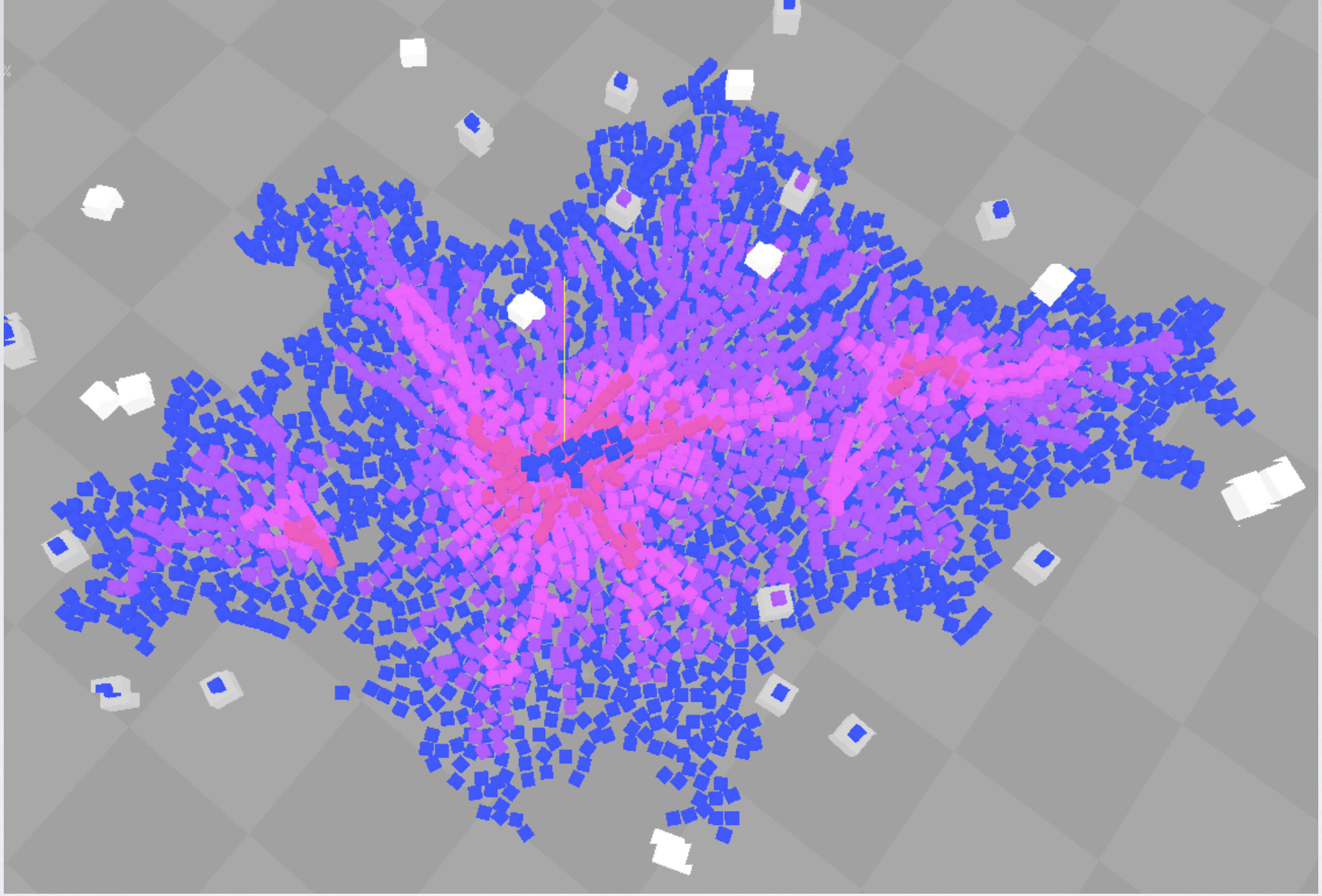
Still from Ductile Flow
(full video on my web site if you are interested)

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

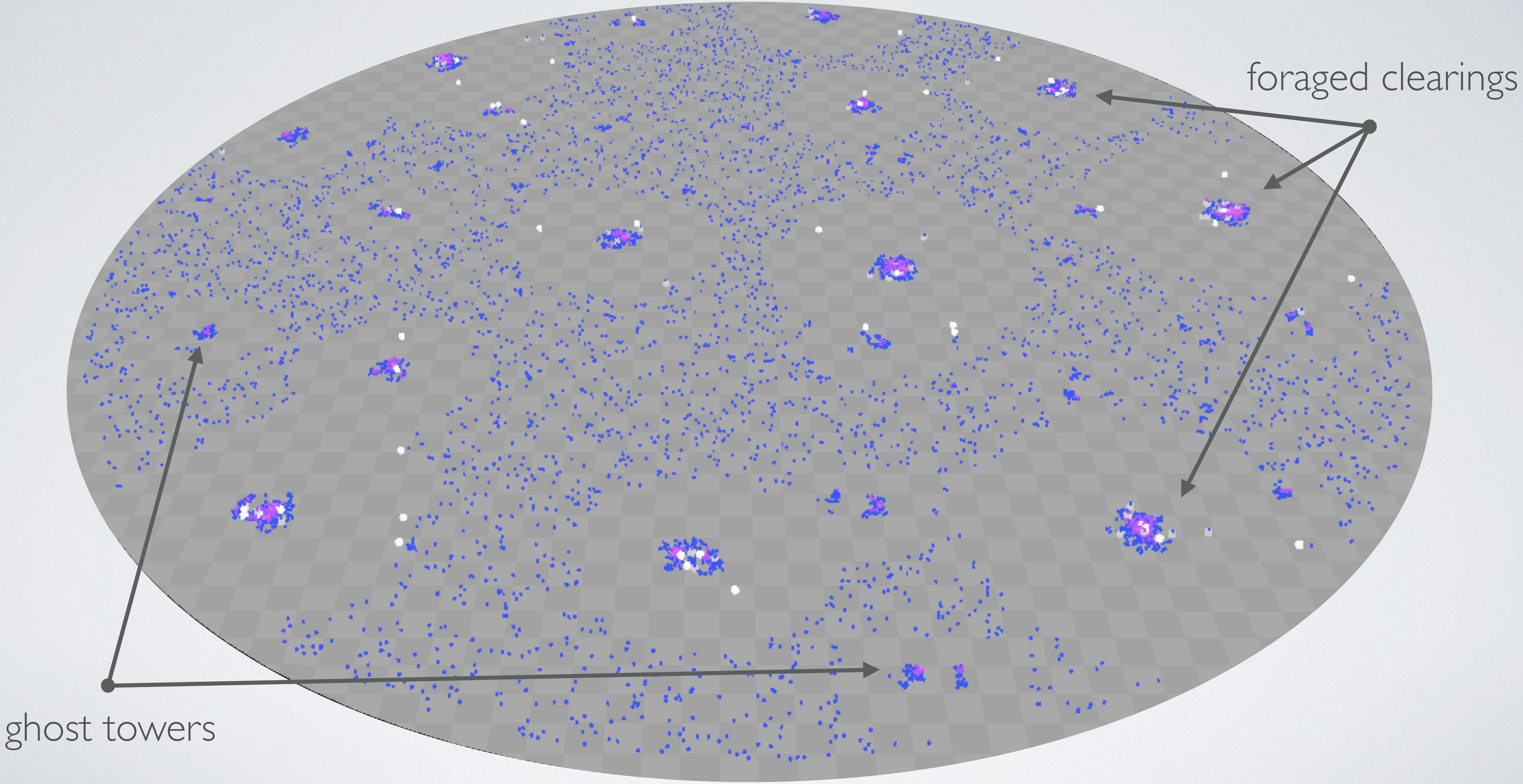
two termite cathedral mounds in the Northern Territory of Australia

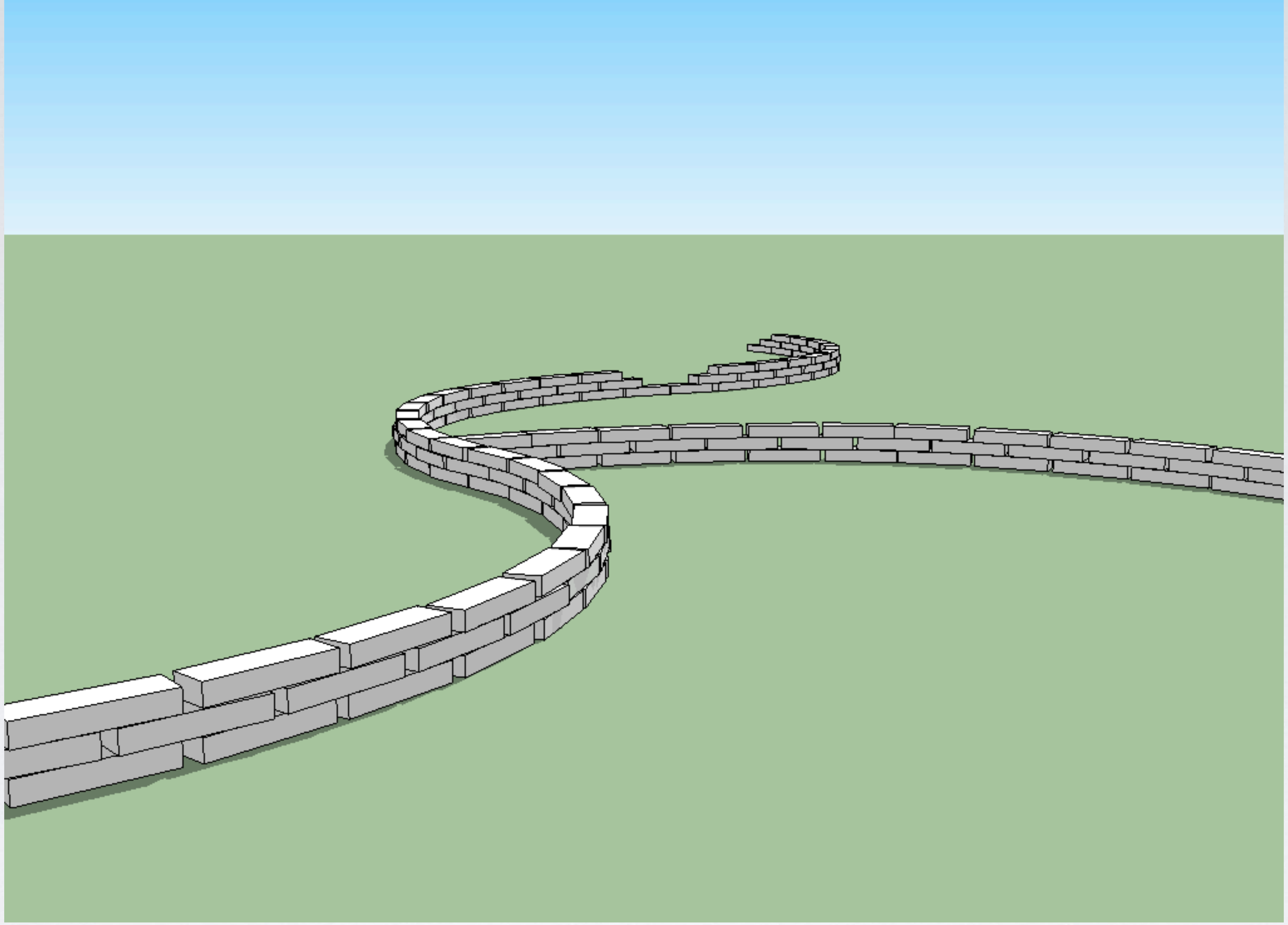


2008 stigmergic multi-agent mound-building simulation

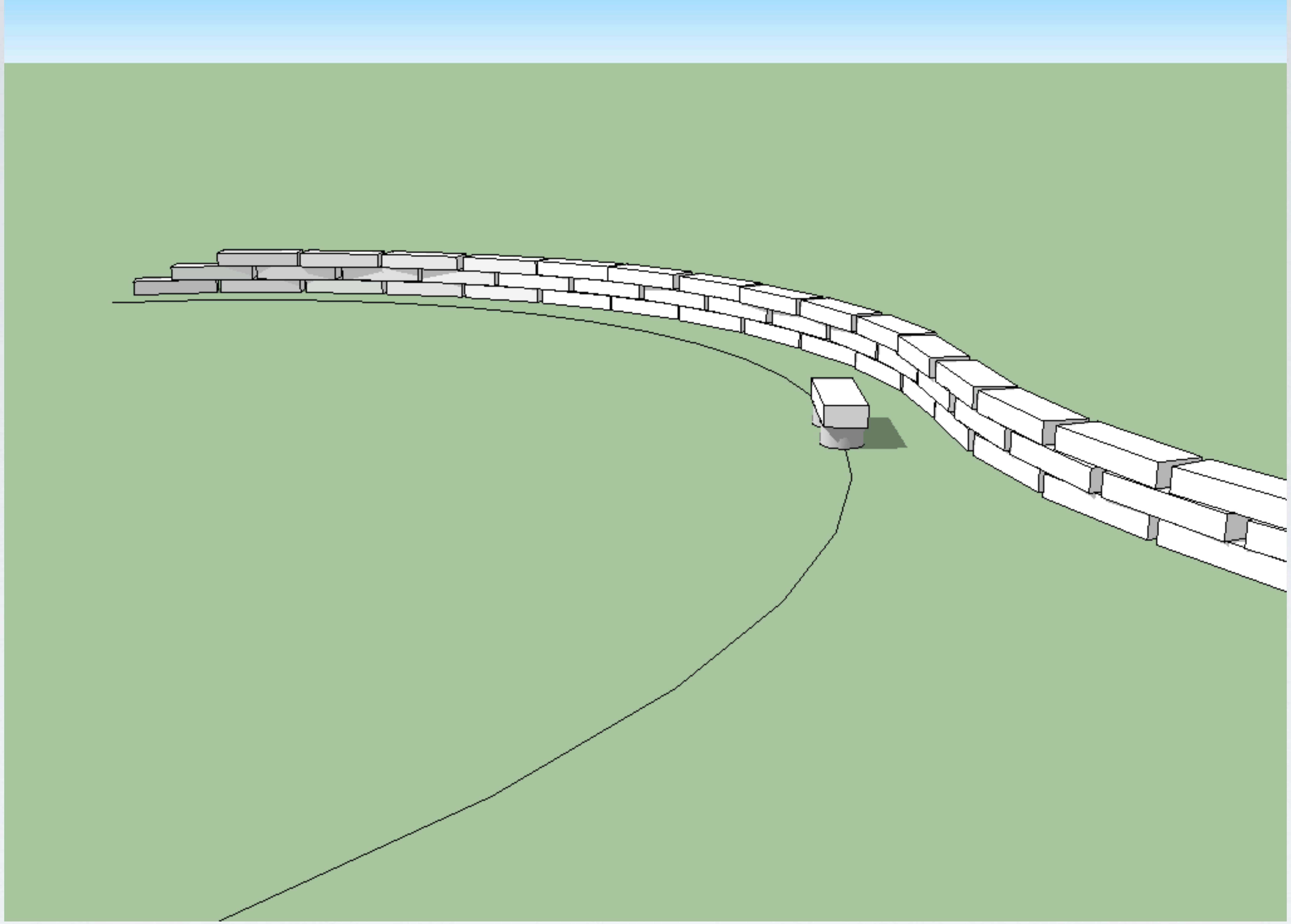
2008 stigmergic multi-agent mound-building simulation

Emergent teamwork: tower construction

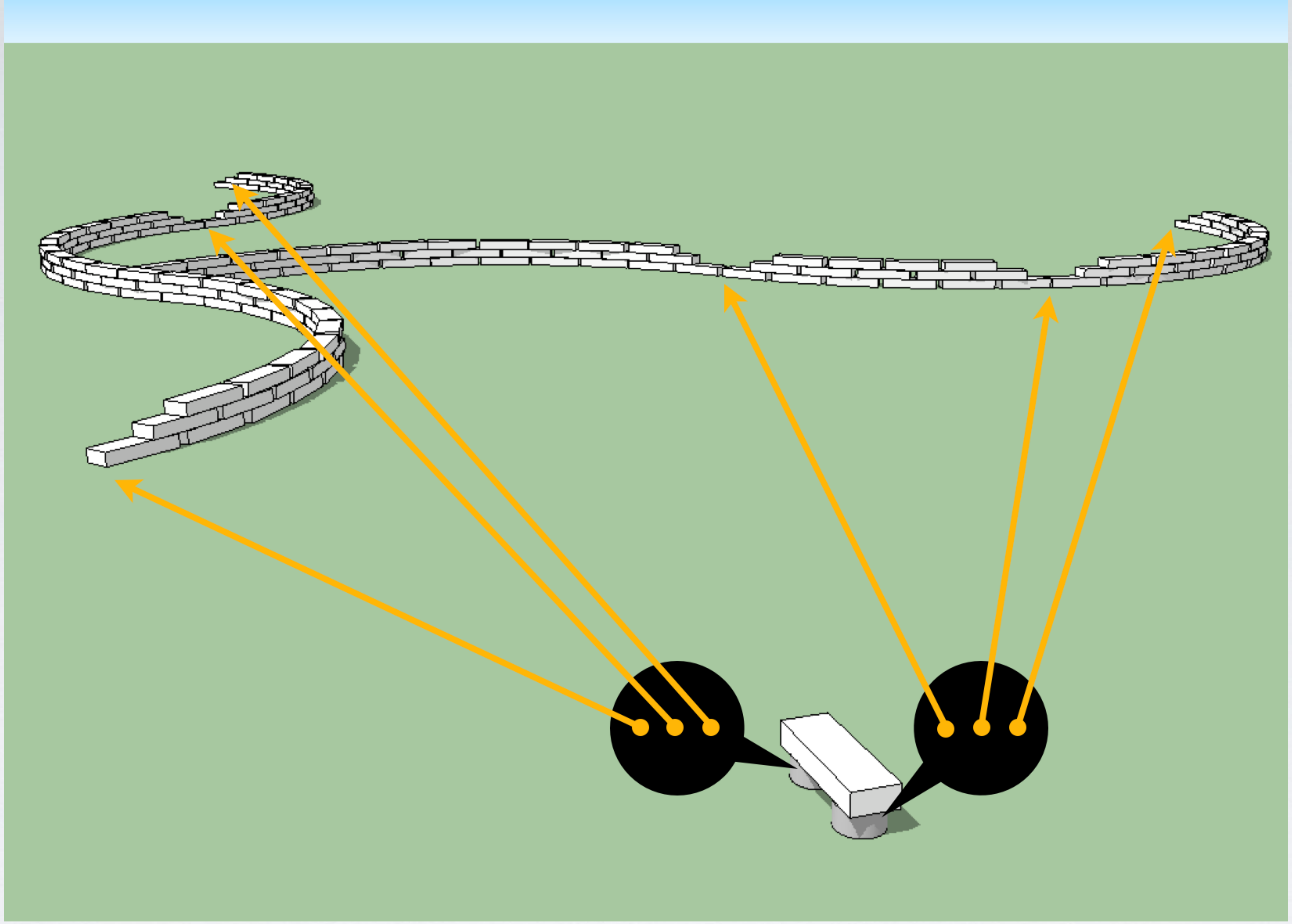




Proposed stigmergic wall-building scenario.



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



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

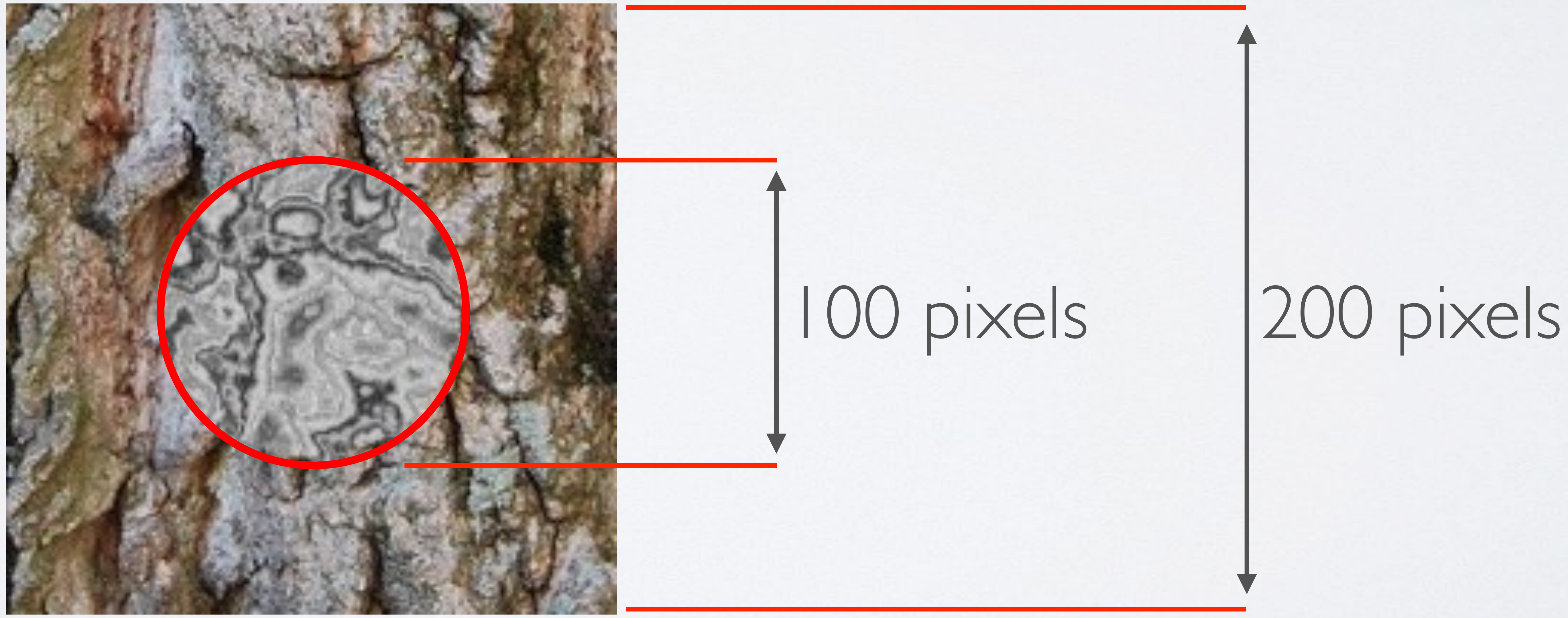
INTERACTIVE EVOLUTION OF CAMOUFLAGE

Interactive Evolution of Camouflage

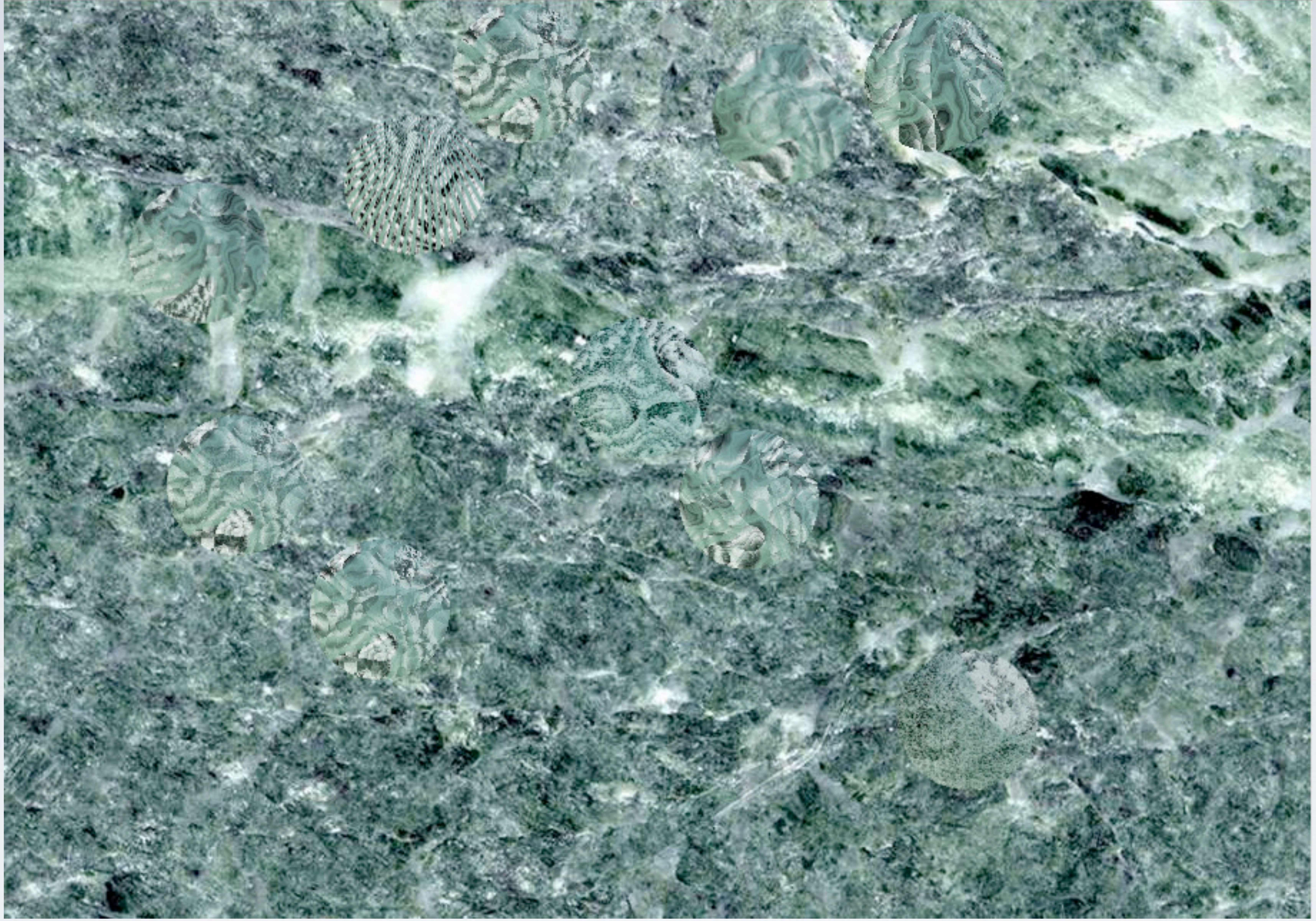
- Abstract model of camouflage evolution in nature.
  - evolutionary computation: genetic programming
  - computer graphics: procedural texture synthesis
  - hybrid system: human vision "in the loop"

Evolved camouflage

Evolved camouflage

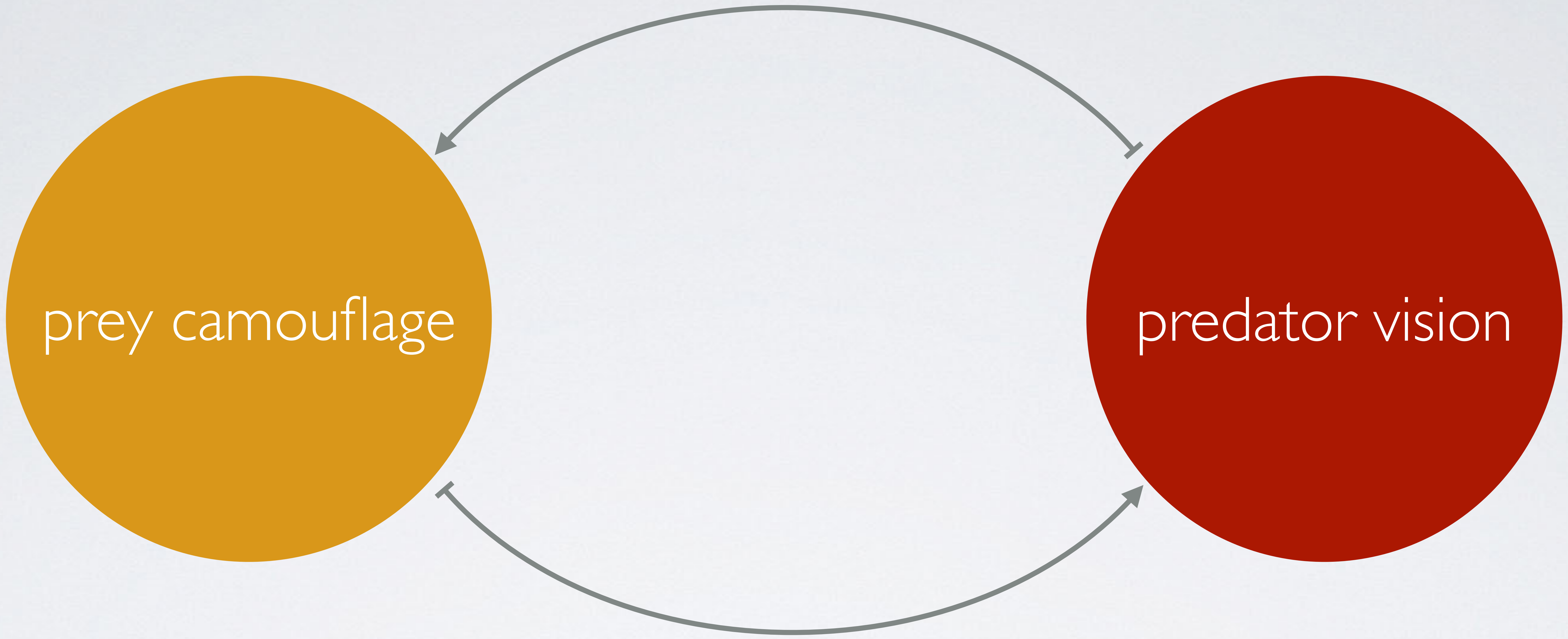


Evolved camouflage

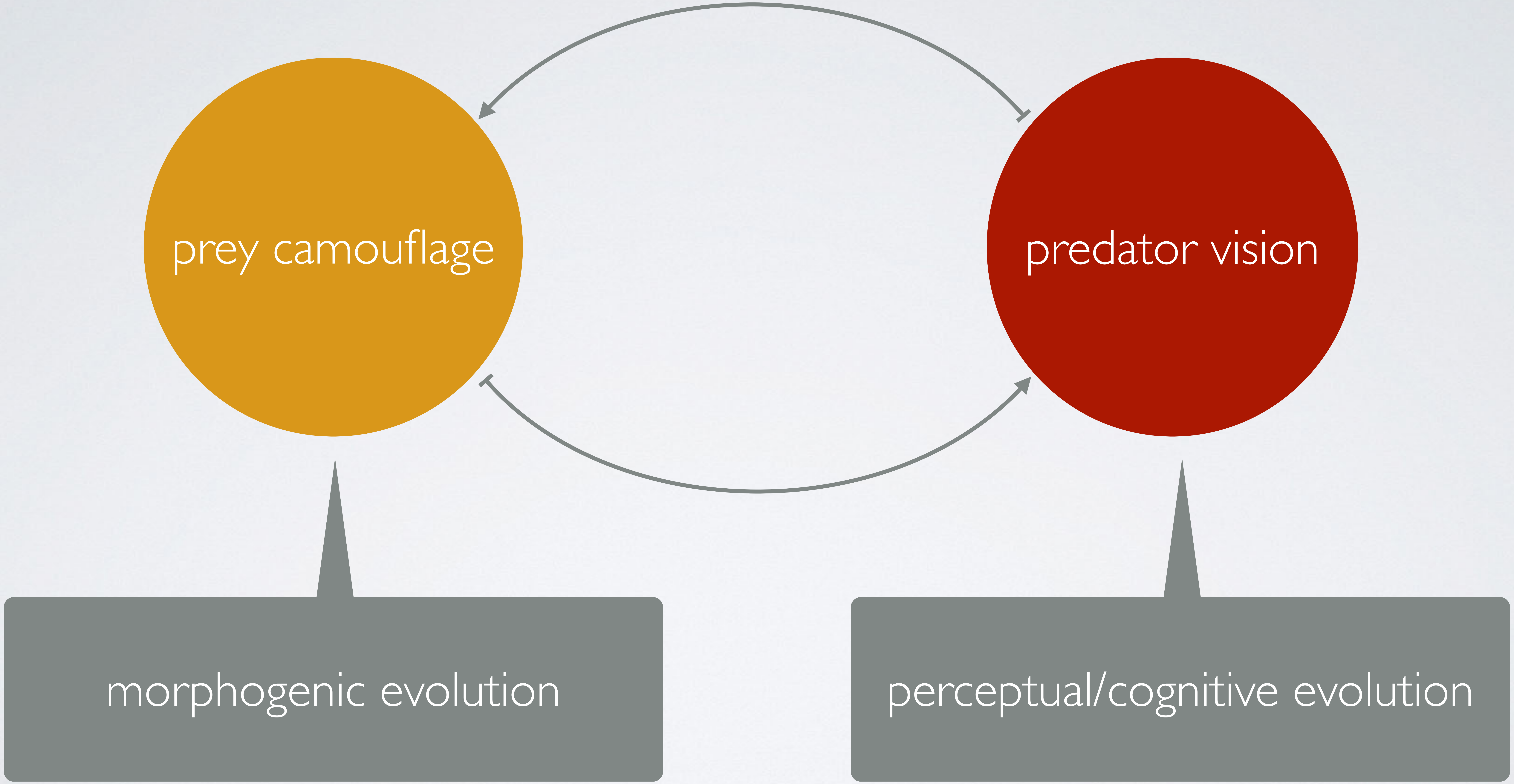


Cohort of ten prey with evolved camouflage over a photographic background of natural texture. In this case: polished serpentine stone.

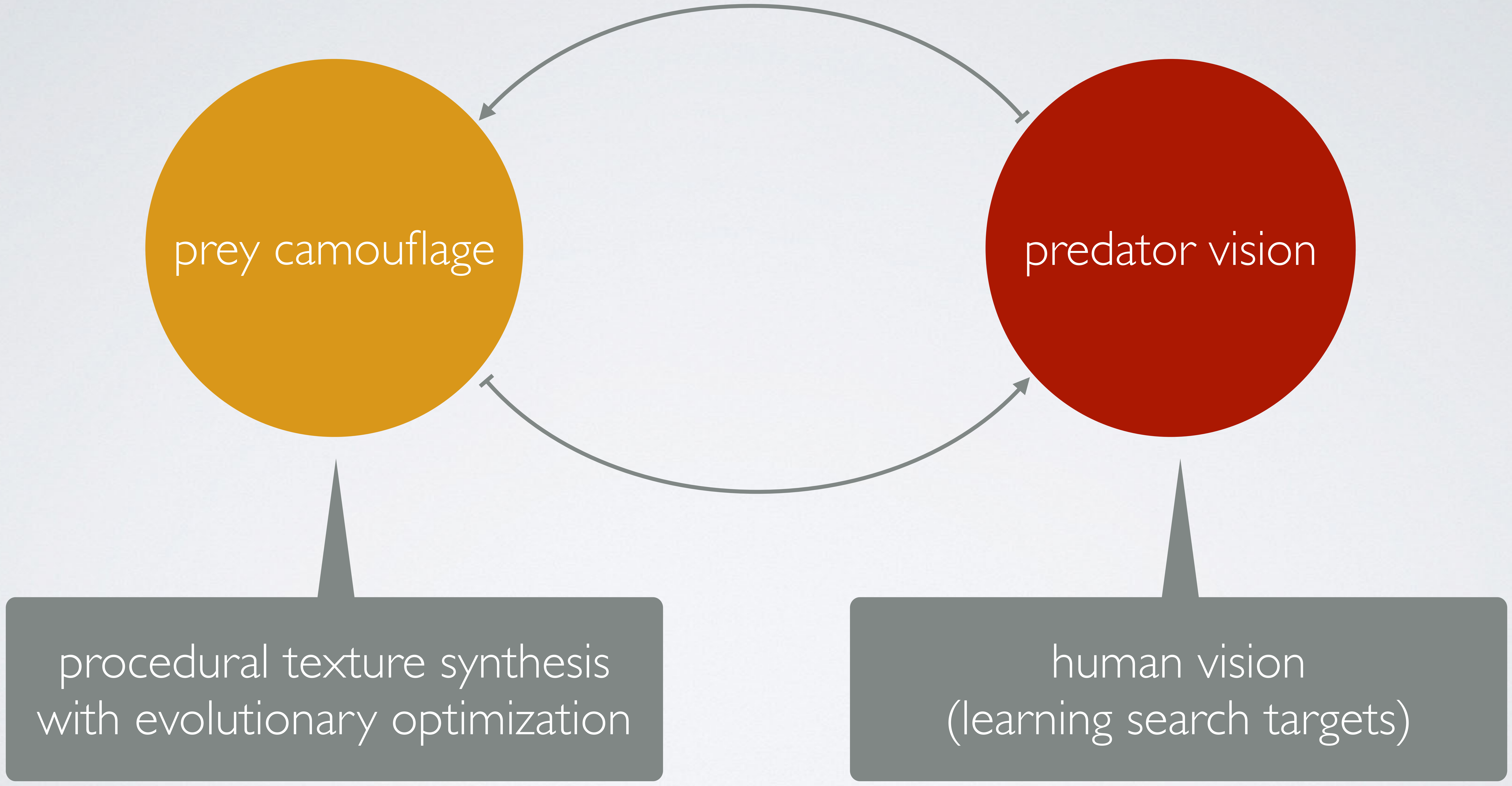
Coevolutionary System:



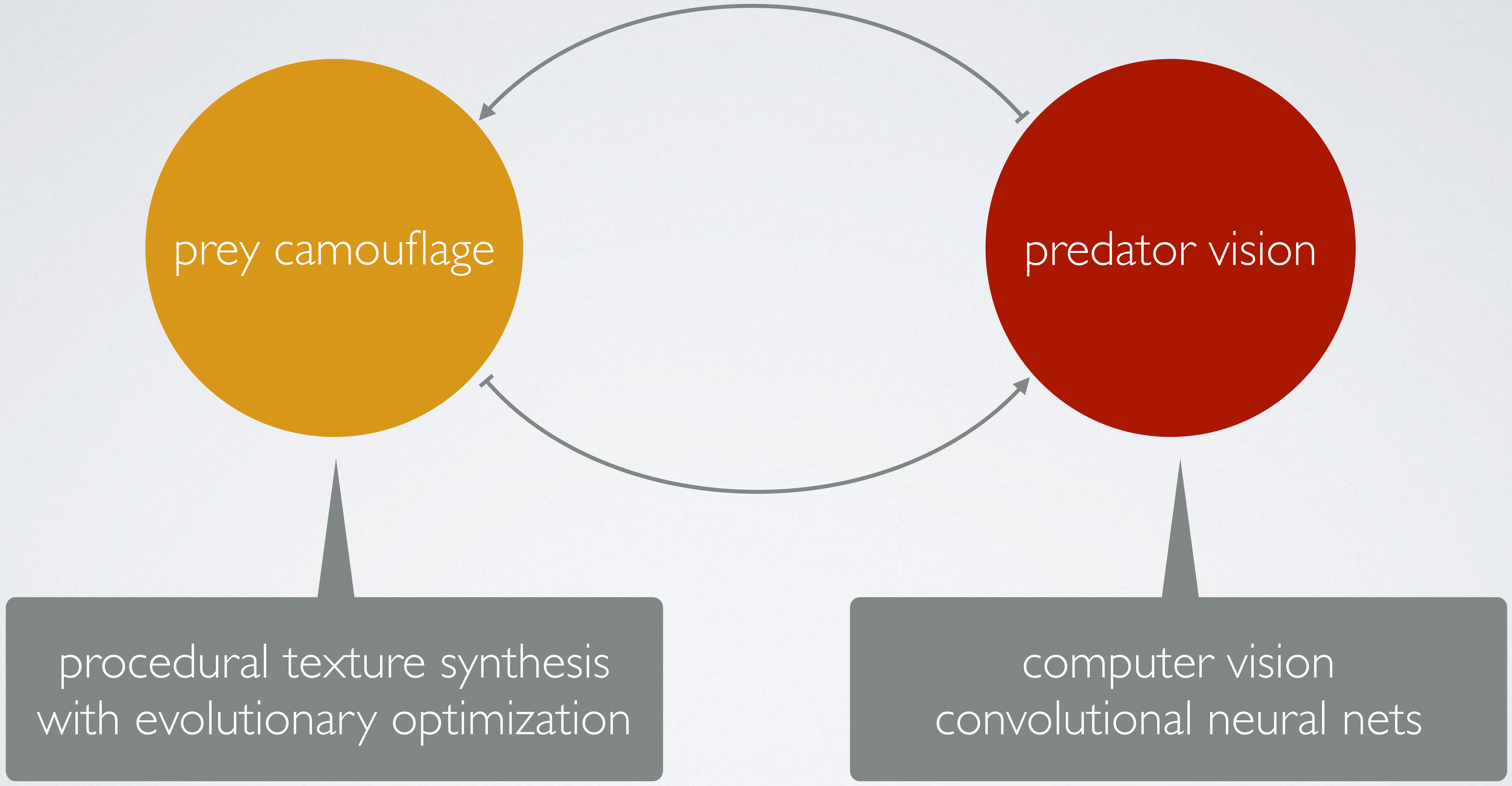
In nature:


prey camouflage
predator vision
morphogenic evolution
perceptual/cognitive evolution

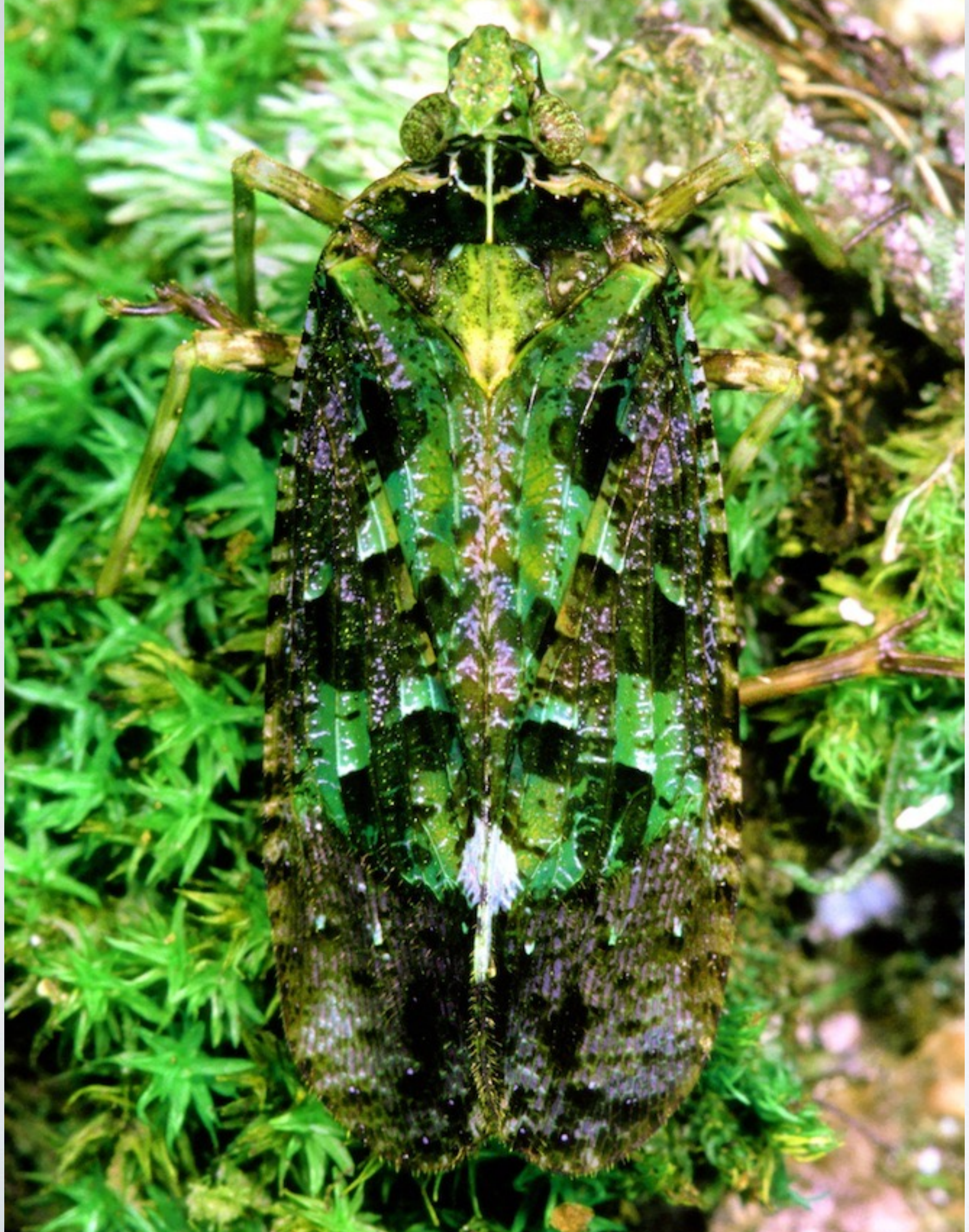
Current version, hybrid of procedural and interactive:



Eventual goal, a fully procedural simulation:



Camouflage in Nature



Malagasy Lanternfly, forest canopy, Madagascar

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

Bark bug, Peruvian Amazon

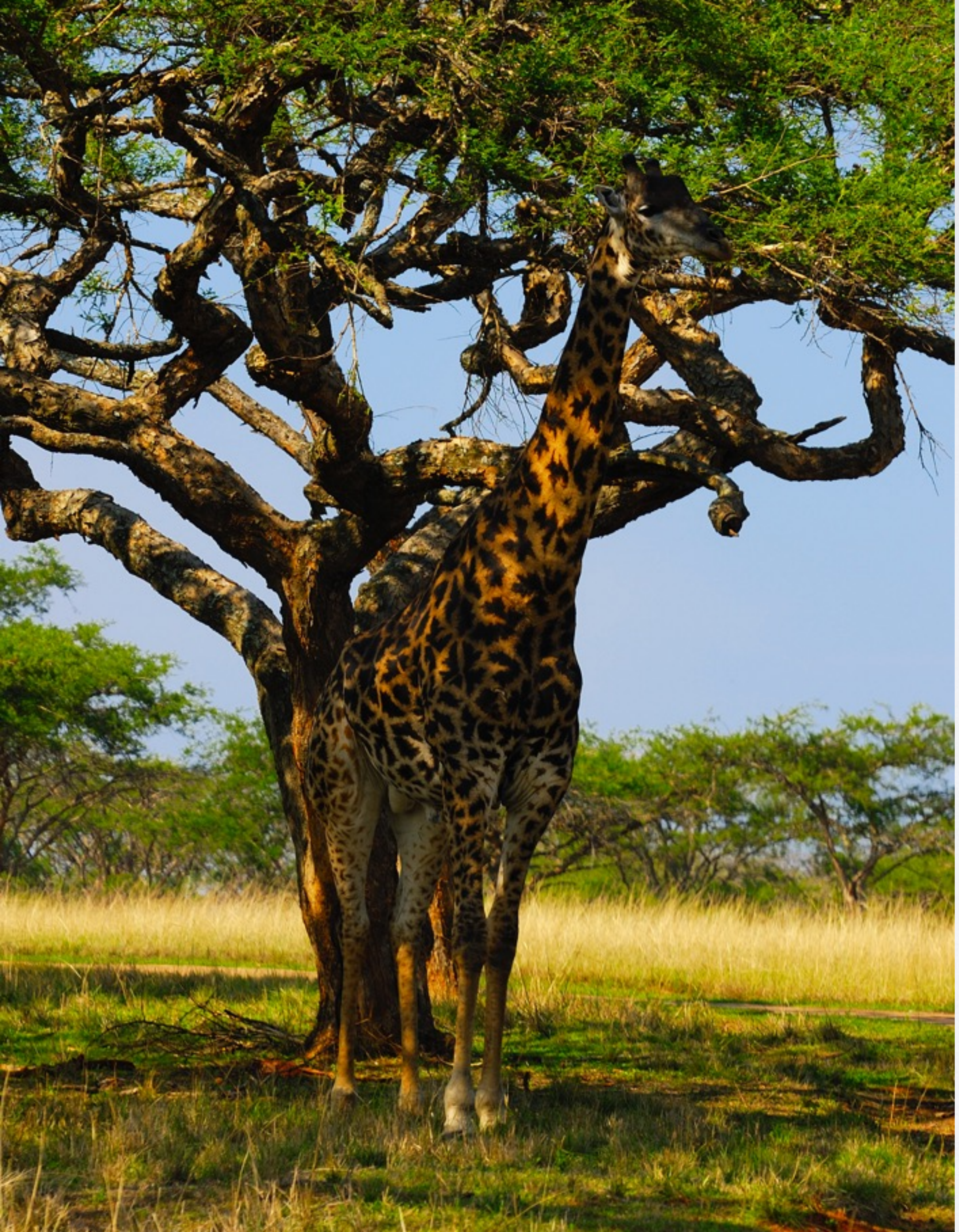
Juvenile C-O sole
(*Pleuronichthys coenosus*)

Tawny frogmouth owls (*Podargus strigoides*)

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



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)))

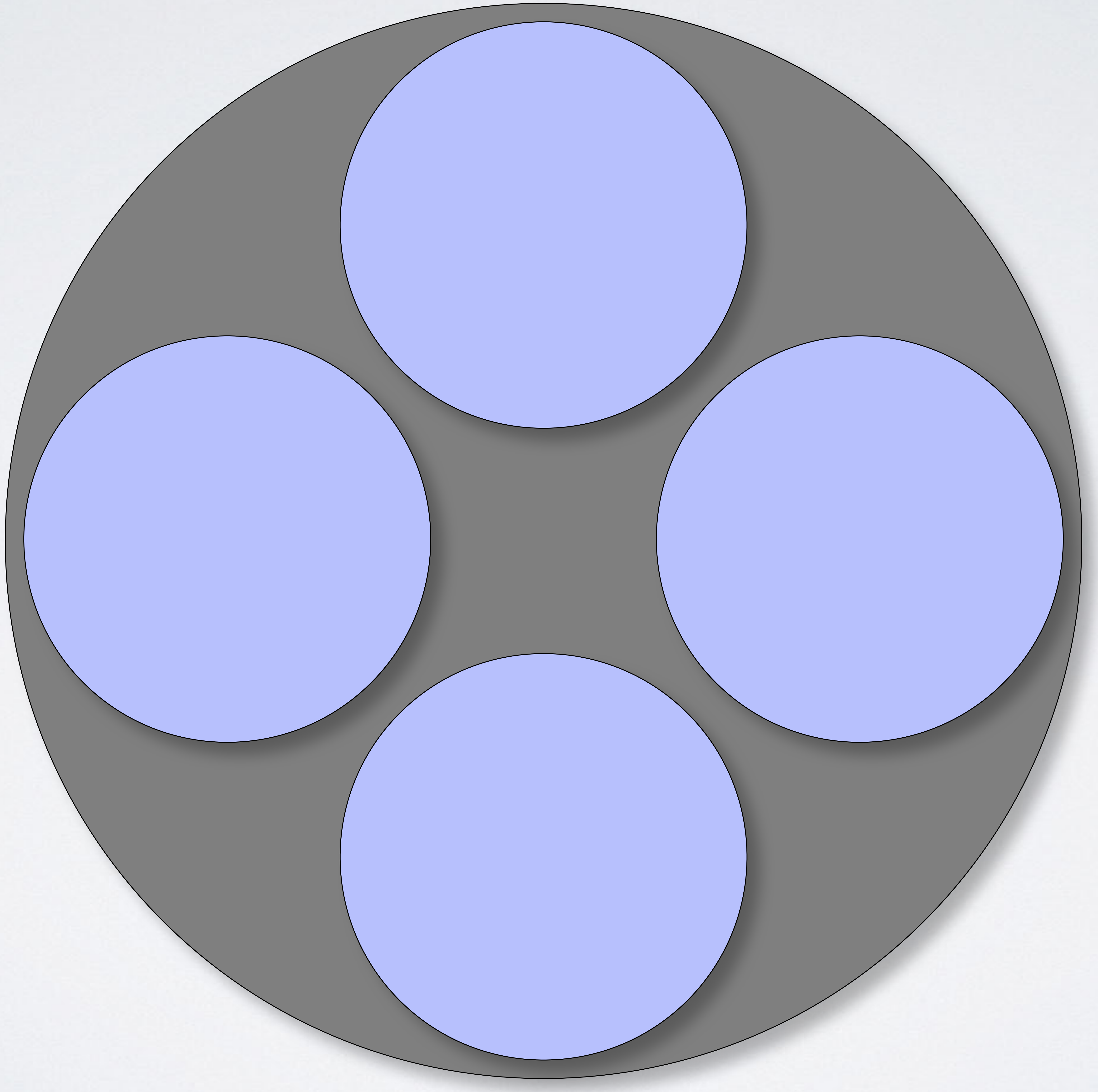
x (y (w (6, 2), 3), z (9))

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

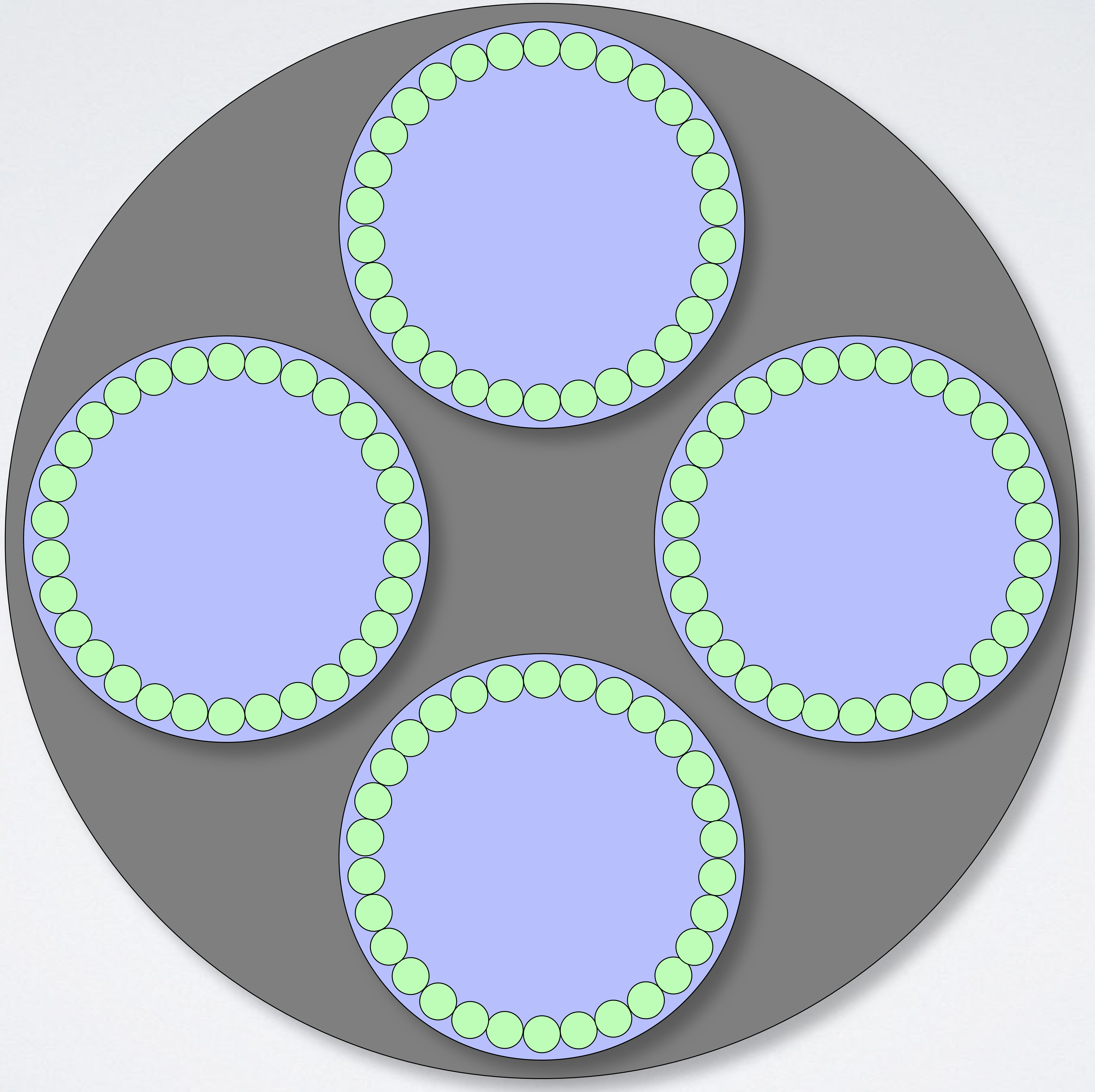
x (y (w (6, 2), 3), z (9))

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

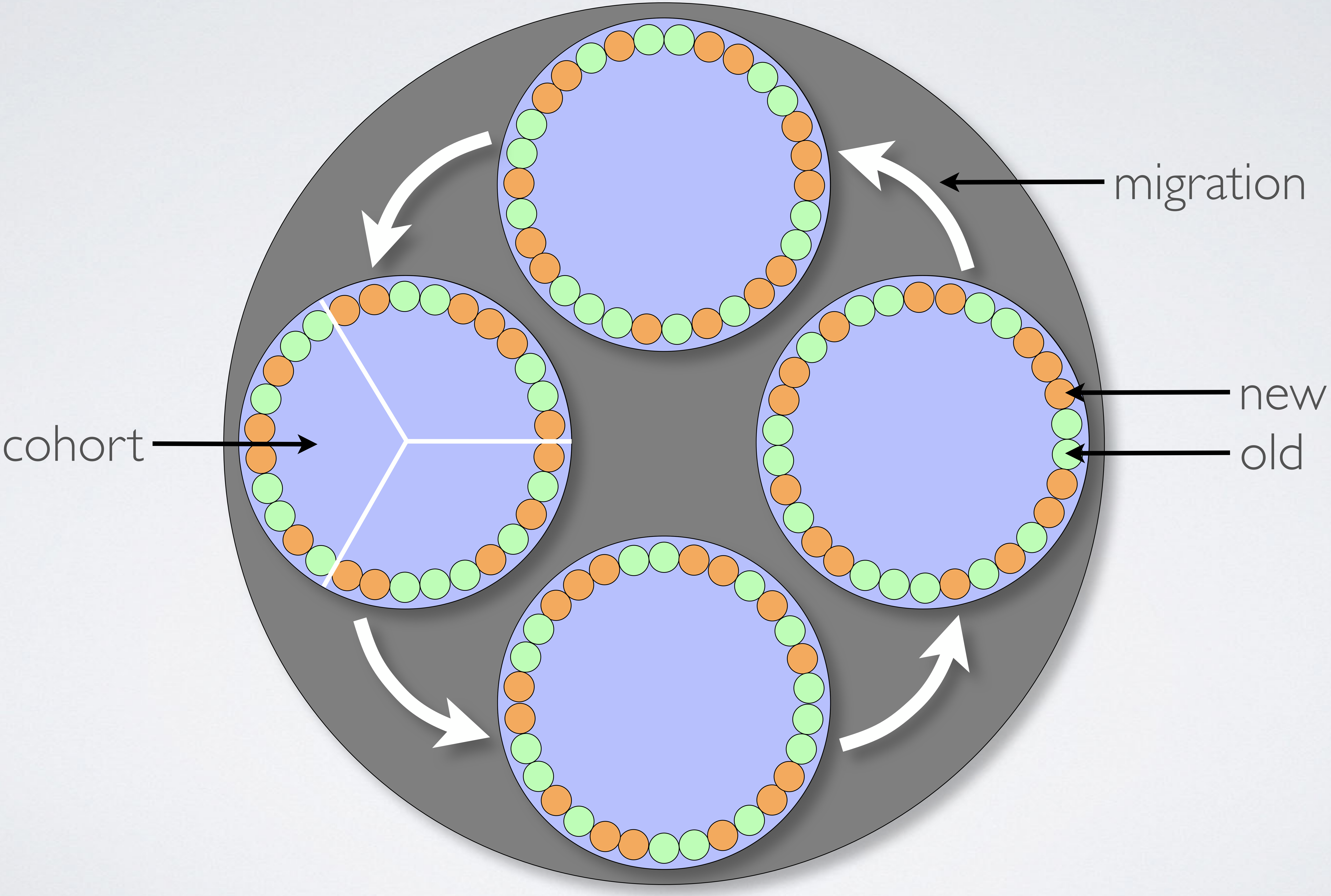
Population divided into 4 demes



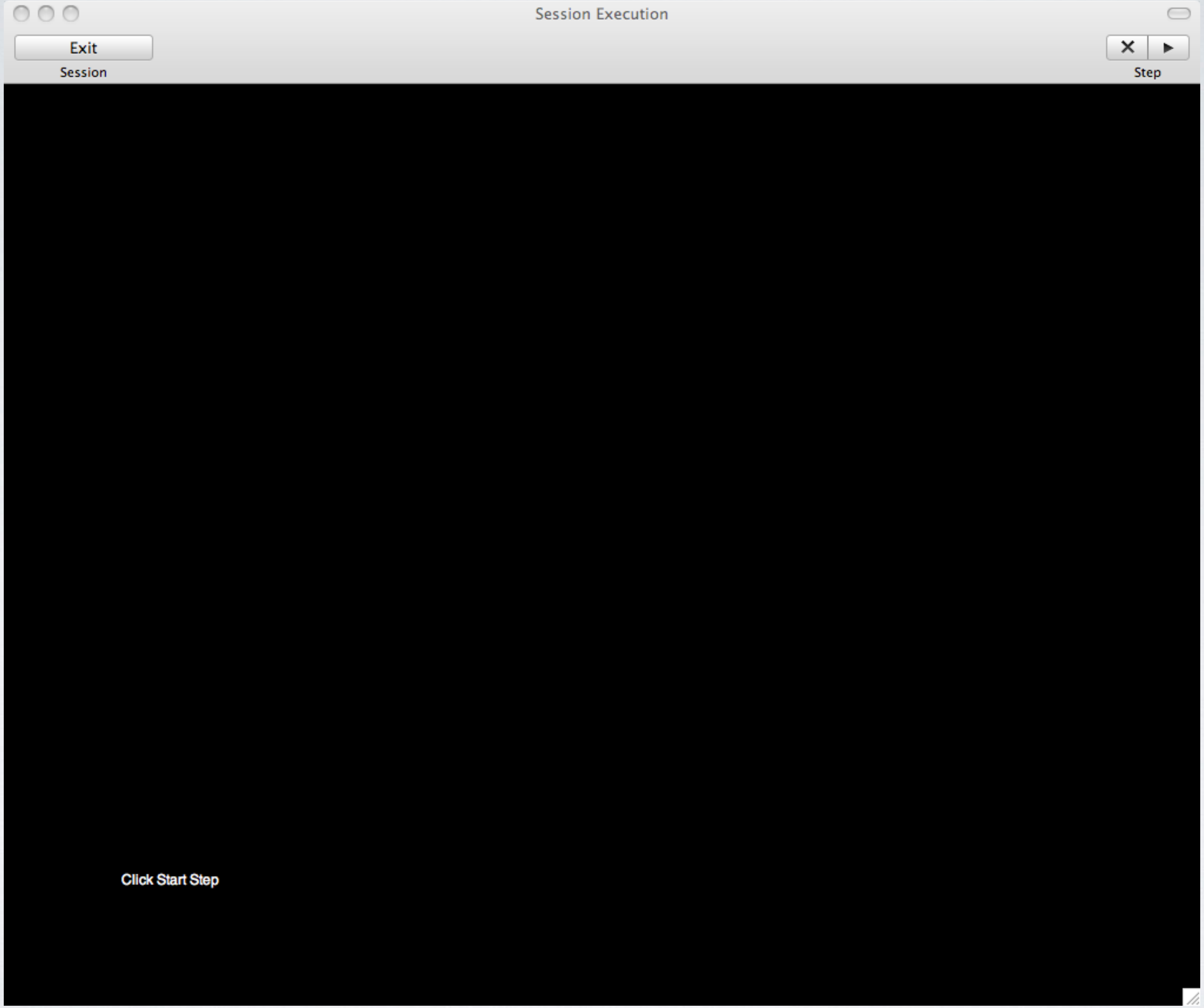
4 demes of 30 individuals



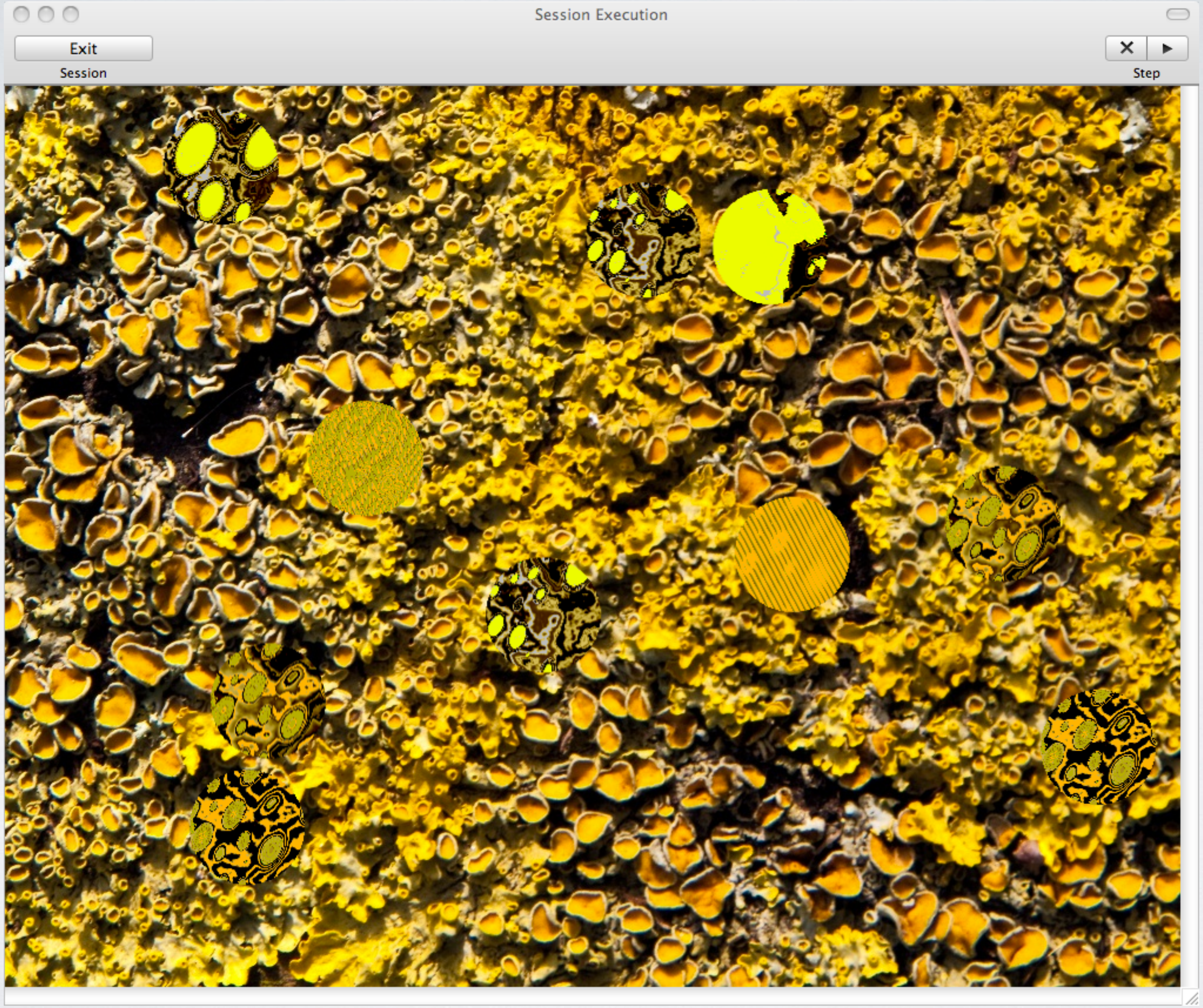
cohorts, migration, elitism



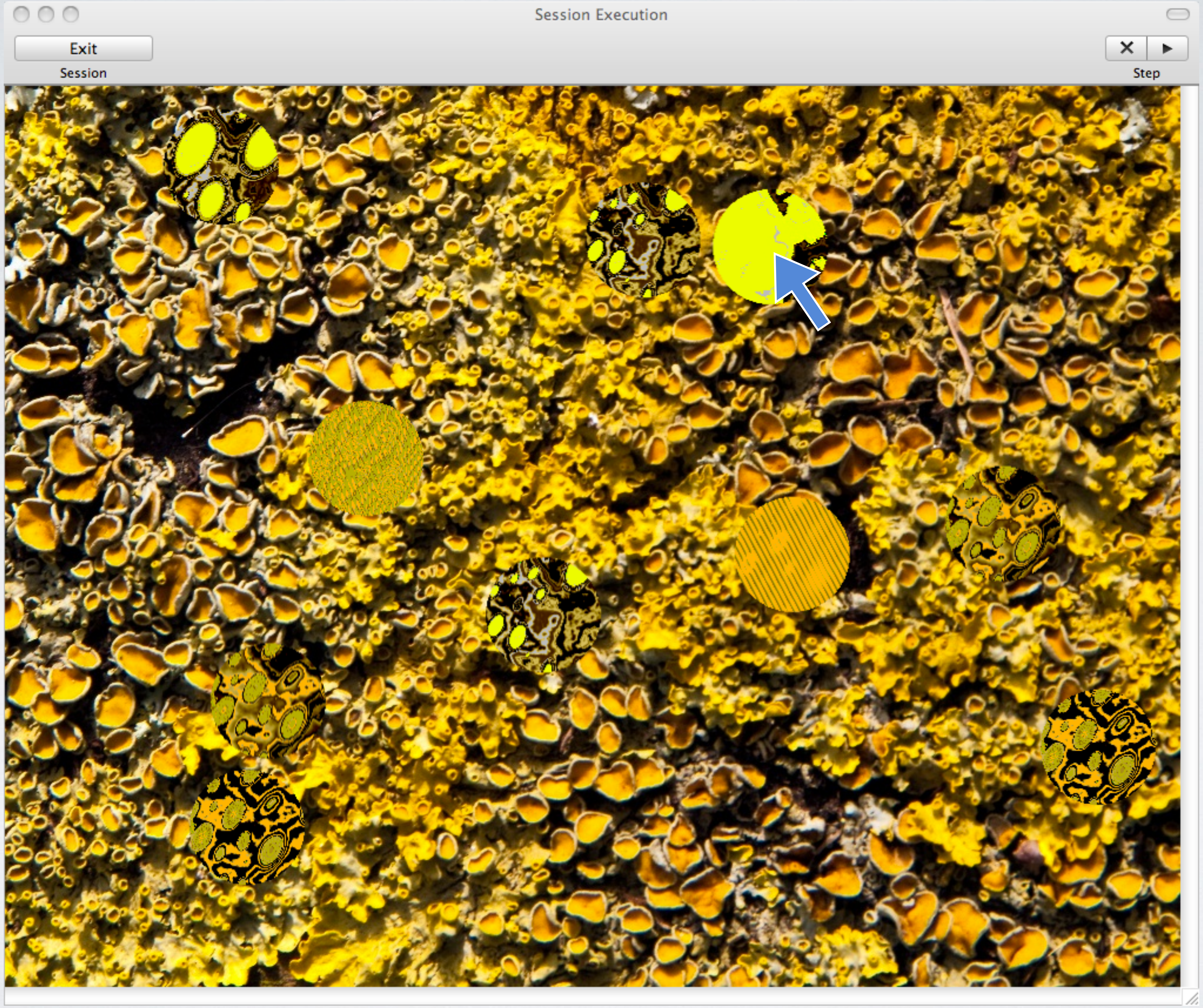
Camouflage:
user interaction and GUI



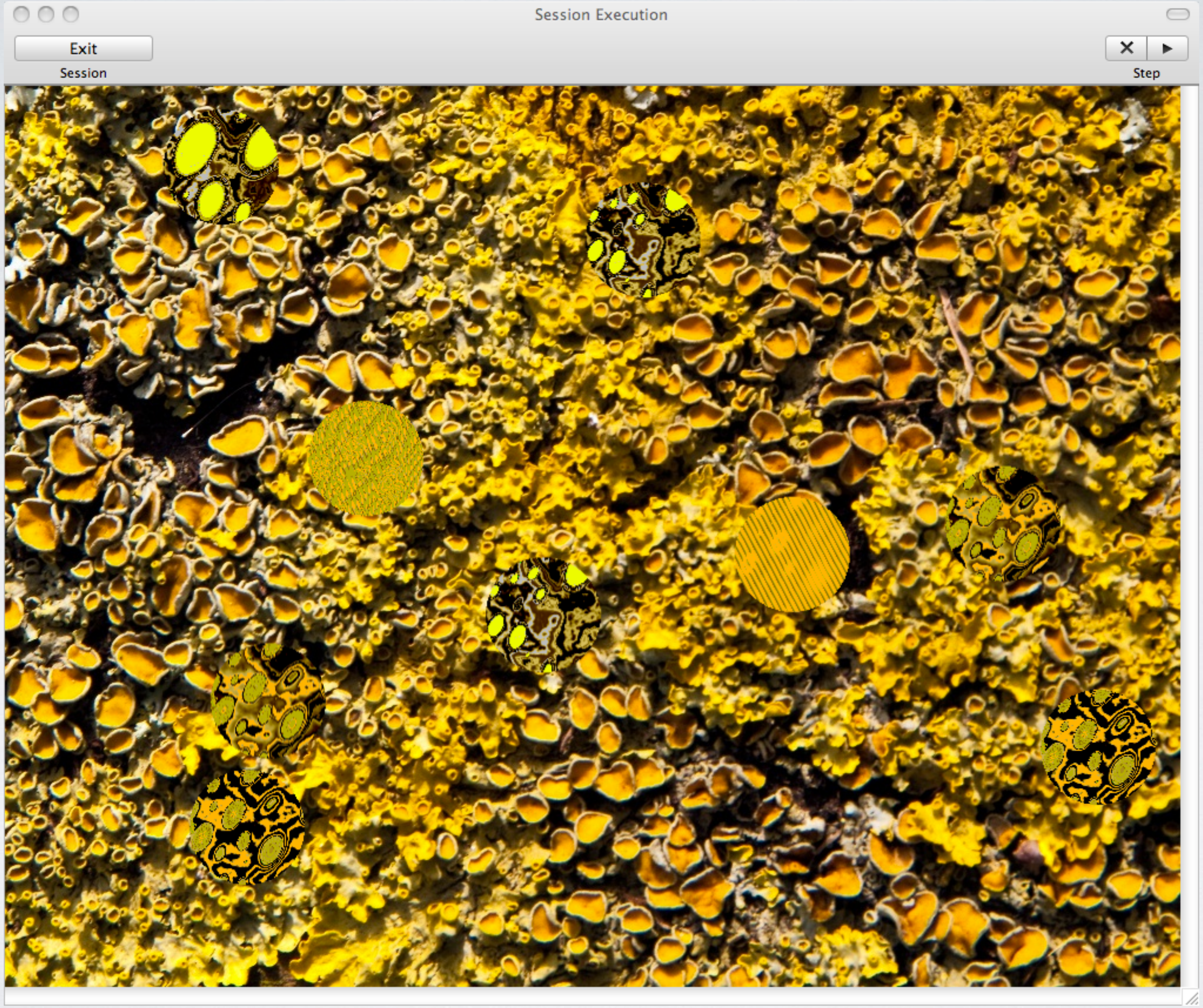
Start of "camouflage game" for one cohort of 10 evolved prey.



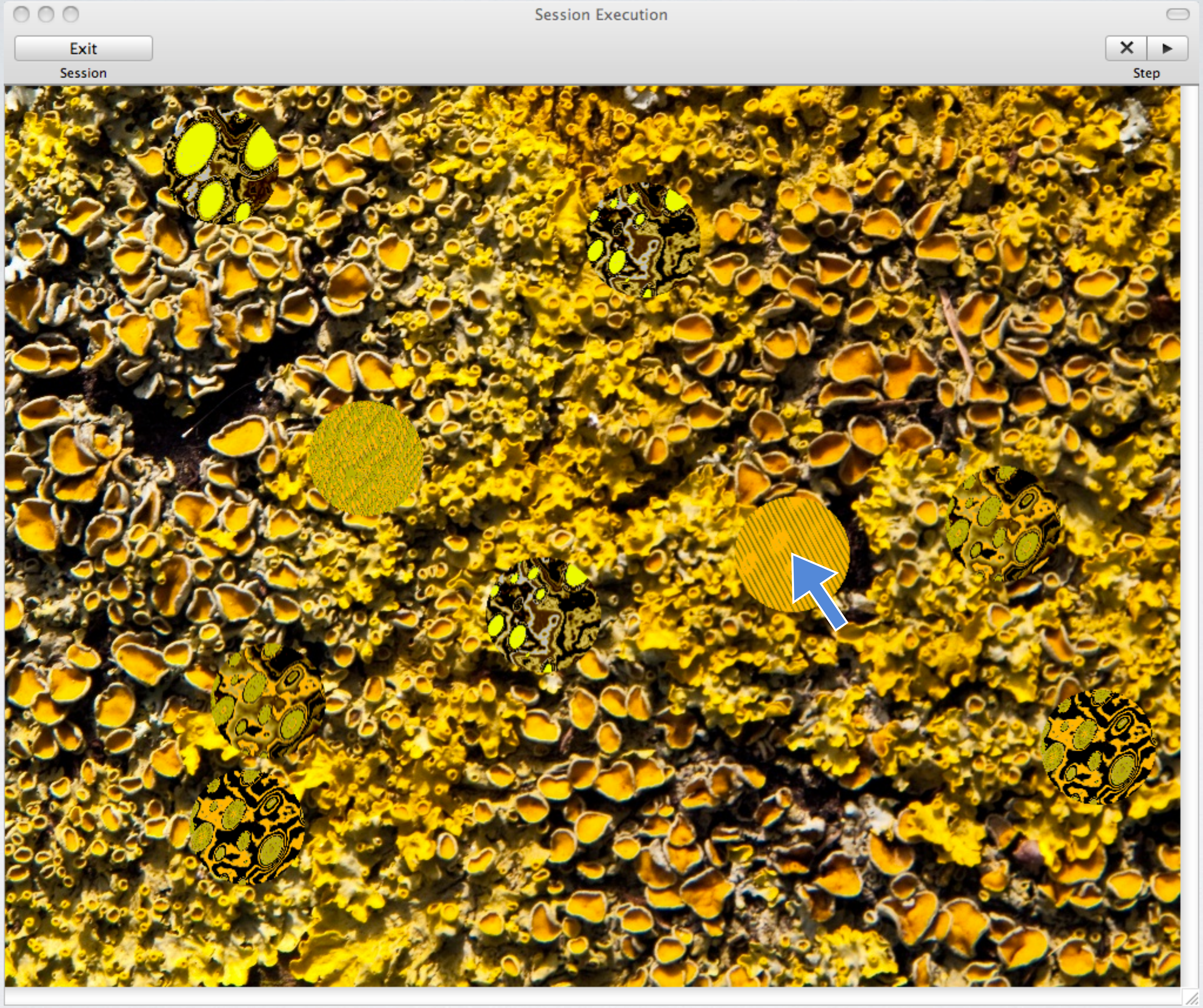
10 prey



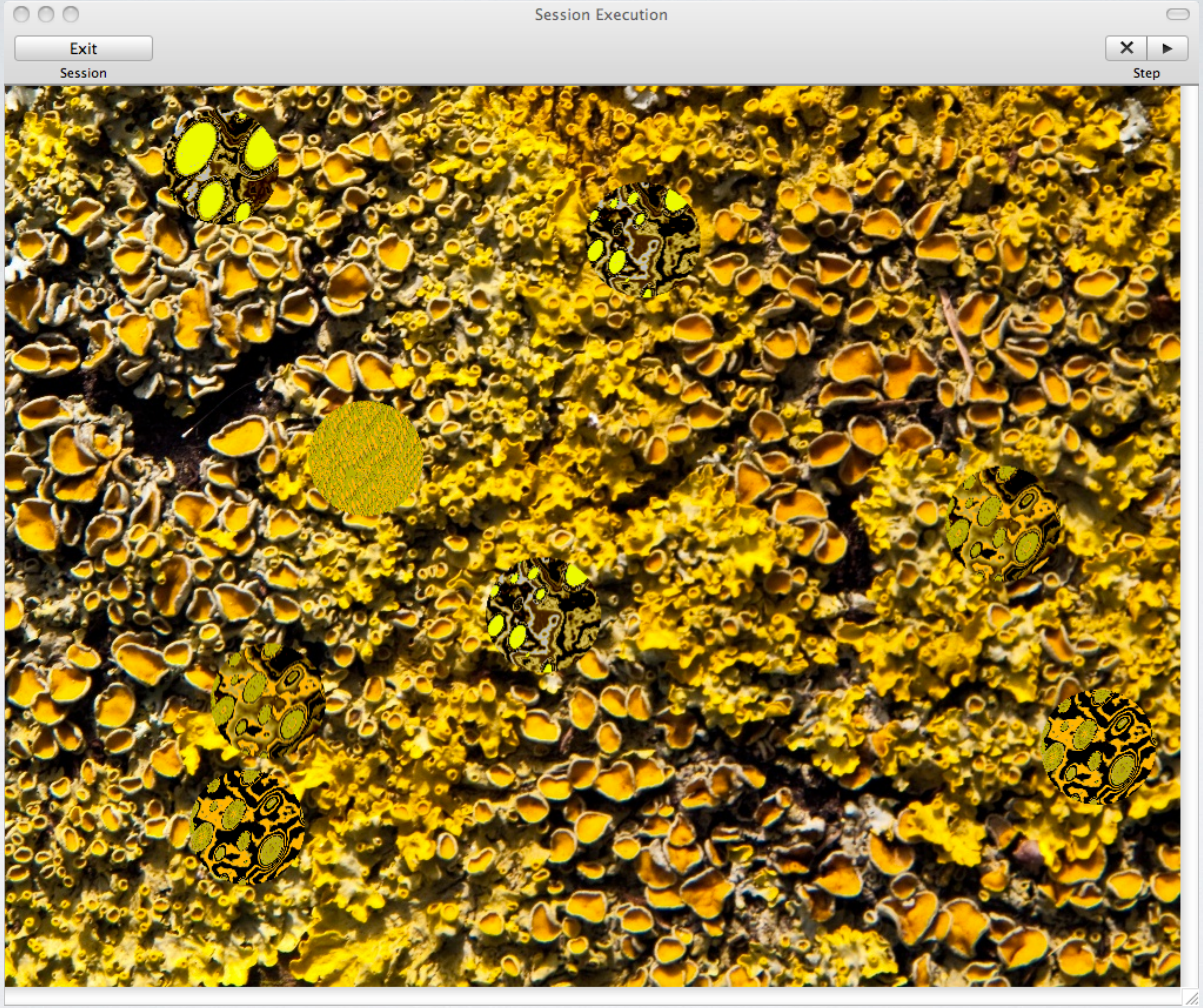
Predator selects prey 1.



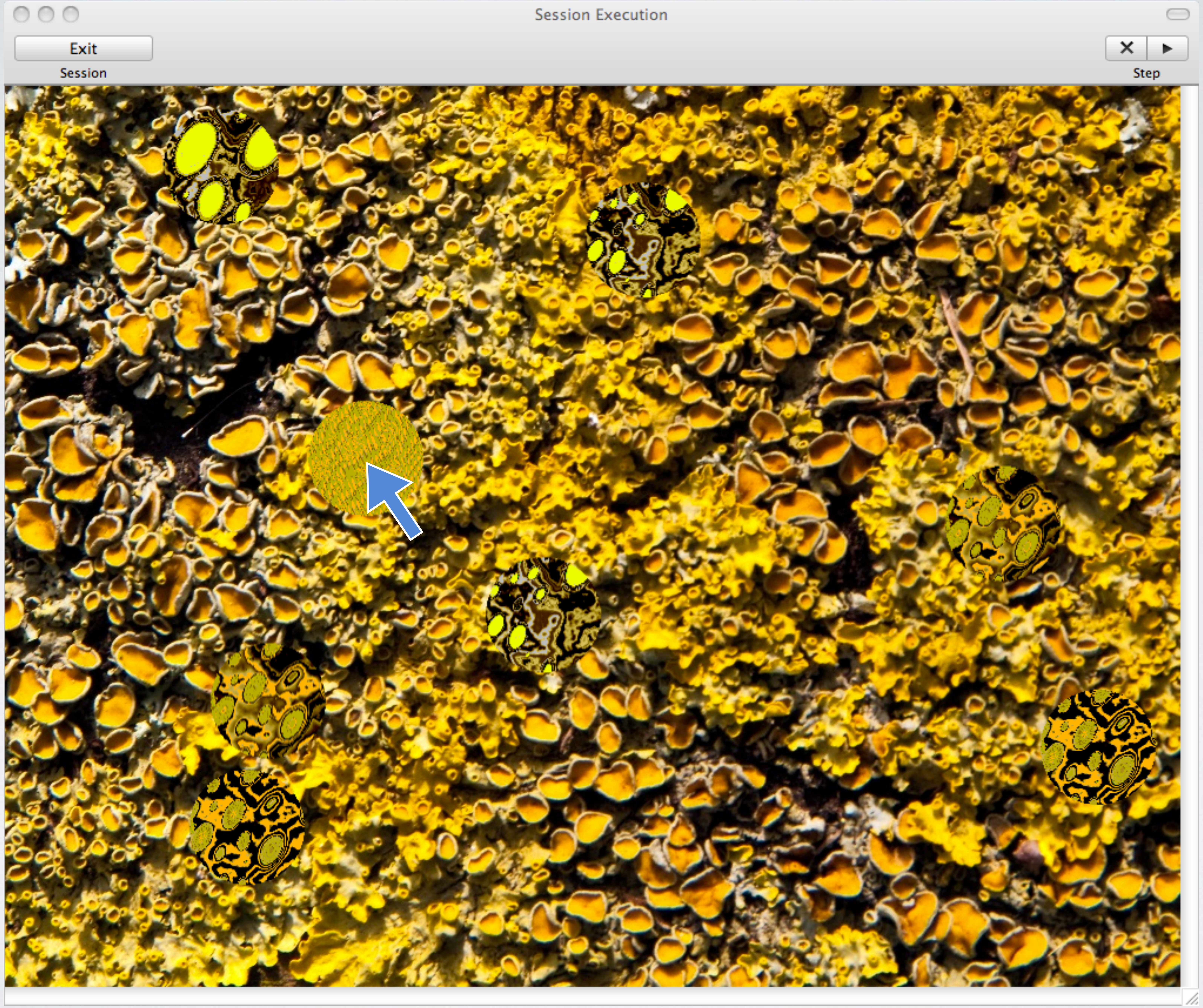
9 prey remain.



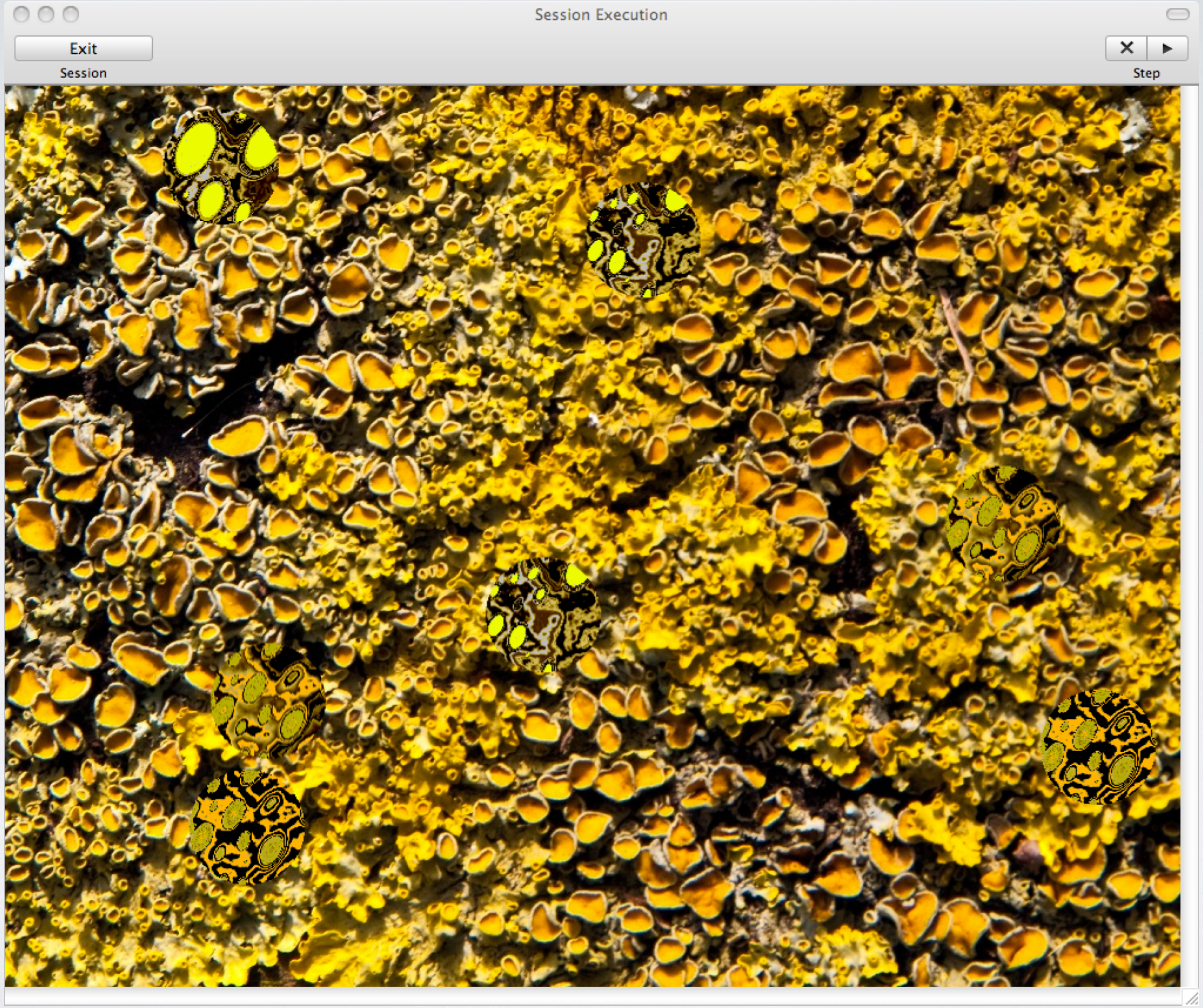
Predator selects prey 2.



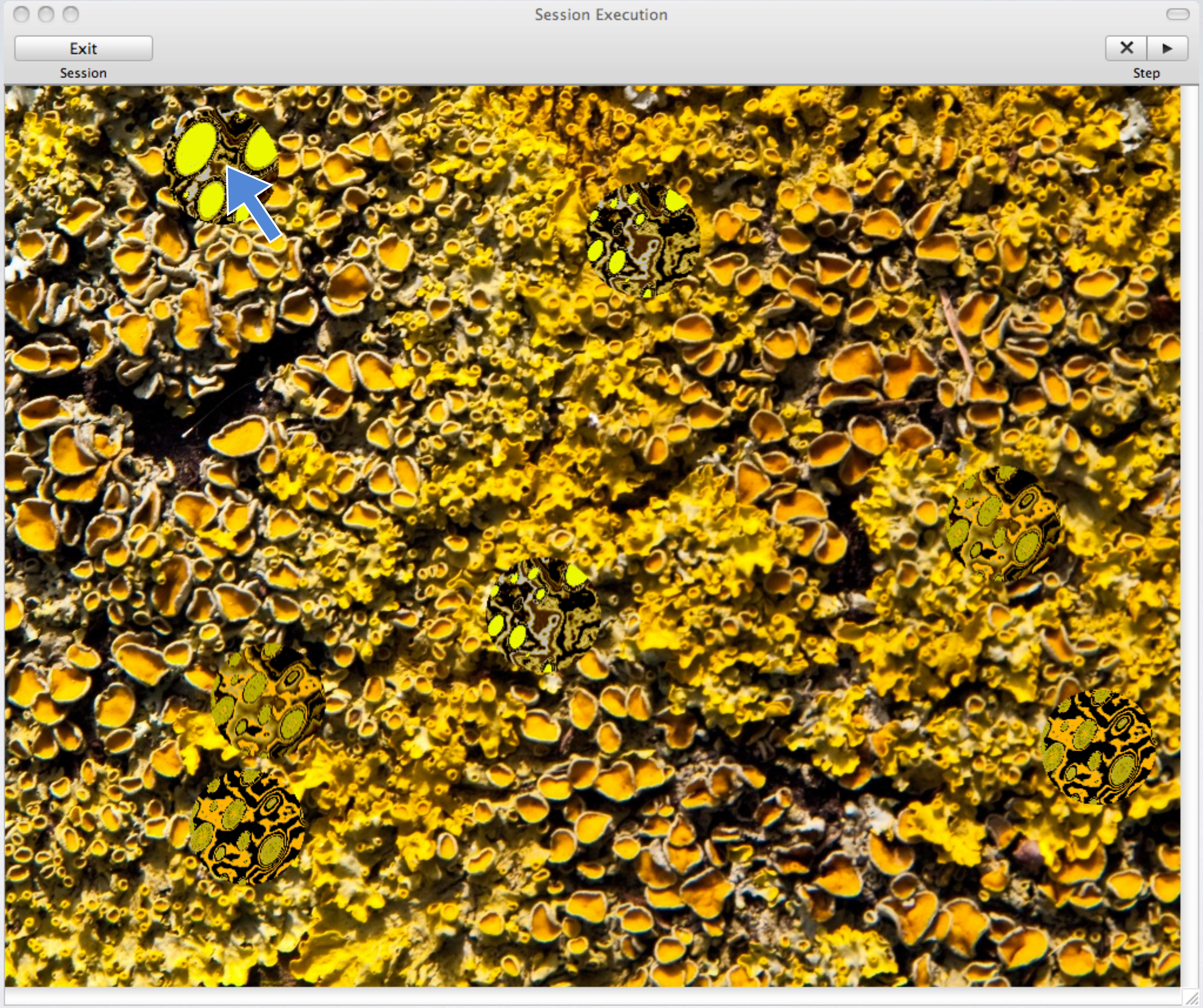
8 prey remain.



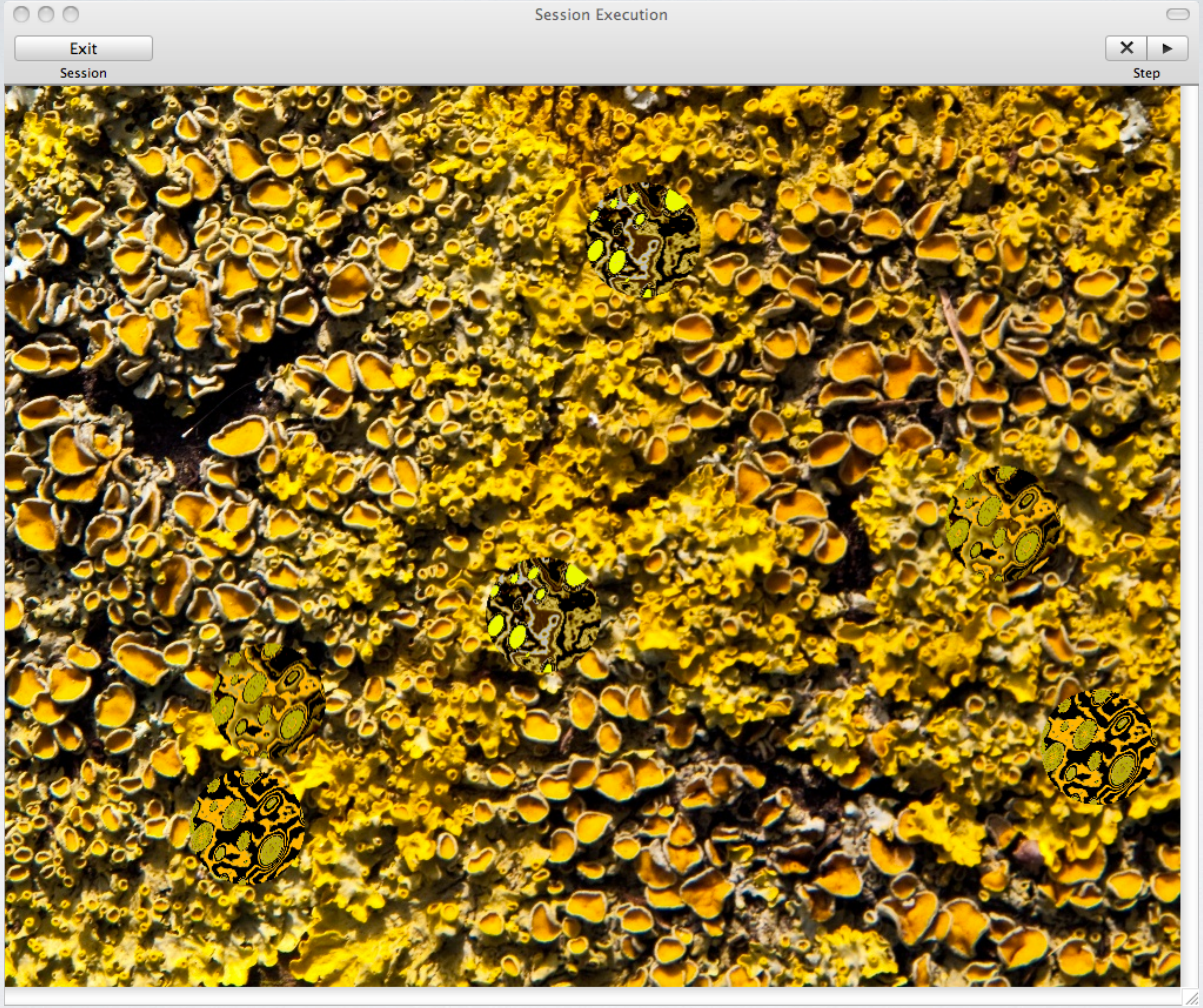
Predator selects prey 3.



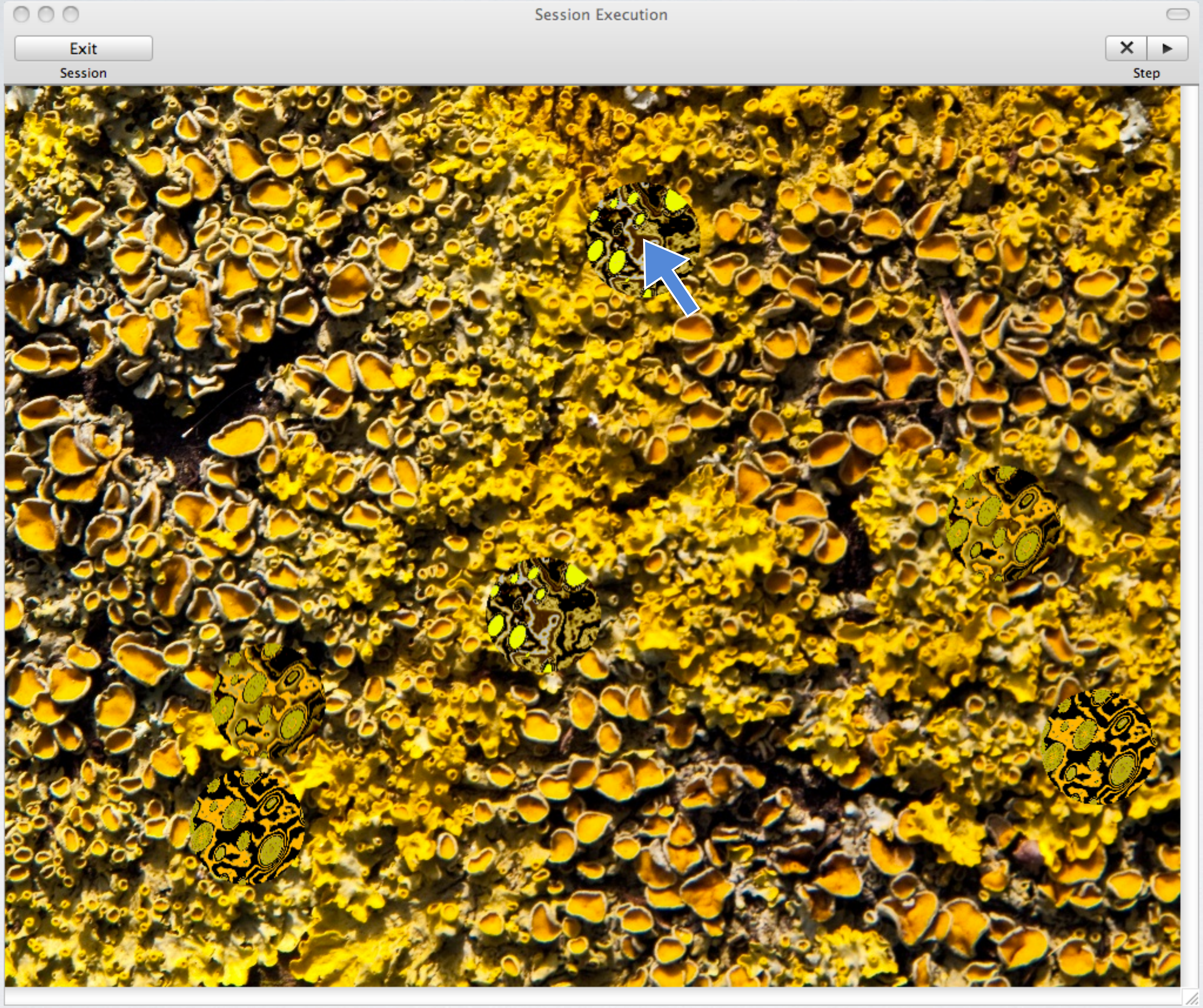
7 prey remain.



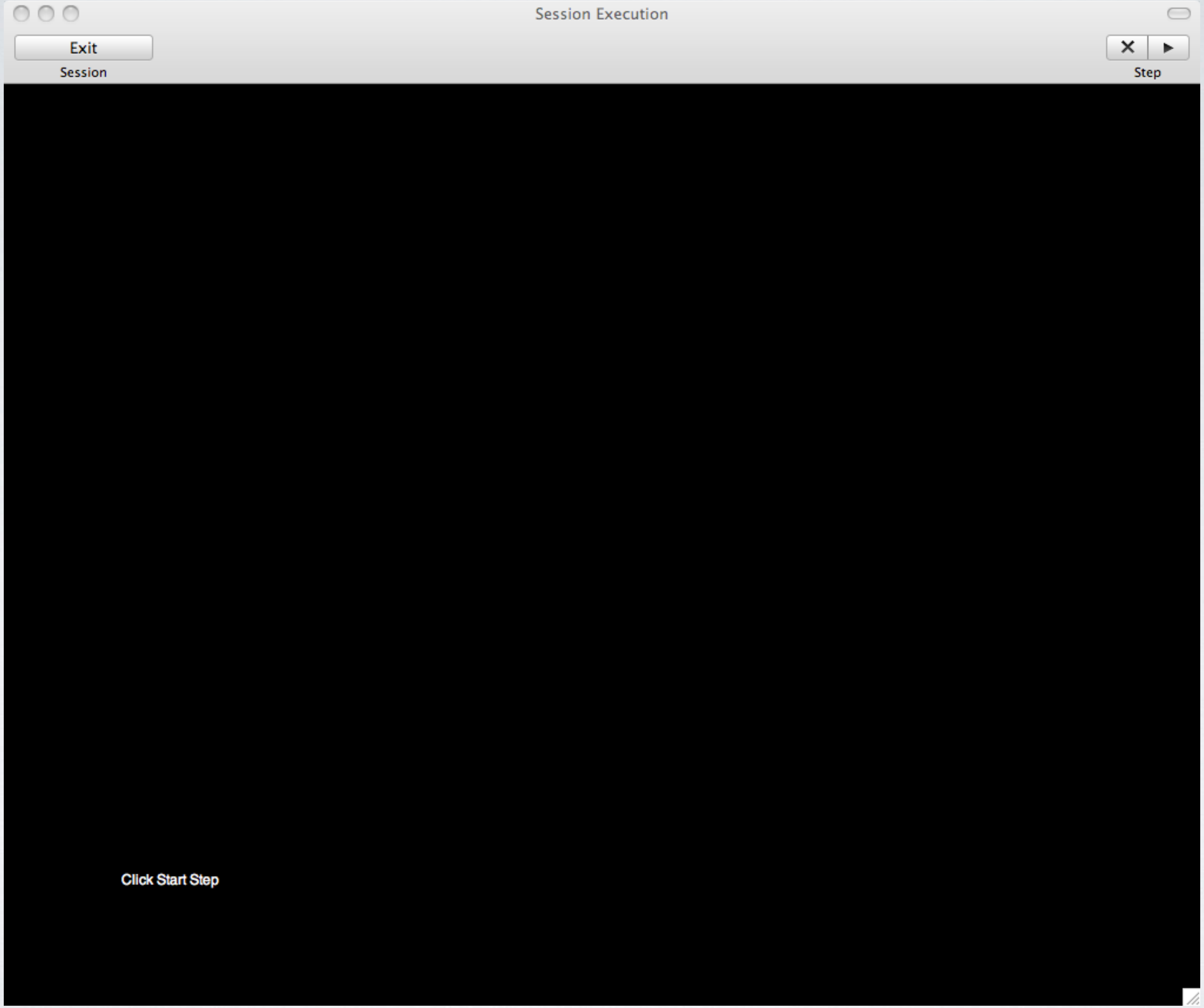
Predator selects prey 4.



6 prey remain.



Predator selects prey 5.



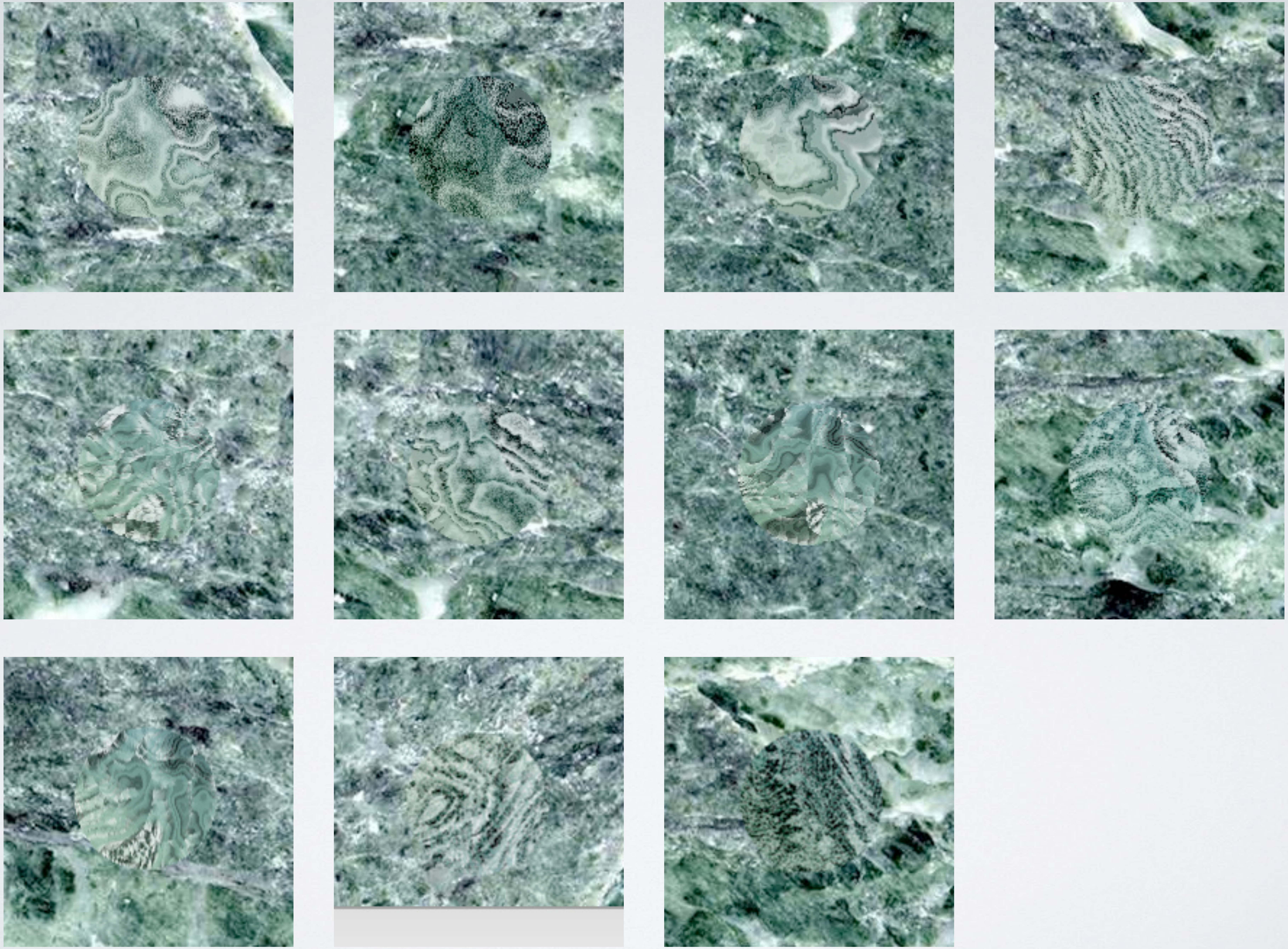
End of "camouflage game" for one cohort of 10 evolved prey. 5 prey have been eaten, and 5 survive.

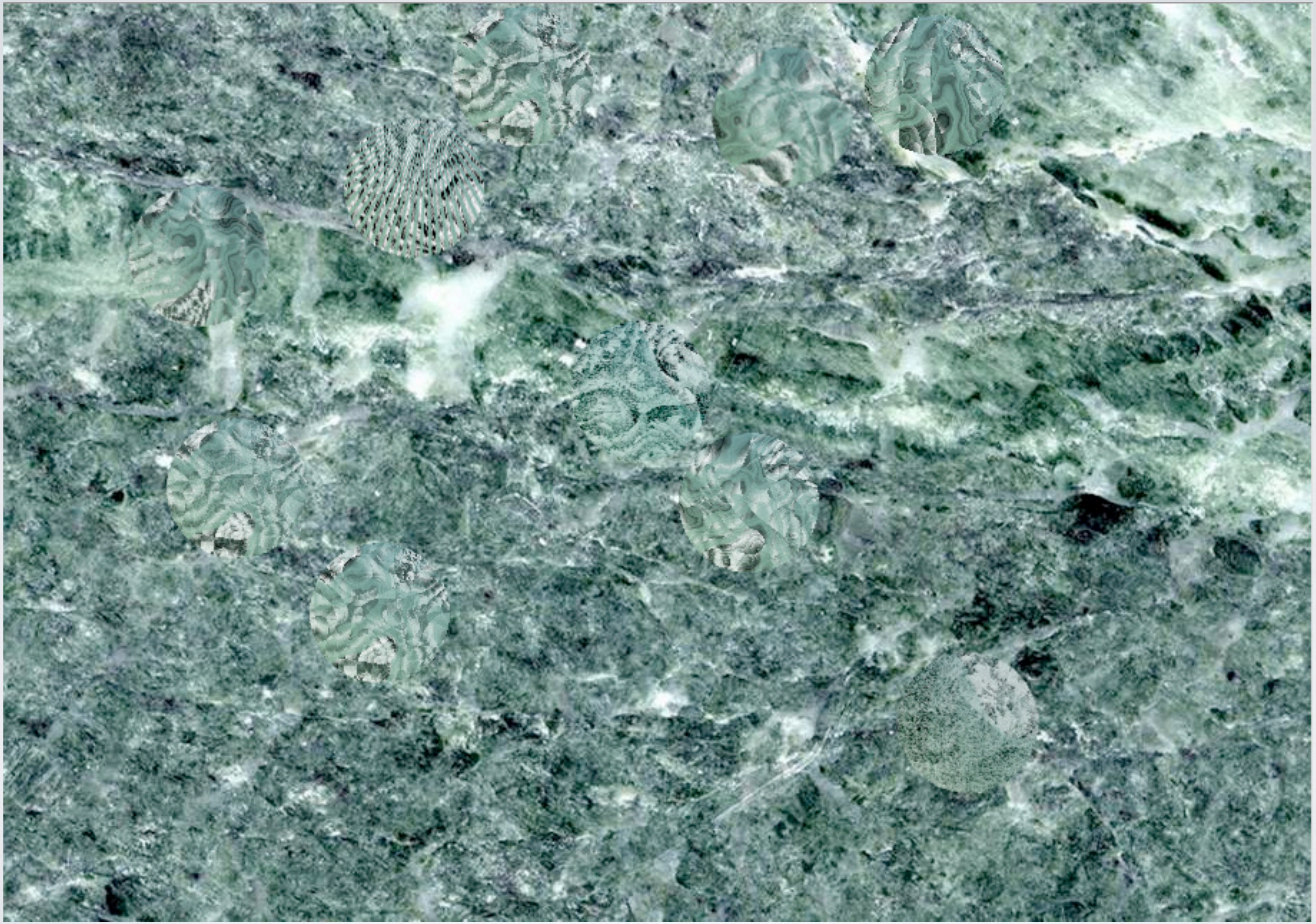
TYPICAL RUN

- 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

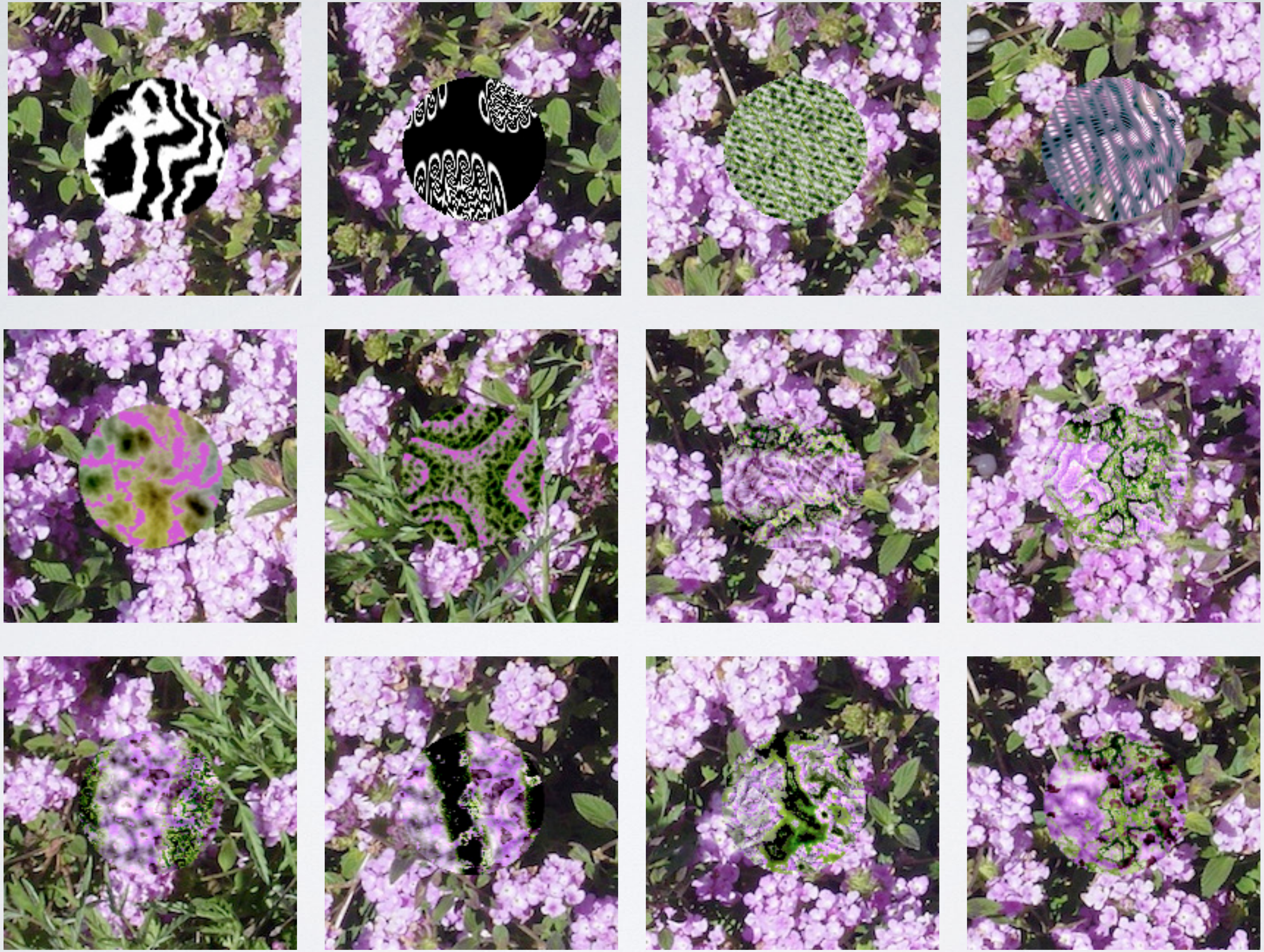
Serpentine
(polished stone)



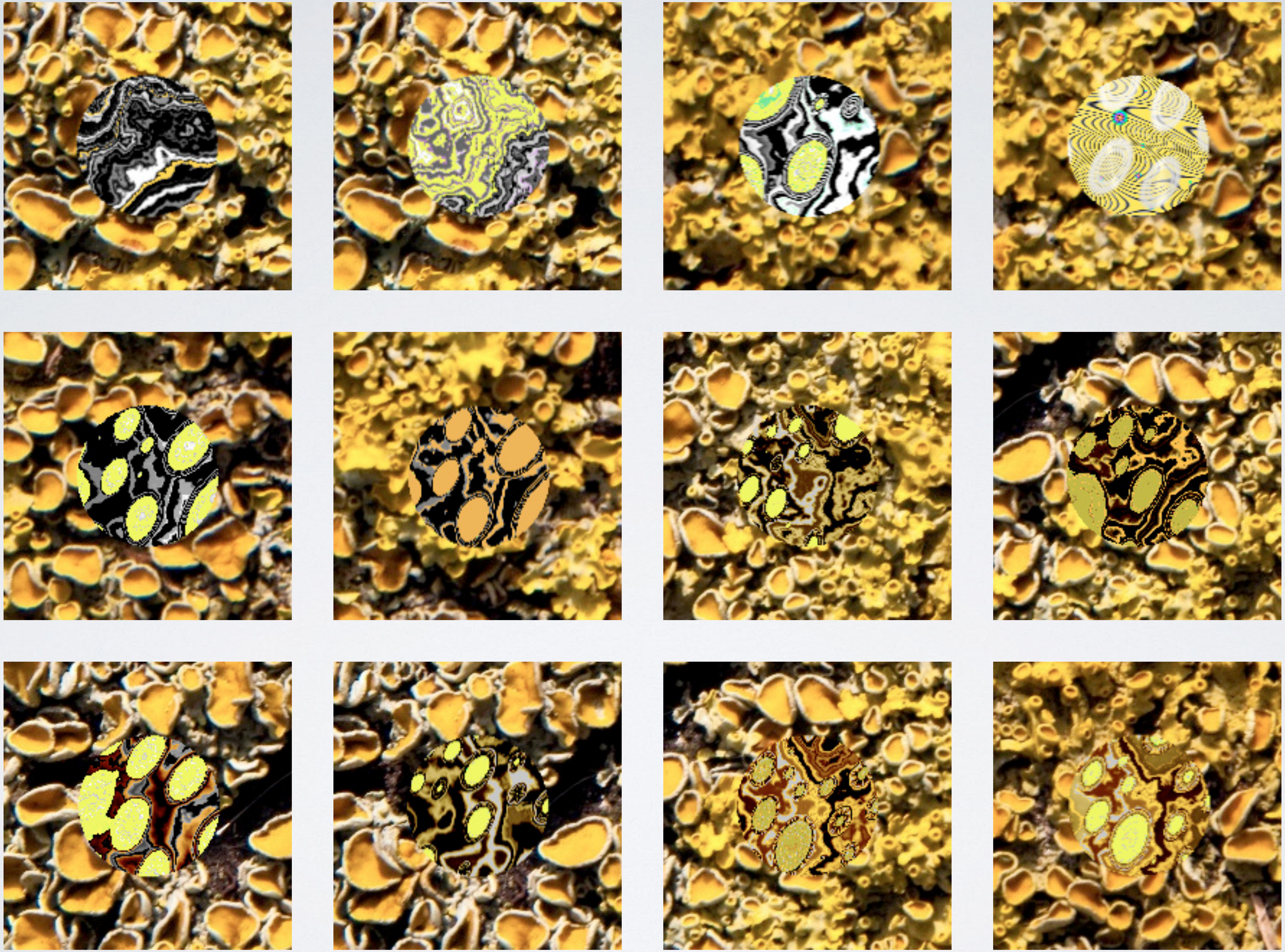


Flowers and leaves

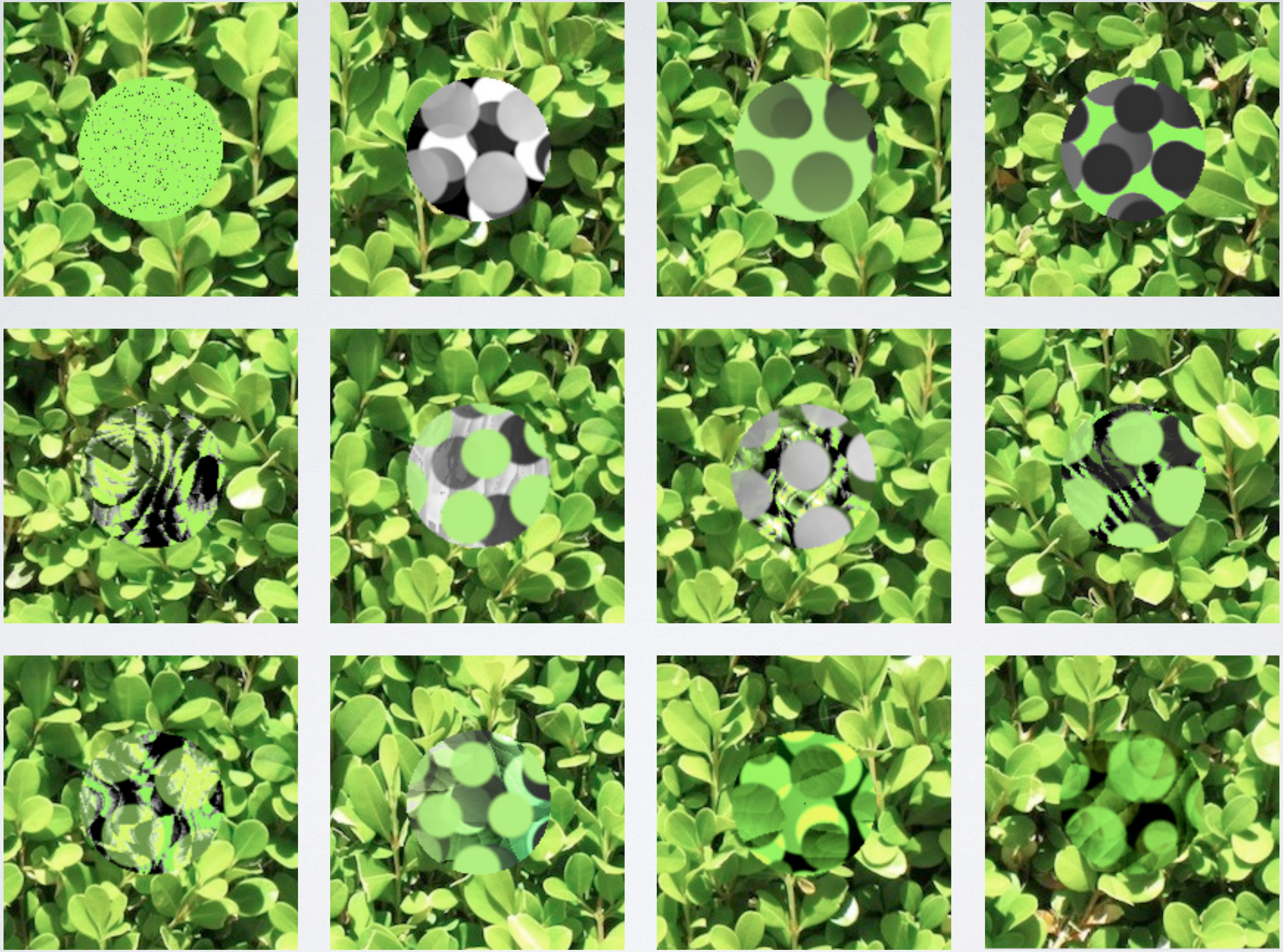
(*lantana montevidensis* in my backyard)



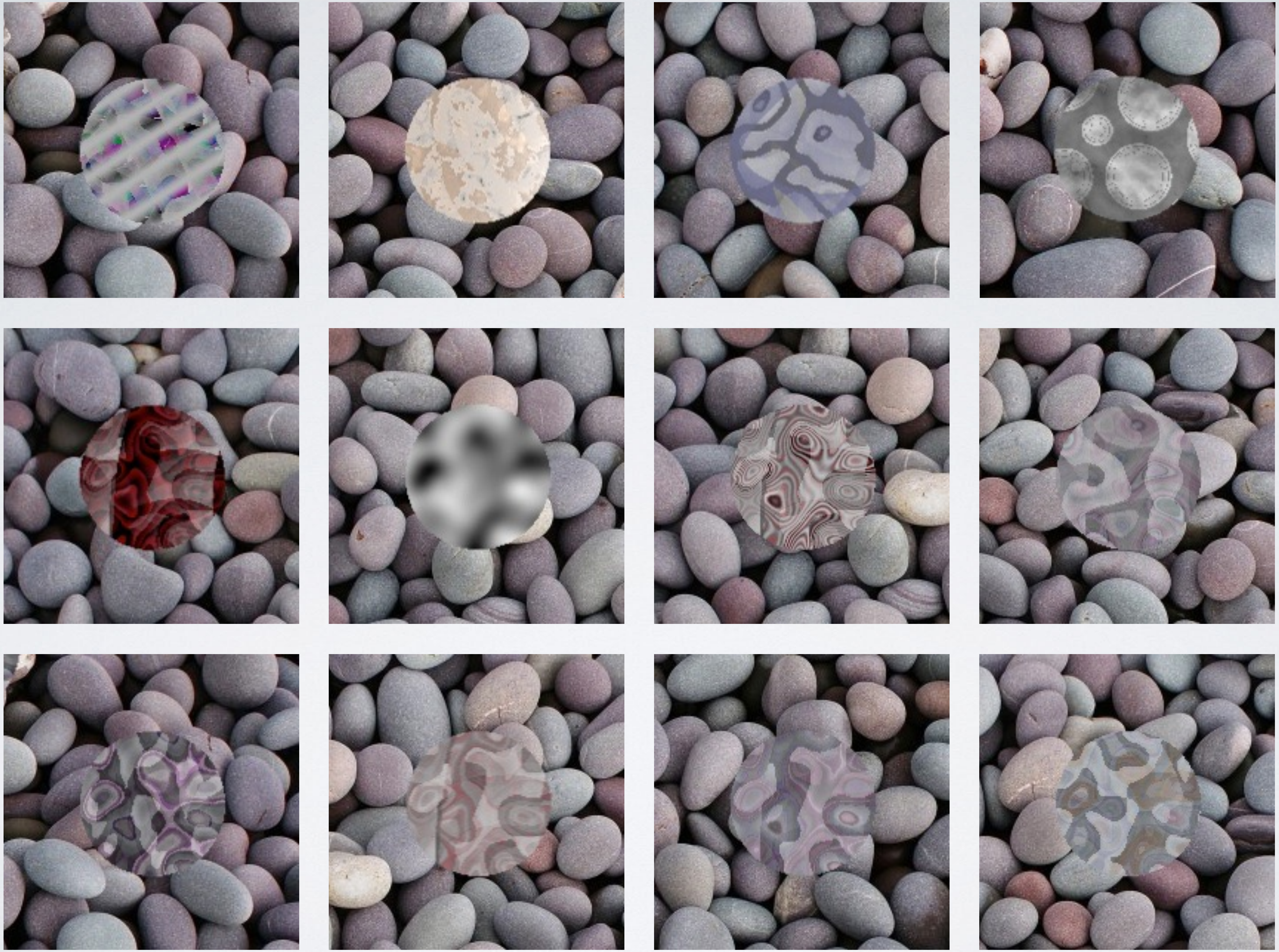
Lichen



My neighbor’s hedge



Beach Pebbles



Research in Industry

(at the risk of ending on a depressing note…)

Despite some occasional good projects, I've found it difficult to do "blue sky" research in industry.

Tomorrow morning Stephen Wolfram may have a different perspective. I am not an entrepreneur.

My jobs have been either software engineering or research intended to lead directly to product development and contribute to the bottom line.

My most innovative work has often been done "off the books", without the boss' approval, or at home on nights and weekends.

The SCCS organizers asked me to discuss this issue. I warned them it would not uplifting "career advice".

I pointed out that Symbolics, where I did my work on boids, eventually laid me off.

At Sony, I pursed research on real time boids, stigmergy, and camouflage. Then they laid me off.

I've become convinced that if you want to do research for it own sake, and not as a step leading to commercial product development, academia is the place to do it.

That is where I would be now, if not for an ill-considered decision to rush into the commercial work after earning my Masters.

Many people love being entrepreneurs and thrive in the commercial world. I wish them well. But academia is a wonderful cultural tradition.

I encourage those who love pure research to pursue an academic career and devote themselves to the quest for knowledge.

Thank You!

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