Sony Computer Entertainment US Research & Development http://www.research.scea.com

Interactive Evolution of Camouflage

Craig Reynolds

presented at:
Computer Systems Colloquium, EE380
Stanford University
October 6, 2010

License / copyright notice regarding photos in this presentation: **no derivative works**

Many talented photographers have kindly given me permission to use their images in this presentation. While you are welcome to share the entire presentation, you are prohibited from reusing or republishing any of the photos without explicit permission of the individual photographer. Contact me if you seek such permission.

Introduction

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

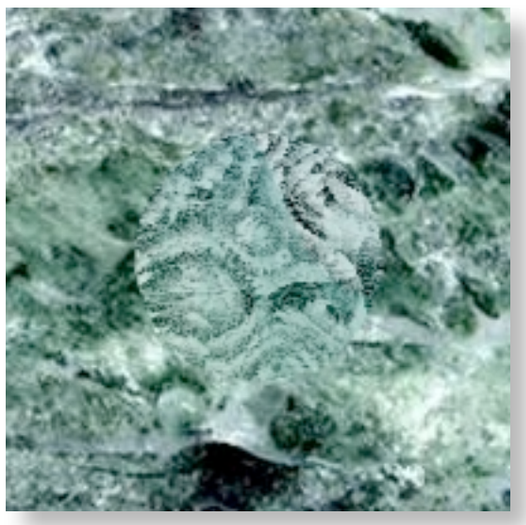
High visual fidelity

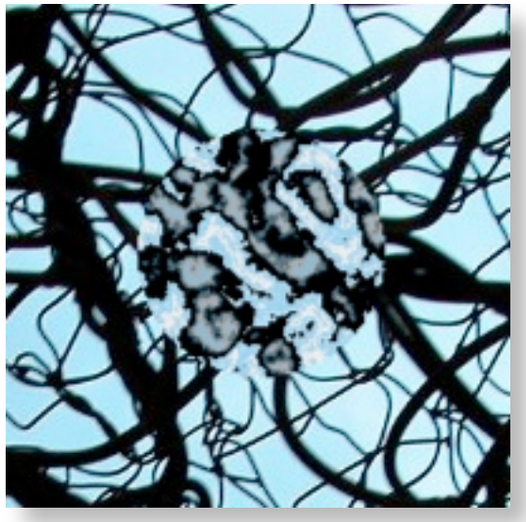
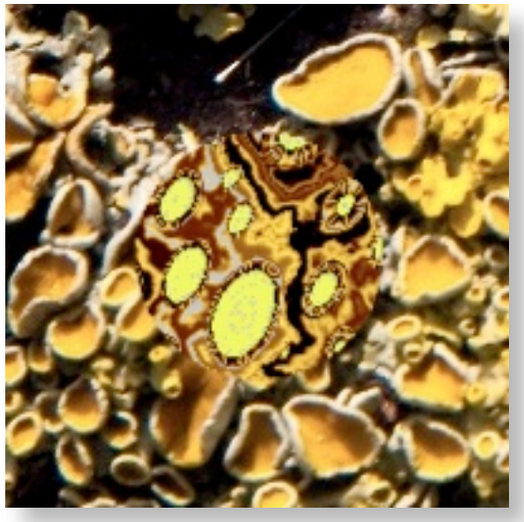
- Differs from earlier work on related topics by using
  - color
  - high resolution
  - natural image complexity from photographs

Limitations

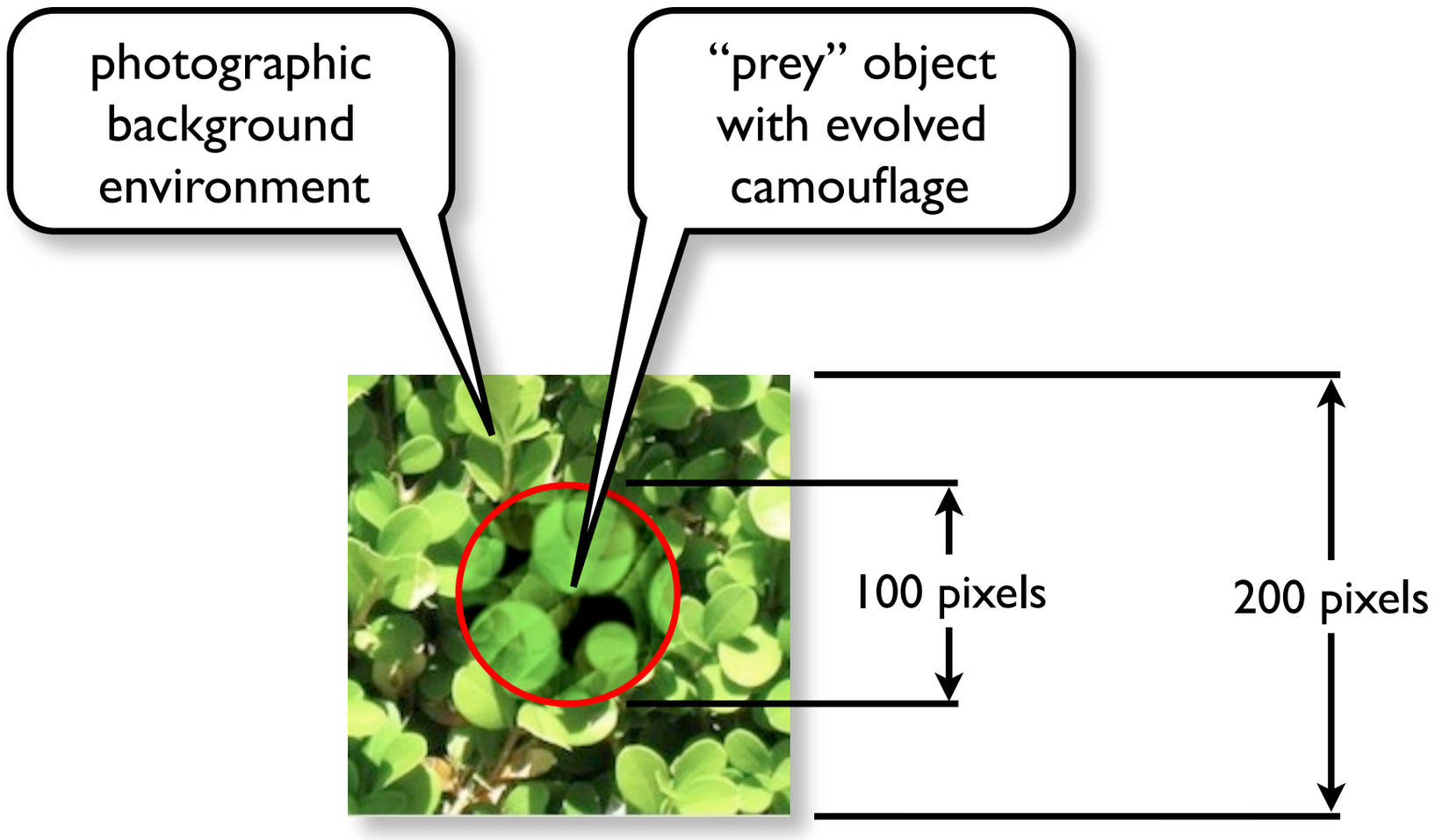
- 2D model
- Slow hybrid computation (requires human effort)
- Body shape and size of prey is fixed
- Camouflage is asymmetrical and unrotated
- Texture synthesis not biological plausible
- No dynamic camouflage (as in chameleon, octopus...)

Evolved camouflage

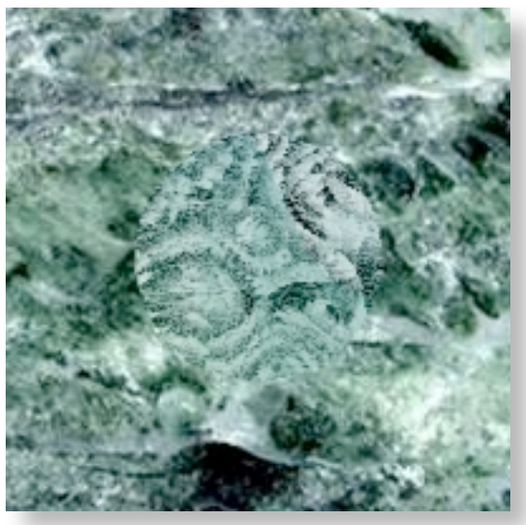



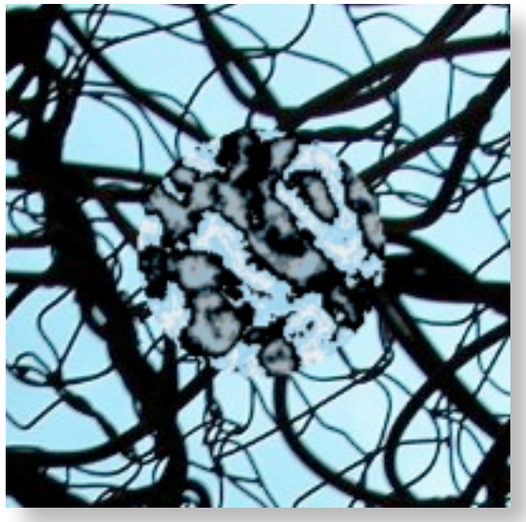
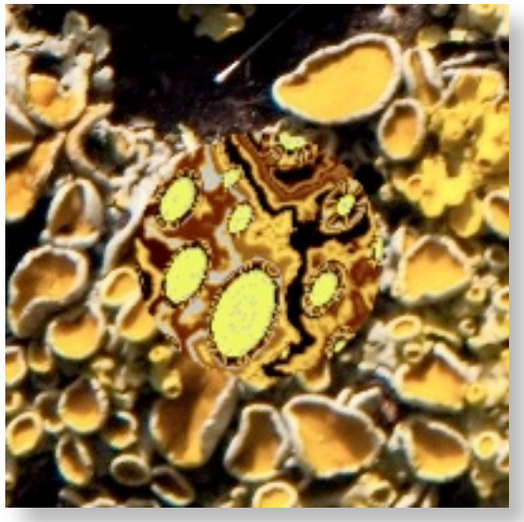




Structure of *thumbnail* images

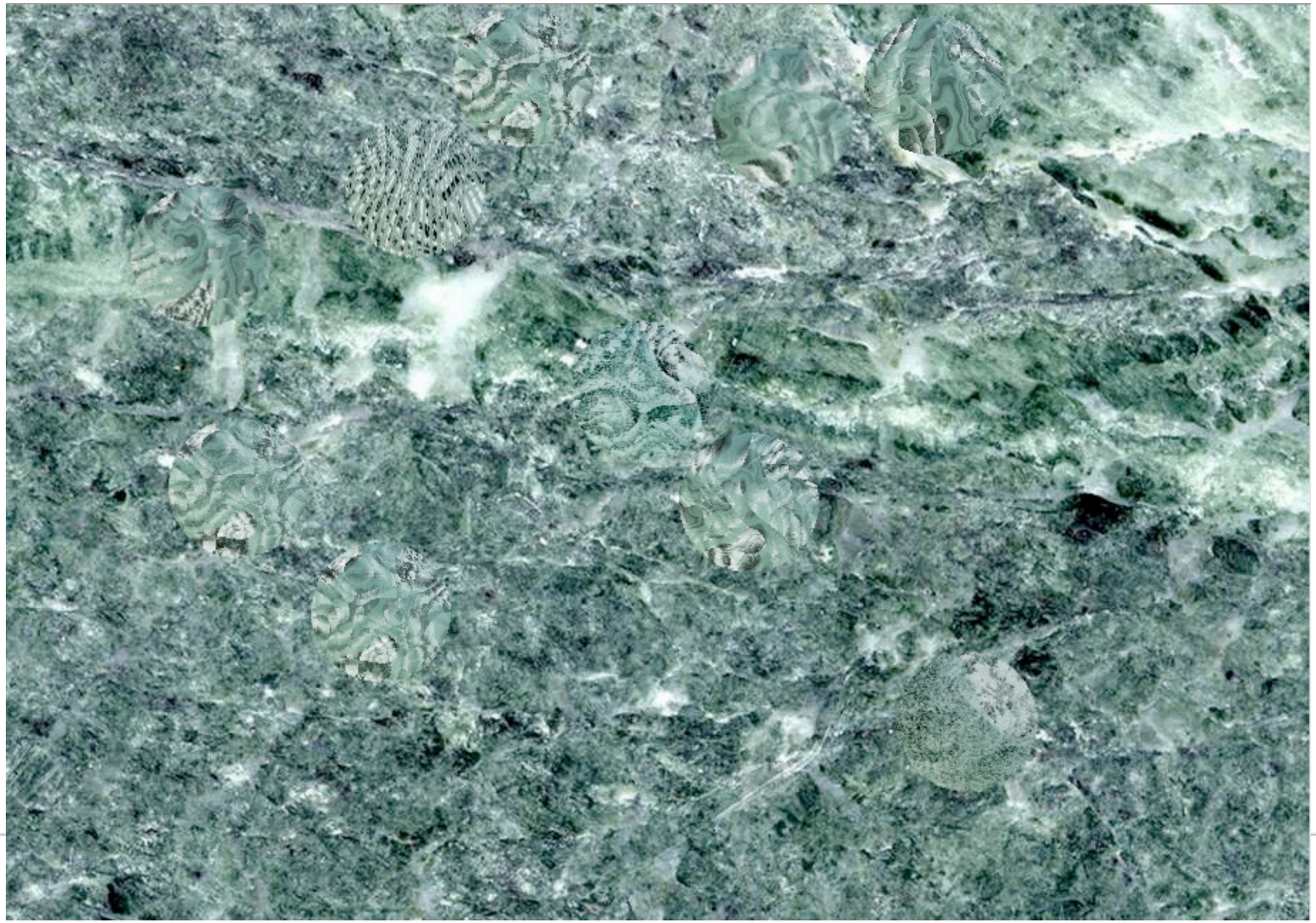


Evolved camouflage

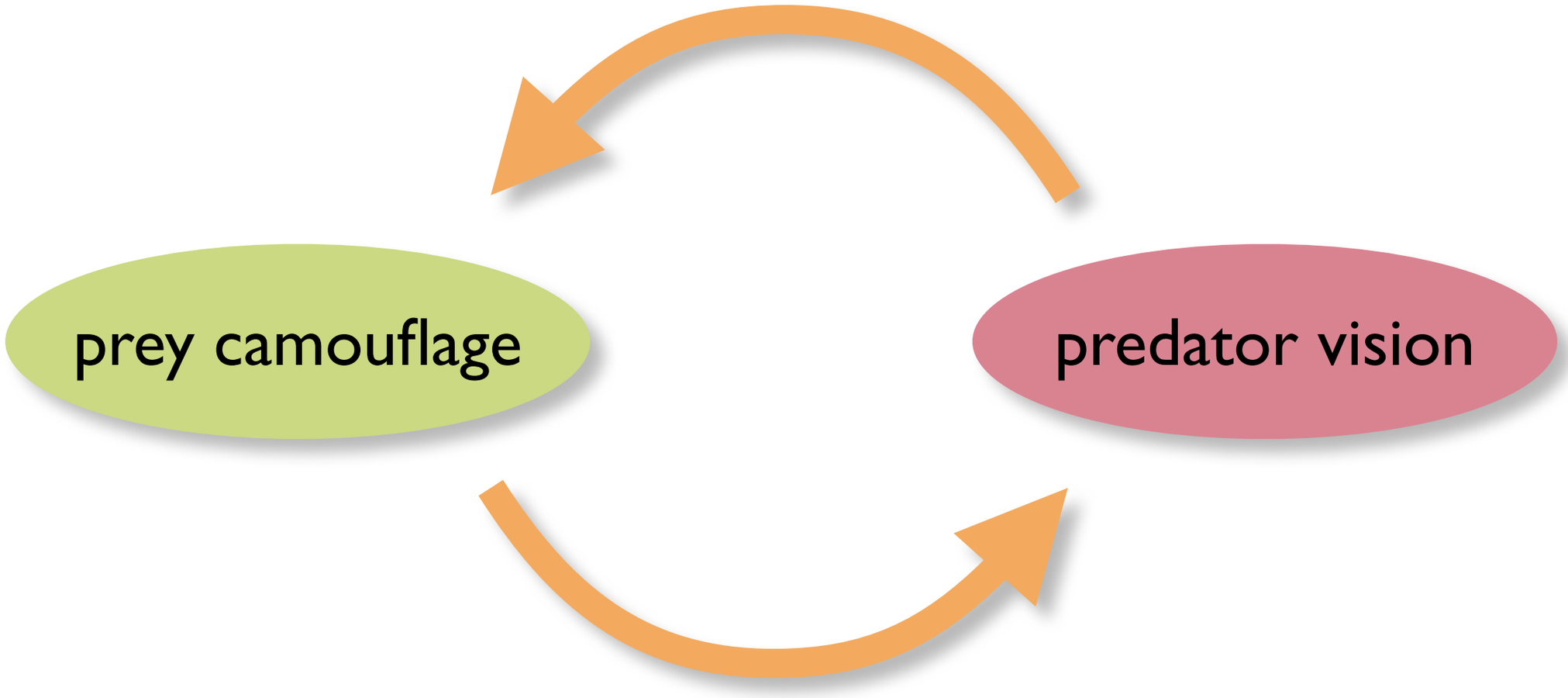




Cohort on environment

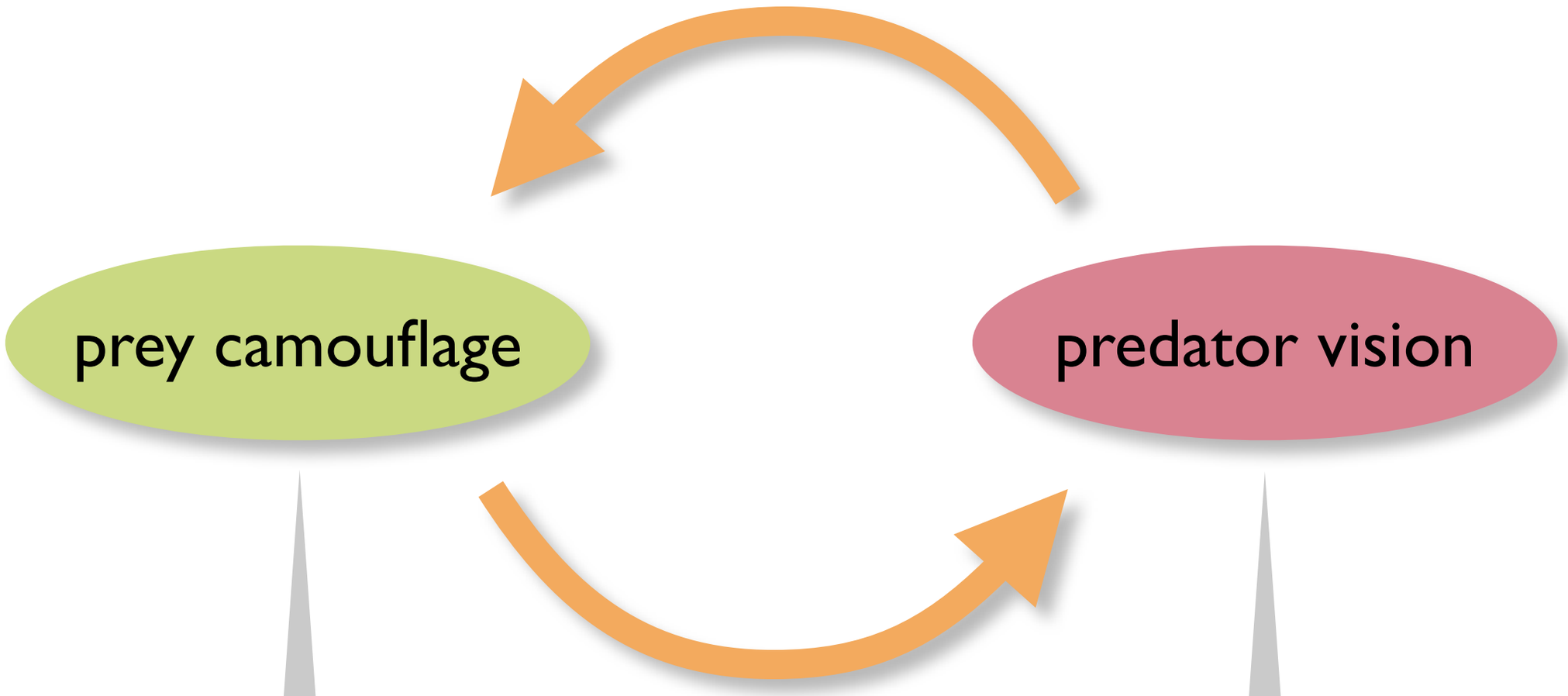


Overview of Model

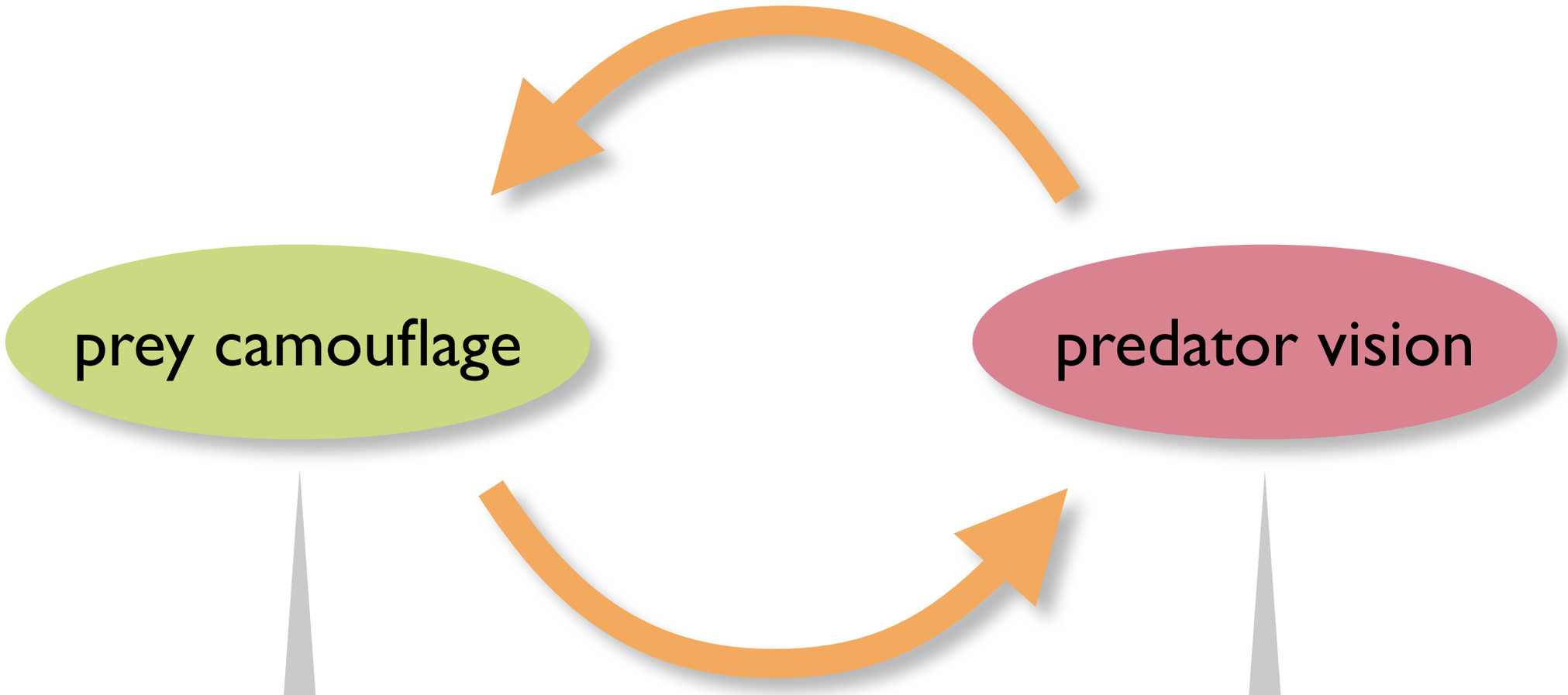
Coevolutionary system



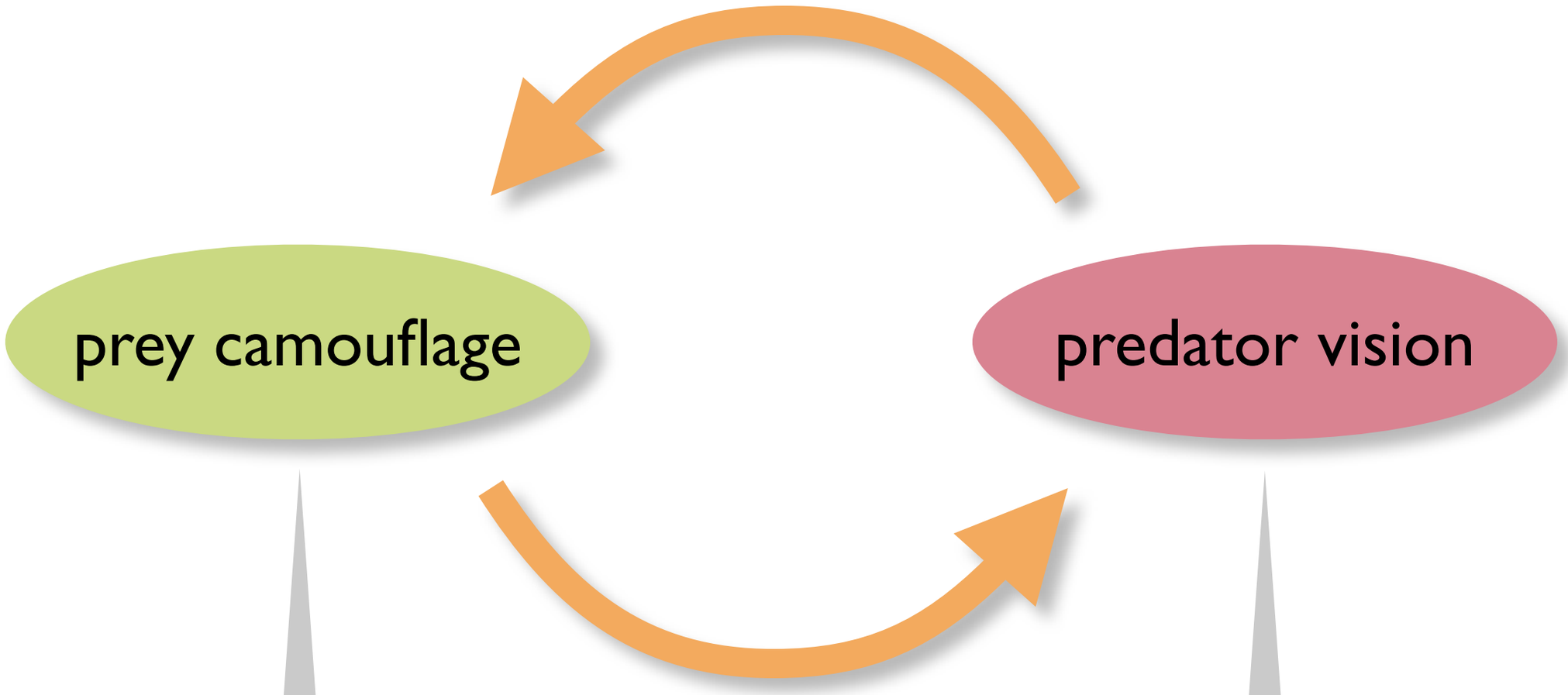
In nature


prey camouflage
predator vision
morphogenesis
evolution
eye / brain
evolution

Current version: hybrid of procedural and interactive



Eventual goal: a fully procedural simulation



Camouflage in Nature

Ladybirds (10-spot (*Adalia decempunctata*), 2-spot (*Adalia bipunctata*) and cream-spot (*Calvia 14-guttata*)) on weeping silver birch tree, England.

Malagasy Lanternfly, forest canopy, Madagascar

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

Oak Beauty (*Biston strataria*) on bark, England.

Bark bug, Peruvian Amazon

Wolf spider (*Ocyale guttata*)

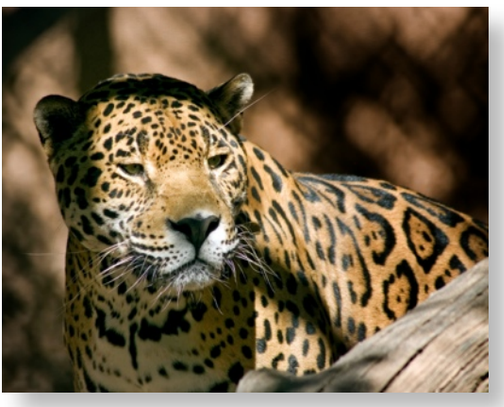
Crab spider (*Thomisus onustus?*), France

Crab spider (*Thomisus onustus*) with prey, France

Crab spider, South Africa

Camouflage change speed

permanent | seasonal | weeks | minutes | instantaneous



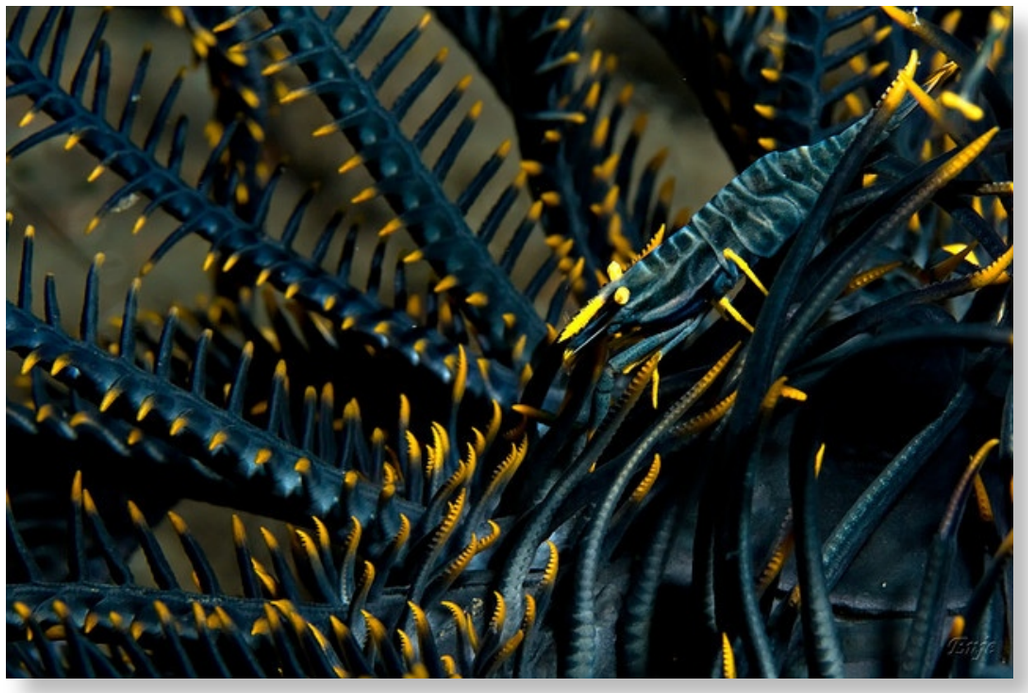


iStockPhoto, Terry L Spivey (Bugwood.org), Ansgar Walk, Hannes Mitchell, Damiano Luchetti, Tennessee Aquarium

Jacky lizard (*Amphibolurus muricatus*), Australia

juvenile C-O sole (*Pleuronichthys coenosus*)

Crinoid with commensal shrimp, Philippines



Crinoids with commensal shrimp

Tawny frogmouth owls (*Podargus strigoides*)

Scops owl (*Otus Scops*) on olive tree

Owl on fir(?) tree.

(photographer unknown)

Northern leopard frog (*Rana pipiens*), Michigan USA

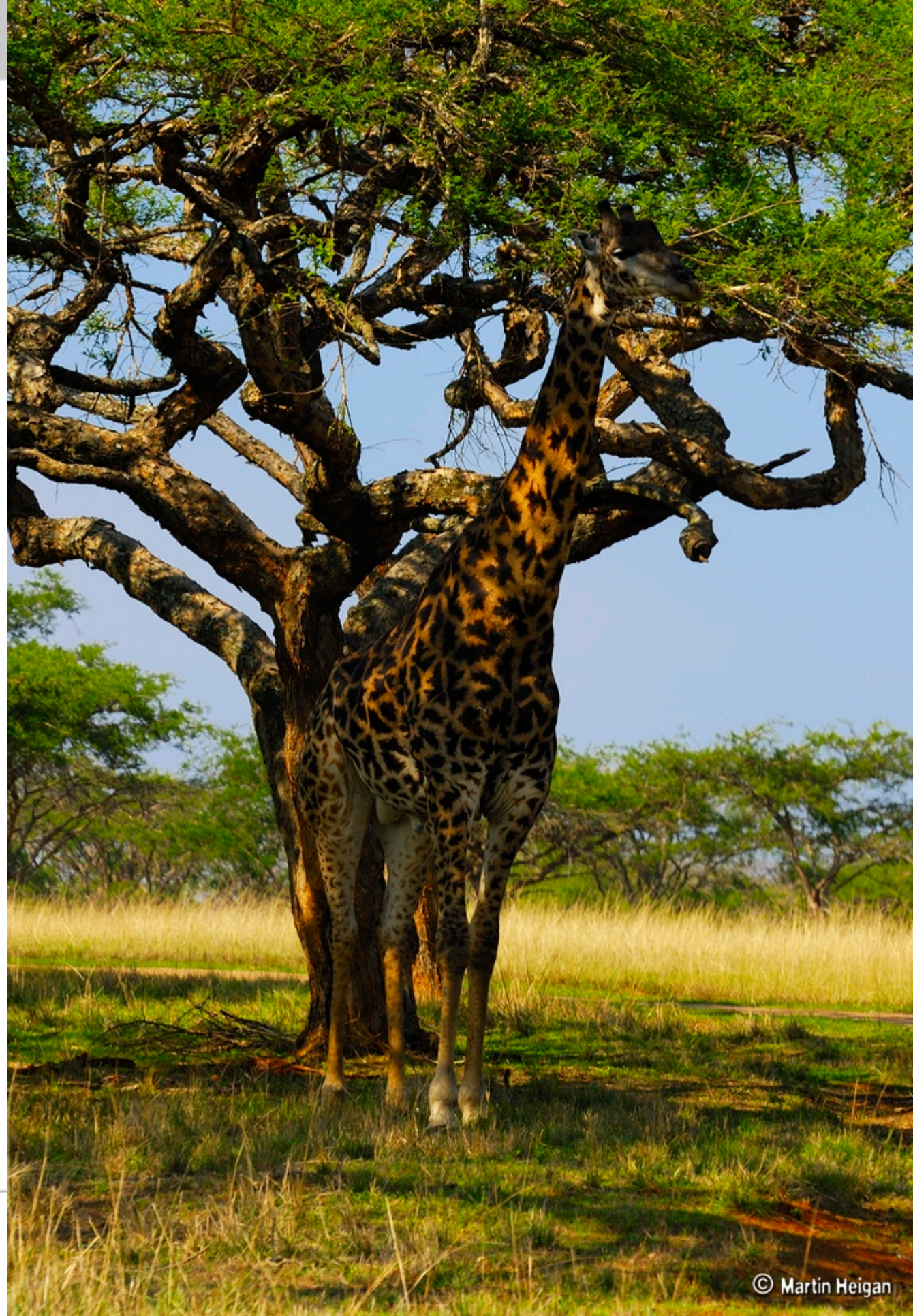
Southern leopard frog (*Rana sphenocephala*), Florida USA

European green toad (*Bufo viridis*) on pebbled concrete, Czech Republic.

Gray Tree Frog (*Hyla versicolor*) on concrete, Indiana, USA

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

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

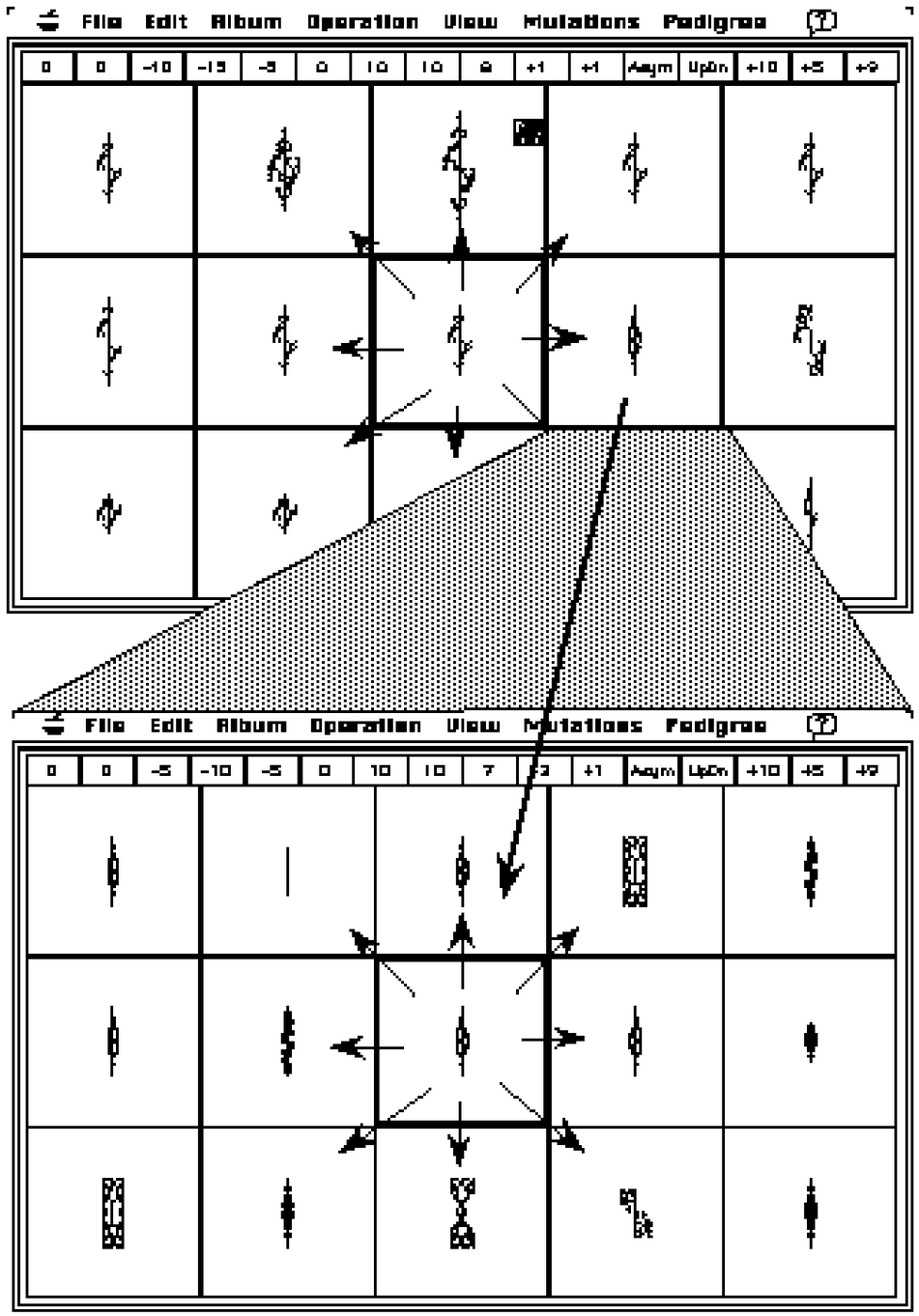


Acacia tree and giraffe (*Giraffa camelopardalis*)

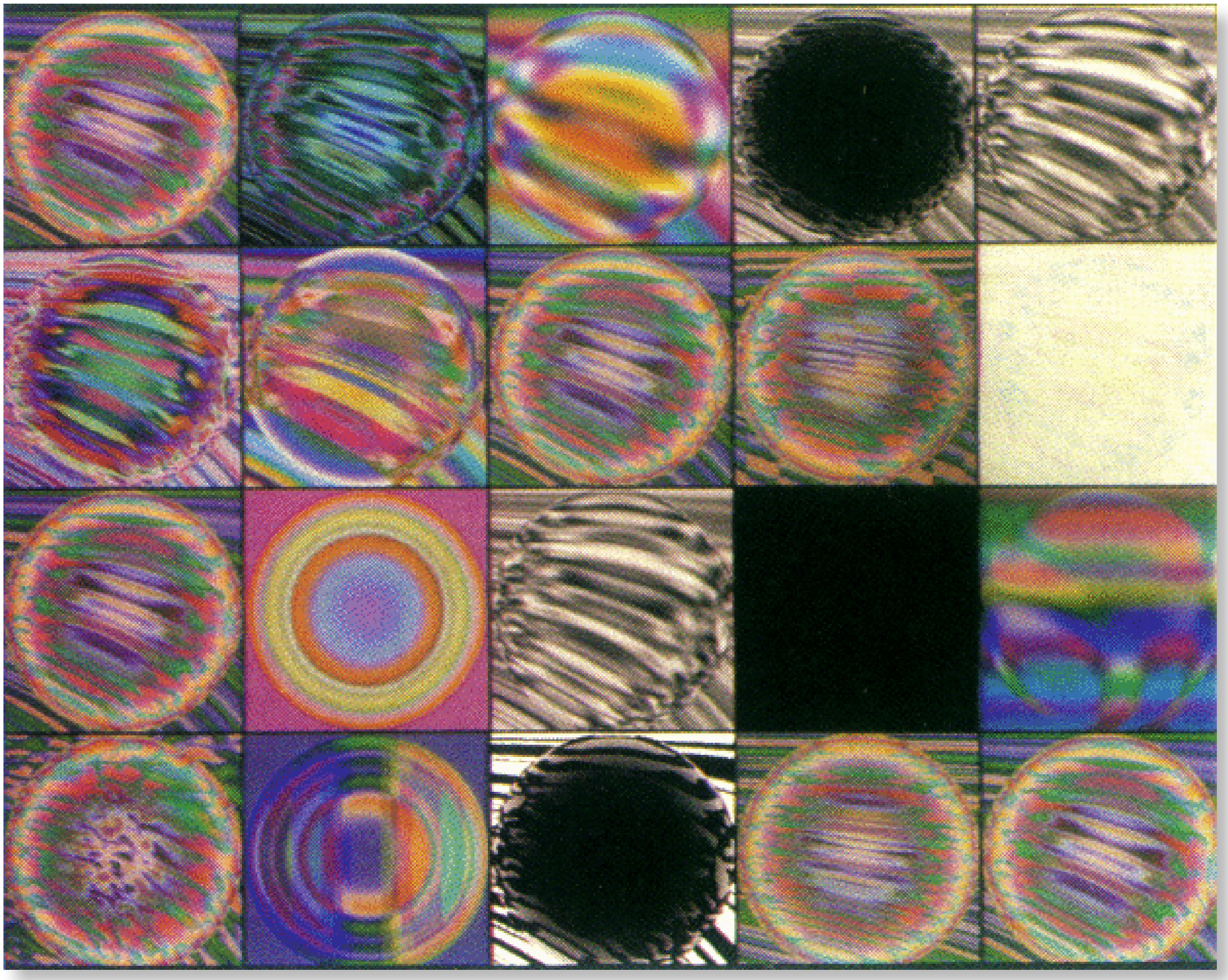
Background

Influences

- Coevolution: Hillis 1990, Angeline 1993, Funes 1998
- "Pure" procedural texture synthesis: Perlin 1985, ...
- Interactive evolution: Dawkins 1986, Sims 1991, Stanley 2008
- Reaction-diffusion: Turing 1952, Murrey 1988, Witkin & Kass 1991, Turk 1991
- Camouflage: Beddard 1895, Thayer 1909, Cott 1940, Bond & Kamil 2002, Merilaita 2003, Cuthill 2005, Schaefer & Stobbe 2006, Sherratt 2007

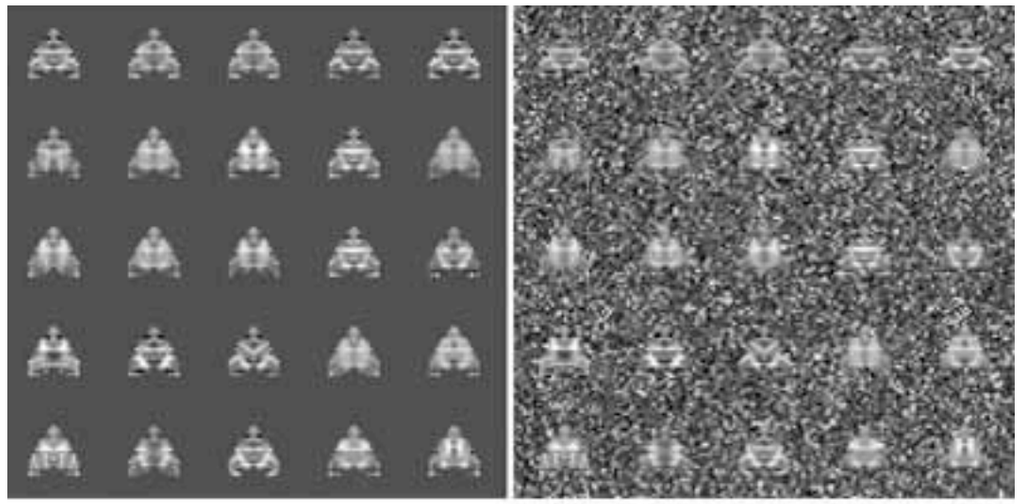


Screen shots of Dawkins' *Blind Watchmaker* software

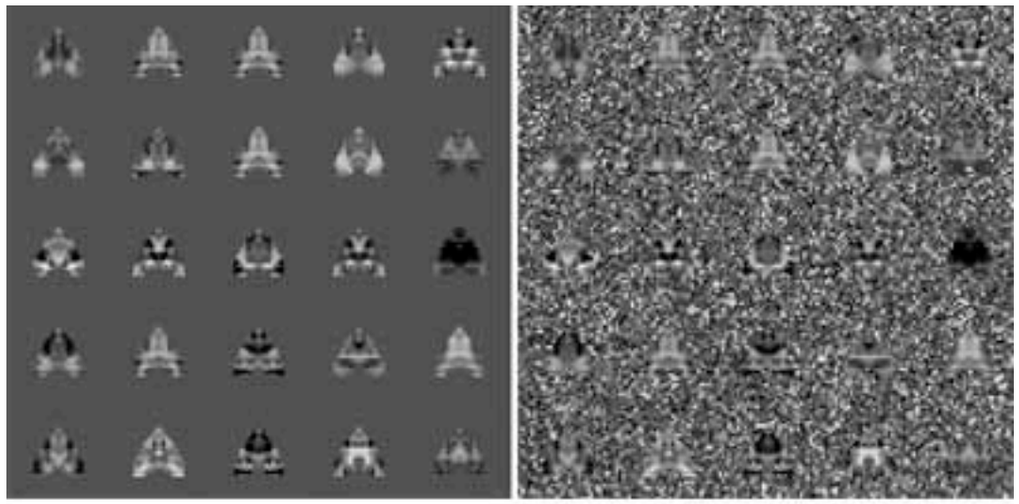


User interface for Sims' interactive evolution of color texture patterns

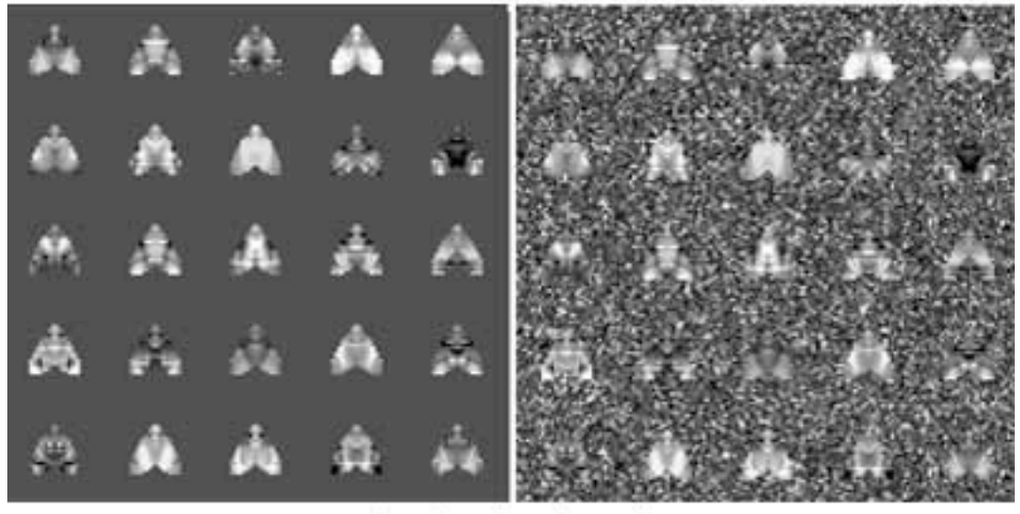
blue jay (*Cyanocitta cristata*) and display screen — Alan Bond and Alan Kamil (1998-2007)



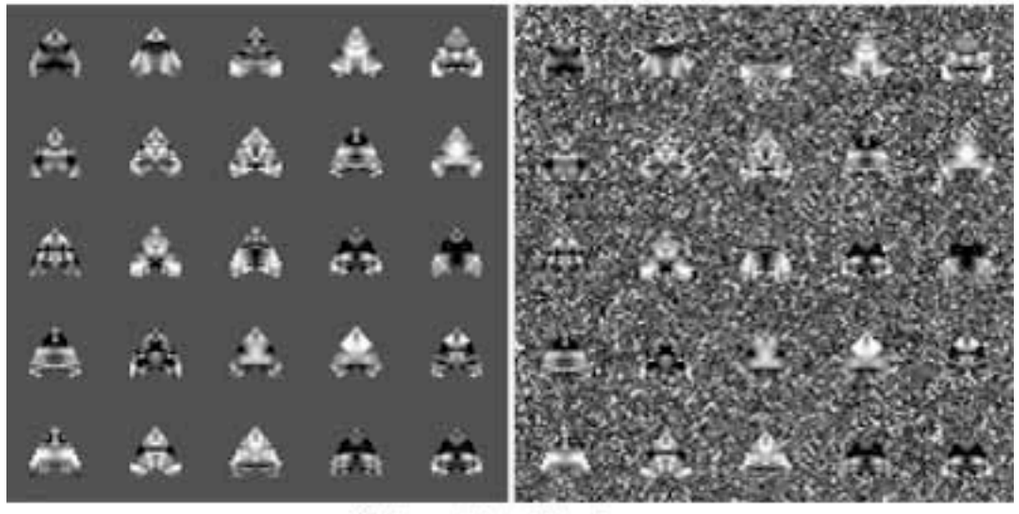
Original population



Selected by virtual predator



Randomly selected

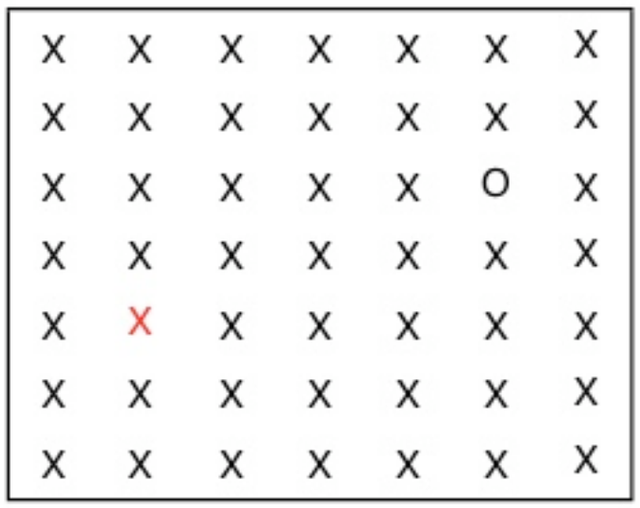


Selected by blue jays

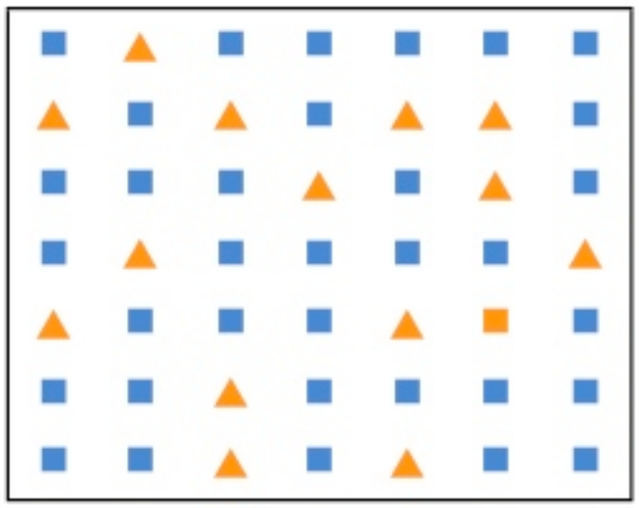
Alan B. Bond and Alan C. Kamil (1998-2007) — evolved virtual prey

Visual search and "pop-out"

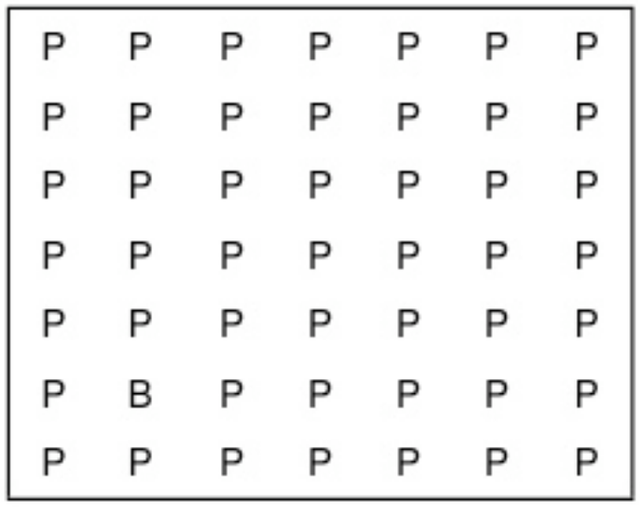
fast pop-out of
color or shape feature

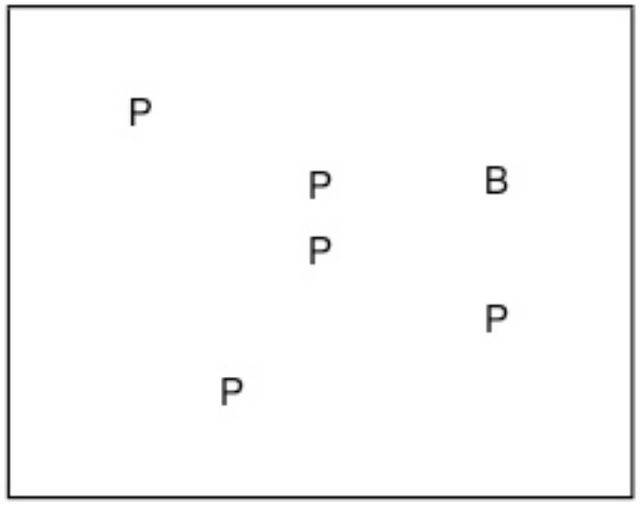


slow conjunction search:
find the orange square



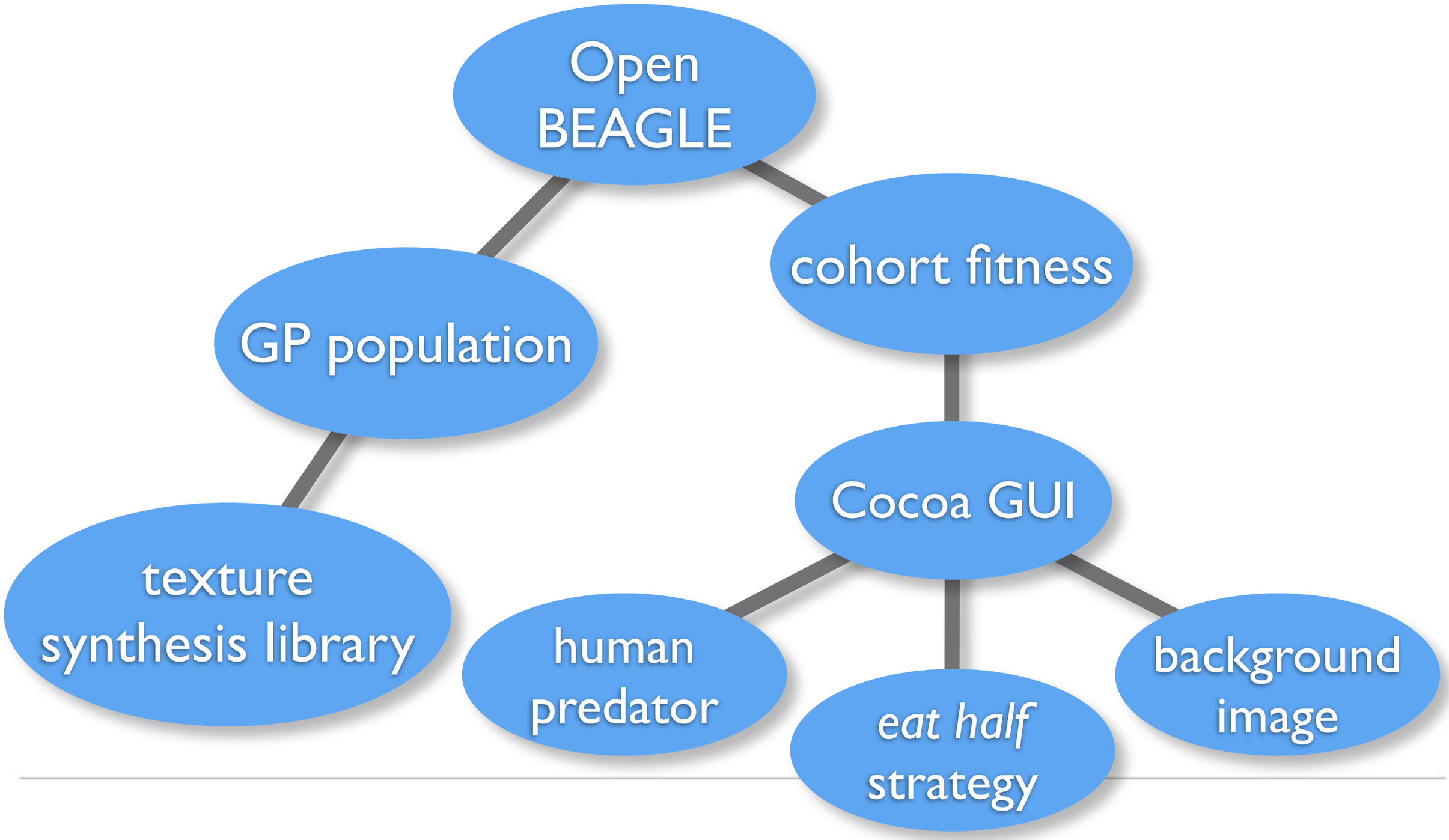
more distractors,
longer search





Implementation

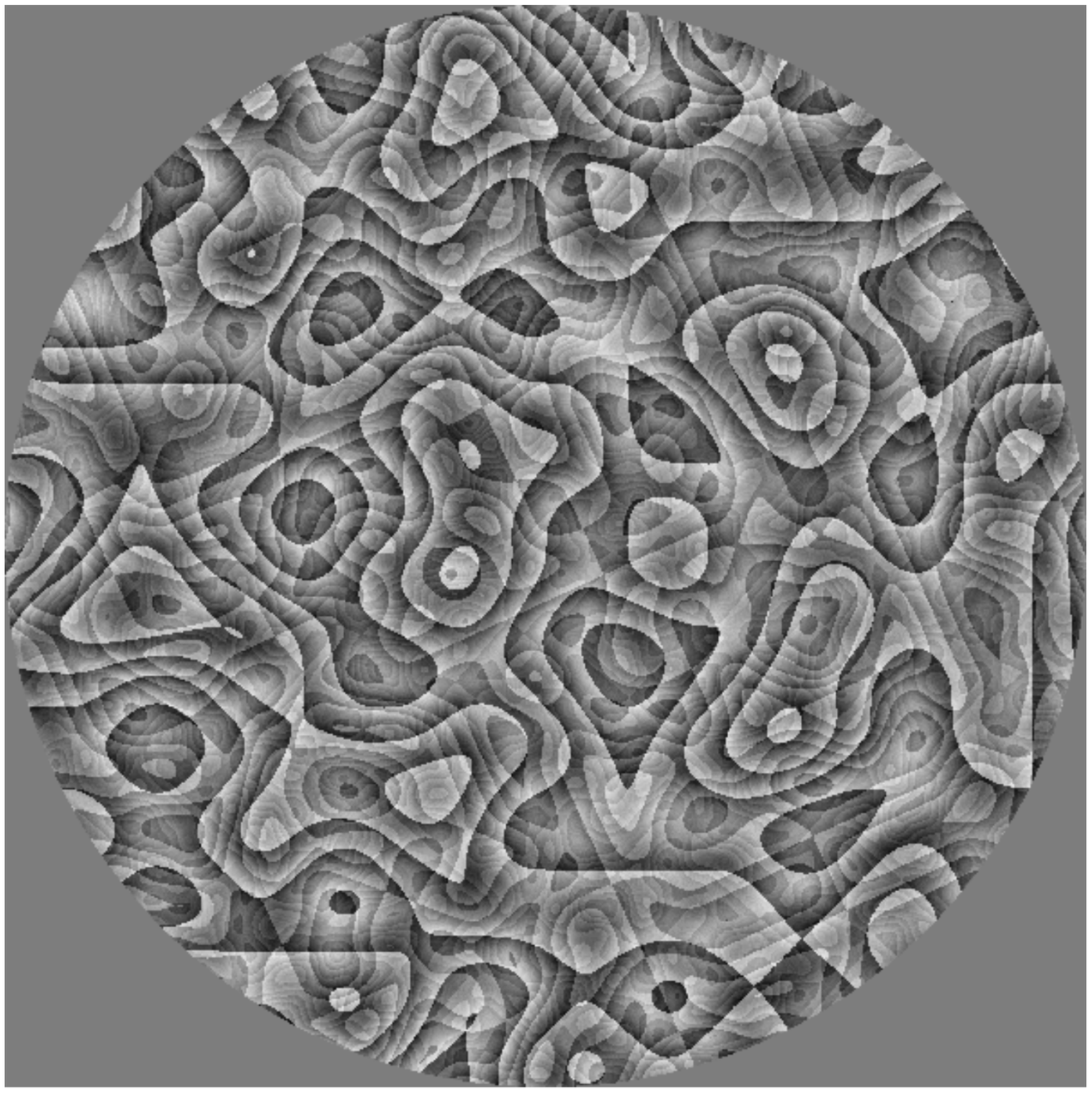
System components



Texture synthesis library

Texture generators: UniformColor, SoftEdgeSpot, Gradation, SineGrating, TriangleWaveGrating, SoftEdgedSquareWaveGrating, RadialGrad, Noise, ColorNoise, Brownian, Turbulence, Furbulence, Wrapulence and NoiseDiffClip. **Texture operators:** Scale, Translate, Rotate, Mirror, Add, Subtract, Multiply, Max, Min, SoftMatte, ExpAbsDiff, Row, Array, Invert, Tint, Stretch, StretchSpot, Wrap, Ring, Twist, VortexSpot, Blur, EdgeDetect, EdgeEnhance, SliceGrating, SliceToRadial, SliceShear, Colorize, Gamma, AdjustSaturation, AdjustHue, BrightnessToHue, BrightnessWrap, BrightnessSlice4, HueIfAny, SoftThreshold, SpotsInCircle and ColoredSpotsInCircle

Wrapulence



edges at several scales, helps camouflage

Evolutionary Computation

Evolutionary computation

- Genetic Programming
  - texture synthesis library
  - Open BEAGLE
- Steady-state population
  - high elitism
  - less generational / more ecosystem simulation
  - remain in breeding population until “eaten” by predator
- Interactive cohort-based fitness

GP crossover

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

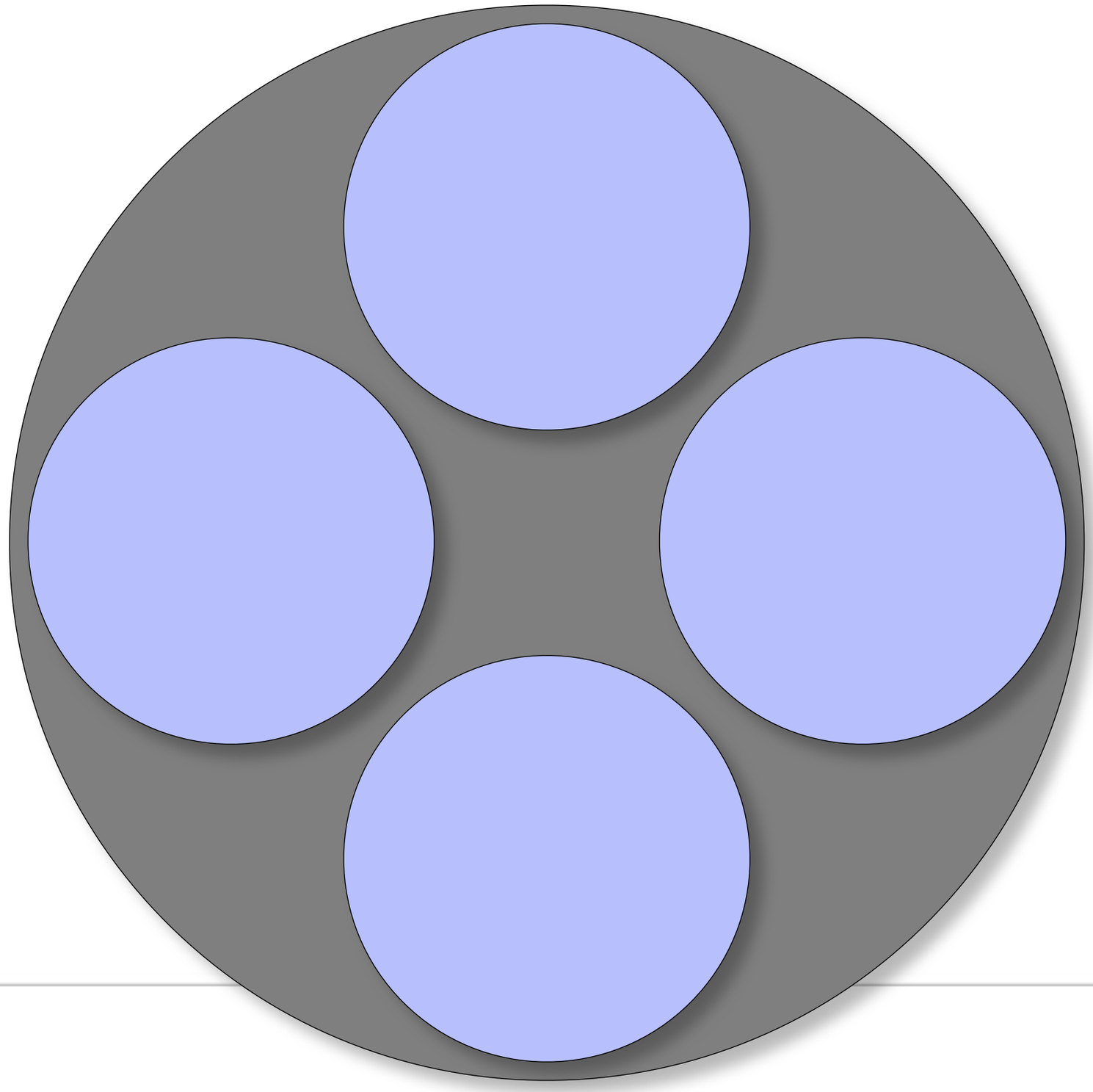
x (y (w (6, 2), 3), z (9))

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

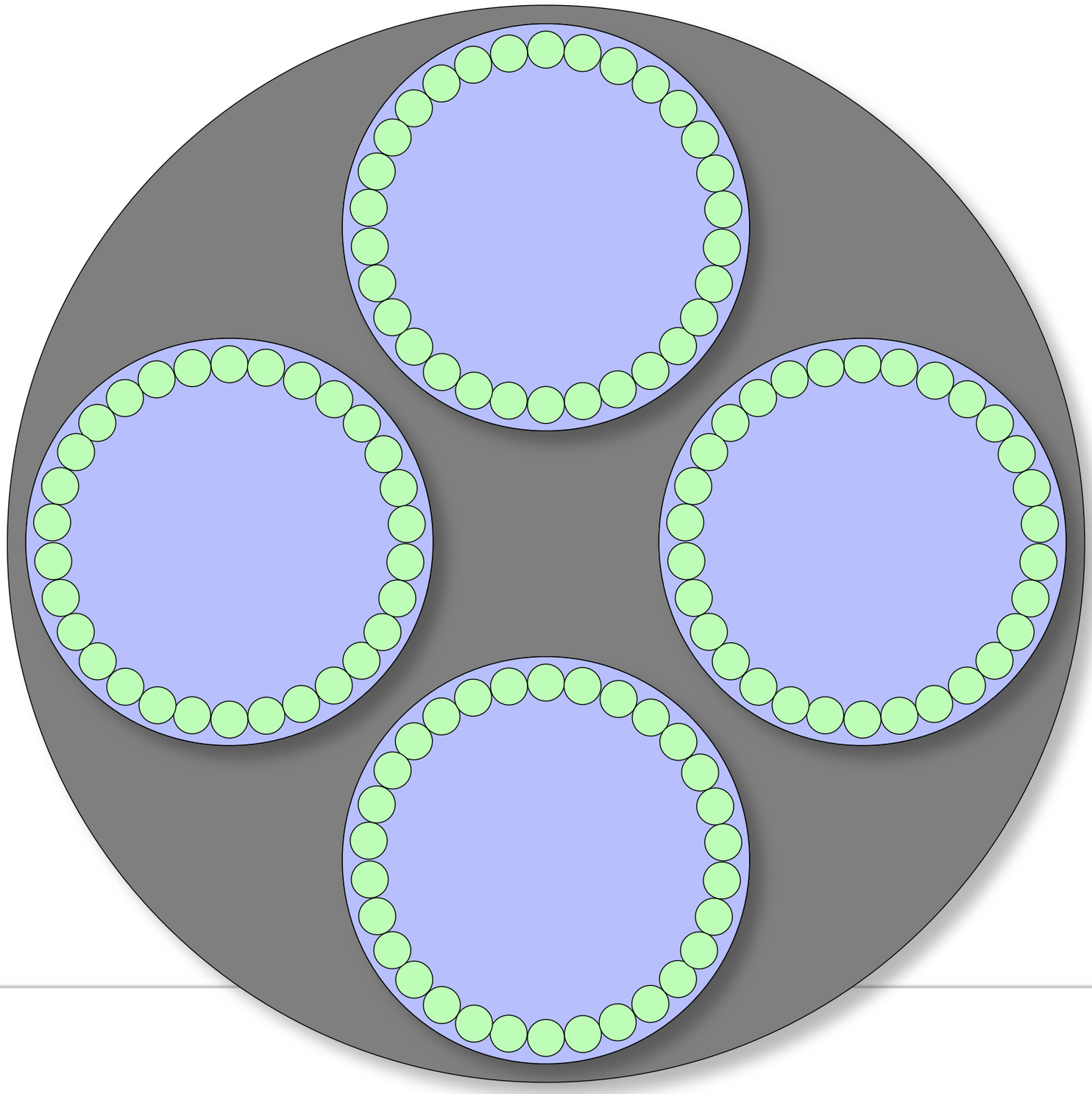
x (y (w (6, 2), 3), z (9))

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

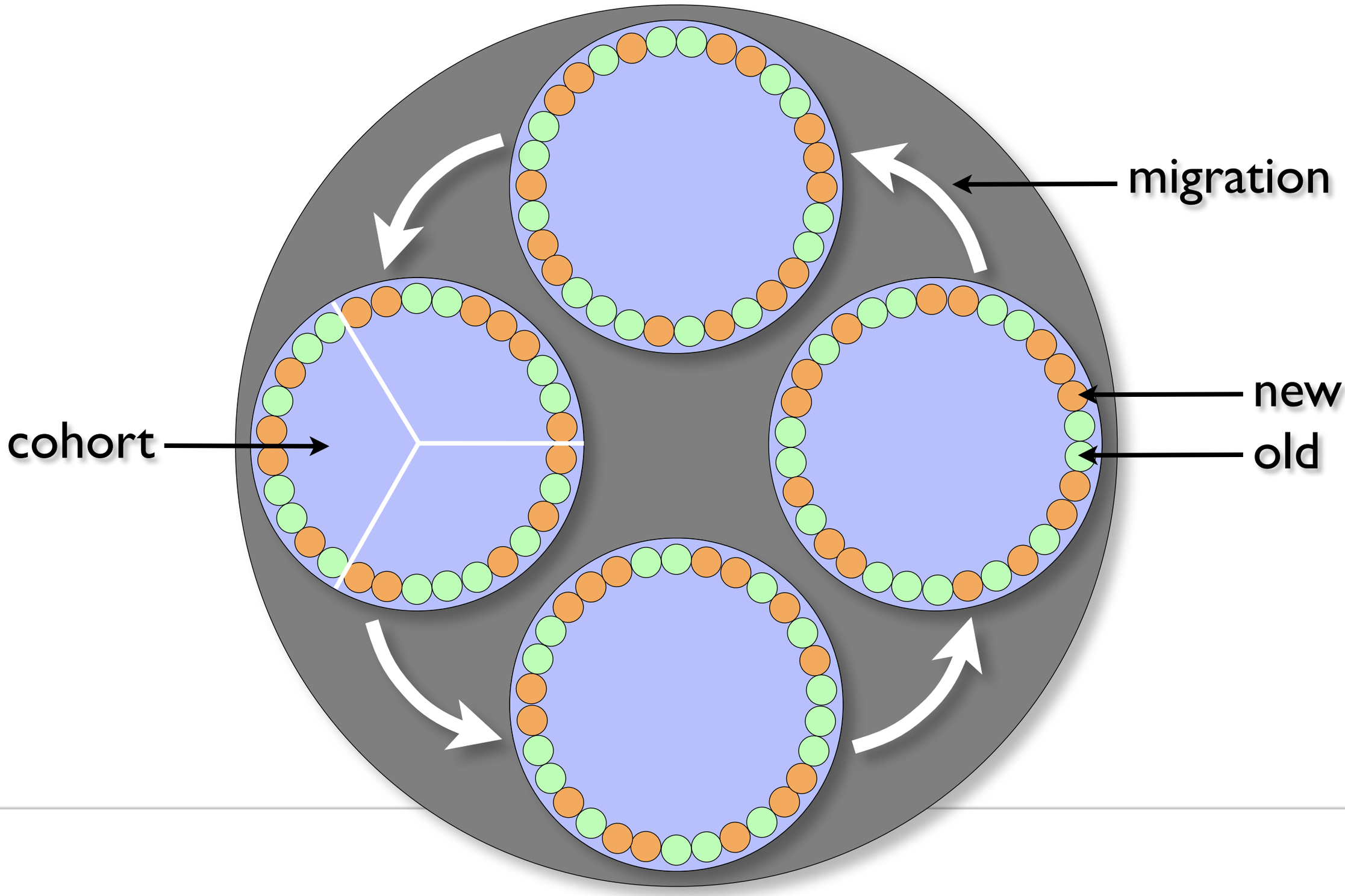
Population divided into 4 demes



4 demes of 30 individuals

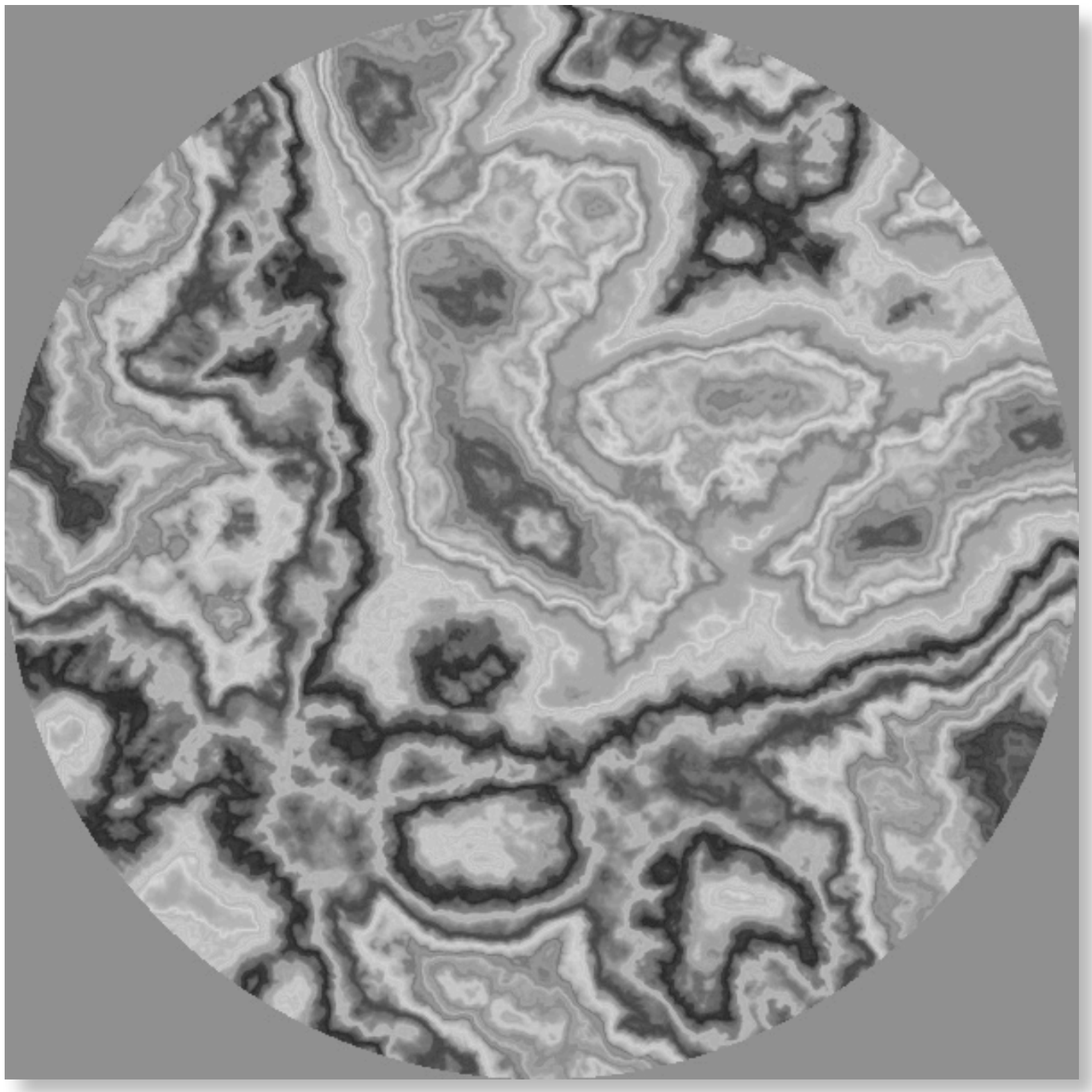


cohorts, migration, elitism



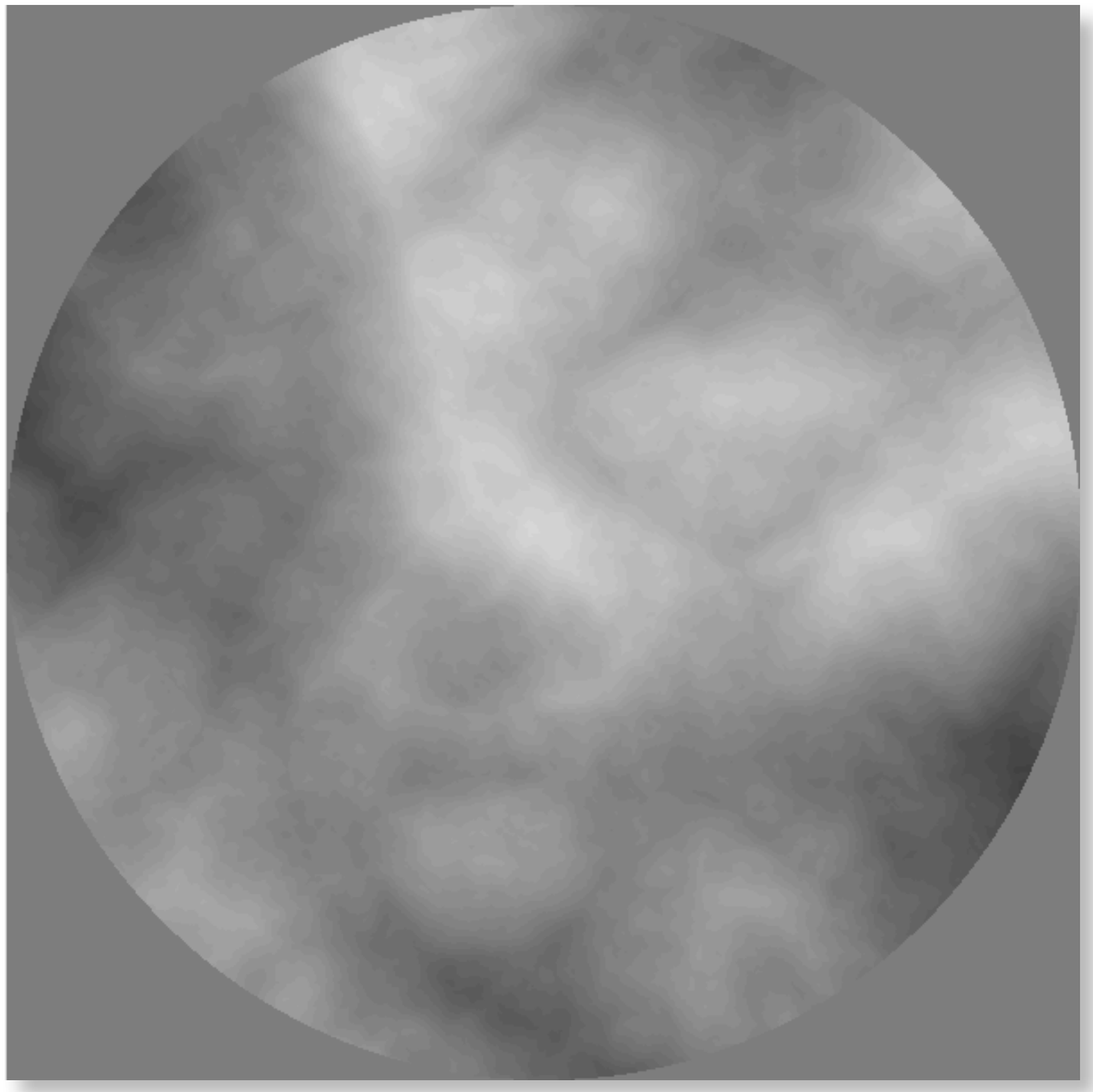
Evolved textures with source code

```
Colorize (Ring (5.80532,
                Vec2 (-2.12073, 0.411024),
                Stretch (0.0449509,
                         -1.06448,
                         Vec2 (-1.37922, 0.946741),
                         Furbulence (1.21806,
                                     Vec2 (1.62529,
                                           2.9815)))),
          Furbulence (1.21806,
                      Vec2 (-2.94693, -1.86416)))
```



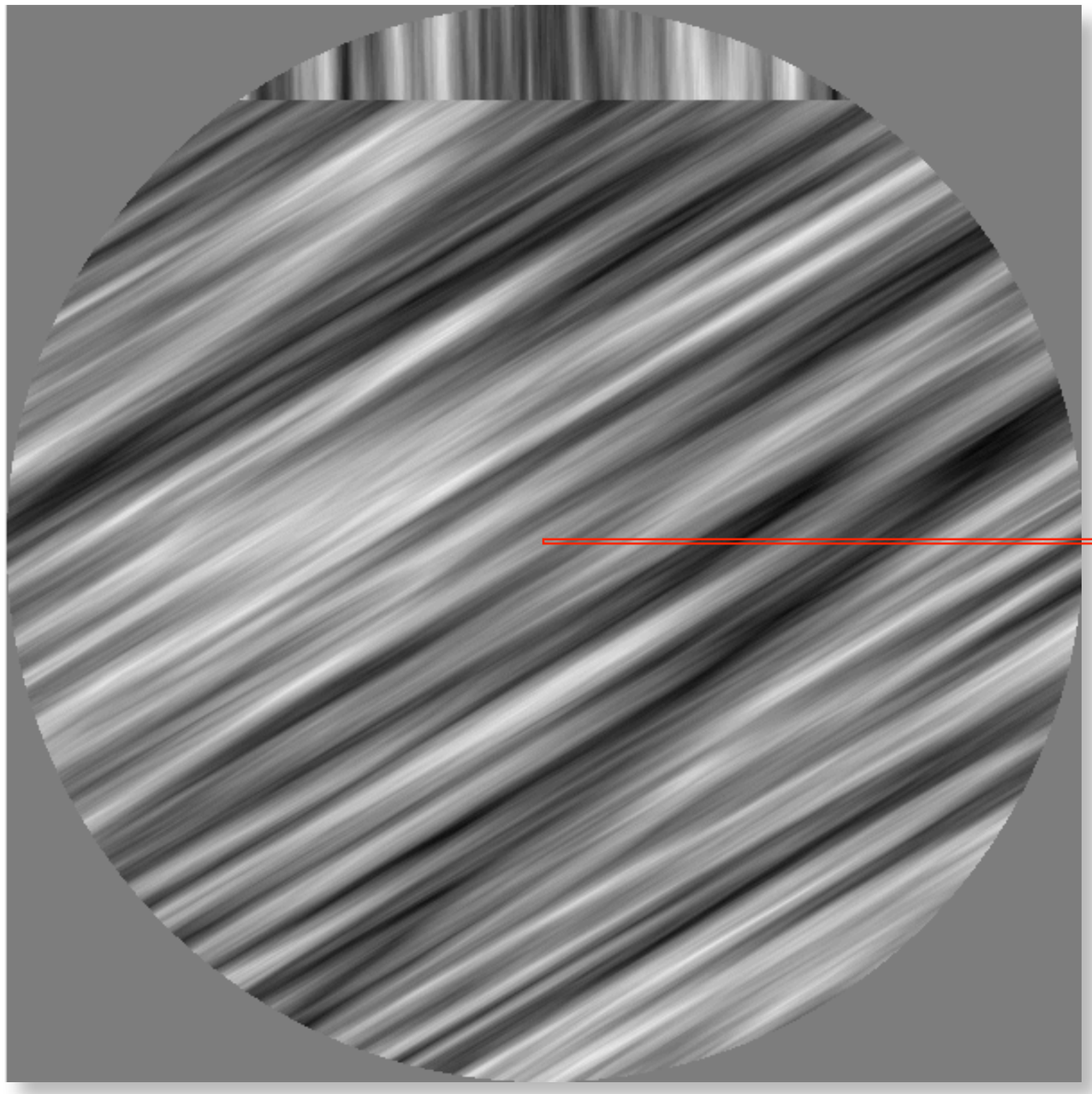
camouflage evolved for oak bark

```
Colorize (Ring (5.80532,
                Vec2 (-2.12073, 0.411024),
                Stretch (0.0449509,
                         -1.06448,
                         Vec2 (-1.37922, 0.946741),
                         Furbulence (1.21806,
                                     Vec2 (1.62529,
                                           2.9815)))),
          Furbulence (1.21806,
                      Vec2 (-2.94693, -1.86416))
```



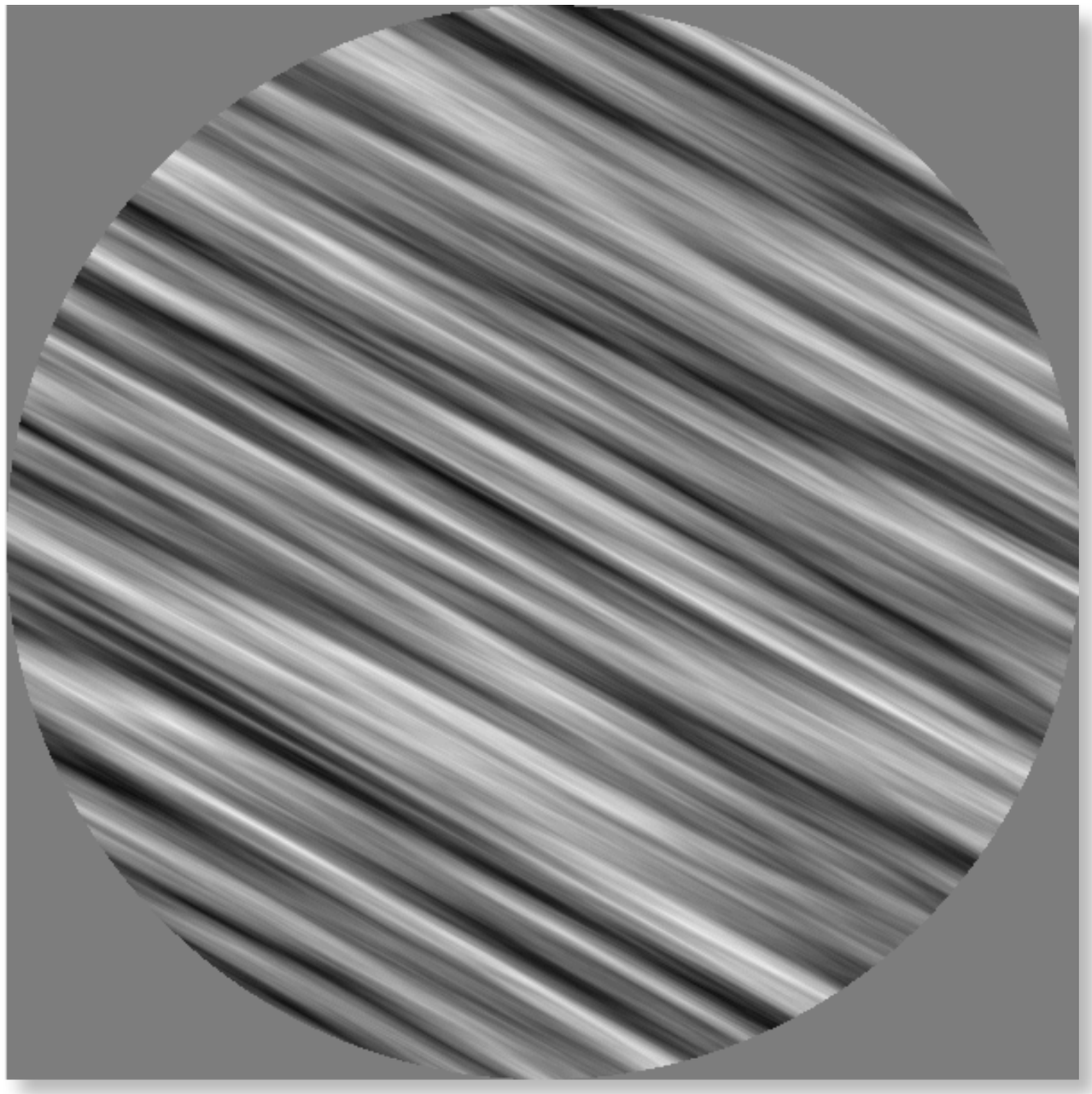
camouflage evolved for oak bark

```
Colorize (Ring (5.80532,
                Vec2 (-2.12073, 0.411024),
                Stretch (0.0449509,
                         -1.06448,
                         Vec2 (-1.37922, 0.946741),
                         Furbulence (1.21806,
                                     Vec2 (1.62529,
                                           2.9815)))),
          Furbulence (1.21806,
                      Vec2 (-2.94693, -1.86416)))
```



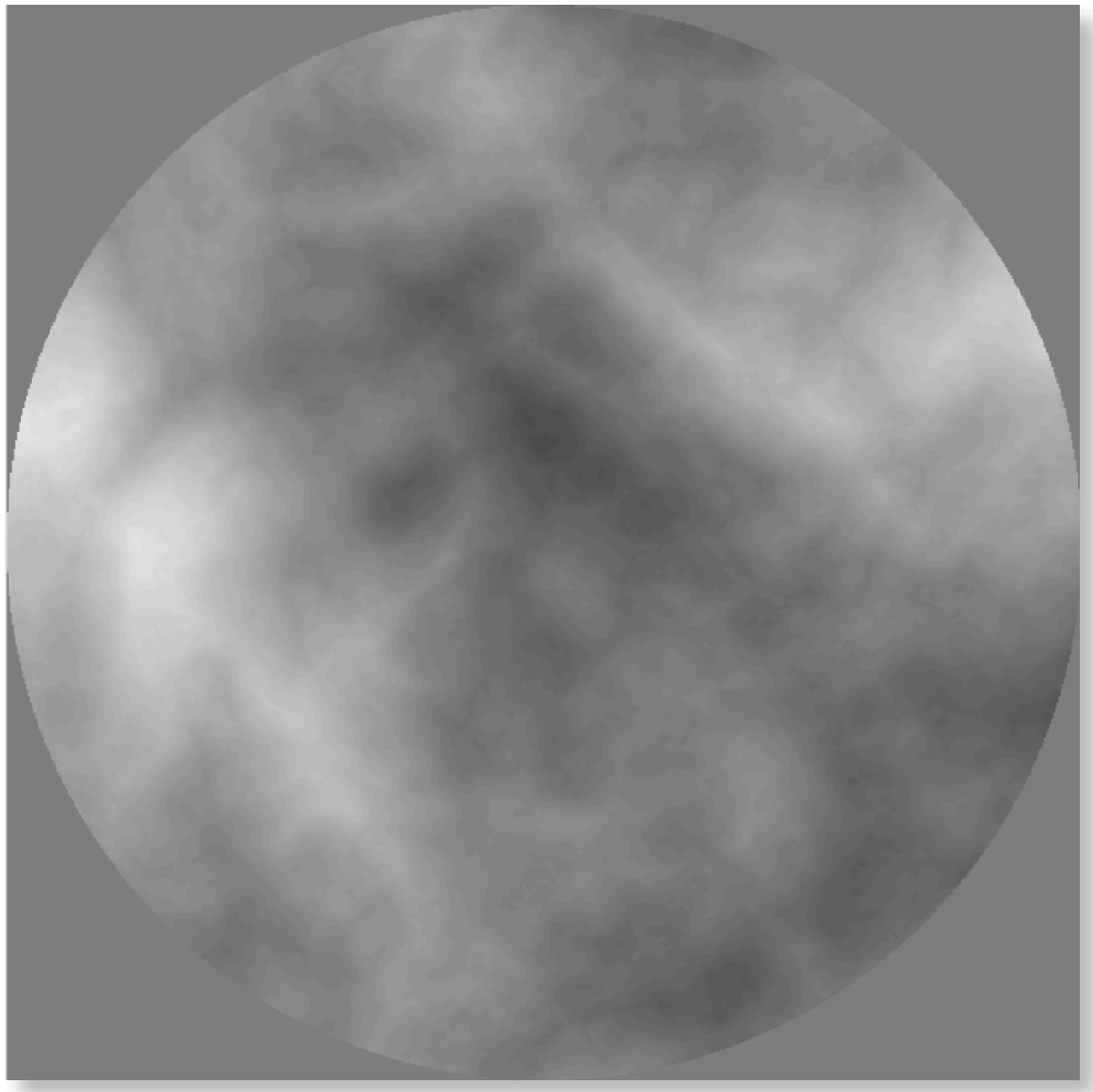
camouflage evolved for oak bark

```
Colorize (Ring (5.80532,
                Vec2 (-2.12073, 0.411024),
              Stretch (0.0449509,
                       -1.06448,
                       Vec2 (-1.37922, 0.946741),
                       Furbulence (1.21806,
                                   Vec2 (1.62529,
                                         2.9815))),
          Furbulence (1.21806,
                      Vec2 (-2.94693, -1.86416)))
```



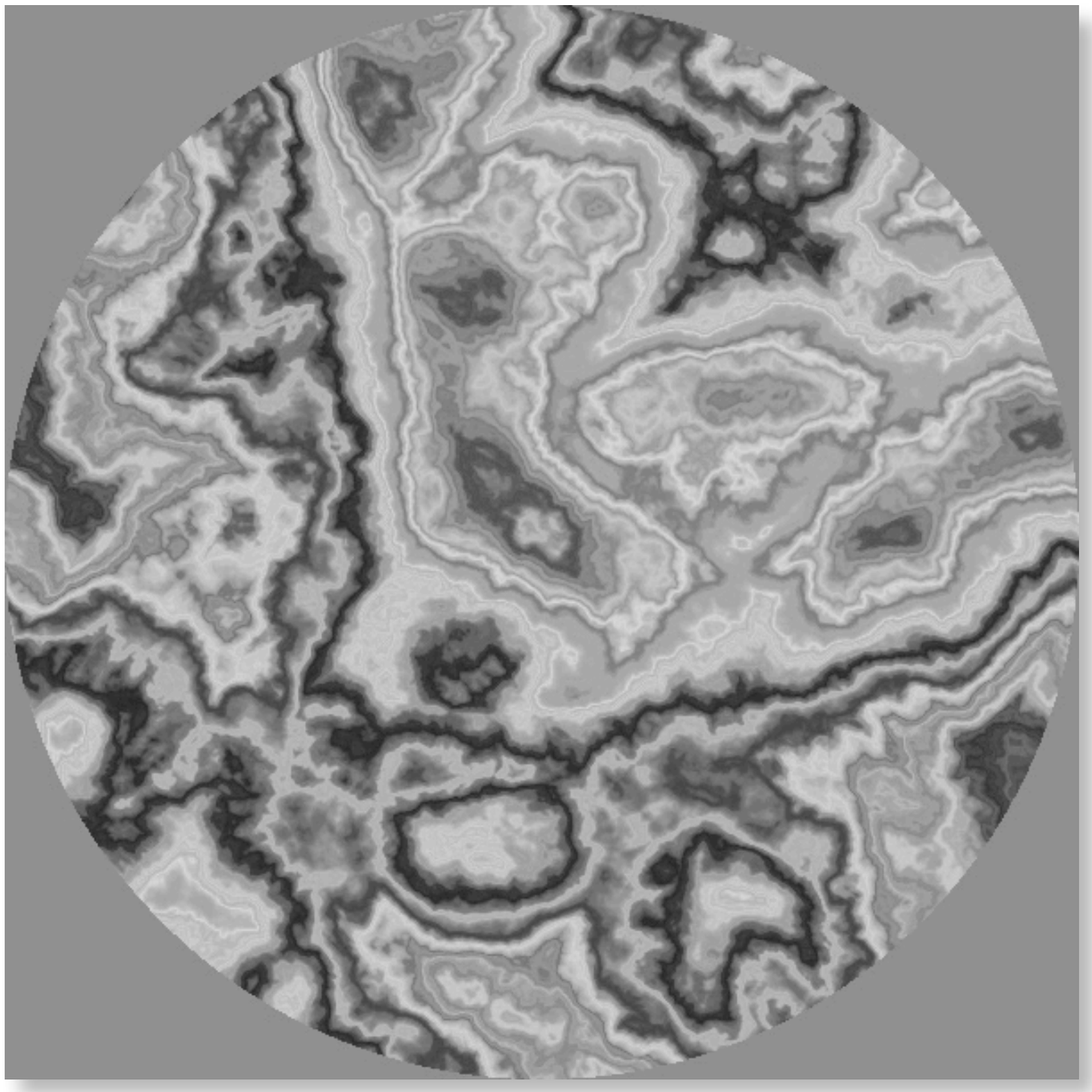
camouflage evolved for oak bark

```
Colorize (Ring (5.80532,
                Vec2 (-2.12073, 0.411024),
               Stretch (0.0449509,
                        -1.06448,
                        Vec2 (-1.37922, 0.946741),
                Furbulence (1.21806,
                            Vec2 (1.62529,
                                  2.9815))),
          Furbulence (1.21806,
                      Vec2 (-2.94693, -1.86416)))
```



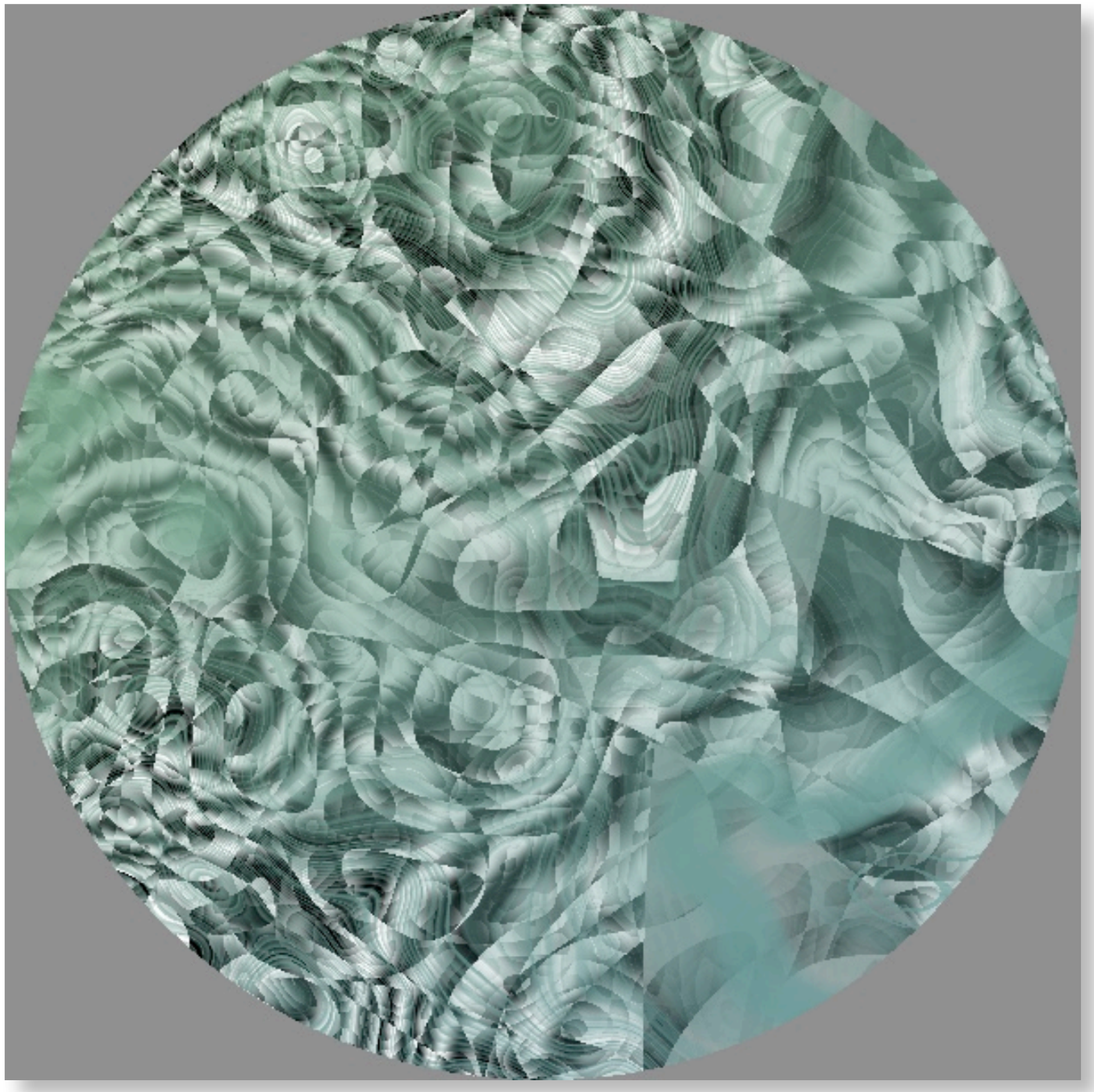
camouflage evolved for oak bark

```
Colorize (Ring (5.80532,
                Vec2 (-2.12073, 0.411024),
                Stretch (0.0449509,
                         -1.06448,
                         Vec2 (-1.37922, 0.946741),
                         Furbulence (1.21806,
                                     Vec2 (1.62529,
                                           2.9815)))),
          Furbulence (1.21806,
                      Vec2 (-2.94693, -1.86416)))
```



camouflage evolved for oak bark

Invert (SoftMatte (HuelfAny (Colorize (Twist (-1.76008, Vec2 (-2.90822, -1.26208), Multiply (Brownian (0.880861, Vec2 (2.80615, 1.14405)), Wrap (6.21909, 5.55726, Vec2 (1.88101, -1.10475), Add (VortexSpot (-2.95874, 4.37424, Vec2 (-2.24113, -0.804409), Row (Vec2 (-1.20827, -0.80333), Wrapulence (5.81646, Vec2 (1.46969, 0.464754)))), Multiply (TriangleWaveGrating (15.0552, 0.251605, 4.92253), Wrap (6.21909, 5.25948, Vec2 (-2.90822, -1.26208), Add (ColoredSpotsInCircle (146.485, 0.573184, 0.103147, Stretch (1.92016, 0.932767, Vec2 (0.994563, 1.8778), SineGrating (17.4233, 0.477075)), Translate (Vec2 (1.3634, -3.05406), Colorize (SineGrating (87.1581, 1.2438), SoftEdgedSquareWaveGrating (138.03, 0.0101831, 0.894823, 1.03307))), SliceToRadial (Vec2 (-1.20827, -0.80333), ColorNoise (1.09284, Vec2 (1.24907, -3.11514)))), Brownian (4.15562, Vec2 (-1.20827, -0.80333))))))))), Brownian (0.880861, Vec2 (2.80615, 1.14405)))), SliceToRadial (Vec2 (-1.20827, -0.80333), ColorNoise (1.09284, Vec2 (1.24907, -3.11514))), Colorize (Twist (-1.90423, Vec2 (0.977825, -0.533419), Twist (-1.90423, Vec2 (0.977825, -0.533419), RadialGrad (195.316, Vec2 (1.24907, -3.11514)))), Wrapulence (5.81646, Vec2 (0.0918581, -0.543768)))))



camouflage evolved for serpentine

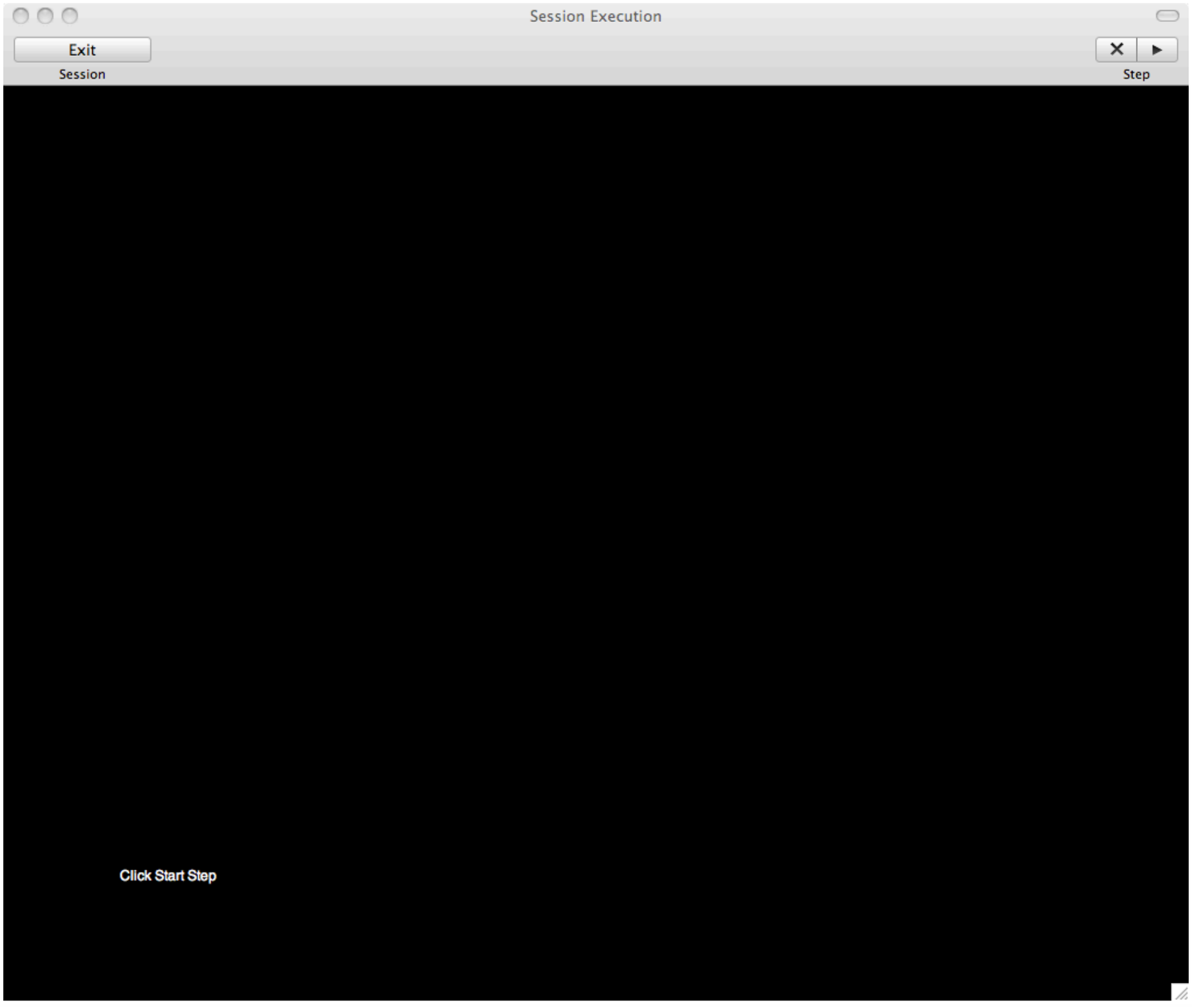
Subtract (EdgeEnhance (0.040705, 4.58566, Add (Wrapulence (2.61481, Vec2 (1.16699, -2.27901)), Furbulence (3.66211, Vec2 (-2.12694, -1.26397)))), Subtract (Subtract (EdgeEnhance (0.0420333, 4.58566, Add (Subtract (Add (Furbulence (0.323467, Vec2 (-2.12694, 1.10331)), Furbulence (3.66211, Vec2 (-2.12694, 1.10331))), Furbulence (3.66211, Vec2 (-2.12694, 1.10331))), EdgeEnhance (0.042568, 4.58566, Add (Wrapulence (2.61537, Vec2 (-2.94796, -2.94796)), Furbulence (3.90532, Vec2 (-2.94796, 0.965091)))))), Furbulence (3.66211, Vec2 (-2.12694, 1.10331))), HueOnly (Subtract (EdgeEnhance (0.042568, 4.58566, Add (Wrapulence (2.84277, Vec2 (-2.94796, 0.965091)), Wrapulence (2.84277, Vec2 (-2.94796, 0.740041)))), Subtract (Add (Wrapulence (3.05225, Vec2 (1.16699, -2.27901)), Furbulence (3.66211, Vec2 (-2.12694, 1.10331))), ColorNoise (0.5612, Vec2 (1.44605, -2.03616)))))))

(non-camouflage evolved texture)

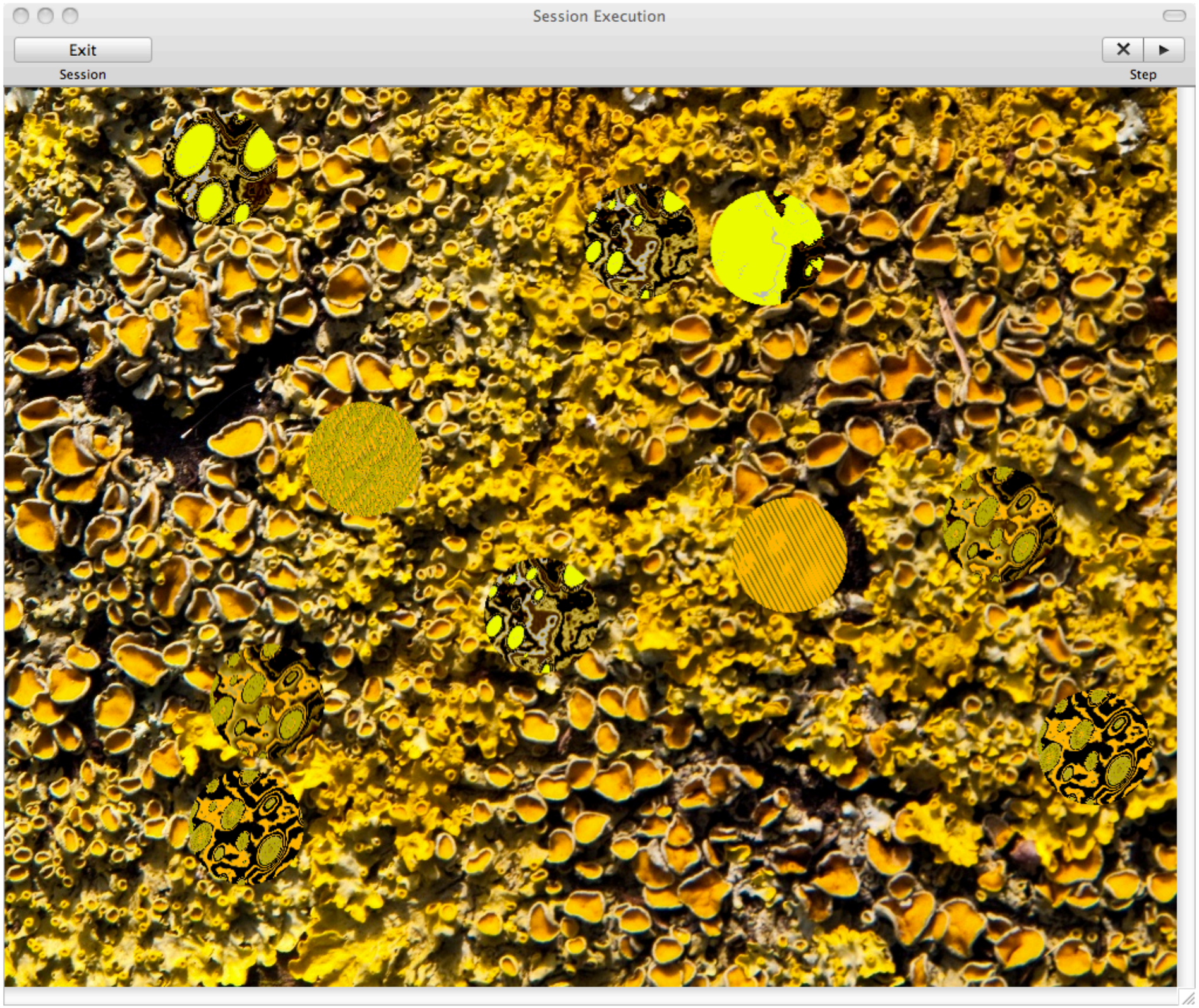
User Interaction and GUI

Each round of camouflage game

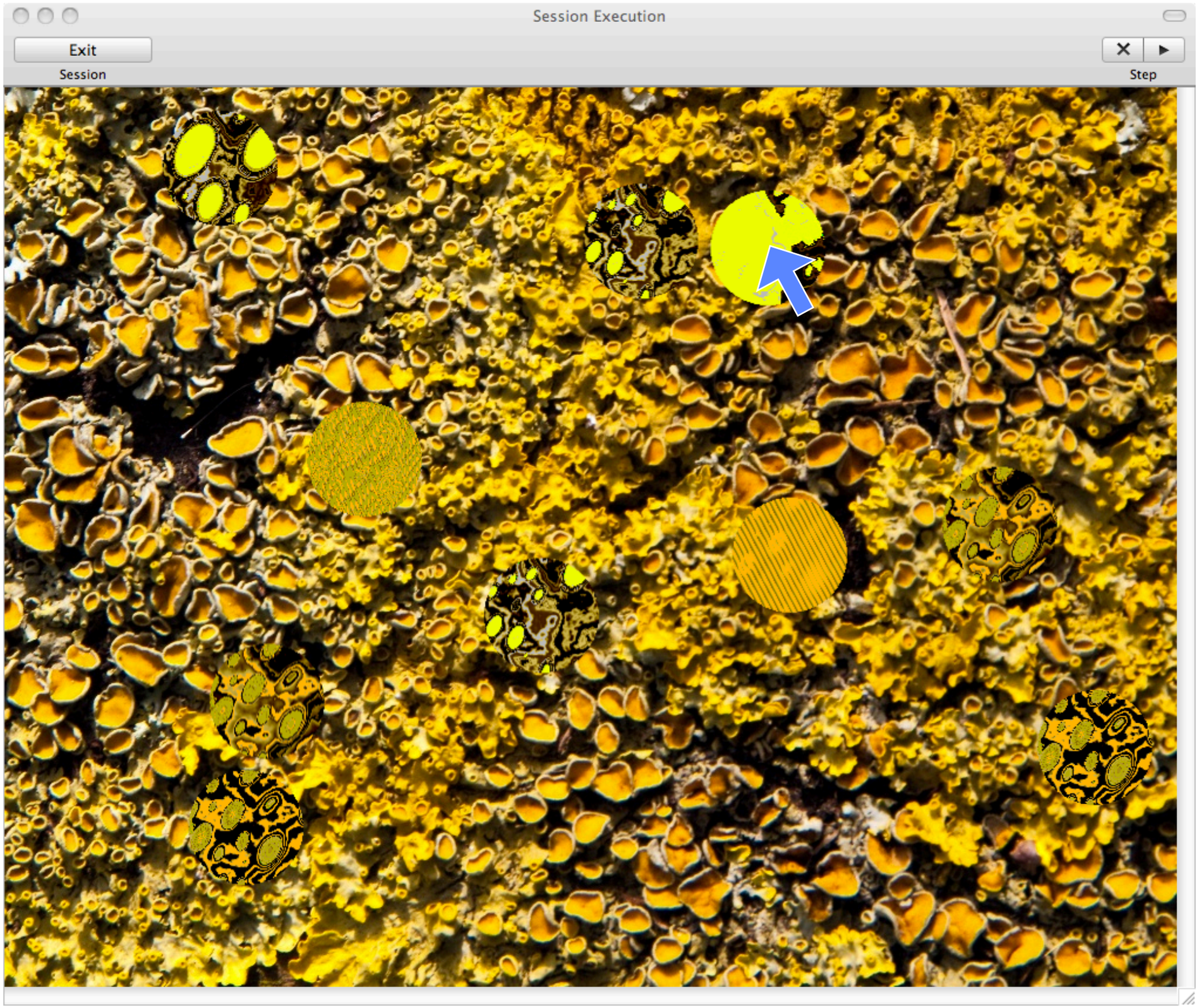
- Start with blank window, click to begin
- Background image displayed with cohort of ten prey
- Repeat five times:
  - Player/predator clicks on most conspicuous prey
  - Prey is *eaten*: removed from population and display
- End of round, blank window



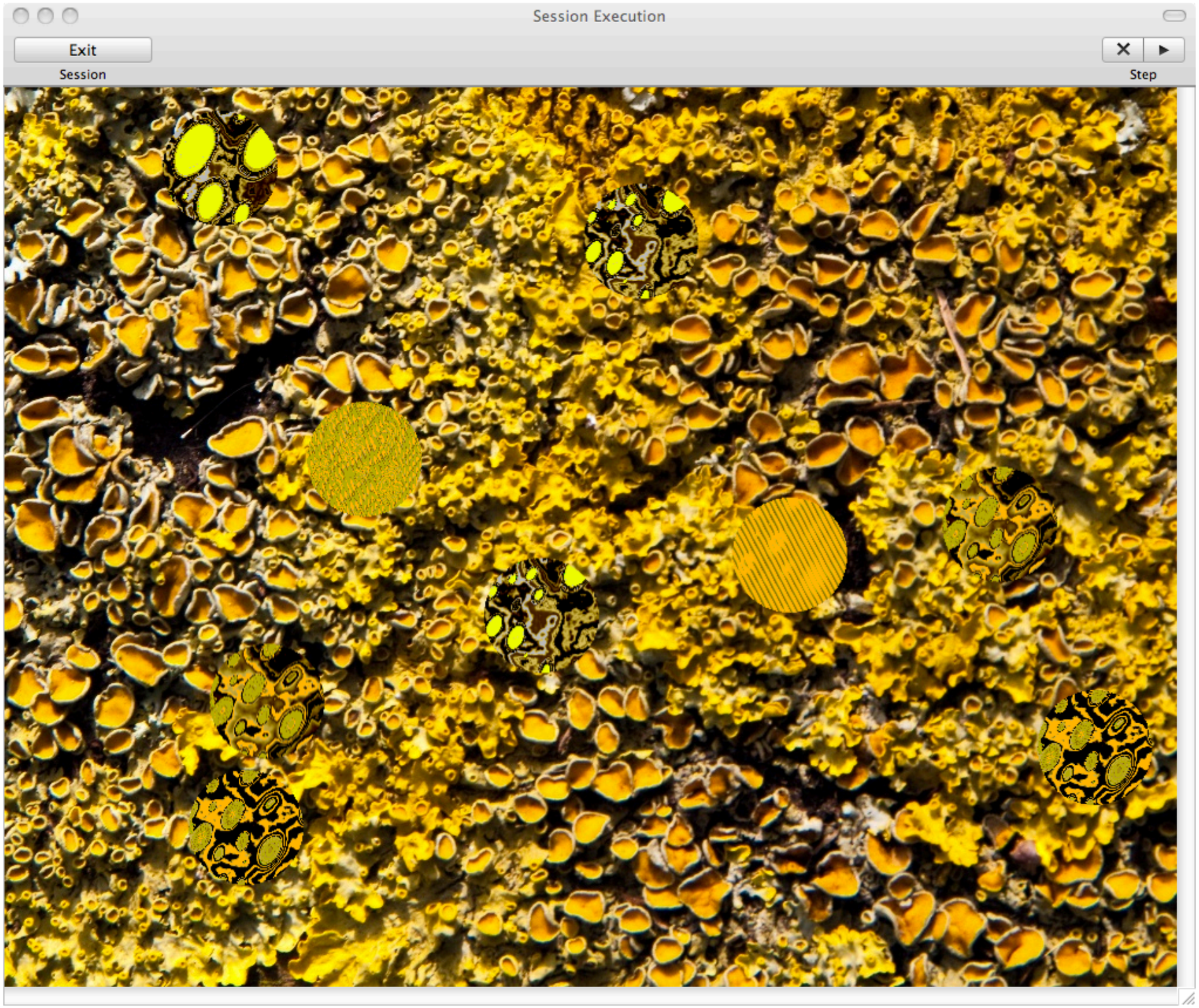
beginning of one “round” of camouflage game



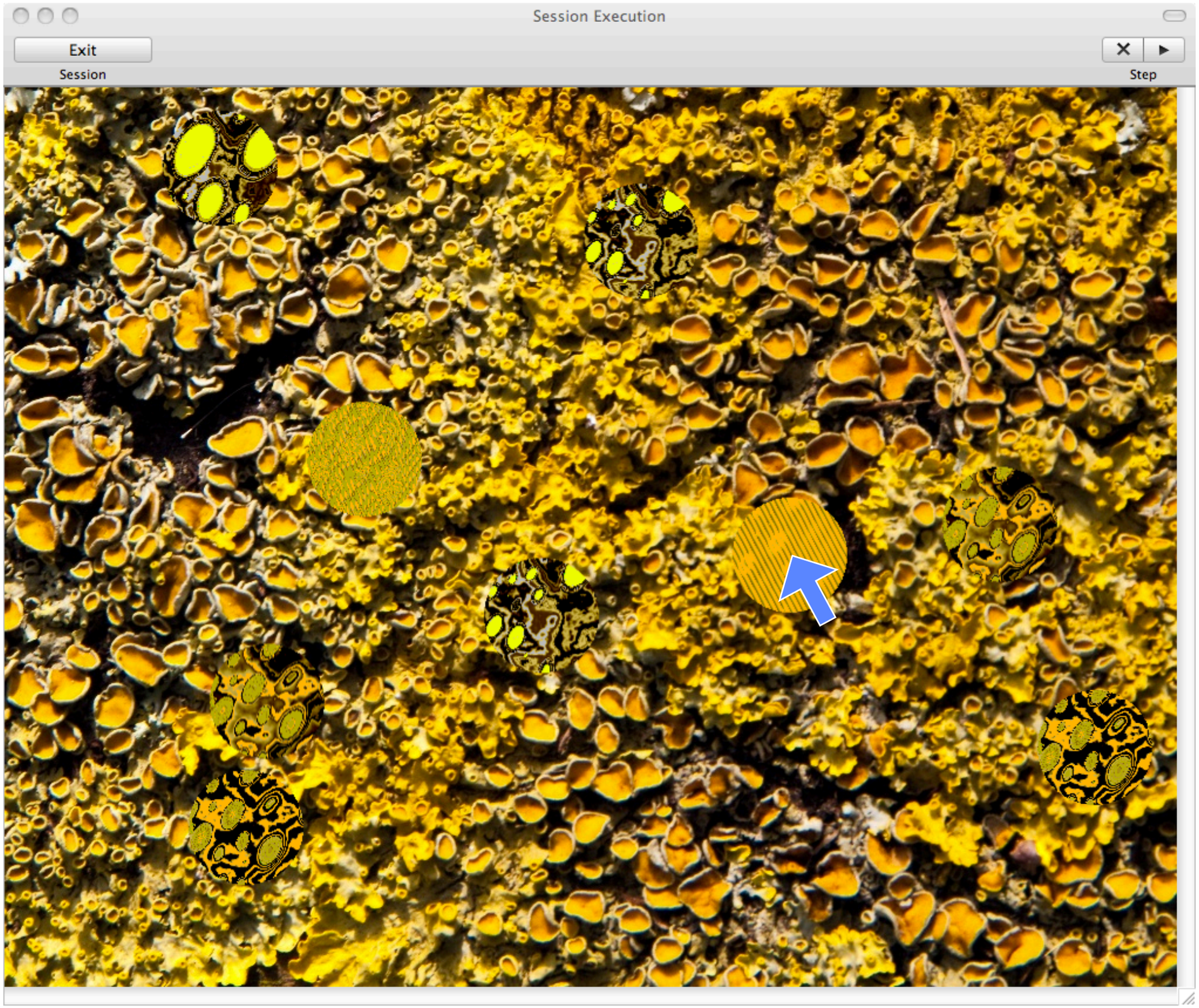
10 prey



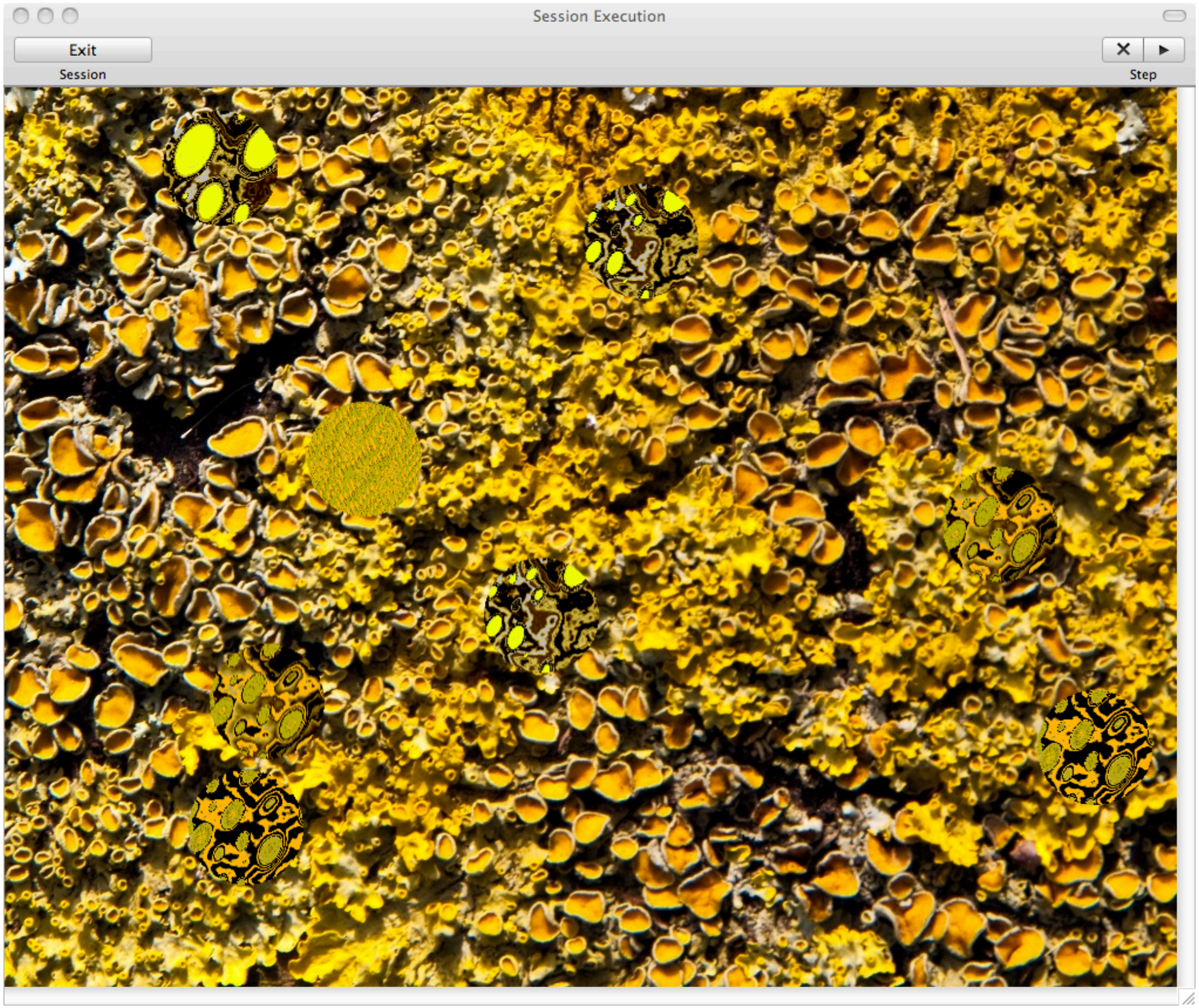
predator selects prey 1



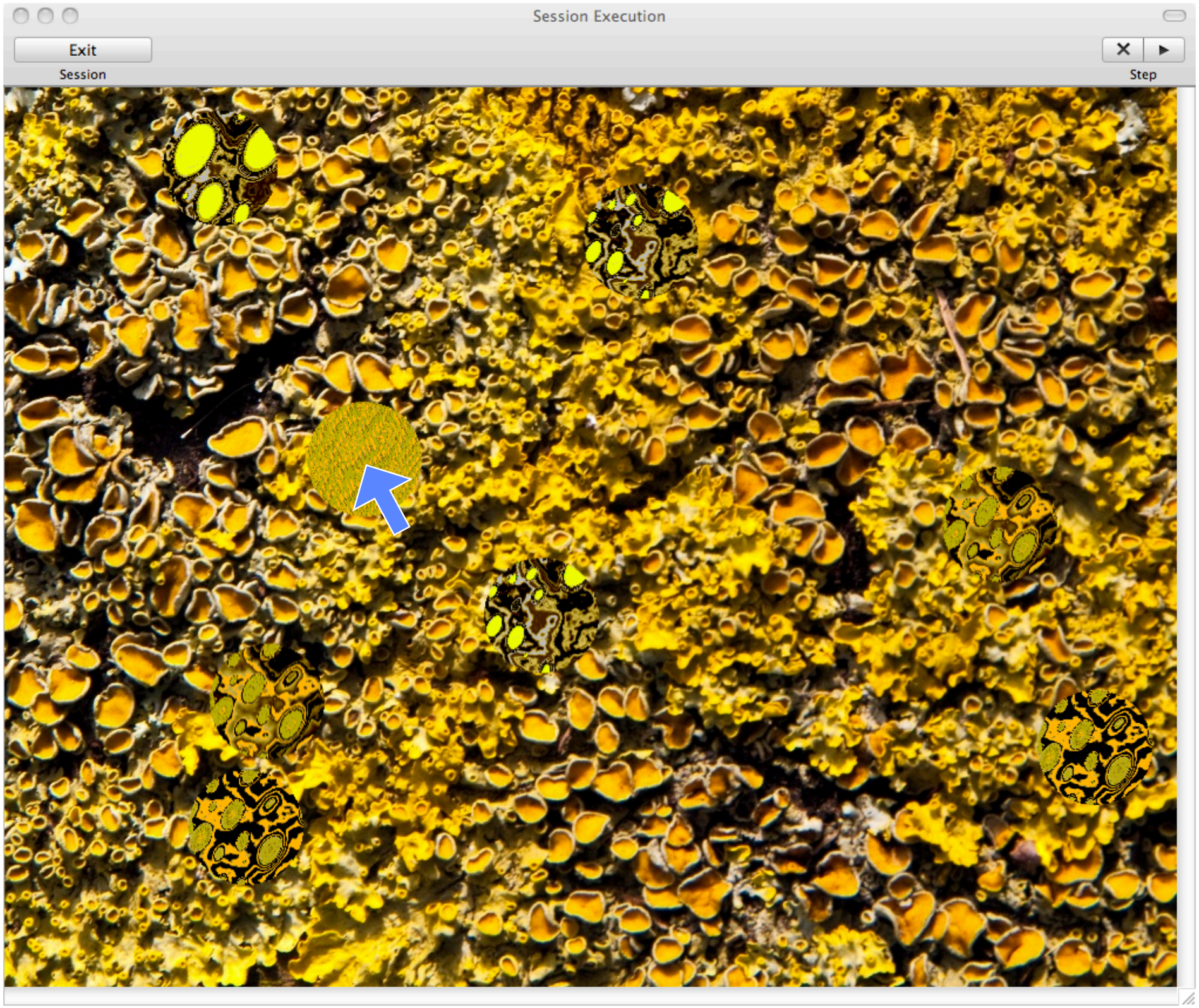
9 prey remaining



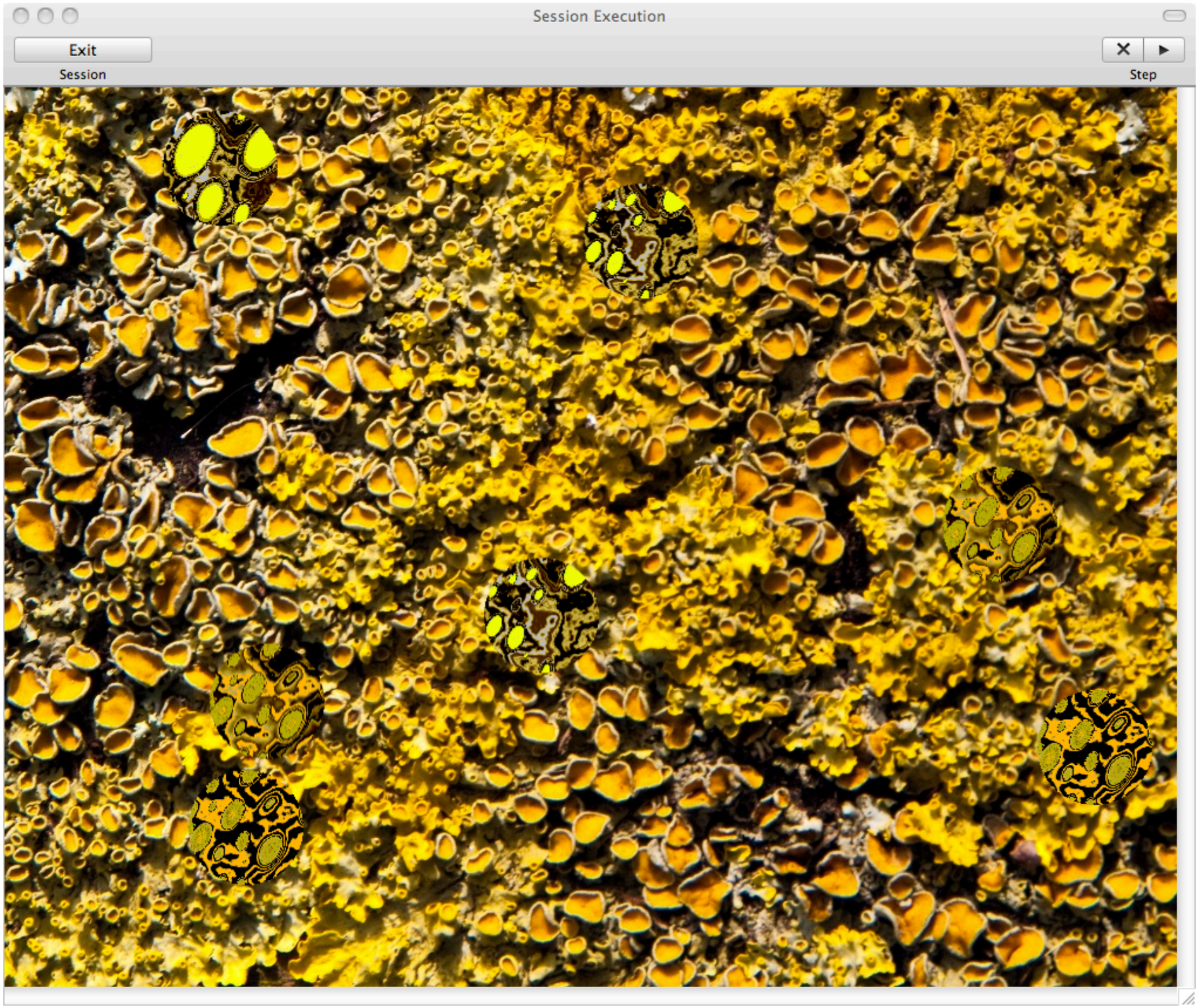
predator selects prey 2



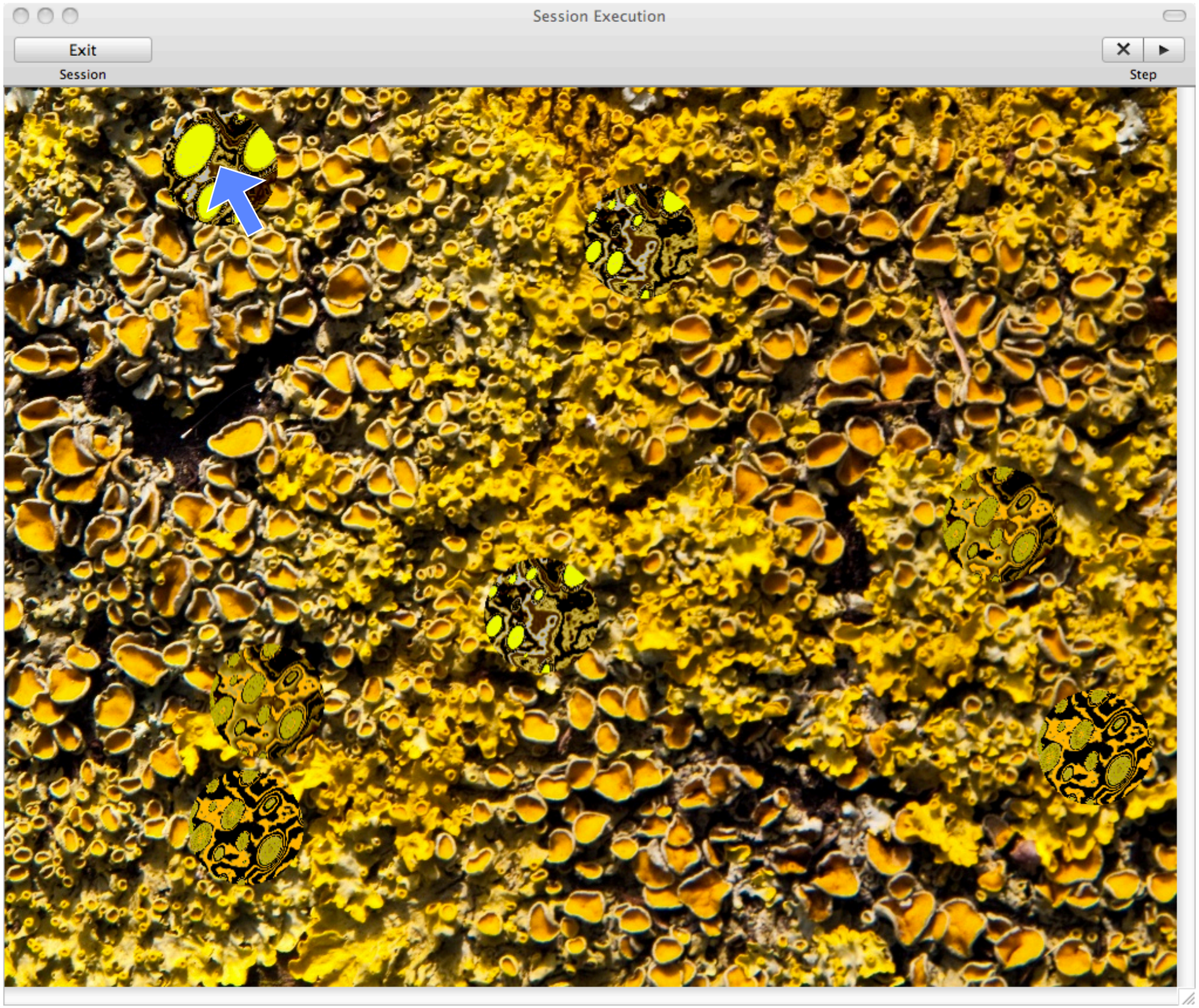
8 prey remaining



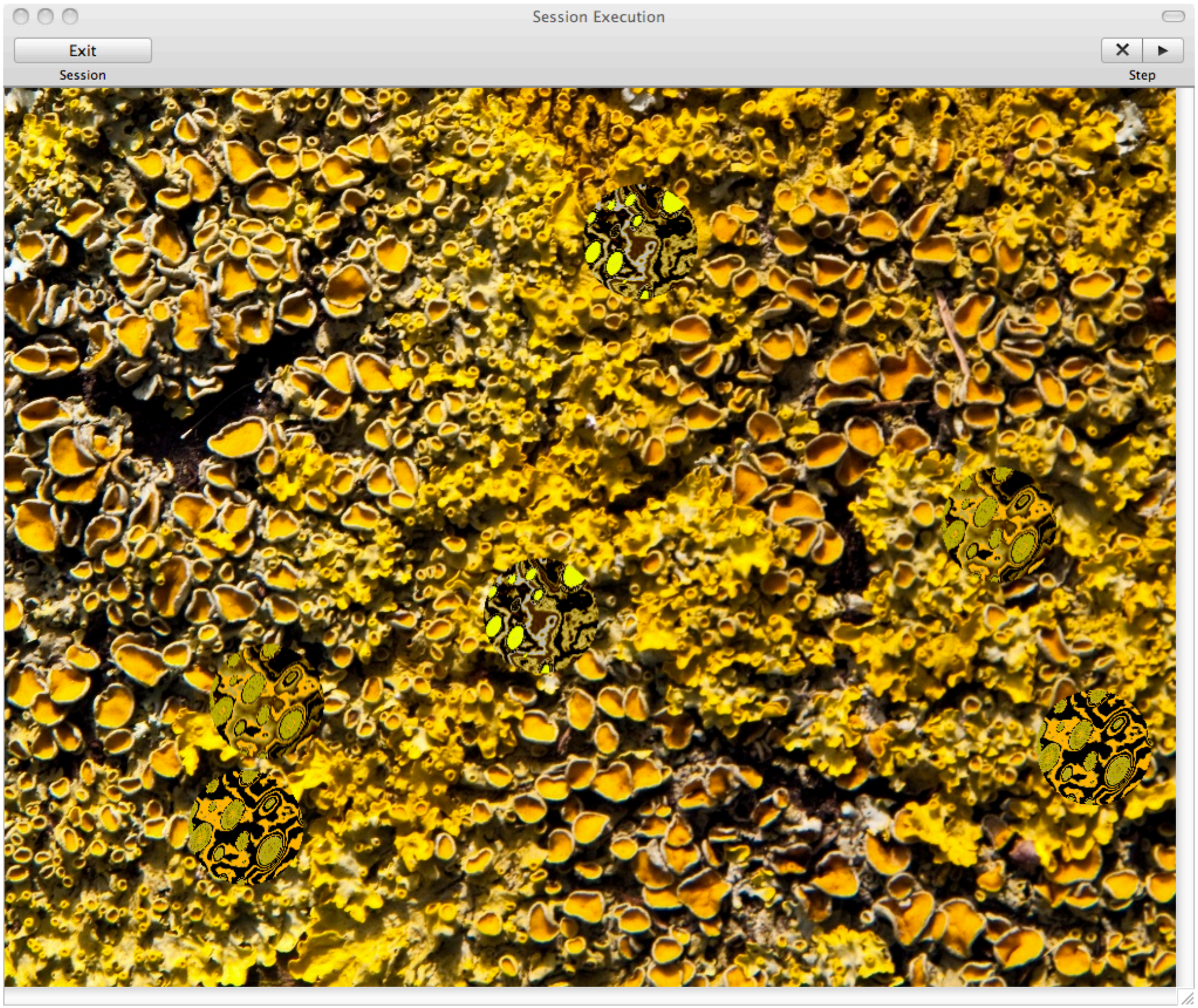
predator selects prey 3



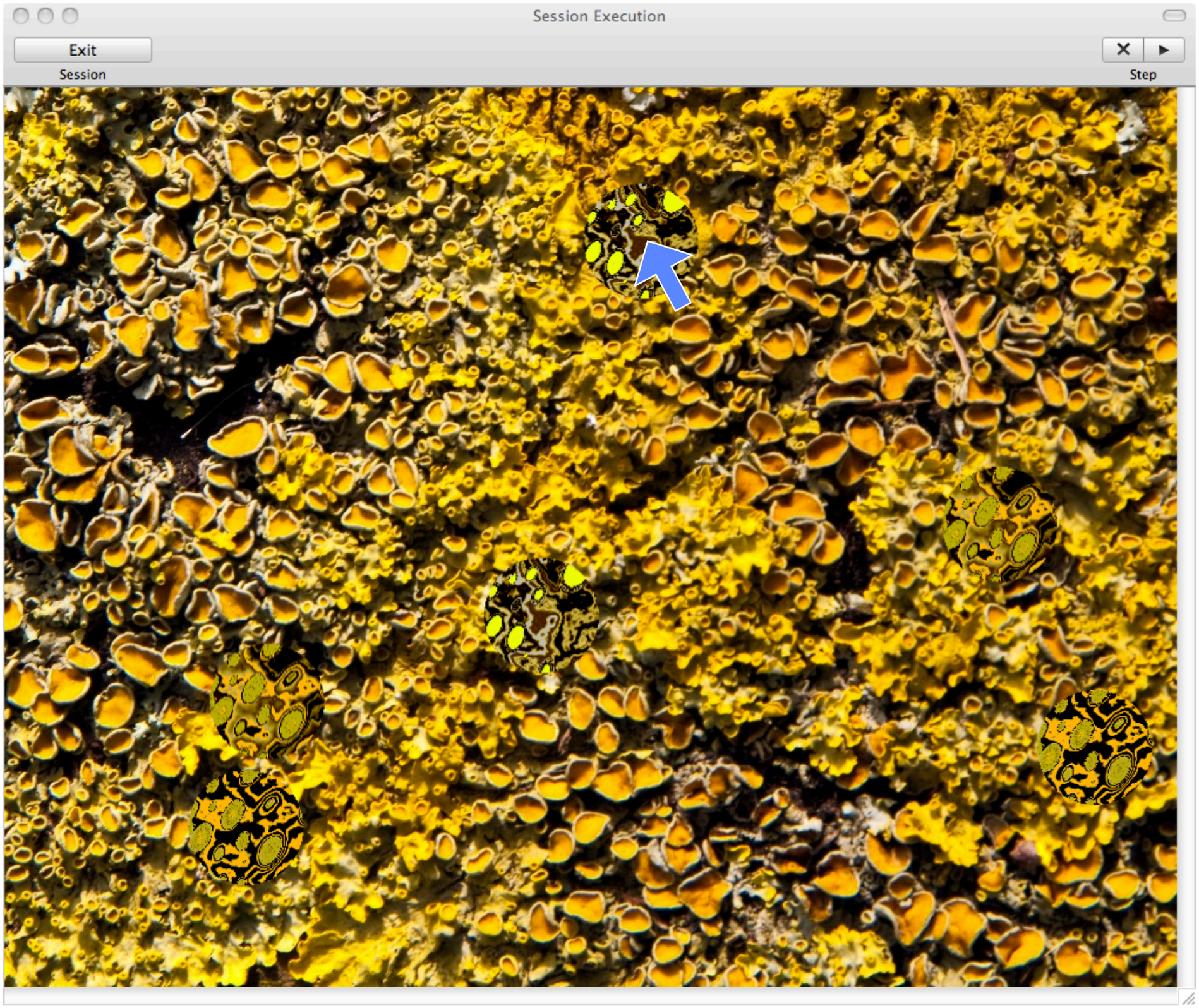
7 prey remaining



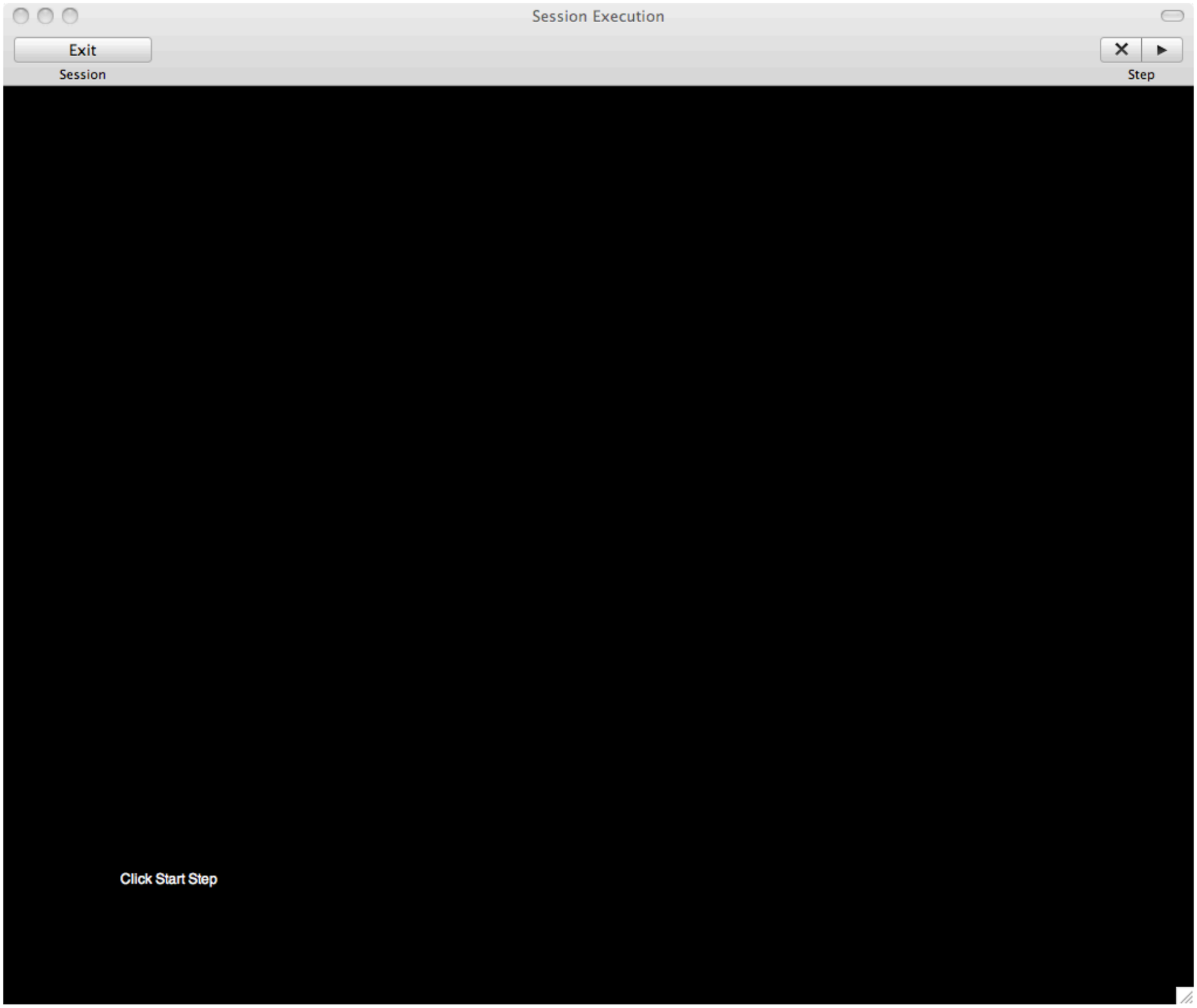
predator selects prey 4



6 prey remaining



predator selects prey 5

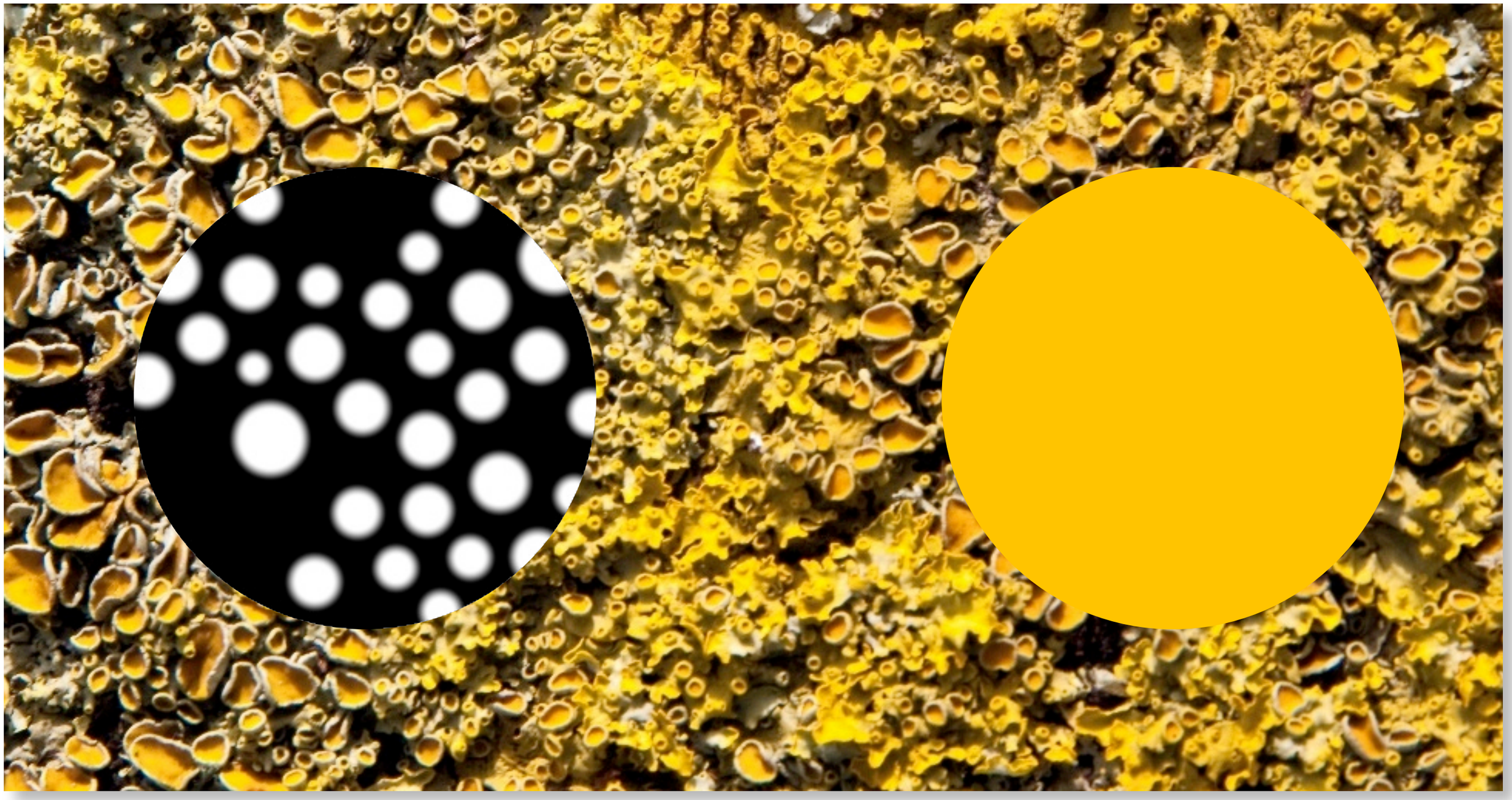


end of one “round” of camouflage game

Typical run

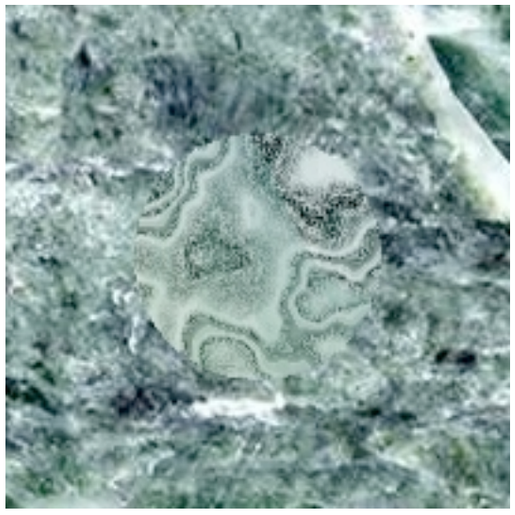
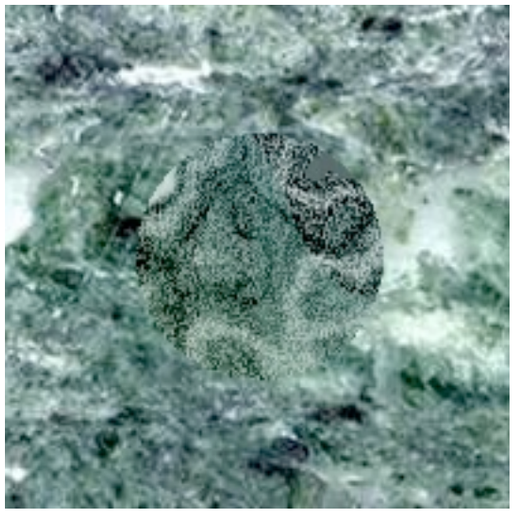
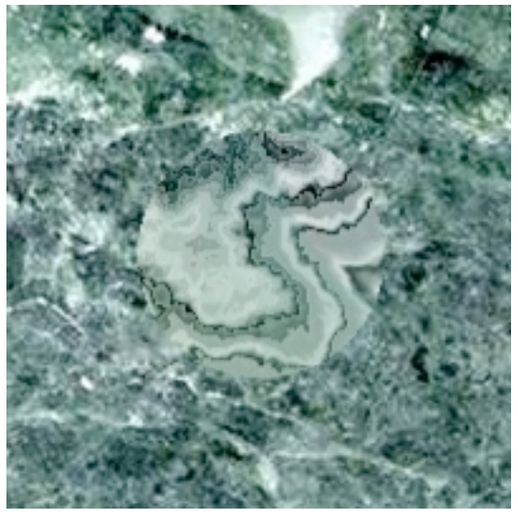
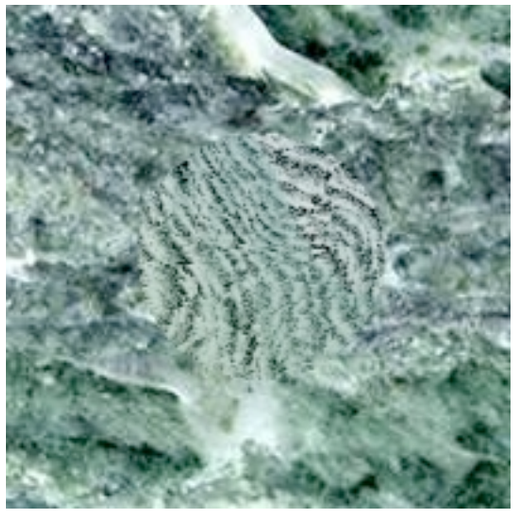
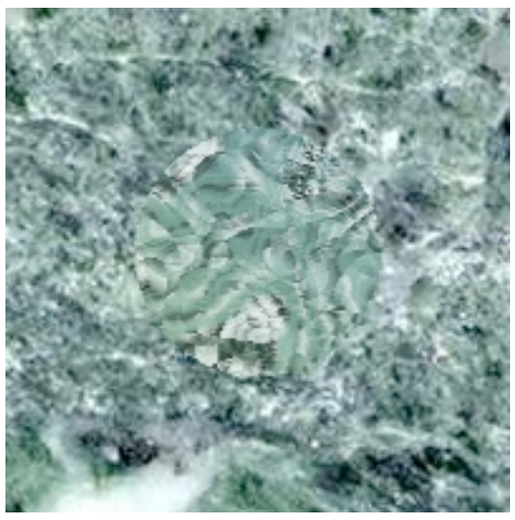
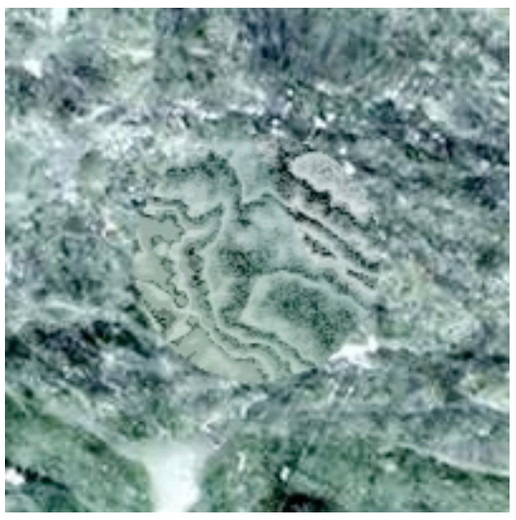
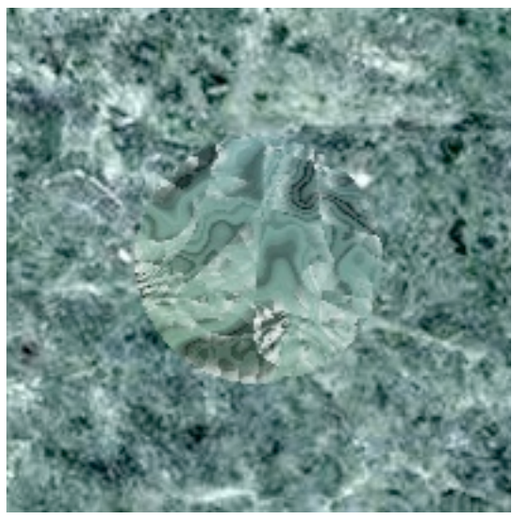
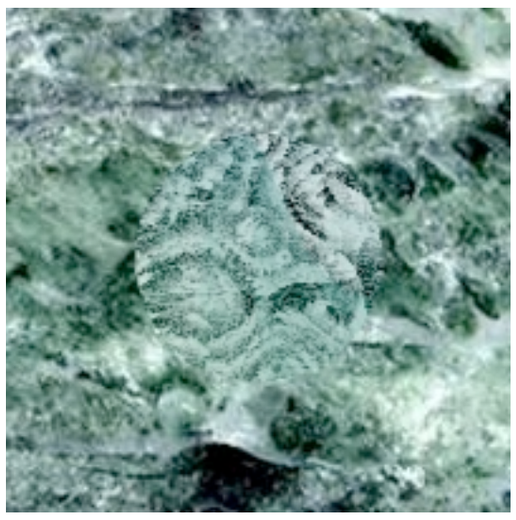
- 1000 cohorts — sometimes 2000 or more
- 10,000 individuals fitness tested
- 83 “generations” in traditional GA/GP (p=120)
- **5000** mouse clicks by human predator
- 3 hours of steady work — usually spread over weeks

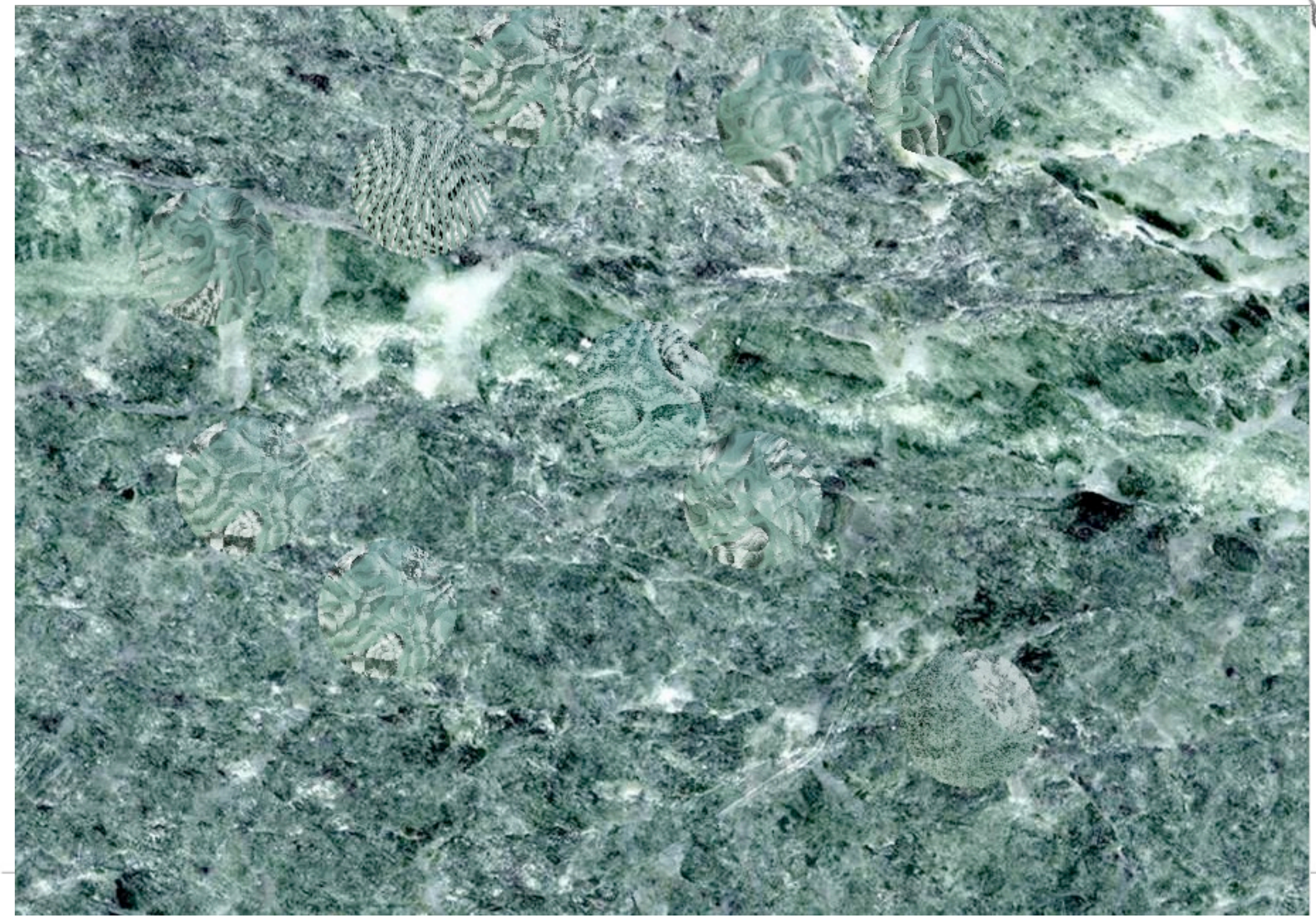
Which is more conspicuous?



Results

Serpentine (polished stone)

Flowers and leaves

(*lantana montevidensis* in my backyard)

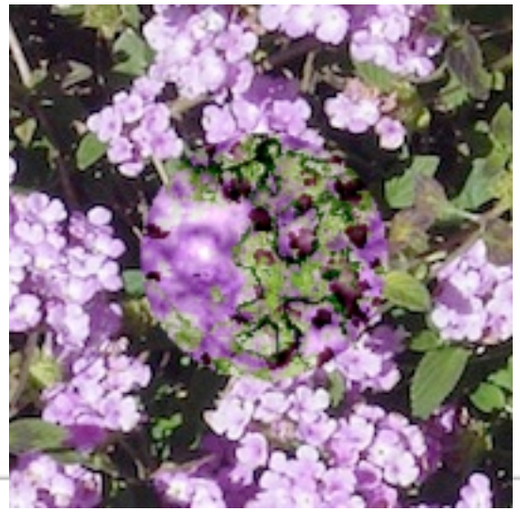




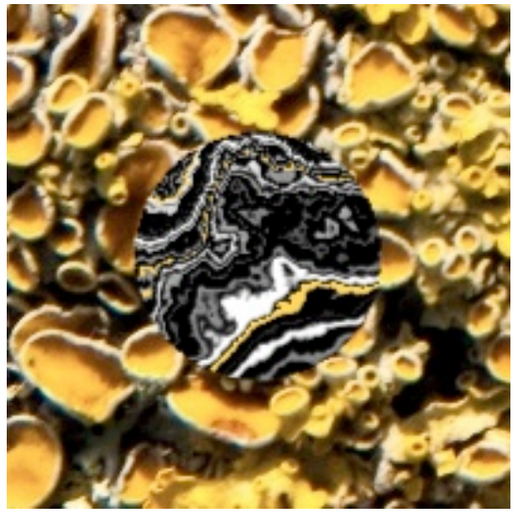
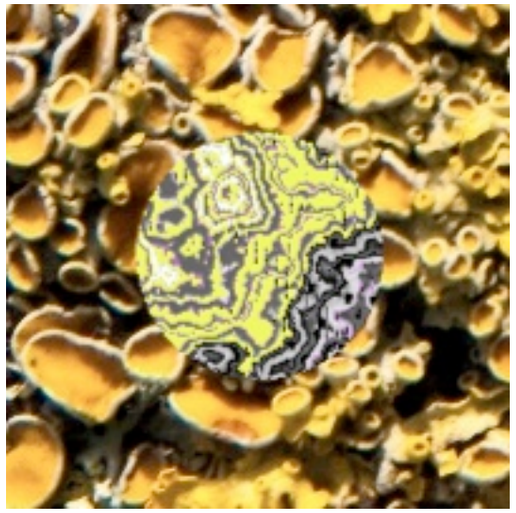
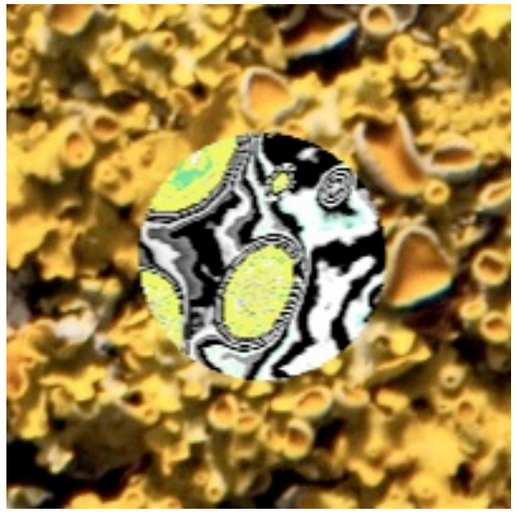
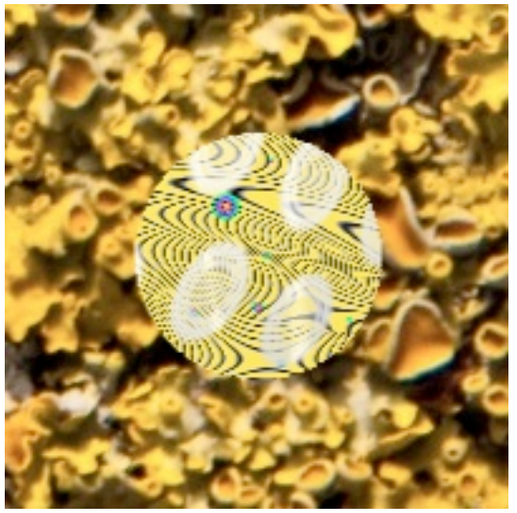
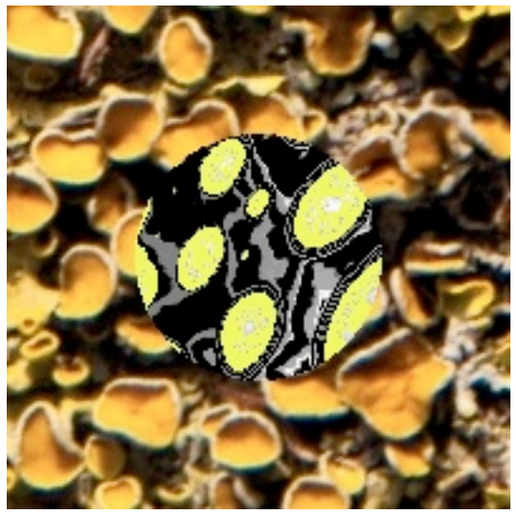
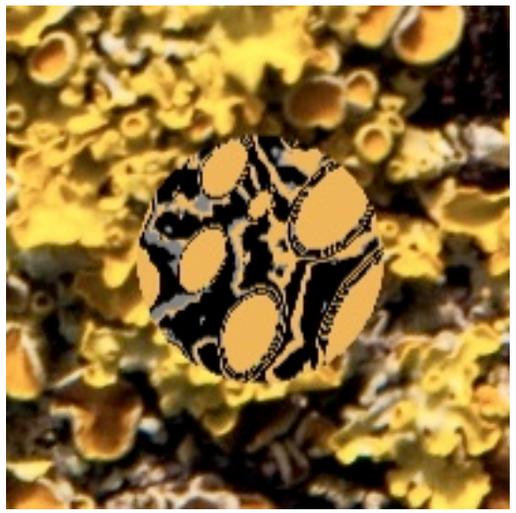
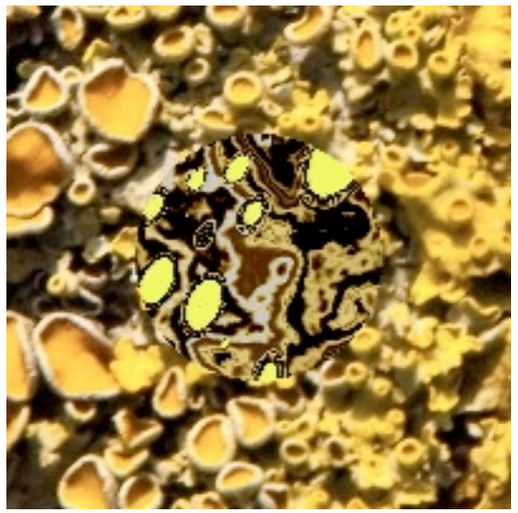
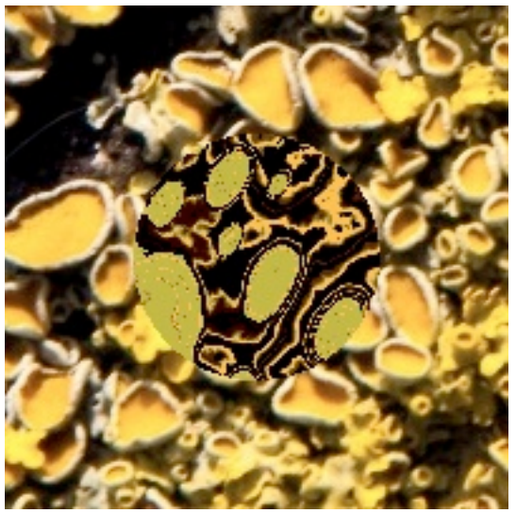
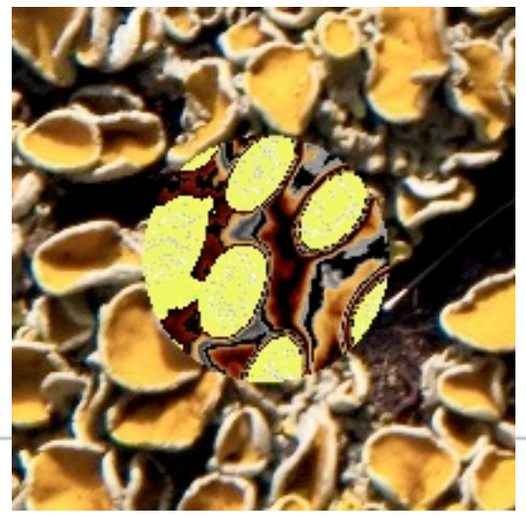
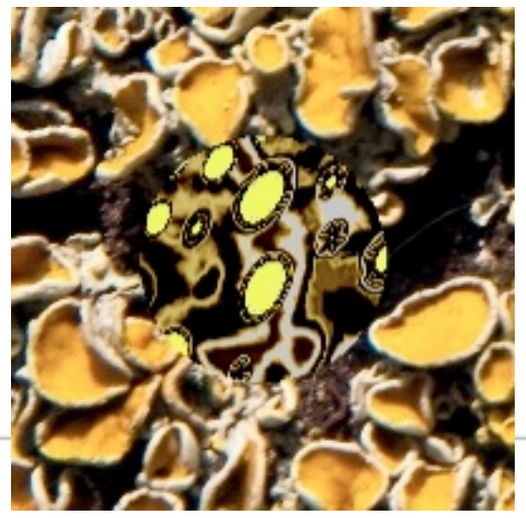
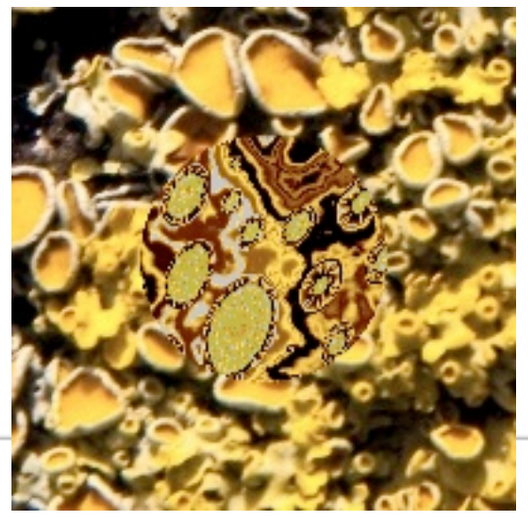
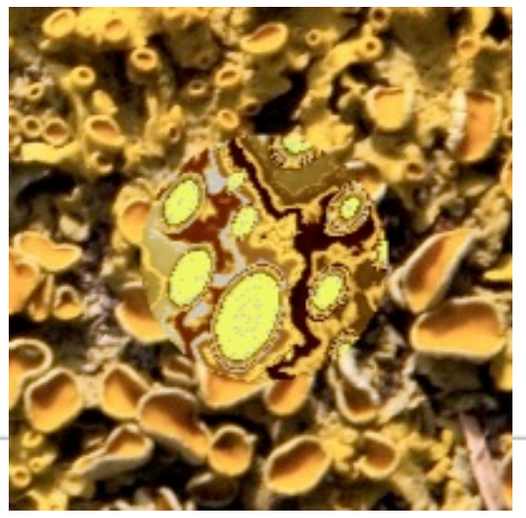




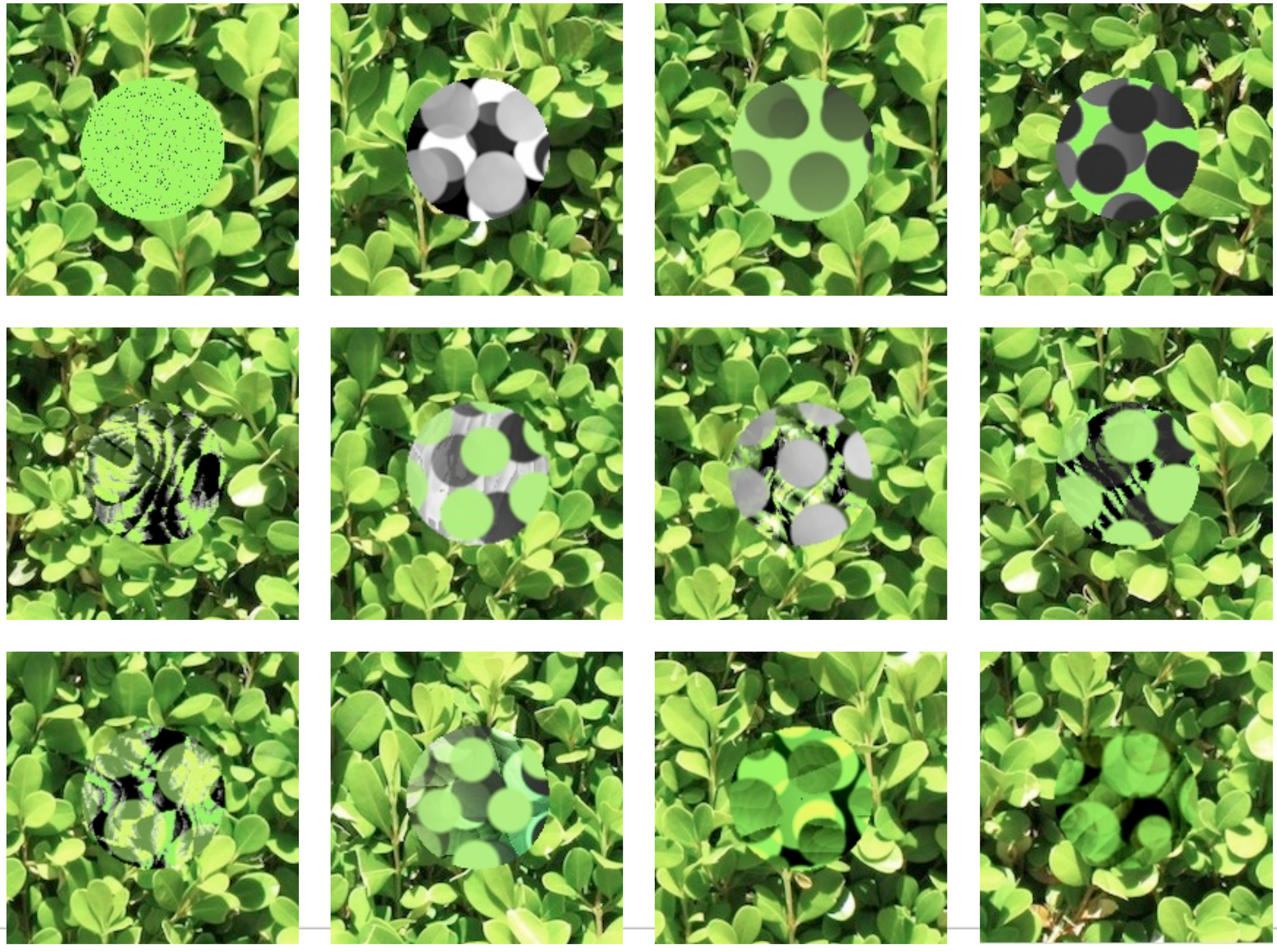


Lichen

Hedge



(shadows?!)

Peppers
(unsuccessful run)

Future work

- Crowd-sourcing
  - Amazon Mechanical Turk
  - Games with a purpose (GWAP)
- Simulated predator (using saliency and classifier?)
- Other applications of evolutionary texture synthesis
- Biological applications? (simulations, classroom tools)

Acknowledgements

- Research sponsor:
  - Sony Computer Entertainment
    - Dominic Mallinson (VP US R&D)
- GUI implementation: Bjoern Knafla
- Advice: Christian Gagné, Daniel Weinreb, Iztok Lebar Bajec, James O'Brien, Lance Williams, Ken Perlin.

Thank you!

craig_reynolds@playstation.sony.com
http://www.red3d.com/cwr/iec/