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Goal Oriented Texture Synthesis

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SONY
COMPUTER ENTERTAINMENT

SCE US R&D

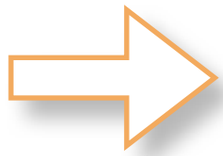
texture synthesis

+

optimization

+

goal



goal-oriented texture synthesis

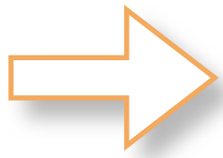
library for procedural texture synthesis

+

genetic programming

+

fitness



goal-oriented texture synthesis

Goal-oriented texture synthesis

- Automatically discover novel images via optimization
- Evolve images based on desired visual properties
- The stochastic nature of evolutionary computation provides an analog of artistic variations on a theme
- Unsupervised or interactive (using human vision)
- Examples:
  - Evolution of textures from high level descriptions
  - Modeling the evolution of camouflage in nature

evolutionary
texture synthesis

unsupervised
procedural fitness

supervised
interactive fitness
based on human vision

Larger perspective of this work

- Related to the concept of evolutionary art
- More specifically aimed at evolving images with objective visual properties
- *Might* be applicable as tool for designers
- Primarily interested in closing the loop between image creation and visual perception

Evolutionary Computation Details

- Genetic programming via Gagné's *Open BEAGLE*
- Uses Montana's strongly-typed genetic programming
- Crossover with "jiggle" mutation of FP constants
- Population 100-200 in 5-10 demes of 20 individuals
- Unsupervised runs:
  - 50 generations, about 5 minutes
  - Textures rendered at 300x300 pixels
  - Fitness examines roughly 10,000 pixels (10%)

Procedural Texture Synthesis

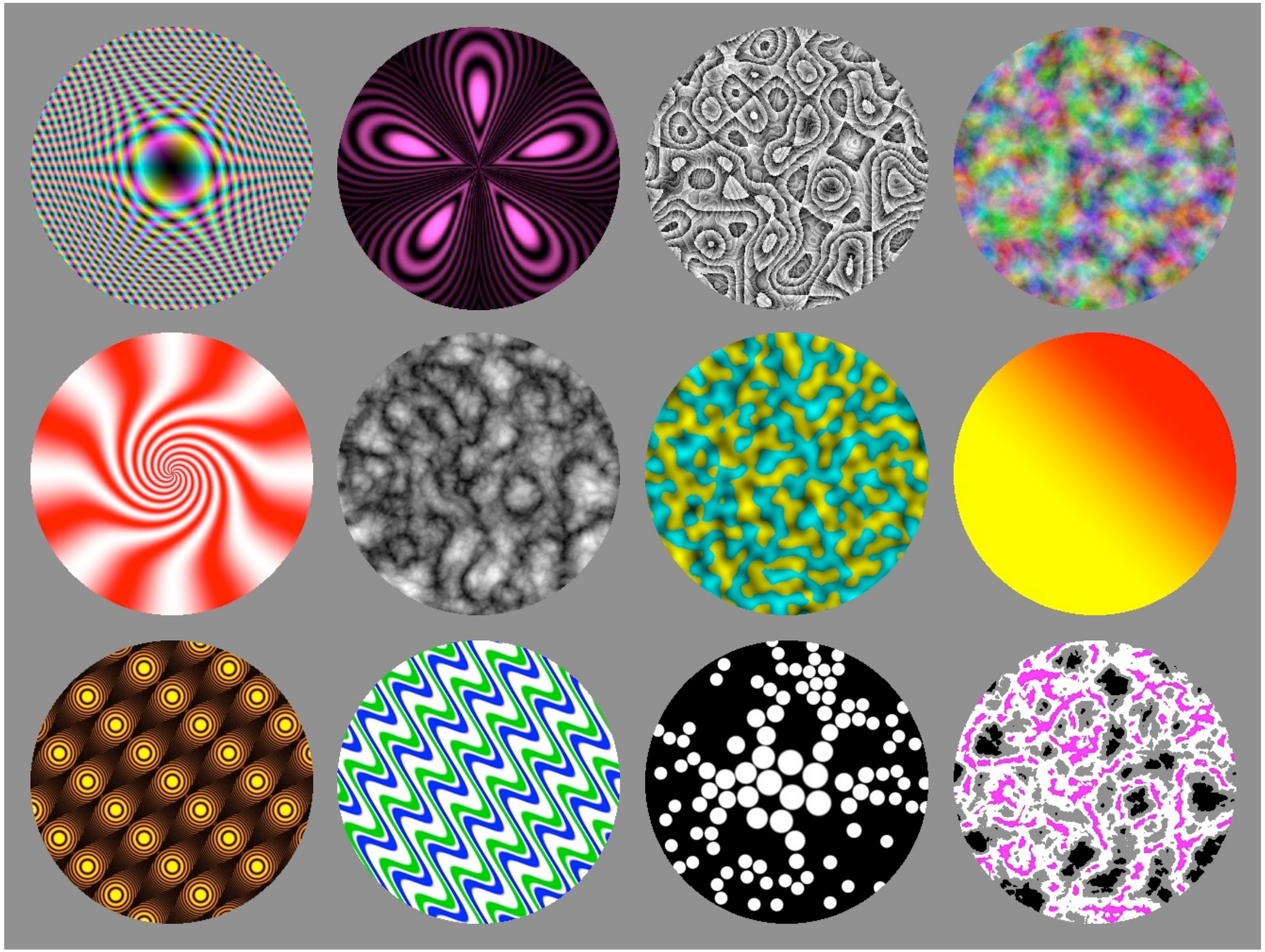
Procedural texture synthesis

- Procedural model: program to make texture
- Library (API) of about 50 texture-valued functions to:
  - generate basic texture patterns
  - operate on one or more textures
- Nested expression of texture functions
- Resolution-independent representation, sample pixel values at continuous (floating point) coordinates

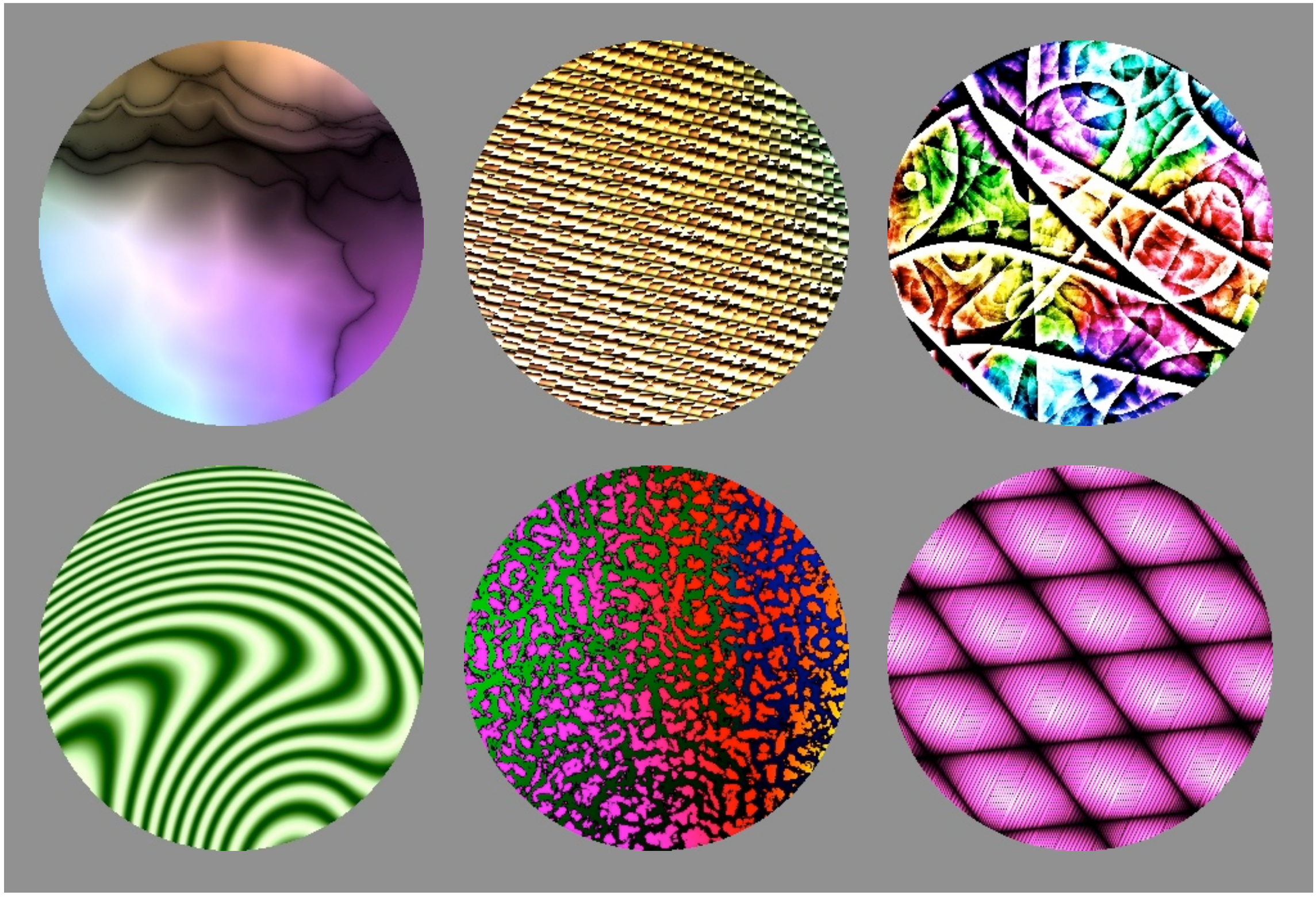
Texture synthesis library

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



simple hand-written combinations of texture synthesis primitives



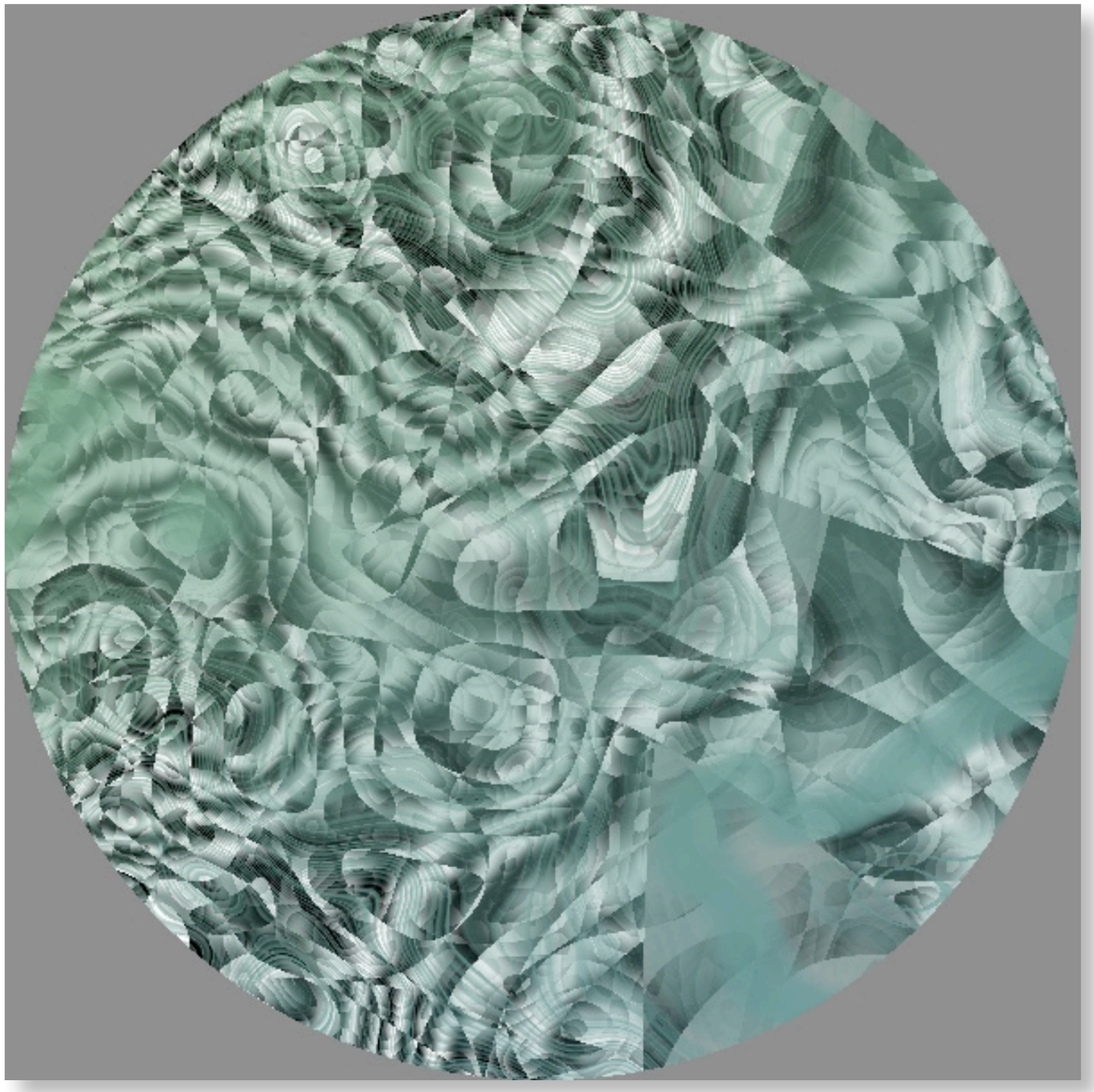
textures evolved with unsupervised GP

Evolved textures with source code

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)))))))

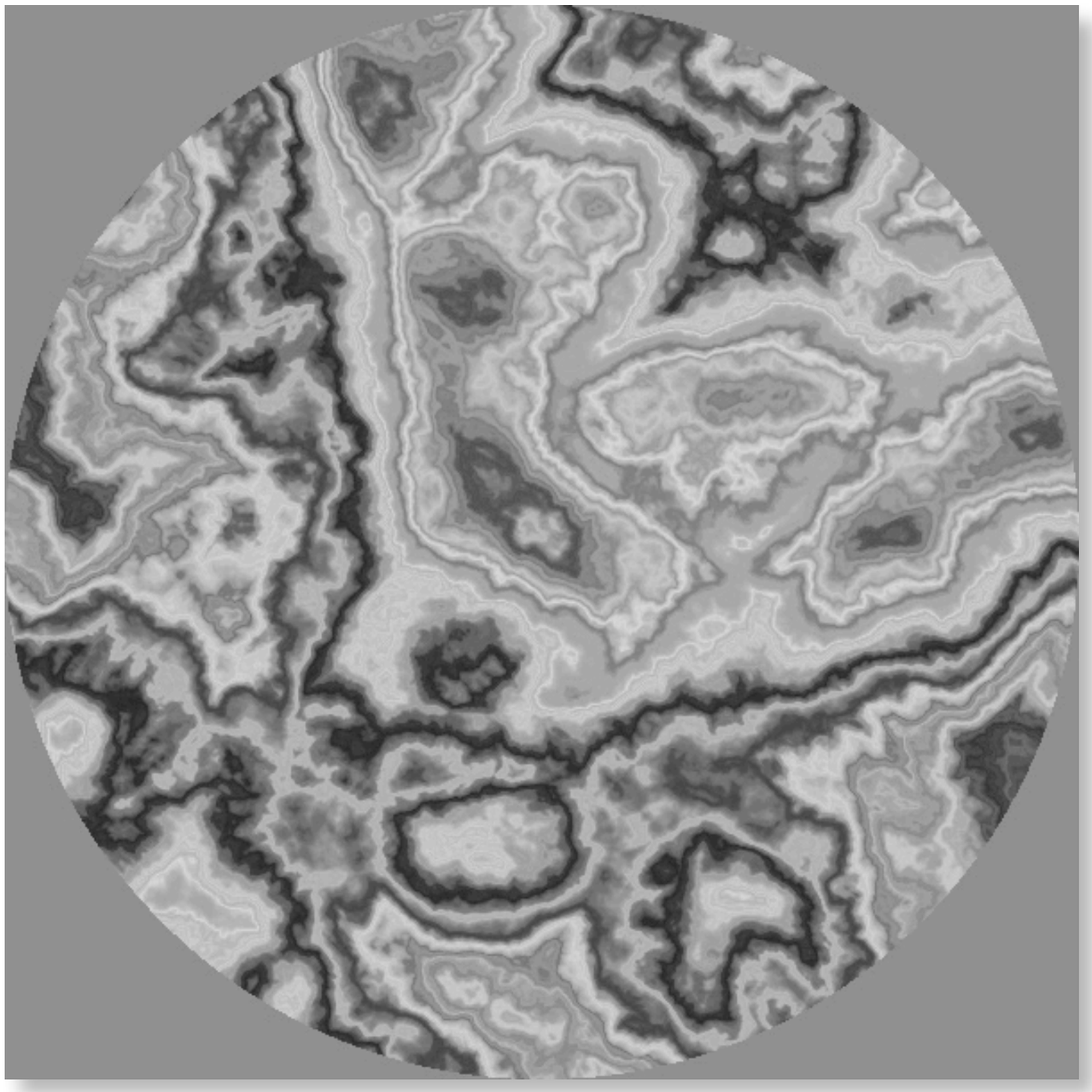
texture evolved from high-level description

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)))))



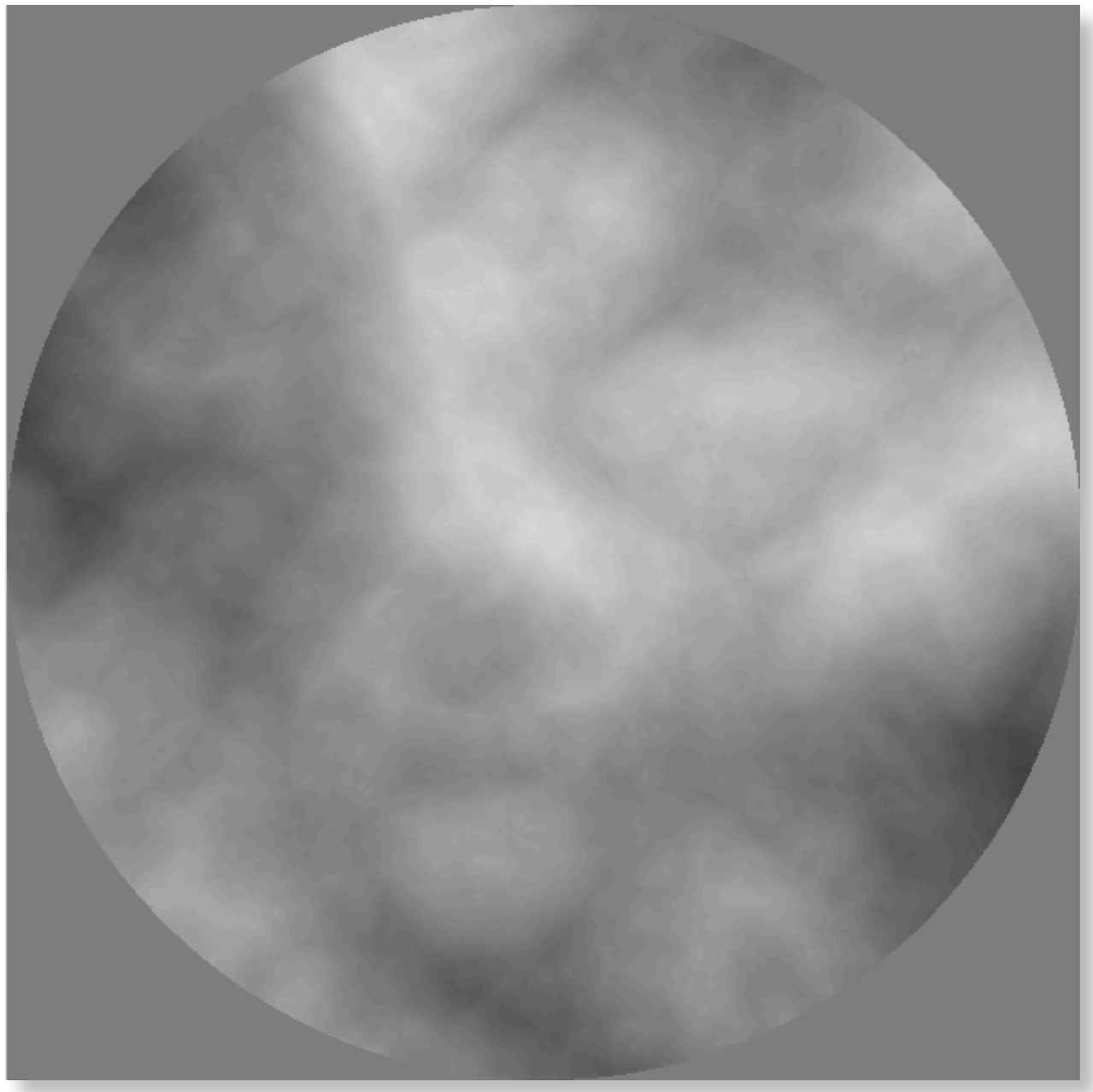
camouflage evolved for *serpentine*

```
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)))
```



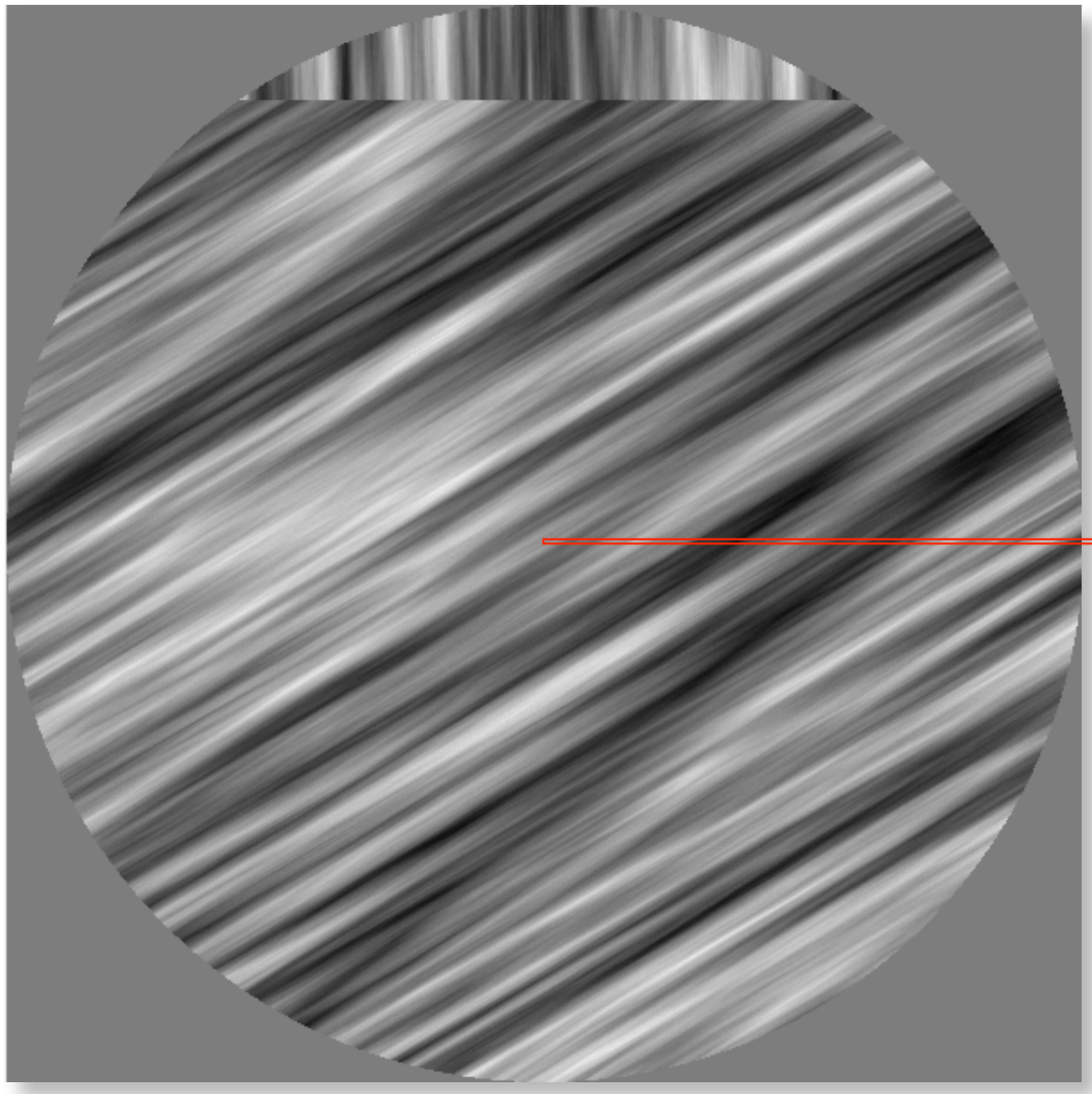
camouflage evolved for *oak bark*

```
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))
```



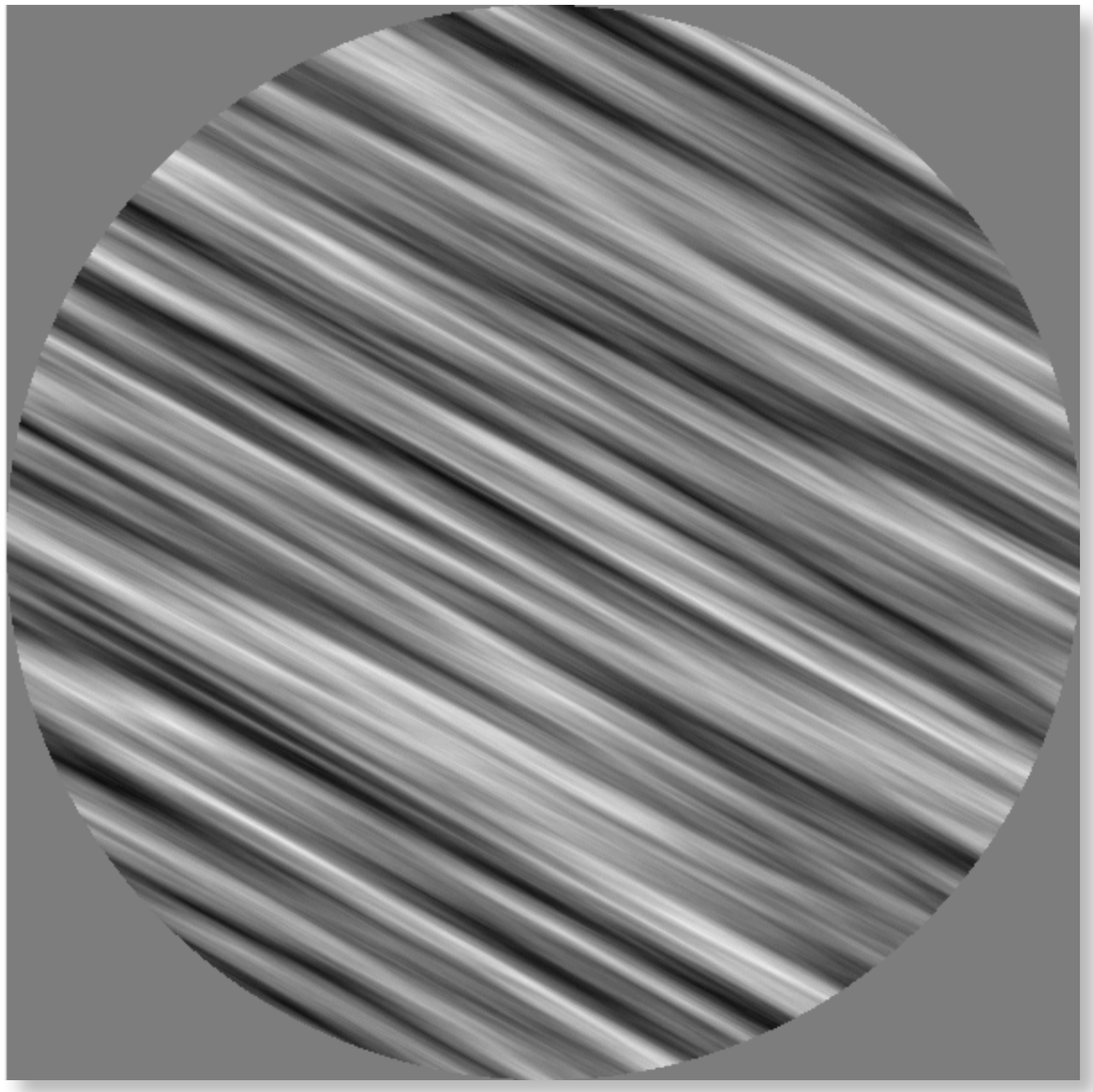
camouflage evolved for *oak bark*

```
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,
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                        Vec2 (-1.37922, 0.946741),
                Furbulence (1.21806,
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                                  2.9815))),
          Furbulence (1.21806,
                      Vec2 (-2.94693, -1.86416)))
```

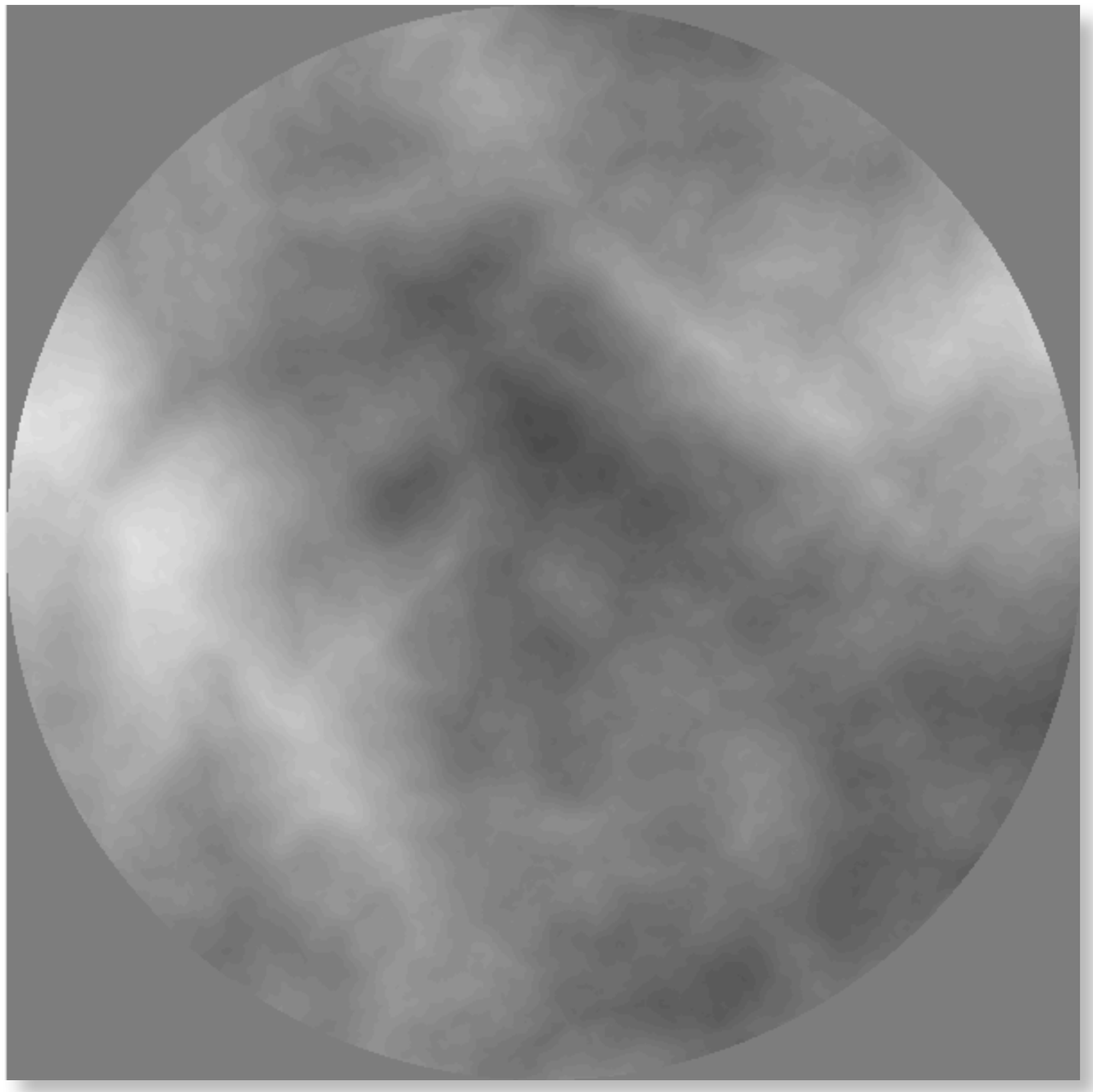

camouflage evolved for *oak bark*

```
Colorize (Ring (5.80532,
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                         Vec2 (-1.37922, 0.946741),
                         Furbulence (1.21806,
                                     Vec2 (1.62529,
                                           2.9815)))),
          Furbulence (1.21806,
                      Vec2 (-2.94693, -1.86416)))
```
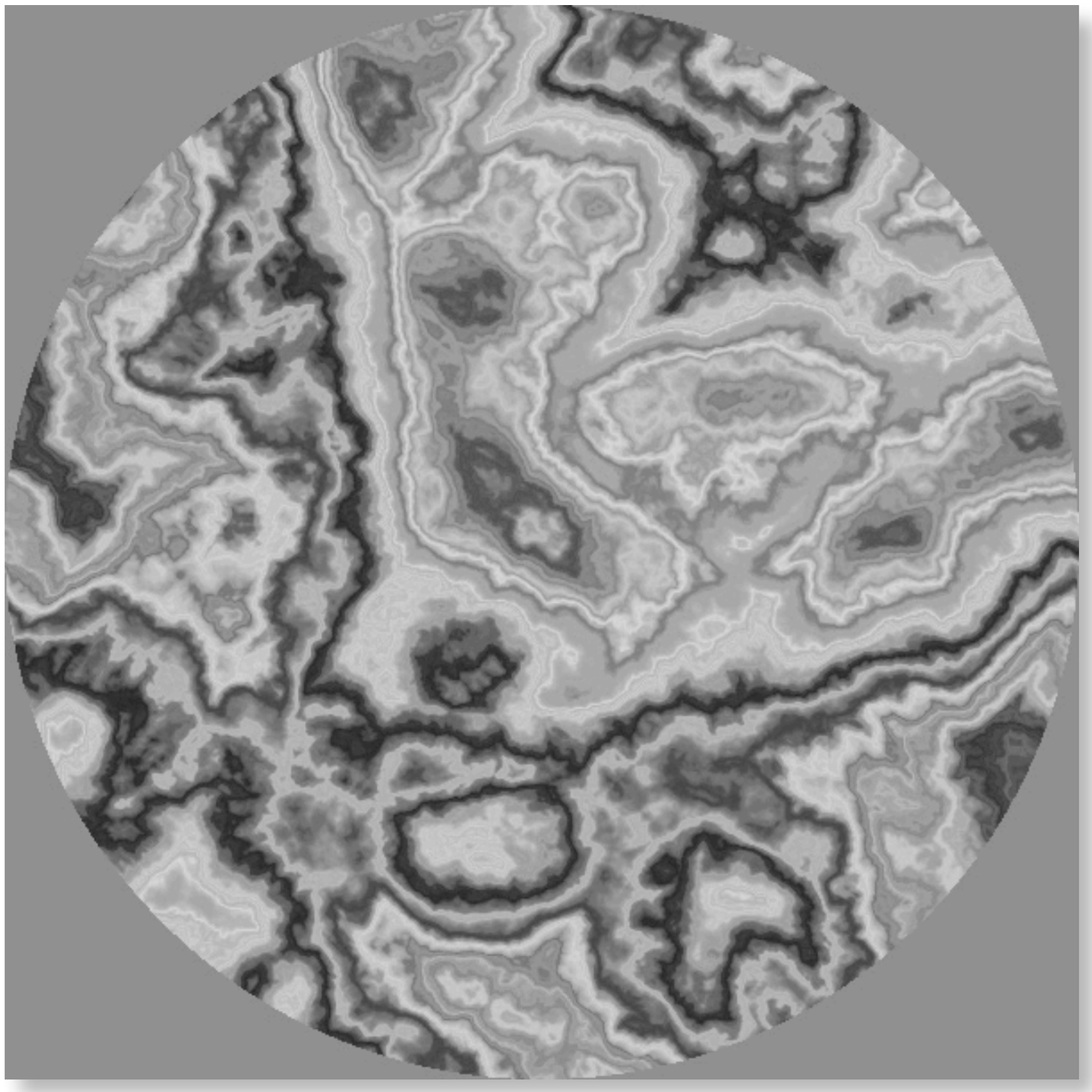



camouflage evolved for *oak bark*

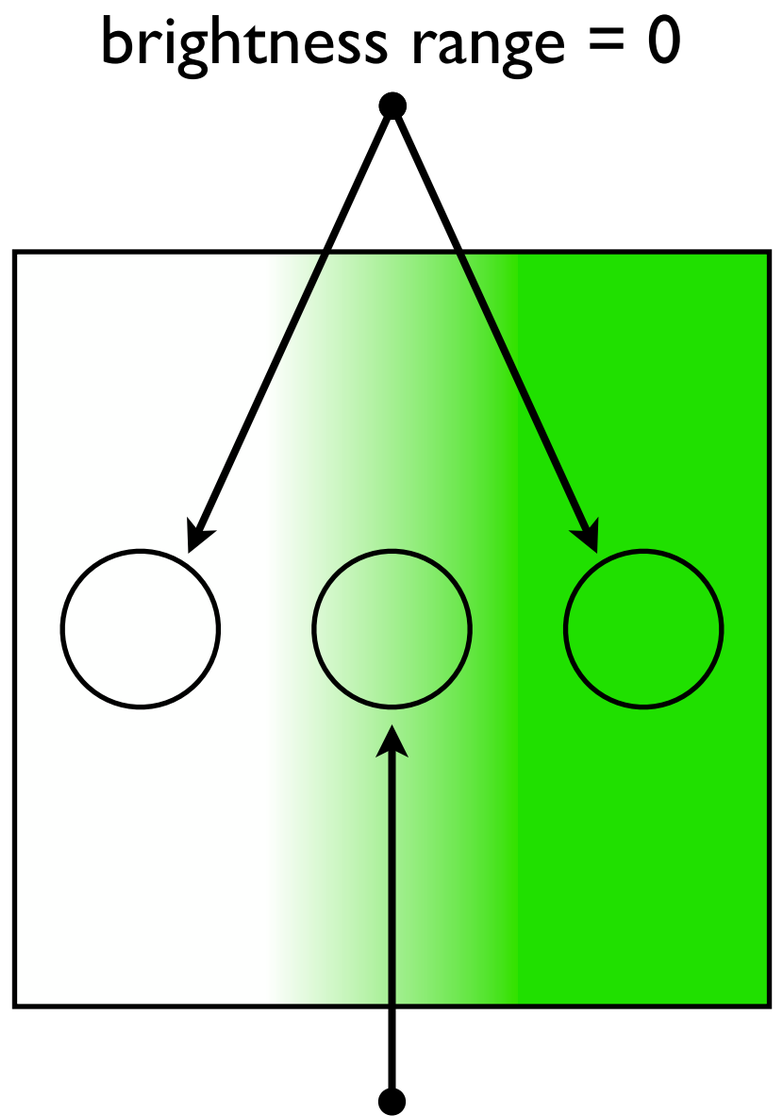
Evolving Textures from High Level Descriptions

Originally a testing procedure

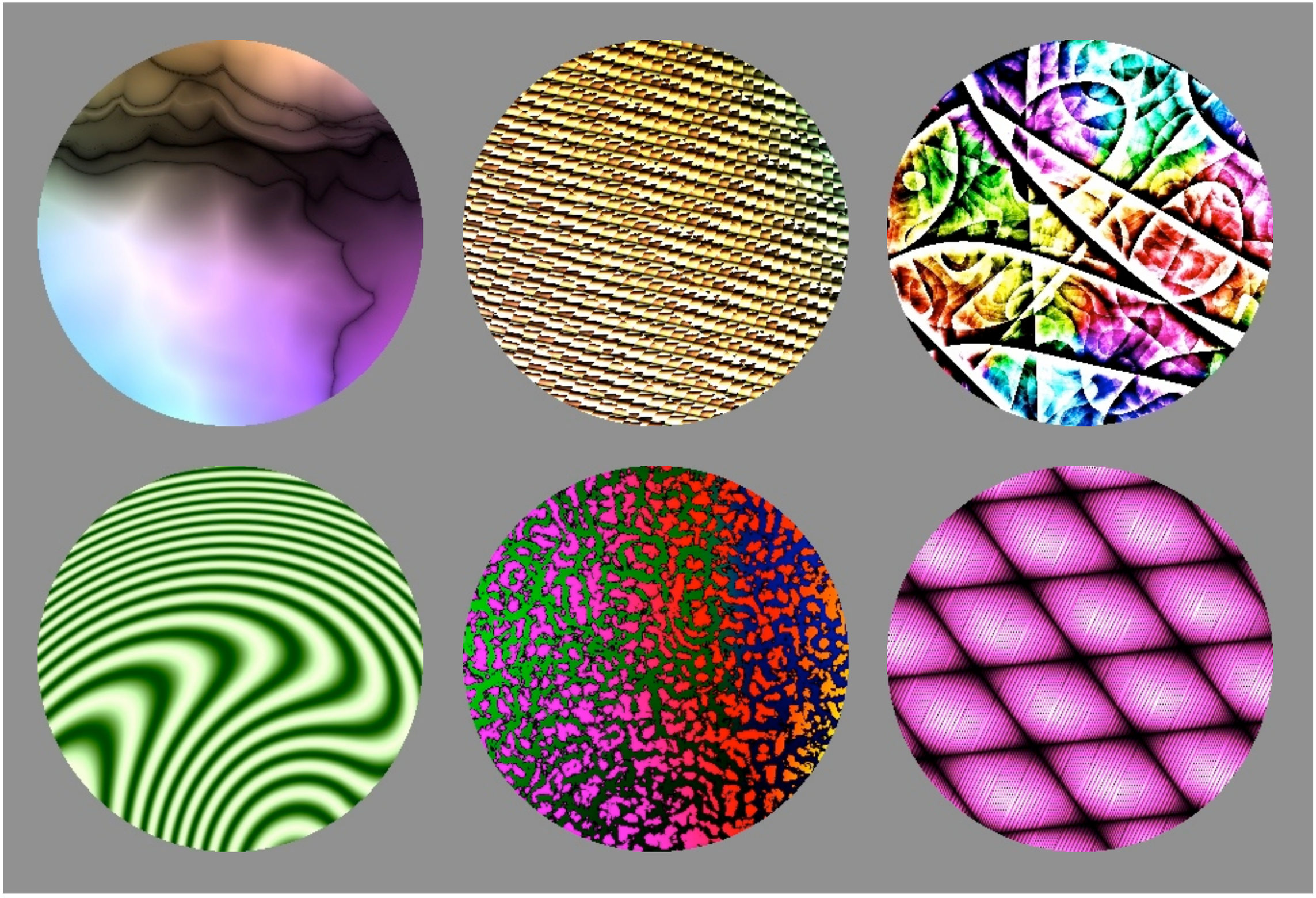
- In preparation for camouflage work:
  - built texture synthesis library
  - connected it to Open BEAGLE
    - needed to test
- Tried some simple fitness functions, which lead to simple and uninteresting results
- Found a set of three metrics that combined to produce interesting results

“colorful, full range, high frequency”

- colorful
  (average pixel saturation above a given threshold)
- well-exposed, full range image
  (semi-uniform brightness histogram)
- textured
  (high average spatial frequency: *variability*)



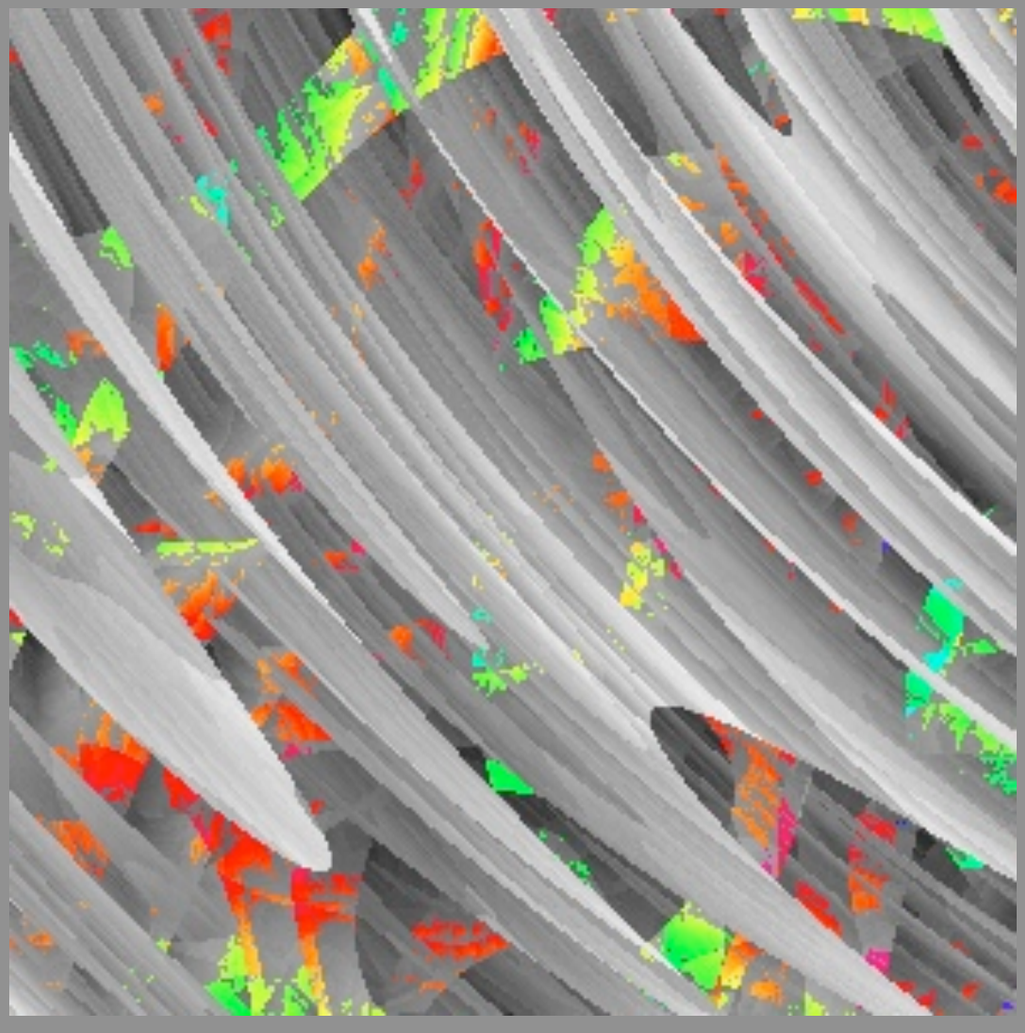
variability: fraction of local neighborhoods whose brightness range (max-min) exceeds a given threshold

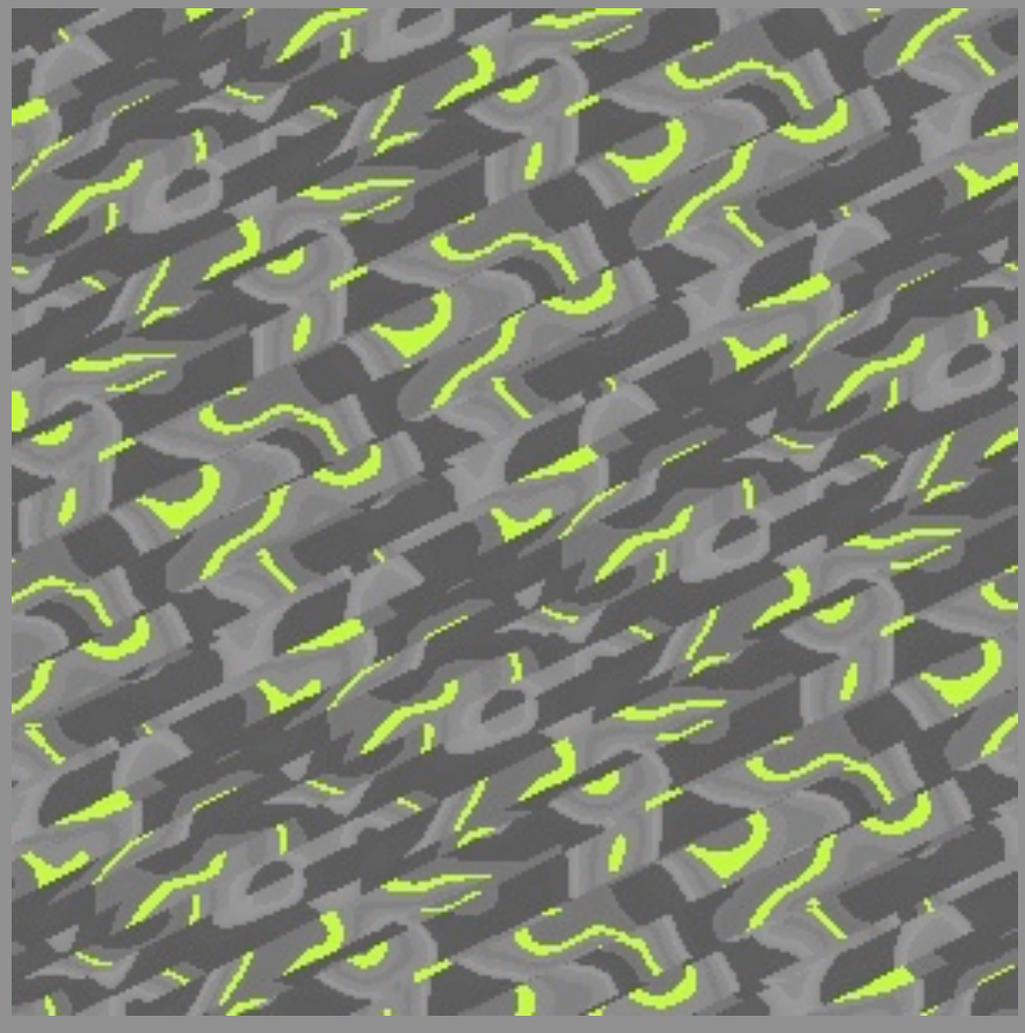


evolved textures: colorful, full range, high frequency

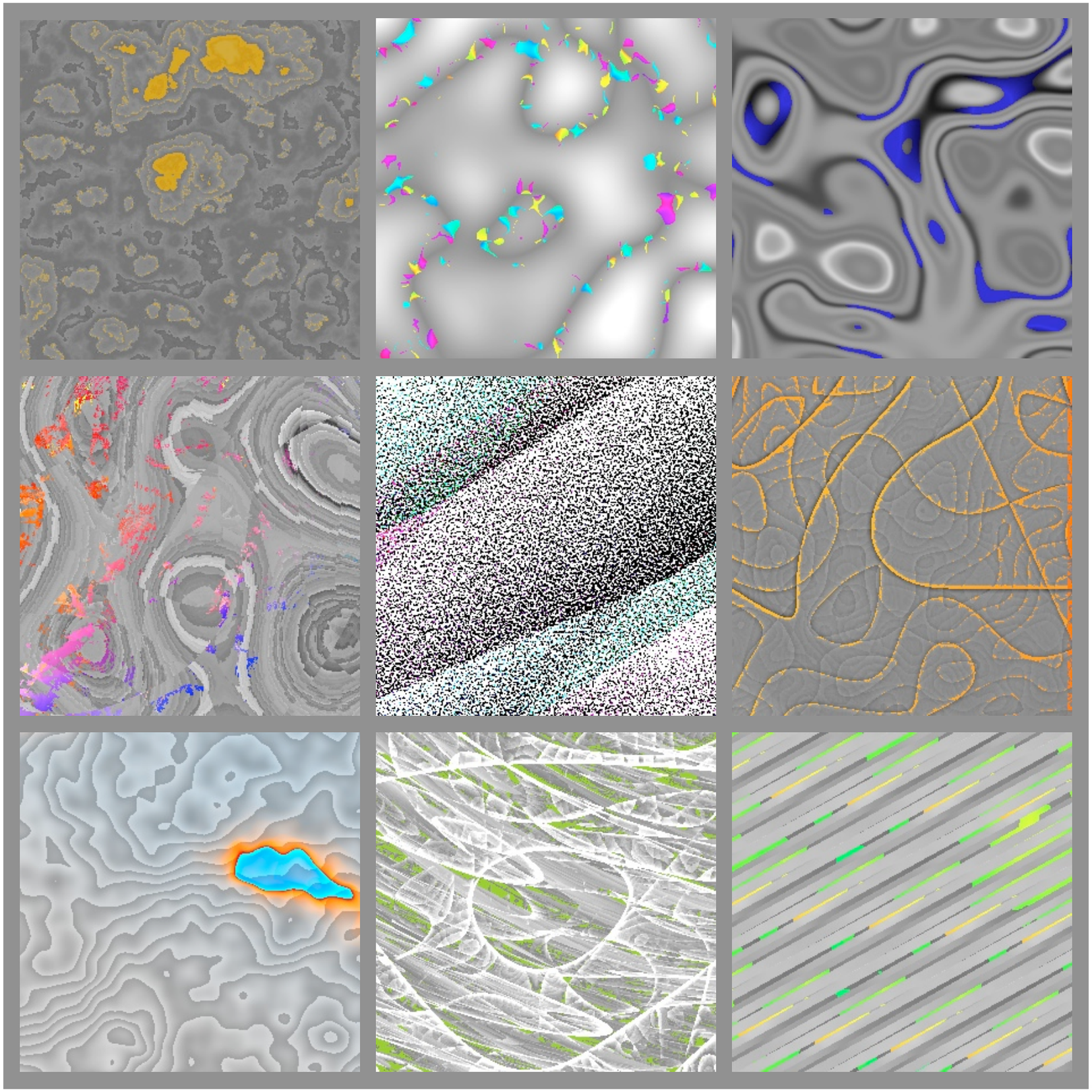
“Gray with accent color”

- fraction of good pixels
  (saturation < gray threshold or > color threshold)
- how close ratio of color/good is to target value
  (5% for a “small amount of accent color”)
- average score for pixel brightness being *midrange*
  (or another target)
- size of bounding box in RGB space for colored pixels
  (promote color variation)
- fraction of variability samples > contrast threshold
  (high frequency)

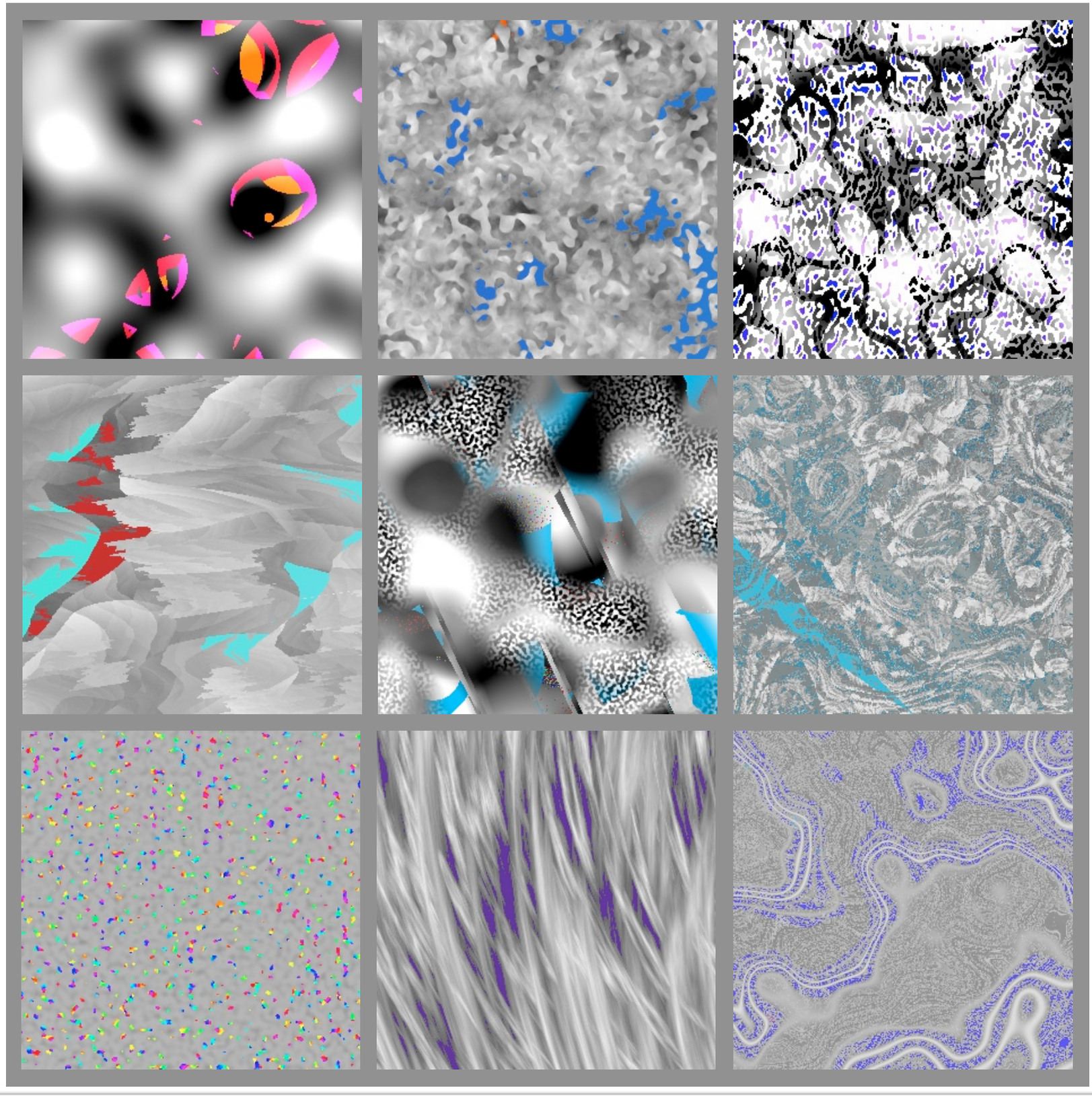




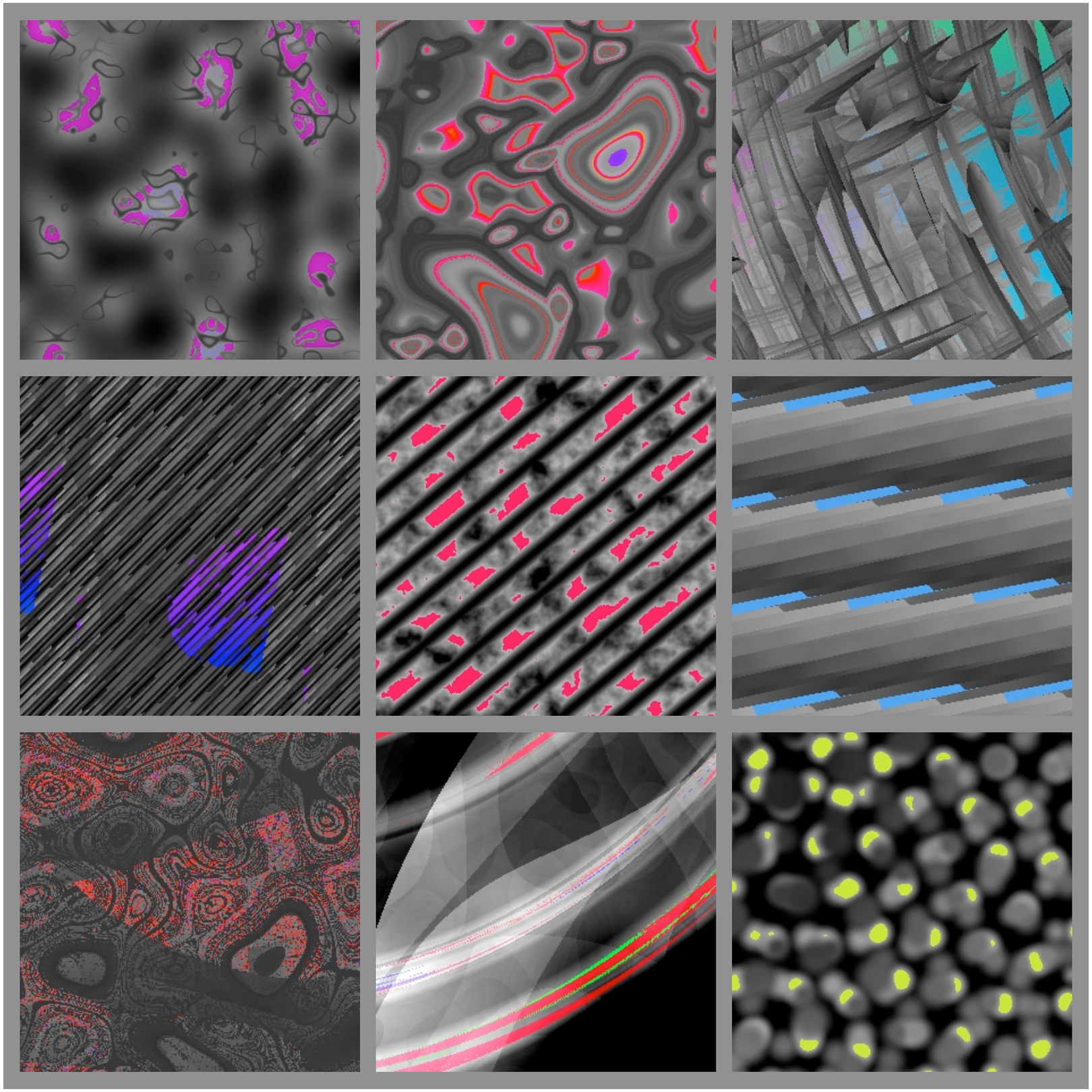
Evolved textures: gray with accent color



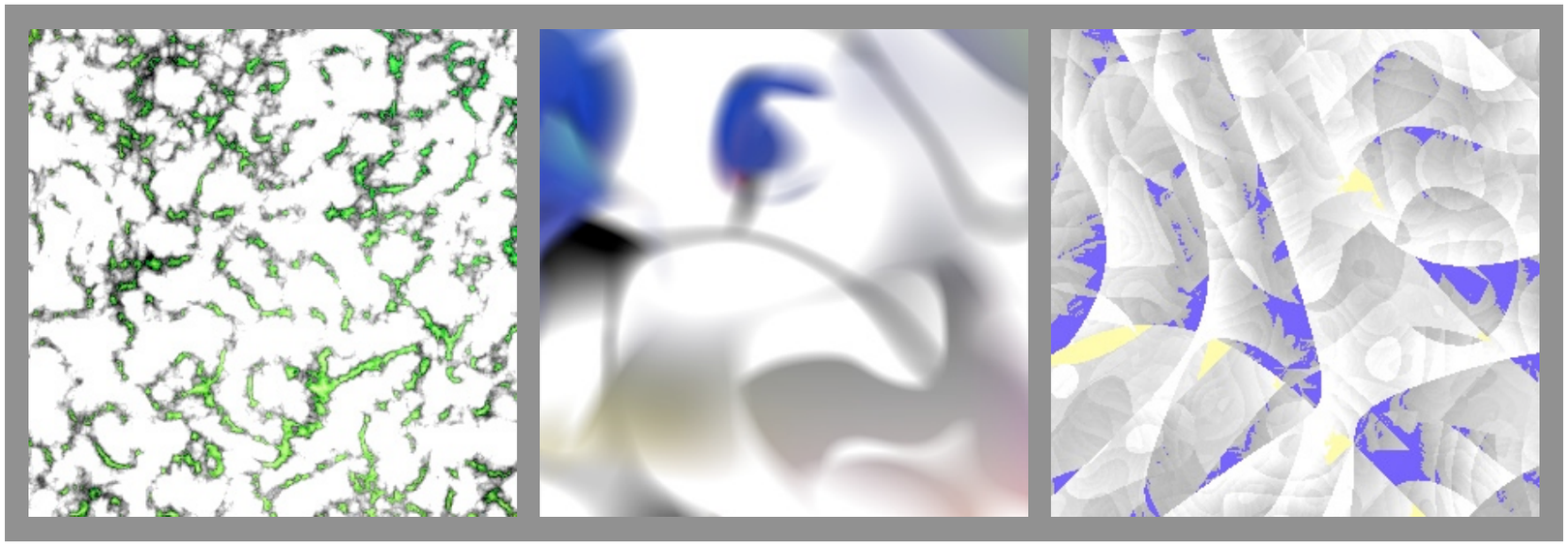
Evolved textures: gray with accent color



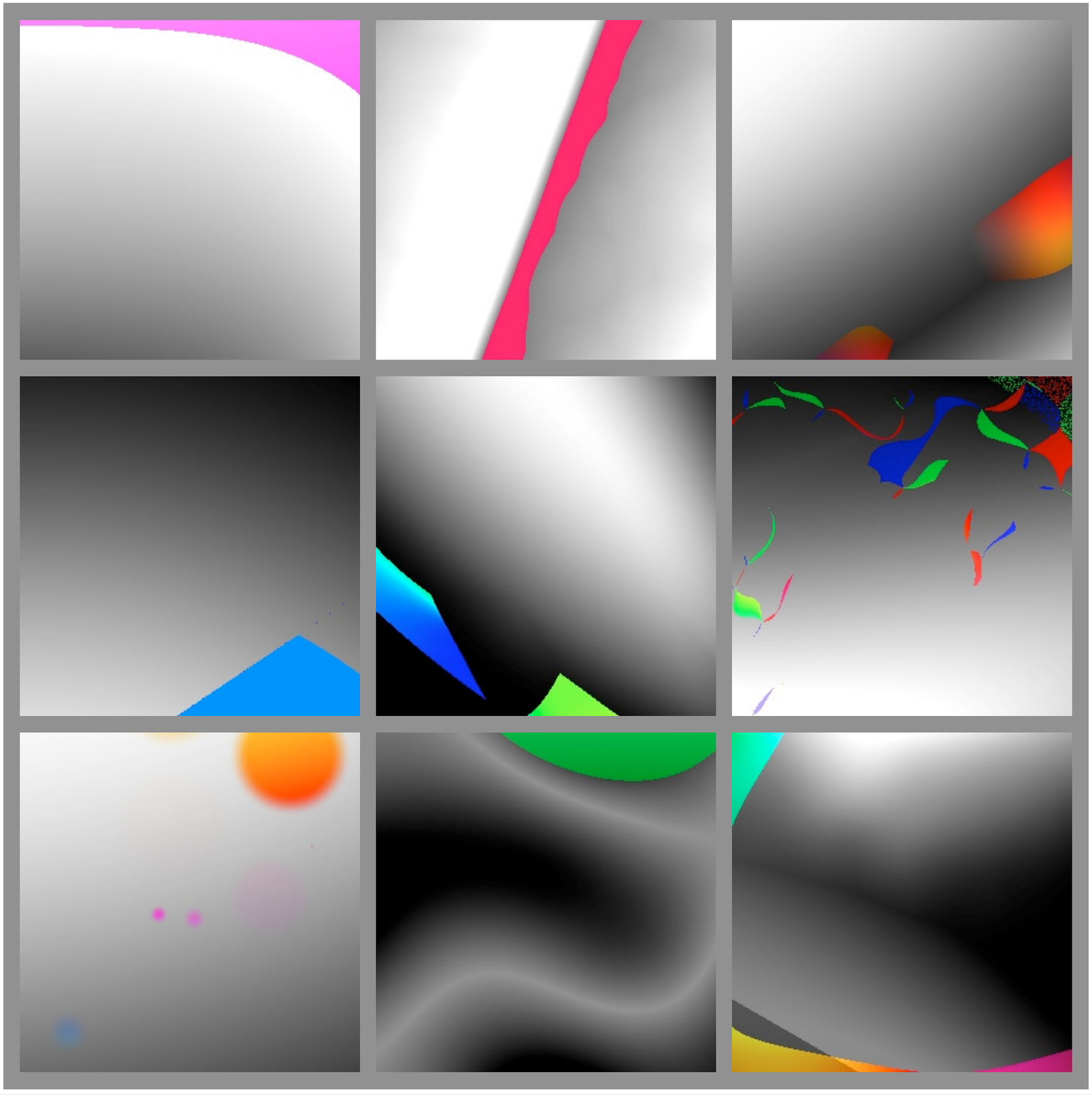
Evolved textures: gray with accent color



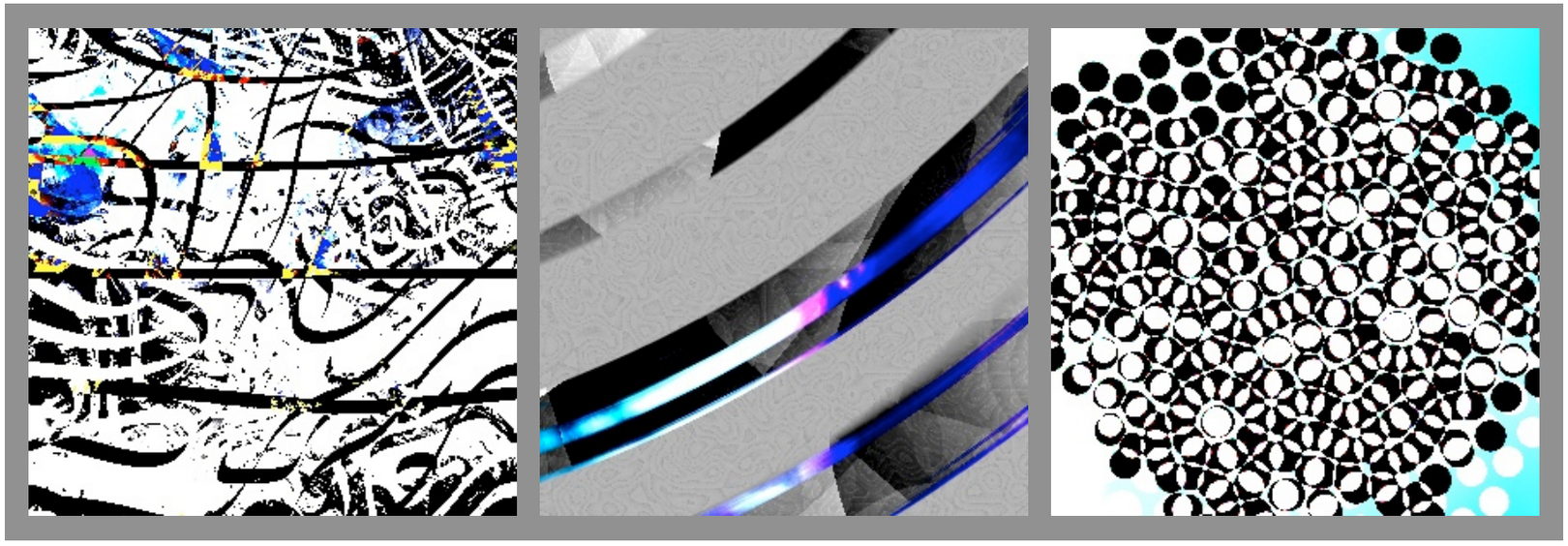
Evolved textures: gray with accent color — dark



Evolved textures: gray with accent color — bright



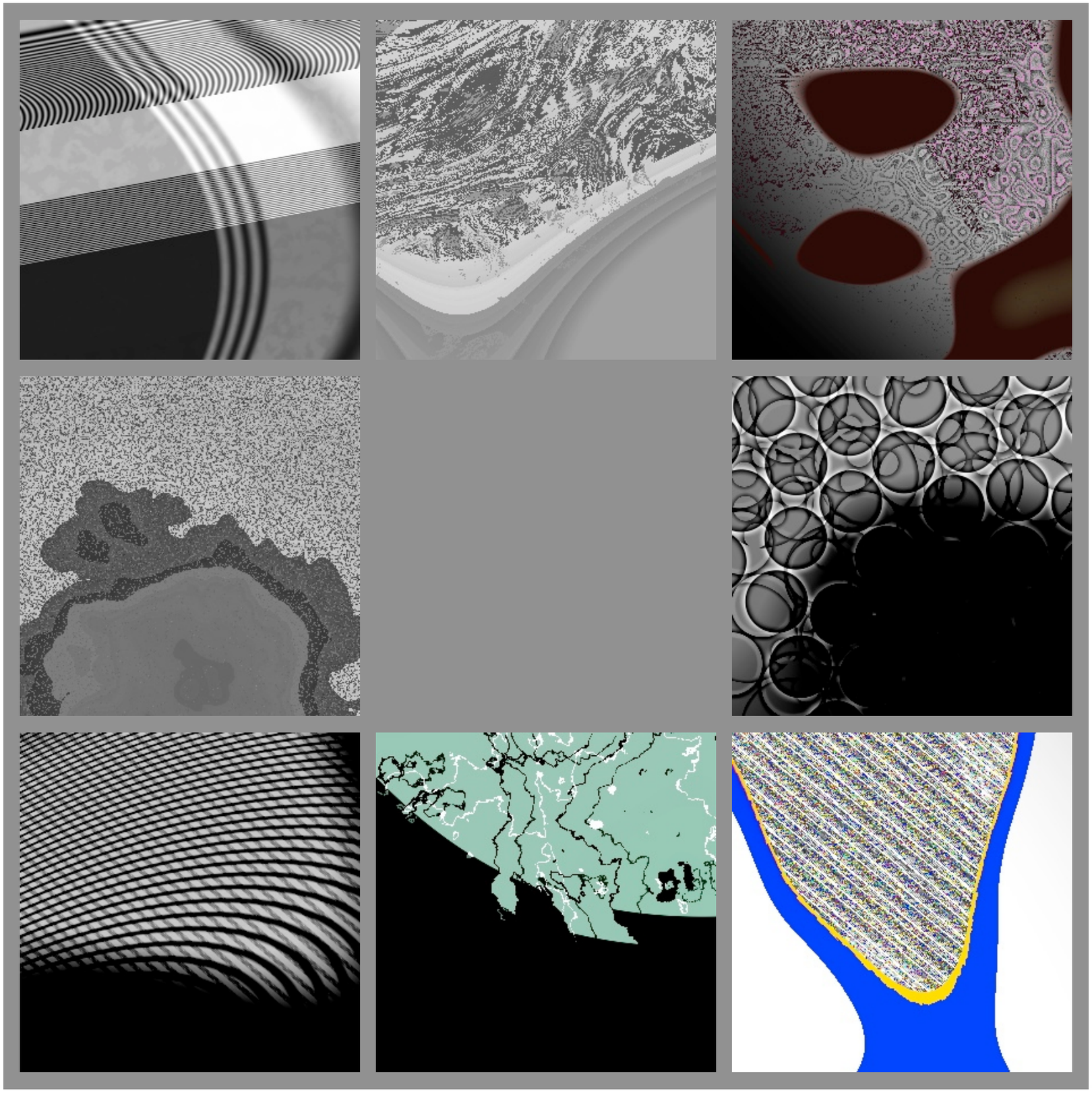
Evolved textures: gray with accent color — “minimalist”



Evolved textures: gray with accent color — no *max/min*

HFTLFB

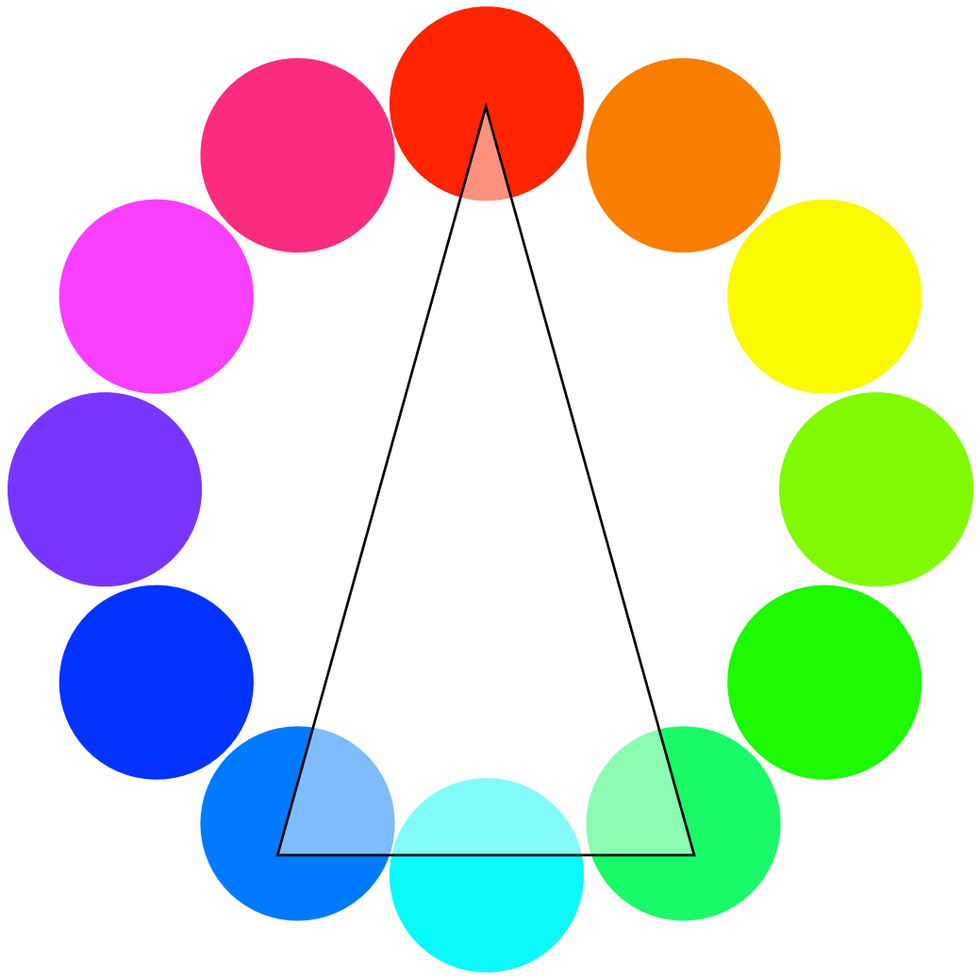
- HFTLFB: “high frequency top, low frequency bottom”
  - high frequency in top 1/4 of image
  - low frequency in bottom 1/4 of image
  - prefer some variation at bottom



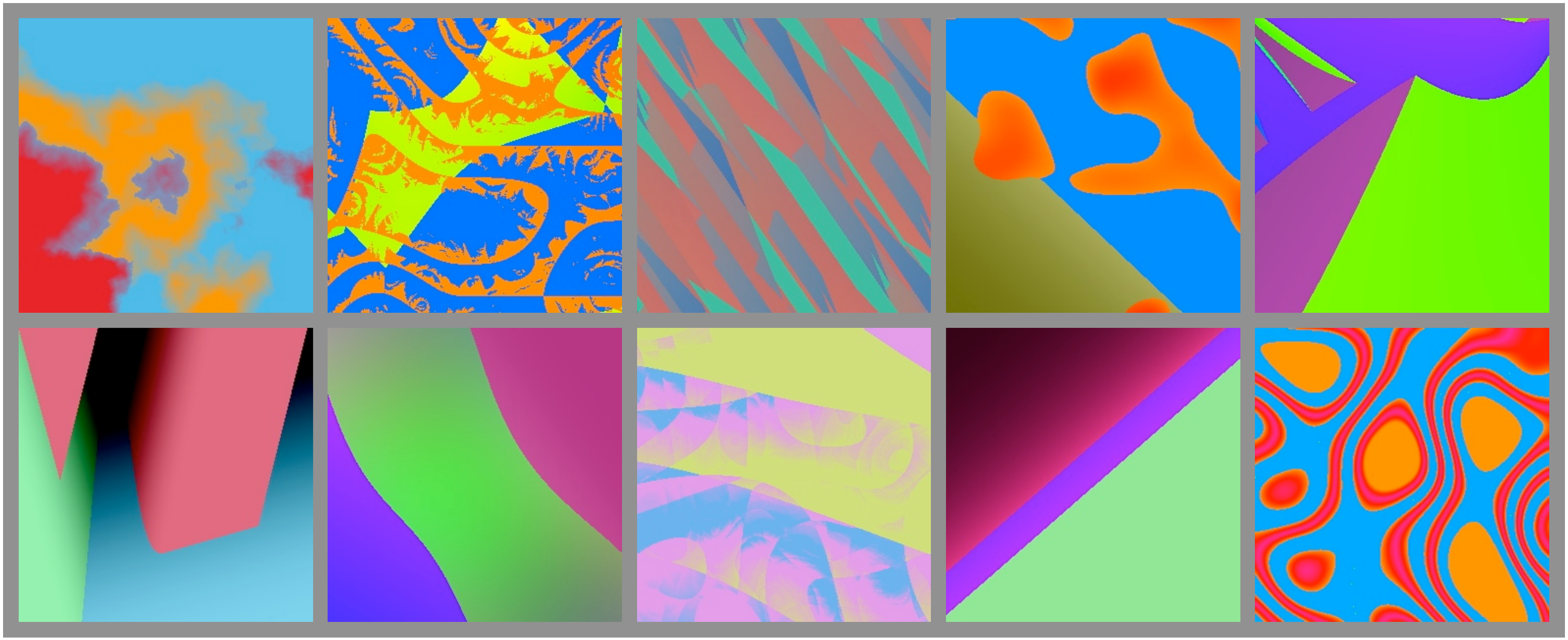
Evolved textures: *high frequency top, low frequency bottom*

Harmonious colors

- Textures with a harmonious color scheme (using a 12 bucket histogram for hue)
  - colorful
  - color mostly in three hue buckets (in ratio of 3:1:1)
  - other nine histogram buckets nearly empty
  - three hues form “harmonious” color triplet



harmonious color triplet



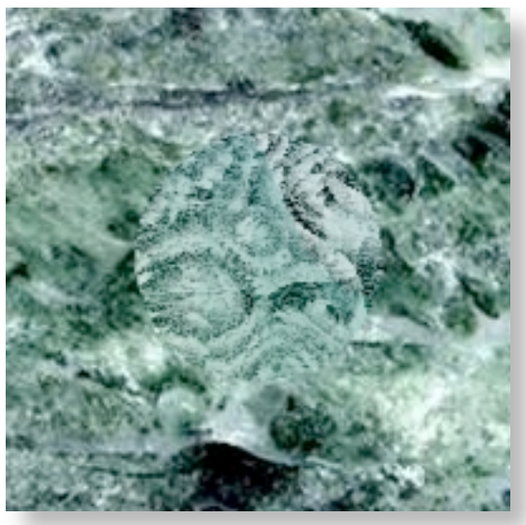
Evolved textures: harmonious colors

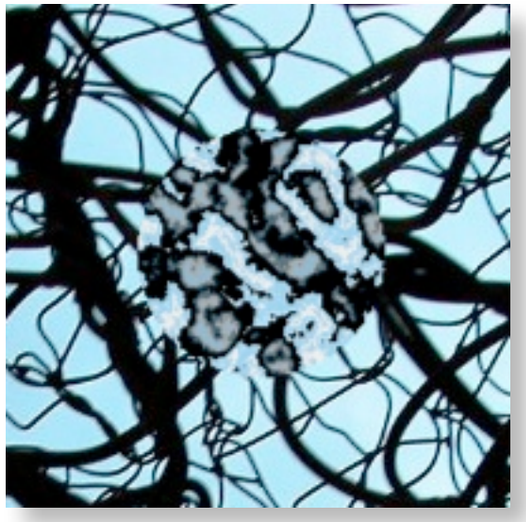
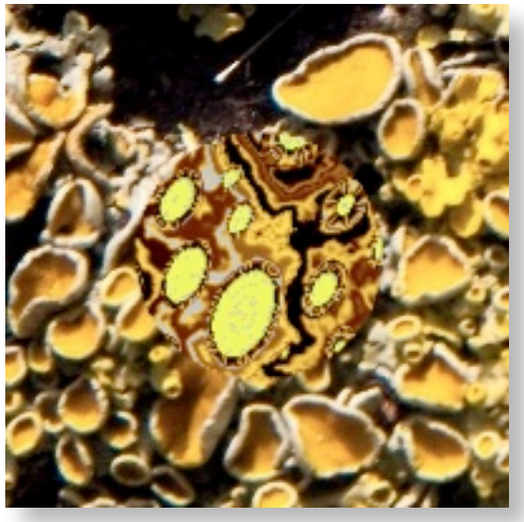
Camouflage

Introduction

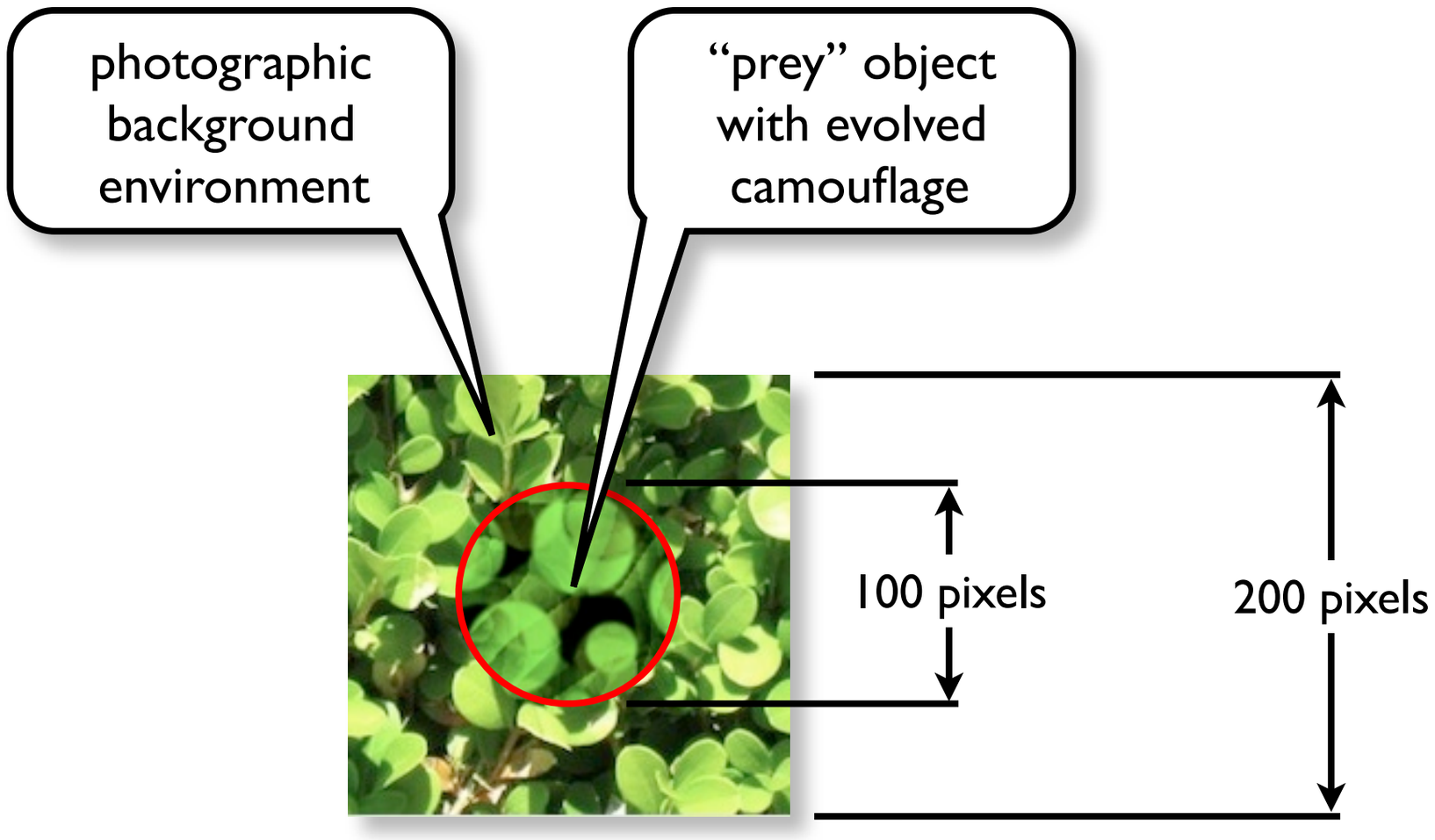
- Abstract model of camouflage evolution in nature.
  - evolutionary computation: GP
  - computer graphics: procedural texture synthesis
  - hybrid computer system: human vision “in the loop”

Evolved camouflage

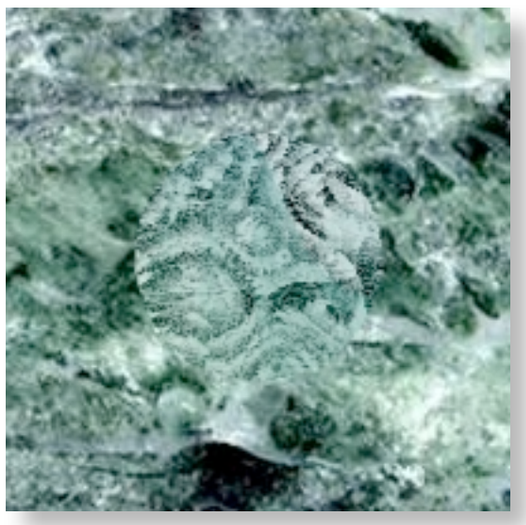



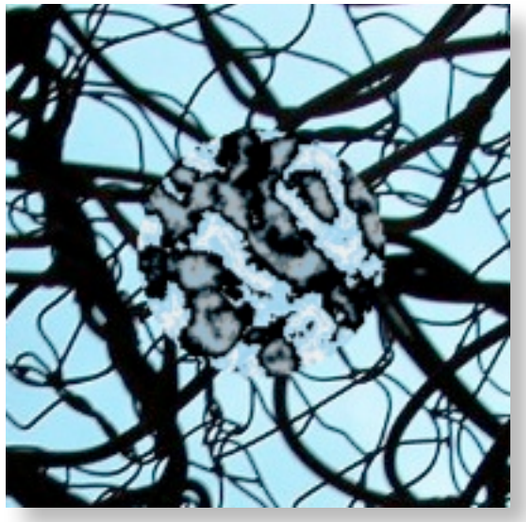
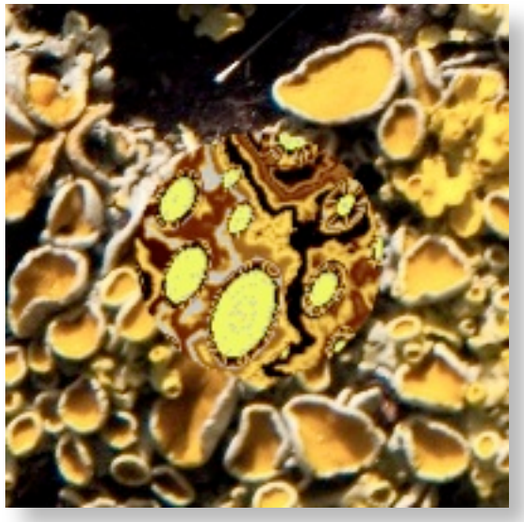




Structure of *thumbnail* images

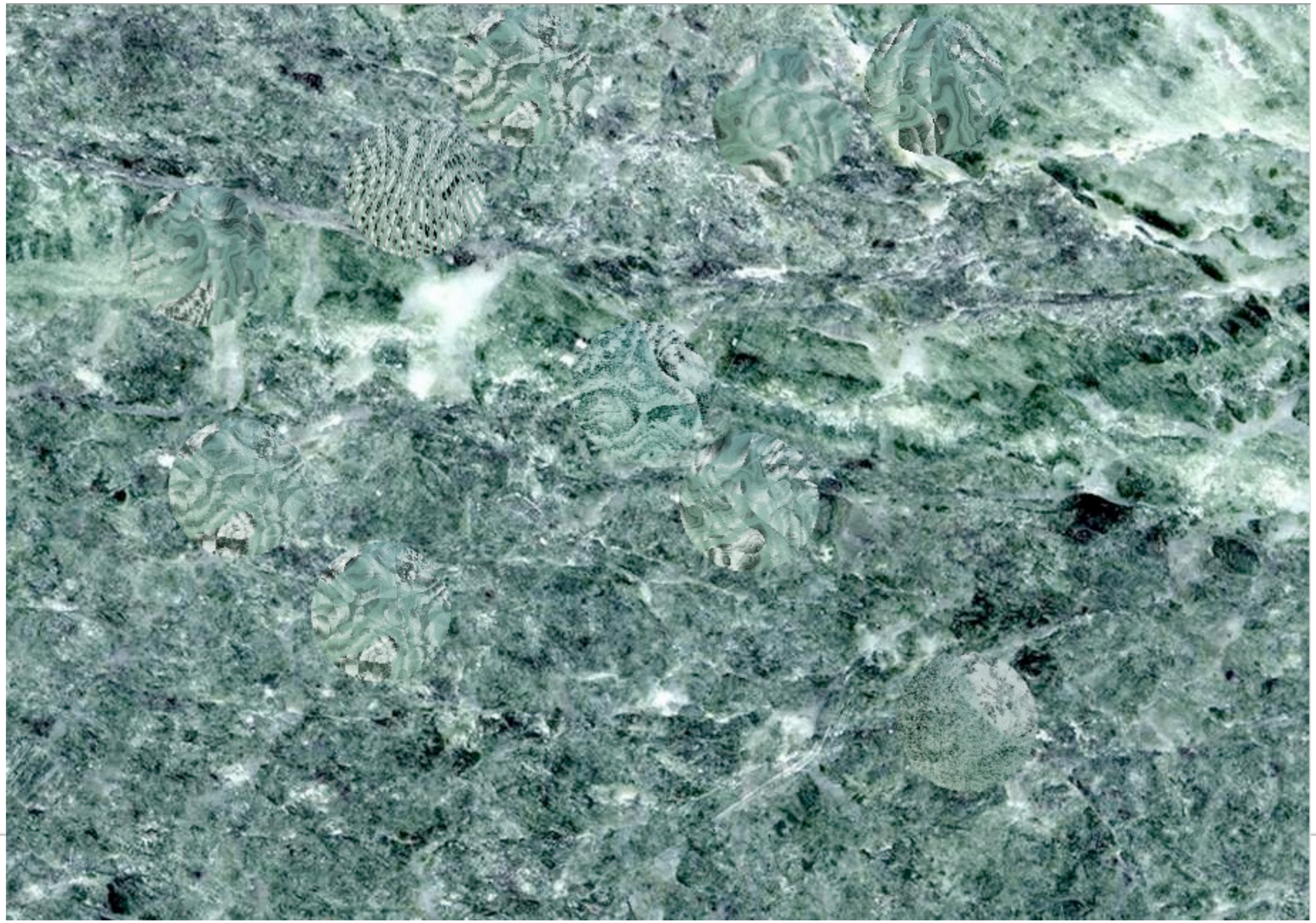


Evolved camouflage

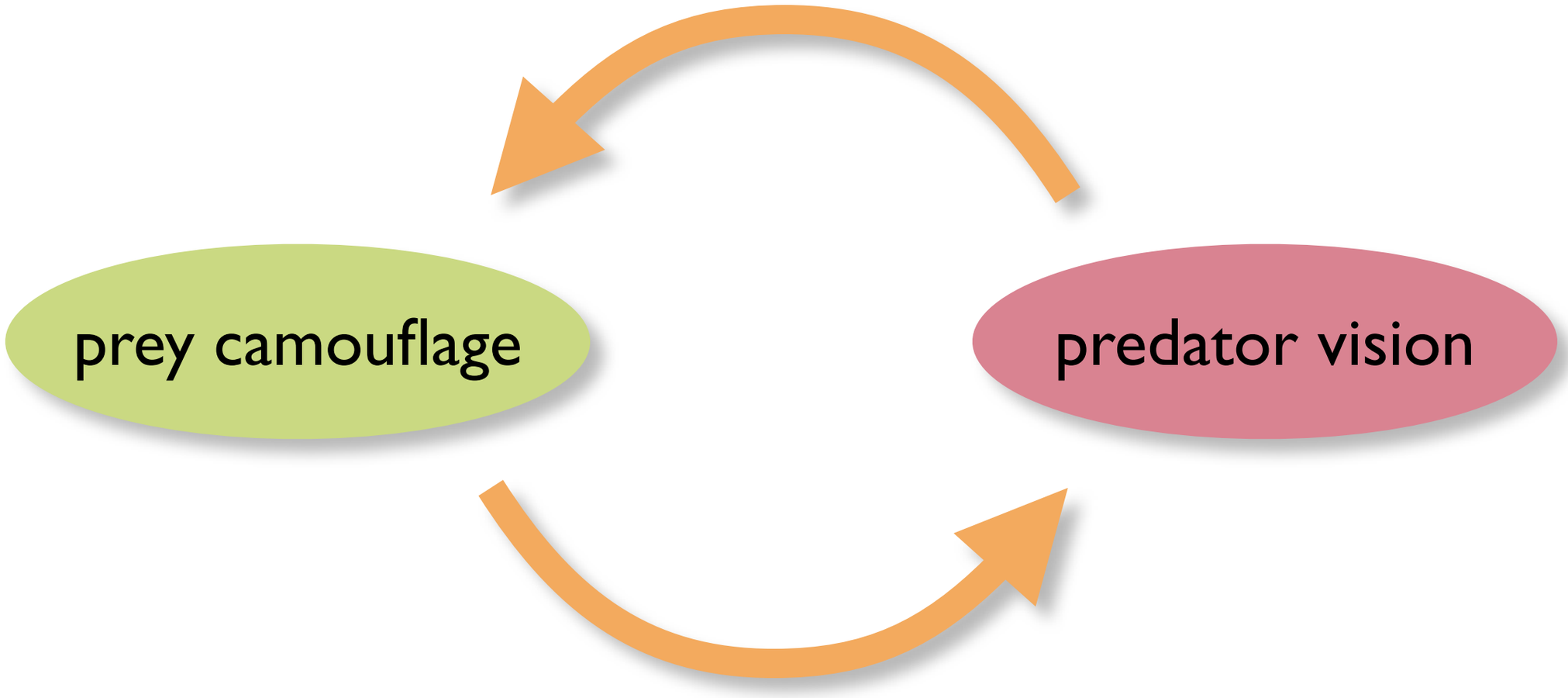




Cohort on environment

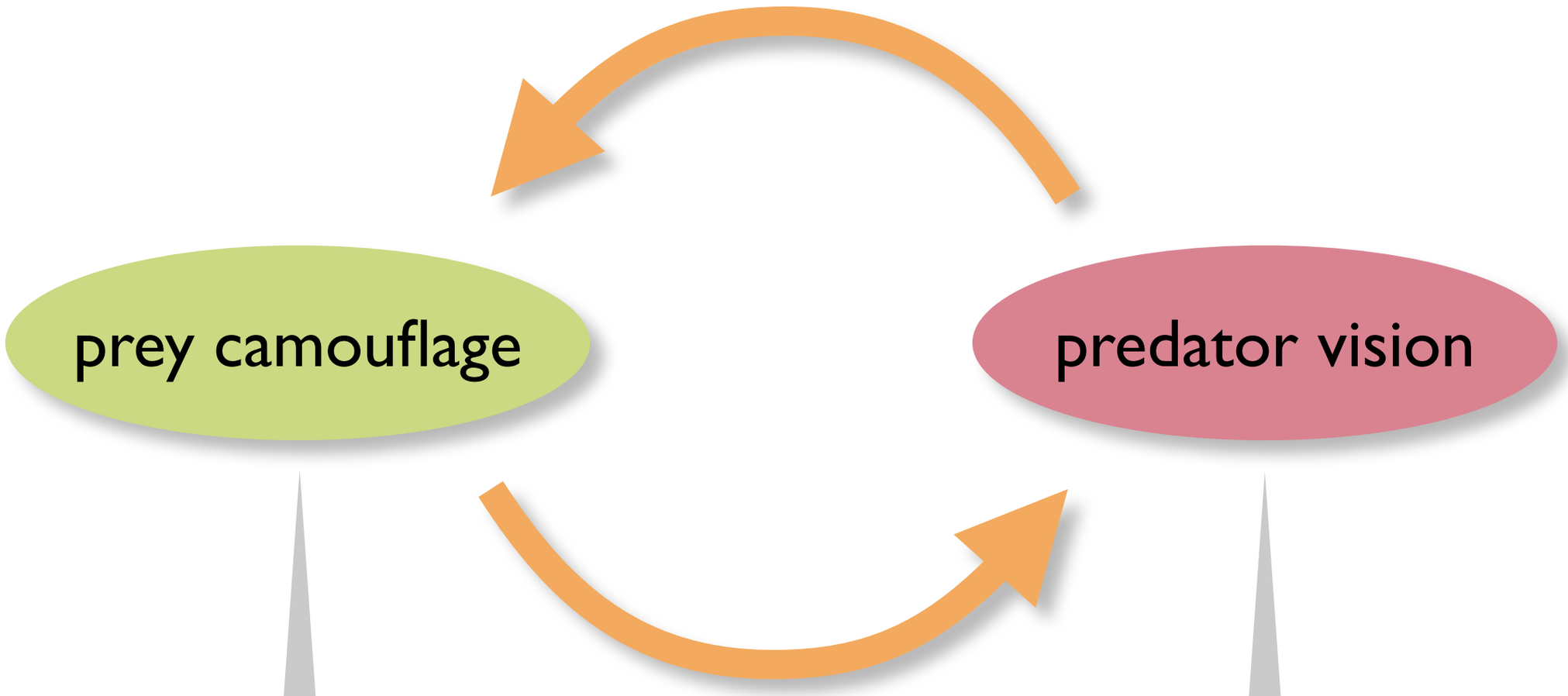


Overview of Model

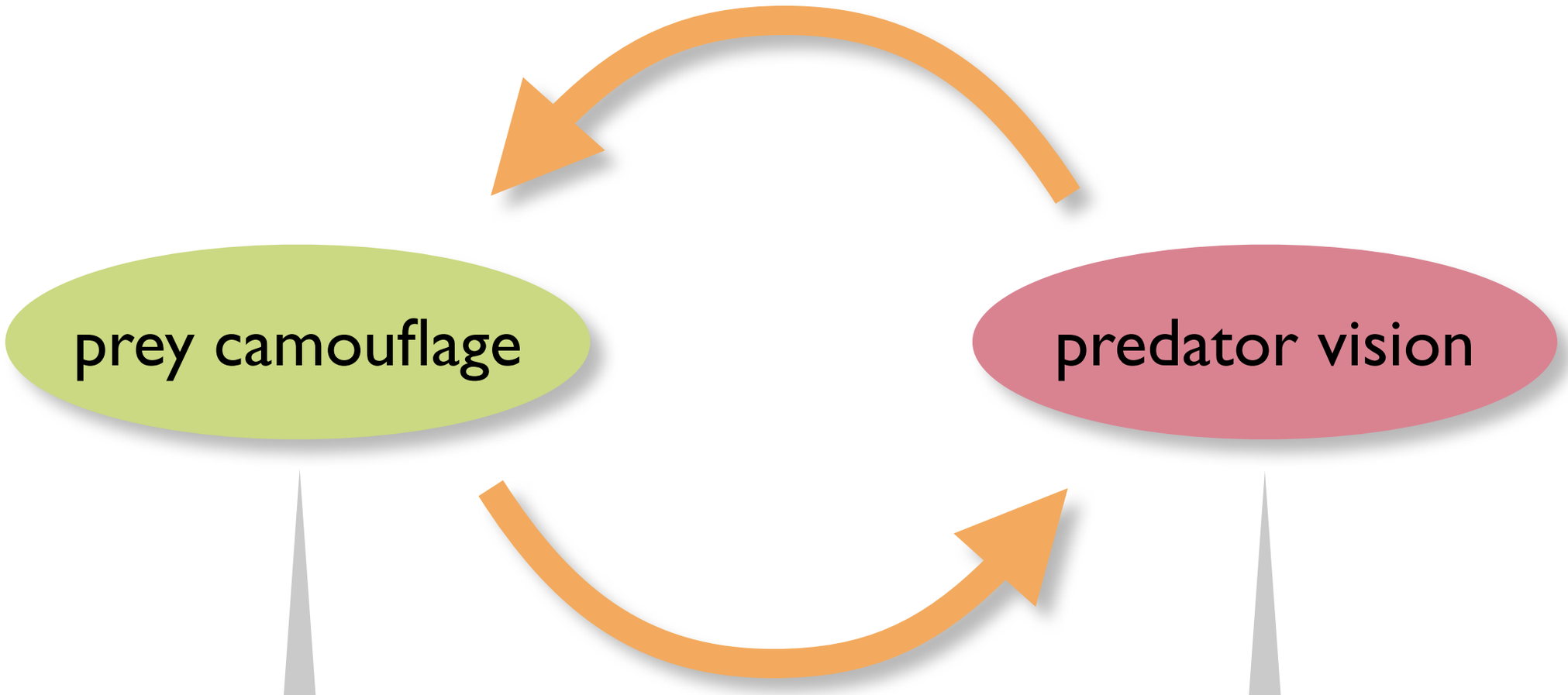
Coevolutionary system



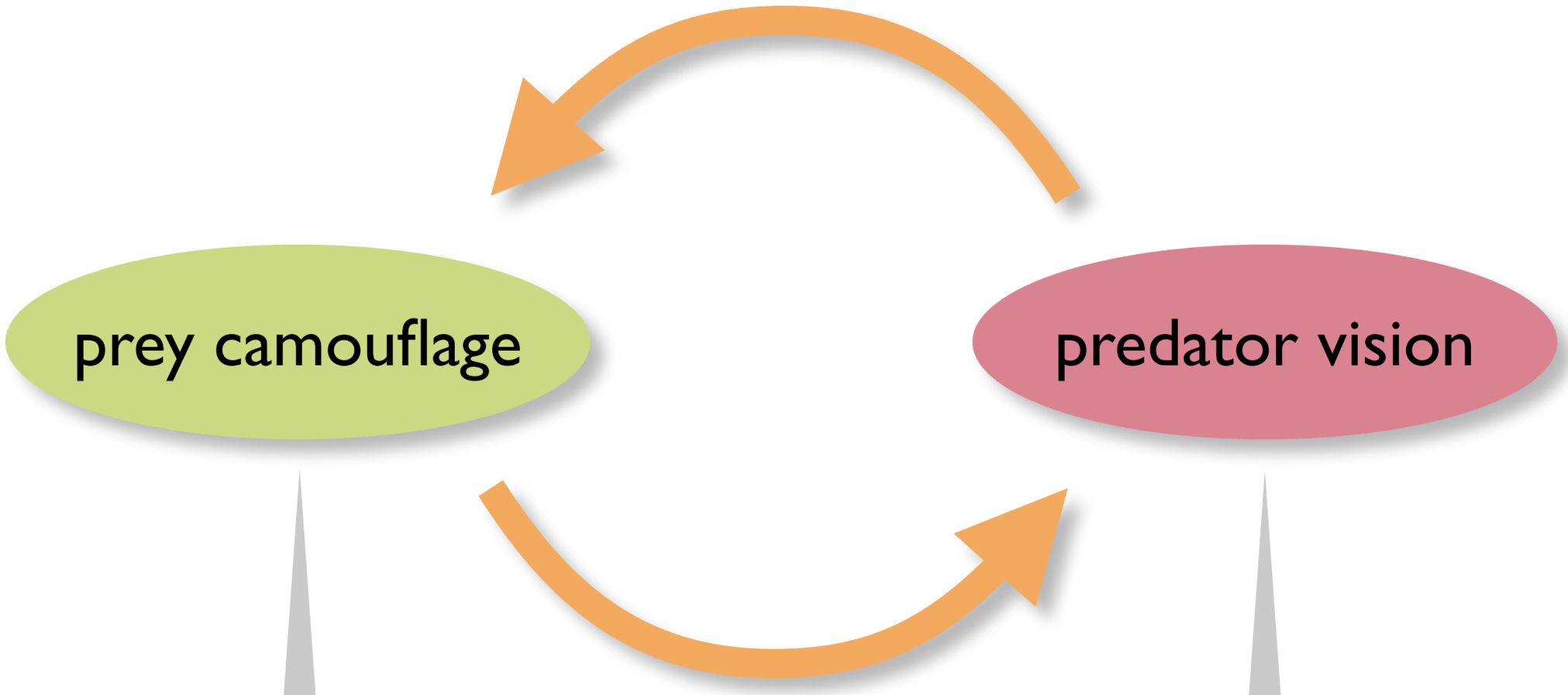
In nature


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

Malagasy Lanternfly, forest canopy, Madagascar

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

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

Bark bug, Peruvian Amazon

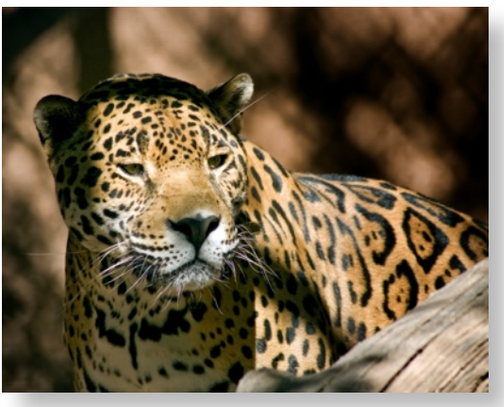
Wolf spider (*Ocyale guttata*)

Crab spider (*Thomisus onustus?*), France

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

Camouflage change speed

permanent | seasonal | weeks | minutes | instantaneous



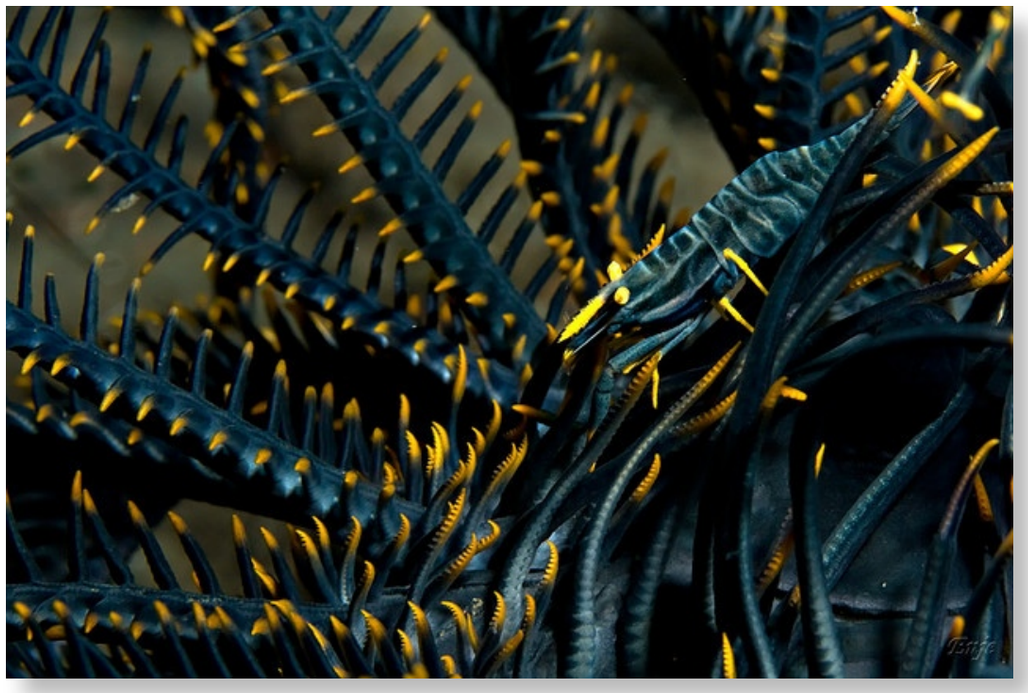


iStockPhoto, Terry L Spivey (Bugwood.org), Ansgar Walk, Hannes Mitchell, Damiano Luchetti, Tennessee Aquarium

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

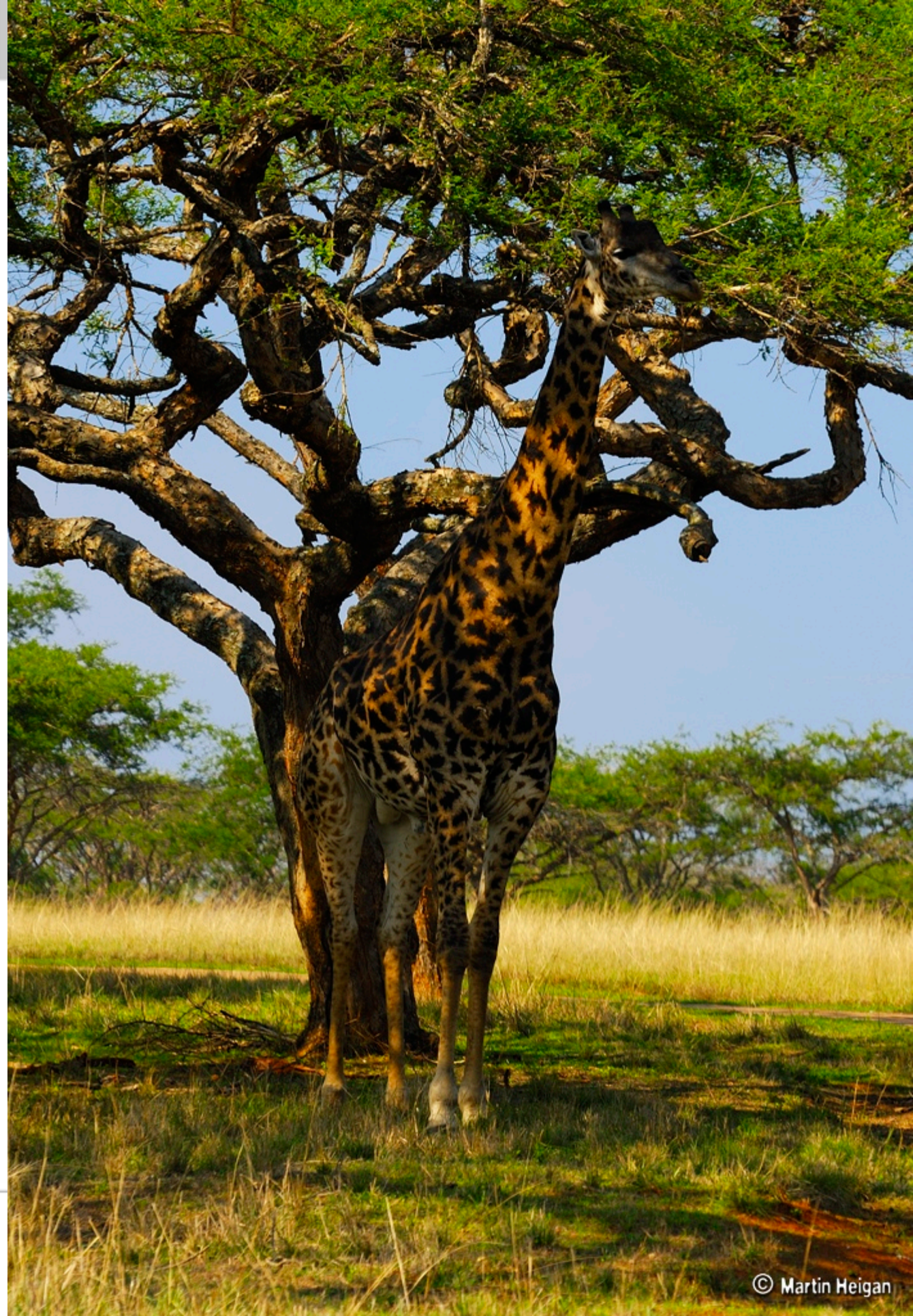
Southern leopard frog (*Rana sphenocephala*), Florida USA

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

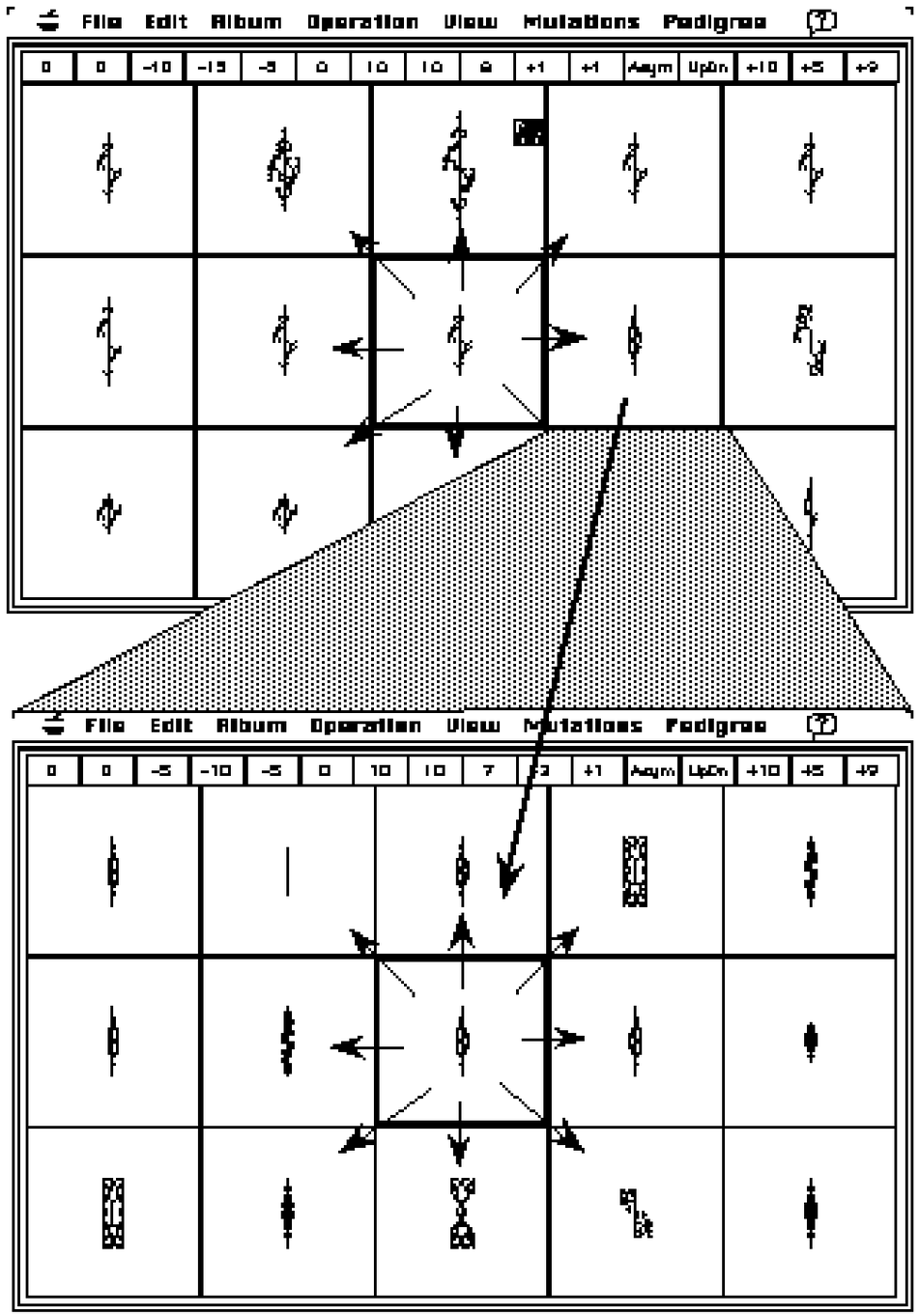


Acacia tree and giraffe (*Giraffa camelopardalis*)

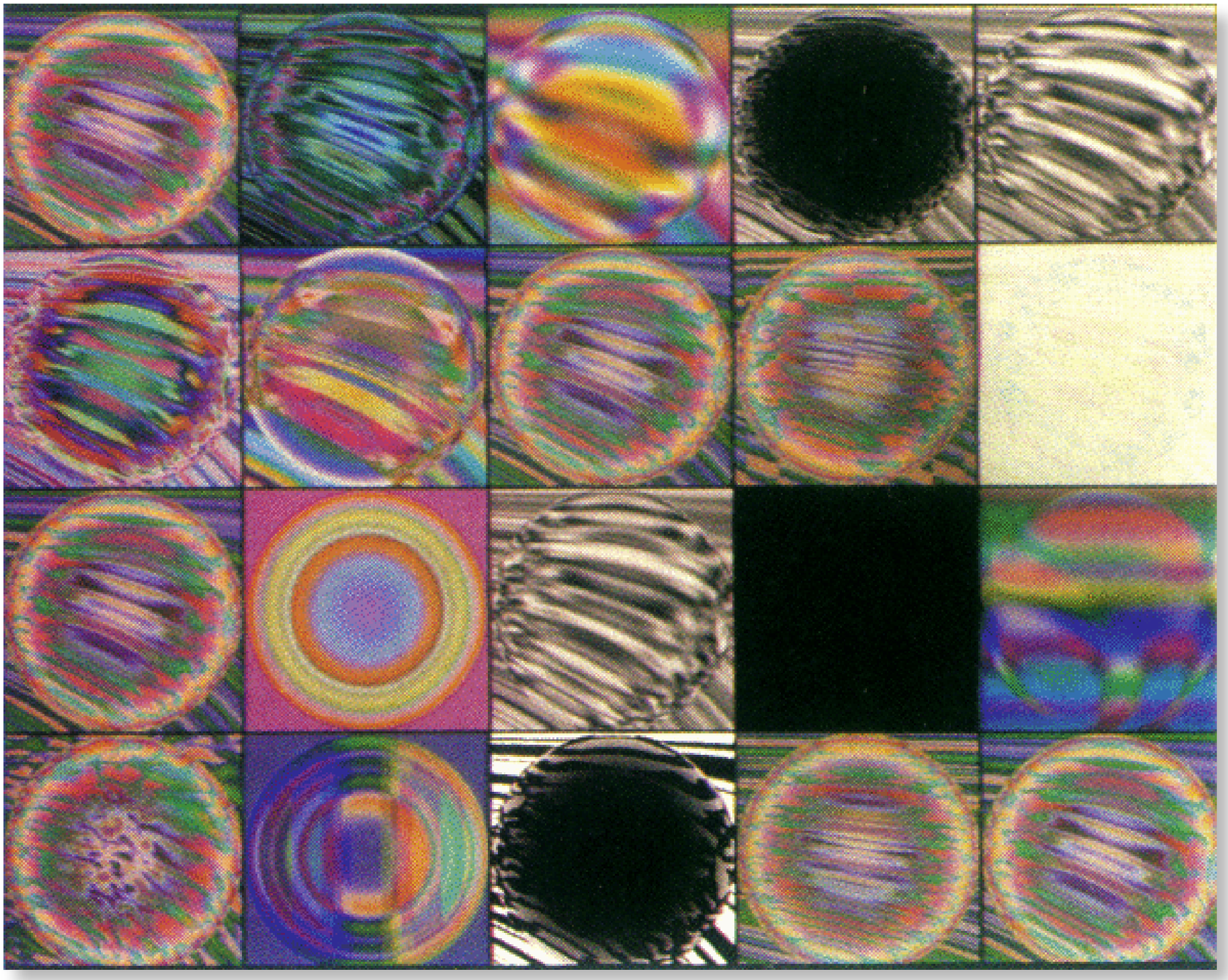
Background

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

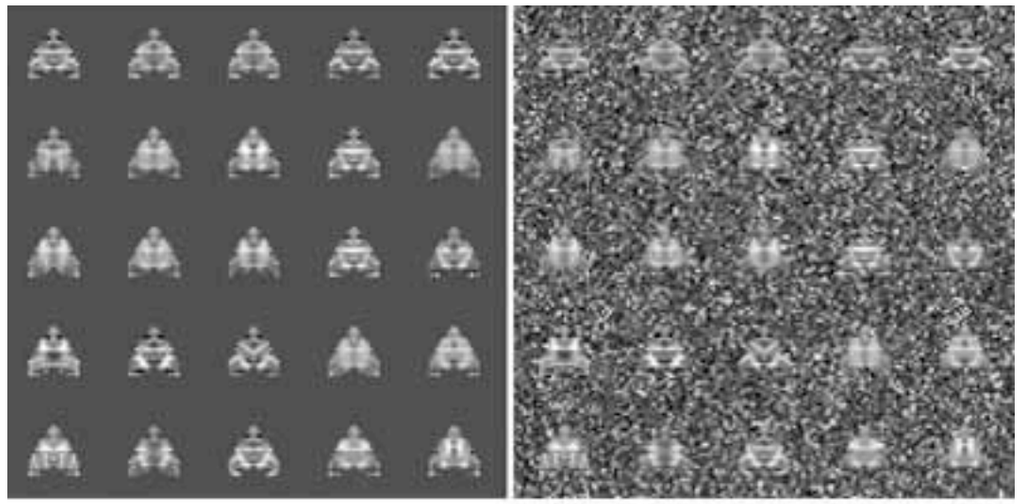


Screen shots of Dawkins' *Blind Watchmaker* software

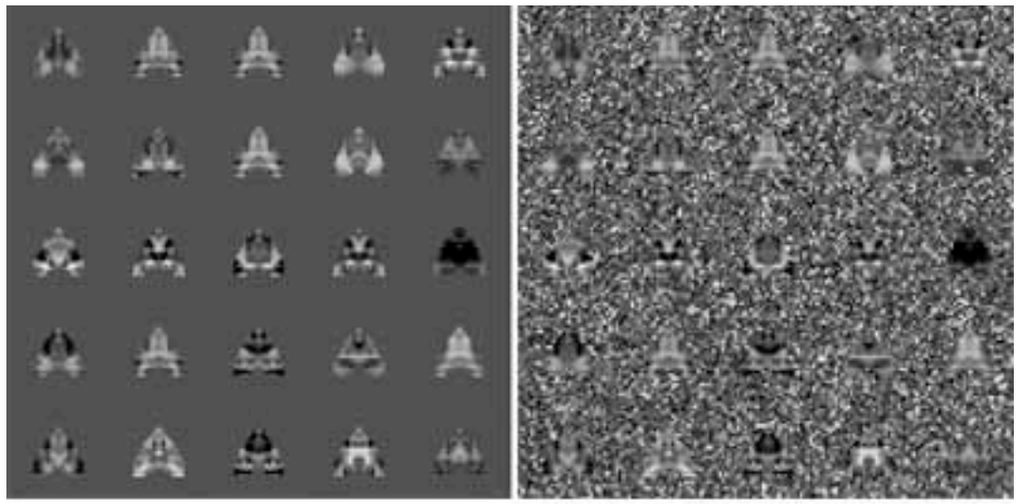


User interface for Sims' interactive evolution of color texture patterns

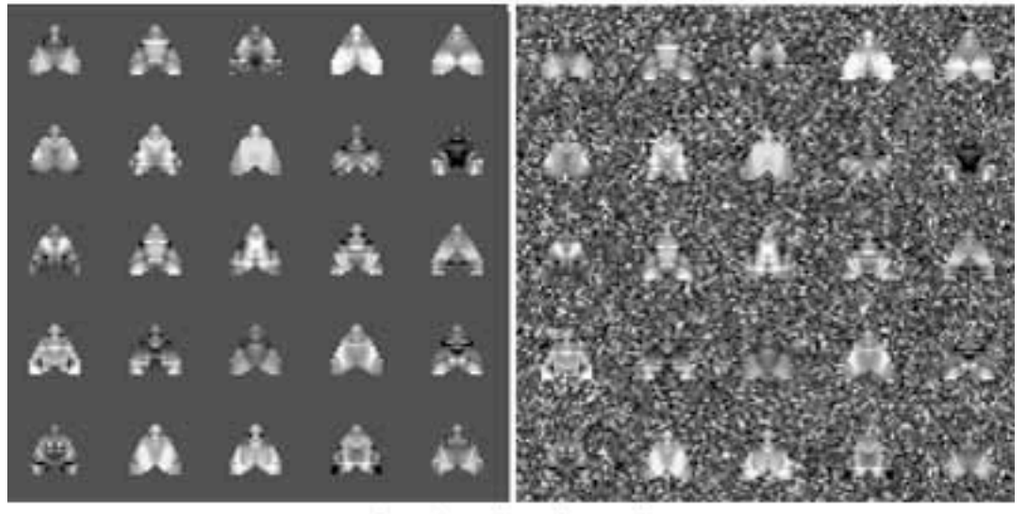
blue jay (*Cyanocitta cristata*) and display screen — Alan Bond and Alan Kamil (1998-2007)



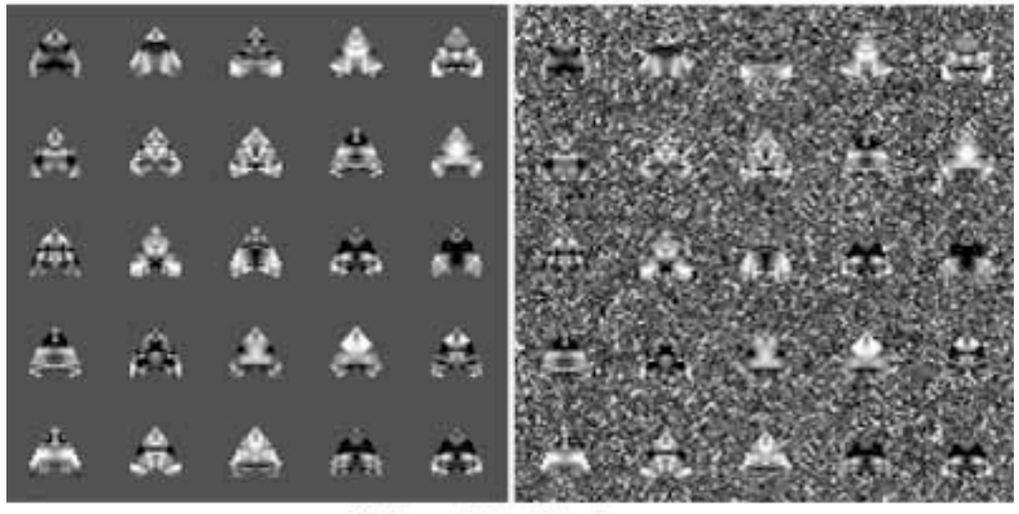
Original population



Selected by virtual predator



Randomly selected

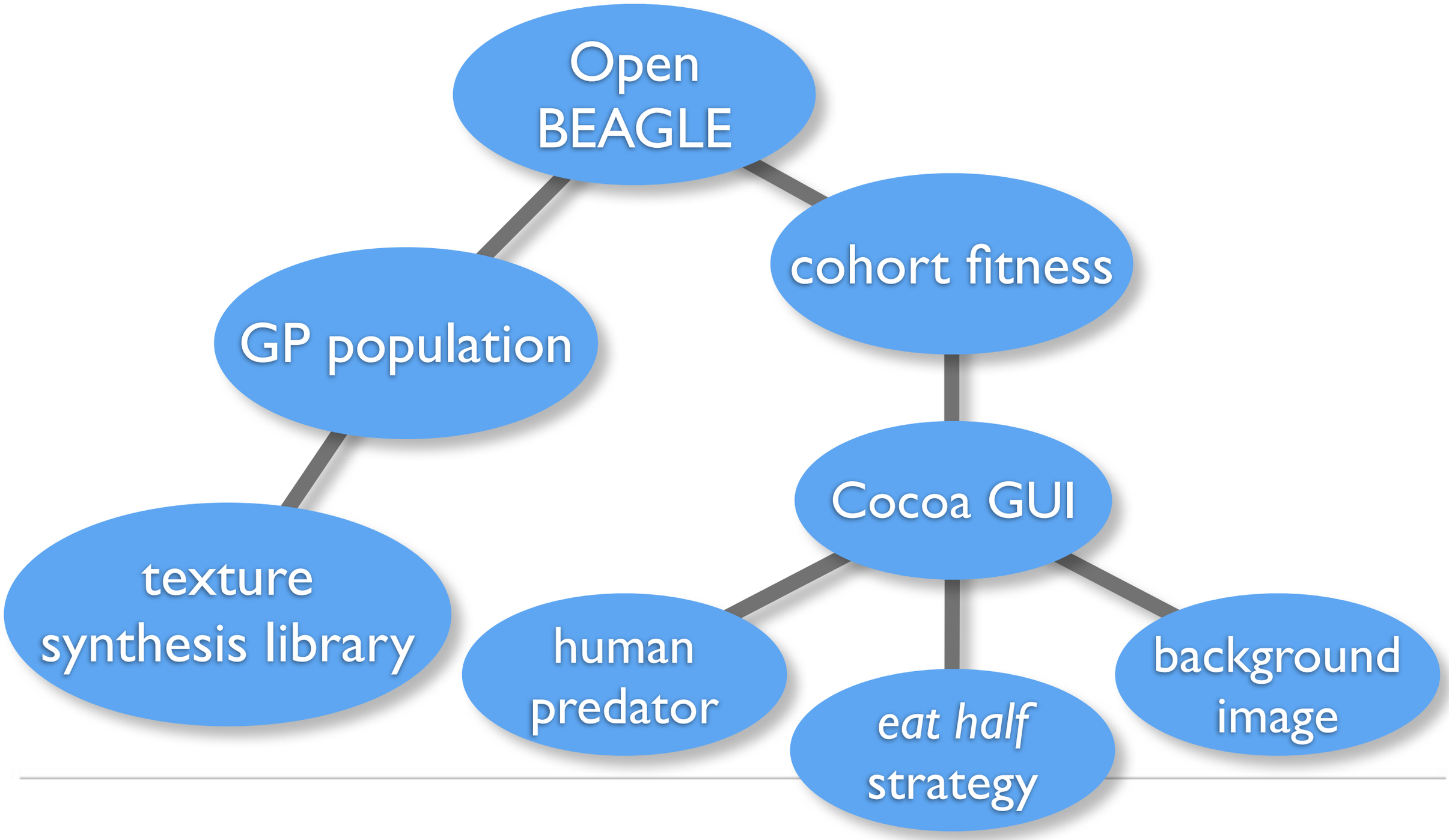


Selected by blue jays

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

Implementation

System components

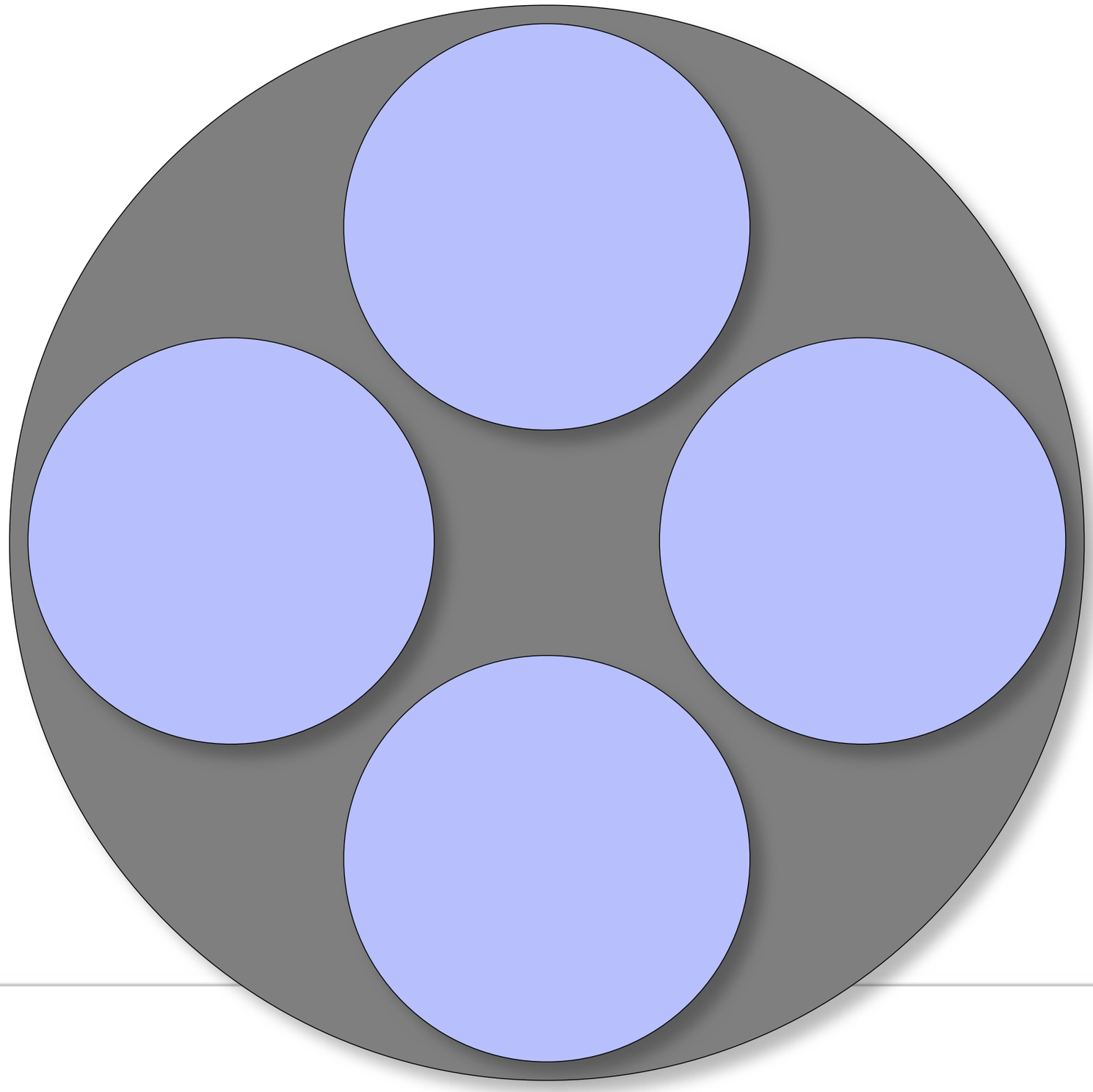


Evolutionary Computation

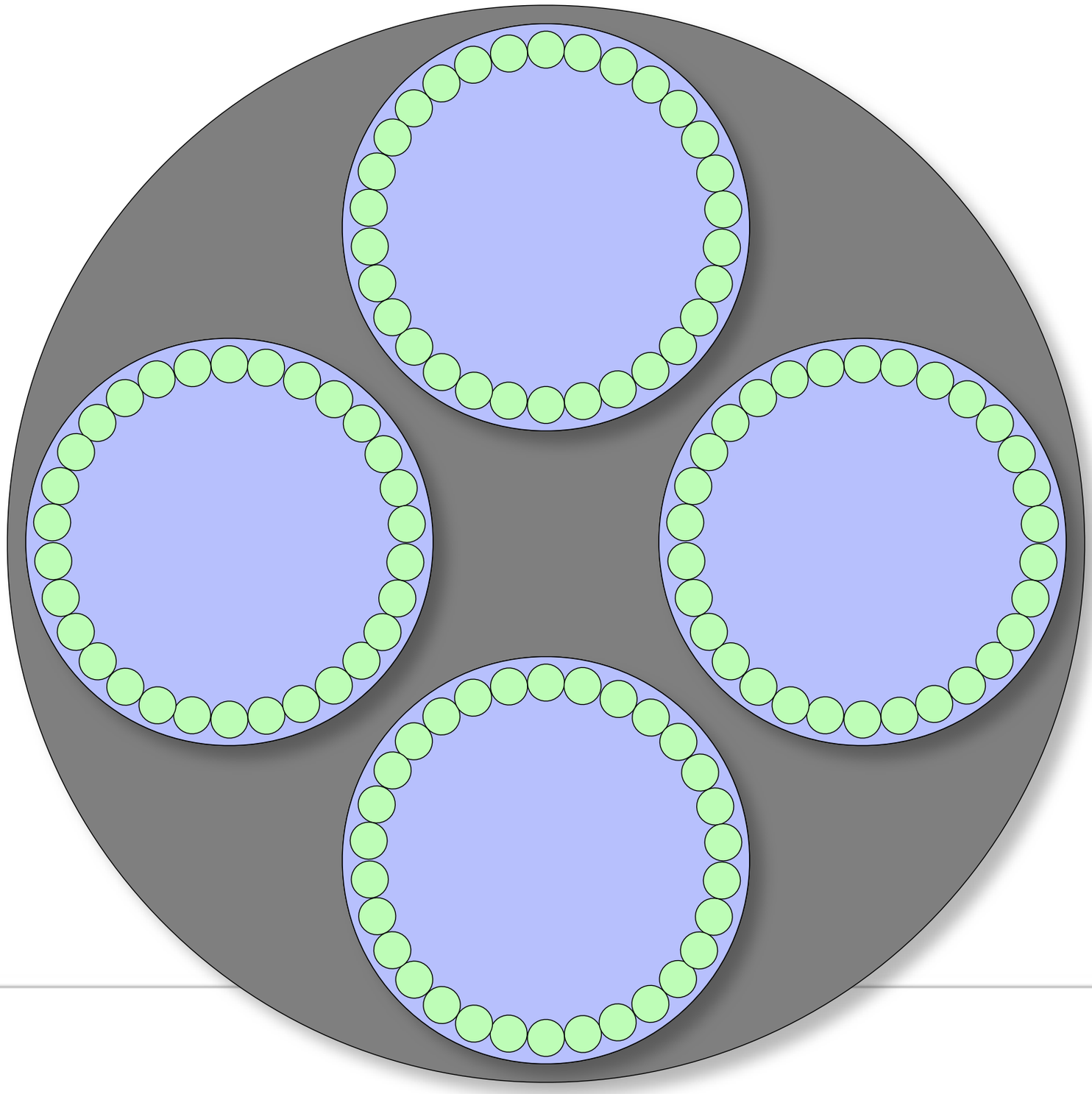
Evolutionary computation

- 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

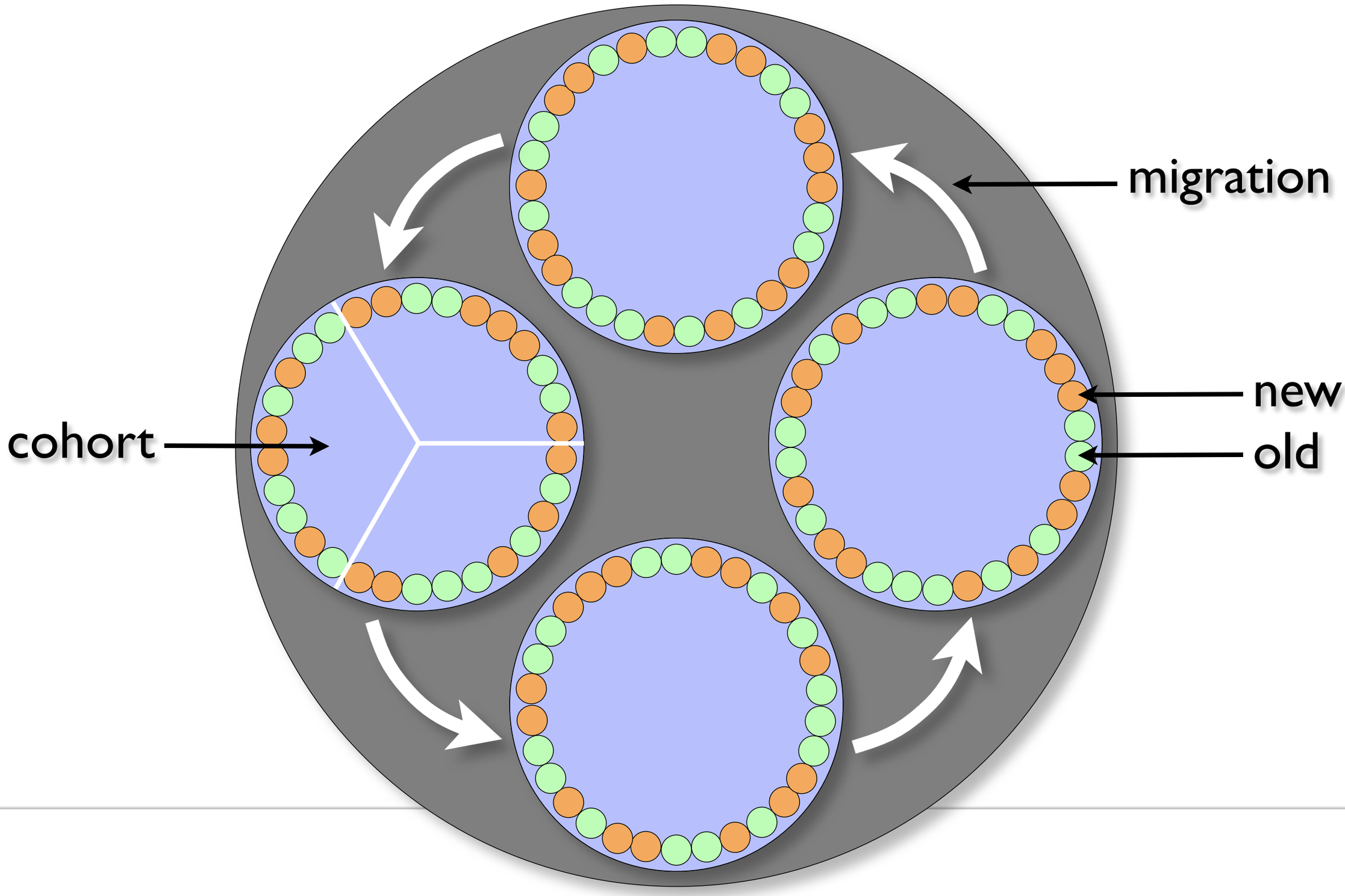
Population divided into 4 demes



4 demes of 30 individuals



cohorts, migration, elitism

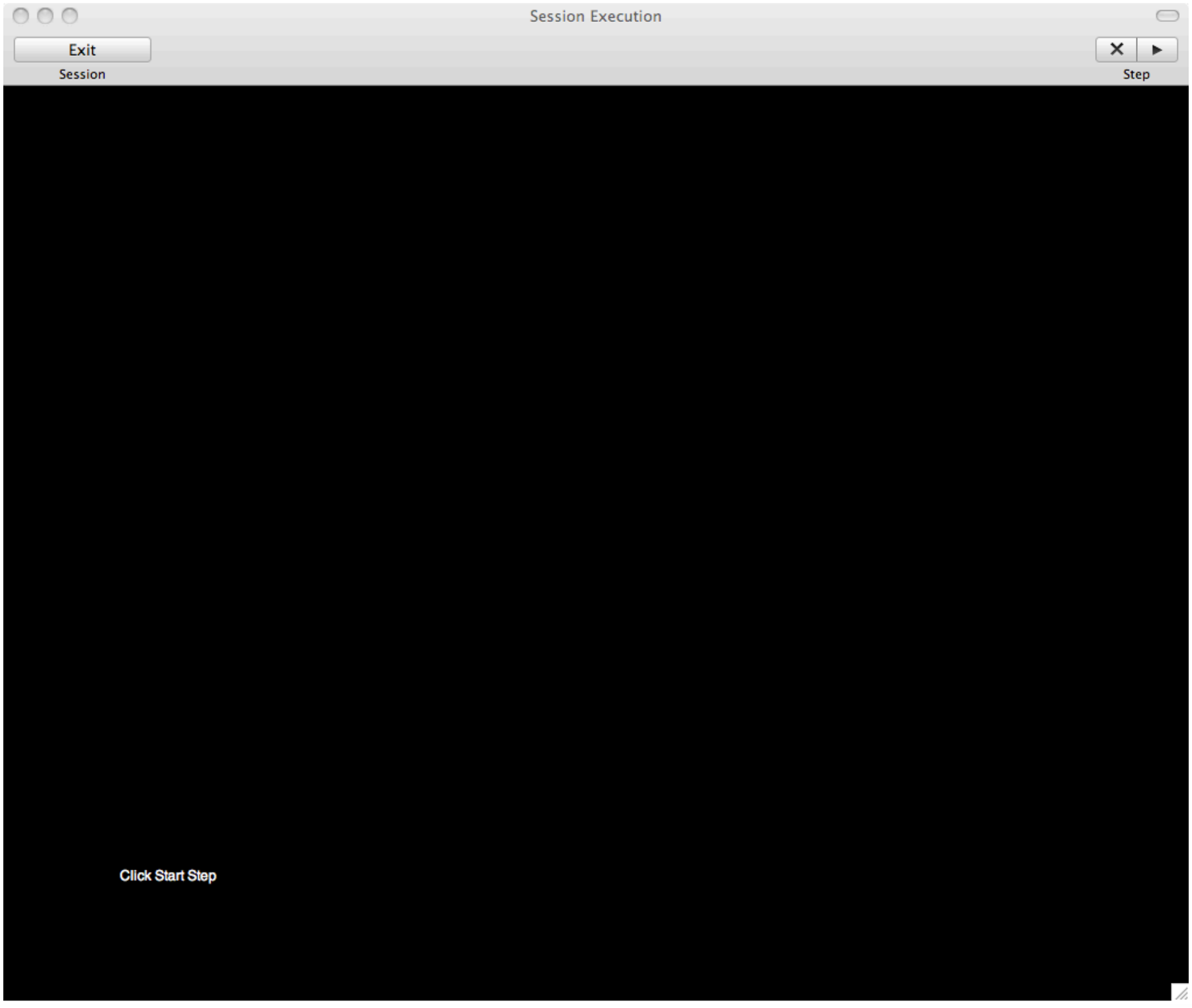


User Interaction and GUI

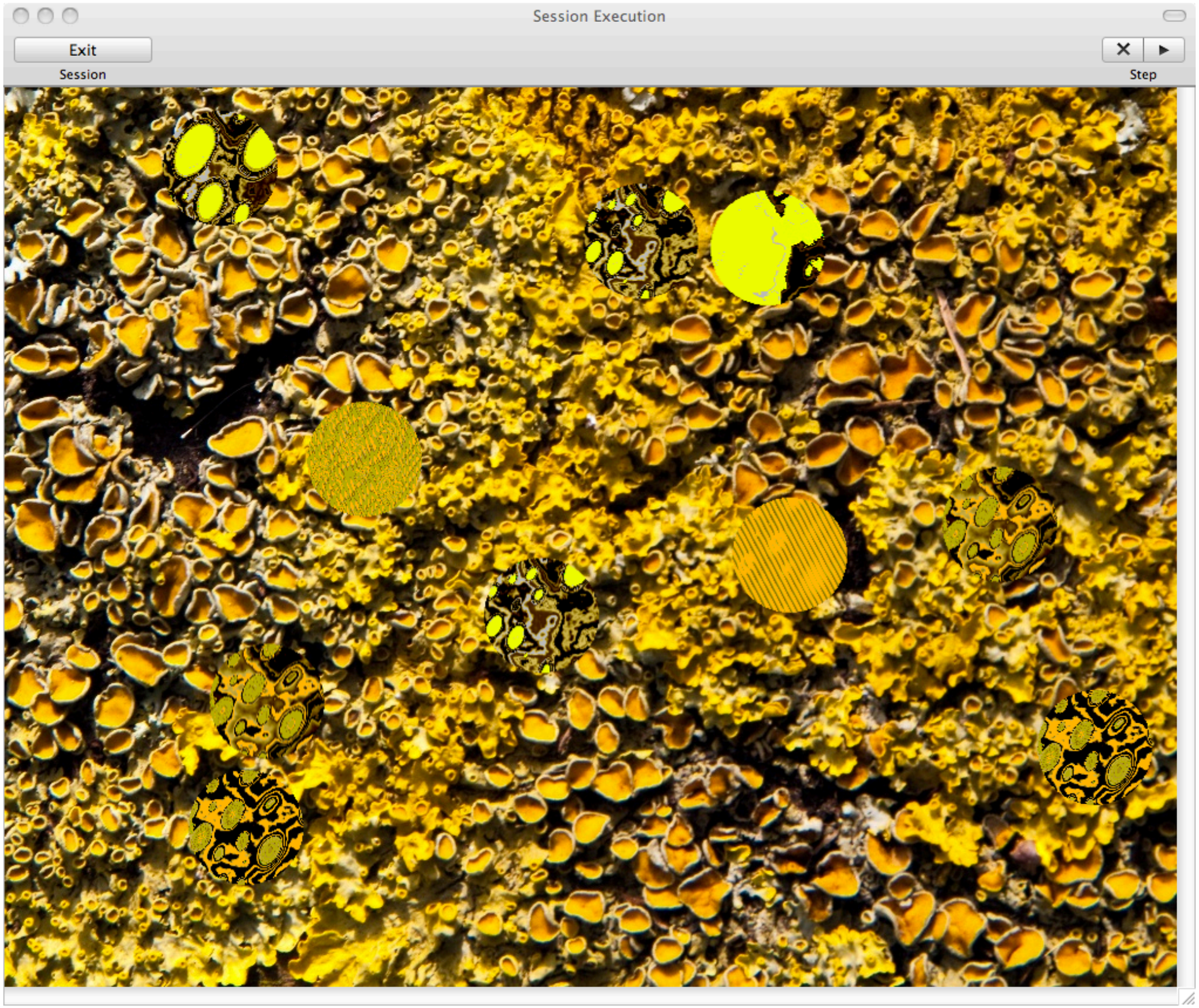
Ladybirds (10-spot (*Adalia decempunctata*), 2-spot (*Adalia bipunctata*) and cream-spot (*Calvia 14-guttata*)) on weeping silver birch tree, England.

Each round of camouflage game

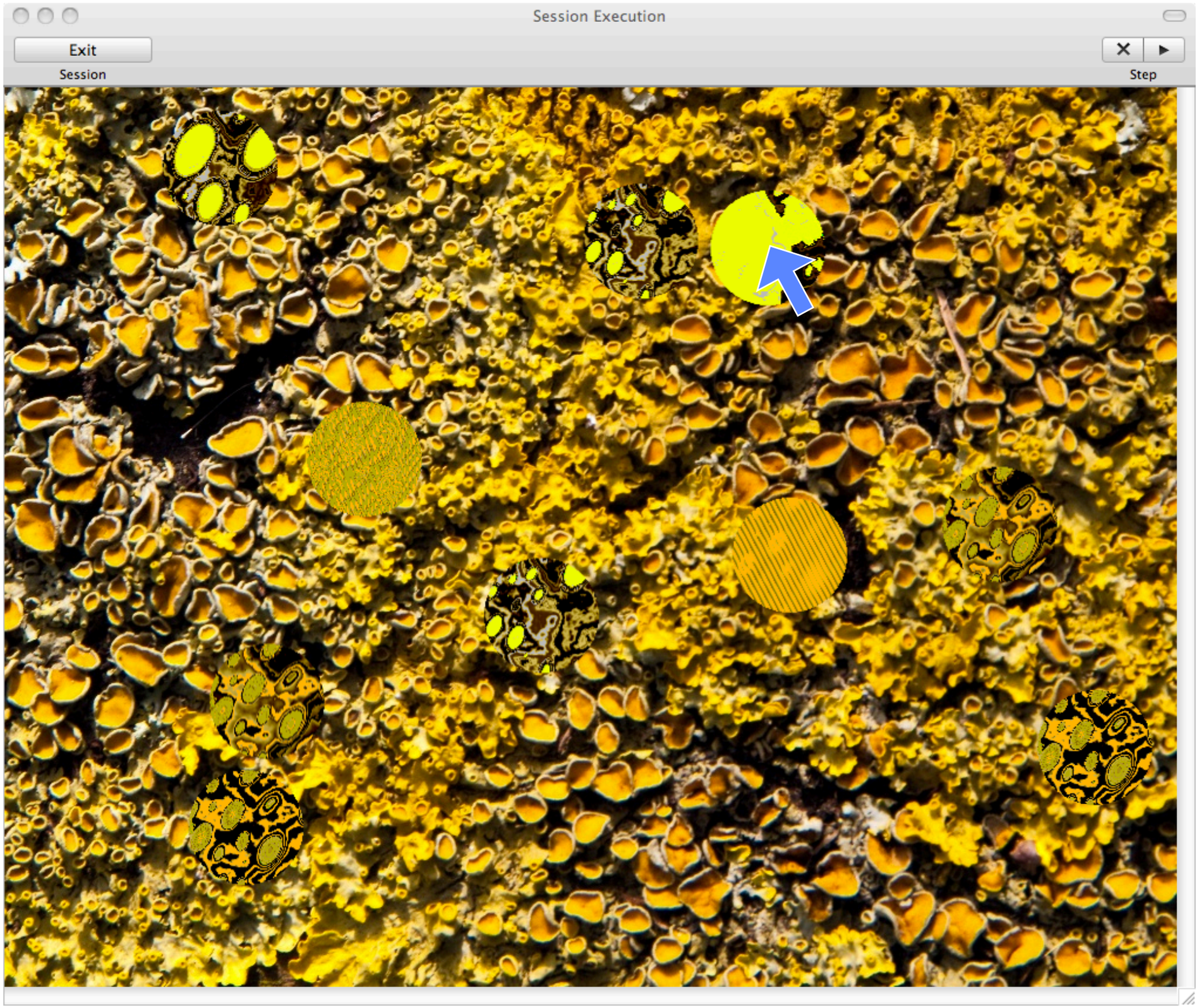
- Start with blank window, click to begin
- Background image displayed with cohort of ten prey
- Repeat five times:
  - Player/predator clicks on most conspicuous prey
  - Prey is *eaten*: removed from population and display
- End of round, blank window



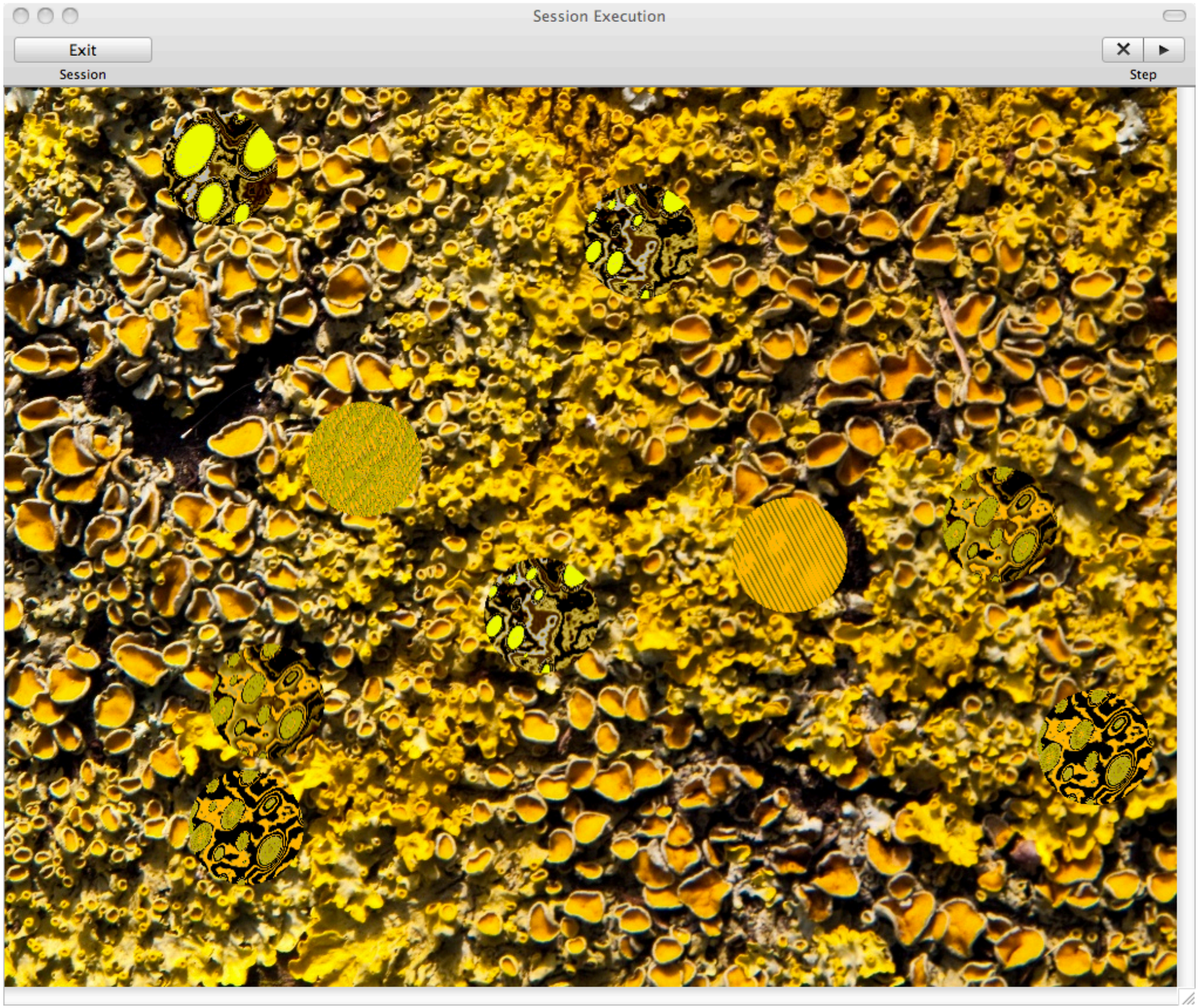
beginning of one “round” of camouflage game



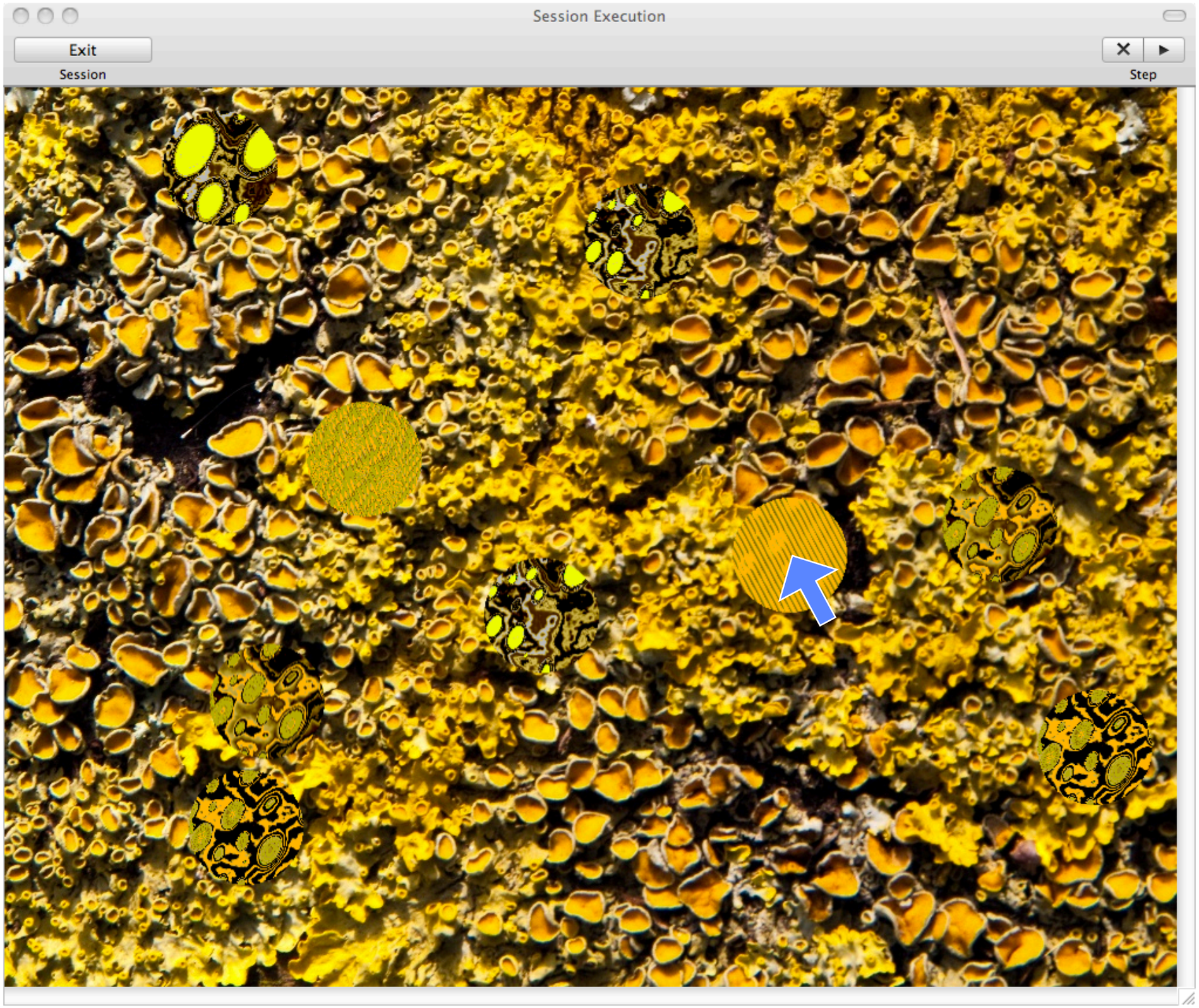
10 prey



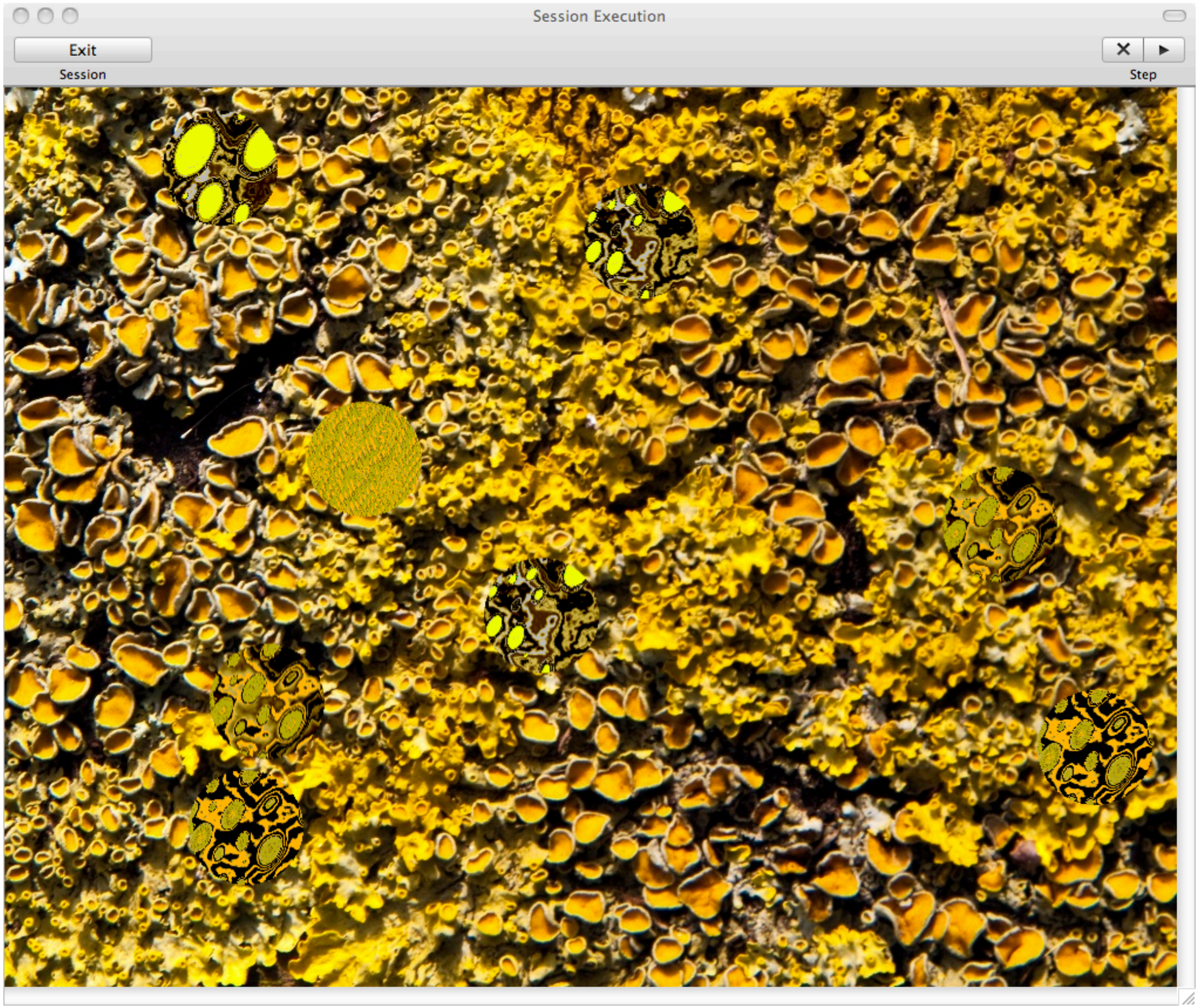
predator selects prey 1



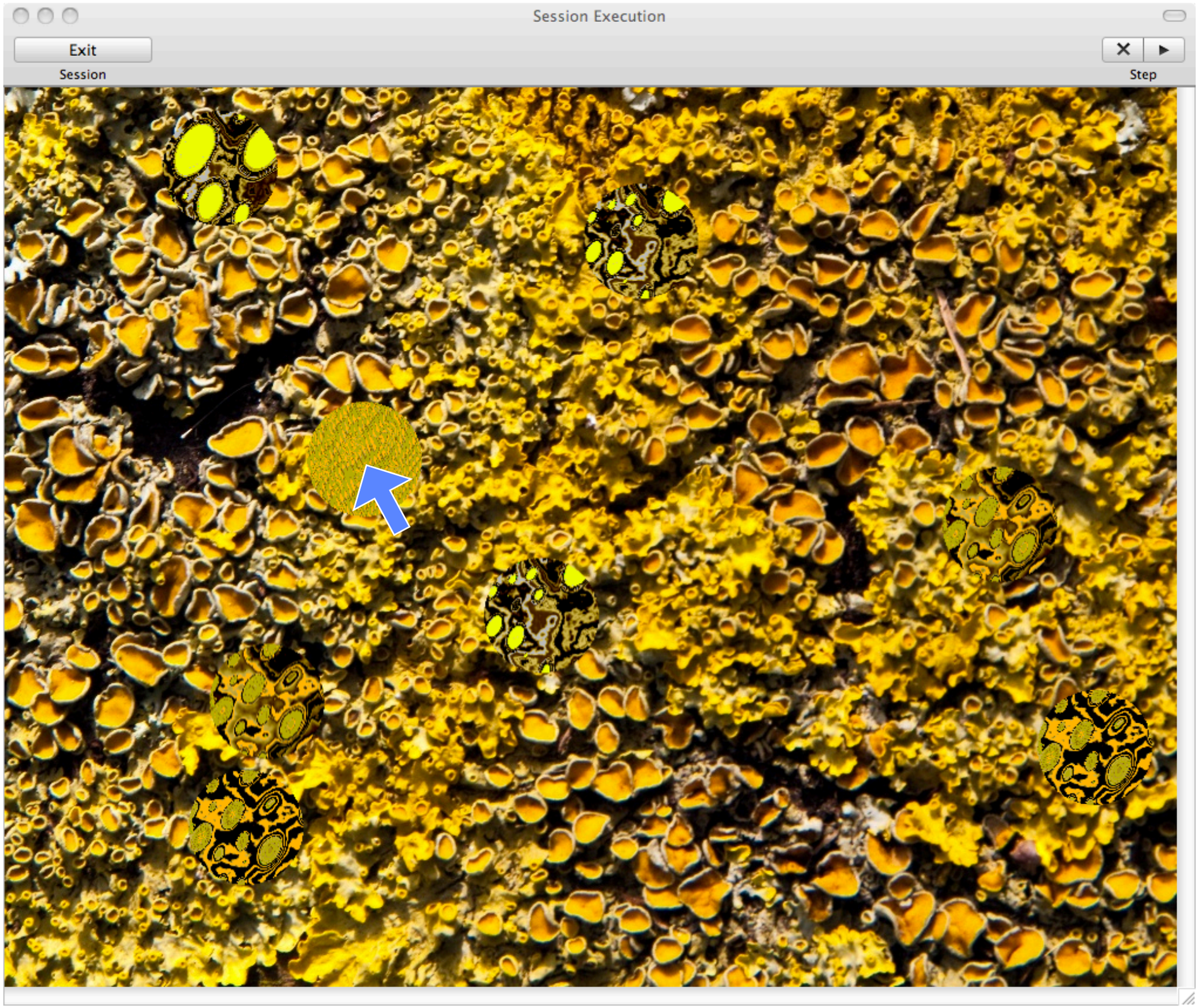
9 prey remaining



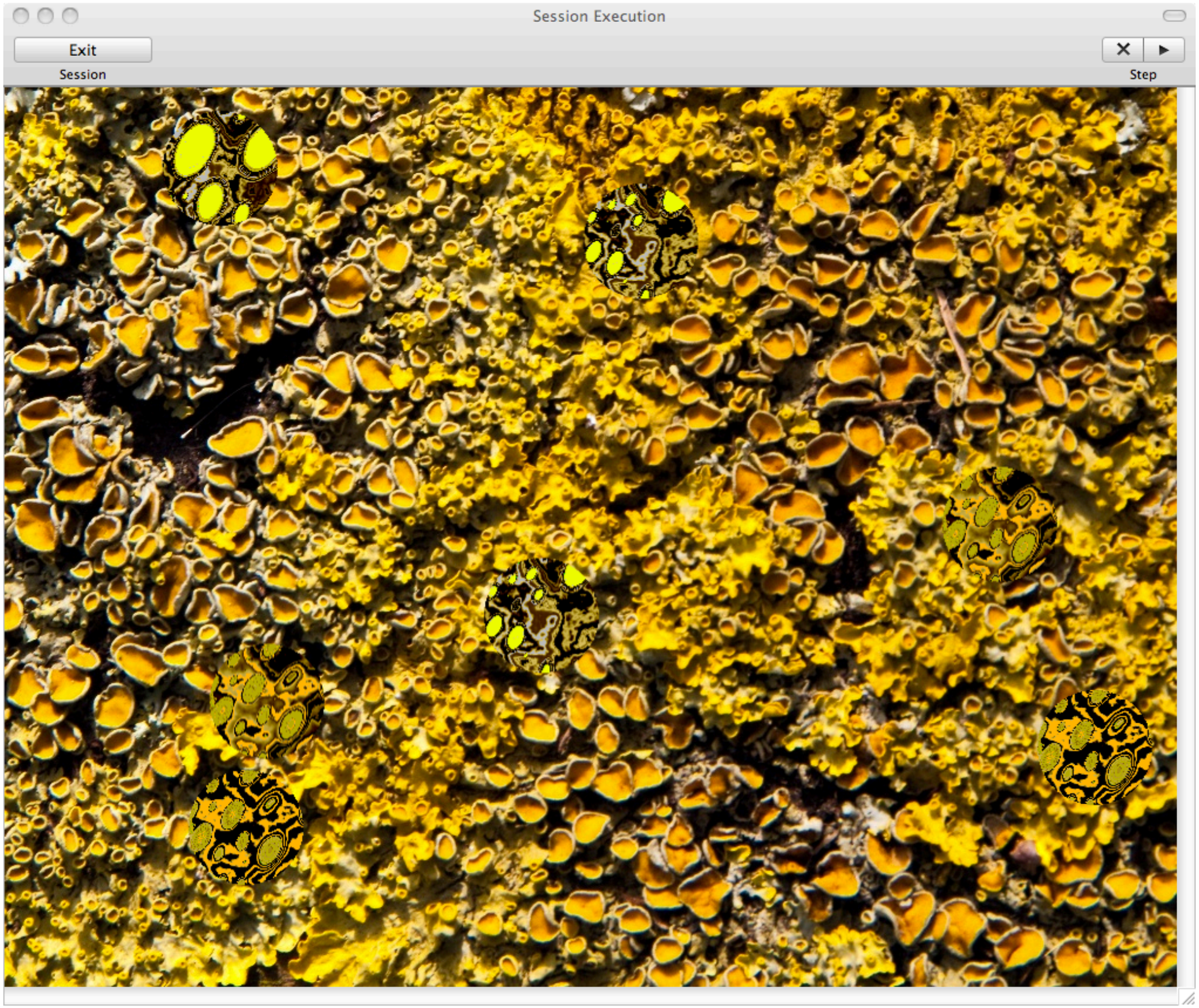
predator selects prey 2



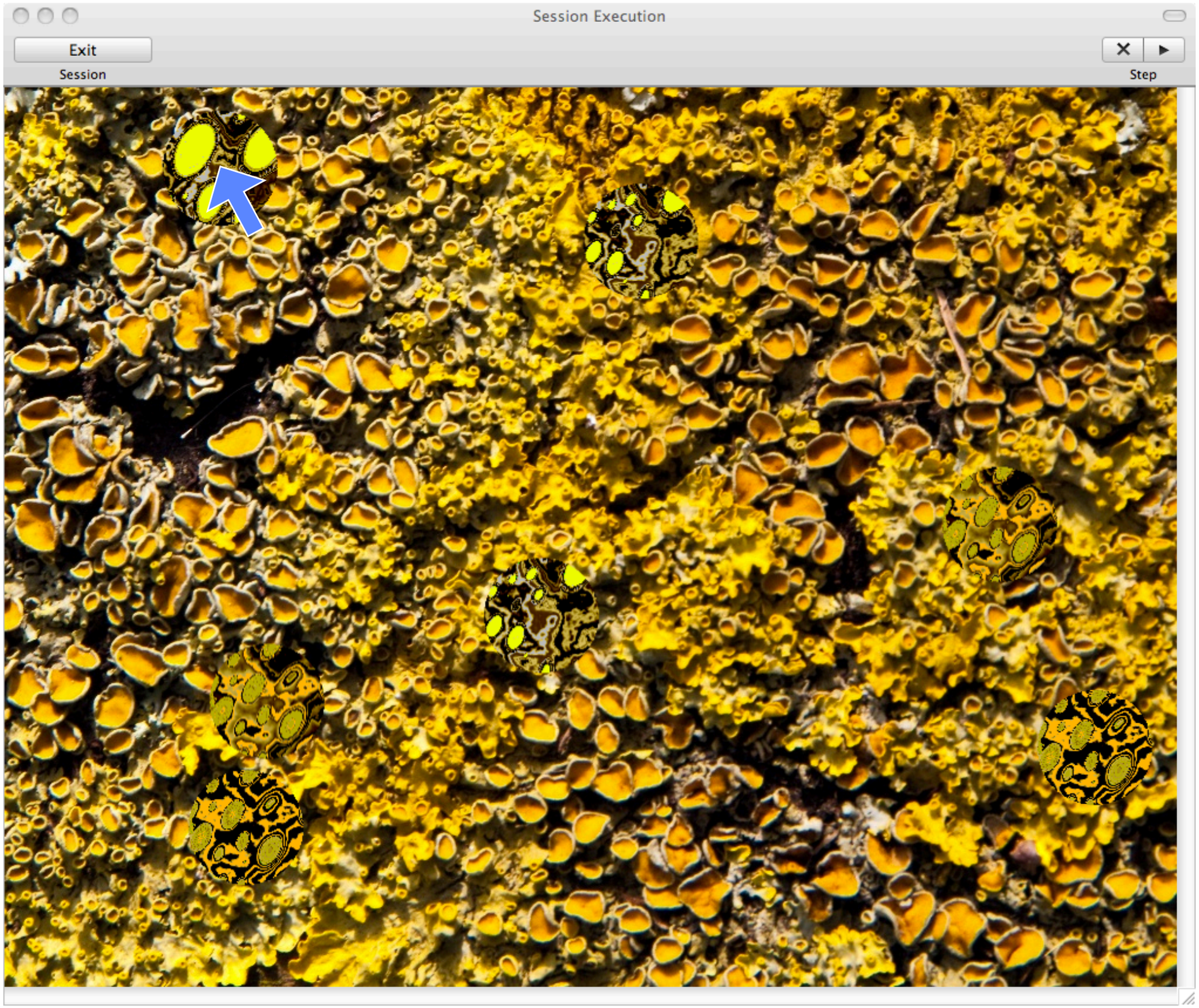
8 prey remaining



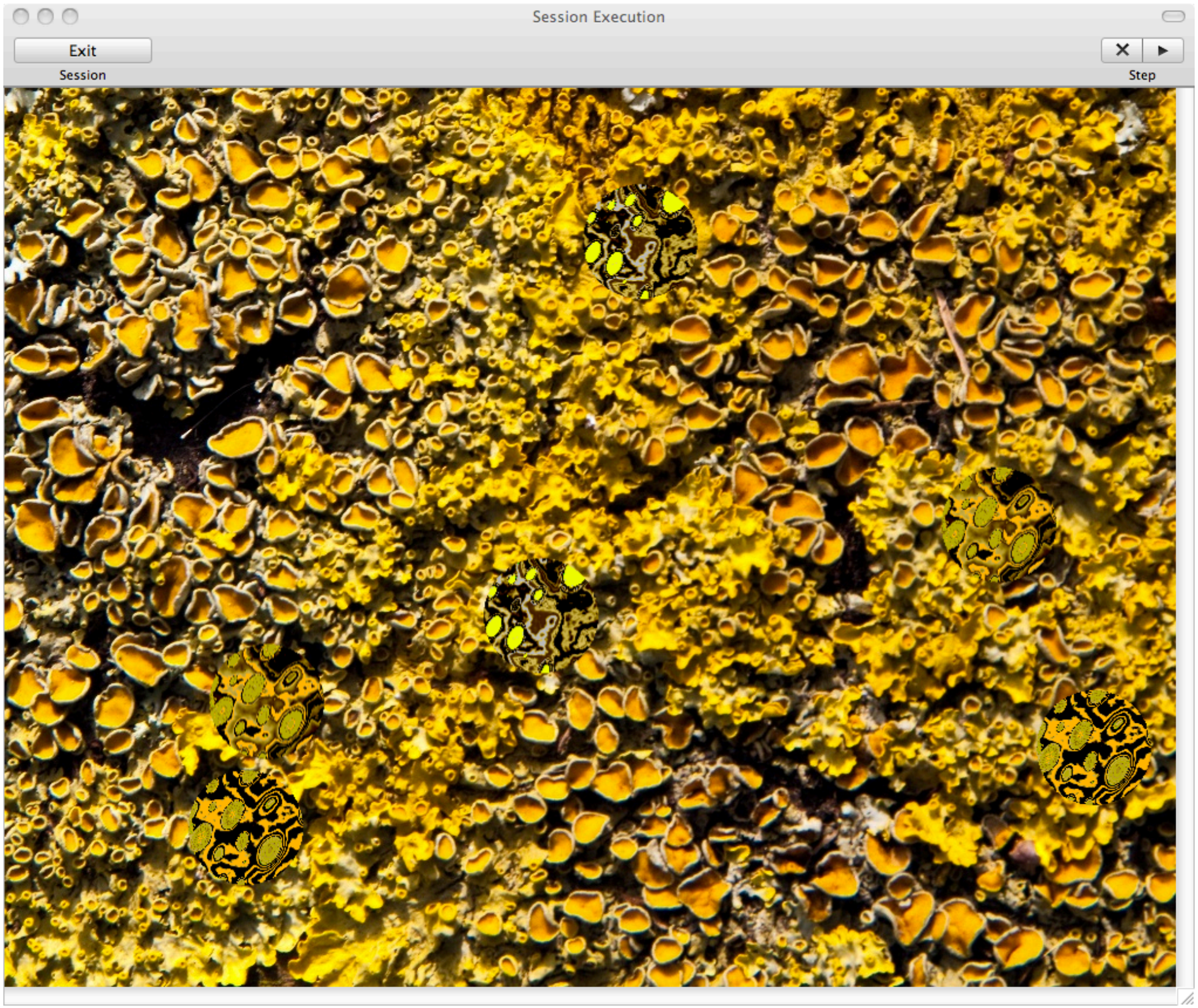
predator selects prey 3



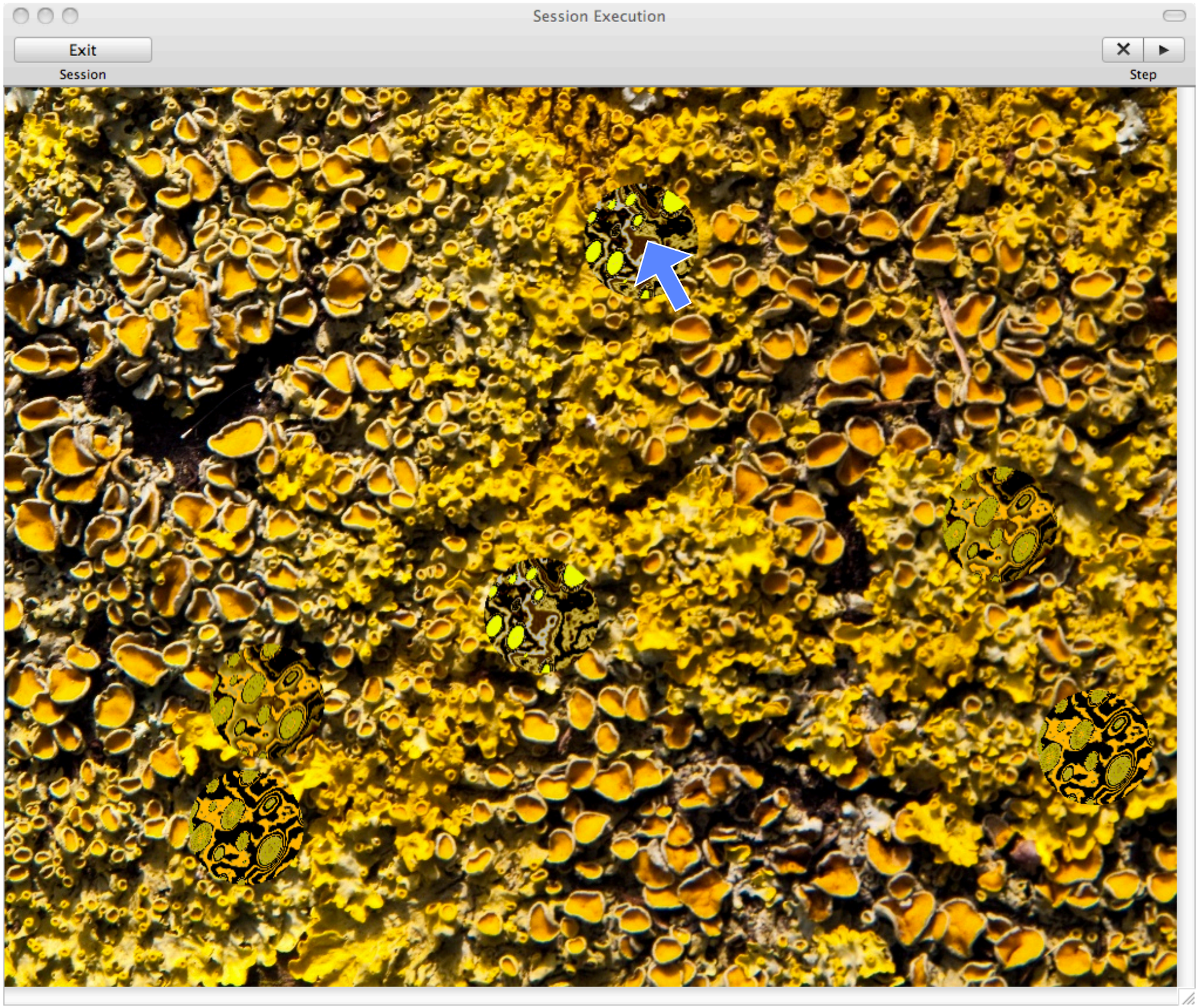
7 prey remaining



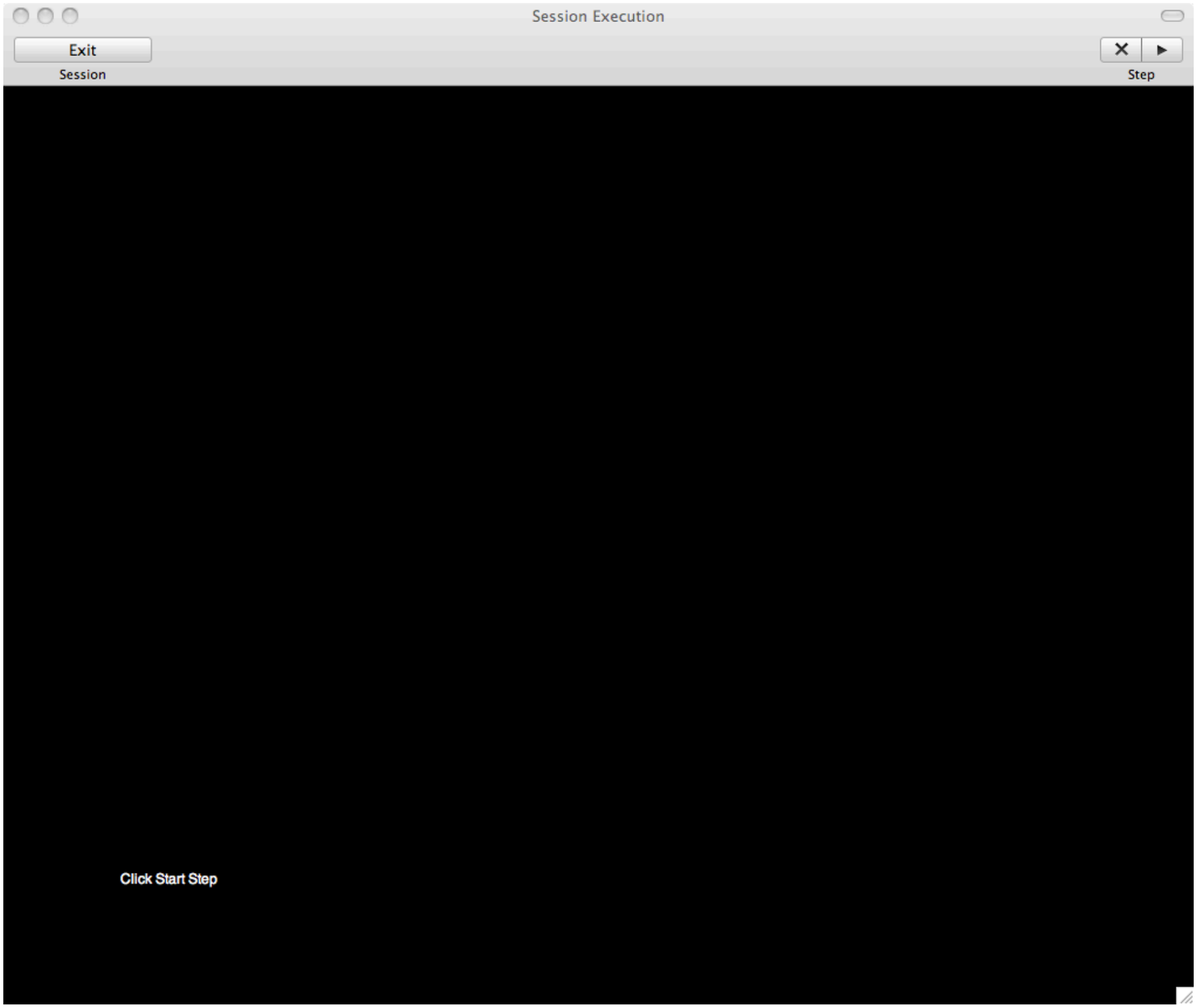
predator selects prey 4



6 prey remaining



predator selects prey 5



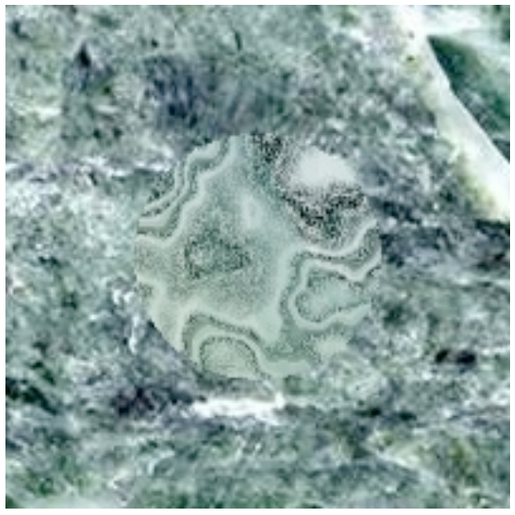
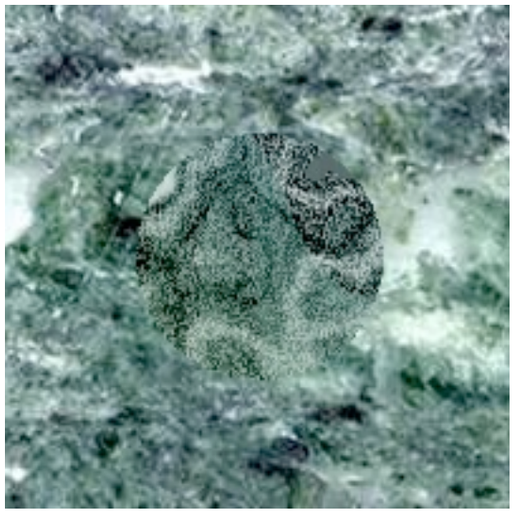
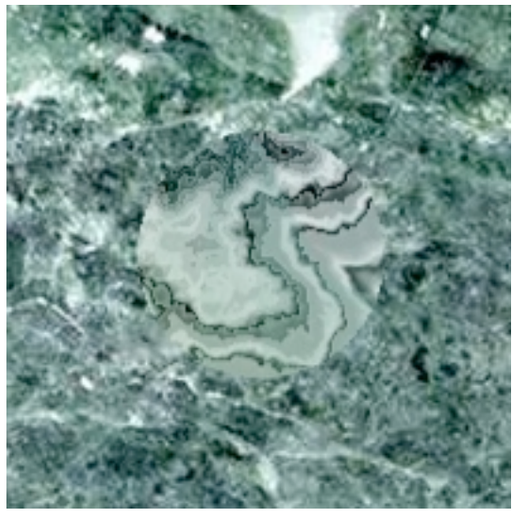
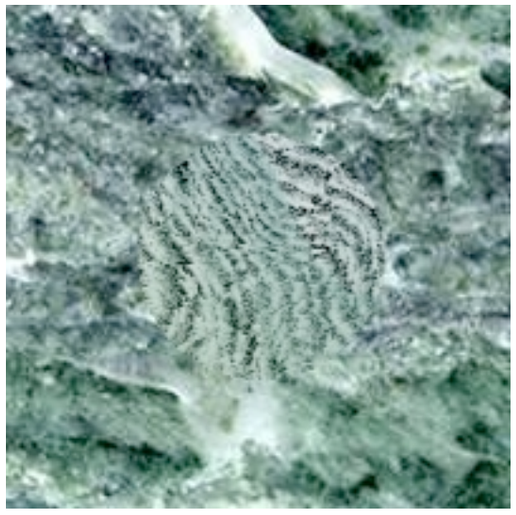
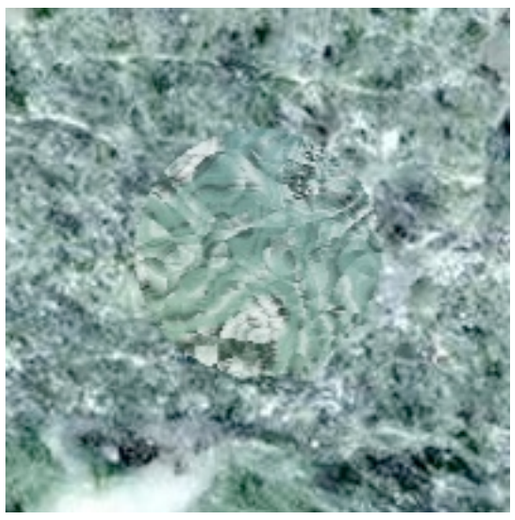
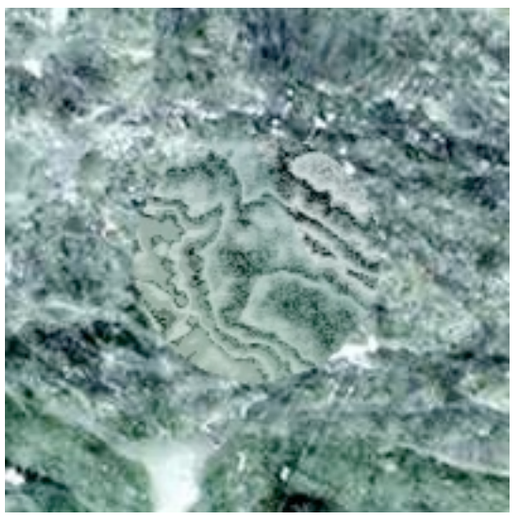
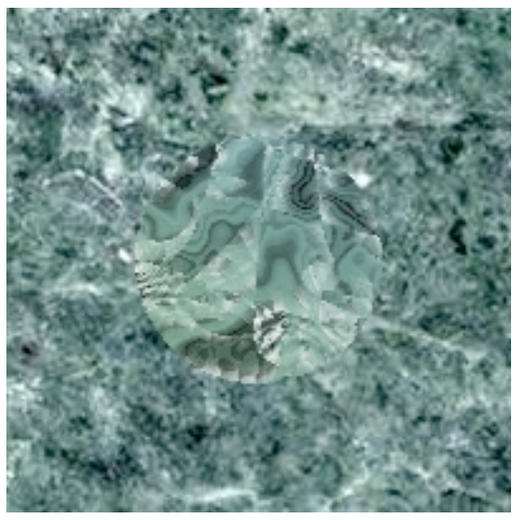
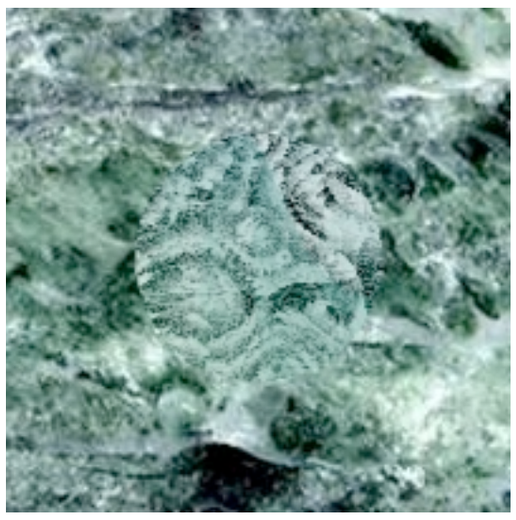
end of one “round” of camouflage game

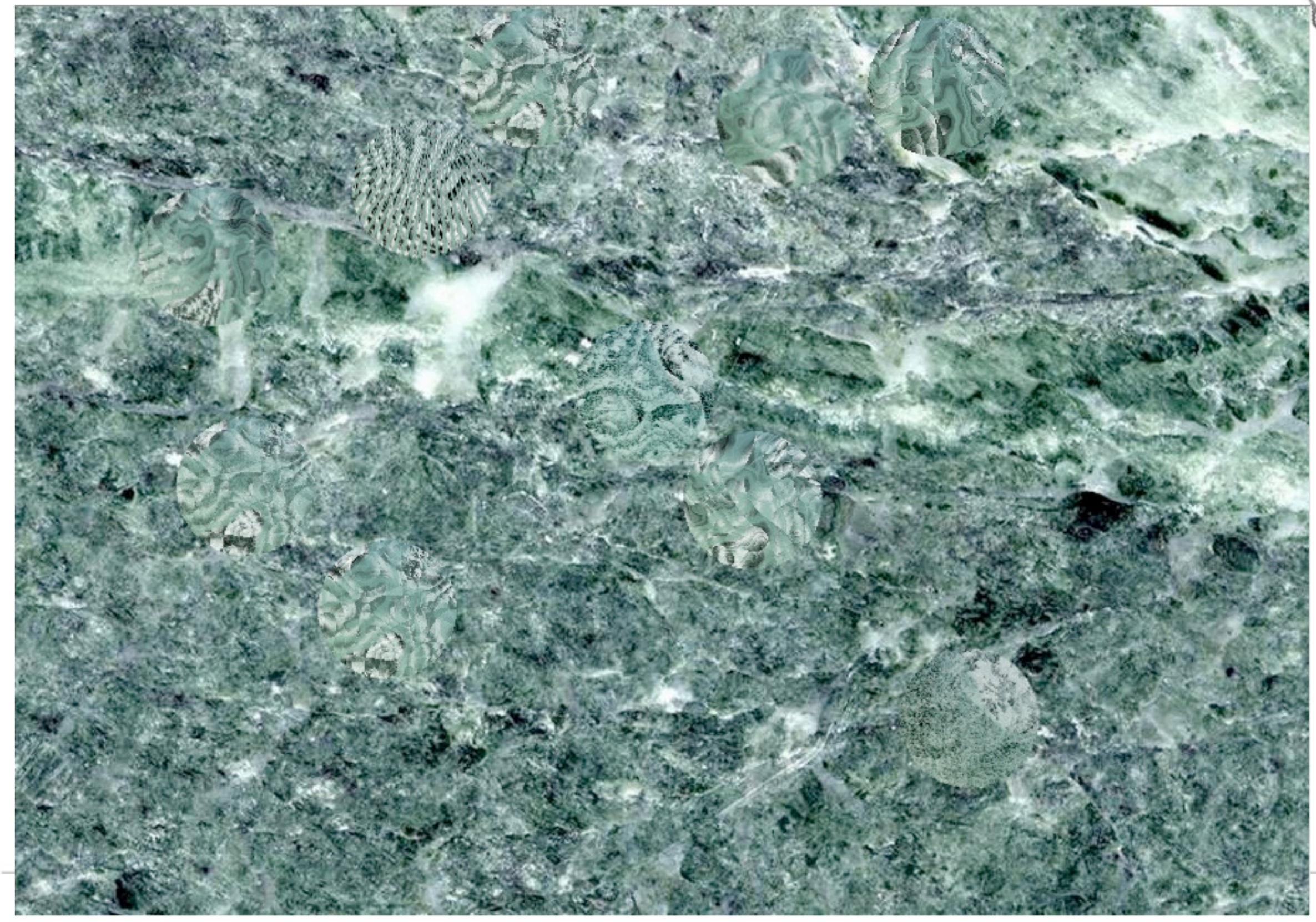
Typical run

- 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

Results

Serpentine (polished stone)

Flowers and leaves

(*lantana montevidensis* in my backyard)

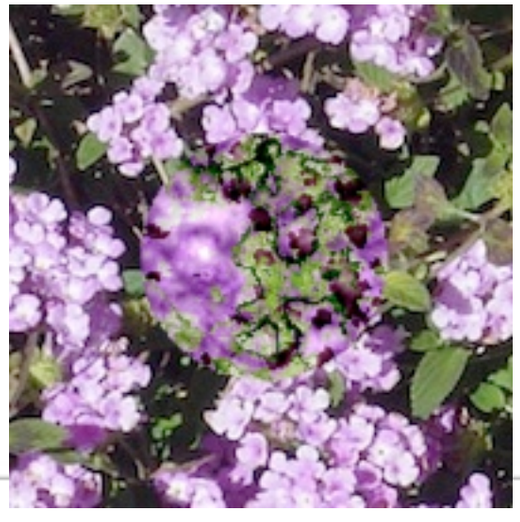




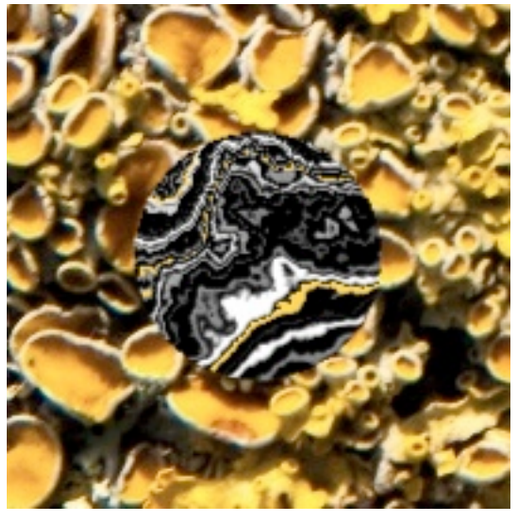
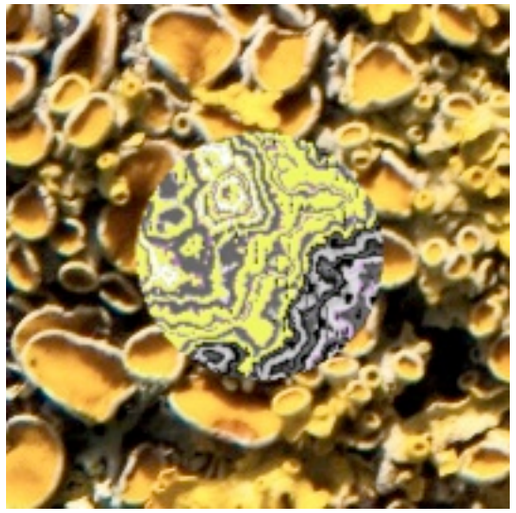
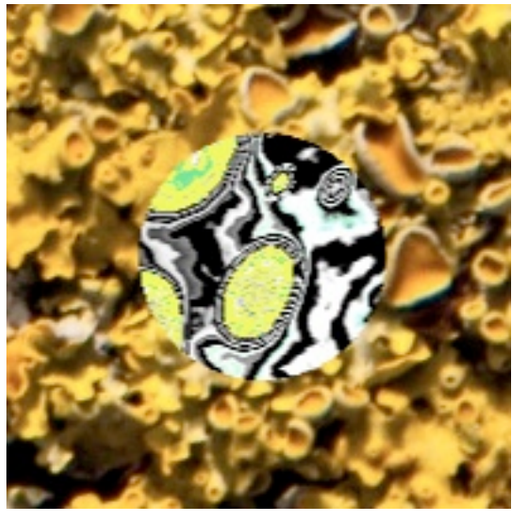
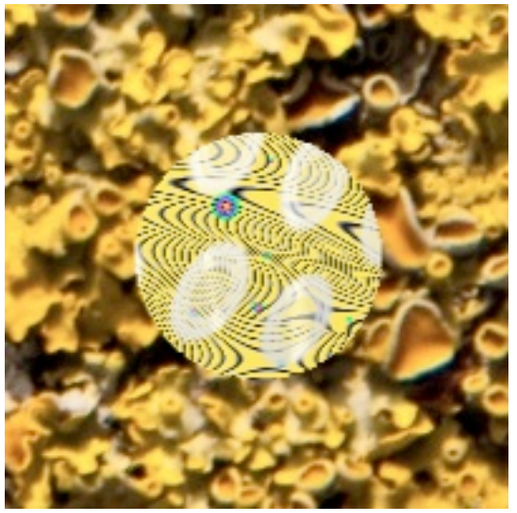
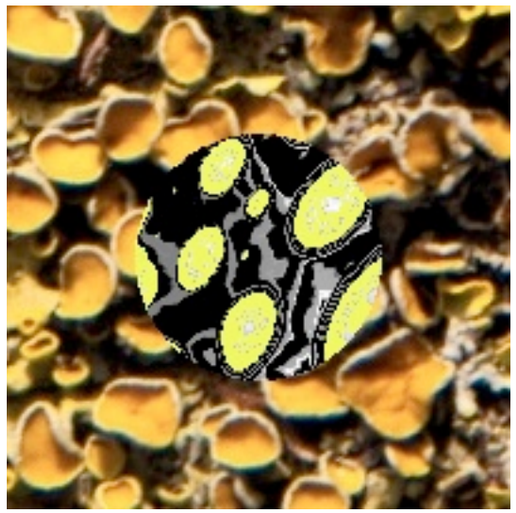
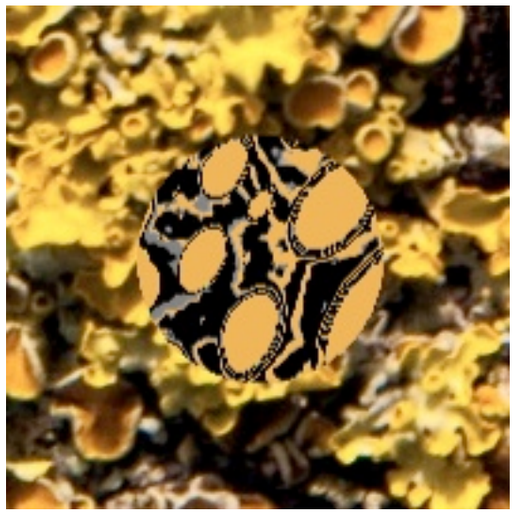
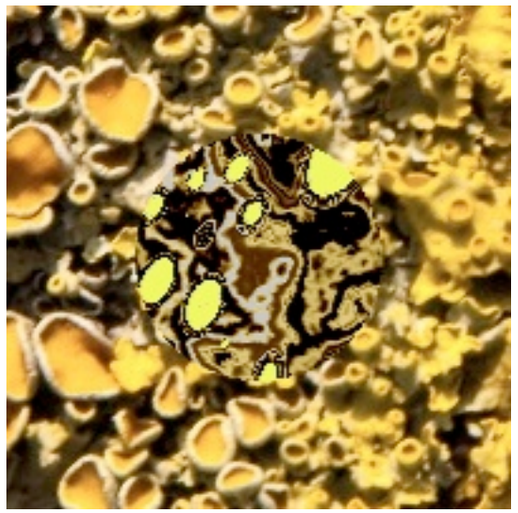
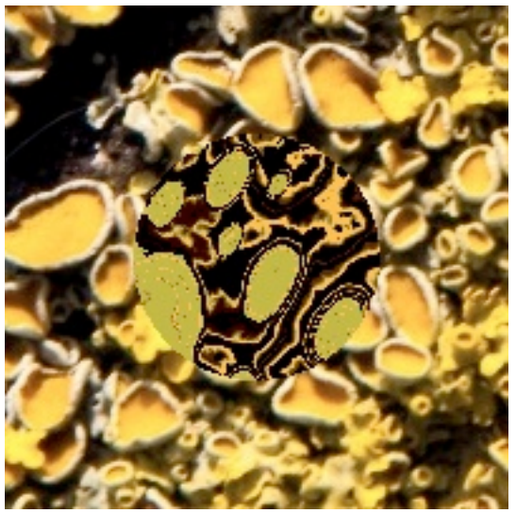
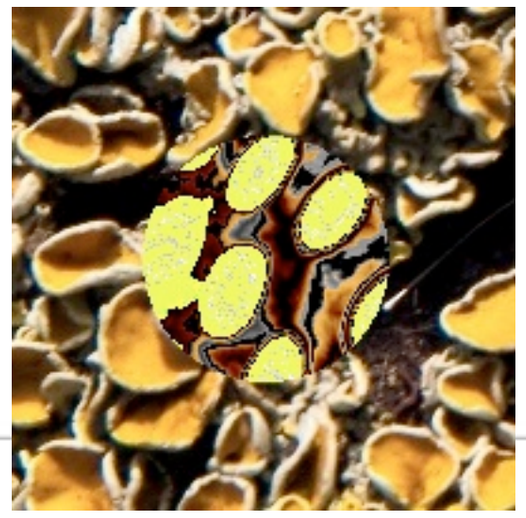
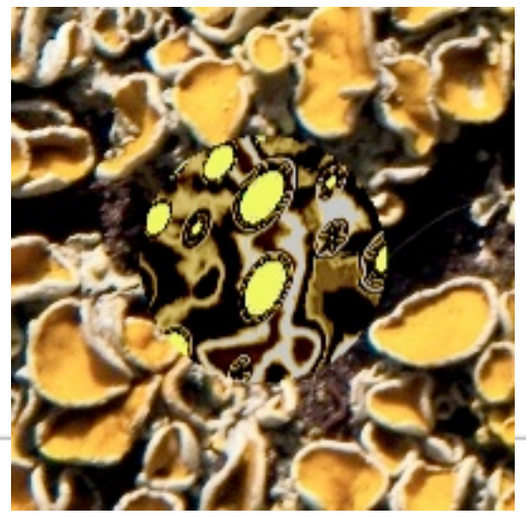
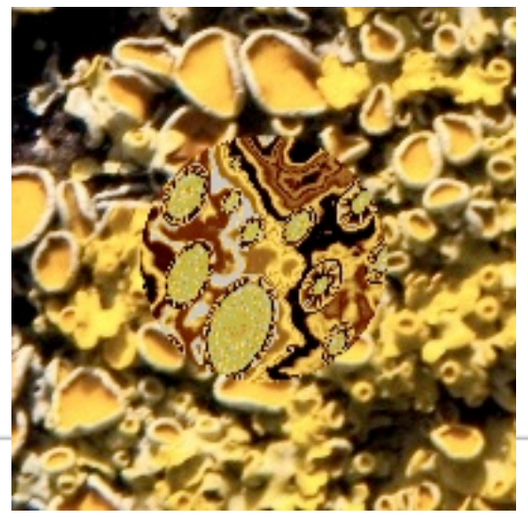
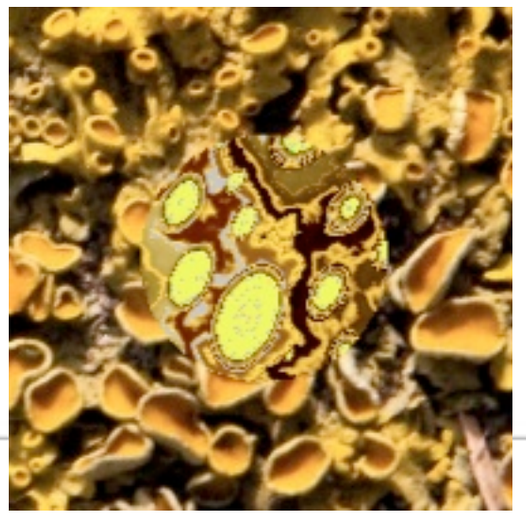




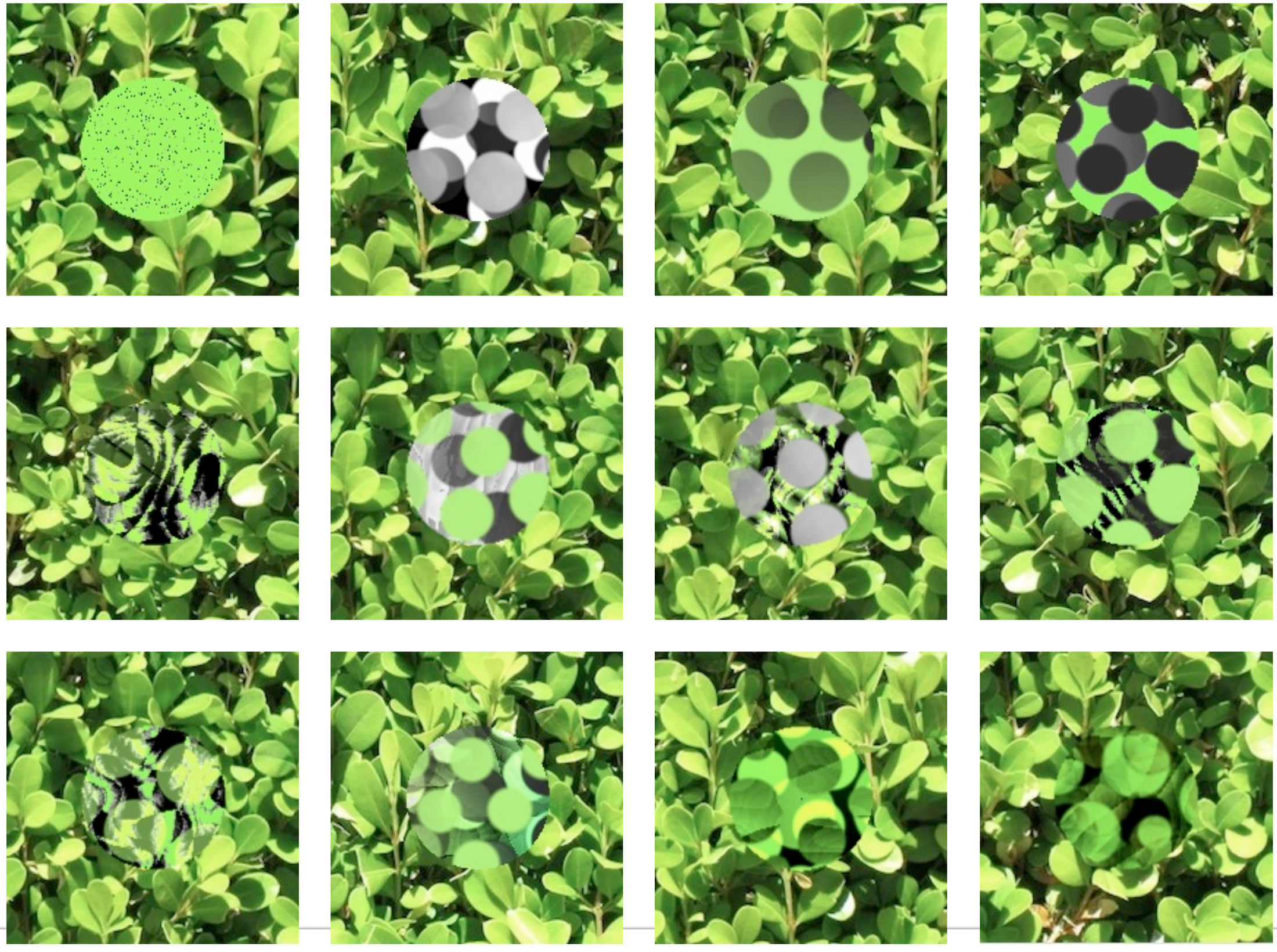


Lichen

Hedge



(shadows?!)

Peppers
(unsuccessful run)

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/gots/