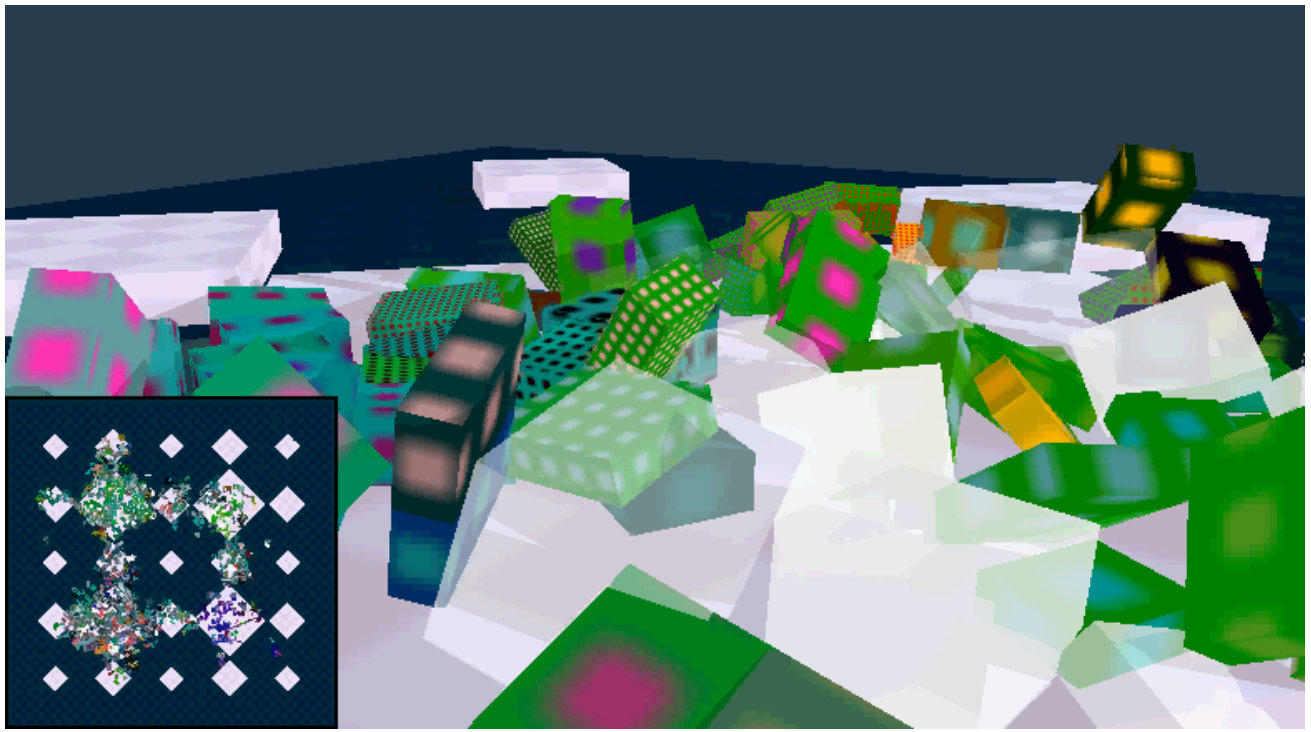
Division Blocks and the Open-Ended Evolution of Development, Form, and Behavior



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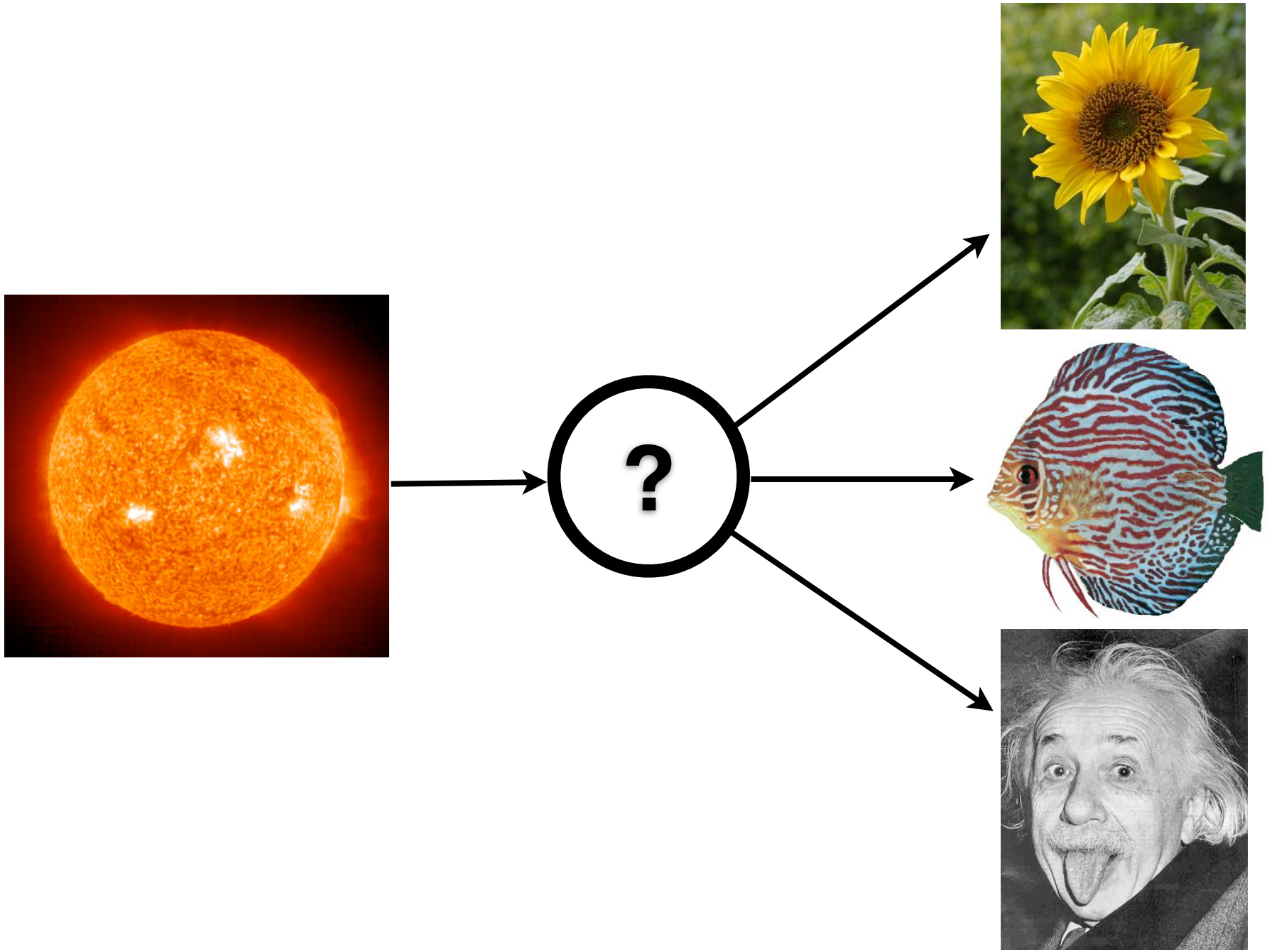


Goal

- Explore, in silico, key interactions among development, form, physics, behavior (including reproductive behavior), and ecology that underpin biological evolution.
- How do these factors interact, under natural selection, to produce adaptive complexity?

Open-Ended Evolution of Development, Form, and Behavior

- Wide repertoire of possible developmental trajectories, forms, behaviors, and ecological interactions.
- No pre-specified goals, just ecological interactions (possibly including aggregation and reproduction) within a resource-preserving 3D physical simulation.
- Reproductive and aggregative behaviors also open-ended and may evolve.

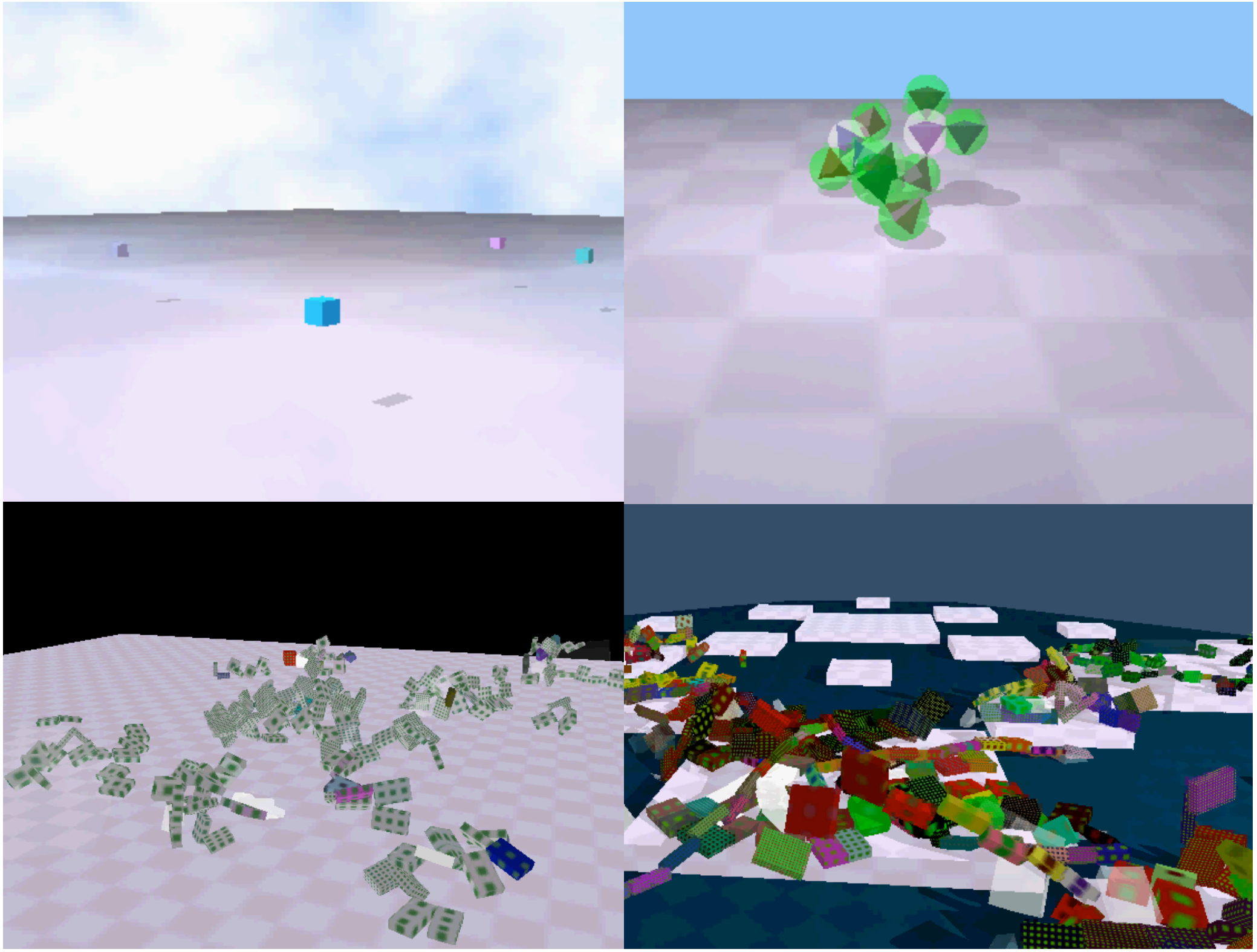
Precursors

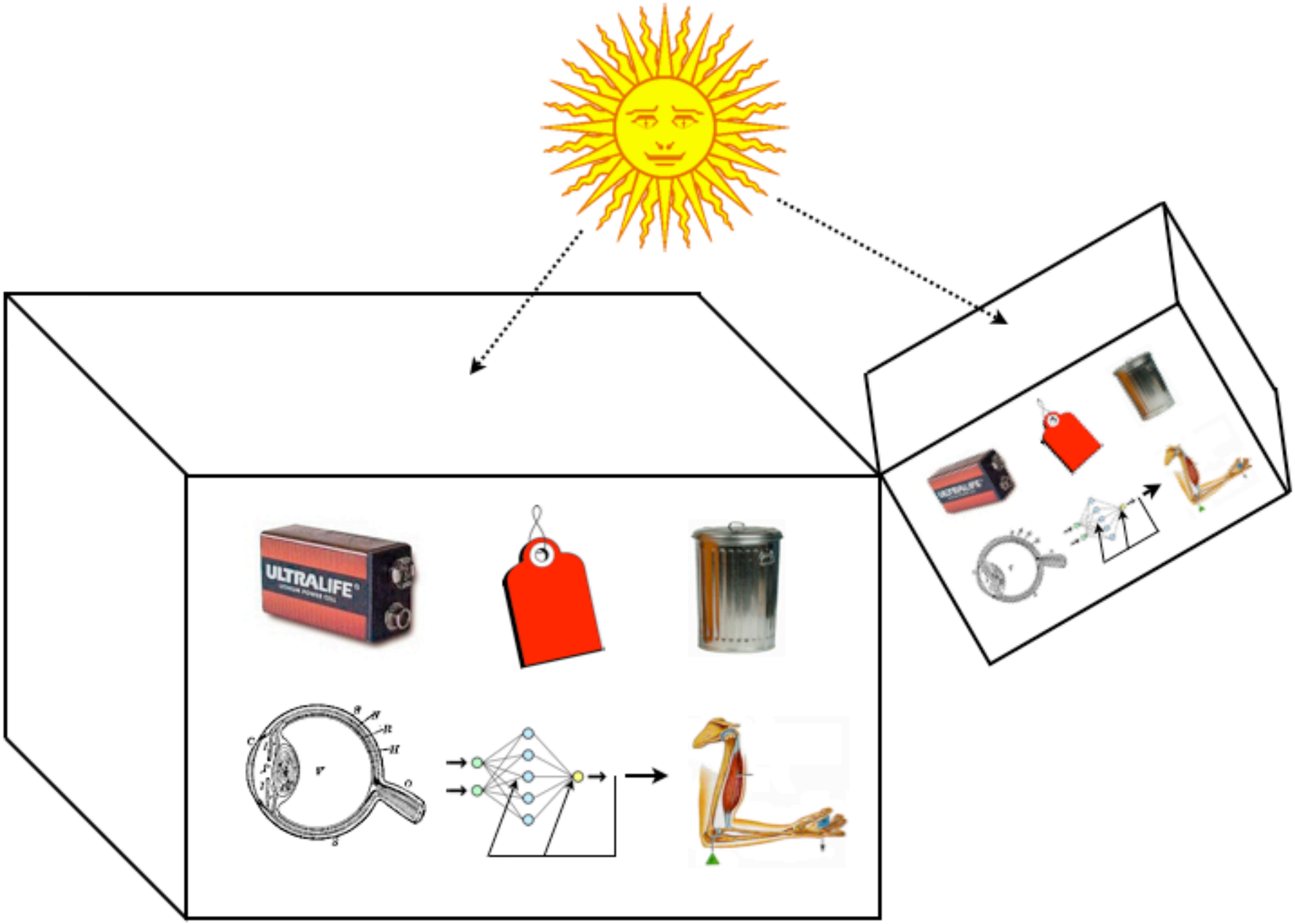
- Tierra
- Avida
- Echo
- Pushpop
- Sims's Creatures
- Framsticks
- Artificial Ontogeny
- SwarmEvolve 2
- Robotic/structural evolution
- Plant growth evolution
- ...

Unfortunately Necessary

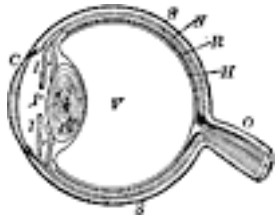
- Outrageous simplifications.
- Combinations of features normally observed at radically different scales.

SwarmEvolve 2



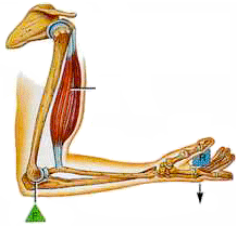

ULTRALIFE

Sensors



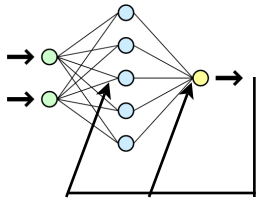
zero, plus, minus, energy, waste, exposure, pulse, rotx, roty, rotz, localtag, localenergy, localwaste, connectedtag, connectedenergy, connectedwaste, stemtag, stemenergy, stemwaste

Effectors



sizex, sizey, sizez, jointx, jointy, jointz, stemx, stemy, stemz, tag, donationsize, donationtolerance, stemdonationsize, stemdonationtolerance, collectionsize, collectiontolerance, stemcollectionsize, stemcollectiontolerance, copyfidelity, mutationlimit, matecontribution, matetag, adhesion, pulserate, sigmoidcompression

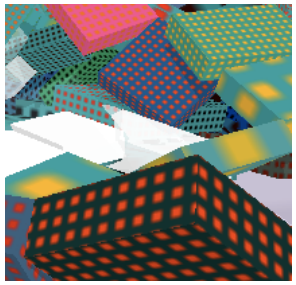
Neural Network



- Arbitrary recurrent architecture, genetically controlled.
- Division (via growth) and genetics (mutation and crossover) controlled by network outputs.
- Sigmoid activation function; steepness controlled by an effector:

$$\sigma(s) = \frac{2}{1 + e^{-cs}} - 1$$

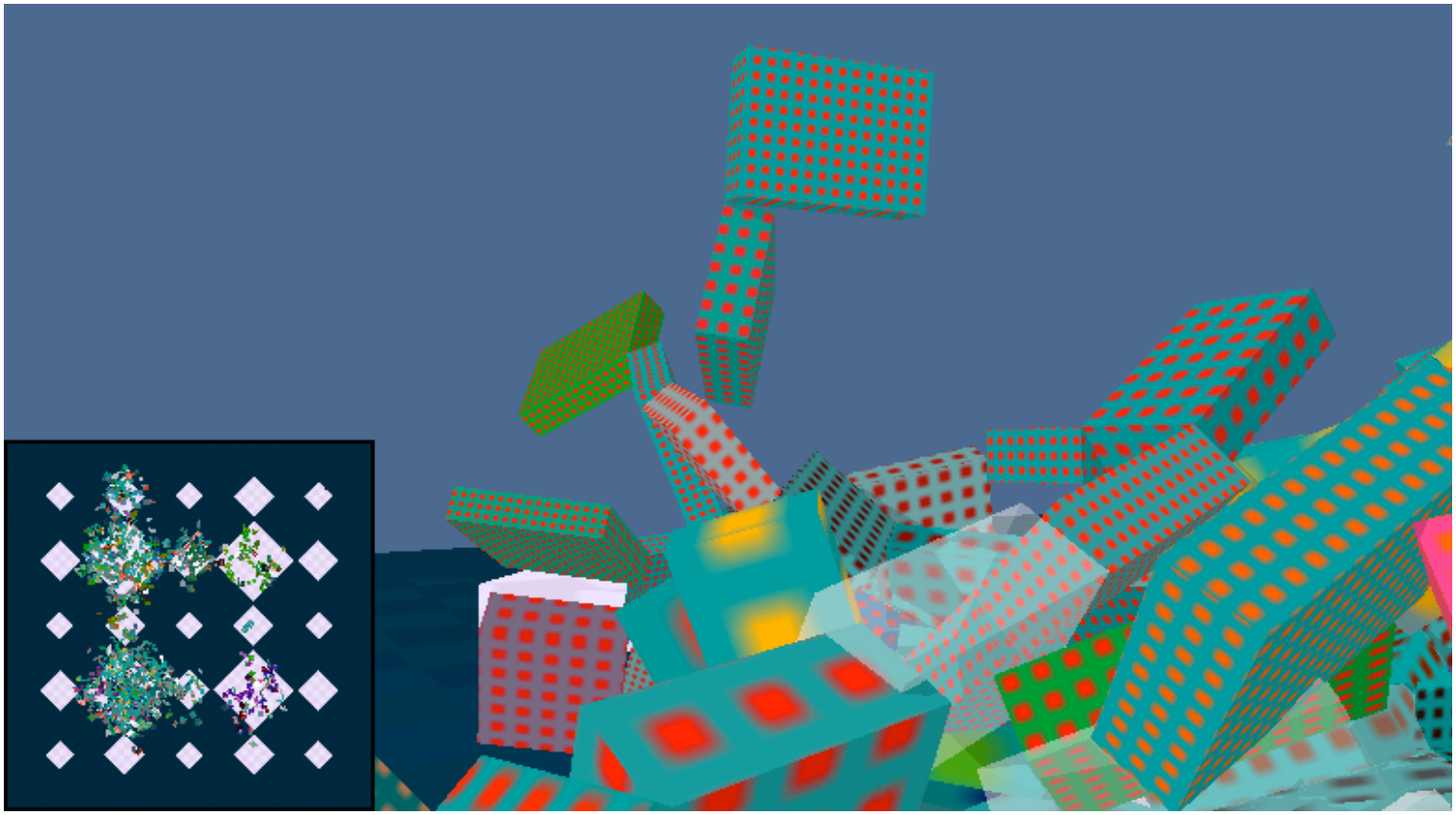
Skin



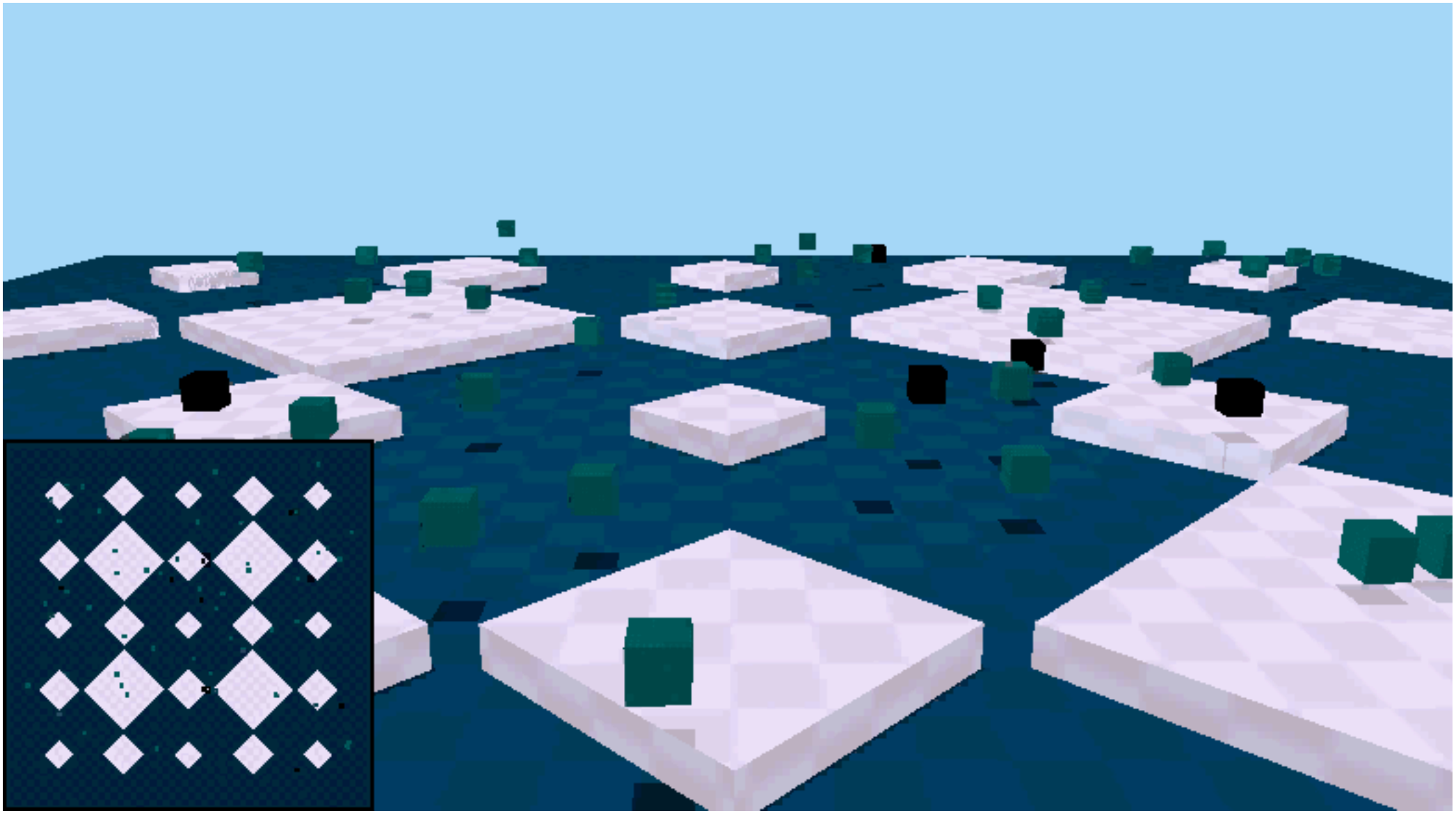
Patterns/colors show state. For results in paper:

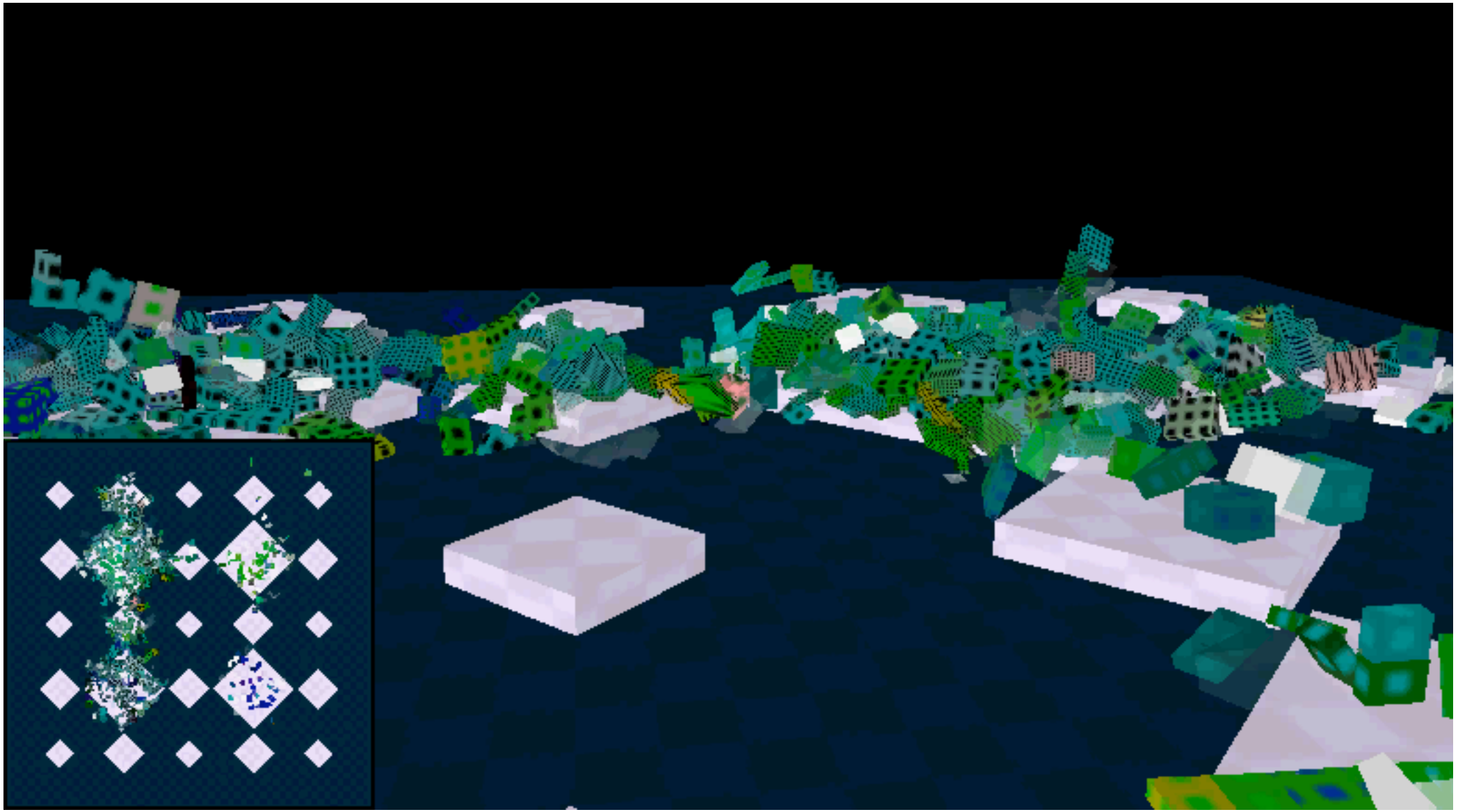
- Dot density = energy
- Frame red = waste
- Frame green = energy donation tolerance
- Frame blue = energy donation size
- Dot red = sun exposure
- Dot green = waste collection tolerance
- Dot blue = waste collection size

Waste

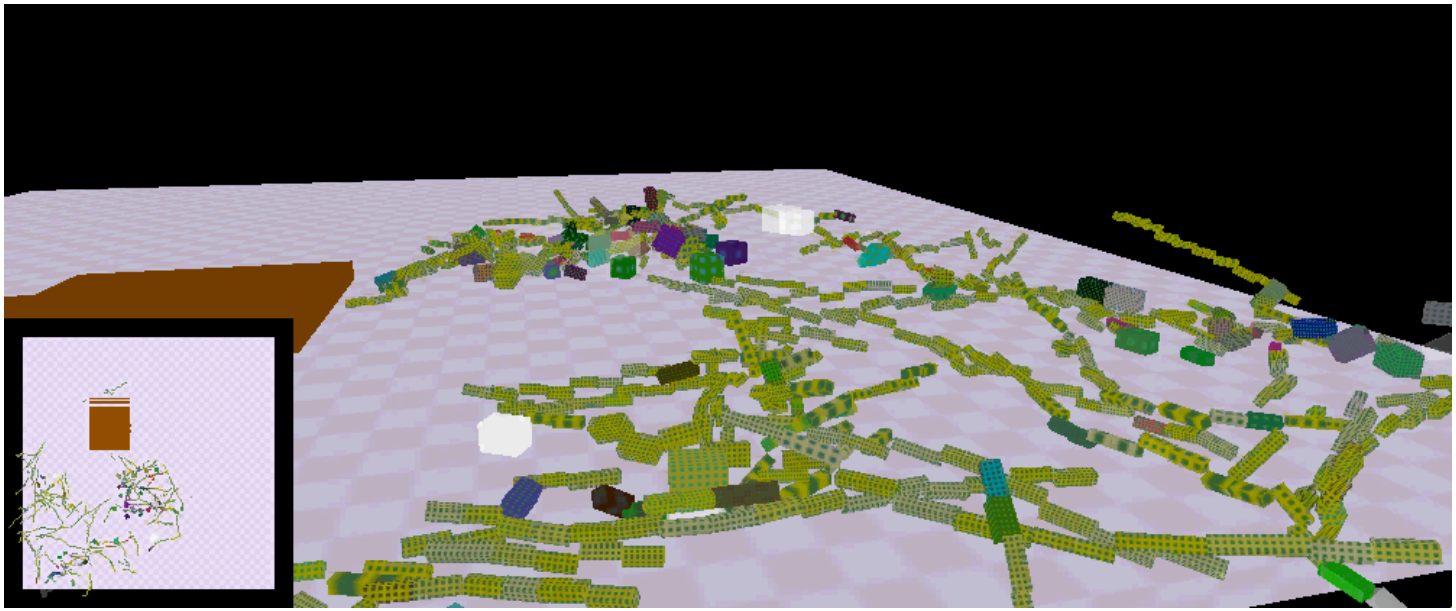


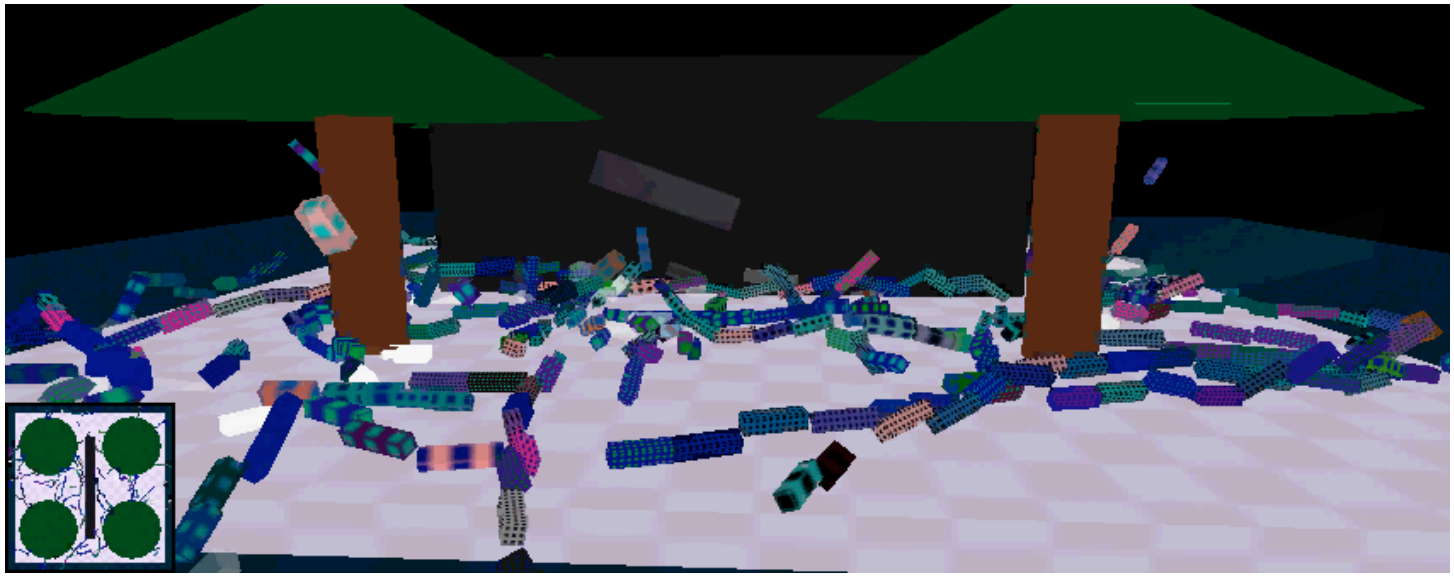
Reproductive Competence

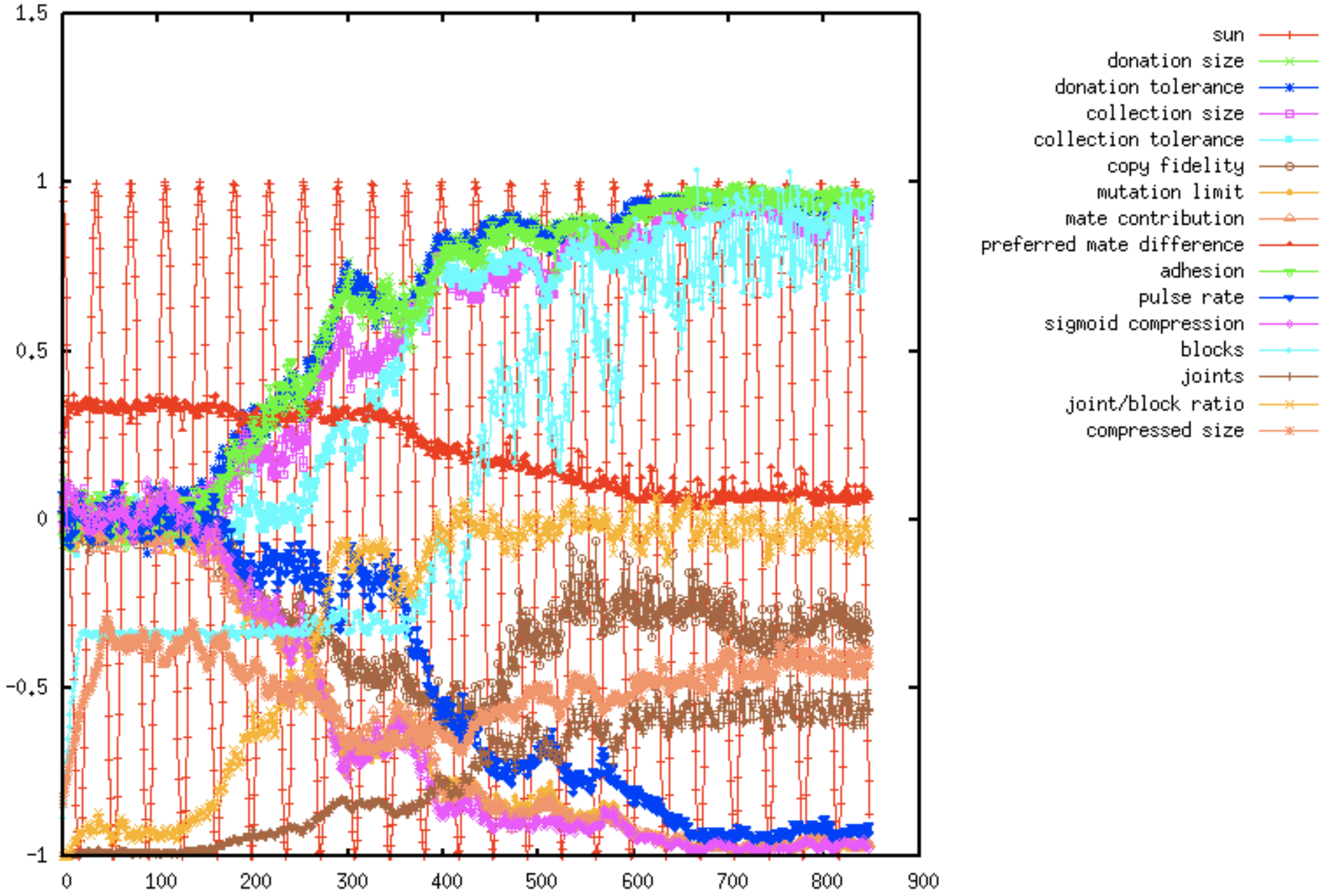




Variations






1.5
1
0.5
0
-0.5
-1
0
100
200
300
400
500
600
700
800
900
sun
donation size
donation tolerance
collection size
collection tolerance
copy fidelity
mutation limit
mate contribution
preferred mate difference
adhesion
pulse rate
sigmoid compression
blocks
joints
joint/block ratio
compressed size

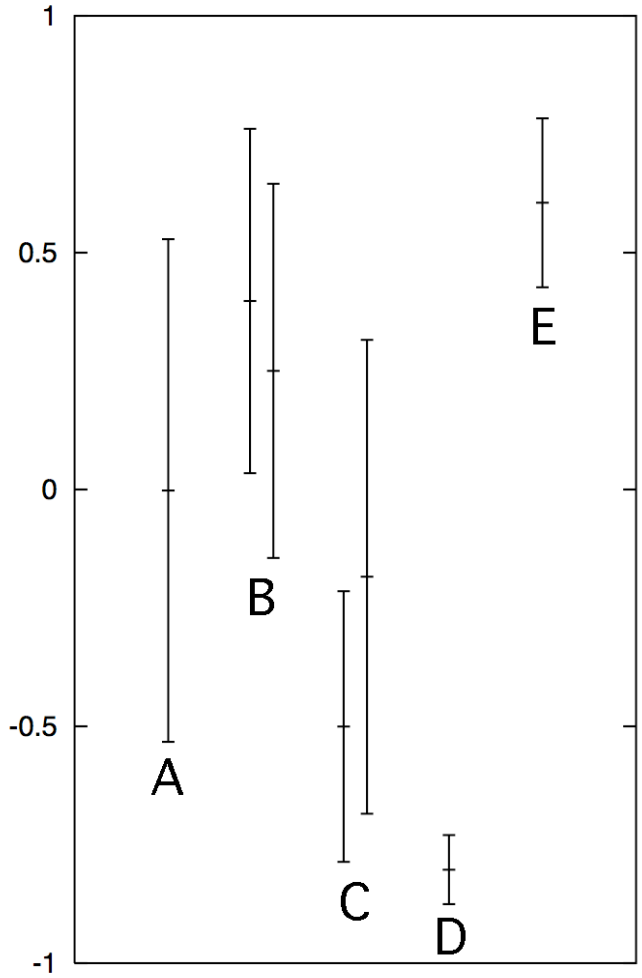


Figure 4: Averaged data from 40 runs of the Division Blocks system, collected after 1000 time steps of reproductive competence. Error bars indicate ±1 standard deviation. A: average tag values; B: average `donationsize` (left) and `donationtolerance` (right); C: average `stemdonationsize` (left) and `stemdonationtolerance` (right); D: average `matecontribution`; E: average `adhesion`.

Prospects

- Cluster-based parallelism in progress.
- Long term evolutionary patterns.
- Unbounded evolutionary activity?
- Track new measures of adaptive complexity.
- Physical division blocks?