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

Lee Spector, Jon Klein, and Mark Feinstein
School of Cognitive Science, Hampshire College
This work was supported by NSF Grant No. 0308540
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
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
Reproductive Competence
Variations
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 donationintolerance (right); C: average stemdonationsize (left) and stemdonationintolerance (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?