Environment as a Spatial Constraint on the Growth of Structural Form

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Some Informal Questions...

- Does the genome of a tree encode the information that the top is skinny and the bottom fat?
- Do the genes controlling the development of a circulatory system encode a description of the organism's overall morphology?

Role of Genes

- Bilaterals: bilaterally symmetric morphology, vascular system for blood
- Echinoderms: radial symmetry, vascular system for water
- Homeodomain associated with the development of the vascular system underwent radical changes in role and expression domain between Echinoderms and their bilateral ancestors (Lowe and Wray, Nature, 1997)

Motivations

We seek to use environment explicitly in Artificial Embryogeny (AE) to:

- Explore alternatives to fitness functions in AE
- Re-use genetic information in different environments
- Pose questions regarding genetic robustness relative to environment

The Deva Model

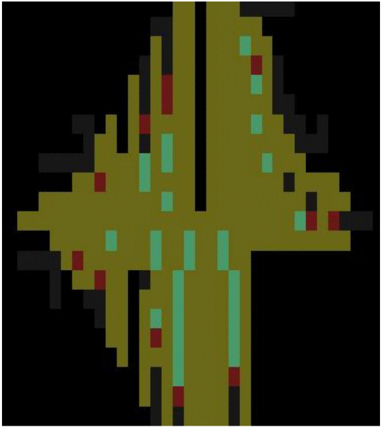
Consists of:

- A Developmental Space, $D \subset \mathbb{Z}^2$, with discrete time
- A set of cell types (colours) C, $|C| = n_c$
- A set of cell actions A
- A transition function, $\phi : N \rightarrow A$, where N is a description of a neighbourhood of cells from C.

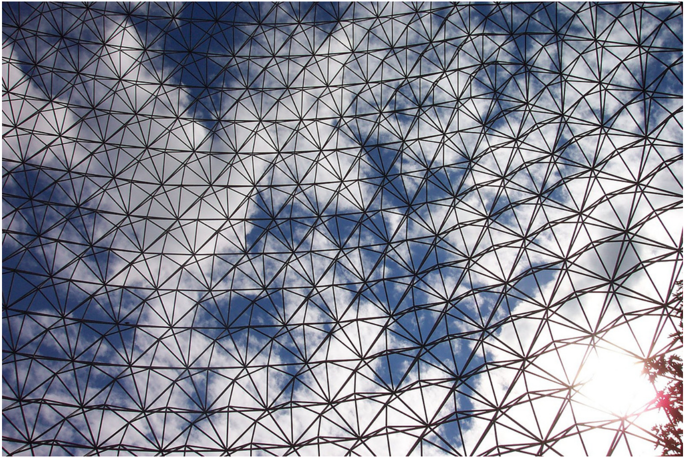
More Deva Model

- Starting from a single cell in D, the cells execute actions from A, leading to some sort of growth.
- Actions include: *Nothing*, *Die*, *Divide*, *Specialize*(x), *Elongate*

Clicky.



The Domain of Application: Structural Design

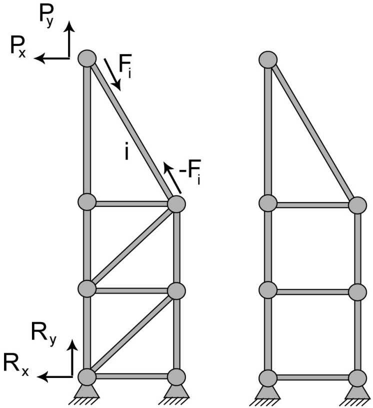


Trusses

- Simple models of structure
- Good approximations of bridges, towers, etc.
- Often form initial design stage of construction

Plane Trusses

- Consist of beams, joints, grounds.
- Want: stability, ability to withstand (distribute) external force.
- Can compute stability, pressure, displacement through system of linear equations ($O(n^3)$)



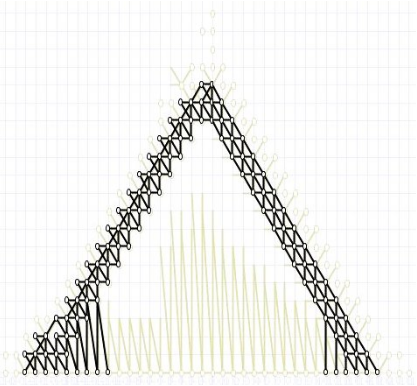
Interpretation of Deva Growth

- We can map from a lattice of cell colours to a Plane Truss
- We can interpret Deva as a means of growing Plane Trusses developmentally
- Deva genomes can be evolved by using fitness to select for good Trusses

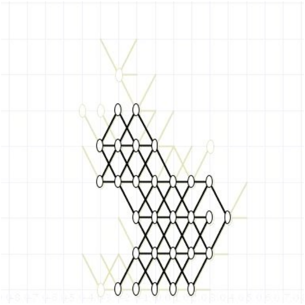
(Kowaliw *et al*; IEEE-Alife 2007)

Evolved Trusses

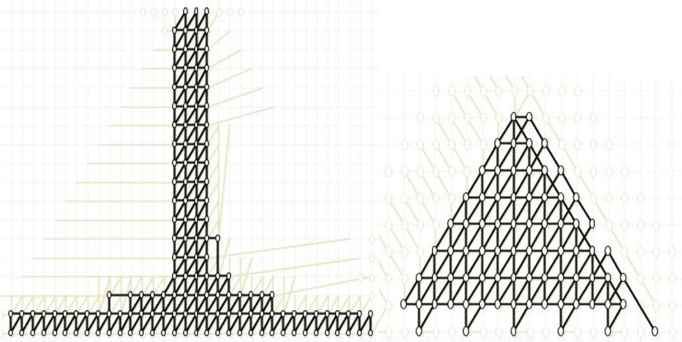
Fitness function 1



Fitness Function 2



Cheaters!

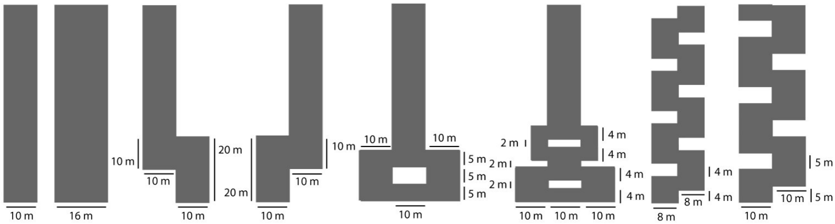


Environment Experiments

- We define several types of environment
- We can evolve organisms in some environment, at some phenotypic size
- We can then re-grow organisms at different sizes, in different environments

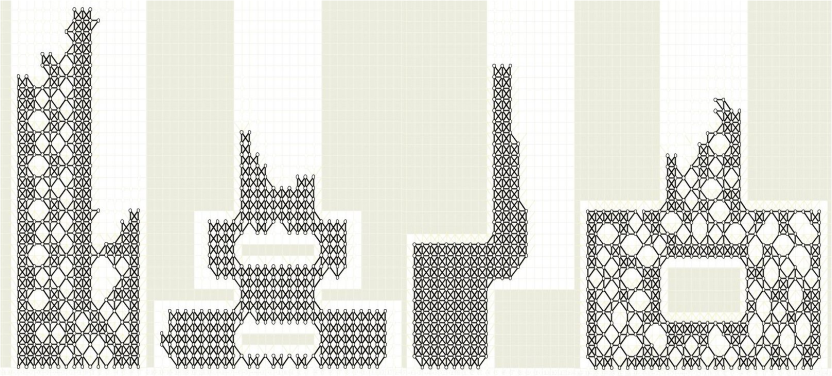
Clicky.

Environments



Some Successful Organisms...

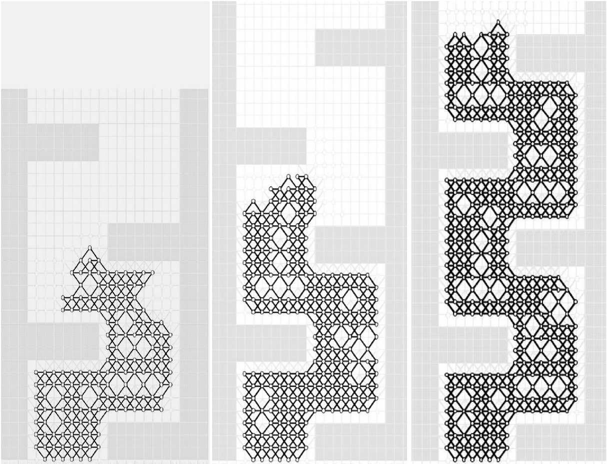
We evolved stable trusses capable of supporting external load in nearly all environments



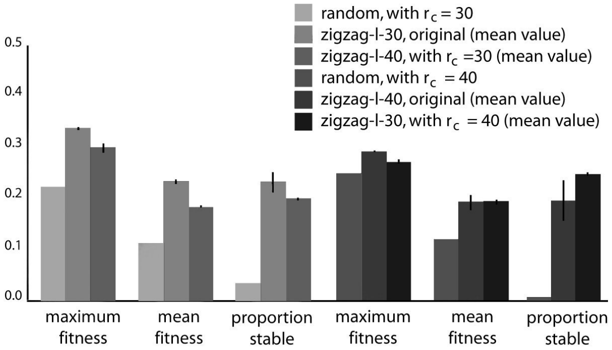
Phenotypic Re-growth

- Deva model specifies a maximum amount of resources that development has available
- We evolved genomes at some maximum size (max height 30m)
- How well do our genomes adapt when given additional resources? (max height 40m)

Phenotypic Re-growth Visual



Phenotypic Re-growth Comparative

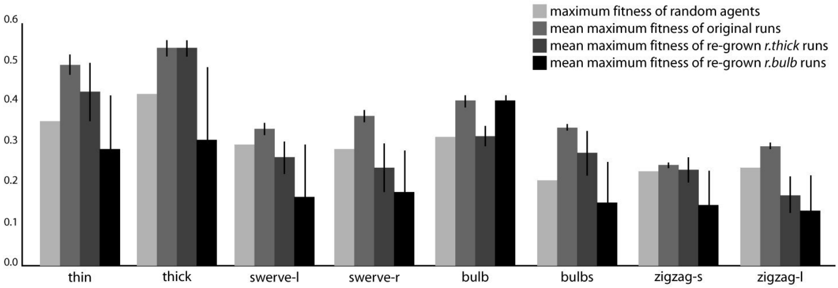


Environmental Re-growth

- Any given evolutionary run takes place in a particular environment
- How well do our genomes adapt to previously unseen environments?

Environmental Re-growth Comparative

No significant difference between random and re-grown genomes.
Much variance in data!

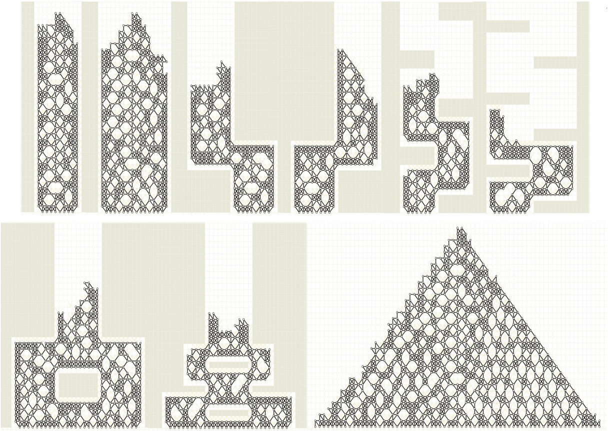


Phenotypic Re-growth Unsuccessful Visual

Many organisms overspecialized, performed far more poorly than random genomes in all novel environments.

Phenotypic Re-growth Successful Visual (Zelig)

Some genomes performed well in nearly all environments.

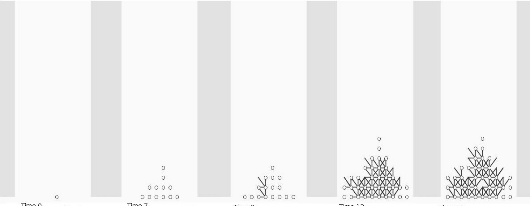


Zelig

- Zelig performed well in all environments in which evolution was successful generally (nine of ten)
- 7 used rules in the genome (compared with average 10-12)
- Similar appearance in all environments, adapting to fit provided space

Clicky 1. Clicky 2.

Zelig



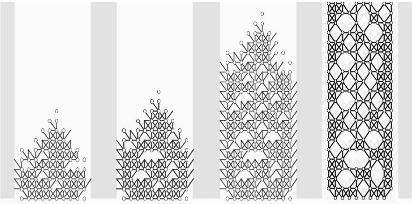
Time 0:
Initial cell of type 1, empty environment

Time 7:
Division via Rule 0

Time 8:
Specialization to type 8 via Rule 103

Time 13:
Continued division via Rule 0, Specialization to type 16 via Rule 77

Time 14:
Death in central location via Rule 11. Empty location in upper left due to nothing command from specialized cells of type 16 (Rules 74, 122)



Time 20:
Continued upward growth and specialization via Rules 0, 103, 77

Time 24:
Additional cell death in crowded central locations via Rule 11

Time 40:
Growth pattern continues, blanks left via death and nothign commands from specialized cells.

Time 83:
Final trimmed structure.

Summary of Results

- Environment may be used as a spatial constraint, easily achieving goals which may be difficult with a fitness function
- Genomes may be re-used in environments other than the ones in which they evolved
- Deva genomes tend to be resistant to changes in phenotypic size
- Deva genomes are sometimes resistant to changes in environment, although usually not
- Some Deva genomes have been found which grow successful agents in nearly all environments

EOF

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