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EVOLUTIONARY ROBOTICS ARTIFICIAL LIFE LAB

LASI Intelligent Systems Associate Laboratory

SPECIES

GRAMMAR BASED EVOLUTION OF POLYOMINOES

Jessica Mégane · jessicac@dei.uc.pt / **Eric Medvet** · emedvet@units.it
Nuno Lourenço · naml@dei.uc.pt / **Penousal Machado** · machado@dei.uc.pt

cisuc.uc.pt
erallab.inginf.units.it
jessicamegane.pt/publication/2024-01-18-polyominoes

POLYOMINOES

Geometric shapes composed of connected unit squares, forming a finite set of cells within a 2-D grid. These shapes are also commonly referred to as **lattice animals** in the physical and chemical fields. Polyominoes can be further enhanced by assigning labels to individual cells, providing additional information for each cell within the structure, which are called **labeled polyominoes**.

Labels =

These structures have been popularly used to model branched polymers, molecules, simulate percolation processes, and among many, also in the Voxel Robots, famous in the EC community. In these fields, it is often crucial to find **one or more polyominoes that maximize specific objectives while satisfying predefined structural requirements.**

We propose:
— Novel approach, **based on grammars**, for describing sets of labeled polyominoes that meet predefined requirements
— Algorithm to develop labeled polyominoes using the grammar

POLYOMINO CONTEXT-FREE GRAMMAR (POCFG)

A PoCFG, G, is a tuple G = **(N,T,N1,R)** where:
— N is a finite set of *non-terminal* symbols
— T is a finite set of *terminal* symbols
— N1 is the starting symbol (or *axiom*)
— R is a finite set of *production rules*.

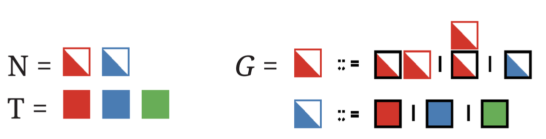
A production rule is a pair composed of a non-terminal symbol (the left-hand-side of the rule) and a referenced polyomino defined over the alphabet (the right-hand-side). A referenced polyomino is a polyomino in which one cell is identified as reference cell.

POCFG-BASED DEVELOPMENT ALGORITHM

The development algorithm maps a genotype, *g*, to a polyomino, *p*, respecting the rules of the PoCFG, *G*.

Parameters:
— genotype, *g*
— grammar, *G*
— sorting criteria, *c*
— overwriting flag, *o*

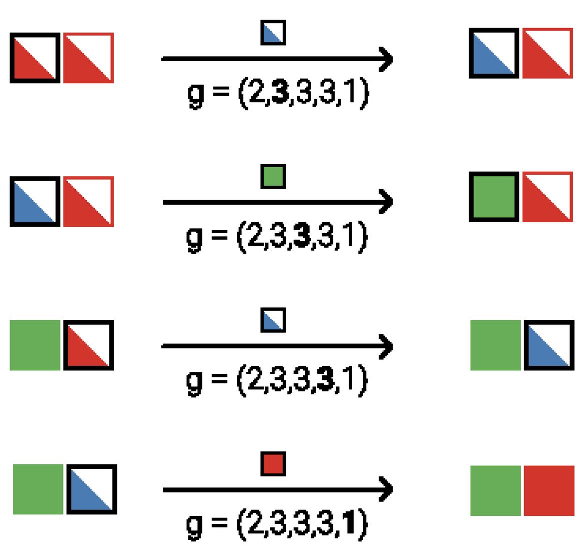
Example of the development of a polyomino:
g = (2,3,3,3,1)
c = Position criterion
o = Overwrite True



Mapping starts with the axiom; select non-terminal to expand (thick black border).

Consume genotype to select rule, and expand polyomino if conditions are met.

Repeat process until there are no more non-terminals to expand or no more values in the genotype to consume, or until some condition is not met (in this case returns None).



DEVELOPMENT AND REPRESENTATION VARIANTS ANALYSIS

We compared three sorting criteria (recency, sides, and position), the overwriting flag (true or false) and five representations (bits(*l*), ints(*l*,4), ints(*l*,16), reals(*l*), structured(*l*,2)) and varied the length, *l*. The analysis consists in three metrics in which a higher value is better: **validity, uniqueness, and locality.**

Analysis of the **development variants:**
— Overwriting resulted in a higher number of valid polyominoes.
— The Sides criterion showed lower uniqueness, while Recency exhibited greater uniqueness.
— Longer genotypes show lower locality, which is generally unfavorable.

Analysis of the **representation:**
— Larger validity does not always mean more unique phenotypes
— Concerning locality, structured(*l*, 2) and reals(*l*) score, in general, better.

Both analysis show that:
— Differences are more visible between grammars than between variants
— Algorithm is robust with respect to its parameters.

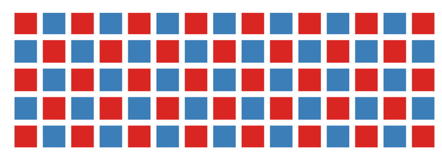
EVOLUTION OF POLYOMINOES

Optimisation problem: evolve to target a polyomino p^*

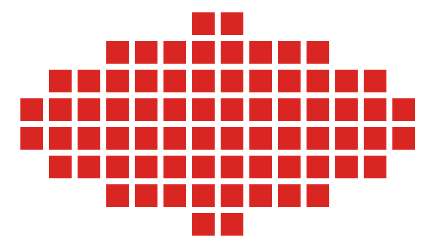
Fitness function: average of the Hamming distance of the evaluated polyomino p to the target p^* and the same distance computed without considering labels.

Target shapes:

Chess



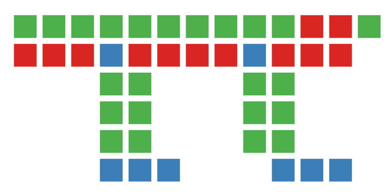
Circle



Worm-1

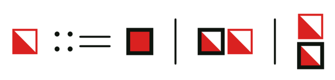
Worm-1

Dog

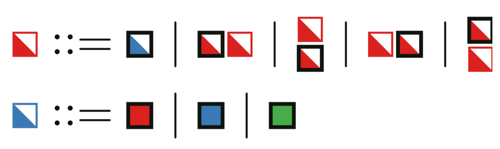


Grammars:

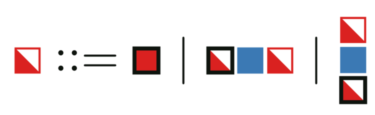
Monodirectional



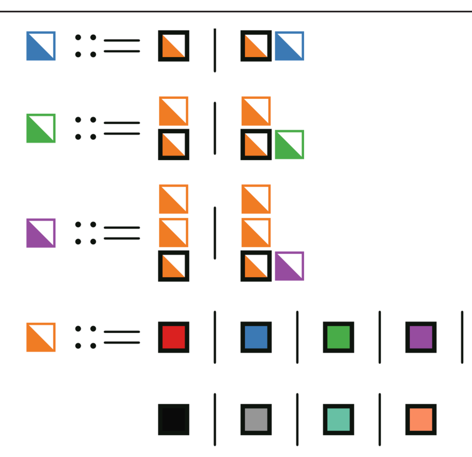
Bidirectional



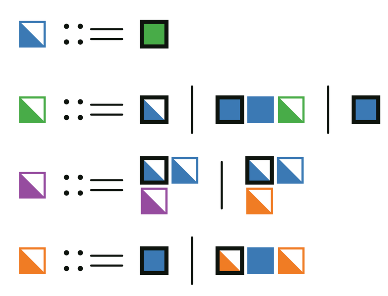
Alternated



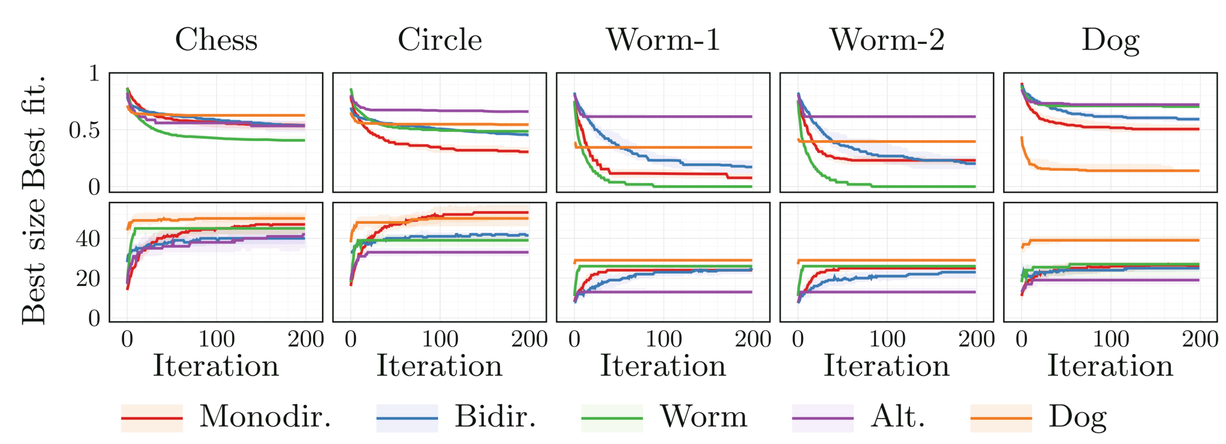
Worm



Dog



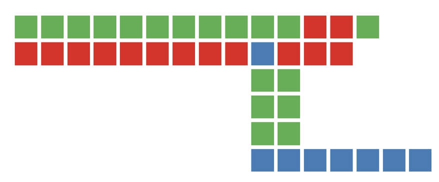
Results are the mean best fitness over 50 runs:



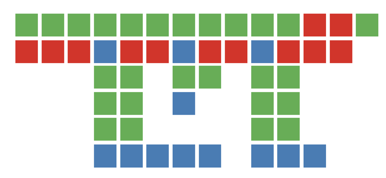
Examples of the evolution of polyominoes:
Figures show an example of polyomino in generation 1, an intermediate generation, and the generation where best fitness is achieved.

Grammar: Dog
Target: Dog

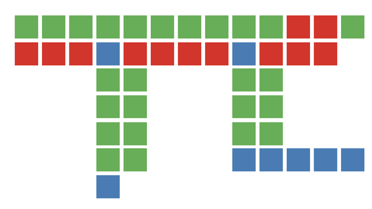
Generation 1
Fitness: 0.3605



Generation 7
Fitness: 0.31

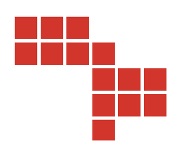


Generation 116
Fitness: 0.1111

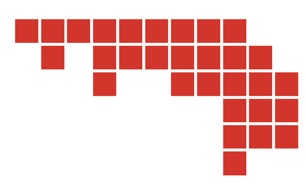


Grammar: Monodirectional
Target: Dog

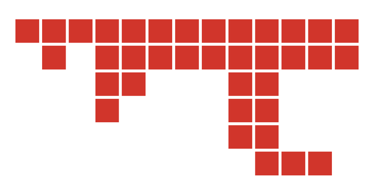
Generation 1
Fitness: 0.8605



Generation 7
Fitness: 0.6744



Generation 102
Fitness: 0.3605



CONCLUSION AND FUTURE WORK

The results align with existing literature of G3P algorithms, which says that grammar design can greatly impact the behaviour of the algorithm. The proposed algorithm integrated within EAs is able to evolve polyominoes towards a specific target, while satisfying some predefined constraints encoded in a designed PoCFG.
Future work aims to explore the applicability of the algorithm by evolving polyominoes in more complex problems, such as the generation and evolution of modular robots, maps for games, or DNA shapes.

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