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Using Quality Diversity to Evolve Flying Machines in Minecraft

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Introduction

MAP-Elites (Multi-dimensional Archive of Phenotypic Elites [1]) is a quality diversity algorithm, meaning that it collects a diverse archive of quality solutions to a problem. We used MAP-Elites to evolve flying machines in Minecraft [2]. These structures are collections of blocks that move perpetually in one direction forever using pistons and other components. The quality diversity approach was more effective than evolutionary computation using fitness alone.

MAP-Elites

- Generates various shapes, to store in an archive
- Shapes are categorized into specific bins in the archive, and scored using a fitness function
- Each bin can only hold one shape.
- More-fit shapes replace less-fit shapes in a given bin and stay in archive

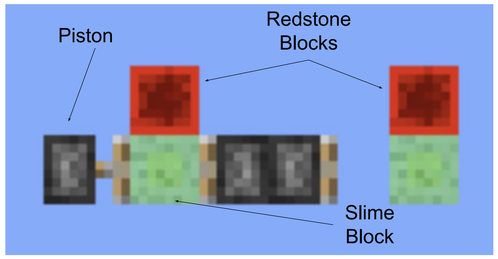

Fig. 1: An example of a flying machine. The first piston pushes the other blocks forward, powering additional pistons that bring the rest of the shape along with it. Slime blocks hold certain blocks together and some piston heads are sticky so that they can pull blocks when they retract.

Binning Schemes

- How the archive of the most fit shapes is organized
- Count: ME.C: number of blocks in the shape
- Count/Negative Space: ME.CN: number of blocks vs. number of air blocks within the bounds the shape
- Piston Orientation: ME.PO: number of (sticky) pistons facing in each orientation (North/South, Up/Down, East/West).

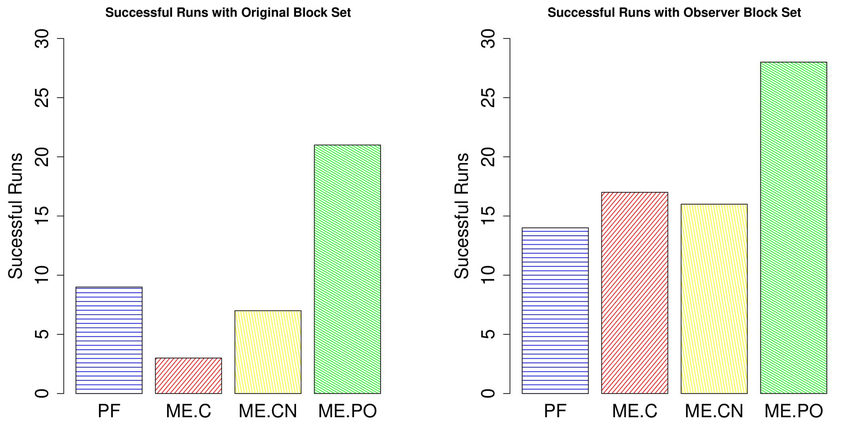

Fig. 2: Number of runs producing flying machines using different binning schemes and two different block sets. The pure fitness (PF) approach for the original block set was not the worst, put it was significantly less successful than the (ME.PO) Piston Orientation MAP-Elites approach. Similarly, in the observer block set, The Piston Orientation was also the most successful, while pure fitness was less successful than all other MAP-Elites approaches.

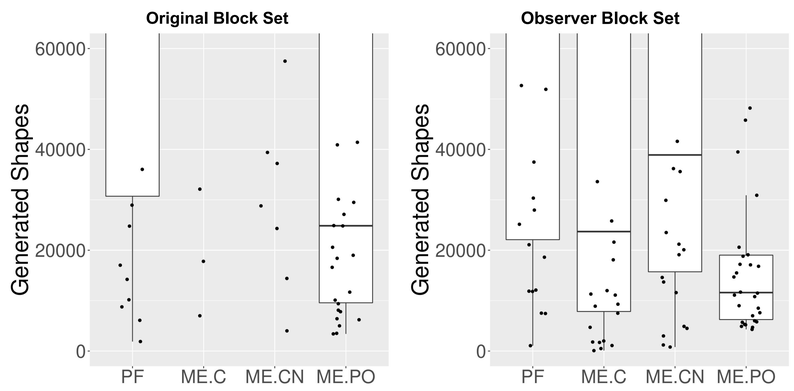

Fig. 3: Number of generated shapes before first flying machine. When using both block sets, pure fitness only shows the minimum and lower quartile but not the median, which indicates that over 50% of runs failed to produce any flying machines. MAP-Elites Count and Count Negative performed the worst with the original block set since over 75% of the runs failed, only outliers are shown. However, both performed better with the Observer block set, but the upper quartile was still not visible. MAP-Elites Piston Orientation performed better with both block sets, doing best with the observer block set since the upper quartile is visible.

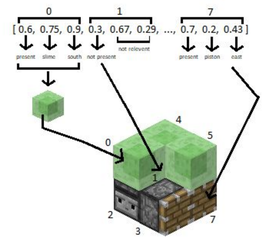

Fig. 4: Example of generating a single shape. The evolved genomes are lists of potential block presences, potential block types, and potential block orientations. Each group of three numbers decodes to a block at a certain position within the shape. The right combinations of blocks in the right orientations can produce a flying machine.

Quality/Fitness Function

- The Fitness Function is the accumulated change in the center of mass as the shape moves during evaluation
- Periodic checks: compare last and current center
- Special case: if most blocks leave the area being observed, the shape is assumed to have flown away
- Definite flying machines get a maximum fitness minus a small penalty for any remaining blocks.

Experiment and Results

- Experiments were done with two block sets: original block set [2], observer block set (adds observer block)
- Compared PF to several binning schemes
- PF was comparable to ME.C and ME.CN
- More successful runs using the observer block set
- Success rates compared using Fisher's exact tests
- ME.PO produced a machine for each direction
- ME.PO produced more variation in flying machines
- ME.PO is statistically significantly more successful when using both block sets ($p < 0.05$)

References

[1] Jean-Baptiste Mouret, Jeff Clune: *Illuminating search spaces by mapping elites*. CoRR abs/1504.04909 (2015)

[2] Djordje Grbic, Rasmus Berg Palm, Elias Najarro, Claire Glanois, and Sebastian Risi. 2021. EvoCraft: A new challenge for open-endedness. *Applications of Evolutionary Computation* (2021), 325–340.