Using Quality Diversity to Generate 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

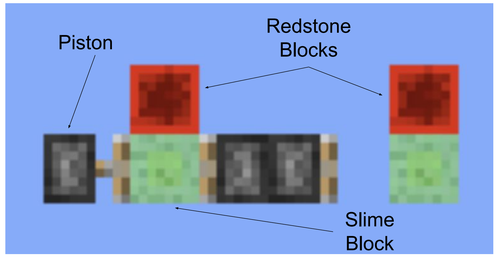

Fig. 1: An example of a flying machine. The first piston pushes the other blocks forward, powering additional pistons that bring the rest of the shape along with it. Slime blocks hold certain blocks together and some piston heads are sticky to that can pull blocks when they retract.

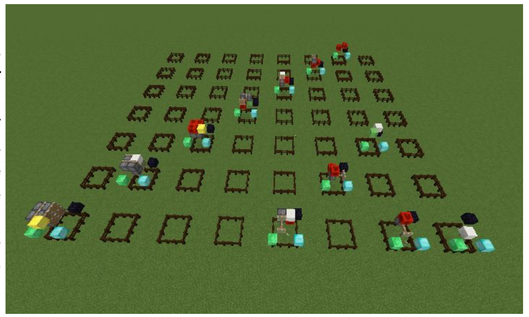

Fig. 2: An example archive. Shapes are placed in rows and column based on their properties. In this example, shapes are categorized by the number of blocks horizontally and the number of negative space blocks vertically. An Air Block counts as negative space if it is within the bounds of the shape.

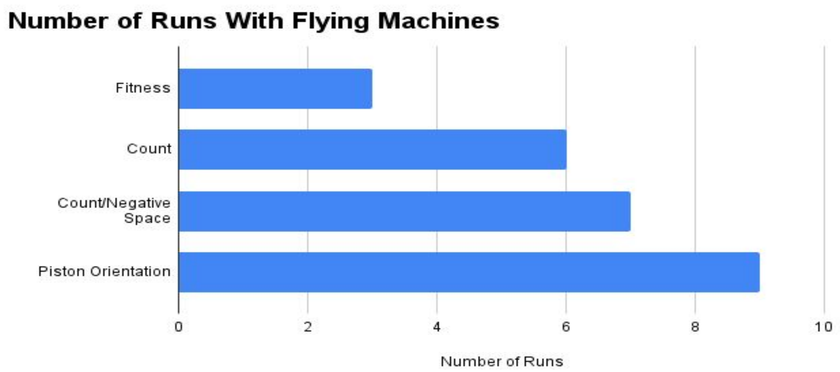

Fig. 3: Bar graphs showing showing results from 10 runs using each approach. Top graph shows the number of runs that produced at least one flying machine. Each of the three MAP-Elites binning schemes had more successful runs than using fitness alone. Bottom graph shows the average number of directions that evolved flying machines moved in, ranging from 0 up to 6. The Piston Orientation binning scheme produced the largest variety in the number of directions machines would fly in, which is why its average is the highest. Piston Orientation runs sometimes had machines flying in up to 4 different directions.

Binning Schemes

- How the archive of the most fit shapes is organized
- Count: 1D: refers to the number of blocks in the specified shape
- Count/Negative Space: 2D: number of blocks vs. the number of air blocks that are within the bounds the shape
- Piston Orientation: 3D: how many (sticky) pistons are facing in each orientation (North/South, Up/Down, and East/West).

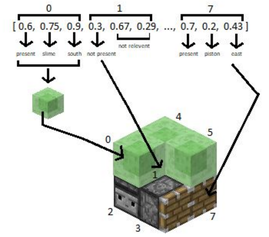

Fig. 4: Example of generating a single shape. The evolved genomes are lists of potential block presences, potential block types, and potential block orientations. Each group of three numbers decodes to a block at a certain position within the shape. The right combinations of blocks in the right orientations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

Quality/Fitness Function

- The Fitness Function is the 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

- Compared pure fitness to several binning schemes
- Flying machines were produced over half the time with MAP-Elites with all binning schemes, but this was not the case for the fitness based approach
- Fitness alone also had the least diversity in the number of directions the flying machines fly in
- The Piston Orientation binning scheme was the most successful in terms of number of successful runs and diversity of directions being flown in
- MAP-Elites was more successful than pure fitness

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.