

Automatic Generation of Level Maps with the Do What's Possible Representation

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Abstract—Automatic generation of level maps is a popular form of automatic content generation. In this study, a recently developed technique employing the *do what's possible* representation is used to create open-ended level maps. Generation of the map can continue indefinitely, yielding a highly scalable representation. A parameter study is performed to find good parameters for the evolutionary algorithm used to locate high quality map generators. Variations on the technique are presented, demonstrating its versatility, and an algorithmic variant is given that both improves performance and changes the character of maps located. The ability of the map to adapt to different regions where the map is permitted to occupy space are also tested.

I. INTRODUCTION

This study uses a recently developed, open-ended, generative representation called the *do what's possible* (DWP) representation [5] to encode level maps. The open ended nature of the representation encodes a sequence of maps, with the next map in the sequence possessing one additional room. The map generator can be run until there are enough rooms or enough space has been filled. An example of one of these maps appears in Figure 2. A strength of this representation is that it can generate arbitrarily large numbers of rooms by simply permitting it to run longer.

The DWP representation has two parts. An evolvable character generator that will always produce a next character when queried, called the *complex string generator* or CSG. In this study the characters are bits, zero or one, used to build integers of any desired size to drive a serial choice process. The CSG is partnered with a *generative possibility filter* or GPF that interprets the characters as a sequence of generative commands, rejecting the impossible ones. The CSG supplies pattern and the GPF filters it to create admissible results. While the evolutionary process used to select the complex string generators is stochastic in the usual fashion, the complex string generators themselves are deterministic. This means that the maps they produce are entirely repeatable.

The map generators in this study use binary CSGs. The bits generated are compiled into integers of various sizes to drive a series of decisions: which existing room will we place a new room next to, what side of it, how is the new room situated, and what are its dimensions. Once these decisions have been made, there is either space for the new room, in which case

it is added, or there is not, in which case the new room is rejected. The GPS consists of tracking occupancy of the map and rejecting rooms that try to occupy already occupied space. This relatively simple scheme permits the generation of huge maps using relatively small data structures.

The remainder of this study is structured as follows. Section II reviews work in automatic level generation and earlier work with the DWP representation. Section III specifies the experimental design including the details of the representation and the map generation problem. Section IV presents and discusses results. Section V gives conclusions and outlines next steps.

II. BACKGROUND

Procedural content generation (PCG) consists of finding algorithmic methods of generating content for games. It is a form of generative design [15] often applied to game content, and often cares about both aesthetic and functional criteria. Search based PCG [21] uses search methods rather than composing algorithms that generate acceptable content in a single pass. Both sorts of content generation can exhibit scaling problems which can be addressed by problem decomposition with an off-line and an on-line phase to the software or through the use of open ended representations, as in this study.

Automated level generation in video games can arguably be traced back to a number of related games from the 1980s (Rogue, Hack, and NetHack), collectively called *Roguelike games*. The task is currently of interest to the research community. In [19] levels for 2D sidescroller and top-down 2D adventure games are automatically generated using a two population feasible/infeasible evolutionary algorithm. Answer set programming is another approach to dungeon generation [18]. In [20] multiobjective optimization is applied to the task of search-based procedural content generation for real time strategy maps.

This study gives an alternate representation for tasks similar to those done in [6] which introduced checkpoint based fitness functions for evolving maze-like levels. This work was extended in [7] by having multiple types of walls that defined multiple mazes that co-existed in a single level map.

Related work includes [8] which prototyped tile assembly to generate large maps and [9] which gave a state conditioned representation that could generate level maps of landscape height maps. A very different sort of representation, based on cellular automata, is used in [13] and generalized in [2], [3].

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A. Past work with the DWP representation

The original publication on the DWP representation [5] used the representation on a variety of problems. It was capable of solving self avoiding walk problems [1] of unprecedented size. Where 12×12 had been a practical limit with even adaptive representations [11], the DWP representation solved 40×40 cases of the problem. Applied to the problem of evolving a Gray code [22] the DWP representation enabled the evolution of an 8-bit Gray code with 256 members. The DWP problem was also used to evolve entropically rich binary strings and a type of classification character for DNA in the initial study. A later study refined the systems power for DNA classification [4].

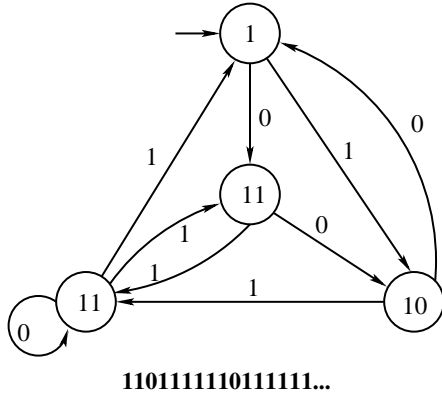


Fig. 1. An example of a self driving automaton over the binary alphabet and the first few characters that it emits. The sourceless arrow denotes the initial state. The strings emitted are shown on the states. The automata's output is used as its input.

III. EXPERIMENTAL DESIGN

In this section we describe the representation, the problem, the evolutionary algorithm, and the experiments performed.

A. Self Driving Automata

Figure 1 shows an example of a self driving automata (SDA). This automata uses a Moore architecture, associating emitted symbols with states. The initial state is the topmost, pointed to by a sourceless arrow. When the machine starts generating bits it emits a 1. That one becomes the next input and the machine transitions to the state labelled "10", emitting a 1 and a 0. The output is compiled and used, one bit at a time to drive transitions. The automata generates as many bits as required. The emission, on some states, of multiple bits permits the automata to encode quite complex patterns including aperiodic ones. The example automata in Figure 1, for example, emits isolated zeros that are spaced ever farther apart and so are aperiodic.

The representation used for SDAs is a linear list of states, each comprising a string to emit and the state to transition to in the event of an input of 0 or 1. The emitted strings associated with each state have length 1 or 2 with that length being selected uniformly at random, then filled with random

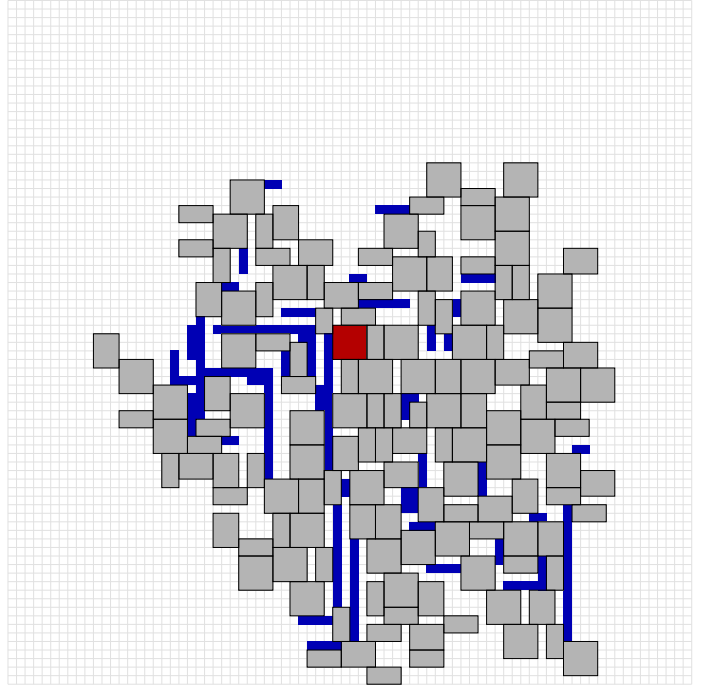


Fig. 2. An example of a map evolved using the DWP representation. Red is the starting room, grey blocks are rooms and blue blocks are corridors.

characters. The crossover used by evolution on this representation is two point crossover of the list of states, associating the initial string emitted with the first state. Mutation consists of changing one emitted string or one transition. The number of states an SDA is permitted to use is an experimental parameter. Using a linear representation for the SDA, rather than a directed graph representation, yields crossover and mutation operators that are much simpler to code and which permit greater heritability of fitness. Direct digraph representations usually require disruptive repair operators.

B. Problem Description

The problem in this study is to place the rooms and corridors of a level map on a grid. Rooms are rectangles with side lengths from two to four; corridors are one wide and up to sixteen squares long. The process starts with an initial room placed near the center of the grid. The evolving part of this is a self driving automata which generates bits that are used to make the following decisions:

- 1) An eight-bit integer modulo the current number of rooms is used to select the room next to which a new room is to be added. At most 256 rooms are permitted; the number of bits used and rooms permitted are easy to change.
- 2) A two-bit integer is used to decide if the new room will be above, below, left, or right of the selected room.
- 3) A three-bit integer is used to decide if the room is a corridor or not. If all three bits are zero, the room is a corridor.
- 4) If the room is not a corridor, two two-bit integers are used to compute its dimensions, from 2×2 to 4×4 . The

dimension 2 is twice as likely as 3 or 4. If the room is a corridor a single four-bit integer is used to determine its length. Corridors run away from the room they adjoin.

Once a series of decisions have been made and a room proposed by the CSG, the GPS checks to see if (i) the location of the proposed room avoids other rooms, and (ii) is completely on the grid that is being populated with rooms. If the proposed room passes both these checks then it is placed, otherwise it is rejected.

The fitness function used to judge the quality of a map in this study is based on the total area A of rooms and corridors placed on the grid and the area B bounding box of the aggregate map. The bounding box is the smallest rectangle on the grid that contains all the rooms. The fitness function is

$$fitness = A^2/B \quad (1)$$

which encourages the placement of many rooms in a compact format.

C. The Evolutionary Algorithm

The evolutionary algorithm operates on a population of self driving automata; varying the population size is one of the experimental parameters. As noted in Section III-A, during population updating two point crossover is used and from 1 to MNM mutations are performed on each new population member where MNM , the *maximum number of mutations*, is another parameter under study. The number of mutations is selected uniformly at random in the range one to the maximum.

The algorithm is steady state, using mating events consisting of size seven single tournament selection. Seven population members are chosen and the two best reproduce to replace the two worst. Unless otherwise stated, 10,000 such updatings are used. This is a relatively modest number of updatings which permitted the completion of a parameter study. Longer runs were performed after a good set of parameters were determined. Each experiment consists of thirty independent runs of the evolutionary algorithm. With two exceptions, each fitness evaluation was initialized with a single 4×4 room.

With the exception of the experiment run for additional time, all the experiments took place on an 80×80 grid with a maximum of 256 rooms. One experiment was run for ten times as long, using a 120×120 grid with a maximum of 800 rooms and an algorithmic modification called the recent room hack. An experiment with standard parameters was also performed using the recent room hack. The recent room hack modified the room selection process to use only four bits to select the focal room for expansion of the map and restricted the choice of room to the ten most recently produced rooms. This substantially enhanced fitness for reasons discussed in Section IV.

D. Experiments performed

The experiments include two parameter studies, one exploring population size and mutation rate, while the other, performed with the best parameters from the first, investigated

TABLE I
EXPERIMENTAL PARAMETERS USED. THE ABBREVIATION RRH REFERS TO THE RECENT ROOM HACK. EXPERIMENTS 1-15 AND 17-21 FORM THE TWO PARAMETER STUDIES.

Exp.	Pop. Size	MNM	States	RRH
1	10	1	12	
2	32	1	12	
3	100	1	12	
4	320	1	12	
5	1000	1	12	
6	10	3	12	
7	32	3	12	
8	100	3	12	
9	320	3	12	
10	1000	3	12	
11	10	5	12	
12	32	5	12	
13	100	5	12	
14	320	5	12	
15	1000	5	12	
16	32	1	12	✓
17	32	1	4	✓
18	32	1	8	✓
19	32	1	12	✓
20	32	1	16	✓
21	32	1	20	✓
22	32	1	16	✓*
23	32	1	16	✓**

*Extended run

**uses a nonstandard starting room

the number of states used in the SDAs. The experiment testing the random room hack was performed after the first parameter study and it was incorporated into the study on the number of states used. Table I gives the parameters used. The last two experiments, subsequent to both parameter setting experiments, were a run with longer evolution time, more rooms, and the recent room hack, and a standard run, using the recent room hack, in which a 40×2 initial room replaced the usual one.

IV. RESULTS AND DISCUSSION

The results of the first parameter study are shown in Figure 3. This study shows that the algorithm is moderately robust to change of population size and mutation rate, with the lowest mutation rate and the population sizes 32 and 100 being the best performers; at the best mutation rate the population size 32 is marginally better and so subsequent experiments used population size 32 and $MNM = 1$. A population size of 10 was clearly the worst among the sizes tested.

Experiment 16, where the recent room hack was added to the algorithm, showed about a 50% increase in the best fitness and the number of rooms deployed improved substantially. Figure 4 shows an example of the types of maps that appear with and without the recent room hack. Contrasting Figure 3 – the parameter study performed without the recent room hack and Figure 5 which depicts a parameter study with the recent room hack, notice that all the fitness values in the first study are lower than all the fitness values in the second study.

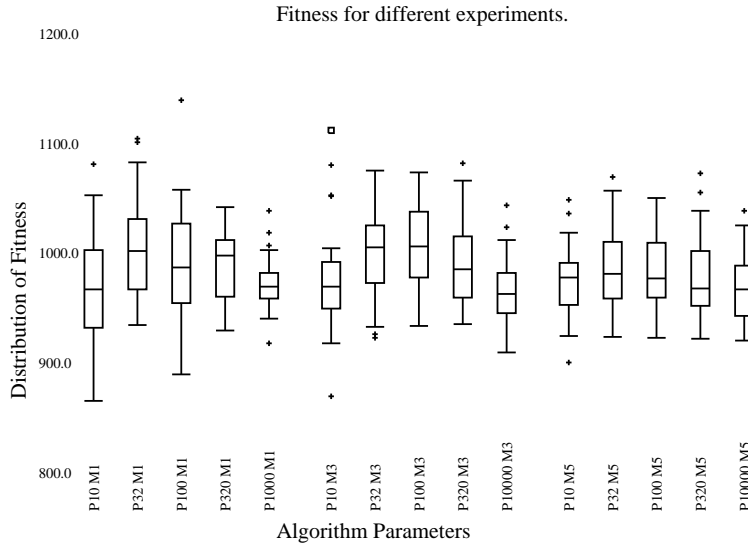


Fig. 3. Results of the parameter study on population size and mutation rate. Shown are box plots of the best fitness values from 30 runs of the evolutionary algorithm for each set of parameters.

The recent room hack addresses a simple problem in the developmental algorithm for the maps used in this study. As the maps fill in, many of the older room have no space next to them for the GPF will reject almost any suggestion by the CSG for a room in their area. Permitting only recent rooms both reduces the number of bits required from the CSG to specify a room and substantially increases the change the room selected will have empty space next to it. In retrospect, the recent room hack is an obvious improvement to the developmental algorithm for creating maps.

Figure 5 shows the results of the parameter study examining the best number of states to use. It is clear that four states are not enough, but the algorithm is otherwise fairly robust, at least at 10,000 mating events, to the number of states used with 16 states turning in the best performance. It may be that if the parameter study were reformed with additional evolutionary time, additional states would have higher utility because it takes longer to discover strategies that use them.

A. Corridors, present and absent

Looking at the examples of maps in this study, some use corridors extensively, others do not use them at all. Both sorts of maps represent high-fitness local optima. The fact that the SDAs are deterministic and generate strings with repeated patterns means that the maps also have a relatively small number of structural elements in each map. If these structural elements contain corridors then the map will as well.

B. Maps made with alternate algorithm settings

To test the notion that additional evolutionary time might help, Experiment 22 used the recent room hack, permitted up to 800 rooms, ran for 100,000 mating events, and used a 120×120 grid instead of an 80×80 grid. The fitness values were astronomically higher, but also not comparable with those

in the earlier experiments. An example of a larger DWP map produced in this run is given in Figure 6.

The final experiment examined the impact of changing the starting room. Changing the starting room to a single, long corridor gave the algorithm far more space to expand the map and resulted in much more even placement of rooms within the grid. A contrast demonstrating the impact of the alternate starting room appears in Figure 7. The location, size, and shape of the starting room are clearly a factor that influences the character of the map that appears. There is no need to start with just one room – using a system of two or three corridors could help shape the overall map and might remove the need for the recent room hack by increasing the available useful perimeter of the growing map.

V. CONCLUSIONS AND NEXT STEPS

This study demonstrated the ability of the do what's possible representation to lay out very large maps. The parameter study showed that the system is relatively robust to the choice of parameters. If we think about why this system is robust to parameter choice, an interesting hypothesis arises.

The system presented here proposes a huge stream of rooms via its SDA and the bit-slicing decision process. These rooms proposals are then filtered by the GPF to yield a map. If we tracked the number of proposed rooms required to achieve the final result then we might see substantially more difference arising from different parameter choices. The filtration of a patterned, endless stream of proposals seems to yield an intrinsically robust system. To make an analogy, if students are permitted to take an on-line quiz over and over until they like their grade, then the final results will not be proportional to the student's effort – less well prepared students will achieve similar grades. Additional study of this hypothesis is a priority for additional research.

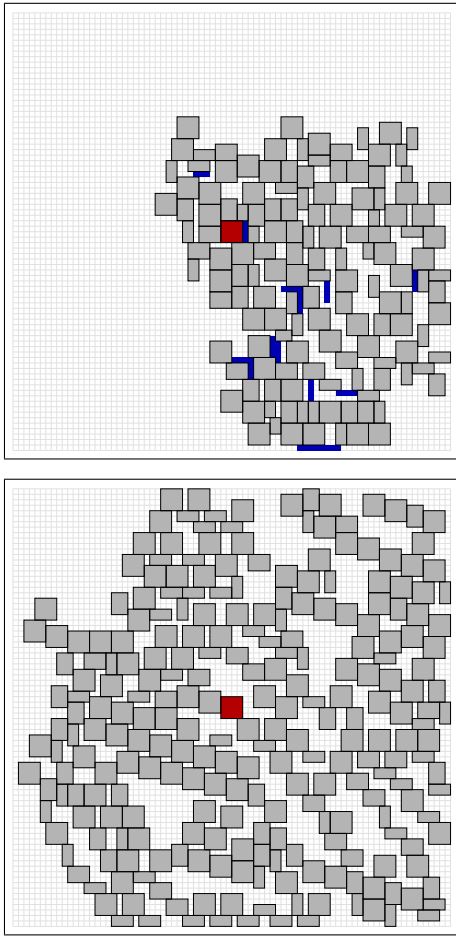


Fig. 4. Examples of maps created before the recent room hack (upper) and after it (lower).

The runs employing additional time and space showed that the system scales to larger problem instances, but it does not begin to test the systems scalability. The rooms added to a growing map are added one at a time, and after each room is added, a connected map is available. This means that a given evolved map builder produces a *sequence* of maps. While we stop the process at a fixed point and evaluate fitness, we do not have to do so. If we allow a larger arena, then we can keep adding rooms; for some of the evolved map builders we can do so indefinitely. Running a map builder is quite fast, so arbitrarily large maps are within the capabilities of the system presented here.

One concern that arose before performing this research is that, because of the way rooms are added to existing rooms, that the map, viewed as a combinatorial graph, would have room adjacencies that formed a tree. The representation completely avoided this by packing in lots of rooms, with many adjacencies arising from fortuitous placement rather than from deliberate action of the map builder.

Given the relatively small number of states in the SDAs, it is a little curious that more pattern is not visible in the final maps. Motifs in the form of collections of similar groups of

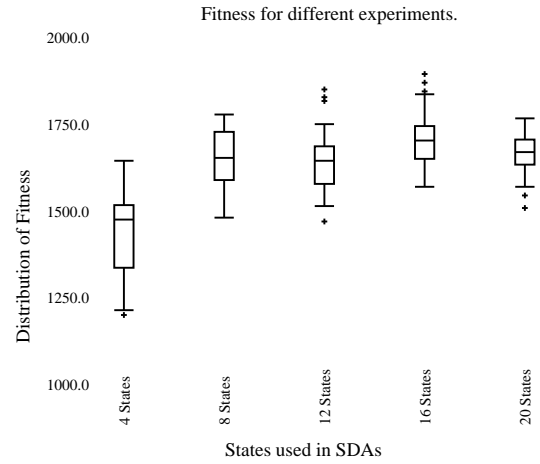


Fig. 5. Results of the parameter study on number of states in the SDA. Shown are box plots of the best fitness values from 30 runs of the evolutionary algorithm for each set of parameters.

rooms appear, but the overall map seems haphazard. This may be an effect caused by obstruction generated via serial addition of rooms. As the map grows, rooms already in place prevent some proposed rooms from being placed. The pattern of this obstruction is idiosyncratic to a particular SDA and breaks the crystalline order that might otherwise arise.

A. Things that could be done

The system presented in this study was tested on a square grid of cells and rooms were added to a map under the influence of a very simple fitness function. A small number of room shapes were used and the system constructively creates a connected map. There are a large number of additional directions the system can be developed in.

One of the most obvious future directions follows from the fact that the system can adapt to grow in different directions via its evolved selection of which rooms to use as a focus for adding the next room. If we are fitting a map into a constrained shape, with areas where rooms cannot be built, it is almost trivial to initialize the drawing arena to forbid rooms in some area. A quick test of this notion was performed and appears in Figure 8. If we start with a high level plan for where patches of rooms need to go, then the DWP room-layout tool can be used to fill in details.

The fitness function used – area of rooms placed squared divided by the area of the bounding box – encourages the representation to lay out as many rooms as it can in a relatively dense form. Many other fitness functions are possible. A fitness function that rewarded a particular density of rooms would be simple to implement and would grant the user additional control of the type of map generated, for example. Slightly more expensive fitness functions could use dynamic programming to work on tactical properties of the map [6], [10], or one could even use different AI personas to adapt maps for a given play style or play preference [12].

Something left out of the current system is the placement of doors. It seems likely that an additional developmental phase

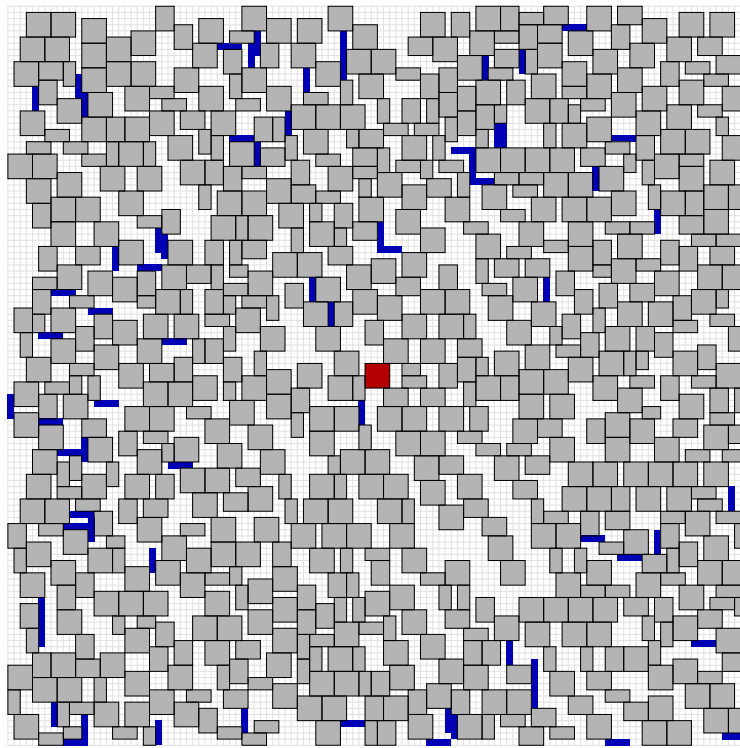


Fig. 6. The map shown is rendered on a larger grid was permitted up to 800 rooms during evolution of the map generator.

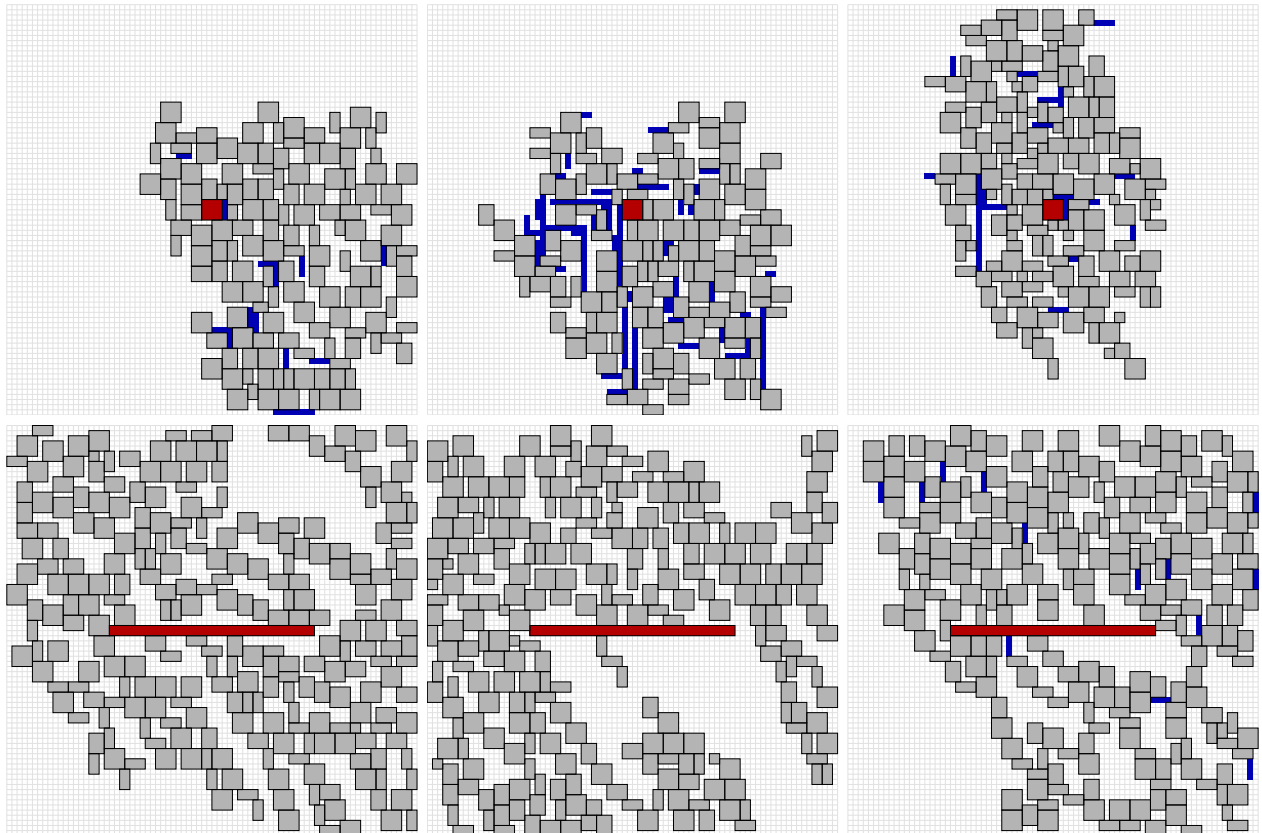


Fig. 7. Three examples of evolved maps with standard and elongated starting rooms. Starting rooms are shown in red.

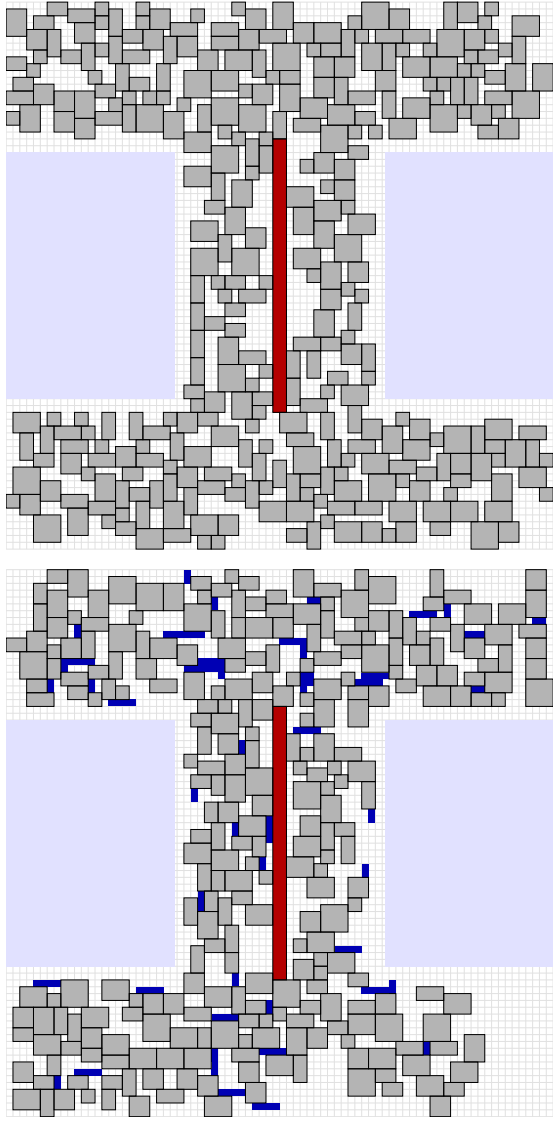


Fig. 8. Shown are examples of maps shaped by placing obstructions in the bounding square of the map. The obstructions are shaded light blue.

that placed doors would be a good follow-on project. The current system insists that a new room share at least one grid's worth of wall with the room it is placed next to. Insisting that one or the other wall be flush, or even that the wall align, would create a very different sort of map. Tinkering with the rules for how rooms are adjoined is a rich area for modifying the system, and different room adjointment rules can be mixed by simply adding another decision to the SDA's decision process.

B. Avoiding the need for the recent room hack

The recent room hack avoids the problem of selecting “used up” rooms, those with no adjacent space, as the foci for addition of a new room. The fairly arbitrary choice of the most recent ten rooms is an additional algorithmic parameter that could be explored. There are two other ways to address

the issue that the hack addresses. The first is a blacklist for rooms.

The blacklist would require a critical number of R rejections. If a room is proposed by the SDA as a place to site an additional room and rejected R times, it is removed from the list of available rooms. This would require maintaining a list of available rooms, not a difficult task, and would allow the system to refine and improve its GPF with information gained during run time. This modification of the algorithm would probably substantially improve performance.

A second and much simpler way to avoid the need for the random room hack is implicit in the final set of experiments with the elongated starting room. The system can accept multiple starting rooms as initial conditions. Build a sparse network of corridors as the initial state of the system. Then the active area where rooms can be placed starts very large and avoids, at least for quite a while, the congestion that plagued the system with an initial 4×4 room.

C. Different room shapes and required content

In [16], rooms with particular shapes were specified ahead of time and incorporated into procedurally generated maps. In this study, rectangular rooms were used for ease of placement. A small upgrade to the code that determines if a room can be placed in a given location would permit the DWP map builder to use a far wider variety of rooms.

If very specific rooms were required they could be placed in a list and one of the possibilities in the CSG's decision process would be an attempt to place a special room. The special room remains in the list until placed or, possibly, until some number of instances of it have been placed.

D. SDA are not the only choice for CSGs

In the original DWP research [5], SDAs were not the only evolvable structures used as CSGs. Another technology, called an *alternator list* was also used. SDAs were chosen for this study because they can generate aperiodic strings of characters while alternator lists must eventually fall into a cyclic pattern; the very long period of evolved alternator lists makes this a largely irrelevant choice.

In fact, though, the maps located with SDAs in this study were a good deal less structured than the authors had originally anticipated. Using a relatively simple periodic stream of characters might yield interesting maps, even a relatively short string repeated indefinitely. In any case, exploration of different choices of complex string generators is a rich area for future research.

E. Adaptivity

One particular strength of this approach is that it is adaptive on two different levels. There is a powerful analogy for this in biology - a plant, for example, adapts through evolution and might acquire certain growth pattern, but then it also adapts to its actual environment during its lifetime, by growing into a certain shape, or around obstacles. The representation discussed here has a similar split. The CSG can evolve to

encode a specific approach to the problem, i.e. what patterns to use, or what solution to try first, while the GPF can adapt the suggested solution to the concrete problem in hand. Fig.8 shows how the rooms are placed around obstacles. In this example it would be possible to evolve the CSG for a different set of obstacles - creating a typical pattern or built style, and then apply this built style to different obstacle patterns.

This two stage adaptivity could be an interesting new approach for the challenges in adaptive procedural content generation, which in contrast to *tabula rasa* PCG, needs to create content in response to already existing content. This adaptivity to existing content should not be confused with adaptivity to the player [14], where generated content adapts to play styles or a player's competence level. An example for the former is the AI Settlement Generation Challenge [17], where participants have to write an algorithm that can generate a city for an unseen Minecraft map. The solution should, among other things, adapt to the underlying terrain. The DWP representation could be used, by providing an appropriate complex string to road element mapping to build a road network that would avoid inappropriate road placement. The CSG could be evolved to produce a style of road network that would fit certain criteria - or a curiosity driven approach could be used to generate road networks of different styles, and those could then be applied and conform to different terrain.

In this context it would then also make sense to soften the evaluation of the GPF to a "whats affordable" representation, similar to the approach in [11]. Placing a new piece of road could not just be allowed or forbidden, but the output string could be used to choose from a distribution of options, with better, more affordable options having a higher likelihood to be chosen. So the algorithm might prefer a flat road on even terrain to a step road over rugged terrain.

VI. SUMMARY

In this paper we show how the "do what's possible" representation can be applied to the concrete problem of procedural dungeon generation. Compared to the range of other dungeon generators this approach is relatively lightweight in its representation - which reduces the search space a genetic algorithm has to go through. Yet the representation is scalable, capable of creating dungeons of arbitrary size, and grows dungeons iteratively in such a way that they process could be stopped at any time with a solution. Of course, this is traded off with various advantages and disadvantages compared to other generators. We also discussed a range of minor modifications that would allow one to enhance or fine tune the output for practical application. A particularly noteworthy feature is the two-tier adaptivity, that would allow for content generation that could be sensitive to existing content, bearing a suitable chosen generative possibility filter. The last property might make this approach particularly useful to generate game content that would typically grow organically over time in response to external stimuli, such as plants, cities, dungeons, etc.

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