

# World In A Word 2013 Competition: Evolving Parameters for a Cayley Graph Visualiser Using 64 bits

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## Abstract

A 64-bit string evolved with a custom-built GA is mapped using the Grammatical Evolution system, to evolve parameters for a visualiser of Cayley graphs. The resulting visualisations, albeit restricted, still exhibit a large degree of complexity and evolvability, and are representative of the domain.

## 1 Introduction

The “World in a Word” 64-Bit Design Challenge is a competition run for the IEEE Congress on Evolutionary Computation. The objective is to evolve 64-bit strings, which are used to explore creative domains. Entries are evaluated based on the originality of the domain, the diversity of the structures evolved, the appeal of the domain and the evolved individuals, and the extent to which the 64 bits are used.

This entry uses the 64 bits as a basis to create an integer string, which in turn is used with the Grammatical Evolution system [4], to evolve parameters for Jenn3d [3], a visualiser of Cayley graphs of finite Coxeter groups. The mapping process is regulated through a context-free grammar, which defines the parameter space to navigate.

The resulting system creates fully-formed images from the start, and adapts quickly to the changing styling preferences of the user. The use of 64 bits limits the range of visualisations achievable, but still allows for an extensive exploration of the domain.

This document describes the approach taken. Section 2 describes the methodology used, ... FIXME

## 2 Methodology

### 2.1 Jenn3d

Our approach is based on previous work [2], in which a rich set of parameters were evolved for the Jenn3d software.

Jenn3d is a visualiser of finite Coxeter groups on 4 elements. These groups can be represented as reflections of Euclidean 4-space, or as reflections of the 3-sphere. It builds Cayley graphs using the Todd-Coxeter algorithm, and visualizes those graphs by embedding them in the 3-sphere, then stereographically projecting the graph from the 3-sphere to Euclidean 3-space, and finally rendering the 3D structure as a 2D picture. Jenn3d renders using OpenGL, and is fast enough to allow the user to rotate and navigate in curved 3D space, and gain an intuition for the geometry of the 3-sphere.

The rich and complex domain of visualisations representable through Jenn3d is defined by the following parameters:

1. the  $4 \times 4$  Coxeter matrix, as specified by the 6 integers in the upper triangle matrix;
2. a subset of up to 3 of the 4 generators, by which vertices should be fixed (the larger the subset, the fewer vertices in the quotient);
3. a list of group elements to define edges, where each element is written as a string in the generating set; and
4. a list of faces, where each face is written as a pair of generating elements.

Note that this parameter set is partial and redundant in that *(i)* most Coxeter matrices result in an infinite group and the Todd-Coxeter algorithm does not converge; *(ii)* permuting the generators results in the same structure, but with a different initial visualization; *(iii)* the lists of group elements defining edges are really sets, and so are invariant under permutation and duplication; and *(iv)* when defining edges, each group element definition can be written in infinitely many ways modulo group equality, e.g.,  $r_4 r_4 r_2 r_1 r_3 = r_2 r_1 r_3$ , since  $r_4 r_4 = 1$  is the identity.

This large and complex parameter space of drawings is very difficult to navigate, and is an excellent candidate for exploration using Grammatical Evolution.

### 2.2 Evolutionary Approach

To explore the Jenn3d parameter space, Grammatical Evolution (GE) [4] was used. GE typically uses a variable-sized binary or decimal string, to choose productions from a given grammar, and thus generate syntactically correct solutions of the search space. A fixed-length string can also be used; however, the search space becomes finite and (somewhat) restricted.

Fig. 1 shows the grammar used. In it both the required and optional parameters for Jenn3d are specified. The Coxeter matrix parameter is drawn from a

fixed set, as overly complex matrices are too computationally demanding, but all other parameters are not only optional, but also variable in size.

```

<cmdline> ::= -c <CoxeterMatrix> <StabilizingGenerators> <Edges>
              <Faces> <VertexWeights>
<CoxeterMatrix> ::= <Torus> | <FreePolyhedra> | <FreePolytope>
<Torus> ::= <Int_2_12> 2 2 2 2 <Int_2_12>
<FreePolyhedra> ::= 3 3 2 2 2 2 | 3 4 2 2 2 2 | 3 5 2 2 2 2
                    | 4 3 2 2 2 2 | 5 3 2 2 2 2 | 3 2 3 2 2 2
                    | 3 2 4 2 2 2 | 3 2 5 2 2 2 | 4 2 3 2 2 2
                    | 5 2 3 2 2 2 | 2 2 2 2 3 3 | 2 2 2 2 3 4
                    | 2 2 2 2 3 5 | 2 2 2 2 4 3 | 2 2 2 2 5 3
<FreePolytope> ::= 3 3 3 2 2 2 | 3 3 2 2 3 2 | 3 3 2 2 4 2
                    | 3 3 2 2 5 2 | 3 4 2 2 3 2 | 3 5 2 2 3 2
                    | 4 3 2 2 3 2 | 3 2 3 2 2 3 | 3 2 3 2 2 4
                    | 3 2 3 2 2 5 | 3 2 4 2 2 3 | 4 2 3 2 2 3
                    | 5 2 3 2 2 3 | 2 2 3 2 3 3
<StabilizingGenerators> ::= | -v <Comb0123>
<Edges> ::= | -e <EdgeSet>
<EdgeSet> ::= <Comb0123> | <EdgeSet> <Comb0123>
<Faces> ::= | -f <FaceSet>
<FaceSet> ::= <FourInt0_3> | <FaceSet> <FourInt0_3>
<FourInt0_3> ::= <Int0_3>
                | <Int0_3><Int0_3>
                | <Int0_3><Int0_3><Int0_3>
                | <Int0_3><Int0_3><Int0_3><Int0_3>
<VertexWeights> ::= | -w <Int1_12> <Int1_12> <Int1_12> <Int1_12>
<Int0_3> ::= 0 | 1 | 2 | 3
<Int1_12> ::= 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12
<Int2_12> ::= 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12
<Int3_12> ::= 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12
<Comb0123> ::= 0 | 1 | 2 | 3
               | 01 | 02 | 03 | 12 | 13 | 23
               | 012 | 013 | 023 | 123 | 0123

```

Figure 1: Grammar used to navigate the Jenn3d parameter space.

## 2.3 Encoding

64 bit binary strings are evolved using a simple Genetic Algorithm [1]. These are then transformed into integer strings. As each of these integers is used to choose productions associated to a *non-terminal* symbol defined in the grammar, the number of bits required to represent each integer is dependent on that grammar. An analysis of the grammar used (Fig. 1) shows that the symbol with the highest number of associated productions is **<FreePolyhedra>**, with 15 productions;

therefore a minimum of 4 bits are required to encode each integer. This first mapping process thus transforms the 64 bit strings into 16 integer strings.

Note that this introduces biases in the exploration of the phenotype space. For the `<FreePolyhedra>` symbol, for example, all productions have a 1/15 chance of being chosen, apart from the first production (`<FreePolyhedra> → 3 3 2 2 2 2`), which will have a 2/15 chance of being selected, due to the fact that each integer has a range of  $[0, 15]$ , and GE’s usage of the modulus operator to map integers to the choice of productions. GE usually deals with these biases by using large amounts of redundancy, through the use of many bits per integer (typically 32 or even 64, in systems directly manipulating integers).

Also note that not all  $2^{64}$  possible binary strings generate unique individuals. Some do not generate valid phenotypes, as the mapping process might not terminate; others generate the same choices in the grammar, and hence the same phenotypes; and finally some combinations of the leftmost bits will generate shorter mappings, which will not use some of the rightmost bits.

Even so, the number of possible combinations is still very large, and the functionality of each bit can vary, depending on the production choices of the bits preceding it.

## 2.4 Fitness Evaluation

As the objective of the system is to evolve attractive and personalised visualisations, it is ran in an interactive manner. Each correctly generated individual is exposed to the user, to receive a fitness score. This allows the individual to directly interact with the 3D-visualisation, have a better understanding of the generated structure, and achieve his/her preferred projection.

Fig. 2 shows the Jenn3D interface, extended so that a scoring process is present. Ideally, the evolutionary process proceeds in an endless manner; every time a fitness score is attributed to a structure, a new one is presented immediately after. If the user instead chooses to *exit* the application, the evolutionary process terminates. The full range of exploration tools in Jenn3d is available for each presented structure; this includes options to save the evolved parameters, and/or export a high-resolution image of the current visualisation.

### 2.4.1 Fitness and Typicality

Table 1 shows the range of possible fitness and typicality scores. Due to the complexity of the Todd-Coxeter algorithm, some visualisations are impossible to generate, causing the Jenn3d software to crash<sup>1</sup>; as these might be close to correct (and potentially attractive) visualisations, fitness and typicality scores of 0.5 are automatically attributed.

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<sup>1</sup>This can be frustrating for the user; a quick way to deal with this problem (in a Mac environment) is to leave the crash report window open, as new crash reports will not be generated.

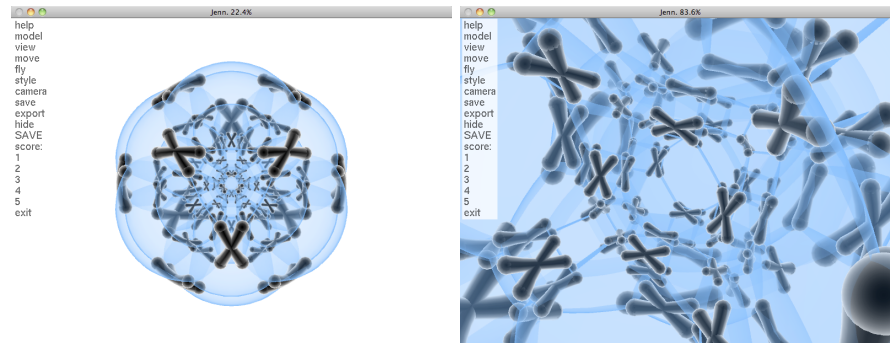


Figure 2: The Jenn3d interface, along with the extensions encoded. An example image is shown in the left; the same image, when zoomed in and rotated (right), can produce a dramatically different visualisation.

Table 1: Fitness and Typicality scores, and events generating those scores; fitness values 1-5 are user supplied

Event	Fitness	Typicality
Unsuccessful GE mapping	0.0	0
Non-convergence of Tedd-Coxeter algorithm	0.5	0.5
Rejected visualisation	1.0	1.0
Poor visualisation score	2.0	1.0
Average visualisation score	3.0	1.0
High visualisation score	4.0	1.0
Visualisation remains in population unchanged	5.0	1.0

Ideally, the user has a large control of the evolutionary process, through the fitness score. A fitness score of 1.0, for example, guarantees that the current visualisation is replaced by a random one in the next generation, whereas a score of 5.0 guarantees that the visualisation is passed unchanged to the next generation, thus potentially being used as a seed for alternative, similar visualisations (as per the scoring process proposed previously [2]).

The GA provided in the Java framework of the competition does not comply with this scoring system, which limits to a small extent the user experience of the system.

### 3 Examples

FIXME

## References

- [1] John H. Holland. *Adaptation in Natural and Artificial Systems*. University of Michigan Press, 1975.
- [2] Miguel Nicolau and Dan Costelloe. Using grammatical evolution to parameterise interactive 3d image generation. In Cecilia Di Chio et al., editor, *Applications of Evolutionary Computation - EvoApplications 2011: EvoCOMNET, EvoFIN, EvoHOT, EvoMUSART, EvoSTIM, and EvoTRANSLOG, Torino, Italy, April 27-29, 2011, Proceedings, Part II*, volume 6625 of *Lecture Notes in Computer Science*, pages 374–383. Springer, 2011.
- [3] Fritz Obermeyer. Jenn3d for visualizing coxeter polytopes. <http://jenn3d.org>, June 2010.
- [4] Michael O’Neill and Conor Ryan. *Grammatical Evolution - Evolutionary Automatic Programming in an Arbitrary Language*, volume 4 of *Genetic Programming*. Kluwer Academic, 2003.

## Appendix A: Software details

The Jenn3d software is written in C++, as is the GE mapping library used. In order to integrate it in the Java framework provided for the competition, the implementation of the *Individual* (abstract) class in `Jenn.java` uses a system call to the C++ framework. This call is made in the `measureQuality()` method. The java code waits for an exit value from the system call and then reads from the file `fitness.txt` (created by the C++ code). The typicality value is then derived from the fitness value (as shown in Table 1).

It is important to note that in addition to the implementation of a new `domain` package, some minor changes to other code in the framework (to facilitate interactive evolution) were also necessary. The superclass `Search.java` was modified to include a new field, `userQuit` and the main loops in subclasses `SearchGA.java` and `SearchMC.java` were modified to incorporate this value.

An ant buildfile has been supplied to aid with building and executing the code. To do this, call `ant run` from the JennWord directory. Note that before this can be executed, the C++ source code of the combined Jenn3d+GE mapper must be compiled first. To do so, run `make` (`make -f makefile.mac` in a Mac environment) in the `GEMapJenn` directory. In a Linux environment, installations of the `libpng` and `freeglut3` libraries are required, whereas in a Mac a recent installation of XCode is required (the software has not been tested in a Windows environment).