GeMuSE: a geometric representation for multi-parameter spaces exploration

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> “Space is the order of coexisting things”
> Gottfried Leibniz, Metaphysical foundations of Mathematics.

Abstract

The present work introduces GeMuSE: a geometric representation for multi-parameter spaces exploration, that provides a complete visualization of all possible parameter combinations. GeMuSE was conceived to provide an interface for the sampling process of a wider methodology for algorithmic composition systems' parameter spaces aesthetic exploration. Such methodology is based on the “exploring-parameters” algorithm, which considers parameter sets together with a perceptual user evaluation as input/output relations. Then, such relations are processed, iteratively searching for regularities and thereby compressing the data to extract human readable and interpretable linguistic rules, able to represent musical entities of low and high-level. When the extracted rules are drawn using GeMuSE they define sets of polygons which can be characterized by polygon similarity metrics. The derived properties could be used to interpolate combinations maintaining the relative ratio among the system parameters defined by the rule. Although this idea needs further exploration, these combinations have shown aural results coinciding with the described perceptual properties. In addition, the proposed representation facilitates space exploration and the establishment of new relations about how we correlate parameter structures and perceptual properties, which in turn, can also suggest new expressive paths and cues for further research.

1. Introduction

Algorithmic composition is the process of creating musical material by means of formal methods (Nierhaus, 2009; Fernández, and Vico, 2013). As a consequence of their design, algorithmic composition systems are (explicitly or implicitly) described in terms of parameters. The possible parameter combinations form the aural space created by the system. Therefore, their exploration plays a key role in learning the system's capabilities. A common practice of the performer/composer is to choose, out of all the possibilities, specific parameter configurations for particular moments or contexts. However, the process of finding such configurations is, in many cases, performed by hand or by heuristic system information.

Nonetheless, some methodologies for finding sets of parameters that successfully describe low and high-level perceptual entities have been proposed. For example, Dahlstedt (2001) and Collins (2002a;2002b) applied interactive evolution (Dawkins, 1986), which uses human evaluation as the fitness function of a genetic algorithm for system parameter optimization. In the first case, this technique was applied to sound synthesis and pattern generation algorithms; in the second, for searching successful sets of arguments controlling algorithmic routines for audio cut procedures. Upon these foundations, i.e. on the possibility of building methodologies for finding sets of parameters for algorithmic systems that create effective aural results for a listener, Paz et al., (2016) developed a linguistic rule approach for algorithmic composition systems' parameter spaces aesthetic exploration. As the systems' outputs are intended to produce an aesthetic experience on humans, audition also plays a central role in the process. In the methodology, each combination of parameters represents a point in the parametric space, which is classified by the user. After the classification, it can be seen as an input/output relation, in the sense that this combination of parameters is associated with a particular output label representing a perceptual property. Such relations can be compacted to get interpretable rules describing the knowledge contained in the instances by finding regularities in the data. Such rules can be used to travel within our perceptual predefined spaces, allowing to produce variability in the outputs without stepping out of the described classes. My special interest in working with linguistic rules relays on its interpretability. Linguistic rules, in contrast with subsymbolic approaches (like neural net classifiers), are human-readable information, which makes them especially attractive for applications in the context of computer music. However, this methodology requires a process for the exploration of the parametric space. This has to do with how to explore the different parameter combinations. Furthermore, given a set of combinations (points in the space) exhibiting successfully aural results, little its known about how they are related and distributed in the space. Are those points close to each other, in "well determined" subspaces? Or they appear to be scattered in the space with no apparent relation? In such case, is there any space representation, or visualization structure, that help us to infer and build possible relations?

The present work addresses these points by proposing a geometrical representation for the parameter combinations in the space. Such representation endows the user with a tool for the exploration process by providing a complete visual representation of all parameter combinations. Beside this, its geometric nature facilitates the analysis and the establishment of new relations about how we correlate parameter structures and perceptual properties, which in turn, can also suggest new expressive paths and cues for further research.

The rest of the paper is structured as follows: Section 2 discusses the problem of representing multidimensional spaces and introduces GeMuSE. Section 3 describes the exploring-parameters algorithm and how GeMuSE is used for the exploration and rule visualization processes. And finally, Section 4 presents some preliminary conclusions and further work.

2. GeMuSE: Geometric Multi-parameter Space Exploration

Building multidimensional space representations has been a recurrent topic in artistic and scientific visualization. Among the central needs, is how to construct a graphical structure for the parameter combinations, such that, not only we can visualize all the dimensions at the same time, but also, that the visual distances among the different points correctly represent the distance among its parameters. This limitation comes from the well known fact, that every projection (or squashing) into a lower dimensional space comes with the loose of the distance information in that dimension.
When working with algorithmic systems we often deal with spaces in which each parameter may vary in a different scale and limits, for example, frequency, number of upper harmonics, and amplitude.
To address this problem, many musical interfaces have used sliders or knobs for controlling the parameter values. However, these kind of interfaces make unintuitive the concept of distance leading to a “bag of presets” with no apparent relation. Other approaches have used different mappings, for example, The Metasurface (Bencina, 2005) is an interface for interactive design of two-to-many mappings that works by placing different parameter combinations in a plane. Interpolations among such combinations are performed by using natural neighbor interpolation, which is a local method based on Voronoi tessellation, that have shown more predictability in comparison with global based methods. However, the selection of the parameter combinations (presets) is still performed through a slide and knob interface, difficulting the visualization from a data acquisition perspective.

In order to perform parameter exploration by representing complex spaces in a simple and intuitive way, but also, from which further results can be obtained, I propose a polygon geometric representation (like spider chart; Chambers, et al., 1983, pp. 158-162) consisting in the one-to-one mapping (linear or logarithmic) of the values of the n parameters into the n lines that connect the vertices with the center of an n-regular concave polygon. Then, each parameter combination is drawn as the polygon connecting the values on the lines. Note that, as the values of each parameter can be any point in the lines, the resulting polygons are not all similar in the sense that their sides are not necessary in the same proportion. For example, at the left of Figure 1 we have different combinations of three different parameters plotted in a triangle (or trigon).

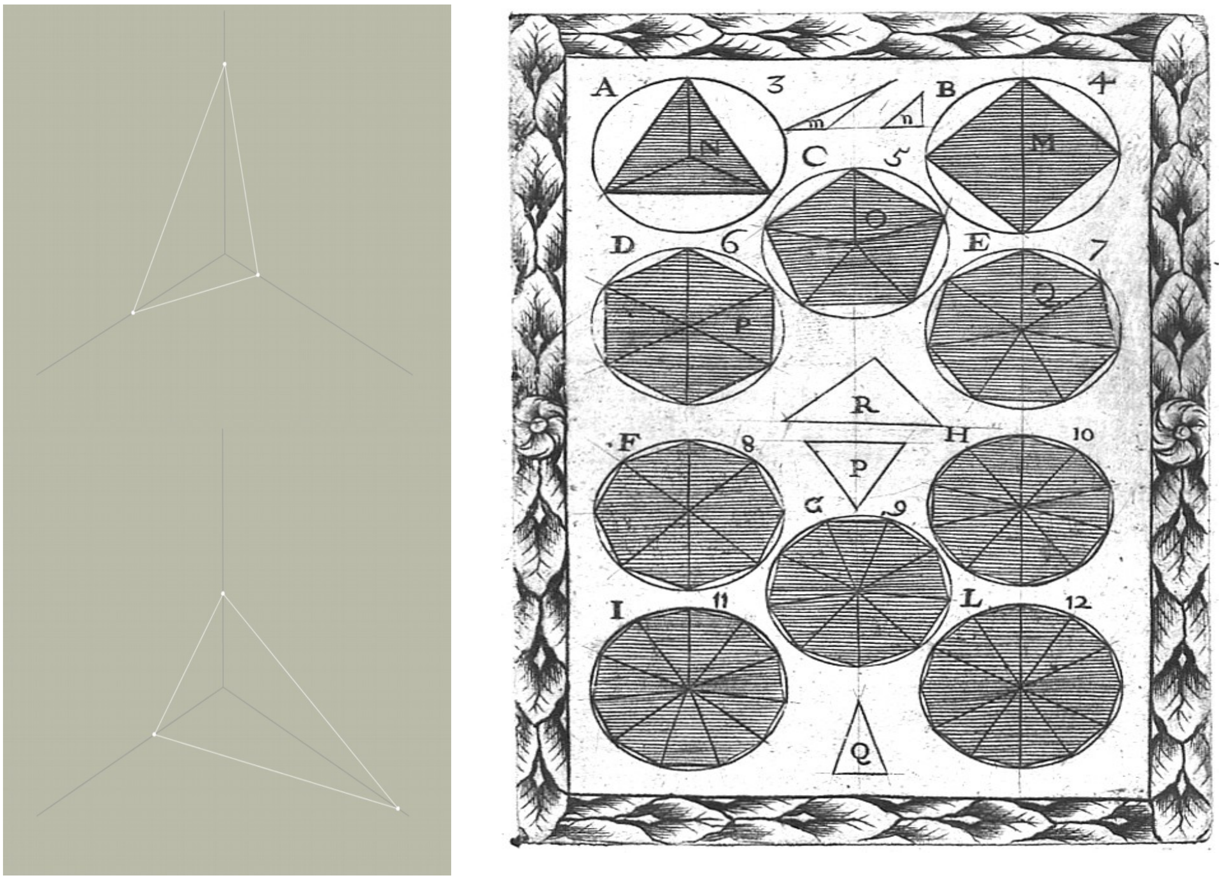

Figure 1. Left three different parameter combination plotted in a trigon. Right a historical image of polygons dating from 1699.

This representation takes advantage of the geometric intuition of the user during the exploration process, and of the geometric theory for the analysis of the data and further applications. Polygons have been studied since ancient times being a common visual reference. The right part of Figure 1 shows a historical image (from 1699) of polygons. Some visualization strategies have been considered for the first interface version. For example, it begins with a “veil” which disappears as the user explore the space, so it is clear which zones are already explored and which remains unexplored. Also, the successful combinations of parameters appear depicted in different colors depending on their assigned class. These strategies seek to help the user in an effective exploration.

2.1 Listening through comparison

Models of the human ear establish that it works by relative comparison independently of the specific location (in their

respective scale) of the stimuli values[1]. Then, many of its properties are described by ratios (or proportions) rather that by numeric distances. For example, the octave relationship is expressed as the double of the frequency. To produce a change in loudness perceived as doubling the volume it would be needed an increment of ten times the actual acoustic energy. This relative ratio property is also present in other physical sound phenomena. To mention an example, consider the beat, or interference pattern among two frequencies slightly different, the same beating period is produced by frequencies of 100 and 101Hz that by frequencies of 1001 and 1001Hz. What defines the periodicity of the beat is the absolute difference between the frequencies rather than the positions of the frequencies in the frequency scale.
In music perception the relations between the components of the system (it could be the tonal or a FM system) do not exist in the physical world (although they are directly associated with it), instead, such relations are the actual knowledge (or aesthetic judge) in the listener’s long-term memory acquired by listening (Povel, 2010). However, the relative comparison analogy can also apply in music perception, like in metric and key induction processes, which are performed by comparisons among the received information (Povel, 2010).

This condition is exploitable on the representation proposed, when is translated into parameter configuration. For example, consider four parameters being frequency1, amplitude1, frequency2 and amplitude2. Then, keeping the amplitudes constant, we can draw the squares defined by (100,amplitude1,101, amplitude2) and (1000,amplitude1,1001, amplitude2). Note that the proportion among the sides representing the respective frequencies in the two polygons will represent the relative change among parameters. This simple idea, and how it can be used in the context of linguistic rules, is deepened in section 3.

3. GeMuSE and the exploring parameters algorithm

The geometric representation of multi-parameter spaces was conceived to provide an interface for the sampling process of a wider methodology for algorithmic composition systems' parameter spaces aesthetic exploration. Such methodology used the “exploring-parameters” algorithm (Paz et al., 2016) that considers the parameter sets and the user evaluation as input/output relations. Such relations are used as the input data for the algorithm, which iteratively searches regularities, thereby compressing the data, to extract human readable and interpretable linguistic rules able to represent musical entities of low and high-level.

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[1] This behavior is not strict (e.g there are small changes in the boundaries of high and low frequencies), however it is a good general description.

3.1 Data and linguistic rules representation in the exploring-parameters algorithm

The input data set for the exploring-parameters algorithm has the following form **A = {a1, a2, . . . , am}**, where each **ai** is composed as follows: **ai =** ((xi1, xi2, . . . , xin), yi). In this notation xij denotes the value of the jth parameter of the ith combination explored, and yi denotes the user classification. Index i satisfies that 1<= i <= m and n is the number of parameters.
After the compression/rule-extraction-process the rules have the following form:

IF X1 is V1 AND X2 is V2 AND . . . AND Xn is Vn THEN Y is yj.

Where X1, X2, . . . , Xn are the input parameters, and V1, V2, . . . , Vn are their respective values. Y is the user classification, and yj denotes a particular class.

In the rules one or more Xj could have an associated value of -1.
For example:

IF X1 is V1 AND X2 is **-1** AND . . . AND Xn-1 is **-1** AND Xn is Vn THEN Y is yj.

In such case, the -1s indicate that there exist a subset of indexes of i, let us say “k”, such that, the classification and all parameter values for each element of **ak,** except xkj are equal. And that this subset contains all the possible values of the parameter Xj present in the input data at the entrances xkj.
In other words, there is a subset **ak** in the input data, with the following form:

ak = ((V1, V2, . . . , Vj-1, **xkj**, Vj+1, . . ., Vn), yj)

Where V1, . . . Vn and yj are fixed values, and xkj contains all the possible values of the parameter Xj.
The parameters having a -1 are used as free parameters because they allow to create variability in the outputs without stepping out of the predefined perceptual subspace.

Another possibility for the rules is to have sets of allowed values at some parameters. For example, X1 is [v1 OR v2 OR,. . ., OR vp]. These compressions occur when there exists a subset of indexes of i, (call it l) such that, the classification and all parameter values for each element of the subset, except xlj are equal. However, the subset does not contain all the possible values of the parameter Xj at entrances xlj.
In this type of compression, the elements in the subset of values (l) satisfy the proximity or “acceptable difference” condition stablished by the user. Then, the subset is composed by numbers, which if ordered from lowest to highest, do not differ more from one another more than the acceptable difference.

This number is set for each parameter independently and defines how “close”, in terms of absolute numeric distance, two values have to be for being included in the subset. For example, suppose parameters Xj and Xj+1 describe a sinusoidal frequency and the number of upper harmonics added into that signal. We could define an acceptable difference of [20Hz and 1000 harmonics]. Then, during the compression, sequences of frequencies at a distance ≤ 20 could be compacted into a subset. Same for combination having the same values for the classification and the parameters and with number of upper harmonics at a distance ≤ 1000.

Then, a general representation of a rule is:

IF X1 is V1 AND X2 is V2 AND . . . AND Xn is Vn THEN Y is yj.

Where each Vi is either -1 or a subset of values of Xj.

The extracted rules have been successfully used in live performance and desk composition. The current implementations allow the user to choose a class and a rule from which its different patterns are extracted.

3.2 Visualizing rules with GeMuSE

The obtained rules are visualized using GeMuSE representation. They are drawn straightforward as the set of possible n-gons connecting all combinations of values contained at the rule.
For example, consider the simple hypothetical rule:

IF X1 is 1 AND X2 is [2 OR 3 OR 4] AND X3 is 3 THEN Y is 2

This rule is represented in Figure 2.

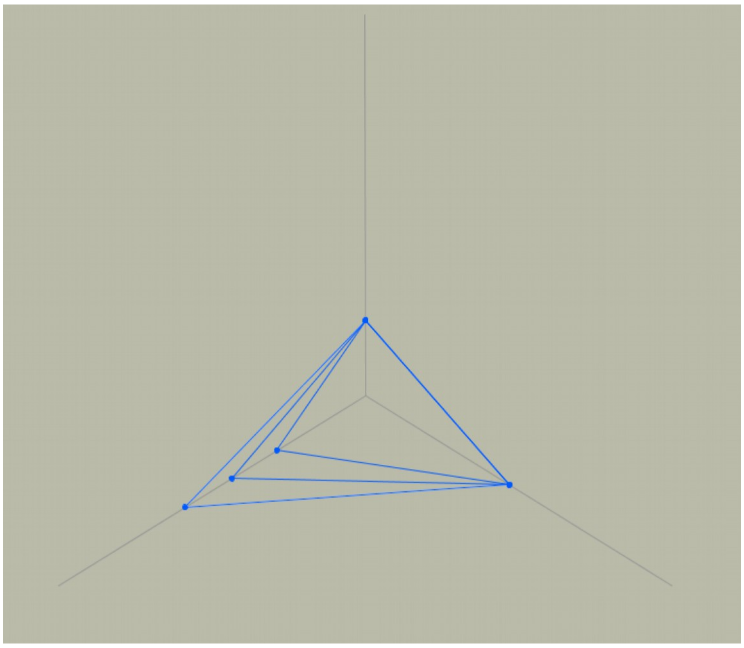

Figure 2. Draw of possible combinations of the rule: IF X1 is 1

AND X2 is [2 OR 3 OR 4] AND X3 is 3 THEN Y is 2. Being: X1 = 1, X2 = 2, X3 = 3, Y = 2; X1 = 1, X2 = 3, X3 = 3, Y = 2; X1 = 1, X2 = 4, X3 = 3, Y = 2.

Now consider the slightly different rule:

IF X1 is [1,2] AND X2 is [2 OR 3 OR 4] AND X3 is 3 THEN Y is 2

This is drawn in Figure 3.

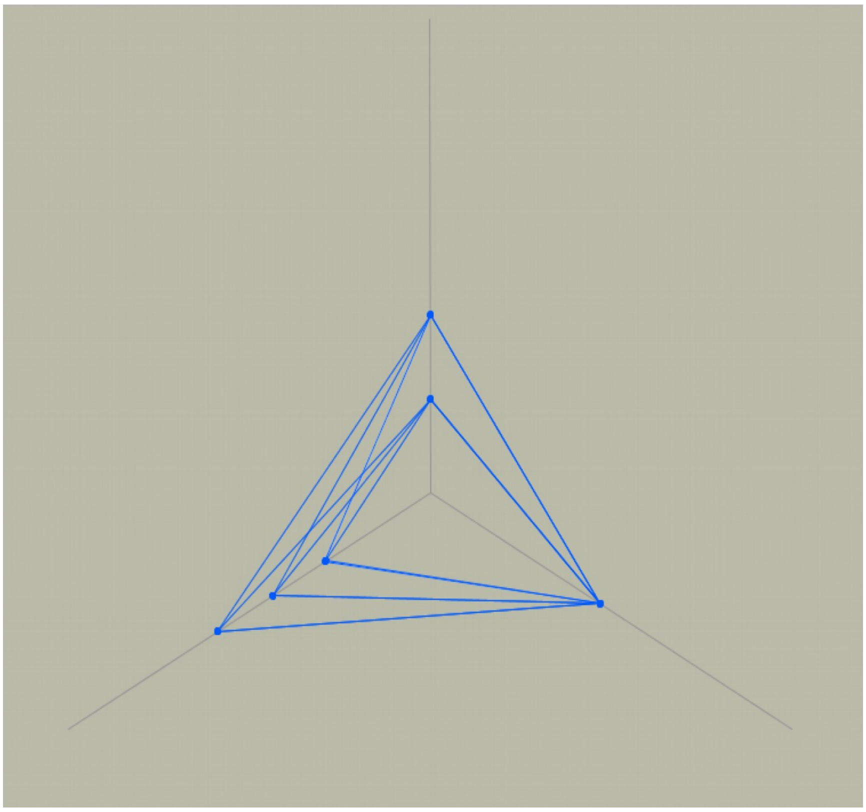

Figure 3. Draw of possible combinations of the rule: IF X1 is [1,2] AND X2 is [2 OR 3 OR 4] AND X3 is 3 THEN Y is 2.

3.3 First interpolation guess

The GeMuSE representation works as a visualization tool that allows you to explore the parameter space. But it also works as a display that allows to infer relationships between those combinations of parameters that produce effective aural results, and to have a view of how they are distributed in the space.

Once represented as polygons, combinations may be thought in terms of the relative relationships between parameters. This fact suggests different things. For example, it is possible to study the relationships between different rules by means of polygon similarity measures or side by side similarity (see for example, Arkin et al,. 1991; Mitchell, 2010).

Beside this, following the idea that computational intelligence methods should be used to extend human capacities rather that to replicate (or replace) it, another possible application of the representation is to suggest new possible combinations effectively fitting within the perceptual subspaces. Therefore, a first interpolation guess for proposing new unheard combinations could be to construct, if possible, polygons with the same relation among sides between the smallest and the greatest polygons described by a rule. Although the effectivity of this approach hardly depends on the space shape of the algorithmic system, as well as, on the generality of the perceptual property, in this way, it is guaranteed that the proposed combinations preserve the relative ratios among the parameters.

A riskier procedure is to define upper and lower bounds for the parameters that have as values either a -1 or a range, and to generate similar polygons between such bounds.

3.4 Implementation

The exploring-parameters algorithm is implemented on the SuperCollider programming language (McCartney, 1998) and it is available at Rohrhuber and Paz (2015) repository. The visual interface was implemented by Barriere (2016) over the Processing programing language (Reas and Fry, 2014).

4. Preliminary conclusions

The original intention of this research was to build a physical interface for the data acquisition process of the exploring-parameters compression algorithm. However, while I deepened into the problem of representing an arbitrary N-dimensional parameter space, so that the user has a visual representation of the combinations, the "physical" interface became secondary. After several attempts (including conceiving interfaces with an arbitrary number of sliders the projection of the x-y plane in a sphere, and representing dimensions in barycentric coordinates) I conceived that, given the properties of the set under study, this polygonal representation could help to explore the space and to assist with the representation of the rules as well as with further extensions for its study in terms of geometrical properties, like side by side comparison. However, when considering an interface as "a device designed and used to facilitate the relationship between systems" (Marzo et al., 2015), the interface is the representation itself, working between the parameter space and the user perception.

Even though at this point the interface and the coupling of the system is still under development, preliminary visualizations show the usefulness of representation for the space exploration process. Representations of the rules suggest that they can be analyzed by using existing metrics, for example, by comparing polygons with the mentioned metrics or by using L2 and turning functions. Subsequently, the results of this analysis can be used to compare different explorations of the same system, so similarities and differences between different “musical personalities” can be studied.

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