Vox Populi: An Interactive Evolutionary System for Algorithmic Music Composition

Artemis Moroni, Jônatas Manzolli, Fernando Von Zuben and Ricardo Gudwin

ABSTRACT

While recent techniques of digital sound synthesis have put numerous new sounds on the musician's desktop, several artificial-intelligence (AI) techniques have also been applied to algorithmic composition. This article introduces Vox Populi, a system based on evolutionary computation techniques for composing music in real time. In Vox Populi, a population of chords codified according to MIDI protocol evolves through the application of genetic algorithms to maximize a fitness criterion based on physical factors relevant to music. Graphical controls allow the user to manipulate fitness and sound attributes.

In Darwin's time, most geologists subscribed to "catastrophe theory": that the Earth would be punished many times over by floods, earthquakes and other catastrophes, able to destroy all forms of life. On his voyage on board the *Beagle,* Darwin verified that the diverse animal species of a region differed from each other in minimal details, but he did not understand how this could result from a "natural" selection. In October 1838, he learned from a small book, *Essay on Population Origin* by Thomas Malthus, about the factors influencing evolution. Malthus, in turn, was inspired by Benjamin Franklin (the same person who had invented the lightning rod). Franklin had noted the fact that in nature there must be locally limiting factors, or a unique plant or animal would spread all over the Earth; it was only the existence of different kinds of animals that maintained them in equilibrium. This was the universal mechanism that Darwin was looking for. The factor responsible for the way evolution happens is *natural selection* in the fight for life, i.e. those who are better adapted to the environment survive and assure species continuity. Furthermore, the fight for survival among members of a species is more obstinate, since they must fight over shared resources; small differences, or positive deviations from the typical, are most valuable. The more obstinate the fight is, the faster the evolution; in this context only those better adapted themselves survive. However, characteristics that are positive in a specific environment may have no value in another.

D. Hofstadter, in *Metamagical Themas* [1], discusses the arbitrariness of the genetic code. According to him, the first moral of this development is: *Efficiency matters*. A second moral, more implicit, is: *Having variants matters*. The ratchet of evolution will advance toward ever more efficient variants. If, however, there is no mechanism for producing variants, then the individual will live or die simply on the basis of its own qualities *vis-à-vis* the rest of the world.

ALGORITHMIC COMPOSITION AND EVOLUTION

R. Dawkins demonstrated the power of Darwinism in *The Blind Watchmaker,* using a simulated evolution of two-dimensional (2D) branching structures made from sets of genetic parameters. The user selects the "biomorphs" that survive and reproduce to create a new generation [2]. S. Todd and W. Latham applied these concepts to help generate computer sculptures using constructive solid geometry techniques [3,4]. K. Sims used evolutionary mechanisms of creating variations and making selections to "evolve" complex equations to be used in procedural models for computer graphics and animation [5].

A new generation of algorithmic composition researchers has discovered that it is easy to obtain new musical material by using simulated-evolution techniques to create new approaches for composition. These techniques have been useful for searching large spaces using simulated systems of variation and selection. J.A. Biles has described an application of genetic algorithms to generate jazz solos [6] that has also been studied by D. Horovitz as a way of controlling rhythmic structures [7]. On the other hand, it is difficult to drive the results in a desired direction. The challenge faced by the designers of evolutionary composition systems is how to bring more structures and knowledge into the compositional loop. This loop, in an evolutionary system, is a rather simple one; it generates, tests and repeats. Such systems maintain a population of potential solutions; they have a selection process and some "genetic operators," typically mathematical functions that simulate crossover and mutation. Basically, a population is generated; the individuals of the population are tested according to certain criteria, and the best are kept. The process is

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Fig. 1. Vox Populi Reproduction and MIDI Cycles: The Reproduction Cycle is an evolving process that generates chords by using genetic operators and selecting individuals and is based on the general framework provided by J.H. Holland's original genetic algorithm. The MIDI Cycle refers to the interface's search for notes to be played by the computer. When selected, a chord is put in a critical area that is continually verified by the interface. These notes are played until the next group is selected. (© Artemis Moroni)

repeated by generating a new population of individuals—or things or solutions—based on the old ones [8]. This loop continues until the results are satisfactory according to the criteria being used. The effective challenge is to specify what "to generate" and "to test" mean.

All evolutionary approaches do, however, share many features. They are all based, like the diagram in Fig. 1, on the general framework provided by J.H. Holland's original genetic algorithm (GA) [9] or, indirectly, by the genetic programming paradigm of J.R. Koza, who proposed a system based on evolution to search for the computer program most fit for solving a particular problem [10]. In nearly every case, new populations of potential solutions to problems (here, the problem of music composition) are created, generation after generation, through three main processes:

1. By making sure that better solutions to the problem will prevail over time, more copies of currently better solutions are put into the next generation.

2. By introducing new solutions into the population; that is, a low level of mutation operates on all acts of reproduction, so that some offspring will have randomly changed characteristics.

3. By employing sexual crossover to combine good components between solutions; that is, the "genes" of the parents are mixed to form offspring with aspects of both.

With these three processes taking place, the evolutionary loop can efficiently explore many points of the solution space in parallel, and good solutions can often be found quite quickly. In creative processes such as music composition, however, the goal is rarely to find a single good solution and then stop; an ongoing process of innovation and refinement is usually more appropriate.

Information Seen as Genotypes and Phenotypes

Both biological and simulated evolution involve the basic concepts of genotype and phenotype, and the processes of selection and reproduction with variations. The *genotype* is the genetic code for the creation of an individual. In biological systems, genotypes are normally composed of DNA. In simulated evolutions there are many possible representations of genotypes, such as strings of binary digits, sets of procedural parameters or symbolic expressions. The *phenotype* is the individual itself or the form that results from the developing rules and genotypes. *Selection* depends on the process by which the fitness of phenotypes is determined. The likelihood of survival and the number of new offspring that an individual generates are proportional to its fitness measure. *Fitness* is simply a numerical index expressing the ability of an organism to survive and reproduce. In simulation, it can be evaluated by an explicitly defined mathematical function or it can be provided by a human observer. *Reproduction* is the process by which new genotypes are generated from an existing genotype. For evolution to progress, there must be *variations,* or mutations in new genotypes having some frequency of occurrence. Mutations are usually probabilistic, as opposed to deterministic.

Note that selection is, in general, nonrandom and operates on phenotypes, while variation is usually random and operates on the corresponding genotypes. The repeated cycle of reproduction with variations and selections of the fittest individuals drives the evolution of a population toward a higher and higher level of fitness. *Sexual combination* allows genetic material of more than one parent to be mixed together in some way to create new genotypes. This permits features to evolve independently and later to combine into an individual genotype. Although it is not necessary for evolution to occur, it is a valuable achievement that may enhance progress in both biological and simulated evolutions.

If the mechanics of an evolutionary system are well understood and the chain of causation is properly represented, the process of evolution can be stated in rather simple terms and can be simulated for engineering and art purposes. Given the complexity of evolved structures, it may be somewhat surprising that evolution here appears reduced to rather few rules [11]. In our approach, the population is made up of four note groups, or chords, as potential survivors of a selection process. Melodic, harmonic and vocal-range fitnesses are used to control musical features. Based on the ordering of consonance of musical intervals, the notion of approximating a sequence of notes to its harmonically compatible note, or tonal center, is used. The selected notes are sent to the MIDI port and can be heard as sound events in real time. This sequence produces a sound resembling a chord cadence or fast counterpoint of note blocks.

Individuals of the population are defined as groups of four voices, or notes. (Henceforth, voices and notes will be used interchangeably.) These voices are randomly generated in the interval 0–127, with each value representing a MIDI event, described by a string of 7 bits. In each iteration, 30 groups are generated. Figure 2 shows an example of a group—the genotype—internally represented as a chromosome of 28 bits, or 4 words of 7 bits, one word for each voice. The phenotype is the corresponding chord.

Two processes are integrated: (1) *Reproduction Cycle*: an evolving process that generates chords using genetic operators and selecting individuals; (2) *MIDI Cycle:* the interface looking for notes to be played by the computer. When a chord is selected, the program puts it in a critical area that is continually verified by the interface. These notes are played until the next group is selected.

The timing of these two processes determines the rhythm of the music being heard. In any case, a graphic interface allows the user to interfere with the rhythm by modifying the cycles. Figure 1 depicts the Reproduction Cycle and the MIDI Cycle.

Fitness Evaluation

Traditionally, Western music is based on harmony; hence, a general theory of music has to engage deeply with formal theories on this matter. The term "harmony" is inherently ambiguous, since it refers to a lower level where smoothness and roughness are evaluated and, at the same time, to a higher aesthetic level where harmony is functional to a given style. However, harmony is a very subjective concept; the perception of harmony does not seem to have a natural basis, but appears to be a common response acquired by people in

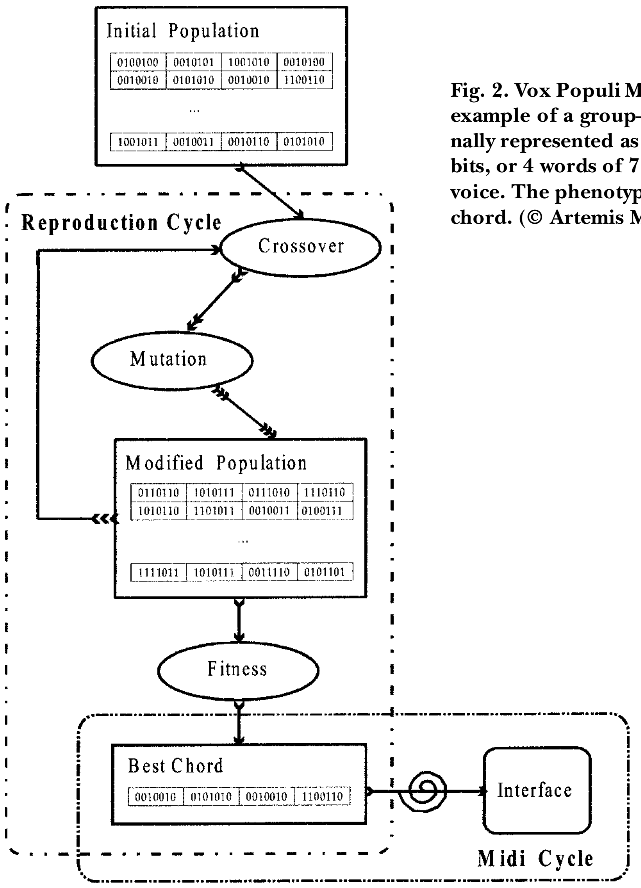


Fig. 2. Vox Populi MIDI chromosome: An example of a group—the genotype—internally represented as a chromosome of 28 bits, or 4 words of 7 bits, one word for each voice. The phenotype is the corresponding chord. (© Artemis Moroni)

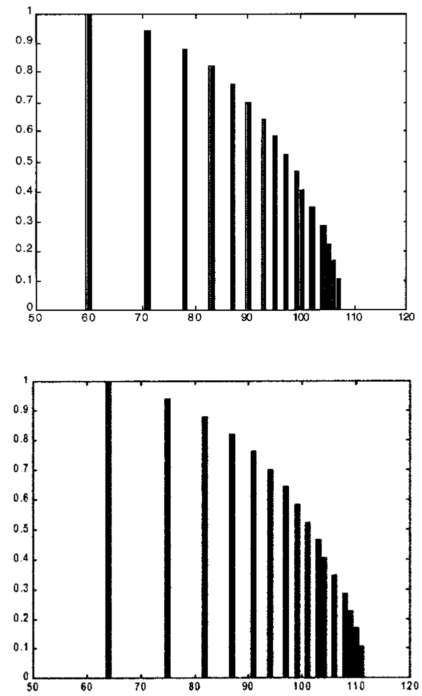


Fig. 3. Vox Populi harmonic series of notes 60 (the piano center, do) and 64 (mi). Each series represents the relative ordering of musical intervals for notes do and mi and is treated as a fuzzy set. (© Artemis Moroni)

specific cultural settings. Nevertheless, while there is a difference of opinion on what constitutes harmony, there is a general agreement on the relative order of music interval consonance. Numerical theories of consonance have tried to capture this aspect, but here again, a lot is left to the imagination, as theory does not clearly define what constitutes the order of simplicity of musical intervals.

In our case, we have applied, as a fitness function, a numerical theory of consonance from a physical point of view. Based on a relative ordering of consonance of musical intervals, a sequence of notes is approximated to its most harmonically compatible note or tonal center. Tonal centers can be thought of as an approximation of the melody, describing its flow. This method uses fuzzy formalism, or fuzzy sets, which are classes of objects with a continuum of membership grades. Such a set is characterized by a function that assigns to each object a grade of membership ranging between 0 and 1 [12]. In Vox Populi, harmony is treated as a function of the commonality, or overlap, between the harmonic series of notes. This overlap measurement is then scaled to be a value between 0 and 1, with 1 denoting complete overlap (i.e. the two notes are the same) and 0 denoting no overlap at all [13].

The harmonic series of notes 60 and 64 (do and mi, in the center of the piano, according to the MIDI protocol) are depicted in Fig. 3, while Fig. 4 depicts their overlap, or consonance measure. According to our approach, approximation to the tonal center is posed as an optimization problem based on physical factors relevant to hearing music. This approach is technically detailed in Moroni et al. [14]. In the selection process, the group of voices with the highest musical fitness is selected and played. The musical fitness for each chord is a conjunction of three partial fitness functions: *melody*, *harmony* and *vocal range,* each having a numerical value.

Musical Fitness = Melodic Fitness
+ Harmonic Fitness
+ Vocal Range Fitness

Melodic fitness is evaluated by comparing the notes that compose a chord to a value *Id* (identity), which can be modified by the composer in real time using the *melodic control* of the interface. This control "forces" the notes of the selected chord to be close to (or distant from) the *Id* value, which acts as a tonal center and is treated as an attractor. Harmonic fitness is a function of the consonance among the components of the chords. Vocal range fitness verifies which notes of the chord are in the range desired by the composer, who may modify it through the *octave control.*

The melodic control and the octave control allow the composer to conduct the music that is being created, interfering directly in the musical fitness, while other controls simply modify attributes of the chord that has been selected. Also, the biological and rhythmic controls allow the user to modify the duration of the genetic cycle by modifying the duration of the evolution *eras*. Eras can be thought as the number of iterations necessary to generate a new population. The combined use of the controls gives birth to *sound orbits*, which can be perceived through intermittent cycles.

Fitness Tuning

Part of the reason why evolution in nature is very slow is that the forces of selection can be imperfect and at times ineffectual. Non-privileged individual organisms may still succeed in finding mates, having offspring and passing on

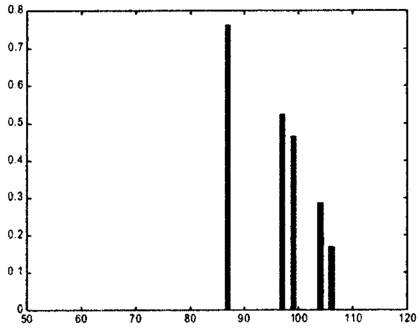


Fig. 4. Vox Populi: Overlap between the harmonic series of notes 60 and 64. Note 60 can be thought of as one of the notes of the chord and note 64 as the tonal center. The sum of heights of the components of the overlap is the consonance measure between the two notes. (© Artemis Moroni)

their genes, while organisms with a new advantageous trait may not manage to live long enough to find a mate and influence the next generation. Todd and Werner have made a charming comparison with the Frankenstein tale; Frankenstein hoped for much more than the creation of a single superior living being—he intended his creature to beget a whole new race that would grow in number and goodness, generation after generation. Later he worried that this process might not go exactly as he planned, with the children becoming more monstrous than their parents, a realization that led him to abandon his efforts to create a female progenitor. But, suppose, like Frankenstein, one wants to enter the "workshop of filthy creation" [15] and replace the human composer with an artificial composition system—due to a wish to ease a composer's workload, an intellectual interest in understanding the composition process, the desire to explore unknown musical styles or mere curiosity about the possibilities. Maybe Vox Populi could have been initially included only in the last group as inspired by a "mere curiosity about the possibilities" but given Vox Populi's surprising results, it can now be included in the first two.

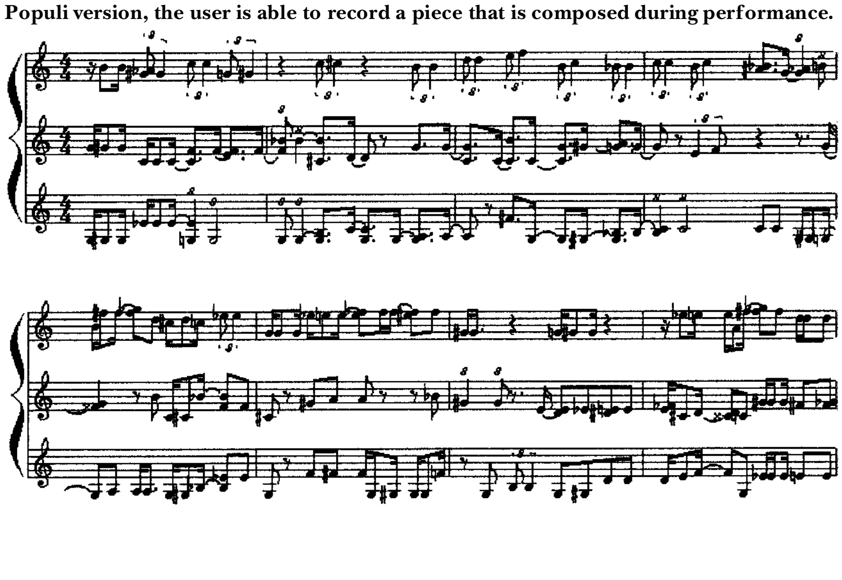
Two main approaches have been tried to express the fitness evaluation, both presenting interesting effects. The first one, derived from a composer's musical experience, provided a faster fitness evaluation. This method allows the use of a large population, 100–200 chords, producing greater diversification and resulting in a slower convergence to the best chord sequence. In the second approach, the consonance criterion is used, and a longer calculation is needed to evaluate musical fitness. In order to assure quick enough real-time performance by the system, the population was limited to 30 chords. The advantage of this approach is that it formalizes mathematically the concept of consonance. It can be easily described and flexibly programmed and modified. Since the musical fitness criterion used was stricter in the second example (using 30 chords instead of 100–200), the resulting sound output was less diversified; it was possible to hear the musical sequence converging to unison. This fact highlighted the notion that, in musical composition, not only consonance but also dissonance is desirable. Figure 5 depicts a Vox Populi musical output.

Vox Populi differs from other systems found in genetic algorithms or evolutionary computation in which people have to listen to and judge musical items; instead, Vox Populi uses the keyboard and mouse as real-time music controllers, acting as an interactive computer-based musical instrument. It explores evolutionary computation in the context of algorithmic composition and provides a graphical interface that allows the composer to change the evolution of the music by using the mouse. These results reflect current concerns at the forefront of interactive composition computer music and in the development of new control interfaces.

Interface controls use nonlinear iterative mappings. They can give rise to attractors, defined as geometric figures that represent the set of stationary states of a dynamic system or simply trajectories to which the system is attracted. A piece of music consists of several sets of musical raw material manipulated and exposed to the listener, such as pitches, harmonies, rhythms, timbres, etc. These sets are composed of a finite number of elements, and the basic aim of a composer is to organize them in an aesthetic way. Modeling a piece as a dynamic system implies a view in which the composer draws trajectories or orbits using the elements of each set [16].

The interactive pad control supplies a graphical area in which 2D curves can be drawn. These curves, a blue one and a red one, are linked to the controls of the interface. The red curve links to the melodic and octave range controls; and the blue curve links to the biological and rhythmic controls. When the interactive pad is active, the four other linked controls are disabled. Each curve describes a relation between the linked variables. They are traversed in the order in which they were created; their horizontal and vertical components are used for fitness evaluation and to modify the duration of the genetic cycles, interfering directly in the rhythm of the composition. The pad control allows the composer to conduct the music through drawings, suggesting metaphorical "conductor gestures" used when conducting an orchestra. Using different drawings, the composer can experience the generated music and conduct it, trying different trajectories or sound orbits. The trajectories then affect the reproduction cycle and musical fitness evaluation.

Fig. 5. Score of MIDI raw material produced by Vox Populi. This material was produced by Vox Populi in an interactive session by Jônatas Manzolli, composer. In the latest Vox Populi version, the user is able to record a piece that is composed during performance.



Interface and Parameter Control

The resulting music moves from very pointillistic sounds to sustained chords,

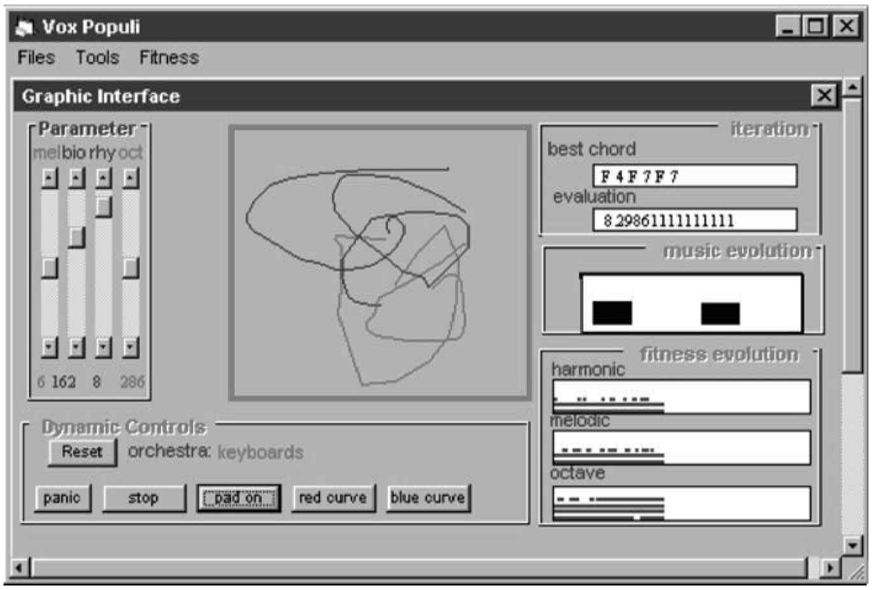


Fig. 6. Vox Populi interface. (© Artemis Moroni)

depending upon the duration of the genetic cycle and the number of individuals of the original population. The interface is designed to be flexible enough for the user to modify the music being generated. Below is a short description of the controls available to the user interacting with Vox Populi. The melodic, biological, rhythmic and octave controls allow the composer to modify the fitness function in real time and are associated with attractors. Vox Populi's interface is depicted in Fig. 6 and in Color Plate A No. 2.

Melodic Control

The *mel* scroll bar allows one to modify the value *Id*, which is the tonal center in the evaluation of melodic fitness. Given an ordered sequence of notes, it seems intuitively appealing to call the note that is most consonant with all the other notes the *coloring*, or tonal, center. Hence, the extraction of the tonal center of a sequence of notes would involve finding an optimally harmonically compatible note. As mentioned before, in Vox Populi, the consonance is measured according to the *Id* value. This value is obtained from the interface control and can be changed by the user.

Biological Control

The *bio* scroll bar allows interference in the duration of the genetic cycle, modifying the time between genetic iterations. Since the music is being generated in real time, this artifice is necessary for the timing of the different processes that are running. This value determines the slice of time necessary to apply the genetic operators, such as crossover and mutation, and may also be interpreted as the reproduction time for each generation.

Rhythmic Control

The *rhy* scroll bar changes the time between evaluations of musical fitness. It determines the "time to produce a new generation" or the slice of time necessary to evaluate the musical fitness of the population. It interferes directly in the rhythm of the music; any change makes the rhythm faster or slower.

Octave Control

The *oct* scroll bar allows enlarging or diminishing the interval of voices considered in the vocal range criterion. The octave fitness forces the notes to be in range *H*, assuming that *H* is the range of the human voice and associated with the central keys on the piano; but since several orchestras of instruments are used, this range is too limited for some instruments. We originally intended to restrict the generated voices to specific ranges in order to make those voices resemble the human voice. Nevertheless, a user can now enlarge these ranges by using the octave control.

Orchestra Control

Six MIDI orchestras are used to play the sounds: (1) keyboards; (2) strings and brasses; (3) keyboards, strings and percussion; (4) percussion; (5) sound effects and (6) random orchestral parts, by taking an instrument from the general MIDI list. Using the order above, these orchestras are sequentially changed into time segments controlled by the *seg* scroll bar.

Interactive Pad Control

The "Pad On" button enables and disables the pad change on the controls defined above. They may be grouped into two pairs, which may be interpreted as variables of a 2D phase space. This allows a user to draw and orient the curve to determine the evolution of the music.

Fitness Displays

Three other displays allow the user to follow the evolution of fitness. The upper display, at the right side of Fig. 6, shows the notes and the fitness of the chord that is being played.

In the middle display, a bar graph shows the four voices (bass, tenor, contralto, soprano) and their values. It is equivalent to the membership function values related to the range of the voices. The bottom display shows the melodic, harmonic and octave fitness bars.

CONCLUSION

Despite the fact that Vox Populi works at the level of sound events controlled by MIDI protocols, or notes, in a macrostructural context, we learned two lessons. First, an evolutionary computational approach was successfully applied to generate complex sound structures with a perceptual and efficient control in real time. Second, applications of evolutionary computation may be foreseen to prospect sound synthesis. Complex behavior systems have been used for sound synthesis, like Chaosynth, which uses cellular automata to control structures [17]. In Chaosynth, the generation occurs via granular synthesis. In another approach, Fracwave [18] uses the dynamics generated by complex systems to synthesize sounds using complex dynamics.

We may say that varying the fitness controls in Vox Populi promotes a "sound catastrophe," in which the previous winner may no longer be the best. Conditions for survival have changed, as they do in nature.

The question we pose is how does an idea, or concept, survive? Vox Populi is simple, efficient and has been used in different ways, which may be considered variants: as an autonomous or demonstrative system generating music; as a sound laboratory, where people can try and experience the sound produced; as a studio, manipulating and generating samples that have been used in compositions and in sound landscapes. Another use currently being considered is to couple the system with sensors, allowing the user to describe orbits in space that would be treated like the 2D curves supplied by the interactive pad. Will Vox Populi survive?

Vox Populi means "voice of the people." Since the individuals in the population are defined as groups of four voices, we can think of them as "choirs," fighting to survive and to be present in the next generation, while the environment and survival conditions are changing dynamically.

One of the first known proposals to formalize composition was made by the Italian monk Guido d'Arezzo in 1026, who resorted to using a number of simple rules to map liturgical texts in Gregorian chants [19] due to the overwhelming number of orders he received for his compositions. The text below is attributed to d'Arezzo. His compositional approach has survived for several centuries, and even today, we still seek strategies for constructing the unknown melody.

> As I cannot come to you at present, I am in the meantime addressing you using a most excellent method of finding an unknown melody, recently given to us by God and I found it most useful in practice. . . .
>
> To find an unknown melody, most blessed brother, the first and common procedure is this. You sound on the monochord the letters belonging to each neume, and by listening you will be able to learn the melody as if you were hearing it sung by a teacher. But this procedure is childish, good indeed for beginners, but very bad for pupils who have made some progress. For I have seen many keen witted philosophers who had sought out not merely Italian, but French, German, and even Greek teachers for the study of this art, but who, because they relied on this procedure alone, could never become, I should not say, skilled musicians, but even choristers, nor could they duplicate the performance of our choir boys [20].

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