Creating Evolutionary Soundscapes with Gestural Data

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Abstract. *In Generative Art produced with computational support, gestural data has been increasingly considered an important source of information that is, at the same time, intuitively created and conveying the artistic meaning of the resulting artwork. In the same way, the concept of self-organization has been used in the study of human creativity and art production. This article describes the implementation of two interactive multi-modal artworks that use these two principles to compute adaptive sonifications. As gestural data, the first implementation uses the mapping of a handmade drawing collection. The second one uses the retrieval of body action movements performed by a dancer. The resulting soundscapes are created by a dynamic system implemented in PD (PureData). It uses principles of Evolutionary Computation (EC), which yields to the creation of a synthetic adaptive population of sound objects based on the retrieved gestural data. That emulates the biological evolution of individuals undergoing the processes of selection and reproduction. The overall sound is constantly generated by all individuals within the population. This is the system output, which can be described as a self-organized synthetic soundscape engendered by the initial artistic generated gestural information.*

Keywords: generative art, gesture, evolutionary algorithm, soundscapes, sound synthesis.

1. Introduction

The literature describes that, throughout Western Art History, the focus was into the resulting artistic object as the final production of an artist endeavor. However, in the 1950s, probably due to the advances of electronic technology, the artistic process started to take over and slowly equaling with the materiality of the final product, bringing about new artistic ideas and concepts. Lucy Lippard, when analyzing the artistic production of Sol LeWitt, said that his work was based on the premise that its “concept or idea is more important than the final object” [Lippard, 1973]. This concept is similar to the one of Generative Art, which is defined as any form of art where “a system, with a set of defined rules and some degree of autonomy, is put on movement” [Galenter, 2003].

Nevertheless, generative processes was already explored in music, even before computers had flourished. Few centuries ago, around the 1650s, priest *Athanasius Kircher*, based on the belief that musical harmony reflected the proportions of the universe, wrote a book entitled: *Musurgia Universalis*, in which he described the design of a musical generating machine [Cramer, 2005]. In 1793, *Hummel* published a system to generate musical score, whose creation is attributed to *Mozart*. In this system, music was generated by a random process, based on a dices tossing game. This system embeds most of todays generative art elements, in which a musician can create, from simple building blocks (predefined musical bars), a myriad of original compositions. Later, this was known as the *Mozart's dice game* and influenced many composers, such as *John Cage* and *Hiller Lejaren* to create a musical piece entitled HPSCHD [Husarik, 1983].

In visual arts, for the processual artwork approach, the act of drawing can be seen as the registration of artistic gestures. This process is analyzed by *Walter Benjamin* as coming from "...another level within the human psyche. It is a locus for signs by which we meet the physical world" [Dexter, 2005]. This aspect can be compared to the technical principle of computer programming language, as defined by *Cramer*, when he commented that programming is similar to "controlling matter through the manipulation of symbols" [Cramer, 2005]. An artwork autonomously created by a generative process, such as a computational system, is not restricted within an specific field, but in a multitude of different areas of knowledge, even beyond visual arts and music. Adaptive methods, such as Artificial Intelligence, Neural Networks and Evolutionary Computation, can then be seen as technological strategies that fit the principles of generative artwork, due to their ability of creating an artistic process that is dynamic and immersive.

Here we describe two artwork implementations using gestural data and evolutionary computation methodology. The first one is an installation where digital images from handmade drawings beget dynamic soundscapes created by evolutionary populations of sounds. This generative process continuously produces new sonic material, based on graphical features retrieved from these images. The second one is based on dance gestures collected using accelerometers attached to the limbs of a dancer. These movements were represented as time series describing these body parts displacements. They were later translated into a population of sounds that altogether produces the soundscape.

Both data types (drawings and dance movements) share the common characteristic of being similar and variant, which means that all drawings from the collection, as well as all dance movements are akin but not identical. This resembles a biological population where individuals are similar, as they belong to the same specie, although there are no occurrence of clones. These data were mapped into what is named here as sonic genotypes, which represents the acoustic characteristics of a sound object, here taken as an individual belonging to a synthetic population. The following section describes the foundations of the evolutionary soundscape system. Section three describes the mapping from gestural data to the genotypes that feeds the evolutionary system. Section four presents the implementation of the evolutionary soundscape system into PD (PureData). In section five we conclude this work with a brief discussion of the achieved results and possibility of forthcoming implementations.

2. Evolutionary Soundscapes

A soundscape can be seen as the acoustic corresponding of a landscape; a sonic environment that, in spite of constantly presenting a stream of original acoustical information, never repeats itself, but has plenty of unique perceptual features in a way that, with only acoustical cues, our mind can easily recognize and set it apart from other soundscapes [Truax,2008]. We can hear examples of natural soundscapes in locations nearby waterfalls, inside a forest, during a traffic jam, in a crowded central station, and so forth.

It is interesting to note that Schafer formally described soundscapes as "natural, self-organized processes usually resultants of an immense quantity of sound sources, that may be correlated or not, but conveys an unique sonic experience that is at the same time recognizable and yet always original" [Schafer,1977]. This can be seen as an open complex system with self-organized emergent properties. About the attempt of artificially creating soundscapes, Truax noted that: "soundscape composition might aim to computationally emulate self-organized biological or natural acoustic environments" [Truax,1978], which is one of the goals of the work here presented. Still in [Schafer,1977], it is defined three types of sonic elements that compound a soundscape. They are: 1) keynotes, 2) signals and 3) soundmarks. Altogether, they weave the immersive sonic environment of a soundscape. Keynotes are the sonic elements that define a soundscape, although they may not always be present or consciously perceived. Signals are the foreground sonic elements, always present in the soundscape. Soundmarks are the sonic elements that are unique to one specific soundscape, which gives its identity and set it apart from other soundscapes.

Several methods for designing an artificial soundscapes were tried already, such as the ones described in [Blauert, 1997], [Pulkki, 1997] and [Chowning, 1970]. They are mostly based on the parametric control of sound-sources (i.e. sound localization cues, random appearances, etc.) but, when compared to natural soundscapes, they still lack the ability of creating a truly self-organized processes. In a systemic viewpoint, we named as self-organization the phenomenon presented by certain complex systems that are opened and formed by the interaction of a variant group of agents (for soundscapes, agents are sound-sources). The interaction of all internal and external agents are perceived by the mind as an emergent self-similar process. As an example, a biological population can be seen as a self-organized system, as it is complex, opened (dynamically exchanging individuals) and self-similar (with an identity). In this work we approach two important features of a natural soundscape: sonic location and self-organization.

There are many techniques that help to emulate the sonic localization field of a soundscape. Some of the most usual ones are: Interaural Time Difference (ITD) [Kelly,1991], Interaural Level Difference (ILD) [Birchfield, 2005] and Head-Related Transfer Functions (HRTF) [Brungart,1999]. ITD cues refer to the time difference for the acoustic waves coming from one single sound-source, to arrive in both ears of one listener. Similarly, ILDs describe the difference of its intensity arriving in both ears. HRTFs, however, are a collection of spatial cues, given by digital filters, that represents the sound processing of the listener's body anatomy, such as the head shape and size, outer ears and torso. ITDs and ILDs can be easily emulated by a computational model. ITDs can be assessed by the time-delay variation between audio channels and it delivers a convincing sound-source localization of its azimuth angle within the horizontal plane. It was used in studies such as in a robotic sound source localization system [Murray, 2004].

Regarding the self-organization of a soundscape; it is known that adaptive computing methodologies can produce emergent, self-similar complex systems [Holland, 1992], [Holland,1996]. Among those, there is the Evolutionary Computation (EC); a method that is inspired in the problem-solving approach observed in nature. This method seeks out, in evolutionary steps, for the best solution among a landscape of possible solutions. Since 2001, the researching group at NICS (Interdisciplinary Nucleus of Sound Communication) has worked with EC in sound design and music composition. Some of these techniques created highly textured sonic outputs, which is a feature found in natural soundscapes [Fels, 2001], [Manzolli,2001]. We developed the *ESSynth*; a system using EC principles, in which a population of waveforms evolves along time, in generation steps, by the action of genetic operators and a fitness functions, where the sound output is the overlapped queue of best-individuals of each generation [Manzolli, 2001], [Fornari, 2001]. Later, we incorporated sonic spatial localization cues in this method [Fornari, 2006], [Fornari, 2007]. These are based on the application of concepts from the theory of Complex Adaptive Systems (CAS) for sound synthesis [Caetano, 2007]. As described in [Holland,1992], CAS consists of a large number of agents with interconnected parameters that, altogether, exhibits coherent emergent properties. It is also known that CAS can generate emergent properties by means of its agents competition and/or cooperation [Holland,1996]. Its systemic behavior is the result of interactions between a large number of its formant agents, leading to the process of self-organization, in which a CAS may pass through several organizational states [Foerster, 1960]. We investigated here whether such process can also be created by an ESSynth model to generate soundscapes [Caetano, 2007]. Originally, ESSynth was based on a population of waveforms (the ESSynth "individuals"). Each individual had its own genotype; a group of psychoacoustic curves that defines how its waveform is perceived and understood.

In this work we aimed to apply an ESSynth method to generate emergent sonic properties based on external aspects. Our model of individual is an algorithm (a Pd patch) in which a genotype is described by few acoustic descriptors, initially mapped from the gestural data and simple interactive parameters, to control the evolutionary soundscape system. As it is later described, this seemed to suffices for the creation of dynamic soundscapes.

Here we implemented an evolutionary system with a variable-size population that starts from only two individuals. As the evolutionary process progresses, new individuals will be born and aging individuals will dye. The output is a soundscape generated by all active (alive) individuals within the population. Individuals will also move inside the population and its location will be perceived as a moving sound source. By proximity, individuals will generate offsprings whose genotype is produced by genetic operators, from the two genotypes of its parents. Each genotype is made of six arrays. Each array controls one acoustic parameters. They are organized in two main blocks: tonal and stochastic. The tonal part is in charge of tonal sounds (presenting pitch). It has three parameters of control: 1) intensity, 2) frequency and 3) distortion. The stochastic part is responsible for the generation of noisy, or percussive, sounds and has also three controlling parameters: 1) intensity, 2) center frequency of a band-pass filter, and 3) distortion, given by this filter bandwidth. It is interesting to notice that, with this implementation, the distortion parameters make a bridge from tonal to stochastic. Without distortion, tonal part generates a sine-wave sound and the stochastic part delivers white-noise. As the distortion rate increases, the tonal part output goes toward a noisy sound (made by the waveform clipping) and the stochastic part, by the constriction of its filter bandwidth, tends to become more tonal, a whisper-like sound.

By default, each array has a fixed length of 100 elements, real numbers, normalized between [-1,+1]. They are time series representing the independent variation of each acoustical parameter. Each initial genotype will receive a matrix M(6x100) from the previous mapping of gestural data. From top to bottom, the M matrix lines are respectively: tonal intensity, tonal frequency, tonal distortion, stochastic intensity, stochastic frequency, stochastic distortion.

3. Retrieving Gestural Data

Gesture, as an artistic expression, is here seen as the movements and actions embodying artistic intention. So, by retrieving its data, it may be possible to access information that resembles, at some extent, the art meaning contained in the final artistic objects (drawings) or action (dance), and expressing it in the sonic domain by using this data to generate dynamic soundscapes throughout an evolutionary system. The retrieval of such data is described in the next sub-sections.

3.1. Gestures from Drawings

We started with drawings picked from a large collection (over 200 conceptual drawings) that are very similar but, as they were hand made, never identical to each other. They were all created through the repetition of a similar, back-and-forth gesture. This naturally creates a collection that resembles a biological population of individuals belonging to the same specie, although, its correspondent evolution only occurred during its artistic process of creation. By using the ESSynth method, it seemed feasible to develop an artistic installation in which characteristics of each drawing could be mapped into genotypes of individuals (sound objects) gathered into a population where its continuing evolution creates a dynamic soundscape.

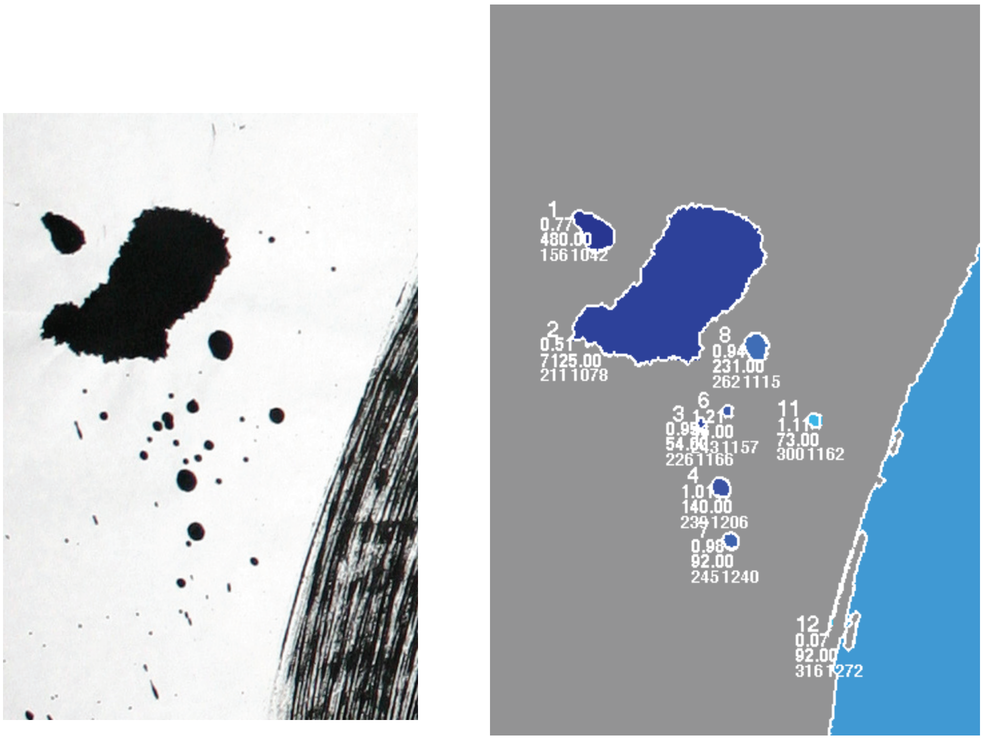

Figure 1.Mapping a conceptual drawing.

The first step was the creation of a method to map drawing features into sonic features. Figure 1 shows, on the left side, details of the digital image of an original drawing belonging to this collection. On the right side, it is shown the mapping of this image, done by an algorithm developed in Matlab. Note that the mapping collects several objects belonging to the same image. Each object has also several features associated with it. Some of them are shown in the Figure above, imprinted at the left side of each object.

By analyzing these objects, we considered that they belong to three types that, altogether characterize the "individuality" of each drawing. Such graphical elements are found in all drawings. They are here named as: Cumulation, Repetitions and Fragments. Cumulation is the biggest object found in one image. There is only one cumulation per drawing. It is usually given by the concentration of paint at the bottom of the image, where the drawing gesture initiated. Repetitions are objects with a stretched shape. They are normally the quasi-parallel traces found at the middle of the drawing, generated by the back-and-forth gesture. Fragments are small, detached and circular spots of paint dripped at the outlying parts of the drawing, spilled due to the gesture intensity. Following that, we related each graphical element with a single sonic aspects that seems to synesthetically represent, in the acoustic domain, each graphical aspect of the drawings. We related the object Cumulation to stochastic low-frequency sonic features, steady and with longer duration. Repetitions were related to tonal sounds, middle-range frequencies and middle time duration. Fragments were related to short time duration , like sparks of either stochastic or tonal sounds. Each image mapped generates several graphic objects, one is the cumulation and the others are either fragments or repetitions. Each object has several features associated with it. They are mapped into a matrix with the genotypes of the initial individuals that will start the evolutionary system.

We used the projection of the bi-dimensional shape of each object into horizontal and vertical coordinates to create the time series of 100 elements. For tonal sounds, we used its horizontal projection. For stochastic sounds, the vertical projection was used. The distortion rate was given by the difference between horizontal and vertical projections. Then, each projection was circularly shifted according to the distance between its object and the image origin. The tonal intensity curve is the blend of all horizontal projections modulated by each object eccentricity parameter. Tonal frequency curve is the blend of all vertical projections modulated by the respective objects normalized angles of orientation. Tonal distortion is the blend of the projections difference, modulated by the inversion of its eccentricity. The stochastic intensity curve is the blend of all horizontal projections modulated by the square of each object normalized area. The stochastic frequency is the blend of all vertical projections modulated by the respective objects normalized angle of orientation. Stochastic distortion is the blend of the projections difference modulated by its eccentricity.

3.2. Gestures from Dance Movements

Rudolf Laban, a famous choreographer and movement theoretician, in his work: the Laban Movement analysis [Pforsich, 1977], postulated eight types of Basic Movement that are the combination of three independent categories of Effort Actions (Space, Weight and Time). They are: Float, Punch, Glide, Slash, Dab, Wring, Flick, and Press. These actions have been used by several acting and dance schools as movements embodying specific emotions. These gestures can be retrieved and used in several ways. For instance, the InfoMus Lab, has developed the software EyesWeb, a multimodal interactive systems for the real-time analysis of movements and acquisition of expressive gesture [Mancini,2007]. Here at Unicamp, in a collaboration between NICS and the Interdisciplinary Group of Theater and Dance, a performance called *Elementaridades* was developed, inspired in the physical movement of particles of matter, and its application of Rudolf Laban´s principles of movement in dance [Maia et al, 2001].

In this work, similar gestures were collected as movement data, using as gestural interface two Wii remotes (Wiimote) and their accessory, the Nunchuck. Each part of these four units (2 Wiimotes and 2 Nunchucks) has embedded an accelerometer that transmit wirelessly, via bluetooth, the real-time acquisition of seven motion parameters. Three of them are named, in aviation terms, as: yaw, pitch and roll. They referred to the accelerometer rotation around each of its three spatial axes [LaValle, 2006]. The next four parameters transmitted are: x, y, z (for each axis rotation raw angle) and *accel* (raw acceleration movement, disregarding its direction).

The equations below show the rotation matrixes describing the correlation between: yaw, pitch and roll with its rotation about the orthogonal axes, related to each respective angle: x, y and z.

$$yaw(x)=\begin{pmatrix}\cos(x) & -\sin(x) & 0\\ \sin(x) & \cos(x) & 0\\ 0 & 0 & 1\end{pmatrix} \quad pitch(y)=\begin{pmatrix}\cos(y) & 0 & \sin(y)\\ 0 & 1 & 0\\ -\sin(y) & 0 & \cos(y)\end{pmatrix} \quad roll(z)=\begin{pmatrix}1 & 0 & 0\\ 0 & \cos(z) & -\sin(z)\\ 0 & \sin(z) & \cos(z)\end{pmatrix} \qquad (1)$$

The data was collected by a computer model (a PD patch) that recorded each movement in synchronism with the seven parameters of each one of the four accelerometers (given a total of 28 time-series) sampled at every 50 milliseconds. The accelerometers were attached at the dancer's knees and elbows. The resulting data was given as a text file, automatically created by this patch.

Table 1 shows the eight body actions described by Rudolf Laban and its formant aspects. The movements retrieved were performed by the a dancer according to the premisses shown in this Table.

Table 1. Body Actions, as described by Rudolf Laban

Action	Space	Weight	Time
Sliding	Direct	Light	Slow
Fluctuating	Flexible	Light	Slow
Punctuating	Direct	Light	Rapid
Shaking	Flexible	Light	Rapid
Pressing	Direct	Firm	Slow
Twisting	Flexible	Firm	Slow
Punching	Direct	Firm	Rapid
Whipping	Flexible	Firm	Rapid

These eight body movements were recorded and processed by the PD patch. The Figure 2 shows two random scenes, with image processing, to pinpoint the movement trajectories of each body actions recorded while the gestural data was collected in real-time by the wireless interfaces. The Figure 2, at the left side, shows a moment where the dancer was less active, almost standing still. The Figure 2, at the right side, depicts a moment where the dancer was very active, quickly waiving her arms, as they almost disappear from the image. It is possible to see, as a detail, particularly in the left image, two of the four accelerometers attached at the dancer's thighs and arms.

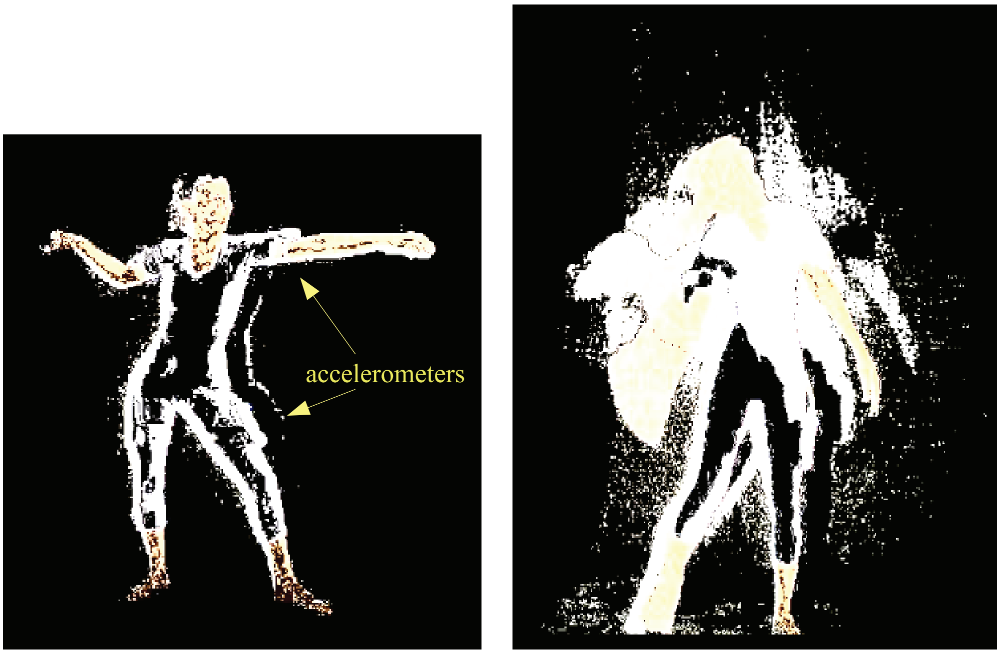

Figure 2. Scenes of the body actions recordings.

Using these interfaces, it was possible to collect gestural data out of the body movements, wirelessly and in real-time. Figure 3 shows a segment of the time series collected by one of the four accelerometers, where there are 7 synchronous curves: pitch, roll, yaw, acceleration, three raw rotation angles: x, y and z. They were then used to create the matrix M(6x100), corresponding to the individual genotypes that initiate the population, in the evolutionary system. These six arrays, compounding the genotype, were fed with data collected from one specific body action recording. In this implementation, we translated the mean variation of the accelerometer parameters attached in the dancer's arms to the tonal intensity and tonal frequency arrays. Similarity, the ones attached to her legs were translated to stochastic intensity and stochastic frequency. The tonal distortion was created from the difference between tonal intensity and frequency, as well as the stochastic distortion, given by the difference between stochastic intensity and stochastic frequency.

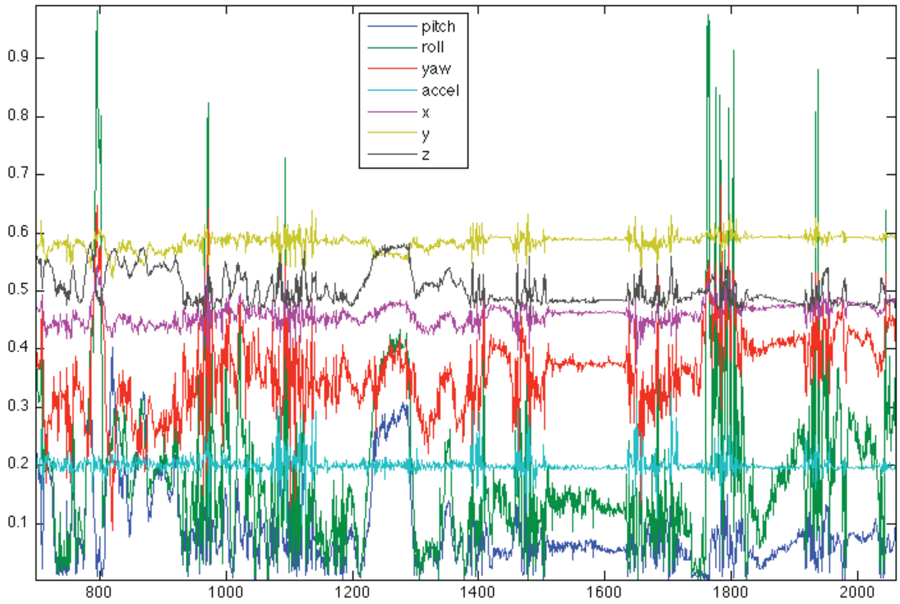

Figure 3. Segment of one body movement. This collected data was given by one accelerometer.

4. Implementation of the Evolutionary System

PD is an open-source visual programming language used for the implementation of real-time multimedia installations (www.puredata.org). A program developed in PD is called a patch, made of interconnected objects. They can be ether: preset objects, sub-patches (a patch inside the main patch) or abstractions (a separate patch that works as an object inside the main patch). An interesting feature of PD programming language is the ability of developing patches that are able to create and control other objects and patches. This follows the meta-programming paradigm, in which code can be written by code, without human intervention. There are recent efforts in the development of objects better shaped for meta-programming, such as the *iemguts* library, been developed by *Iohannes Zmölnig*, that aims to emulate self-aware agent system [Zmölnig, 2008]. Nevertheless, PD is already capable of exploring, at some extent, the automatic generation of patches by other patches.

The evolutionary sound synthesis, as originally introduced in [Manzolli, 2001] has a population of individuals, a Target set and two dynamic processes: 1) reproduction and 2) selection. The Target set guides the evolutionary process, similarly to the conditioning environmental pressure over a biological population. Selection uses fitness function to select the population individuals by measuring their fitness. It eliminates individuals not fit and find the fittest one, according to the sonic characteristics of individuals within the Target set. Reproduction uses the genetic operators: crossover and mutation, to create new individuals, offsprings of the best individual and the other ones within the fixed-size population.

In this work we used instead a variable-size population that starts with few individuals whose genotypes where mapped from a select group of gestural data. Then, the reproduction process creates new individuals. The output sound is given by the coexistence of all population individuals, which generates the dynamic soundscape. Figure 4 shows the implementation of the reproduction process. This figure depicts, on the top, twelve tables. On the left side, there are six tables. They belong to the genotype of the first individual. On the right side, there are the correspondent six tables with data from the genotype of a second individual. The genotypes are the mappings from the gestural data (drawings or movements) that are stored as text files. Both have the same organization. They are formed by seven lines, each one finished with a semicolon. The first line can be either the word "active" or "inactive", that informs the evolutionary system whether this individual is active, where active means that this individual is "alive" and can be picked by the reproduction process to create a new individual, as shown in Figure 4. The other six lines represent one of the six arrays of the individual genotype. Each line is a sequence of one hundred normalized real numbers (from -1 to +1). They all receive the data from the gestural matrix M(6x100).

Individuals are implemented as a PD abstraction (a separated patch). Each individual is an instantiation of this abstraction which one numeric argument. By this argument, the instantiation reads the correspondent genotype text file. The initial arguments are used to pass its unique name to all six arrays belonging to each individual genotype. Using the ITD sound location technique, as described in section 2, we emulate the individuals dynamic position in a horizontal plan, as if they were moving inside a sonic location field. The casual encounter between individuals raises the chances of an offspring creation. This process entails to a varying-size population, different from the original ESSynth method, where the population had a fixed amount of individuals. Another distinction is that the output sound in ESSynth was given by the queue of each best individual from a population generation (audio samples of several ESSynth simulations are available at: www.nics.unicamp.br/~fornari). In this work, the sound output is given by all individuals coexisting at each moment with the variant population. This also makes possible the events of: population extinction; when its number of individuals decreases to zero, or super-population; where all computational resources of the machine running this Pd patch would be taken. We can set thresholds to avoid these two extreme scenarios but the natural variation of population size inside these limits is enticing and welcome for the perspective of this artwork.

The data from two groups of six tables corresponding to the genotypes of two active individuals are used by the genetic operators: crossover and mutation to create the group of six tables corresponding to the genotype of their offspring. These genetic operators are implemented in the sub-patch named "pd genetic operators", as seen also in Figure 4. This sub-patch receives two normalized scalar parameters, from the vertical sliders. As labeled, they are the coefficients of each genetic operator rate. These parameters go from zero to one, meaning that they vary from null to full genetic operation. They can be set on-the-fly by the user.

Similar to the ESSynth original method, this implementation also embodies the paradigm of variant similarity. However, with the sound output resulting from a dynamic population formed by all active individuals generated by the reproduction process, a soundscape will be naturally self-organized.

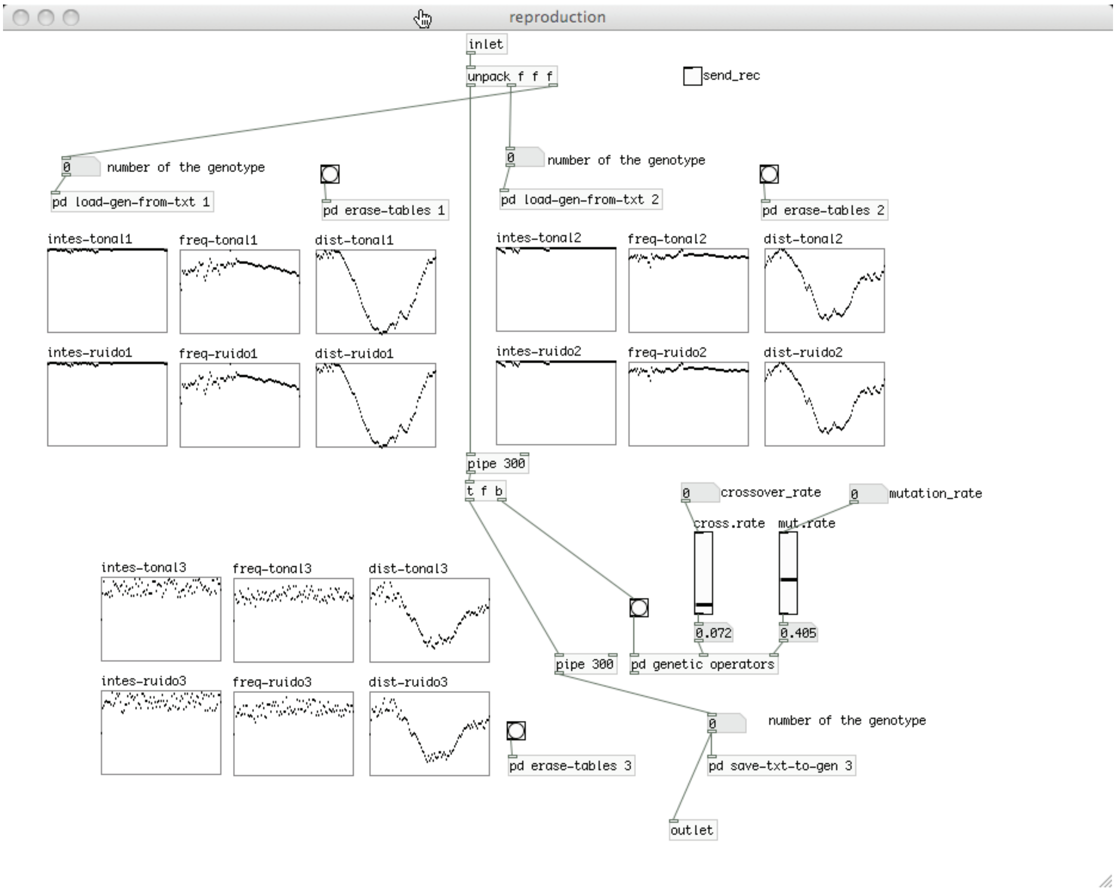

Figure 4. Implementation of the Reproduction process.

5. Conclusions

This work is about the implementation of an evolutionary soundscape system in PD that used as genotypes two types of artistic gestural data: one from the mappings of conceptual drawings and another from the time series retrieved out of dance movements.

The evolutionary system implementation made possible to indefinitely extend the duration of a processual artwork into the sound domain. We aimed to experience with these multimodal gestural data that seeded the evolutionary sound process in the creation of a soundscape resembling gestures that came from processes that originated art installations of other medias. The drawing collection, here seen as the registry in paper of gestures from a processual artwork, was finnished by the time we had collected its data, by the image mapping of of some drawings. Differently, the dance movements were collected as the dance performance was taking place. The evolutionary system took these gestural information and turned them into a soundscape that can exists for as long as the system is running, thus creating a dynamic population that does not repeat itself although retaining its sonic identity. Examples of the sound generated by this system, as well as the entire implementation in PD can be downloaded from the following link: www.nics.unicamp.br/~fornari/sbcm09.

The implementation of this system derives from the ESSynth method, in which there was a population of waveforms evolving in time guided by a Target set, representing the pressure of environmental conditions found among any biological population. However, in the implementation shown here, there is no Target set. This is due to the fact that, as the population is growing out of few individuals, we thought that a selection criteria could restrict the chances of this system to create a rich soundscape. Nevertheless, we plan to implement in further works a selection process based in some enhancements that will enable the external interaction with the dynamic soundscape creation process. We may experience with the usage of sensors and/or interface controls. Motion sensors and web-cams can easily be used with Pd patches to emulate external conditions that guide the evolutionary process. One topic that we plan to implement is the concept of energy intake, also known as "synthetic forager" where individuals can seek out and compete for food. The concept of individual gender is also still to be implemented. We plan to experiment with the notion of multiple gender individuals. We may as well implement a childhood period in the system, where individuals wont be able to go through the reproduction process but could receive information from other active individuals, somehow emulating a learning period. As seen, there is a myriad of interesting possibilities using the evolutionary method to create new implementations that can turn out into artwork installations, as well as being used by processual artworks exploring the multi-modality and interactivity, in order to reach immersive and adaptive sonic experiences.

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