[clone _dac 124]: Real-time Massively Multichannel Music in Pure Data

Federico Cámara Halac
Ohio State University - School of Music - Advanced Computing Center for the Arts and Design
fdch.github.io
camarahalac.1@osu.edu

ABSTRACT

This paper describes and discusses several approaches to working with massively multichannel music live using pure data. traditionally, most computer music works have had a tendency towards fixed media due to its stability and robustness when it comes to performance. Likewise, the spatialization paradigm that has governed most electronic music continues to be stereo, with the use of diffusion or ambisonics as last resort spatialization techniques. Emphasizing the importance of space, this paper describes the design of a real-time computer music piece called Lorenz Variations, written directly for high density loudspeaker arrays (HDLAs) of variable lengths. In using point-source location techniques and vector-based amplitude panning (VBAP) as composing tools instead of spatialization tools, I argue that space is not just a musical parameter but a compositional source that expands our listening experience into yet unknown dimensions, and it is our duty to explore the many aesthetic potentials it advances.

1. INTRODUCTION

Spatialization is a topic of great discussion in music because computer–in fact, all writing that deals with spatialization begins with a similar sentence–, so in this paper I will only refer to the most recent space incursions involving over 20 speakers, tracing a brief historical journey needed to demonstrate the need, as Kerry Hagan would say [**?**], for work space.

Analogical spatialization techniques have existed since the late 1930s, both within the stream of musique concrète (Varese, Schaeffer, etc) as in electronic music (Stockhausen, Meyer-Eppler, etc). [1] Although much of the electroacoustic production has came to frequently use four channels, for Harrison [**?**], stereo has been their norm, due to a "relatively easy availability of stereo tape recorders that supported the consumer LP stereo market since the late 50 and up." [**?**, 4] [2]

[1] This is the case with the famous four-channel percussion piece *Kontakte* by Stockhausen, for which the composer made spatializations with a turntable and a series of microphones, and the renowned live electronics performance of the *Symphony for a lonely man* by Schaeffer and Henry [**?**].

2. A BRIEF SPATIAL HISTORY

2.1 American quad

2.1.1 *Chowning*

With the emergence of computer music in the United States, mainly through Max Mathews at Bell Labs, and then the assembly at CCAMLR's Stanford, Chowning was already in the late 1960s pretending digitally locating the sound using quadraphony, using a series of equations that contemplate an equidistant listener the speakers in the centre, with the indication that there would be "a geometric distortion of the spatial image for any other listener depending on their distance from the center" [**?**]. This capacity of the computer to calculate trajectories by returning sample values (samples) required for the transducers, is contrasted in some measured with the practice of stereo broadcasting in a multi-channel space [**?**]. However, we will not stop at this dichotomy which for many counts as identity, aesthetic background, and even political, and we will emphasize the possibility of the coexistence of both ways of manipulating sound, either by means of a physical potentiometer or through a computerized solution.

2.1.2 *Moore*

Another spatial approach in quadraphony is that of F's double room. R. Moore [**?**], in which the values necessary for the energies of the speakers that act as 'holes of an internal room (where the audience is located), leaving pass on the sounds that move in the virtual space of a room external. Ballan, Mozzoni and Rocchesso [**?**] would carry this concept to a real-time implementation using MIDI and the then recent IRIS-MARS system [**?**]. Mott and Sosnin [**?**] also led to the Moore's model, emphasizing the construction of the interface ultrasonic (i.e., a magic wand) controlled by the listener to manipulate the spatialization of sound within the inner room. Currently, there is the external one for Pure data made by Shahrokh Yadegari [3] that implements in real time the formulas of the double Moore's room [**?**].

2.1.3 *IID / ITD*

In 1986, with the Chowning system being a strong precedent, Kendall and Martens describes a spatial reverberation system in which "a reflected and spatially distributed sound

[2] However, Harrison clarifies, "I'd say this isn't so bad —it is, after all, a substantial improvement on monkey." [**?**, 4]

[3] http://yadegari.org/space.html

field is intended to help listeners locate sounds... while imparting a very strong impression of a specific reverberant environment" [?]. It is important to note Kendall's research in the simulation of sound source locations in headphones, particularly his studies on the difference in interaural intensity (IID) for bass frequencies and the interaural time difference (ITD) for high frequencies [?]. Following these two precedents, Alain Martel [?] builds the SS-1 Sound Spatializer, a spatialization processor using the MIDI format for real-time operation. In both cases, the algorithms of spatialization combine IID, phase decoupling [4] and change of amplitude to simulate distance, as well as the manipulation of frequencies by simulating the Doppler effect and inclusion of elevation by the then novel concept of periphery' (or full sphere) [?] precursor, of some way, from the *ambisonics* technique.

2.1.4 Lezcano

Fernando Lopez Lezcano [?] would build a four-channel spatialiser written for Common Lisp Music, using distance simulations based on fractional delays and Doppler effect, attenuation and filtering based on distance '1/r'. (where 'r' is the distance between the sound source and the listener), and the angular component, or *azimuth*, with the implementation of a crossfade non-linear equivalent to a *spread*, to better control distribution of energies between channels. It's remarkable how Lezcano rules out the implementation of the ITD precisely because "its effect depends very much on the position of the listener with respect to the speakers." [?, 2] Another precedent of the movement The first space project on four channels was the Quad Pan, made by Pérez et al [?], a spatialization system with a visual for the design of spatial trajectories using the formulas proposed by Chowning and Moore. [5]

2.2 European quad

2.2.1 GRM

In the same way, but on the old continent, according to Teruggi [?], spatial modifications within its categories "Morpho Conceptual" of the now known *GRM Tools*, included the Doppler effect, the complex panning, simulations of spatial positioning, and reverberance. [6] A Interesting spatialization work was done in 1989 under the direction of Luciano Berio at Tempo Reale called 'TRAILS', which combined software and hardware to provide real-time control and reading graphic scores for trajectories space. [?]

2.2.2 IRCAM

In 1992, the "spatializer" [?] performed at IRCAM, based on convolution [7] and reverberation with databases taking models of room acoustics and taking them to what they called virtual acoustics, presents an important antecedent for the development of software based on real models that will bring, thanks to the work of Jean-Marc Jot (among several others) to the recent 'spat' [?, ?].

2.3 New Concepts

2.3.1 Ambisonics

The evolution of *ambisonics* is more than 30 years [?, ?], and presents a concept novel for the understanding of the sound space. Mainly, and leaving aside the technical explanation on which it's based, *ambisonics* seeks to make 'disappear' the speakers, and "which in turn implies that the speakers must treated as a system to produce a large sound field in the space, rather than as individual sound sources that can be perceived as such." [?, 1]

2.3.2 Vectors

In the same way, but using another very efficient technique, Ville Pulkki [?] introduces amplitude panning based on vectors (VBAP), with an implementation in the MAX/MSP environment and in Pure Data (currently,) [?] during his residence in CNMAT [?, 3]. [8] On the other hand, the spatialization spectral [?] is a new way of constructing the space, since it allows to make frequency band distributions in multichannel systems in time real.

2.3.3 Transfer Functions

The concept of stereo, however, still applies in the late 1990s as Harrison rightly mentions. [9] That is, a (ideal) listener located equidistant to the speakers, as suggested by the indications in the spatialization of *Dialogue de l'ombre double* by Boulez, made by Sandroff [?]. This means that, for more that there are more than two speakers, the concept of left and right rules immutably. Within the stereo frame, a strong space audio development was born in the early nineties with the advent of virtual reality (VR) technologies [?, ?], [10] using mainly head-related transfer functions (HRTFs). [11] The limitations of these are known [?] but have been extensively developed and continue to be useful for headphone listening [?, ?, ?, ?, ?, ?] and for the composition itself, as in Lee Gilboa's *In(n/H)er Head* [?]. One of the biggest acoustic problems that the HRTFs have not yet been able to solve is the location of acoustic spaces in front and behind that for a listener is intuitive and simple to turn your head slightly, which cancels any computer if the listener is not wearing headphones.

2.3.4 Wave Field Synthesis

An important spatialization technique that has a long line of development is that of Wave Field Synthesis, both in institutions such as the Technical University (TU) in Berlin

[4] For a detailed analysis of phase decoupling, see [?]

[5] For other interface designs for spatialization, see [?, ?, ?, ?, ?]

[6] It should be noted that these tools are the equivalents of the GRM studios that since 1948 promoted more than 1400 works at the time of the writing of the cited paper.

[7] For more information on convolution, see [?, ?]

[8] It is worth commenting on the appearance of different file formats for the storage of spatial information such as MPEG-4 [?, ?, ?] the SDIF [?], the multichannel extensions to WAV and AIFF formats [?], and the inclusion of sound information within the Virtual Reality Modeling format Language (VRML) [?]

[9] For stereo job references, check [?]

[10] The Whitehead Audio Browser [?] is one of the first virtual navigation interfaces of sound database

[11] It's worth noting the numerous databases of HRTFs that have emerged over the years, including CIPIC [?].

[?], IRCAM, [12] and EMPAC, as well as personally, as in the case of Paul Koonce, who uses this technique and has a series of open-source programs for this purpose, including others. [13]

2.3.5 *DVD era*

In the early 2000s, and already moving slightly away from the regime stereo, the '5.1' and '7.1' formats are converted into other standardization, mainly by the film industry and the DVD appearance. The composition for these formats, as mentioned Field [?], requires dedicated attention by part of the composer, not only dedicating a precise and unique composition for the low frequency channel (LFE, or `.1`), but also a awareness of the need for space work that calls for a certain musical choreography in which "it is not necessary to make the sounds dance' as an end in itself," he clarifies, but "we must examine first the nature of the musical relationship between the sound elements constituents and the spatial environments they occupy... the relationship between the object and space." [?, 2]

2.4 Massively Multichannel

Moving on to multi-channel systems with more than 20 speakers, the Osaka [?], which had certain designs of Stockhausen but with the realization of the engineer Claus Amberg is, in 1970 Osaka World Fair (FDR), one of the first eight speaker rings, controlled by a 7x7 matrix capable to space out to 49 speakers but little is known of the internal functioning of the same. [14] . It is not necessary to name the *acousmonium* by François Bayle [?, ?], or Jonty Harrison's *BEAST* [?, ?], unique and pioneering multi-channel structures in the promotion large-scale spatial research, sound image and acoustic music. [15] Also, it is worth mentioning other centers with long-range multi-channel facilities such as CARL [?], ZKM [?], IRCAM, CNMAT [?], Allosphere [?, ?], EMPAC [?] and Cube [?]. These constitute pillars of space research which, while starting from a and institutional, they propose an aesthetic opening in their annual calls to action that make their search resonate with music outside the academy, such as MONOM [16]. Other centers of smaller scale were formed in a mobile way, like the concerts made by the Centro Ricerche Musicali (CMR) [?], or the Spatialization and Auditory Display Environment (SpADE) built by Kerry Hagan at the University of Limerick [?], and are probably not mentioned in this text for reasons of space.

[12] `http://recherche.ircam.fr/equipes/salles/WFS_WEBSITE/Index_wfs_site.htm`

[13] `https://sourceforge.net/projects/pvcplus/`

[14] Other forays into space by TU Berlin were made in the 80s but if greater impact

[15] It's worth noting that there are also spatialization techniques are directly involved in the construction of the loudspeaker, as are the spherical (geodesic) speaker designs by Trueman, Bahn and Cook [?], or the now numerous *laptop orchestras* like the ones at Stanford `http://slork.stanford.edu/`, Virginia Tech `http://l2ork.music.vt.edu`, among others: `https://en.wikipedia.org/wiki/Laptop_orchestra`

[16] `https://www.monomsound.com/`

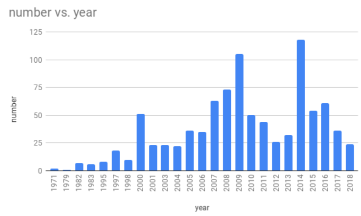

Figure 1. Approximate number of works found in ICMC, SMC, Organized Sound and CMJ with the words 'space' or 'spatialization'

2.5 Closing with a note

At the time of this historical journey, undermining the word spatialization in ICMC, SMC, Organized Sound and Computer papers Music Journal I had access to. I had to stop at papers towards early 2000's, since that word occurs exponentially until 2009 (appearing in more than 100 jobs), and after a drop to 30 jobs by 2013 it goes back up radically in 2014 with 118 jobs found (see Figure 1). While I plan to continue this research, I will stop suddenly to honor the title of this work, not without first emphasizing Hagan's work [?, ?] on textural composition.

2.6 Textural Composition

Hagan takes concepts that come from both Xenakis and acoustic of the concrete music when it speaks of the 'sound meta-object,' central concept in their notion of textural composition. Carrying this idea into practice in real time, Hagan demands that "first, the sound must be complex, consisting of many smaller sounds but united into one complete object. Second, the sound must be big, surrounding the listener and extending beyond the perceptible horizon. Finally, the sound must not favor a perspective, and it must not have a frontal orientation" [?, 44]. Such a conception of treatment The spatial texture forms a before and after in the conception of the composition for speakers, and its only limitation is the fact that it can live the space experience in a center with multi-channel capabilities long term. In my personal work, which I will briefly address I then attempt to carry out this notion of the treatment of space as a texture without front or back, all around, and a internal complexity such that it reconfigures our notion of space as mere parameter, to become an aesthetic fact in itself.

3. LORENZ VARIATIONS

The Lorenz Variations [17] focus on different interpretations of the Lorenz System (Figure 2) [18] both as a signal generator and as a control, and explores their patterns and deviations on various scales of time. The work is the result of the Space Music Workshop during Cube Fest 2017 at Virginia Tech in Blacksburg, VA. Along with 6 other participants, we develop specific research and compositions for the Cube, an establishment consisting of 134.4.2 speakers

[17] `https://fdch.github.io/lorenzvariations`

[18] Also known as the 'Lorenz Attractor,' `https://es.wikipedia.org/wiki/Atractor_de_Lorenz`

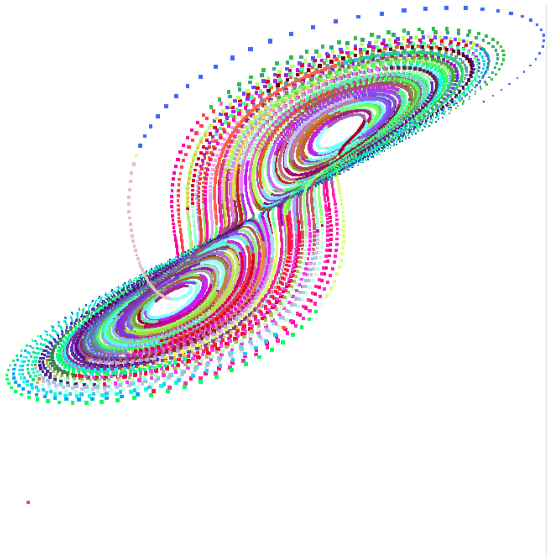

Figure 2. Plotting of the Lorenz system with data structures in Pure Data

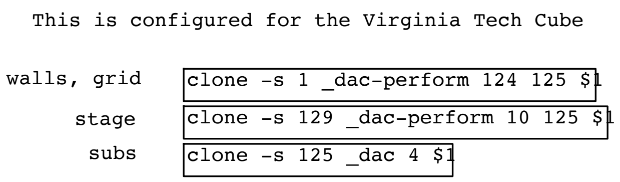

Figure 3. [_maindac] abstraction which facilitates the assignment of the [_dac-perform] abstraction since it only receives one argument which is the actual number of speakers (see Figure 4)

in a series of rings from the stage to the 30-metre ceiling that surrounds all of space. It's a unique instrument and we had the honor of to spend time in such a sound vortex.

3.1 The last gesture

Towards the end of the work there is only one gesture that moves simultaneously from the space of rhythm to that of height, and from the stability overload and saturation, resulting in a drastic sonic shift. This last section has a unique Lorenz system in each speaker, which is first read at (sr=48khz) 28/sr, and then goes up to 8/sr (which is when a tone emerges). This is done automatically until you reach a moment that I call the 'stop line. Then of this moment, the speed of the generator and therefore the work, is controlled by hand, with the instruction to slide slowly and gradually up to 1/sr, then (also gradually and musically) up to 0.02/sr You can also speed up the 'spatialization' and click on the bang' of 'divergence' as many times as necessary while doing that slip. However, once the value of 0.02 is reached, it is more or except when the system starts to break down, and that's when it no longer there's a way back. The sound will slow down because there's not much you can program into the Pure Data clock. At that point, either wait for it to reset (by moving the speed back to a reasonable number, like 16, and waiting) or you hit 'end."

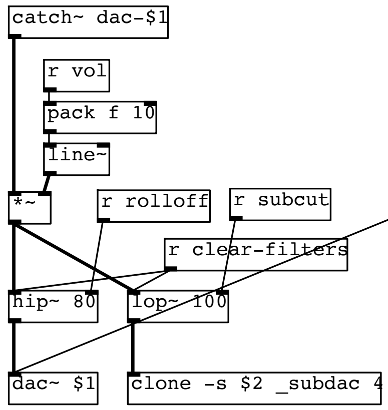

Figure 4. [_dac-perform] abstraction cloned inside [_maindac]. The The first argument corresponds to the channel number (of the digital to analog), the second argument is the number from which subwoofers start (this is specific to the Virginia Cube Tech), and the third argument is the number of (real) speakers that in the system. The latter allows the final [dac~] assign duplicates falling through a module, then if we have only two speakers, we assign as a third argument the number 2, by making the [catch~ dac-1],[catch~ dac-2],[catch~ dac-3],[catch~ dac-4]. . . , fall back on [dac~ 1], [dac~ 2], [dac~ 1], [dac~ 2]. . . , etc.

3.2 About the work

The focus of my research lies in both space and computing itself. That is to say, on the one hand, the centre of the work lies in the computer's ability to perform live calculations and system, reaching a point of complete saturation of the CPU that could cause the part to crash. Thus, it questions the endurance and virtuosity of processing, as well as the Pure Data DSP chain attached to through the programming language 'C'. The choice is then, when except for the frames where this work was first done, to use a portaudio or Jack, but that should be left to the performer of the computer. The piece has 3 sections, each of which has its own texture and treatment, but it is linked in some way by the use of this system.

On the other hand, the spatial search in the sonification of this system was a strong motivator for the construction of the instrument called 'spacelor.' This instrument (see Figure 11) is centred on the abstraction, which thanks to Pure Data's recent object called , can be 'cloned', i.e. instantiated numerous times, and the The main objective of the object is to make each speaker receive the distance travelled from each Lorenz system (there are 40 clones) But, before I continue the explanation of this instrument, I will begin by setback.

3.3 Signal routing

In this abstraction (Figure 3), you can see how the abstraction is assigned which is the last step before you get to the sound board, is that is, where is the digital/analog converter that Pure Data opens with an assigned channel. Now, in (Figure 4) you can see one that is unique to each instance

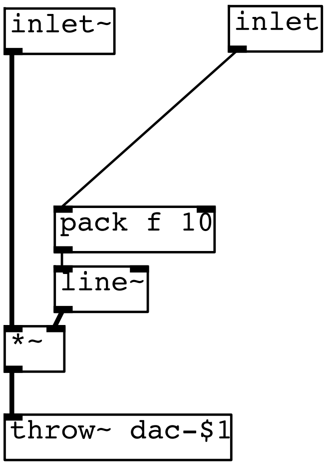

Figure 5. [_spk-vbap] abstraction, cloned inside [_router-disis], that gets a signal and multiplies it by the second [inlet] and sends it to a [catch~] assigned by its arguments (in this case, [catch~ dac-65] would be the first one, and [catch~dac-104] the last.

of the abstraction and which is responsible for receiving the signal sent from one or more s, which are, by the way, of variable assignment in each DSP block.

With this multi-channel output structure, we can build different instruments with virtually infinite s. For example, if we see the abstraction called (Figure 5), the only thing it does is to receive a signal, multiply it by the value of the second and send it to an assigned for the arguments. So, if we encapsulate such an abstraction within a routing system of, on the one hand, audio signal and, on the other hand, amplitude control, we will give spatialization to any signal in undefined numbers of speakers. [19]

This is how in (Figure 6) abstraction is newly integrated (Figure 5). For spatialization, however, the only thing this system allows is to vary the amplitude of the signal before sending it to its respective . So, here it comes, the outside already of Ville Pulkki which allows panning based on speaker vectors. To this end, the loudspeaker arrays were defined earlier taking into account the provision of the speakers in the room, information that is of vital importance when designing for any room in any place which, thankfully, is openly provided by the designers of the Cube and of Cube Fest.

3.4 _spacelor

Up to this point, any signal received by the (Figure 6) can be baked in the amount of speakers established by both the previously calculated matrix for (using), and in the number of instances of the abstraction. In this case, this number is 40, as this is how the design of the instrument, which is only found in the two upper rings of the Cube (aka. Cakewalks 2 and 3) containing a total of 40 speakers (Figure 11). But, before we see the instrument it is necessary to understand how it is composed. On the one hand, has a signal generator called (Figure 9) and on the other hand a space panning generator called (Figure 10). Both connect to the aforementioned (Figure 6) and so they make the (Figure 7) abstraction.

[19] Of course, the definition of these numbers is made at start the program and it is done based on the audio system and hardware in the performance room.

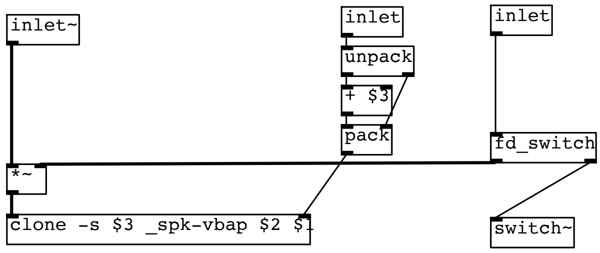

Figure 6. [_router-disis] abstraction, inside [_spacelor], that distributes the signal and the values calculated by [vbap] to the established channels.

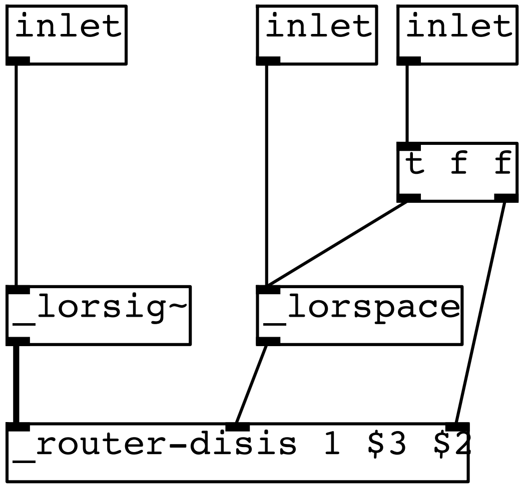

Figure 7. [_spacelor] abstraction, cloned in the main window (see Figure 11). Note that the first instance cloned starts at 65 and the number of instances equals 40.

3.5 _lorsig

The signal sent to is a sonification of the already mentioned Lorenz. To achieve this sonification, an external () was made to Pure Data is available under an open source library called `fd_lib` [20]. With a [metro] determined in '1/r' (where 'r' is the sampling rate) the solution of a Lorenz system is computed established at the beginning, within the subpatches called 'randomize. This ensures that, as much as this implementation of the system is deterministic–that is, as much as the values of the solutions are always the same given the same initial conditions—, when initialize

[20] Available at Pure Data via 'deken' (Help \mskip\medmuskip Search External) or at: https://github.com/fdch/fd_lib. Many of the objects and abstractions made during this residence were stop at such a multi-purpose library.

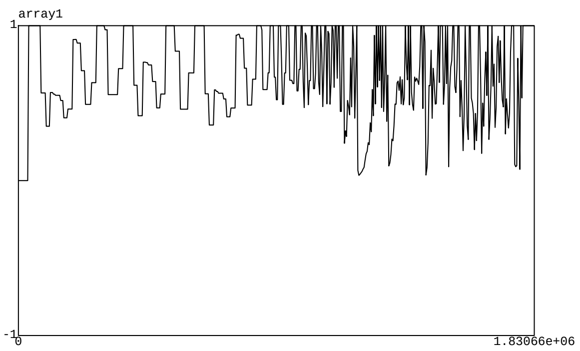

Figure 8. Signal sent to the speakers that clearly falls wrong within the range 0..1 instead of the range -1..1, shows how the distance values of the Lorenz system vary, from left to right, when changing the computation speed of the same from 30 to 0.01 milliseconds.

the system with different values the point of divergence between system and system (remember that there are 40 systems being computed in simultaneity) cannot be determined. This is the essence of the content chaotic system of Lorenz, and that's what effectively opens up the space acoustic.

3.6 Chaotic space

With the latter, please imagine the reader a space in which compute the same values of the same equations and these are brought to forty speakers distributed in space. Of course, we are in the presence of a monophony, an iterated sound that responds to the distance variations of a deterministic system. After a moment, the divergence between speaker and speaker, system and system, sample and sample, begins to be noticed in a multi-monophonic chaotic. This effect is achieved by sounding out the system in a multichannel center, and by accelerating the computations a height begins to be heard, vague but present, that while the faster you compute, the louder you hear. Now, the sonification of the The same comes from the calculation of the distance travelled in each step of each particular system using an external one (). However, this distance is limited between 0 and 1 (depending on the system, approximately the range of this distance is usually between 0..30) and is carried to a 64-sample signal block using , only if you have there's been a change of direction on one of its 'x', 'y', or 'z' axes (Figure 9). In this way, the value sent to the speaker falls between 0 and 1, but mostly 1 as the range is pretty high. This is clearly a programming error, as the values are only positive, making the signal have no values negatives (Figure 8). [21]

[21] In a recent discussion on the Pure Data, it's clear what happens when you send this type of poorly formed signals to the digital converter analog:`https://lists.puredata.info/pipermail/pd-list/2020-03/127024.html`

4. CONCLUSION

In this paper I have traced a brief historical overview of the spatialization in computer music, showing different techniques that have emerged over the years, leading to systems multichannel, more than 20 speakers that open calls for young people composers to perform space experiments (or, rather, to living the spatial experience of music). I have shared some Hagan's [**?**] basics on textural composition and he worked in one of these centers with my own research on the chaos and noise. The *Lorenz Variations* presented in this paper contains a real-time composition design that becomes complex enough to generate an imprecise texture and The concept of noise (but it is neither white noise nor pink, nor brown). Rather, you get a noise that has space, making the notions of space or spatial texture merge with the notion of noise in something that cannot be defined, but that can listening from anywhere in the room, moving, walking, by turning your head. In other words, it invites an active listener more than a passive one, invites to make listen with the body more than with the ears.

Acknowledgments

I would like to thank Eric Lyon for his openness to work on the Cube from Virginia Tech, to Kerry Hagan for her contributions to music in time Miller Puckette and the Pure Data community for maintaining and developing a program as efficient as it is simple, to Jaime Oliver La Rosa for cultivating my interest in programming, and to Elizabeth Hoffman for her constant support in my space raids. Finally, I would like to thank Judy Klein who, among so many others things, shared with me her fascination with chaos.

5. REFERENCES

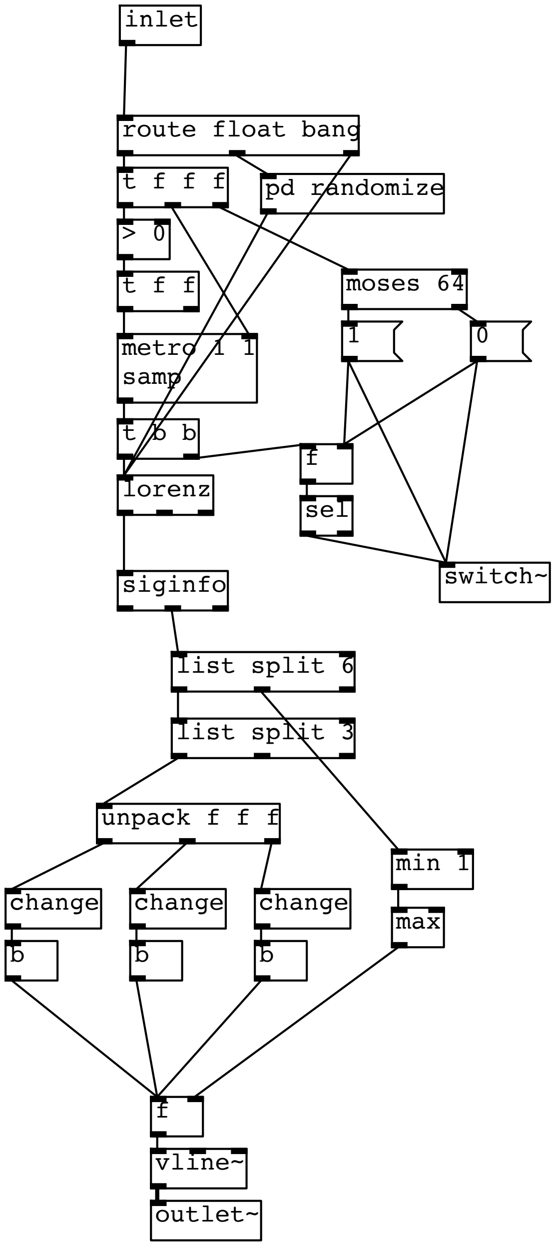

Figure 9. [_lorsig~] abstraction, inside [_spacelor], generating a signal with a [metro] set at `1/r` (where `r` is sample rate) in combination with the [lorenz] and [siginfo] externals to send the total distance at every step of the Lorenz System (clipped between 0 y 1) on every DSP block with default size of 64 samples, only if there was a change in direction in any of the `x`, `y`, and `z` axes.

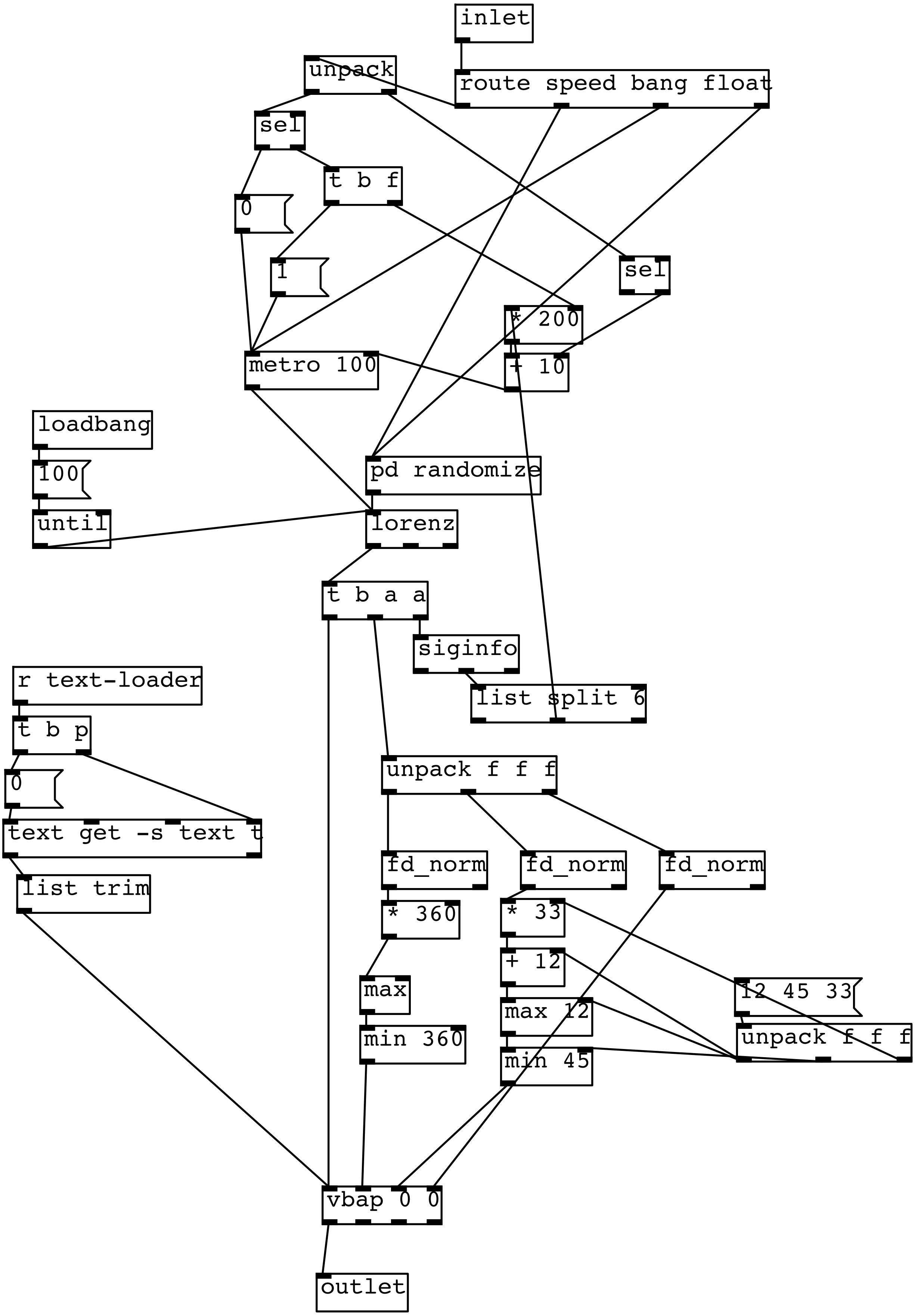

Figure 10. [_lorspace] abstraction, inside [_spacelor], taking care of the spatialization by normalizing the valuse of yet another Lorenz system at a rate tethered to its own distance. This controls the azimuth (0..360, full range), elevation (12..45, from a total range of 0..100) and spread (using only values between 0 and 1, from a full range of 0..100.

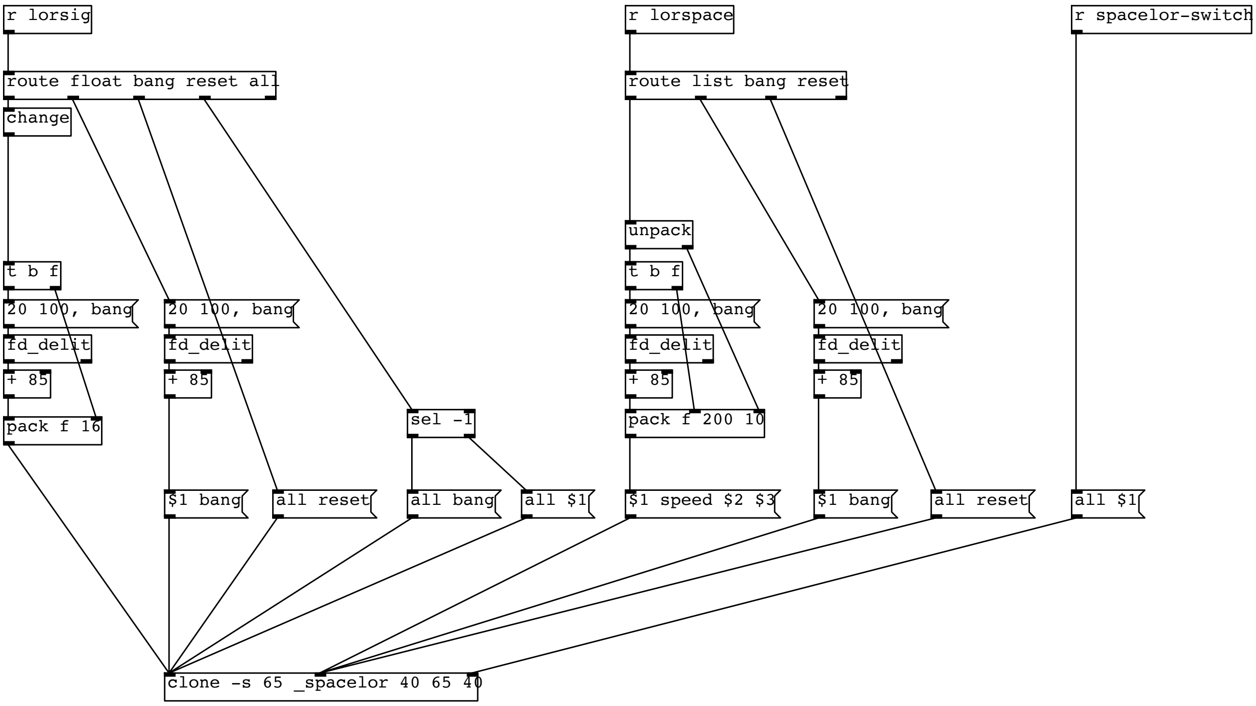

Figure 11. Main subpatch called ‘spacelor’. This uses 40 channels starting at number 65, assigning final dacs 65 through 104, corresponding to cakewalks 2 and 3 of VT’s Cube..