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The virtuoso computer: redefining limits

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Aural Weather Etude: Installing Atmosphere

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ABSTRACT

The Aural Weather Etude is a collaborative work that explores the spatial dimension as the primary means of organizing music and the devolution of narrative agency to the audience, inspired by the wall drawings by Sol Lewitt. This paper presents the work, the related creative process and some novel computational techniques related to efficient realization of a large number of sound sources in rapid spatial modulation and distance-based amplitude panning.

1. INTRODUCTION

The *Aural Weather Etude* is a concert piece or a sound installation, the result of our collaboration. The work deals with the matter of installing atmospheres in public space in a generative manner, implemented in the *Kronos* signal processing language. We started from the instructions given by Sol Lewitt for his *Wall Drawing #118*, and interpreted them in the context of multi-channel audio and rapid spatial modulation.

In our previous projects involving Urban Sonic Acupuncture strategies, panning trajectories have been intentionally avoided, as they seem to imply the existence of a sweet spot or an advantaged point. We have chosen to give up panning altogether, handing agency in spatialization to the visitor/listener, expressed by walking or choosing a listening spot. The present project represents a case in which panning trajectories can be interesting in generating sonic fields, while still not laying exclusive claim to the realm of spatialization. Rapid panning trajectories can be valuable in modulating the space and its perceived atmosphere while delimiting sonic areas and distinctly pinpointing the various intersections of panning trajectories.

We set out to develop a system that can be adapted to a wide range of spatial contexts spanning from audio installations in gallery spaces or concert halls to urban scale sonic interventions. We were interested in a scalable process that can work regardless of the sonic material used, indoors or outdoors, a process that is modular enough to be calibrated in-situ. We looked for inspiration in previous examples of such systems in the visual arts and in the work of sound installation artists. The *Wall drawings* by Sol Lewitt and the work of Bernhard Leitner, who wanted to draw in space with sound, became the main sources of inspiration to the present work.

2. BACKGROUND

In this section, we discuss the concepts and practices that helped in building the conceptual and technical background of the *Aural Weather Etude*.

> "On a wall surface, any continuous stretch of wall, using a hard pencil, place fifty points at random. The points should be evenly distributed over the area of the wall. All of the points should be connected by straight lines."
>
> *Wall drawing #118*
> *Sol Lewitt*

2.1 Wall Drawings - Sound Drawings

Sol Lewitt's *Wall drawings* are outstanding examples of visual atmospheric composition that are not created site-specifically, but once realized, are inherently site-specific. The way they are designed and described allow for great specificity and great neutrality, and they tend to work on various euclidean scales. *Wall drawing #118* in particular (see Figure 1), implies a musical connection to us, and we set out to implement that connection.

A direct inspiration for the present work are the early 'sound drawings' of Bernhard Leitner and his investigations into the possibilities of sound travelling through space, which led him to explore parameters such as *"the speed of a sound-line, back and forth movements, changed tempi in repetition, staggered lines, changes in direction, angled lines, sound lines crisscrossing on a plane, parallel sound lines as part of a path;..."* [1]. In the case of the *Aural Weather Etude*, we opted for using measured speakers set-ups and rapid spatial modulation algorithms (see Section 4.1) as means for drawing lines in space, instead of mounting speakers on wooden beams.

2.2 Aural Weather in the context of Urban Sonic Acupuncture

Sound is a powerful tool to create a sense of place, giving atmospheric 'tint' to our daily spaces by coloring, accompanying and impregnating them. According to Thibaud [2], to master those three arts is paramount to install atmospheres.

In the same way as some architects and urban planners have opted for *urban acupuncture* [3,4] implementing small-scale local and generally participatory interventions in public spaces that have an impact beyond the area in which the intervention happens, we named *urban sonic acupuncture* as the proposed sonic take on those practices, conceptually based on the field of aural architecture [5]. We believe that

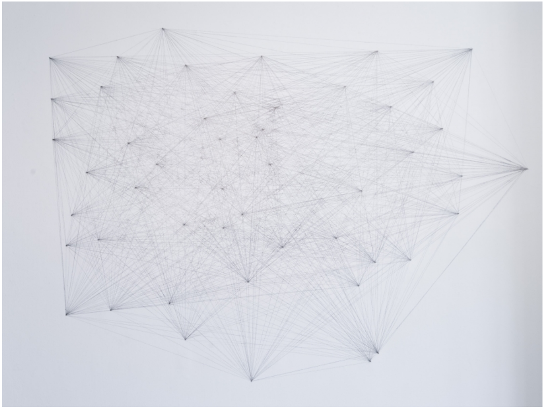


Figure 1: *Wall drawing #118* completed by "an unemployed veteran" and documented by Anthony Warnick

applying sonic pressure points on key spots in public spaces is a very powerful strategy to facilitate engagement with the site fostering more conscious dwelling.

In our previous work on urban sonic acupuncture we coined the term *aural weather* [6] to mean both an atmospheric [2, 7, 8] approach to music making and a generative non-linear approach to sound that considers time as a secondary parameter. *Music as weather* [9] was proposed by Cage to refer to music with a more fragile structural configuration. Adkins links the concept of atmosphere to different forms of fragility (structural, dynamic, referential,...) applied to music-making in the context of ambient music [10]. Rendering the temporal dimension of music as secondary, transform music into spatial art [11] facilitating dialogue with other space-based artforms. Finally, this hands the responsibility for agency to the audience, as these works are best experienced by walking, in other words, *form as [...] first-person narrativization of experience* [12].

2.3 Kronos, the DSP Implementation Language

Kronos is a signal processing language aimed at efficiently modeling static data flow circuits on general purpose hardware; similar to Faust [13]. It is capable of generating, in real time, highly optimized executable machine code via the LLVM [14] code generator. As such, Kronos is very well suited for the task of implementing a computationally intensive, temporally static piece.

3. METHODOLOGY

Our theoretical and conceptual starting point was well-defined, but far removed from any sonic realization. We proceeded by experimenting on audio material and synthesis techniques, with a workflow based on a spatial speaker system and live-coding in a text editor, articulating the parameters of the algorithms and equations. The interactive nature of on-the-fly programming fed back into the creative process. The workflow itself is not novel, but its application to the real-time generation of optimized native machine code is unusual. The mixed-rate facilities in Kronos enabled us to sidestep and defer the computational efficiency concerns by using a custom control rate as an initial approximation. Indeed, it is difficult to productively intermix the artistic creative flow with program optimization tasks.

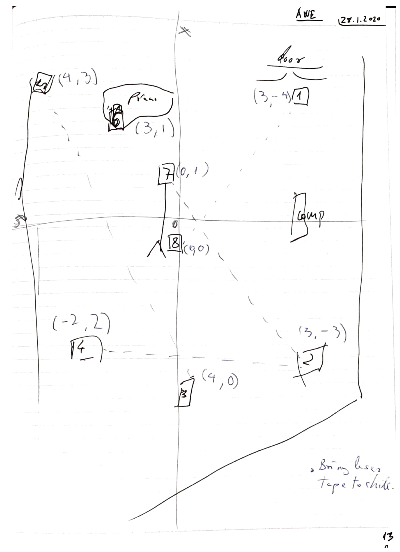


Figure 2: Sketch of Loudspeaker Placement

Despite the visual nature of our inspiration, we found ourselves gravitating towards textual programming while implementing the *Aural Weather Etude*, despite the fact that visual programming is a focal point of our recent work [15]. Perhaps that is due to the fact that the signal flow in this piece is simplistic: there is no need to visualize complex flows, and the topology of the piece unfolds in space rather than on the screen. The large number of trajectories and their inherent symmetries lends itself to a generative approach and metaprogramming, adding further distance between the work and its programmatic implementation.

Further, by building the program in a text buffer, evaluating bits and pieces incrementally, exploring alternative strategies in parallel and gradually grooming a set of equations and algorithms was a powerful way of developing an intuition, bridging mathematics and the aural experience, without any desire for further visual aids from our part.

3.1 Structure of the Piece

The work is based on a set of pitches and timbres that move rapidly back and forth between points in space. We chose eight spatial points that, in the installation setting, coincide with irregularly positioned loudspeakers. Each point is numbered in clockwise order. A pitch, a panning trajectory and a slowly modulating additive timbre – with an occasional intervention by processed human speech – is associated with each pairing of an even and an odd point.

The sound sources move at dynamically changing rates ranging from the upper subsonic to the audible, resulting in a spatialization matrix of 32 sources into 8 loudspeakers, panning at the audio rate. The sketch of the loudspeaker placement in our practice space is illustrated in Figure 2.

4. IMPLEMENTATION

Spatialization is a fundamental aspect of the present work. We wanted to design a system which could work in a variety of settings, including as a concert piece or an installation. Further, the installation should allow for an irregular speaker array. Considering the visual inspiration behind the work, the speakers act as both a functional and a visual anchor for the sonic trajectories in space.

The work is intended to be experienced while moving: either by walking inside the installation, or virtually, inside the revolving sound field of the concert version. Hence there is an aesthetic need to avoid the sweet spot.

In addition, our model consists of 32 trajectories of rapidly moving sound sources that should be distributed to a speaker array of 8 or more speakers for a total of 256 active routes.

4.1 Distance-based Amplitude Panning

Distance-based amplitude panning (DBAP) [16] fullfills all the stated requirements. Similar to ambisonics [17], it provides good reproduction over a large area, but allows for arbitrary speaker placement. DBAP works by computing a set of coefficients based on the inverse law of distance to the virtual sound source form each speaker. The coefficient array is then normalized for constant gain.

4.2 Spatial Panning at the Audio Rate

The present work aims for immersive sound synthesis by rapid spatial modulation [18, p. 26] of sound sources that trace the edges of a spatial graph. While moving, the listener should be able to distinguish the points in space where the edges intersect.

The challenge here is the computational intensity of DBAP spatialization of rapid spatial modulation, due to high-rate computation of the speaker distribution coefficients. Traditionally, the update rate of the coefficients is constrained, which makes sense for sources that move at a perceptible rate. However, for immersive high rate spatial modulation, the process acquires characteristics of amplitude modulation. Using the control rate for the modulator results in zipper noise in the waveform, producing unpleasant high-frequency noise.

Audio-rate DBAP is mentioned in the literature as being too intensive for a high number of sound sources [19]. During the process, we explored several strategies to overcome this limitation.

4.2.1 Fine Control Rate

Due to ease of initial implementation, our first solution was to compute the spatialization at a high control rate, specifically $\frac{F_s r}{8}$. The results were acceptable, but some zipper noise is still generated.

Interpolation of gain coefficients after the DBAP computation would be the logical next step, and would likely produce good results. However, we wanted to explore panning at the actual audio rate.

4.2.2 Optimizing the DBAP computation

The computational cost of DBAP comes mainly from the power function required to implement variable pan law [16] for the source–speaker distance. To optimize the computation, we first transform the equation from the literature to use power-of-two (Equation 1).

$$v_i = \frac{k}{d_i^a} = \frac{k}{2^{a \log_2 d_i}} = k 2^{-a \log_2 d_i} \tag{1}$$

Due to the characteristics of the floating point format used by modern microprocessors, 2^x can be approximated very quickly. We ported a fast approximation attributed to Paul Mineiro [1] . The routine makes use of the fact that the exponent field of a IEEE754 floating point number is an integer; by punning the type as a 9.23 fixed point integer, we operate on a piecewise linear logarithmic scale. As DBAP is agnostic to the scale of the coordinate system, we can adjust it to minimize the loss of precision. The optimal range of (non-positive) exponents is $[-126, 0]$.

The approximation is very fast, requiring only two float–int conversions, one addition and one multiply. Considering this, the approximation error is surprisingly low, peaking at 2.87% for the required range. We could not perceive the difference in informal listening tests – by its very nature, DBAP is not surgically precise, and does not need to be. The ported routine in is shown in Listing 1.

Listing 1: 2^x approximation in Kronos

```
FPow2(x) {
  v = Coerce(Int32
          Math:Pow(#2 #23) *
          Max(0 x + #126.94269504))

  Cast-Float(v)
}
```

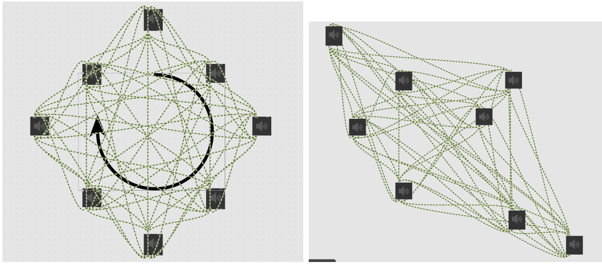
For a set of eight speakers, we can make use of vector hardware to compute all the weights in one pass. This requires the shape of data to match the *structure of arrays* convention: the x and y coordinates for each speaker are combined in two homogeneous vectors. As per Kronos semantics, type derivation [20] causes the vectorization to happen automatically, encompassing the 2^x approximation shown above. The vectored routine is shown in Listing 2.

Listing 2: DBAP panner

```
Pan(speakers R r sig x y) {
  ; obtain X and Y vectors
  (sx sy) = speakers

  ; compute euclidean distances
  ; and add 'spatial blur'
  dist = Distance(sx sy x y) + r

  ; compile time computations
  a  = R / (#20 * Math:Log10(#2))
  al = Math:Log(a) / Math:Log(#2)

  ; speaker weight computation and
  ; normalization
  dw = FPow2(-0.2 * dist * al)
  norm = #1 / Math:Sqrt(
      Vector:Horizontal(Add dw * dw))

  sig * norm * dw
}
```

Together, these optimizations were sufficient to have the piece running reliably in real time on our development machines – the primary goal of this optimization work.

[1] https://lib.rs/crates/fastapprox



(a) concert (b) installation

Figure 3: Alternative speaker configurations

4.3 Real-time Waveset Synthesis

The second aesthetic aim of the work was to adopt the human voice as a component of the sonic trajectories. We set out to explore the relationship of this rich and organic timbre to the linear, angular and graphic nature of Sol Lewitt's work.

To reconcile the two worlds, we explored waveset microsound synthesis, extracting both miniscule pitch-synchronous grains and recognizable fragments of sound from speech that occasionally overcome the synthetic timbres.

The waveset-like timbre is achieved with a technique derived from the PSOLA [21] family, based on fundamental-frequency estimation of the audio material. We generate wavesets by occasionally freezing time, splicing audio at pitch-appropriate (and inappropriate) intervals. We used a phase-locked loop to estimate f_0 due to its capability of quick, low-latency tracking. [22]

The excellent real-time characteristics of the PLL enabled us to test a novel configuration: instead of pitch tracking the source material, we perform f_0 estimation on the PSOLA *output signal* through a unit-delay feedback path. This resulted in interesting sonic interaction between the splicing algorithm and the PLL estimator that drives it.

4.4 Sound Installation and Concert versions

The aural weather etude can be presented in two alternative forms; the sound installation form, or the concert form – an audio-architectural version and a concert-space version. The main difference between the versions is addressing the fact that in a concert situation, the audience's agency expressed by walking is not usually possible, therefore, the spatial aspect of the work has to be delivered differently. Possible speaker layouts are demonstrated in Figure 3.

In our proposed concert version, a clockwise rotation is applied to the entire sound field, causing the panning trajectories and their intersections to move in relation to stationary listeners. The concert version ends after a full cycle has been finished, in ca. 9 minutes.

5. FUTURE WORK

The work described in this paper is presented in 8 channels, but the system is highly flexible. Therefore, we can create versions on significantly larger amounts of audio channels and at bigger spatial scales while still maintaining the main musical properties and structural features of the work.

Examples of further applications include scaling the number of channels and the distance covered, perhaps up to urban scale. Different sonic materials could be used throughout the same system. Further work could be done on extending the modularity of the system and implementing interactive elements.

Finally, preservation of works should be looked at: the present system could be archived as statically compiled, dependency-free standalone applications and virtual machine images of compatible host platforms.

6. CONCLUSIONS

This paper presented the *Aural Weather Etude*, a spatially oriented work, its principal inspiration in Sol Lewitt's work, and the process where both aesthetical and technical considerations informed each other and our creative practice.

We explored rapid spatial modulation as means of generating sonic spaces and boundaries, and some possible solutions to the computational challenges of doing so. Our hardware-aligned solutions enabled us to create a flexible and – hopefully – engaging work, adaptable to a wide range of sites and contexts, while handing narrative agency to the audience, who are free to explore the gently unfolding aural weather patterns.

Acknowledgments

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