Composing in Spacetime with Rainbows: Spatial Metacomposition in the Real World

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Figure 1: Musical flight performance of metacomposition Aileron One, 2020.

ABSTRACT

There exists a long tradition of incorporating acoustic space as a creative parameter in musical composition and performance. This creative potential has been extended by way of modern sensing and computing technology which allows the position of the listener to act as an input to interactive musical works in immersive, digital environments. Furthermore, the sophistication of sensing technology has reached a point where barriers to implementing these digital interactive musical systems in the physical world are dissolving.

In this research we have set out to understand what new modes of artistic performance might be enabled by these interactive spatial musical systems, and what the analysis of these systems can tell us about the compositional principles of arranging musical elements in space as well as time.

We have applied a practice-based approach, leveraging processes of software development, composition, and performance to create a complete system for composing and performing what we refer to as *spatial metacompositions*. The system is tested at scale in the realisation of a musical work based upon the path of a sailplane in flight.

Analysis of the work and the supporting system leads us to suggest opportunities exist for extending existing intermodal composition theory through the analysis of audiovisual renderings of performed spatial works. We also point to unique challenges posed by spatial arrangement, such as effective strategies for structuring musical notes in three dimensions as to produce strong harmonic movement.

Beyond enabling new modes of artistic expression, the understanding garnered from these musical structures may help inform a more generalisable approach to non-linear composition, leveraging virtual representations of musical space that respond to arbitrary input data.

CCS CONCEPTS

• **Applied computing** → **Sound and music computing**; *Performing arts*; *Media arts*.

KEYWORDS

Performing arts, music, musical performance, flight, music technology, composition, metacomposition, sonification.

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1 INTRODUCTION

Artists and researchers have explored various approaches to the relationship between music and space. Examples of musical works considering the position of performers date as far back as 1550 with Adrian Willaert's *Vespers* [4], whilst modern examples of spatial music now tend towards electroacoustic works employing distributed speaker arrays (for example [11]). Works have also cross-pollinated with architecture and geometry, for example Iannis Xenakis'extrapolation of concepts from his soundmass piece *Metastasis* to Brussels' Philips Pavilion [29], or John Coltrane's motific application of the golden mean in *A Love Supreme* [27]. Beyond composition, purely analytical geometric approaches have been applied to the understanding of music including the tonnetz [7] and more recently Dimitri Tymoczko's general geometric tonal framework [23].

Now, advances in virtual reality and geolocation have lead to works that respond directly to a listener's position in space, and indeed, such works are becoming common place (see examples [3, 6, 9, 10, 18], and earlier [8]).

Additionally, with now ubiquitous sensing technologies, there is little barrier to implenting virtual interactive musical spaces of the like developed by Hamilton [10], Barri [3] or Ciciliani [6] in physical space. We have come to describe this latter category of works as *spatial metacomposition*, a discrete subform of spatial music in which space is used to *arrange* musical elements rather than being treated merely as an acoustic environment. Succinctly put, spatial metacompositions generate musical output as a function of a performers position in space.

This paper stems from our research into new modes of artistic performance that may emerge from real-world implementations of spatial metacomposition systems. The works we are particularly interested in place the performer in direct interaction with environmental forces such as rising air or flowing water, with a specific interest in the tension between these forces and performer agency (Figure 2).

We seek to create situations where this real-time musical system can act as a mediator that expresses the sum of a performers intent and the influence of their environment, providing them with a kind of aesthetic situational awareness, and resulting in a musical output that is a product of the feedback between performer agency and complex natural systems. From here, we are interested in how these works can be presented in collaboration with other musicians and performers, and how they can be presented to live audiences.

To realise this we are applying processes of systems design, software development, composition, performance, and music analysis to develop a complete system for the composition and performance of spatial metacompositions and their application in real-world contexts.

1.1 Project Overview

The system we have developed consists of sensing hardware, generally worn by the performer, that that logs and broadcasts positional data. This data is received by a laptop running Ableton Live and a suite of tools [14] we have developed to aid in the composition and playback of spatial metacompositions. Decoupling the sensing and playback of the system allows for multiple instances of the Ableton set to be run, rendering real-time musical feedback to the performer, or remotely to an audience or collaborators.

To validate the system, we captured flight data during a series of short sailplane flights with a flight instructor in regional Victoria, Australia. The sensing unit was worn by the researcher in a chest harness and a GoPro camera was clipped to their seat. These were secured to the satsifaction of the flight instructor to ensure they would not come loose or interfere with safe operation in flight or in an emergency. Realtime musical feedback was not provided to the pilots in-flight. We intend to focus the next stages of research on this realtime feedback loop, the associated pilot/performer experience, and the potential for live musical flight performance.

The data and video captured during these flights was synchronised and replayed, allowing the creation of a spatial metacomposition and associated audiovisual demonstration of the system in action. The resulting musical work was titled *Aileron One* [13] and serves as a demonstration of the system at scale, and the emergence of musical form stemming from the flight path of an aircraft.

Previous examples of integrating human flight and musical performance are sparse, with Stockhausen's Helikopter-Streichquartett [21] being perhaps the only notable example. There does however exist precidence for realtime sonification of flight in the form of the audio variometer which is commonly used by pilots of gliding aircraft [15]. In contrast to the strictly functional role of the variometer, the development of a system for musical feedback in flight could be viewed as contributing to what Stephen Barrass describes as *the aesthetic turn* in sonification [2] (see more [22, 24], and counterpoint [12]).

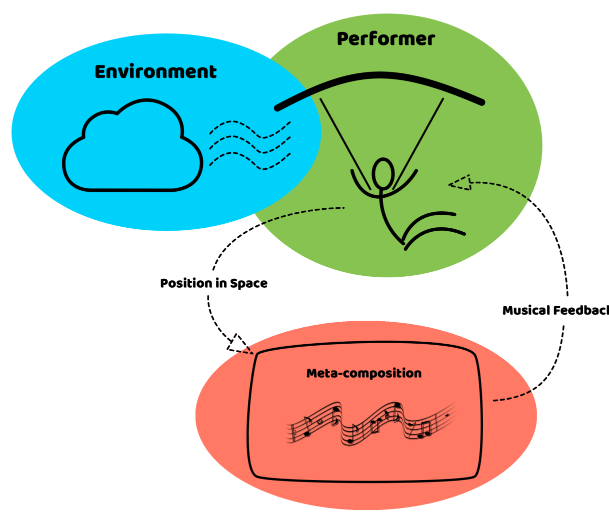

Figure 2: A high-level outline of the system in action showing roles of the performer, metacomposition and environmental forces.

2 METHODOLOGY

We have employed a creative practice-based methodology [5] to this project, relying on reflection of processes and outputs resulting from the development of creative works. Thorough, contemporaneous documentation of the creation of the work is carried out to maximise the validity of reflection, analysis, and conclusions [17].

The creative practice includes not only musical composition, but also software development, coming under the colloquial umbrella term *creative coding*. Although requirements for the software have been considered, and there is an iterative development cycle, the tools themselves are allowed to emerge from the bottom up, rather than being designed from the top down. This allows the process to remain flexible and respond to unexpected findings as the work develops.

We suggest creative practice methodologies are well suited for the development of new musical systems where creative exploration is paramount, and there is unlikely to be a well defined *correct* solution. Albert Schneider notes that that music itself seems to resist such absolute findings [19], and other researchers have demonstrated the importance of flexible processes in pursuit of creative goals [20]. We also note researchers working on comparable projects have applied similar reasoning [6].

3 SYSTEM ARCHITECTURE

The requirements of the system are to:

- Sense and log positional data of a performer.
- Interpret positional data in relation to a spatial metacomposition.
- Output real-time musical feedback to performers (local) and audience (remote).
- Support composers to create spatial metacompositions.

We have developed a sensing unit comprising of a Raspberry Pi computer and NAVIO2 flight controller which is responsible for sensing, logging and transmitting positional data. Logged sense data can be replayed by a playback tool built in Max that is capable of synchronising captured video. Finally, a suite of Max for Live plugins called *Aileron* [14], provide the tools for composers to create multi-dimensional musical structures that respond to incoming positional data.

These components are modular and can operate in different configurations to allow composers to work with captured data offline, and to then playback metacompositions in real-time by substituting the telemetry playback tool for live streaming data (Figure 3). The modular architecture is achieved in part by providing a simple Open Sound Control (OSC) [28] interface that defines the format of the positional data. This allows the integration of any sensing hardware provided it conforms to the interface specification. The system has been tested with the Raspberry Pi based sensing unit, Leap Motion hand tracking hardware, and an android mobile device.

3.1 OSC Interface

The Aileron OSC interface specification (Table 1) was developed to define units and coordinate systems to be used throughout the system. The coordinate system was chosen to conform with the openGL standard (X: right, Y: up, Z: forward). This was chosen as different conventions exist for different physical contexts, for example north-east-down for aviation, east-north-up for ground-based vehicles. Working to a graphics standard allows for composers to

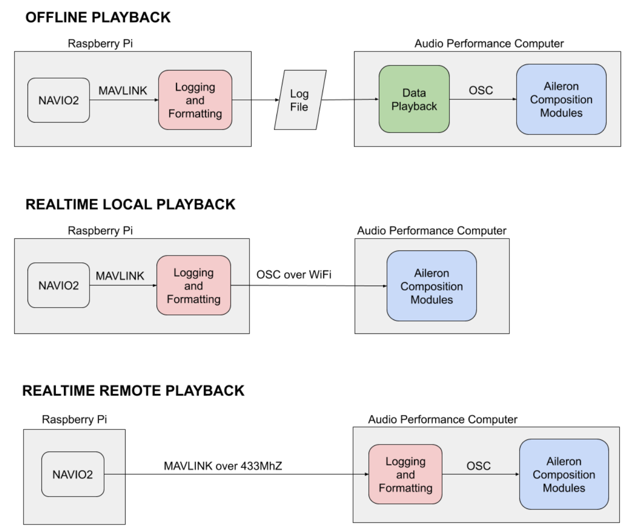

Figure 3: Diagram detailing communication between system components in different configurations.

work in a consistent compositional space as well making the task of developing compatible tools easier for developers. A particular composition may not require every data element, for example a metacomposition could be built entirely around vertical acceleration, thus a flexible interface allows sensing hardware to be chosen on a case by case basis.

4 SENSING AND LOGGING

The sensing unit is built atop a Raspberry Pi computer and NAVIO 2 flight controller board generally used for drones and other unmanned aerial vehicles. This hardware was chosen as it offers very accurate positional tracking at a range of scales from centimetres to thousands of kilometres. The NAVIO board includes dual IMU sensors and a high resolultion baromenter, while the inclusion of a Raspberry Pi allows for onboard logging, formatting data to the system's specification, and broadcasting as OSC. A program written in Python using the Dronekit API reads MAVLINK telemetry from the NAVIO's Arducopter system and formats it to conform to the interface specification. This Python program can also be run remotely allowing telemetry to be transmitted over large distances via 433MHz radio (Figure 3).

The sensor unit can be mounted to a vehicle or to the performer's body by way of a chest harness. A simple button interface is provided to allow for synchronisation of video footage. This is achieved by clapping or clicking in view of the camera whilst simultaneoulsy pressing the designated button on the unit. This sets a flag in the log file which can then be aligned to the corresponding video frame for playback.

The sensed data is stored in a plain text file with each sample being stored as an array of values corresponding to the OSC specification. Storing the data in an array simplifies parsing for playback and minimises bandwidth when transmitting as OSC.

OSC Address	Type	Description
/time	float	Time in seconds since start.
/sync	int(0-1)	A value of 0 or 1 acting as a flag for synchronising video footage.
/pos	float[3]	The position in metres of the sensor relative to its location at start, in east, up, and north directions.
/latlonalt	float[3]	The latitude, longitude and altitude of the sensor. Altitude is described as metres above mean sea level (ASL).
/rot	float[4]	A quaternion describing the orientation of the sensor. Relative to the sensor facing north, level with the horizon.
/vel	float[3]	The velocity of the sensor unit in metres/second, in right, up, and forwards directions.
/acc	float[3]	The local linear acceleration in metres/second^2, in right, up, and forwards directions.
/angvel	float[3]	The angular velocity in revolutions/second, in pitch, yaw, and roll.
/angacc	float[3]	The local angular acceleration in revolutions/second^2, in pitch, yaw, and roll.
/t	float[24]	A condensed form of all data points used for logging. Elements are ordered as described above from top to bottom.

Table 1: Aileron OSC Interface Specification

5 DATA PLAYBACK

The data playback component of the system is realised as a Max patch which loads a log file from the sensing unit and optionally an associated video file. The log file is able to be replayed and is output as OSC in an identical format to that output by the sensing unit. In this way, metacompositions created in response to streaming OSC data from the playback patch can also receive and respond to real-time data with no alterations. Video timing is controlled using the timestamp stored in the log file to maintain synchronisation between video and data playback. This enables the offline creation of metacompositions using a process similar to film-scoring. The composer is able to scrub, pause and rewind the video, with streaming data remaining in sync.

An interesting consequence of this film-scoring-like workflow is that it provides an avenue for analysing metcompositions as rendered audiovisual works in and of themselves. This may offer a bridge for developing a theoretical understanding of spatial metacomposition by extending existing audiovisual and intermodal composition theory (for examples see Kapuscinski Basic Theory of Intermodal Composition [16], and Whitney's Digital harmony [26], [1]).

The playback patch is also able to proxy live OSC data, acting as a monitor and having the ability to record to a log file of its own. This allows for recording playback data from another source such as a mobile phone or Leap Motion hand tracking device. The system is agnostic to the kind of sensing being used, as long as it conforms to the OSC interface.

6 AILERON MODULES

Aileron [14] is the composer-facing component of the system. It consists of a suite of Max for Live modules responsible for:

- Structuring Ableton clipslots in multidimensional space.
- Panning and attenuating channels in response to orientation data.
- Distributing pitches in multidimensional space.
- Mapping arbitrary Ableton parameters to input data.
- Managing unbounded input data through scaling, wrapping, clipping and mirroring procedures.

Data is brought into Aileron via the hub module which exposes an OSC interface on port 4813. Streaming data is sent to this port from the playback system, the sensor unit, or conceivably any other source. The hub provides basic monitoring of incoming data and is responsible for forwarding that data onto the other Aileron modules.

6.1 Hyperclip

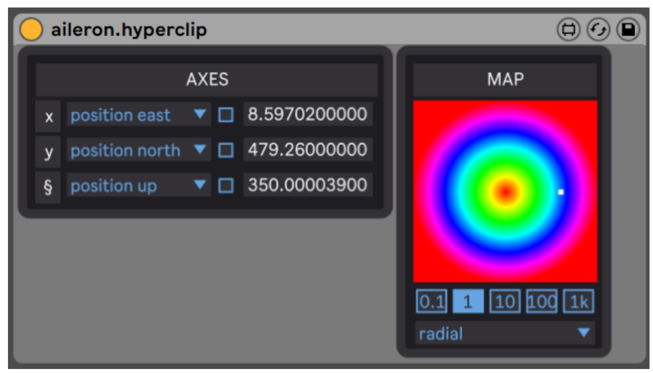

Figure 4: The Aileron Hyperclip module built in Max for Live.

The concept of a *hyperstave* was developed early in the project, the purpose of which is to give composers a method of associating related musical ideas without presupposing how those ideas might be arranged in space. The section sign "§" has been adopted as a hyperstave clef symbol borrowing its use in denoting document sections as well as its visual similarity to existing musical clefs.

The hyperstave is a one dimensional array of *n* musical staves organised against a hue gradient (Figure 5). The hyperstave can be read in two directions—horizontally to be read in time or vertically to be read in space. The system is designed to constrain the spatial arrangement of neighbouring phrases, ensuring they will remain neighbouring when arranged in space.

Although other visual features such as brightness or saturation could have been used to a similar end, the advantage of mapping to hue is its visually cyclical quality. This quality has previously been exploited in forms of musical analysis, for example in mapping the colour wheel to the circle of fifths where hue's cyclical nature enables a useful visualisation of consonance and dissonance [25].

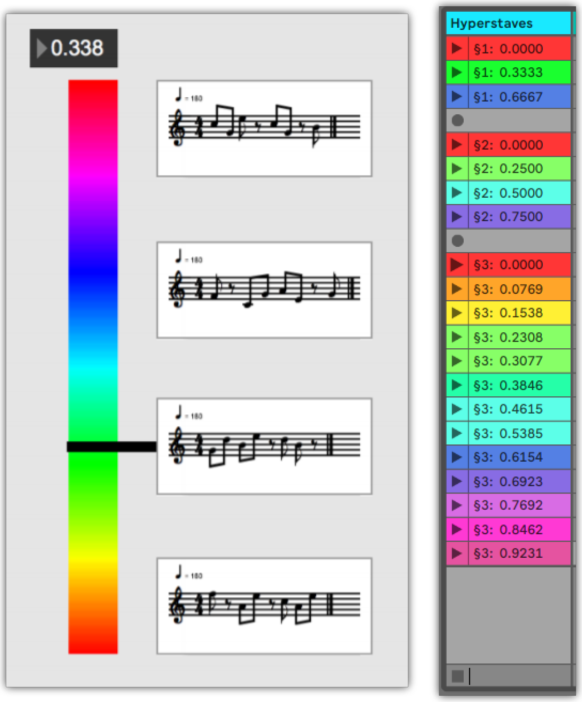

Figure 5: A prototype hyperstave built in Max (left), and the Ableton-specific implementation with hyperstaves delimited by empty clipslots (right).

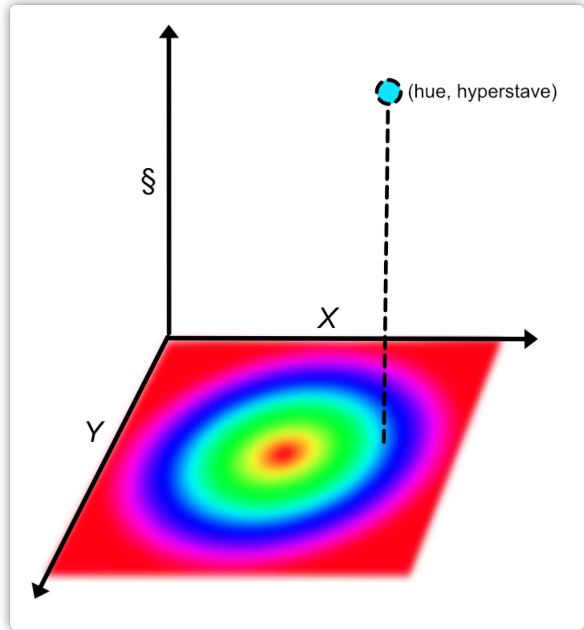

Figure 6: A diagram of a hyperstave compositional space based upon a radial hue gradient.

Constraining musical phrases along a hue gradient in this manner correlates to the constraints of traversing physical space. As it is not possible to instantaneously teleport from one point to another, similarly, a composer can consider that a performer exploring a meta composition will need to pass through each of the phrases in order, though importantly, the direction and speed of travel is not predetermined.

Applying hue as an index in this fashion has the additional advantage that a hyperstave can consist of an arbitrary number of staves, allowing for compositional control over the density of staves in a given volume of space.

The hyperclip Aileron module is an Ableton-specific implementation of the hyperstave concept. It groups neighbouring clips into hyperstaves, mapping them to a hue gradient and automating clip-triggering using a two dimensional colour map.

Empty clipslots delimit hyperstaves and the currently active hyperstave is able to be mapped to a data source. The result of these mappings is a three-dimensional compositional space (Figure 6), where the progression of active clips is constrained to neighbouring clips, or clips of comparable hue in neighbouring hyperstaves. These constraints allows a composer to connect neighbouring musical ideas without dictating the order in which they may be played, separating the processes of composition and spatial arrangement.

In use thus far we have set clips within hyperstaves to be of the same length and have used Ableton's legato feature meaning, in effect, all clips play synchronously with only the active clip being audible. We have taken this approach due to its simplicity and predictability but there is far more creative territory to explore regarding hyperstaves with clips of differing lengths, tempos or other contrasting musical properties.

In a prototype implementation of the system, a graphical user interface was developed that allowed the user to arrange coloured spheres in three dimensions and then use hue interpolation to distribute the contents of associated hyperstaves throughout the space (Figure 7). This was replaced in the current implementation with two-dimensional hue maps for both ease of use and ease of implementation. Although working with a two-dimensional map enforces more constraint on the composer, the approach offers enough flexibility for this stage of the research. Effectively visualising a multi-dimensional compositional space has proven to be a key challenge and further work is required to develop an interface that would be suitable for wider adoption.

6.2 Direction

The intended use of the direction module (Figure 8) is to read orientation information and apply panning and attenuation to a sound to produce the impression of directionality. The module does not attempt to simulate acoustic properties of a sound source in space as in other frameworks (for example [3]), but is more intended as a composition and arrangement tool. This module can be used to create different *views* of a composition. For example, a piece may be slow and melancholic when facing south, then up-tempo and joyous facing when facing north. Additionally, groups of similar sounds

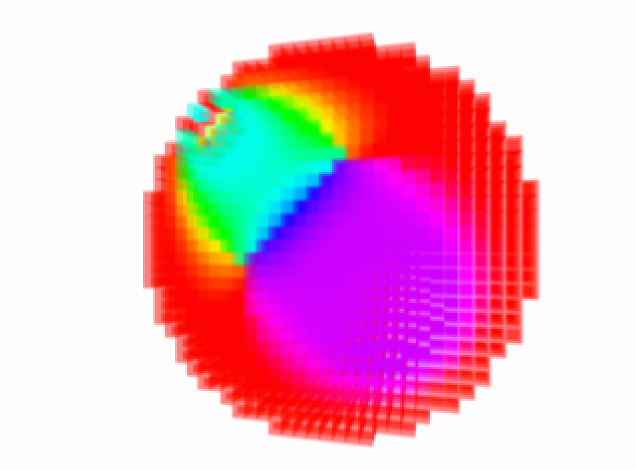

Figure 7: A cross-section of the prototype three-dimensional compositional space.

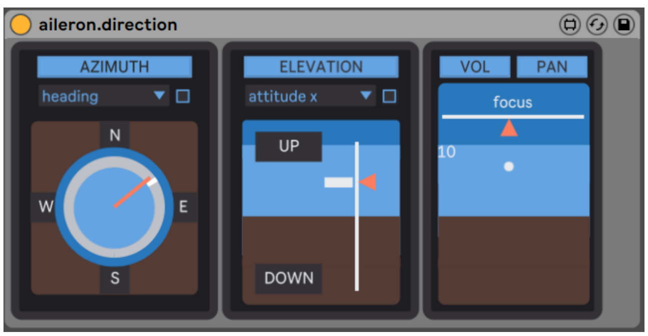

Figure 8: The Aileron Direction module built in Max for Live.

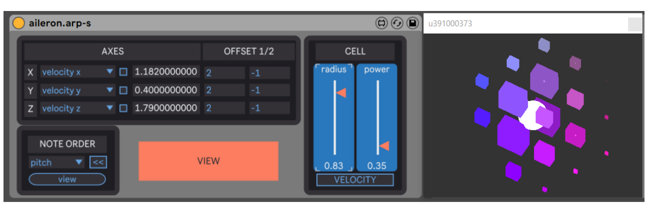

Figure 9: The Aileron Spatial Arpeggiator module built in Max for Live (left) with a visualisation of its active pitchfield (right).

can be placed at neighbouring orientations to create a cohesive voice that responds to changes in perspective with timbral shifts.

6.3 Spatial Arpeggiator

The spatial arpeggiator takes a set of notes from the active Ableton clip slot and provides basic operations for distributing those notes in a three-dimensional grid. The resulting pitch field is then translated in response to input data and notes within a given radius of the centre of the space are output as MIDI.

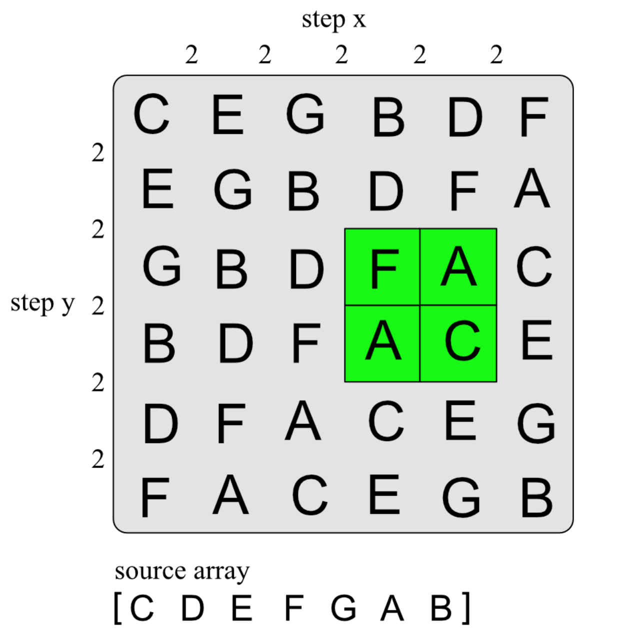

Figure 10: A diagram demonstrating the creation of clusters of triads by distributing notes from a C major scale in a two-dimensional pitchfield. When extended into three dimensions the same configuration creates 7th chords.

The motivation behind the spatial arpeggiator is two-fold. Firstly, it was created to interrogate the differences in time-based and spatial arrangement by applying arpeggiation operations commonly applied in time, to space. Secondly, it provides a tool for constructing simple three-dimensional pitch fields to explore how harmony might function in multiple spatial dimensions.

Notes from the active clipslot are retrieved and stored as an array which can then be ordered by the sequence in which they appear in the clip, their length, their velocity, or their pitch. These notes are then distributed sequentially in a 10 x 10 x 10 grid. Offsets can be applied at each cell step allowing for, for example, triads to be built from a major scale by offsetting each cell by an additional step (Figure 10). A second offset is provided to allow for more complex permutations.

Controls are provided for defining the radius of active notes, in effect controlling the number of chord tones output at any point in time. Duplicate notes have their velocities summed and a *power* parameter reduces the influence of notes that are further from the centre of the space. A toggle is provided to disable velocity summing, instead outputting all unique notes with a velocity of 127.

Initial work with the module investigated distributing pitches in such a way as to achieve strong harmonic movement. This revealed a challenge when working with this system, specifically that it is very difficult to achieve strong cadences between neighbouring cells due to the fact that strong harmonic resolution tends to rely on a preceding chord containing dissonant "avoid" notes of the following chord. In the current implementation these notes are required to be near in space, and as such are likely to overlap as the field translates from one chord to another. In contrast, pitch fields that are distributed in thirds result in consonant chord voicings though produce weak harmonic movement from one chord to the next.

On reflection, one can see that this is not the first time in musical history this problem has been encountered. Consider the arrangement of notes on a blues harmonica where neighbouring notes are required to be consonant so strong harmonic movement is provided by placing an alternating set of reeds in the opposite direction such that one set resonate when the player inhales, the other when the player exhales. It follows that a similar solution could be applied to three-dimensional pitch fields by interlacing two independent fields, such that each is consonant with itself, and movement to neighbouring cells produces strong harmonic movement. This initial experimentation provides a glimpse into the nature of multidimensional musical arrangement, the challenges it presents, and the potential depth of music theory that can be developed to describe these systems.

6.4 Input Data Management

One of the challenges when working with data types such as position and velocity is that maximum and minimum ranges are, to a great extent, unpredictable. Direct parameter mapping tends to rely on scaling input ranges to output ranges and this becomes problematic when, for example, attempting to create a piece that responds to latitude and longitude and is intended to be experienced anywhere on earth. Every data source in Aileron is picked from and processed by a common subpatch that applies a set of operations to transform the input data range. The order of operations was inspired by the Math Operator in the creative coding tool TouchDesigner. The set of operations allows for addition (bias), multiplication (scaling), range mapping, and bounds management by way of a minimum and maximum value. Values beyond the minimum and maxim ranges can be set to clip, wrap or mirror operations inspired by common pixel sampling procedures in Max. Together, this set of operations allows the composer to constrain and manage the behaviour of unbounded data to a predictable range.

7 COMPOSITIONAL SPACES

The Aileron modules were created with a principle of encouraging creative misuse. To this end, any data type can be used by any of the modules, even though a module may be designed with a primary use case in mind. In practice this has allowed for the creation of other virtual compositional spaces. For example, a pitch field generated with the spatial arpeggiator, which was built with the intention of interpreting positional data, can be driven using velocity instead, creating a virtual velocity space.

When applied in practice, we found that simultaneous musical voices can be arranged in separate, superimposed compositional spaces, and that the musical result retains a sense of synchronicity with the video and data playback. In fact, having musical feedback from simultaneous voices in separate positional and velocity spaces has a reinforcing, intermodal effect. During the composition stage of development we used the term *polydimentionality* to describe this process.

It can be extrapolated that non-positional data such as biosensors, environmental data or game-state could be used to create virtual composition spaces, allowing for the theoretical understanding of spatial metacompostion to be applied to non-spatial domains.

8 AILERON IN USE

The development of the tools described in this paper followed an iterative creative process incorporating cycles of testing, composition and development. When the tools reached a satisfactory level of functionality, the first composition was produced and titled *Aileron One*. The piece is based upon sailplane flight data and uses altitude as the foundational element on which it is arranged (Figure 11). The piece can be considered as a vertical structure rising to approximately 900 metres above the ground. A circular chord progression (Fmaj9 Fmaj9/E Am9 G) repeats along the up vector with instrumentation becoming denser in six, discrete, evenly spaced layers. To add variation and movement, a set of instruments are panned to four evenly spaced compass headings using the Aileron direction module. Total velocity is then used to control the speed of melodic and percussive elements throughout the piece by way of a virtual velocity space.

The spatial arrangement approach applied in the piece leads to interesting temporal harmonic consequences–as the glider ascends, the repeating chord progression is played in one direction, as the glider descends the progression is played in the other direction. The rate at which the progression moves is dictated by the vertical velocity of the glider. Some notable musical features emerge from this mapping–the harmonic progression ascends at a steady rate as the glider is towed into the air, leading to a point of contrast when the tow is released and the glider transitions to a slow, steady descent. The musical effect of this moment is a feeling of suspension–an aesthetic mirroring the dynamics of the aircraft. It can also be seen that during periods of rapid ascent and descent such as during aerobatic manoeuvres, the musical result is less coherent as chords pass too quickly to establish effective tension and release. This highlights a challenge of composing spatial metacompositions, that is how to spatially scale musical properties such that passing through them at a range of velocities produces satisfying musical results.

9 FUTURE WORK

The driving motivation for this project is the realisation of a suite of metacompositions created for a variety of performance contexts, each placing the performer in direct interaction with natural phenomena. To this end we are exploring applications in kayaking and rock climbing to further our understanding of the properties of spatial metcomposition at various scales and in contrasting physical environments. The composition Aileron One uses only a subset of the features of the system and remains a work in progress. We will continue developing this, along with other pieces, to further our practical and theoretical understanding of spatial metacomposition. By continuing an iterative creative development cycle, we will continue to refine the tools presented in this paper in response to the requirements of the performed works.

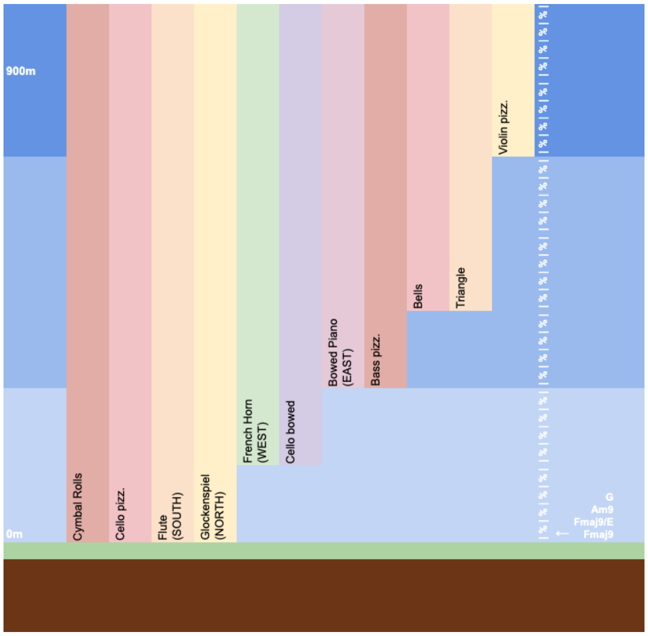

Figure 11: A spatial arrangement diagram of the metacomposition *Aileron One*.

We also consider that composing works for multiple performers warrants further investigation, and that integrating metacomposition playback into a mobile application is a promising avenue to realise this goal.

10 CONCLUSION

We have presented a system and set of tools for the composition and playback of spatial metcompositions. We have given an example of the system applied to the creation of a work titled Aileron One that investigated structuring musical elements vertically in physical space, using the flightpath of a sailplane to explore that spatial composition.

Through developing this project thus far, and reflecting upon the work in the context of similar works, we suggest the possibility of an emerging subform of dynamic music we are refering to as spatial metacomposition. Our initial exploration into composing within this form leads us to suggest there is substantial theoretical understanding to be gained regarding the nature of multidimensional musical structures. We have shown that by synchronising data and video playback, a compositional process similar to film scoring can be used to create spatial metacompositions, and that analysis of video renderings of these works may allow us to extend existing intermodal composition theory into this spatial domain.

We have presented two approaches to structuring musical elements in space: the hyperstave and three-dimensional pitch fields. We have discussed how virtual compositional spaces can be created from arbitrary data sources and how these spaces can be superimposed in a process we are referring to as polydimensionality.

We also suggest that effective visualisation of compositional space is a key challenge to developing a more widely usable system and that an effective interface to structure musical elements in multiple dimensions may allow for a generalisable approach to the creation of dynamic metcompositions beyond strictly spatial works. We hope our work can help spur innovative approaches to musical interactions in physical, virtual and mixed realities.

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