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Artistic Research in Audiovisual Composition, Performance & Perception

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COMPOSING (AND DESIGNING) *TROIS MACHINS DE LA GRÂCE AIMANTE*: A VIRTUAL REALITY STRING QUARTET

Fig. 1
Rehearsal of *Trois Machins de la Grâce Aimante* at the IEM in Graz, Austria.

Composing electronic and electroacoustic music in the twenty-first century already requires artists to reconcile their own future-facing creative intents within multiple contexts of historical performance practice and precedent. The use of virtual reality environments as spaces for musical performance, creation, and content dissemination introduces exciting new creative possibilities while at the same time adding significant amounts of technical and logistical complexity. The application of gaming mechanics and interaction schema to issues of musical instrument control offers specific physical affordances designed to bridge the analog-to-digital divide while offering fluid and responsive control over virtualized parameters. This chapter describes the artistic and technical compositional processes and observed problematics devised and discovered during the composition of the virtual reality string quartet *Trois Machins de la Grâce Aimante*, the first work written for Coretet, a physically-modeled stringed instrument and networked performance application.

INTRODUCTION

The act of musical composition has always been a delicate balancing act, with composers weighing their own creative drives and decisions against the possibilities and idiosyncrasies offered by the instruments, performers, spaces, and audiences that take part in the realization of their works. In the beginning of the twenty-first century computer-based musical systems and instruments have afforded composers an impossibly large palette of sounds, control systems, and interaction schema with which to compose. Computers and digital technology have facilitated incredible sonic possibilities, as pioneer of computer music Max Mathews stated in 1963, introducing the ability to produce "any perceivable sound" (Mathews 1963, p. 553). No longer limited by the inherent physical constraints of wood, wind, steel, and wire, composers are now faced with both the opportunity and the daunting task of purposefully constraining their reach and direction. As such, a significant challenge facing composers and performers working with electronic and software-driven musical systems is the control and manipulation of such sounds into compelling and engaging musical form.

One manner in which composers self-impose constraint into their own work has been through the creation of and subsequent composition for new musical instruments. Physical, digital or virtual new instruments can be and have been designed to impart limitations in the shape of specific performance affordances and practices, regulated by the pairing of performance control or gesture and the mapping of control data to sound generation and spatialization processes. In this manner instrument design can be viewed as an interrelated or derivative process of the very act of composition, with the instrument itself serving as a performative and interactive filter for the composer's own intention.

Composers working with self-designed musical instruments have a long and storied tradition of exploring both newly minted fantastical creations with few ties to the performance practices of their musical forefathers (Gilmore 1998) and with augmentations or models of prior instruments, in recent years often incorporating digital technologies (Overholt, Berdahl, and Hamilton 2011, pp. 154–165). Through the use of physical modeling techniques whereby the characteristics of a sonic instrument or interaction can be represented computationally (Cook and Scavone 1999, pp. 164–166), purely digital recreations of the aural signatures of traditional instruments not only can be generated by computer systems but also can be augmented, hacked, and bent in manners similar to the physical augmentations carried out by performers and luthiers in years past (Werner and Sanganeria 2013, pp. 1–7).

Researchers building technology systems for music and performance have at the same time explored both our histories of musical performance practice and the ever-evolving paradigms of user interface and user experience design to craft systems that connect with our very human propensity to convey meaning through gesture (Huberth and Nanou 2016, pp. 96–99). Musical control through gesture becomes even more important when dealing with virtual reality and digital representations of instruments within human-scaled three-dimensional space. For even though virtual spaces can exist

outside of our natural world's reliance on the fundamental laws of physics, the very physical world in which we exist dictates that our own body state and formed gestures follow those same fundamental laws. Simply put, in virtual reality we can stand 50 meters tall, breathe underwater, and jump over the highest buildings, yet if we allow our hands to fall to our sides, they still feel the ever-present tug of Earth's gravitational pull.

It was such an understanding of the interconnected nature of any human-occupied virtual space with our own physical world that has informed my own artistic research, resulting in the creation of Coretet: a wholly virtual family of musical instruments descended directly from traditional physical instruments. Using computational algorithms that effectively model the physical characteristics of a sound-producing system—in this case a plucked or bowed string coupled to a resonating body—I designed and developed a set of virtual reality musical instruments that exploit and explore traditional musical performance practices, leveraging both the affordances of human gestural control and the flexibility of VR-rendered environments. Game-based control systems combining both the real-time tracking of the translation and rotation of human hands with accessible thumbstick, button and trigger controls act as a bridge between human action and motion and game-world reaction. At the same time interactions between performers and their virtual instruments pass parameters describing human control and gesture into the instruments' physical models, generating synthesized sonic responses that resemble those of an actual excited string. It is through this combination of human physical action and virtual interaction that such a system exists, directly linking physical gesture to virtual sonic output.

Trois Machins de la Grâce Aimante—loosely translated as "Three Things of Loving Grace"—is a composition intended to explore twenty-first century technological and musical paradigms. At its heart, *Trois Machins de la Grâce Aimante* is a string quartet descended from a tradition that spans back to the eighteenth century. As such, the work primarily explores timbral material based around the sound of a bowed string, in this case realized using a set of physically modeled bowed strings driven by Coretet. The composition is for four performers and in its entirety takes the form of three distinct movements,[1] each exploring different capabilities of the instrument itself and requiring different forms of communication and collaboration between each member of the 'coretet.' For each movement a different method of notation and scoring is used: in Movement I, a fully improvisational percussive performance; in Movement II, a graphical reference score; and in Movement III, an interactive visual in-engine scoring solution.

1 During the period of artistic research carried out within the GAPPP project, only the second movement of *Trois Machins de la Grâce Aimante* was investigated, rehearsed, performed, and recorded. As such, while artistic and technological features relating to the first and third movement of the work are briefly presented in this chapter, the bulk of analysis and discussion will focus on the second movement.

PRIOR WORK

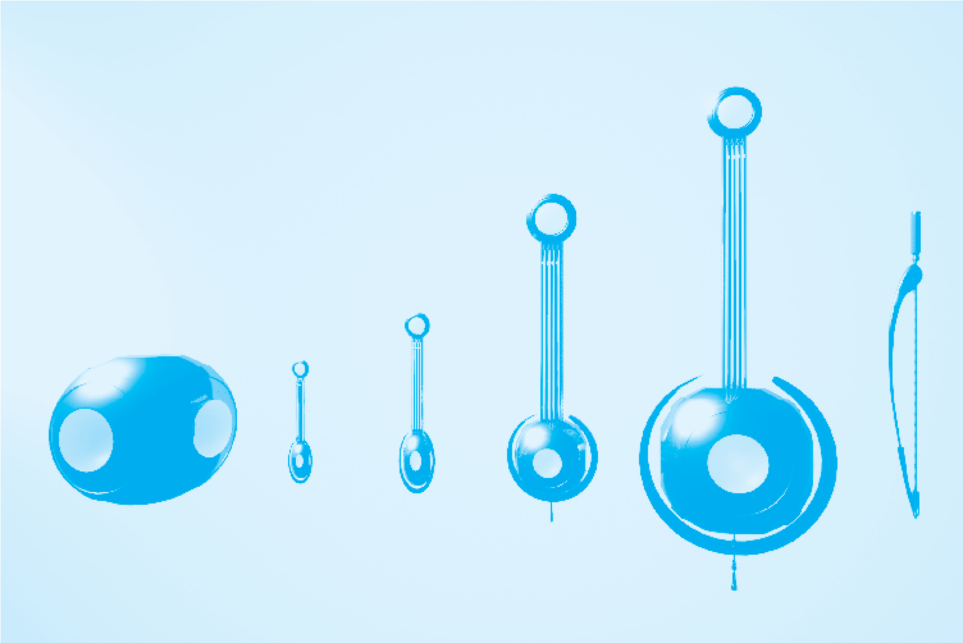
Trois Machins de la Grâce Aimante and Coretet leverage infrastructures (such as a networked client/server model), hardware (Oculus Rift head-mounted displays and Touch controllers), and software (Unreal Engine 4) commonly found in computer gaming systems. The combination of game-based technologies, presentations, and interaction modalities with musical form and function have started to become more prevalent over the last few decades. As part of a 1993 exhibit on virtual reality at the Guggenheim Museum in New York, Thomas Dolby presented *The Virtual String Quartet*, a pre-recorded and non-real-time animated performance of Mozart's *String Quartet no. 18* in A Major viewable through head-mounted displays and spatialized by tracking audience members' positions in a gallery space (Dolby 2016, p. 166). Ensemble performance works that utilize networked software environments have a long history ranging from early work by The Hub (Gresham-Lancaster 1998, pp. 39–44), to laptop orchestra performance (Trueman et al. 2006, pp. 443–450; Wang et al. 2009, pp. 505–508), to musical works based upon existing/hacked video games (Cerqueira, Salazar, and Wang 2013, pp. 243–247; Hamilton 2008, pp. 1–8). As commodity VR devices have become both readily available and more affordable and the computing hardware necessary to run such equipment has become faster and cheaper, it has become significantly easier for artists to leverage virtual reality as a platform for musical performance (Hamilton and Platz 2016, pp. 337–340). And the use of game engines to create enactive and interactive VR and rendered musical environments has been explored as well (Climent 2018; Hamilton 2019, pp. 243–257; Serafin et al. 2016, pp. 22–40).

CORETET

Coretet is a real-time virtual reality musical instrument modeling basic bow and string interactions and performance practices idiomatic to stringed instruments such as violins, violas, cellos, and double basses. Performers wearing VR headsets and holding wireless game controllers manipulate their digital instrument within a game-like rendered 3D virtual space. Interactions for Coretet are fundamentally derivative of the physical gestures used to play traditional string instruments, incorporating a hand position along four virtual strings and a bow's collision with the instrument or a plucking gesture to generate interaction parameters such as string frequency, bow pressure, and strength of excitation. Each parameter is then passed to a physical model of a string to compute the generated sound.

Designed and developed in 2018, Coretet makes use of commodity technologies such as the Oculus Rift virtual reality head-mounted

Fig. 2
The family of Coretet virtual instruments, from left to right: the orb, violin, viola, cello, double bass, bow.



display (HMD) and the Unreal Engine, a software development platform commonly used to build commercial video games and digital simulations. Audio for Coretet is generated using the Pure Data (PD) (Puckette 1996, pp. 269–272) audio programming language driving a physical model of bowed strings from the Synthesis Toolkit (STK) (Cook and Scavone 1999, pp. 164–166). Communication between the Unreal Engine and Pure Data is carried out using the Open Sound Control (OSC) protocol (Wright and Freed 1997, pp. 1–4).

Fundamentally Coretet is a single instrument which can be shaped and scaled by performers into different configurations [Fig. 2]. Parameters such as neck length, body size, and number of strings can be manipulated in real-time to either recreate traditional stringed instruments such as violin, viola or cello, or to create new and physically impossible instruments. Those parameters are used by the audio engine's physical models to adapt the sound of the instrument to reflect changes in its size. For ease of use during performance of *Trois Machins de la Grâce Aimante*, parameter presets for violin, viola, and cello can be chosen and recalled instantly as can a double bass and an experimental spherical instrument configuration known as the orb.

PERFORMANCE PRACTICE

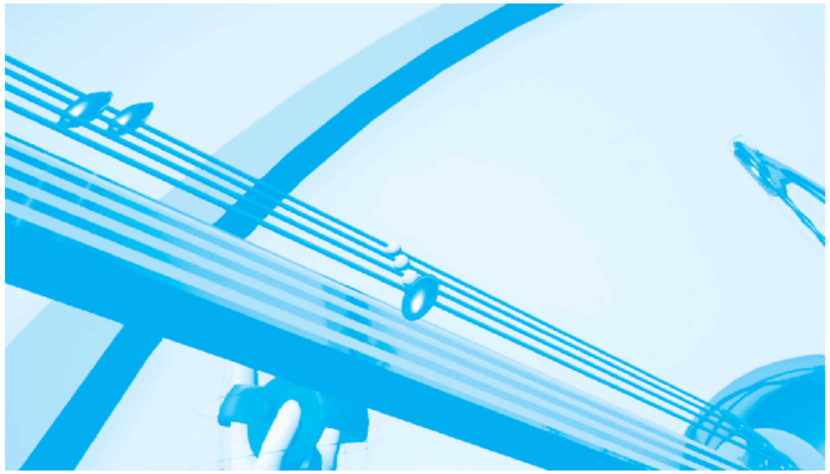
Performers in *Trois Machins de la Grâce Aimante* control a virtual bow [Fig. 2] modeled after a traditional string instrument bow

Fig. 3
A–D: Views of the Coretet system from left to right:
A) a performer as seen through the server's camera;
B) the hand of a cello performer with targeted pitch locations visible at the low end of the instrument's neck;
C) the bow interacting with the bowing bar, causing it to display a glowing outline;
D) the hand of a cello performer with selected pitches visible as larger dark ovals.


A


B


C


D

to activate the set of bowed string physical models when the bow comes into contact with a specific bowing bar on the instrument. Figure 3C shows an outline around the bowing bar indicating a collision between bow and bar, for which a tracking marker indicating the collision is represented as a white sphere. Bow pressure is controlled by calculating position along the bowing bar with one end representative of a high level of bow pressure and the other end representative of a low level of bow pressure. Bow speed is calculated by windowing bow position deltas. By pressing buttons on the left-hand Oculus Touch controller, performers choose which string will be activated [Fig. 3B]. By moving their left hand along the instrument's neck and pressing each string's associated button, performers change the pitch of the current sounding note or notes. String positions activated by button presses are marked in real-time by dark gray oval markers [Fig. 3D].

For *Trois Machins de la Grâce Aimante*, each string of Coretet is tuned to the same base fundamental frequency as the corresponding string on the violin, viola, and cello in concert A 440 Hz tuning. In concert performance such as is utilized for *Trois Machins de la Grâce Aimante* a game server hosts each Coretet client instance (representing each performer) connecting across a local ethernet network. Performers in Coretet see each others' head, bow, and instrument in real-time within the virtual concert space [Fig. 3A], allowing for the use of communicative visual gestures both of the head and of the instrument and bow. In live concert situations, a view into the networked space is presented to audiences from the game server. In a manner similar to eSports broadcasts of networked games, a series of virtual cameras on the server are projected in 2D for viewing by audiences seated in traditional concert halls.

TROIS MACHINS DE LA GRÂCE AIMANTE

Trois Machins de la Grâce Aimante was composed alongside the development of the Coretet instrument, and as such explicitly explores the performance practices and ensemble strategies made possible by Coretet. Initially commissioned as part of the GAPPP project in 2018, in its entirety *Trois Machins de la Grâce Aimante* consists of three distinct movements, each combining improvisational and pre-composed materials in fundamentally different ways. Only Movement II was workshopped, rehearsed, performed, and documented[2] during the GAPPP project and as such, its analysis forms the primary focus of this chapter. That being said, a brief description of the structure and notation systems explored in Movements I and III is also given.

Movement I serves as an introduction to the performance, with performers first engaging Coretet using its orb configuration. The structure of Movement I is improvisational and rhythmic with a metronomic pulse being established by the ensemble. Notes on the orb are triggered by the collision of the avatar's skeletal mesh and the surface of the orb generating pitched percussive sounds, triggered by each performer 'striking' the surface of the orb with their virtual hand and the virtual bow. Performers move from performing rhythmic hand strikes to bowing the orb, creating a single pitch similar to that of a bowed steel plate or saw. The movement concludes as each performer bows the orb, resolving to a harmonically rich four-note chord spread across the ensemble. Movement I was not rehearsed or performed during the GAPPP sessions.

Movement II explores a function of Coretet that allows finger positions activated along each instrument's neck to be quantized to a variety of modes and scales. To denote each selected mode or scale, 'fret' markings similar to those found on a viola da gamba or guitar are made visible along the instrument's neck.

These modes and scales include:

- Octave: the neck is divided into two regions.
- Triad: major triad built on a string's root pitch.
- Pentatonic: a five note scale.
- Whole tone: a six note whole-tone scale.

2 On the included USB stick the reader finds a documentation of *Trois Machins de la Grâce Aimante*, Movement II recorded in March 2019 by Barbara Lüneburg (1st violin), Osman Eyublu (2nd violin), Francesca Piccioni (viola), and Myriam Garcia Degalgo (violoncello).

- Chromatic: a single octave chromatic scale.
- Quantized: the full range of the instrument with pitches quantized to the nearest note in a chromatic diatonic scale.
- Free: the full continuous range of the instrument without quantization.

For the initial series of GAPPP rehearsals and performances carried out in September 2018, the overall shape and specific events occurring within each section of Movement II were derived through a close dialog and collaboration between myself as composer and the members of the ensemble. To better guide the performers and to clarify my own compositional directions I initially composed a simple text description for each section, instructing individual members or the group as a whole with high-level goals and gestures describing compositional concerns such as pitch contour, style of articulation, note density, duration and velocity of note events, and rhythmic interplay. These descriptions served as the starting point for the ensemble's structured improvisation and subsequently became the basis for an ongoing discussion and evolution of the piece as both myself and the performers became more comfortable with the manner in which four Coretet voices could blend and coexist. Before the second series of GAPPP rehearsals and performances in March 2019, I codified these instructions in the form of a six-section graphic score, used during rehearsal and discussion with a goal of providing greater clarity and structure for the manner in which the ensemble approached the work.

Whereas the first two movements of *Trois Machins de la Grâce Aimante* are largely improvisatory in nature, Movement III was composed using traditional notation practices and focuses on vertical harmonic structure and rhythmic synchronicity. Within a virtual reality environment where performers wearing head-mounted displays are unable to view notated scores in a traditional manner, for Movement III Coretet displays notes from a musical score in real-time as glowing blue pitch location indicators along the instrument's neck. Scores are synchronized across each of the clients and read individual MIDI tracks exported from a parent score using standard music notation software. Movement III was not workshopped either during the GAPPP project.

GRAPHIC SCORE

In Movement II the ensemble performs a structured improvisation within each selected mode that focuses on specific rhythmic, harmonic, and melodic ensemble performance practices. While the form of Movement II is improvisatory by nature, my intent during its composition was to explore the manner in which the ensemble as a whole could create, change, and communicate sonic gesture within a purely virtual space. Each of the six graphic scores prepared for Movement II explores a specific instrument scale or mode as well as an underlying compositional form or structure, using abstract graphic notation to convey higher-level organizational gestures, focusing on elements of rhythm and synchrony, harmony, gross frequency range, density, tempo, and time. These notated gestures function as organizational suggestions for the ensemble; each individual marking is to be taken not as literal instruction but as a higher-level map suggesting which types of musical gestures should be employed and how their performance should be approached and coordinated across members of the ensemble. And while elements of each graphic score borrow liberally from both traditional musical notation and the design and configuration of the instruments themselves, I viewed their purpose during the GAPPP project primarily as a means for conveying my own compositional intent and generalized vision of the overall work to the ensemble in a fixed yet flexible form.

During the first section of Movement II, performers use the octave setting of Coretet where each string is quantized to produce only its root frequency and the octave above. For the performer, any finger placement between the 'nut' of the neck and the midpoint of the fingerboard will produce the same pitch, in this case the lowest frequency playable on each string. Any finger placement above the midpoint of the fingerboard will generate the same pitch raised an octave. In this way, performers have a greatly reduced set of possible pitches from which to choose, suggesting they focus primarily on the shaping and articulation of each note through subtle variations in right-hand bowing technique. The ensemble is instructed to use long bow strokes choosing single pitches that eventually resolve to their upper octave while performing a slow and gradual crescendo/decrescendo. This limitation in pitch range combined with the graphic score's simple dot-and-line design elements and widely spaced events are intended to guide the ensemble to focus on the act of bowing itself, exploring the subtle variances in timbre caused by increasing or decreasing virtual bow pressure, increasing and decreasing bow speed, and shifting the point of contact between bow and bowing bar.

Section II employs Coretet's triad mode, wherein string finger positions are quantized to a major triad built on the root of each string. Central to the performance of this section is each performer's oscillation between notes of a given triad, either as short linear gestures—progressing from low to high, or vice versa—or as repetitive oscillations or trills. The section also includes a short solo violin cadenza, where in the GAPPP performances a trill of extreme duration and

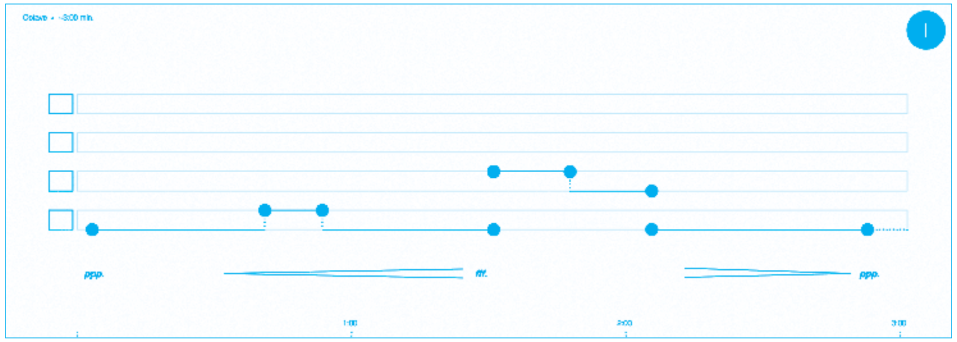


Fig. 4 Graphic score for the cello part of Section I "Octaves."

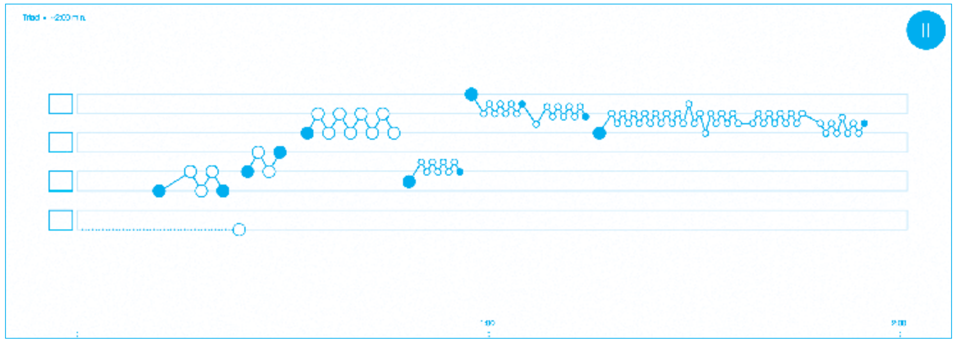


Fig. 5 Graphic score for Section II "Triads."

speed initially improvised by Osman Eyublu forms the central gesture before the section concludes.

Whereas the first two sections of *Trois Machins de la Grâce Aimante* allow performers to freely interpret and guide the ensemble's rhythm and tempo, Section III focuses on the conducted rhythmic synchronies necessary to allow the ensemble to perform unison chords. Using Coretet's ability for performers to see one another across the shared virtual performance space, each member of the ensemble takes turns conducting two chords of varying duration and dynamic. Communication for the quality of each chord is conveyed by the motion of one member's bow hand, counting off a new tempo. By framing the counting gesture as small and delicate or large and forceful, unison chords of varying intensity and duration can be communicated. Pitch content for each string is quantized within a five-note pentatonic scale.

In Section IV, ensemble members work together to create a series of interlocking rhythmic pulses using pitch material from a quantized whole-tone scale. Each performer is tasked with choosing a note and performing a steady pulse of staccato bow strokes, establishing a rhythm. The goal of Section IV is to create a composite rhythmic structure, dynamic yet connected, with each performer varying their choice of pitch and rhythm at various times during the section.

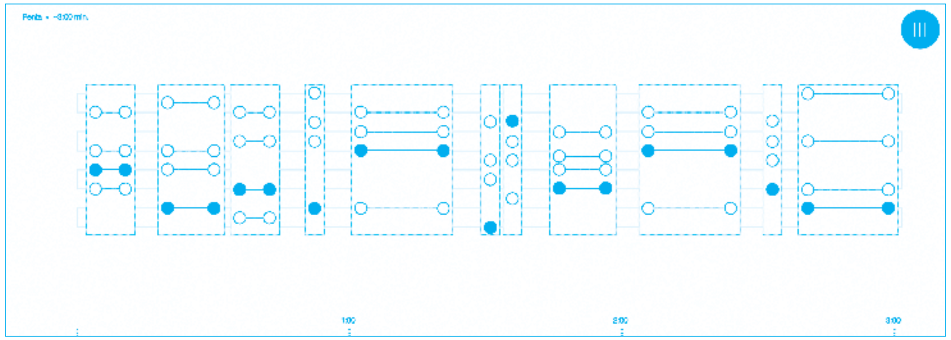


Fig. 6
Graphic score for Section III "Pentatonics."

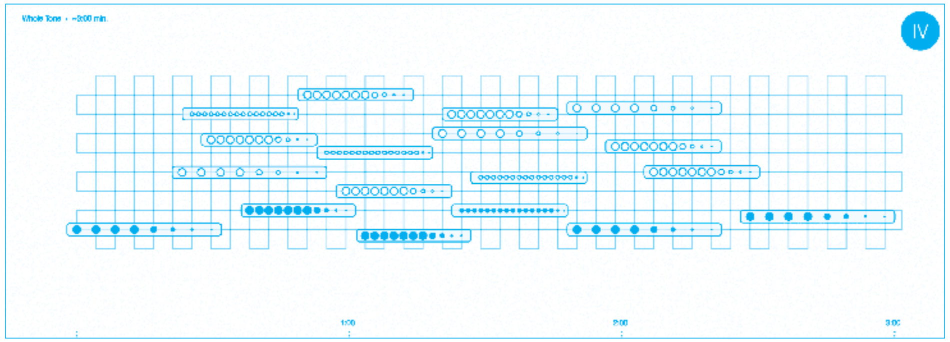


Fig. 7
Graphic score for Section IV "Whole Tone."

Timbral variation and chromatic dissonance are the central characteristics of Section V "Chromatics." The same single pitch is played by each instrument—denoted as an Eb in the score—with long bow strokes. Gradually each performer introduces half-step chromaticisms either above or below that central pitch, first as short perturbations before returning to the Eb, and later as whole-step and larger intervals, always returning to the root Eb. The emphasis again lies on timbre and texture, with chromatic movement and dissonant relationships serving as the manner in which performers synchronize to and deviate from one another.

In the final section of Movement II, an open tuning is used with no quantization, modeling the logarithmic scale positioning of physical stringed instruments. Performers begin Section VI together playing the highest pitches possible on their respective instruments, a pitch range that due to Coretet's digital design allows for pitches to be selected above the Nyquist limit imposed by the system's sampling rate. The resultant sounds are digital noise, constantly fluctuating in an incredibly high pitch range, alien to the bowed string timbres of the rest of the piece. Each performer gradually moves down the neck of their instrument while bowing continuously, creating downward glissandi broken up by short trills recalling the gestures used in Section II. A free energetic improvisation of widespread timbral and dynamic quality brings the section to a climax and ultimately serves as the movement's resolution and final gesture.

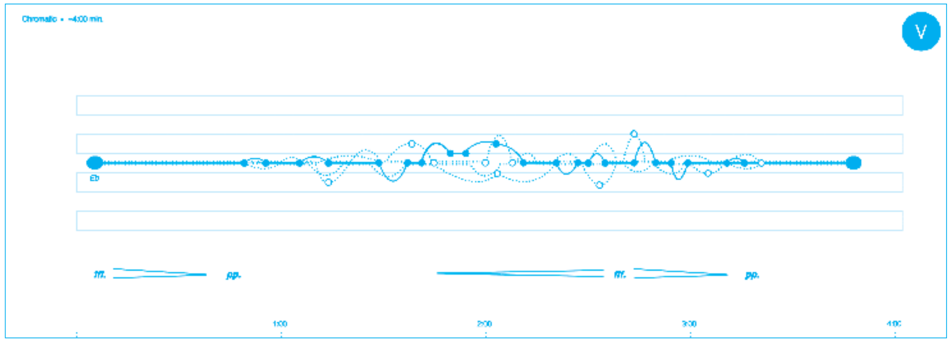


Fig. 8
Graphic score for Section V "Chromatics."

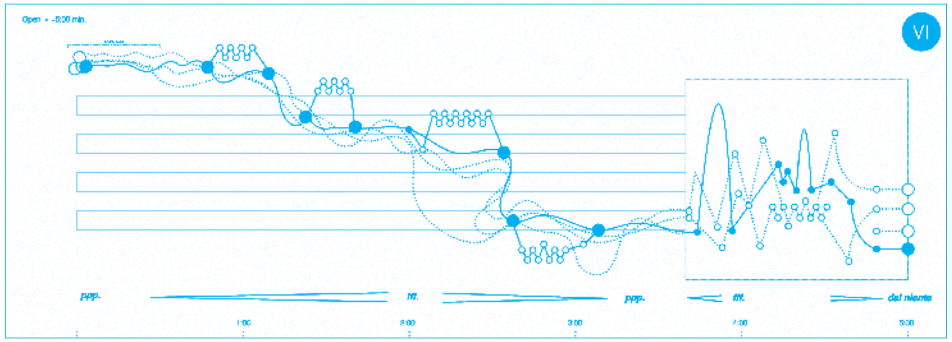


Fig. 9
Graphic score for Section VI "Open."

DISCUSSION

From the time of its inception, in the role of both composer and instrument designer I intended *Trois Machins de la Grâce Aimante* and Coretet to exist respectively as a composition and as an instrument firmly descended from traditional ensemble instrumental performance practices with a primary goal of exploring how virtual implementations of musical instruments could leverage learned expert behaviors of highly skilled musicians. While the work's grounding in traditional performance practice and the inherent limitations of the Coretet instrument have helped focus and constrain potential sonic and gestural exploration, as with any musical work composed for a novel musical interface, instrument or system, a significant upfront investment of time and resources was necessary to both design, create and then explore the physical and virtual affordances made available by Coretet. The design and development of Coretet were both strongly influenced by the particular affordances offered by the first generation of hardware on which it was to run, namely the Oculus Rift "consumer version" head-mounted display, Oculus Touch controllers and external tracking towers, as well as by the particularities inherent in the software systems used (Unreal Engine 4 for interaction design, Pure Data and the Synthesis Toolkit for audio generation). As such, there are certain performance aspects of Coretet and transitively of *Trois Machins de la Grâce Aimante* that are limited by the constraints of those particular hardware and software platforms.

SINGLE-POSITION HAND TRACKING

Tracking of Coretet performers' left hands along the length of the instrument neck happens simultaneously for all four strings, meaning the concept of 'hand positions' and the ability to use finger displacement to play intervals from the same position is not currently supported in Coretet. This is a significant limitation of the current version of the instrument which had a clear impact both on the manner in which I as a composer could approach writing discrete and specific melodic and harmonic materials as well as on the rhythms and tempi possible for performers to recreate specific patterns or phrases.

LACK OF TACTILE FEEDBACK

As with any virtual reality system, the virtualization of a physical control system is typically lacking the same haptic and tactile feedback offered by the original. In Coretet, when quantization of frequency is not selected, it is difficult to articulate specific notes without any fluctuation, as the performer's hand is held in midair without any tangible surface on which to rest. While the Oculus Touch controllers do offer the ability to send haptic pulses and buzzes in response to events generated in software, the lack of a physical object with which to interact requires new contextualization for performer gesture and for the types of music that can be composed for the instrument.

OCCLUSION OF NON-VIRTUAL SPACE

Most current VR systems are differentiated from augmented reality (AR) systems by their focus on rendered spaces as a context within which presence is focused (VR) as opposed to the augmentation of physical spaces with digital constructs and information (AR). The occlusion of the performers' vision when wearing the current generation of Oculus VR head-mounted displays prohibits the use of any visual traditional methods of musical scoring, performance, and communication that trained musicians have spent significant time and effort perfecting. And while within the Coretet software I was eventually able to build a functional visual notation system for Movement III of *Trois Machins de la Grâce Aimante*, that functionality was not available for either the composition of Movement II or the GAPPP project's work on its interpretation and presentation.

PRODUCTION CONSIDERATIONS

In its current state, the production of a performance of *Trois Machins de la Grâce Aimante* is a challenge requiring a significant allocation of resources. To place four performers in a shared virtual reality space, four full virtual reality setups are required, each consisting of an Oculus Rift head-mounted display, two Oculus Touch hand controllers, two Oculus tracking stations, and a laptop with the CPU, memory and video card speed capable of running Coretet at high consistent framerates on the Rift headsets. Each laptop is connected via ethernet to a network switch, which is also connected to a dedicated server computer, also running the Coretet software. The server hosts all four game clients and displays camera views within the virtual environment selected by an engineer in real-time using keys on the computer keyboard mapped to individual cameras or camera sequences to a projector or display in the concert space. A separate laptop also connected to the network switch runs a four-channel Pure Data audio server for Coretet.

While complex technology requirements for computer music performance works are hardly novel, a goal of both *Trois Machins de la Grâce Aimante* and Coretet has been to create a system that could practically and reliably be used in live concert performance by musicians around the world. Commodity virtual reality headsets like the Oculus Rift are now priced at a relatively affordable level but are by no means ubiquitous amongst consumers, neither amongst gamers nor amongst musicians. As such, it is not at this time reasonable to assume or require that musicians purchase or gain access to the necessary computing power to perform the piece. In that light, performances of *Trois Machins de la Grâce Aimante* have only taken place with the composer not only present, but also providing all equipment necessary to run Coretet and perform the piece. Similarly performers currently are only able to rehearse both the instrument and also the composition itself when the composer is in attendance. Indeed, for all four performances of *Trois Machins de la Grâce Aimante* to date, ensembles have only had between four and five days to first acquaint themselves with the Coretet instruments, and then, as an ensemble, learn the piece. Until these limitations are overcome it will be difficult to expect musicians to independently engage with either the composition or the instruments themselves.

GAMING MUSICAL DESIGN

For composers and performers searching for highly-responsive and articulate technological systems within which to create new sonic and musical interactions, one increasingly attractive direction of research has been towards the use of video games as platforms and inspirations for new artistic exploration. Contemporary video game technologies offer incredibly high-end graphics and sound capabilities, often bundled with complex networking capabilities and support for standard and customized hardware controllers. Commercial game-development tools such as Unreal Engine's Blueprint workflow programming language have evolved to a level where programming complex interactions and even complete systems can be carried out using the same techniques that many musicians already employ in their own creative technology projects when using audio and music workflow programming languages such as Max/MSP and Pure Data. Using technologies borrowed from game design and development as well as virtual reality and simulation sciences, composers and researchers can now create virtual facsimiles of musical instruments—faithful replicas or fantastical modifications—capable of mapping human physical gesture onto parameters of sound and music.

In Coretet and *Trois Machins de la Grâce Aimante*, the interaction design, control schema, and overall aesthetic are directly influenced by gaming. Users interacting with Coretet control virtual finger presses, bow strokes, and string plucks by manipulating the buttons, analog joysticks, and physical location of Oculus Touch game controllers, themselves heavily influenced by the design of the current generation of gamepad controllers. Within virtual reality, digital representations of these controllers are made visible to the performers, along with a representation of their hands, helping to align and interrelate the physical reality in which we feel ourselves with the virtual reality presented to us through stereoscopic head-mounted displays. The graphic design of the Coretet instrument components was purposefully futuristic and non-photorealistic, with glowing textures on the bowing bar and bow activated during active bow strokes as visual feedback to the performer. And the virtual stage on which *Trois Machins de la Grâce Aimante* is presented is itself sparse, with the goal of focusing an audience's attention primarily on the virtual instruments and performers and not on the environment itself.

CONCLUSIONS AND FUTURE DIRECTIONS

Compositionally, the work carried out on Movement II of *Trois Machins de la Grâce Aimante* during the GAPPP rehearsal and production sessions showcased the dynamic nature of the piece, both in the varying interpretations brought forth by each member of the ensemble, but also in the way that I as a composer was able to rework sections, adding context and clarity to similar ideas in certain places while completely changing others. Due to the experimental and exploratory nature of the GAPPP project's multiple rehearsal and work periods, I was able to reflect on our initial performance

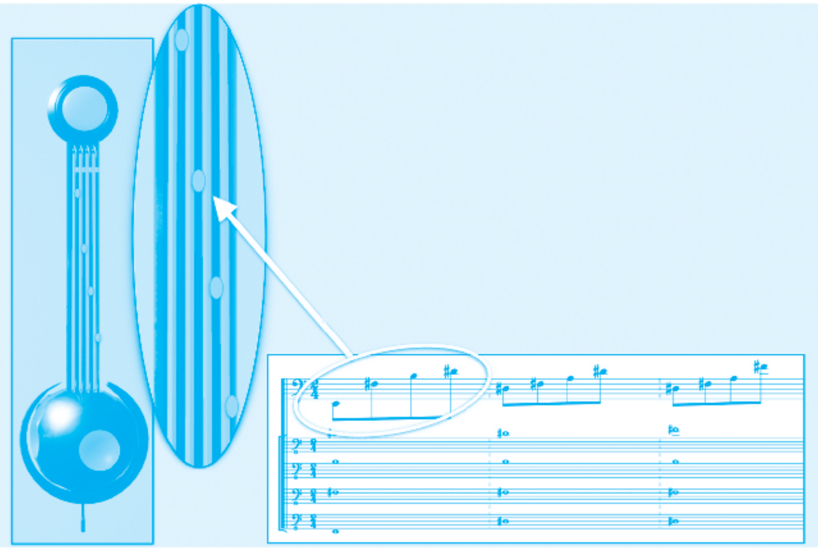


Fig. 10
Dynamic scoring system employed during Movement III of *Trois Machins de la Grâce Aimante*.
Notes from a MIDI score imported into the software are rendered in real-time as finger positions on the neck of each instrument.

and subsequently make significant changes in the direction and focus of individual sections between the initial and secondary work periods. For instance, the initial version of Movement II, Section III featured an emphasis on short higher-register notes, with a significant amount of silence and space, interspersed with occasional melodic phrases. Similarly the initial version of Section IV focused on a rhythmic pulse between ensemble members, with the instruction to gradually shift one's timing, moving in and out of phase with one another.

Following the conclusion of the GAPPP project, development of Coretet has continued, both focusing on general improvements in the performability, stability, and accessibility of the instrument to new users and new musical works, as well as continuing specific development initiatives to support continuing work on *Trois Machins de la Grâce Aimante*, in particular a dynamic system for musical score presentation within the virtual environment. In Movement III of *Trois Machins de la Grâce Aimante* performers play notes from a scoring system displayed on the neck of each instrument [Fig. 10]. A traditionally notated ensemble score was composed and formatted as a sixteen-track MIDI file, with one track allocated for each string of each of the four instruments. These MIDI files are loaded into Coretet and, when triggered on the server, are processed note by note in real-time. Finger position for each note on each string of each instrument is calculated and a glowing blue marker is positioned automatically at the appropriate location along the instrument's neck. Performers then play the appropriate note at the marked location. This scoring system has already been used in live concert performance with a new composition *Elegy (Ready, Set, Rapture)* for solo Coretet double bass.

To date, a series of successful performances of *Trois Machins de la Grâce Aimante* in Austria, France, and Mexico suggests that the modes of networked virtual reality instrumental performance afforded by the composition and by the Coretet instrument could be a viable form of musical performance. While the production considerations in staging a performance of *Trois Machins de la Grâce Aimante* are indeed considerable, they are not so far out of reach that such a project could only be performed once, by one ensemble in one fixed location. In contrast, the staging of *Trois Machins de la Grâce Aimante* in multiple countries around the globe by multiple performance ensembles suggests that we have crossed a technological and financial inflection point, after which the composition, production, and performance of such works can only get easier.

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ARTWORKS & LECTURE

The artworks presented in
this section can be found as
video documentations
on the USB stick,
and accessed online via the included
QR codes or directly on
the complementary website
gappp.net/english/ludified.html.

Rob Hamilton

TROIS MACHINS DE LA GRÂCE AIMANTE

a virtual reality string quartet. Movement II.
performed by Barbara Lüneburg (1st violin-Coretet), Osman Eyublu (2nd violin-Coretet), Francesca Piccioni (viola-Coretet), Myriam Garcia Fidalgo (violoncello-Coretet), and Rob Hamilton (VR-system)

audio recording: Ulrich Gladisch
video recording: ndbewegtbild
video and audio editing: Rob Hamilton
recorded on March 31, 2019 in the György Ligeti Hall/Mumuth of the University of Music and Performing Arts Graz, Austria.
duration of video: 20 minutes 26 seconds

While electronic musical works featuring new instruments often explore novel interfaces to guide musical performance practices and control parameters of sound generation, note articulation, and temporal presentation, the Coretet instrument designed for *Trois Machins de la Grâce Aimante* looks to the historical performance practices of bowed stringed instruments in a new and virtualized form. The composition itself borrows its language and *zeitgeist* both from improvisational ensemble works of the twentieth century and from strictly notated and prescribed works for contemporary string quartet. In Movement II of the three-movement work, which featured in the GAPPP project and recording sessions, performers use a graphical reference score to base their improvisation on. The score describes both individual and ensemble texture, density, dynamics, and timing. In this way, performers study the musical work as if they were performing on traditional physical instruments, but the realization of the work is entirely virtual. Musically, the structure of Movement II was composed to explore the capabilities of the Coretet instrument itself, with each 'section' of the movement exploring different pitch-class settings of the instrument. Section one focuses on simple octaves, using the Coretet setting to split each string on the instrument's neck into two notes each an octave apart. The bowing gesture itself and the ensemble textures become the focus of this section. Section two shifts to a quantized neck setting of major triads, built upon the open-string pitches of each instrument. The textures of ensemble performance again explore the new pitch classes, especially the quantized crossover between notes, allowing performers to create short trills. Section three focuses on the pentatonic scale and vertical chords played in unison by the ensemble.