SUPER COLLIDERS: A GAMIFIED SCREEN-SCORE

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ABSTRACT

This paper introduces *Super Colliders* (2018), a piece written for three pitched instruments and a computer. This piece applies gamification to the screen-score as a compositional approach to achieve playful human-computer interactions. The piece features a game design that encompasses various game mechanics and elements. The paper describes the technical details of the game's design, the role and effects of the featured game elements from the perspective of motivational affordances. Finally, through the analysis of a performance of the piece, the paper reveals how motivational affordances in the screen-score supported to generate the musical structure through the playful performer-computer interactions.

1. INTRODUCTION

In recent years, there has been increasing interest in gamification in human-computer interaction studies. The term 'gamification' first appeared in a blog post written by Brett Trill [1] in 2008 and is defined as "the use of game design elements in non-game contexts" [2] to evoke users' playfulness and address specific challenges. This approach has been applied to, for example, educational software design to motivate learners. Although this approach primarily aims to increase user engagement with difficult challenges, gamification drew the author's attention as a design method for human-computer interaction (HCI) in interactive computer music composition.

Interactive computer music refers to "a music composition or improvisation where software interprets a live performance to affect music generated or modified by computers" [3]. In this field of music, HCI has been used to incorporate the inherent variability in human performance into various projects [4] while posing a question about what the design of interactive systems that can listen, interpret, compose, and respond to a human performer in a way to make sense could be [3] [1]. Numerous precursors have addressed this question, such as George Lewis's *Voyager*, which is a computer program designed for improvising in response to what a computer hears during a performance [6]. Joel Chadabe developed *interactive composing*, a compositional method during which he performs with his self-built 'intelligent' instruments that give quasi-unpredictable responses to a human performer [7]. These precursors have compelled "a paradigm shift from interactive composing [...] to composing interactions" [8]. Designing interactive systems has become a central issue in the compositional process.

This paradigm shift raises a question about what the optimal notation systems are: while interactive systems need to be responsive to performers' actions, most traditional musical scores are prescriptive and represent a predetermined course of music. The screen-score concept was developed, in part, as a solution to this problem of fixity. Thus, screen-scores are often designed to not only project a score on a video screen but also generate musical symbols, graphics, or performance instructions in real-time, as in *KOMA* (G.E. Winkler, 1996) [9] and *music for 2* (D. Kim-Boyle, 2010) [10].

The precursors revealed the problem of an extreme sight-reading. Performers seldom have the opportunity to study a screen-score prior to the performance as the system often generates a unique version of the score in real-time during every performance, and most screen-scores show musical symbols or graphics for only a few seconds on a video display during the performance. These limitations situate the performers against the risk of misinterpretation [11], which conflicts with the concept of perfection prominent in an age where the proliferation of music records has heightened audience engagement with the reproduction of recorded performances in concerts [12].

This cultural condition highlights the game aspect inherent in music performance: the player's challenge to achieve perfection, that is, a game of either success or failure. *Super Colliders* explores an alternative approach to turn the risk of failure into an engaging performance, embracing the game aspect of the music performance by combining gamification with a screen-score in interactive system design. Gamification can create a performance ecosystem in which mistakes play a meaningful role in engendering playful HCI, while a screen-score can mediate performer-computer communication through musical symbols or graphics in a way that is perceptible to the audience [2].

[1] A comprehensive overview of the discussions on interactive systems can be found in [5].

[2] Although the concept of gamification emerged only recently, the merger of games and music was attempted in 'Game Piece,' a musical composition without a predetermined course, like most pieces of classical music, but determined in real-time according to rules, chance operations, and competitive engagement between performing opponents toward a goal, similar to sports and video games, as in *Cobra* (J. Zorn, 1984) [13] [14] and *Duel* (I. Xenakis, 1959) [15]. In recent years, the term 'gamification' has been applied to various pieces, such as *Contraction Point* (K. Giannoutakis, 2015) [16] and *Game Over* (C. Ressi, 2017)

This author's vision of integrating gamification with a screen-score raise two additional questions: which design elements engender playful performer-computer interactions in a piece using a gamified screen-score, and what musical structures and components emerge from these interactions? In this paper, the author reveals the design elements and their musical effects through the analysis of the game elements and a performance. The paper introduces the piece in the following order: (1) game design, (2) the identification of game elements from the perspective of motivational affordances, and (3) the analysis of a performance.

Additionally, the piece is a reflection of the author's artistic point of view, which is to integrate the enthusiasm of game-play with historically inherited compositional devices (e.g., fugato in counterpoint, modulations in tonal music, cyclic form predominantly in romantic music, etc.) into a single composition. To do this, the author introduced two approaches, (1) the use of a midi sequence data of Invention No. 1, BWV 772 (J.S. Bach) to determine initial contents on the screen-score, and (2) the use of a second-order Markov chain algorithm to transform the initial contents according to the performers' interventions. The first approach aimed to introduce the contrapuntal compositional devices in the Bach's music into the initial contents on the screen-score, thereby enriching the musical texture. The second approach was used to transform the initial contents on the screen-score according to the performers' enthusiastic game-play. Applying the two approaches, the piece was envisioned to unfold a course of music, in which, performer's interventions gradually overwrite the Bach Invention.

In Section 2, the game design is explained, including the game mechanisms (i.e., goals and rules) and actions of gaming components (i.e., performers, the gamified screen-score, the interactive computer system, and the second-order Markov chain algorithm). Section 3 identifies elements that can afford players' motivational needs during a performance in light of a taxonomy of motivational affordances as an analytical framework. Section 4 focuses on the observation of musical structures and materials emerging from the interactions between performers and the identified elements. Section 5 presents an evaluation of the piece in light of the author's artistic objective, and future works to improve the game design for enriching the musical structure. In the conclusions section, the author emphasizes the importance of optimizing the difficulty level of challenges (i.e., blob behaviors) during a performance and the need to tune the Markov chain algorithm more effectively so that more engaging playful performer-computer interactions can be achieved.

2. GAME DESIGN IN *SUPER COLLIDERS*

Super Colliders is a game piece for three pitched instrumentalists or vocals with an audiovisual projection setup. The author aimed to design the piece in such a way that the player's desire to win the game results in an enriching musical performance. Therefore, while some music video games, such as *Guitar Hero* [18] and *Dance Dance Revolution*, are played by the haptic manipulation of a game controller, in this composition, the game is played by sound. A key approach was gamifying the 'scrolling score and fixed playhead' model in the taxonomy of animated scores [19]. This approach enabled the author to design a performance ecosystem in which the interactive computer system poses challenges as musical symbols, which the players must interact with to perform (Figure 1).

Indeterminacy is introduced to several levels as the instrumentation, duration, and detailed figure of contours that musicians play. There is no prescribed score or fixed musical sequence. Although performance instruction is provided, it does not specify when and what the performers must play during the game. It informs them of the general objective of the game and the attitude needed to meet challenges imposed by the interactive computer system. Performers are free to choose several musical parameters such as the desired playing technique, contour type, and dynamics for their performance.

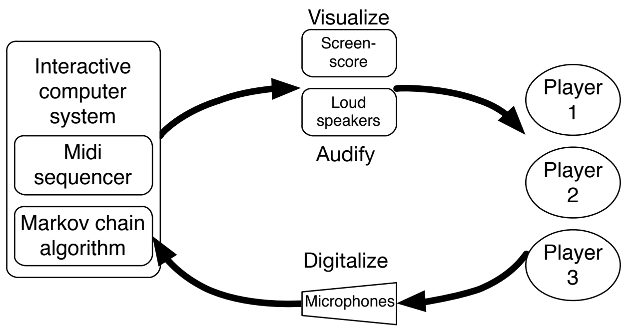

Figure 1. Performance ecosystem in which the interactive computer system and players communicate using a screen-score

2.1 Goals and rules

The players compete with each other in four rounds of the game. One grand winner is identified at the end of the game. To be the grand winner, a player must win the most rounds.

Players must earn 1,080 life points faster than other players to win each of the four rounds. They clash their avatars with blobs moving continually from left to right on the screen-score to earn life points. The players begin the game with 540 life points.

Players earn one life point per clash. However, all three players lose a point if all of them miss a clash. Therefore, there are two possible consequences of the game. One scenario is that one musician earns the most points, so he or she wins the round. Another option is an 'all dead' scenario, meaning all the musicians lose and the computer wins. Notably, the third round is designed such that a human performer always wins.

[17] in the field of interactive computer music. These attempts use a computer as an opponent against the human player in a game.

2.2 Gamified screen-score

The term screen-score refers to the graphical or symbolic representation of music projected visually on a screen. This model typically shows musical notes (or symbols that represent musical information) moving from right to left and a fixed playhead. The notes are played when they overlap on the playhead.

In this piece, the 'scrolling score and fixed playhead' model [19] is gamified as mentioned previously. The musical notes on the scrolling score are replaced by moving blobs (orange rectangles and grey dots) that are representations of midi notes and 'targets,' which players must clash with their avatars, replacing the fixed playhead.

The gamified screen-score shows three types of elements: three musicians' avatars, three life-point indicators, and moving blobs (Figure 2). The three avatars are represented by three dots in different colors. Each avatar is labeled with a musician's name and positioned on the right side on the screen. The three life-point indicators represent the players' life points, and each indicator elongates to the top of the screen as the performer earns life points and drops toward the bottom of the screen as the player loses life points. The moving blobs represent musical notes in a midi file, as well as 'targets,' with which the avatars must collide to earn life points in the game.

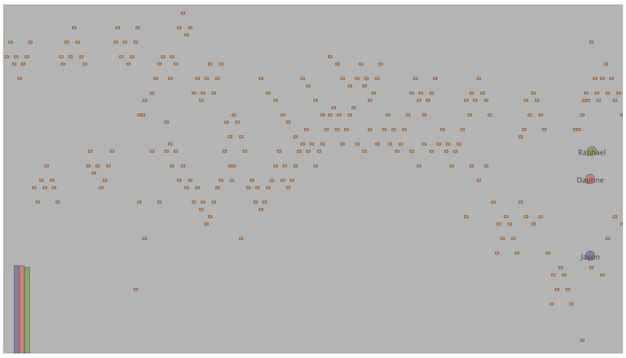

Figure 2. Screen graphics showing three avatars on the right, three life-point indicators on the left, and target blobs moving from left to right.

The vertical position of each blob is mapped to the pitch parameter. The blobs appear in the order of musical notes in a midi sequence in every round, and the blobs move continuously from left to right except during the third round. During the third round, the blobs bounce up, down, left, and right. Although the blobs are still mapped to musical notes to determine the initial vertical position by the computer, the bouncing behavior makes it more difficult to associate the blobs with particular pitches.

2.3 How performers play the game

The piece allows two alternative setups. Either the musicians face the main gamified screen-score with their backs to the audience, or the players face the audience and look at monitor displays (Figure 3).

The performers control their avatars by performing ascending or descending glissandi quietly or loudly. The pitch change is mapped to the vertical position of the performers' avatars. Avatars move to the upper edge of the screen when the musicians play ascending pitch changes and to the bottom of the screen when they play descending pitch changes. The performers need to play the optimal length of the glissandi in the desired direction (up or down) at appropriate timings to adjust the avatar's position to the location of their target blobs.

Loudness is mapped to the horizontal position and the size of the avatars. The avatars are aligned on the right side of the screen when the performer plays silent or very quietly. The speed at which avatars move from right to left depends on how loudly the musicians play. The performers need to play loudly to clash against a blob with their avatar before other players hit it. The size of avatars enlarges as the performers play louder. The enlarged surface allows the avatar to clash with more blobs. This feature is intended to motivate players to perform louder so they can earn more life points.

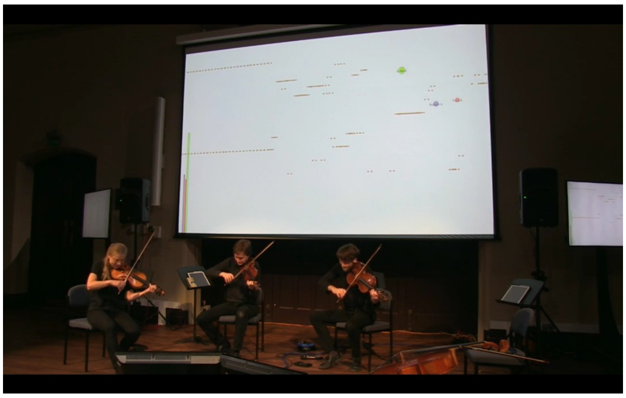

Figure 3. Three string players facing a small monitor display with their backs to the main screen-score.

2.4 Interactive computer system design

The interactive computer system is effective when optimizing the challenges' difficulty to the commensurate level with the performer's skills. The computer system consists of two components: a midi sequencer and a second-order Markov chain algorithm. The midi sequencer sows the initial seed challenges, and the algorithm monitors the performer's ability and adjusts the difficulty level of subsequent challenges in real-time. The midi sequencer outputs midi notes from a preprogrammed midi sequence of the Bach's intention No. 1 as elements of the challenges. The system visualizes the midi notes as blobs on the screen-score.

The second-order Markov chain algorithm plays a key role in optimizing blob behaviors. These behaviors have a significant impact on the level of challenges posed to the performers. The algorithm continues tailoring the difficulty level according to the performers' history of successes since the beginning of the performance.

Another important role of the Markov chain algorithm is a contribution to achieving the author's artistic aim, performers' interventions that gradually override the Bach

Invention, mentioned in the end of Section 1. As the algorithm continues tailoring the difficulty level of the challenge, so does the algorithm overwrites the midi sequence of the Bach Invention with a more dissimilar sequence from the original.

The Markov chain algorithm's behavior changes in every round. During round one, the algorithm learns the moving blobs representing the musical notes in the Bach's intention No. 1. During the performance of the first round, the algorithm creates a state transition matrix (STM) that stores a weight of the probability of every pitch progression between three subsequently clashed midi notes, represented by blobs on the screen-score.

In the following rounds, the algorithm performs two tasks simultaneously: generating a blob sequence according to weighted random choices of the pitch progressions entered in the STM and renewing the weight of the probability based on the newly detected pitch progressions, represented by blob collisions. Notably, the STM is not flushed after every round but maintained for further renewal in subsequent rounds.

Progressions are detected in three different ways. During rounds one and three, they are detected when the moving blobs on the screen-score collide with avatars. During round two, they are detected when the moving blobs are missed by all avatars. During round four, they are detected when the blobs are intercepted and missed by avatars.

2.5 Implementation

A game system was implemented in Cycling '74's Max for audio signal processing and the playback of prerecorded sound files, as well as in the Processing programming environment for real-time visual processing. The system captures acoustic sounds from microphones and then streams the sounds to Max as separate audio signals in real-time. In a Max program, a sigmund~ object tracks the pitch change, and a peakamp~ object detects amplitude. The detected pitch changes and amplitude are mapped to the vertical and horizontal position of avatars, respectively, in a processing program.

The prerecorded sound files are classified into two different sound types: a drone sound and fragmentary sounds. While the drone sound is played in the background throughout all the rounds, the fragmentary sounds are triggered in response to each collision between the avatars and blobs. The fragmentary sounds are further subcategorized into two different types of sounds: piano-like sounds and synthetic attacks. The piano-like sounds are used to play a single pitch that each collided blob represents, thereby possibly reproducing the Bach Invention if all the blobs are collided in the order they appear in the first round. The synthetic attack is triggered each time a collision occurs, so that the synthetic attack sounds give the players and audience audible feedback of the collisions.

The piano-like attack sound was created by EXS24, a built-in synthesizer on the Logic digital work station. The synthetic attack sounds and drone sound were created by TAL-NoiseMaker, a VST plugin synthesizer used on Logic.

3. IDENTIFICATION OF GAME ELEMENTS FROM THE PERSPECTIVE OF MOTIVATIONAL AFFORDANCES

Zhang's article [20] proposes effective design principles for enjoyable human-computer interactions. According to the article, enjoyable human-computer interactions emerge when players' *motivational needs* are fulfilled by the *motivational affordances* of featured elements (e.g., life points and avatars) in a game. The term *motivational affordances* refers to "the properties of an object that determine whether and how it can support one's motivational needs." [20]. *Motivational needs* are users' psychological or social desires (e.g., autonomy and competence) that they want to be fulfilled. This hypothesis was applied in the context of gamification by Weiser *et al.* [21].

To this end, the author applies a taxonomy of motivational affordances [21] as an analytical framework to identify properties of concrete elements (e.g., life points and blob behaviors) in *Super Colliders* and clarifies what motivational needs these elements afford.

3.1 Motivational needs

Taxonomical research [20] and [21] identified the following motivational needs:

- *Autonomy* - the desire to make decisions by themselves rather than being forced to follow a particular regulatory guideline;
- *Competence* - the desire to acquire better skills through challenges that are "neither too easy (boredom) nor too difficult (frustration)" [21];
- *Relatedness* - the desire to engage with others through, for example, recognition, acceptance, and being valued;
- *Achievement* - the desire to demonstrate one's competence to others;
- *Affiliation and Intimacy* - the need for other people's approval and the inclination toward secure and rewarding relationships, respectively;
- *Leadership and Followership* - the desire to gain authority and impact, control, and influence others and the desire to support or be subordinate to a leader, respectively.

3.2 *Mechanics*

When *mechanics* help meet the aforementioned motivational needs, users perceive the experience as playful while interacting with a system. Therefore, these components are particularly relevant to interactive system design. The aforementioned study [21] identified six *mechanics*, which are defined as "possible means of interaction between a user and the system" that can help meet motivational needs.

- *Feedback* - visual and aural information about the user's current actions. This mechanic can optimize users' actions and increases their motivation to achieve a goal.

- *User education* - advice that compensates for the user's lack of knowledge and helps achieve a goal. This mechanic can fulfill the need for competence and, to some extent, satisfy the need for followership.

- *Challenges* - something difficult to overcome, such as a task or quest. This mechanic fulfills the desire for competence.

- *Rewards* - something valuable (e.g., life points or money) given in exchange for the user's accomplishment. Rewards can satisfy the need for achievement and competence.

- *Competition and comparison* - competition is a situation where a player has to win a challenge against rivals. This mechanic can fulfill the player's need for achievement and leadership. Competition is often between players.

- *Cooperation* - collaborative action with other players to achieve a goal. This mechanic can fulfill the desire for affiliation and leader-/followership.

3.3 Featured *Elements*

These *mechanics* (i.e., means of user-system interaction) can be implemented by various design components called *elements*. The term *elements* refers to specific tasks or objects that support *mechanics*, such as quests (for challenges), points (for rewards), and leaderboards (for achievement). Although Weiser *et al.* [21] identified seven types of *elements* as universal and context-free categories, this subsection explains the author's observations about how these *mechanics* are embodied as concrete *elements* for this piece in a context-specific way.

3.3.1 Feedback

The featured *elements* for *feedback* are as follows:

- obedient avatars;

- responsive collision sounds.

Responsive avatars and collision sounds give players immediate visible and audible feedback regarding their performance on the screen-score. This feature satisfies the need for self-determination during the performance and, thus, can afford the need for *autonomy*. Importantly, the predictable reaction of musicians' avatars to their sounds gives musicians the possibility of gaining better control of their avatars. When the musicians are immersed in gameplay, this possibility affords the desire of *competence*.

3.3.2 User education

The featured *elements* for *user education* are as follows:

- written instructions;

- rehearsals;

- rounds.

These *elements* complement the player's lack of knowledge regarding what is required in their performance and, thus, support the need for *competence*. If competence contributes to improving the performers' skills enough to win, user education can also help fulfill the need for *achievement*. The written instructions explain the concept of the piece and how to play it, thereby giving the performers a general understanding of the piece and helping them prepare for the performance. Rehearsals give performers the opportunity to learn how to play with the interactive computer system in action. They may conceive strategies to win the game, as well as contribute to musicality in the performance.

The rounds set up a heuristic process for performers during the performance. The rounds in this piece are designed similar to each other, with slight variations in rules and mechanisms. Thus, the rounds can be a learning opportunity where the performers develop their skills and interpretation further as the piece proceeds.

3.3.3 Challenges

The featured *element* for *challenges* is as follows:

- moving blobs.

The players' task is to clash the moving blobs with their avatars. Succeeding at this task can satisfy the performers' motivational need for *competence*. This task requires performers to be alert to the visual information and virtuosity for agile responses to the time-sensitive nature of the blobs' behavior. The task needs to be optimized to strike a balance between boredom and frustration among players. In this piece, blob behaviors are the essential factor that controls the difficulty level of the challenges. A concrete example of the challenges is presented in Section 4.

3.3.4 Rewards

The featured *element* for *rewards* is as follows:

- life points.

This mechanic rewards the player's success in clashing with blobs and, thus, fulfills the need for *competence*. Since the life point indicators explicitly show the audience the player's success, this mechanic can afford the need for *achievement*. The concept of life points places players in a competitive mode in which each player's health is compared to other players, and it may be threatened enough to 'die' in the game. The concept of life points is a crucial element that engenders both competition and cooperation. While comparisons to others may predispose players to view others as rivals, the threat of 'dying' in the game could make them view others as strategic temporal collaborators to avoid ‘dying’ due to difficult challenges. Thus, this element can also satisfy the need for survival, which is related to *leadership and followership*.

3.3.5 Competition

The featured *element* for *competition* is as follows:

- leaderboard.

The leaderboard announces the winner at the end of each round. After all four rounds have been played, the leaderboard announces the grand winner of the game to the audience. This element addresses the need for *relatedness* and *achievement*.

3.3.6 Cooperation

The featured *element* for *cooperation* is as follows:

- ‘all dead’ scenario.

The game can end with an ‘all dead’ scenario in which all players miss so many blobs that their life points are depleted. Although the players are primarily rivals, as only one player can win the game, this scenario gives players an incentive to cooperate and avoid missing blobs. Therefore, this element can satisfy the need for *leadership and followership* between ensemble members.

4. ANALYSIS OF A PERFORMANCE

This section describes an analysis of how the featured *element* of moving blobs affects the emergence of playfulness and musical results, referring to two video recordings of a performance by members (Vln I, Vln II, and Vla) of a professional string quartet, the Ligeti Quartet. The performance took place at Victoria Gallery Museum - Leggate Theatre at the University of Liverpool in UK on October 30, 2019. One of the recordings shows the performers and the screen-score on stage [3] , while the second recording shows the same performance, but only the screen capture of the screen-score is shown. It is noted that the electronic sounds were not played due to a technical problem in this performance. Thus, the performance will not be analyzed from the perspective of how the electronic sounds influenced the performers.

The studies on motivational affordances [20][21] suggest that playful human-computer interaction emerges when *motivational needs* are met, and *competence*, one of the motivational needs, is afforded at the highest level when the level of difficulty is commensurate with the performer’s skills. Hence, it is suggested that the target scenario of the game is a ‘close battle,’ which means players, including the computer system, win fairly throughout the game with close life-point scores. Notably, moving blobs are the only variable *element* the system uses to adjust the difficulty of the challenges to the performer’s skill level. Other *elements* are not designed as variable parameters that players’ actions can influence. Therefore, blob behaviors appear to be the most essential *element* that sways the emergence of playfulness in this piece.

There is, unfortunately, no way to compare the final life-point scores of the performance, as the precise life-point data were not recorded. However, the approximate life points on a video recording of the screen-score are available. Additionally, since close battles result in a longer round, it is possible to infer the closeness of the battle by comparing the duration of each section in the performance. This comparison reveals how close the battles were indirectly.

Therefore, the analysis focuses on the following:

- how many times each performer won throughout the performance;
- how long each round lasted in the performance.

The author’s analysis illuminates the influence of blob behaviors on the time structure and choice of the following parameters:

- playing techniques - techniques used to play instruments, such as normal bowing, pizzicato, and tremolo;
- contour types - types of phrases, such as linear, leaps, and accelerando;
- dynamics - loudness of the performances, such as fortessimo and pianissimo;
- ensemble - a musical unit built by a performance of more than one player.

The following subsections describe the author’s observations of how the blob behaviors affected the performers’ choice in each round.

4.1 Round one

4.1.1 Game-end conditions

This round ends when one of the following game-end conditions is met:

- when one player reaches the maximum life points (i.e., 1,080 points);
- when the sequence data ends;
- when all players die.

4.1.2 Blob behavior

The blobs move from left to right on the screen in the order of musical notes in the preprogrammed sequence data of the Bach Invention. The speed of the blobs are constant, and it takes them approximately seven seconds to arrive at a point where the avatars can intercept them. The blobs are widely spread out vertically, and it is reasonably difficult to capture all the blobs.

[3] The video recording is available at https://vimeo.com/382978696.

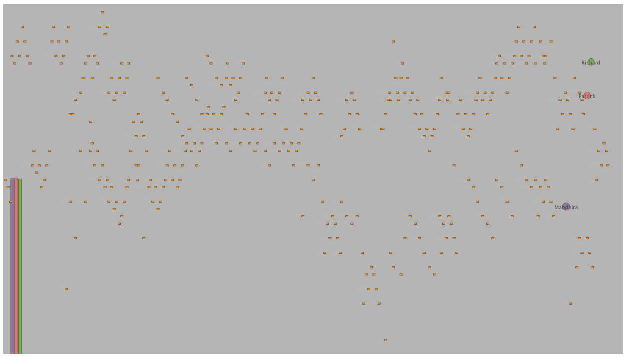

Figure 4. Widespread blob behavior in round one.

4.1.3 Performers responses

The blob sequence ended before any of the performers were able to win the first round by earning 1,080 points. Therefore, the second violinist, who earned the most life points during the round, was considered the winner. The end scores of all the players were low and close to each other. This result suggests that if the blob sequence had lasted longer, they all might have died. The round lasted for 55 seconds.

4.1.4 Musical results

Structurally, the round was separated into three sections: (1) before the moving blobs arrived in the vicinity of the avatars, (2) after the arrival of the moving blobs, but before all the blobs passed, and (3) after all the blobs had passed. Three playing techniques were observed: normal bowing with pizzicato during the first section, normal bowing with tremolo and pizzicato during the second section, and normal bowing during the third sections. Three contour types were also observed: a quick and short scaler phrase, long linear glissandi, and accelerating repeating notes. Four levels of dynamics were found. During the first and third section, the dynamics floated between piano and mezzo piano. During the second section, the dynamics rose to the range between mezzo forte and forte. Two ensemble units were found. The first ensemble unit was at the beginning of the first section, where the viola and violin II played a contrapuntal phrase together [4]. When the viola was performing an ascending phrase, violin II played an inversed descending phrase fairly concurrently. Another ensemble unit was in the third section, during which the viola and violin II played a cadence in collaboration [5].

4.2 Round two

4.2.1 Game-end conditions

There are two game-end conditions, as follows:

- when one player reaches the maximum life points (i.e., 1,080 points);
- when all players die.

[4] 0:19 in the video
[5] 1:01 in the video

Similar to round one, in round two, the players are challenged to earn more life points than the other players. However, the round continues until one player achieves the maximum number of life points (1,080 points). This is different from round one, which ends when the fixed blob sequence concludes, regardless of the player's life points.

4.2.2 Blob behavior

The moving blobs drew linear arrays during this round. These array forms were the result of the Markov chain algorithm optimizing blob progression. The linear arrays mean that the avatars engaged in less vertical movement to collide with blobs during the preceding round. As a result, the algorithm entered a higher weight in the repetition of the same pitches in the STM (see Section 2.4 for more details.)

Figure 5. Linear blob behaviors in round two.

4.2.3 Performers' responses

The round ended in an 'all dead' scenario occurred and no one won. The round lasted for 2 minutes and 24 seconds, which seems to be the longest round of the piece. The long duration of the second round suggests that, although all the players died, the players had a close battle with each other, as well as with the interactive computer system. This further indicates the blob behaviors were optimized as intended.

4.2.4 Musical results

Structurally, the round was divided into two sections: (1) before the moving blobs arrive in the vicinity of the avatars and (2) after the arrival of the moving blobs.

Four playing techniques were found: normal bowing and pizzicato during the first section and normal bowing, tremolo, pizzicato, and overpressure during the second section. Four contour types were also observed: a quick and short scaler phrase, long linear glissandi, repeating short notes, and accelerating and repeating notes. Four dynamic levels were found. The first drew the gradual dynamic change from piano to forte toward the second section. The second section showed a louder dynamic range between mezzo forte and forte. One ensemble unit was found. At the beginning of the first section, the viola and violin II played a heterophonic unit [6] in which the

[6] 1:10 in the video

viola first played a glissando, delineating a swell in pitch. Next, violin II played an ascending scale to the same pitch as the highest pitch that the viola had just played, drawing a shadow of the viola's part.

4.3 Round three

4.3.1 Game-end conditions

There is only one game-end condition in this round:

- when one player reaches the maximum life points.

4.3.2 Blob behavior

The third round is comprised of different blob behaviors from other rounds in two ways. First, the round introduces the concept of gravity for the blobs' motions. Unlike other rounds, the blobs gradually fall to the bottom of the screen, then bounce back to a slightly lower height than their original position. After repeating the bounce several times, the blobs gradually stay at the bottom of the screen. Second, the round restricts the space within which the blob can move. In the other rounds, the blobs move away and off the screen, but in the third round, they bounce back at the frame of the screen-score. As a result, once the blobs appear, they remain on the screen-score until clashed by the avatars. Therefore, this round guarantees that one performer wins by preventing an 'all dead' scenario from occurring, but this type of blob behavior may deflate the value of rewards (i.e., life points). The Markov chain algorithm is used to determine the initial vertical position of the blobs. However, the optimization seems irrelevant in this round as all the blobs remain within view of the players.

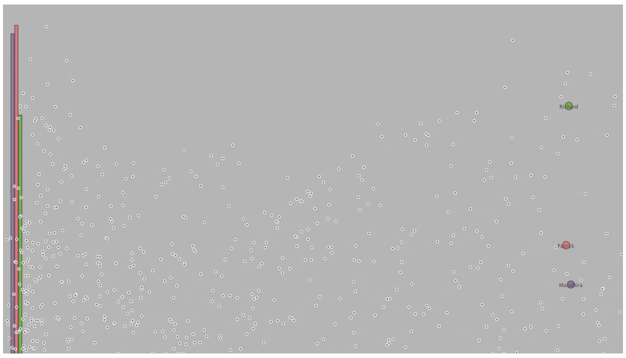

Figure 6. Bouncing blob behaviors in round three.

4.3.3 Performers' responses

Violin II won the third round, but it was a close battle, as violin I's final life points were extremely close to violin II's. The round lasted for 1 minute and 48 seconds.

4.3.4 Musical results

Structurally, the round was divided into three sections. The borders between these sections are, unlike the other rounds, not according to the blob's horizontal positions, such as one division when the blobs arrived in the avatars' territory and another when passing from the territory. The vertical position seemed to have more influence. The first section was mainly played by several quick, short glissandi. This suggests that the players were eager to reposition their avatars to the hight of their target bouncing blobs. The second section was mainly performed by pizzicato. This suggests that the players were motivated to intercept several blobs at every pluck, as one pluck of the pizzicato results in a quick pop of the avatar further to the left than normal bowing. If several blobs are on the path of the avatar, this playing technique helps the player clash with multiple blobs. The third section was played by normal bowing with which the players drew gradual increments of loudness to the end of the round. The change in playing techniques from pizzicato to normal bowing seems to have less impact on the competition and contributed to drawing a tutti at the end of the round.

Three playing techniques were found: normal bowing and pizzicato during the first section and normal bowing, tremolo, and pizzicato during the second section. Three contour types were observed: quick and short glissandi, repeating short notes played by pizzicato or normal bowing, and irregular rhythmic step-wise motions. Three dynamic levels were also found. The entire round showed a gradual increase in the dynamic level from mezzo forte to forttessimo. One potential ensemble unit[7] was found. All the instruments together intensified the loudness and created a tutti until the end of the round. However, it is unclear whether this musical effect was the performers' intentional choice or an incidental emergence influenced by the game system.

4.4 Round four

4.4.1 Game-end conditions

There are two game-end conditions, as follows:

- when one player reaches the maximum life points;
- when all the players die.

4.4.2 Blob behavior

The blob behaviors show an intermediate property between the widespread sequence in the first section and the linear arrays in the second round. This is because the Markov chain algorithm weights the likelihood of successfully clashed blobs during the first round and missed blobs during the second round. As a result, the difficulty level of the blob behavior is supposed to be higher than in, for example, round two. In addition, the speed of the moving blobs gradually increases over time. This also heightens the difficulty of intercepting them since the blobs pass by momentarily as their speed increases.

4.4.3 Performers' responses

The 'all dead' scenario occurred, and the round lasted for 56 seconds, which suggests that the challenge was too difficult.

[7] from ca.5:09 to 5:27 in the video

Figure 7. Blobs showing an intermediate property between linear arrays and a widespread constellation in round four.

4.4.4 Musical results

Structurally, the round was divided into two sections. During the first section, before the arrival of the blobs, the performers played a fugato. The second section was mainly performed by normal bowing. This choice was optimal for adjusting the height of their avatars to their target blobs.

Two playing techniques were found: normal bowing during the first section and normal bowing, tremolo, and pizzicato during the second section. Two contour types were observed: quick and short glissandi and repeating short notes played by pizzicato or normal bowing. Two dynamic levels were found: mezzo forte during the first section and forte during the second section.

One ensemble unit was observed, a fugato [8] at the beginning. Since strict phrasing rules, such as a fugato, do not normally contribute to adjusting an avatar's position to the ideal height for clashing with the blobs, performing the fugato seems to be for the purpose of enriching the music rather than gaining a strategic advantage in the game. It is worth mentioning that the phrasal material of the fugato was a short and quick step-wise motion used as a component in the ensemble unit performed at the beginning of the first round. This shared material draws a link to the historically recognized cyclic form.

4.5 Discussions

The analysis illuminates the influence of the featured blob behaviors on two different aspects of the music performance: competitiveness and the emergent musical structure. Competitiveness is related to performer's engagement with the game aspect of the music, while the emergent musical structure is related to performers' contributions to the form and components in the music.

For competitiveness, the result of the performance highlights the importance of the avatars' responsiveness to be equal across all the performers. The video recording shows that the second violin's avatar pops further left than other avatars with similar dynamics. This implies that the amplitude mapped to the horizontal position of the avatar was increased somewhere between a microphone and the screen-score. This flaw gave the second violinist an unintentional advantage to intercept the moving blobs earlier than other performers.

In addition, the result of the performance brings into question the effectiveness of the Markov chain algorithm in optimizing the difficulty level of the blob behaviors. As mentioned above, close battles are a crucial component of engendering playfulness in game-play. However, the analysis reveals a strong deviation in the results of the game. The second violin won twice, and the 'all dead' scenario occurred twice. Neither of the other two players won a round. It is remarkable that the rate of victories by the computer against human players was even. This result suggests that the challenge was optimal for the three performers playing against the computer as a group. Furthermore, the longer duration of the second round indicates that the Markov chain algorithm's optimization of the blob behaviors was effective to some extent. However, the challenge is not balanced between the three players. One prospective modification for this problem is to implement some kind of functionality to impose different levels of challenges to each of the three musicians, which means introducing the concept of handicapping in some way such as decreasing the input gain of an advanced player.

Regarding the emergent musical structure, it became clear that the moving blobs often resulted in dividing a round into at least two sections, before and after the blobs arrived in the avatars' vicinity. During the former, the musicians performed some complex units in collaboration, such as inversed contours (in round one) and a fugato (in round four). The moment before the arrival of the moving blobs seems to have been 'free time' for the musicians.

In contrast, after the moving blobs arrived in the avatars' vicinity, the performers chose to play more favorable materials with advantageous dynamics for winning the game rather than performing a complex musical unit as an ensemble. It tended to draw a clear border between the section before and after the moving blobs arrived in the avatars' vicinity. This observation suggests that there might be compensation between the risk of defeat and musical freedom. If this hypothesis is proven to be reasonable, competition might not be always the most effective gamification archetype to invoke playful interactions between human players and a computer.

It is remarkable that, in the third round, the border between the section one and section two was not divided according to the horizontal proximity between the moving blobs and the avatars. Instead, the border emerged from the choice of playing techniques that were advantageous for clashing the dense area of blobs near (and not moving away from) the bottom of the screen-score. Although all the players changed their choice of playing techniques, the timing of their changes was not as synchronous as the change from the first to the second section in other rounds. This lessened the clarity of the border and created a gradual transition. This example suggests that blob behavior influenced the musical structure.

Additionally, the transition from section two to section three in round three seems less relevant to winning the game. The author hypothesizes that this transition was the

[8] from 5:47 to 6:00 in the video

result of the performer's choice of musicality induced by the infinite accumulation of the blobs in the screen-score. The accumulation deflated the value of the blobs towards the end of the round, resulting in a situation where the avatars can clash with the blobs regardless of the choice of playing techniques. This further suggests that the excessive amount of the rewards delivered a certain degree of freedom to the performers. Interviews with the players would help explore this choice further.

Notably, the blob behaviors play a pivotal role in weighting the emphasis of the performance on either competitiveness or a musical structure. Different forms of blob groups influenced the choice of musical parameter settings. For example, a linear array often invoked competitiveness. Performers tended to await the arrival of the blob array at the same position in height. In this case, the performers tended to play louder to intercept the blobs further away before the other performers reached them. This situation turned the performance into a dynamic level competition. In contrast, the widespread blob sequence emphasized the musical structure. Performers tended to reposition their avatars vertically on the screen-score by playing the glissandi. The pitch changes sometimes entailed interweaving the contrapuntal lines (e.g., at 0:19 in the video). Thus, the performance was more focused on a musical structure.

5. EVALUATION AND FUTURE WORK

5.1 Evaluation

The piece can be evaluated as partially successful in fulfilling the artistic objective, which was to integrate historically inherited compositional devices and enthusiasm of game-play into a piece of music. One approach was to use the midi sequence data of the Bach Invention as the initial contents on the screen-score in the first round. This approach worked fairly effectively, since the approach resulted in the contrapuntal interweaving between voices during the performance in the first round. Another approach was to use the Markov chain algorithm in order to involve enthusiasm of the game-play into the musical structure while keeping the elements of the compositional devices in the Bach Invention. The author found that the second approach requires some modifications to fulfill the artistic goal. Although competitiveness in the piece invoked enthusiasm of the game-play, the aforementioned conventional compositional devices (e.g., a fugato, a cyclic form) appeared only during the sections where the blobs symbolizing pitch notes in the Markov-generated midi sequences are away from the performers. The absence of the compositional devices questions the effectiveness of the Markov chain algorithm in the game context to create a synergy of the performers' game-play and the compositional devices.

5.2 Future work

In order for competitiveness to contribute to the enriching musical structure, the author envisions two further explorations: more drastic changes of the blob behaviours and the use of various mapping combinations between acoustic parameters of the instrumental sounds and behavioural parameters of the avatars.

For the former, one idea is to implement vertical blob motions from top to bottom in order to induce more contrasts in dynamics in music. The author expects that the vertical motions will induce a competition on dynamic level control instead of the competition on their loudness level observed in round one, two and four, since the performers need to adjust the avatar's horizontal position onto the course of the target blobs by a precise loudness control. Another idea is to implement horizontal blob motions from right to left for the emergence of a quiet music, as the performers would compete to adjust the avatars' vertical positions while playing as silent as possible to stay further ahead to the right on the screen.

For the latter, one idea is to map spectral centroid of the instrumental sounds to the avatars' vertical position. This mapping could invoke a competition on brightness in timbre, which may induce the use of various alternative playing techniques for the avatars' control, thereby contributing to enriching the musical textures. These modification ideas call for a further exploration on the influence of behavioural patterns of the blobs on various musical parameters for achieving the contribution of competitiveness to the musical structure.

6. CONCLUSIONS

Super Colliders applied the concept of gamification to a screen-score to invoke playfulness in performer-computer interactions. The paper introduced conceptual and technological aspects of the game design (i.e., the goals and rules, the behaviors of performing agents, and the design and implementation of the gamified screen-score). Next, elements relevant to the emergence of playfulness in light of the taxonomy of motivational affordances were identified. Finally, a performance was analyzed to investigate how the performers play a close battle with the game system and what musical results the performer-computer interactions entailed. Comparisons with the motivational affordance study illuminated the significance of the motivational need for *competence* in this piece. However, the analysis found the interactive computer system overpowered human players. This result indicates the need for modifying the second-order Markov chain to optimize challenges (i.e., blob behaviors) more effectively, which is essential to evoke playfulness. The author believes that the gamified screen-score has the potential to support the future adjustment of game mechanics, as the gamified screen-score is not just an intermediary of musical symbols between the Markov chain algorithm and human performers. Instead, it is a performance ecosystem in which multiple active agents continuously interact with each other through various modalities regardless of whether they are humans or computers.

Acknowledgments

The author would like to thank the members of Ligeti

Quartet for their commitment to the performance, McGill University and CIRMMT for production support, and the FRQSC for financial support.

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