TYG: Collaborative Music Creation in an Unreal Engine-Based Local Multiplayer Instrument

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This paper sets the background for and then introduces TYG, a single-screen local multiplayer digital musical instrument (DMI) created by Payne and Dalgleish (2024) and developed in Unreal Engine 5. Noting the absence of specialised multiplayer instruments in the acoustic domain, we survey the NIME literature to introduce the general design challenges and opportunities brought about DMIs. Drawing on this body of literature and aspects of local multiplayer games design, we then discuss issues specific to multiplayer DMIs and the design of the TYG system. This includes composition and performance modes and a variety of key parameters for performance setup and customisation. We present a prototype level and share preliminary findings before proposing directions for future research.

Most traditional musical instruments still in use today have evolved over hundreds or thousands of years (Montagu, 2007), but Magnusson (2019) notes a general stagnation of designs after the late 18th century. This has fostered a belief that traditional instrument designs are optimal or idealised, but they are in fact inherently imbalanced. That is, their designs evolved primarily for acoustical rather than human reasons (Marshall, 2009), and ease of use and player comfort (etc.) were at best a secondary consideration. The physical and mental demands placed on players because of this prioritisation are substantial to the extent that some individuals are ultimately excluded from participation (Blatherwick et al., 2017). At the same time, however, conventional models of musicianship that centralise the need for players to overcome these demands remain in place and barely challenged.

The resistances to be overcome by the player are closely related to the physics of acoustic instrument construction, particularly the sound generation mechanism (SGM). For example, a specific SGM might need to be chosen to achieve desired output properties, and this choice in turn constrains the design possibilities of the performance interface, as this must be able to physically and usually directly act on the SGM (Marshall, 2009). These constraints largely determine both the overall design of traditional instruments and their performance properties. The close physical connection between performance interface and SGM also contributes substantially to instrument feel. Specifically, the activated SGM passes vibrations back to the performer through the performance interface, providing rich, moment-by-moment feedback on instrument state and behaviour (Saitis et al., 2018).

These haptic sensations are also fundamental to the development of what Rebelo (2006) terms performer-instrument intimacy.

Equally relevant is that the performance interface-SGM coupling is designed for predictability and to produce repeatable responses to performer input, at least at the macro-scale. Thus, any errors are firmly attributed to the performer, and, over centuries, perfection has become enshrined as a key sign of performance attainment and mastery (Leech-Wilkinson, 2020). If this provides a means (however insufficient) by which performances can be evaluated, the social pressures generated can also impose further barriers to participation.

Designers have emphasised that the problems brought about by DMIs differ significantly from those raised by traditional musical instruments (Armstrong, 2007; Marshall, 2009), most notably in relation to the player-instrument connection and audience reception. Also pertinent is that, while there are very few examples of traditional (acoustic) musical instruments designed for multiplayer use (Symons, 2022), several multiplayer DMIs have been developed by the New Interfaces for Musical Expression (NIME) community (NIME, 2024) and its precursors in a comparatively short period of time.

Nevertheless, there are no widely adopted examples and multiplayer DMIs remain a niche concern. Thus, we also draw on aspects of other fields where relevant. Local multiplayer games, for instance, have played a key role in the history of video games more generally and their facilitation of emergent interactions and behaviours has been well documented elsewhere (Taylor, 2020). Although a survey of local multiplayer videogames is beyond the scope of this paper, we are informed by aspects of these games and contend that local multiplayer games can help multiplayer DMIs to find their unique or distinctive qualities. Particularly, we seek to address how comparisons between DMIs and traditional instruments are often framed to heavily favour the acoustic. That is, rather than acknowledge traditional instruments to be a series of nuanced design compromises, many of the potential advantages DMIs, especially in terms of accessibility, are turned against them: DMIs are too easy to play, involve little skill, have limited output, and are more toy than instrument. These distortions are in turn used to explain why there are still relatively few examples of long-term DMI use and virtuosity.

The reality, as can be observed empirically, is quite different. Although DMIs differ significantly from traditional instruments, even a brief review of the instruments presented since 2001 at NIME reveals their enormous variety and that they can assume almost any properties imagined by their designers is a defining characteristic. This versatility has also made DMIs a site for diverse interests. For instance, the centuries-long drive for standardisation has distanced today's players of traditional Western instruments from making or modifying their instruments (Rebelo, 2006), but Masu et al. (2023) contend that Makers are the primary constituent of the NIME community. Similarly, Marquez-Borbon and Stapleton (2015) have identified Maker-related communities of practice centred around technological platforms such as the Satellite CCRMA and Patchblocks. More recently, a significant community has developed around the Bela platform (Bela, 2024).

Like Boluk and LeMieux's (2017) theorisation of video games as vessels that enable multiple different games to be played inside the shell game, these mixed interests mean that DMIs can reasonably be conceptualised as sites of making, performing, modification, and composition (etc.), but also ultimately of social interaction. These roles may not all be active simultaneously and can shift over time (Tahiroğlu, 2021). For instance, a performer might make several modifications over many years, each time followed by testing and evaluating these changes through performance.

Before proceeding, it is important to mention that alternatives to 'instrumental' models of DMIs have been proposed. For instance, Malloch et al. (2006) observe that a computer can also 'encompass' one or multiple instruments. Beyond NIME and arguably more radically, Haraway (1985) proposes machine-organism hybrids as means to transcend the ingrained notion of technologies as extensions of human capabilities. By inseparably merging humans and technology, Haraway (1985) suggests, prior understandings of their characteristics and roles are also undermined. Nevertheless, non-instrumental models have yet to significantly influence DMI design. Thus, to fully engage with the literature, discussion in this paper maintains the widely adopted model whereby a DMI = performance interface + mapping + sound generation (Hunt and Kirk, 2000; Jordà, 2005; Armstrong, 2007; Marshall, 2009). At the same time, we recognise that the NIME community's relentless pursuit of novelty is sometimes unhelpful and potentially harmful (Morreale et al., 2020) and try instead to plot a more balanced course.

Digital Musical Instruments: Properties and Prospects

Player-Instrument Connection

The performance interface can be a physical element of a larger DMI system, but it can also be conceived as a boundary between player and system (Bongers, 2006). Unlike to the acoustic instrument case, the input (performance interface) and output (sound generation algorithm) ends of DMI have no requirement for a physical-mechanical connection and are instead only loosely connected by wired or wireless signals (Dalgleish, 2016). Although not recommended by Jordà (2005) for reasons of instrument coherence, this freedom allows the ends of the instrument to be designed entirely independently, and each end can have essentially any desired properties. These can then be bridged afterwards by a software mapping (Jordà, 2005; Marshall, 2009; Hunt and Kirk, 2000). The possibilities of this freedom are arguably still to be fully exploited, but by focussing on the performance interface, DMIs can be designed around player bodies or needs, and this need not impact sound generation (Jordà, 2005). For example, a DMI designed for a player with limited movement might use minimally actuated sensors (Human Instruments, u.d.).

This design freedom is seen to comes at a price, namely that the mediated and potentially entirely dematerialised connection between sound generation algorithm and performance interface results in few if any vibrations being passed back through the interface to the body of the performer (Marshall, 2009; Armstrong, 2007). Haptics have been identified as key to instrument navigation (Marshall, 2009), but the loss of tactile feedback is also seen to deteriorate performer-instrument intimacy (Rebelo, 2006). This loss is compounded in what Harris (2006) calls inside-out instruments, whereby loudspeakers or other means of sound diffusion are located outside the instrument body (Marshall, 2009).

The addition of artificial (active) haptic feedback technologies and the embedding of loudspeakers have variously been proposed to mitigate these issues (Marshall, 2009). However, these technologies are far from universally adopted, and, as well as adding weight and complexity, their physical requirements inevitably shape DMI design, thereby likely limiting the potential for design around the body.

Control

Conventional models of musicianship frame control in terms of a player's quest for maximal physical command over their instrument and equate fine and total control with mastery. This view of control remained largely unchallenged until the mid-20th century, when, as the quest for new sounds continued (Manning, 2013), music shifted toward systems-based ideas like chance operations, randomness, stochastics, and cybernetics. These concepts soon influenced new electronic instruments, notably the live electronics of David Tudor and contemporaries such as Gordon Mumma.

Where magnetic tape as a medium was strictly non-real-time and laborious, and more traditional instruments (including other electronic instruments) favoured strict predictability and repeatability, the homebrewed circuits of Tudor instead emphasised liveness and spontaneity. Their complex feedback paths actively courted instability and unpredictability, and it was rare for his circuits to be configured in the same way twice. Thus, rather than known and precise control, Tudor had only loose influence over a precariously poised system where repeated input could produce very different output each time (Dalgleish, 2016).

Moreover, to portray traditional (acoustic) instruments as entirely predictable is slightly misleading, as beneath their macro-level predictability of response to player input, there is hidden complexity. Mudd et al. (2020) for instance remind that many acoustic instrument designs exhibit significant input-output nonlinearity at the micro-level. Like the provision of haptic feedback, this is also largely the result of the melding together of performance interface and SGM. Mudd et al. (2020) also note that these instrument's respective nonlinear dynamic processes are fundamental contributors to their behaviour. They are inherently unpredictable, at least initially. For example, a clarinet player might blow too gently to produce any sound at all, but then, as Mudd (2017) describes:

> *[…] blowing with a particular breath pressure produces a particular note, blowing harder pushes the note into a higher partial, but then returning to the original level of breath pressure does not necessarily correspond to a drop back to the original partial: the system can 'lock' into particular states.*

This micro-scale unpredictability may seem at odds with the fundamental predictability of traditional instruments, but Magnusson and Hurtado (2007) argue that a degree of unpredictability can form part of control, provided the player understands where this unpredictability is situated within the instrument's parameters. Additionally, the effort expended in overcoming these non-linearities and the resultant impositions on the player are seen to have the potential to increase performer engagement (Magnusson and Hurtado, 2007) and as being closely related to expression (Ryan, 1991).

The inherent precision and programmability of computers served only to proliferate counter-reactions that explore alternative models of control. For instance, Perkis (1989) described how “instead of attempting to gain more complete control over every aspect of the music, we seek more surprise through the lively and unpredictable response of these systems, and hope to encourage an active response to surprise in the playing.” Waisvisz (2006), creator of The Hands and notable for being one of few performers to develop a long-term relationship with a DMI, went further still:

we should abolish the illusion of ‘control’

merge our intentions into those of the instrument and the audience

get inspired by change, miscalculation, invested instinct, insightful anticipation, surprise and failure.

Mapping

Mapping relates to the shape and characteristics of the connection between the performance interface and sound generation algorithm. The study of mapping began in earnest around the start of the NIME era (Hunt and Kirk, 2000), but mapping is now widely recognised as a key part of DMI design and another main contributor to instrument feel and behaviour (Hinkley, 2002). It also impacts performance reception (Cascone, 2002). Unlike the acoustic case, the mappings of DMIs are not largely pre-determined by the combination of interface and sound generation mechanism. The mappings can instead be almost any imaginable but must be explicitly described by the designer (Jordà, 2005).

Arfib et al. (2002) distinguish between mapping types according to the criteria pairs of explicit/implicit, simple/complex, and dynamic/static. Explicit mappings are where the links between the input and output mapping parameters can be exactly described, while implicit mappings are a black box for which general rules rather than precise values can be defined. Static mappings are fixed and thus will not adapt to or learn from any input, while dynamic mappings can adapt or change over time. A related definition of a dynamic mapping based on internal change is also presented by Momeni and Henry (2006).

Three basic types of mapping are set out by Wanderley and Orio (2002):

- One-to-one - a single input parameter is mapped to a single output parameter.
- One-to-many - a single input parameter is mapped to multiple output parameters.
- Many-to-one - many input parameters are mapped to one output parameter.

Only the many-to-one (Arfib et al., 2002) type broadly resembles the mappings typically found in acoustic instruments, but an additional, many-to-many type, often considered to be complex but ‘deep’ (Jordà, 2005), can be derived from combinations of the other types.

Regardless of the mapping type adopted, there can be a single mapping layer or multiple layers, and multiple layers can be arranged in series or parallel (Callear, 2012; Momeni and Henry, 2006). Multi-layered systems can offer greater depth at the cost of transparency. In terms of the performer, transparency is rooted in conventional models of musicianship and is closely related to control and mastery; as a player's skill improves, the act of playing becomes more transparent, thereby reducing the distance between player and instrument (Williams, 2023). At the extreme, the instrument may come to feel like an extension of the body (Nijs et al., 2013). Gadd and Fels (2002) define transparency similarly but add that this connection needs to be understood by an audience. This understanding is socially constructed (Fels et al. (2002) and may be different to the player's (Gadd and Fels, 2002). Hunt and Kirk (2000) also note that more complex mappings take longer to learn. Thus, the audience's lack of exposure to the instrument relative to the 'inside' perspective of the performer may help to explain why they (the audience) experience opacity while the performer does not.

Reception

Beyond mapping, audience reception is influenced by other aspects of player-instrument connection. For example, the sensitivity of contemporary sensors allows for even tiny gestures to be mapped to sound generation parameters. This can lower the physical demands on the player, but it can also impact the perception of the instrument. In particular, the reduced scale of input gesture can lead to misconceptions around expressiveness based on a perceived lack of sonic causality, physicality, and effort (Cascone, 2002; Stuart, 2003).

While there may be no direct equivalent to the Toplap (2024) manifesto's demand of "show us your screens", numerous DMI designers have used integrated and projected visuals to increase performance transparency. Notably, the Yamaha Tenori-on (Nishibori and Iwai, 2006) features a 16x16 grid of LED buttons mirrored on the controller underside so that audience and player receive the same view of the performance. Elsewhere, the Reactable (Jordà et al., 2007) projects real-time visualisations of sound and control paths onto its surface, using a mixture of dynamic animations and 'auras' around its tangible pucks to provide feedback to players and enhance audience engagement. In comparison, the visual feedback provided by the AudioCubes (Schiettecatte and Vanderdonckt, 2008) is starkly minimalist, with embedded LEDs changing colour to convey cube functionality.

Towards Multiplayer Instruments

Precursor Instruments

The influence of early social computing technologies (Wooley, 1994; Rheingold, 1993), saw the first systems for multiplayer music performance relatively early in the timeline of real-time computer music. Notably, the San Francisco Bay-based League of Automated Composers (LoAC), founded in 1977 and active until 1983, conceived of their local network of microcomputers "as one large, interactive musical instrument made up of independently programmed automatic music machines" (Perkis & Bischoff, 2007). By 1984, Gehlhaar's (1991) SOUND=SPACE brought accessible music-making to multiple players in a 10x10m space, and by 1986, Bischoff and Perkis of the LoAC had formed The

Hub (Gresham-Lancaster, 1998). Contrary to prevalent trends of the period, Perkis (1989) notes that rather than minimise human imperfections, this network music ensemble's use of technology tried to further the social dimensions of music performance.

The 1990s saw ongoing advancements in processing power, sensor technology, and connectivity, but Soundnet, used in performances by Sensorband (Bongers, 1998), remained an outlier. Both architectural in scale and highly physical, Soundnet required performers to climb its cargo net-like structure and, as they moved around, sensors encoded their combined movements as input (Tanaka, 2000).

Since 2001, numerous multiplayer instruments have been presented at the NIME conferences. The influence of tangible user interface (TUI) research was especially apparent in its early years. Examples include: the ToneTable interactive installation (Bowers, 2001); the Musical Trinkets system based on RFID-equipped tangibles (Paradiso et al., 2001); the tag-based Audiopad (Patten et al., 2002); the Block Jam TUI for dynamic poly-rhythmic sequencing (Newton-Dunn et al., 2003); the Reactable (Jordà et al., 2007); and the AudioCubes (Schiettecatte and Vanderdonckt, 2008). Of these, only the Reactable and AudioCubes were released commercially.

Used on Bjork's Volta tour (Reactable, u.d.), the Reactable (Jordà et al., 2007) is perhaps the best-known multiplayer DMI to date. Its players move fiducial marker-equipped objects (pucks) around a tabletop tracked from below by an infrared video camera. These pucks are mapped to sound generation modules and the signal topology is shaped by moving the pucks around the tabletop and projected visual feedback is provided.

As the NIME field has matured and themes in HCI have shifted towards entanglement (Frauenberger, 2019), the number of multiplayer instruments appears to have slowed slightly. Nevertheless, Feng et al. (2024) have explored the use of a co-designed collaborative DMI for group music therapy, and Scholz et al. (2021) have developed Sssnake, a remote multiplayer musical toy. Particularly relevant to our project is Gamelan Land, a multiplayer Virtual Reality game (MVRG) developed by Syukur et al. (2023).

Embedded/Integrated Composition

While the early days of computer music were characterised by the slowness and laboriousness of institutional mainframe computers (Lansky, 2004), the live electronics of Tudor and associates had already pointed towards more spontaneous, real-time forms of music making. Subsequently, as computer technology advanced, real-time approaches to computer-based composition emerged, often including aspects of improvisation. Chadabe (1977), for example, describes a model of interactive composition whereby, in real-time, "an improviser specifies and performs data in reaction to another improviser, but here the composer specifies and performs control strategies rather than data."

Tudor had also blurred the distinctions between score and instrument. The subsequent arrival of the first DMIs not only shifted the timeframe of computer-based music creation firmly into the real-time domain, their (re)programmability also brought about the comprehensive integration of composition and the instrument as platform. Gehlhaar (1991), for instance, created programmatic spatial compositions for his SOUND=SPACE instrument that he termed topologies. Today, it is commonplace for DMIs to include integrated compositional aspects and Winkler (2001), for example, contends that mapping is a fundamentally compositional activity.

Local Multiplayer

After a creative and commercial peak in the early 2000s (Karhulahti and Grabarczyk, 2021), the last twenty years have seen online multiplayer gradually replace local multiplayer as the most common form of multiplayer gaming. Nevertheless, local multiplayer games retain a sizeable presence in the Steam marketplace (Valve, 2024).

Basic gameplay types include cooperative and competitive, but Karhulahti and Grabarczyk (2021) note that “even when players compete against each other, a level of cooperation is necessary for the game to function: The players want to win, but they also wish to prolong the pleasure of play.” The authors (Karhulahti and Grabarczyk, 2021) note that, within this balancing act, ensuring continued player engagement and motivation is a significant design challenge.

As in a group musicianship context (Seddon, 2005), player communication is vital and a significant part of total player interaction. The type and qualities of player communication are different between online and local multiplayer. As well as encouraging socialisation through meeting up (Neuhaus, 2014), interaction in the local multiplayer context includes avatar-to-avatar interaction in the virtual environment, but also physical gestures, facial expressions and verbal communication between players in a shared physical space. The online multiplayer context typically reduces this to avatar-to-avatar interaction plus (mediated) voice and/or text-based communication between remote players.

The TYG Instrument

System Design

TYG is a three-player, local multiplayer DMI named after a three-handled drinking cup. Currently at a functional prototype stage (Payne and Dalgleish, 2024), TYG is built in the Unreal Engine 5 (UE5) game engine. UE5 was chosen for its capabilities around real-time 3-D environment and multiplayer game mode creation, and its close integration with the MetaSounds audio system (Epic Games, 2024).

TYG has two distinct modes: setup mode and performance mode. Setup mode is compositional and used outside the timeframe of performance. It enables fundamental musical structures and related parameters to be specified by the lead player in a top-down manner. The nominal lead player (player 1) can set up and place the following:

- Audio spheres:
  - Subtypes: drums, bass, melody, and chords.
- Synth spheres:
  - Subtypes: filter cutoff frequency, delay time, reverb feedback (all velocity-reactive), and fixed (a non-reactive version).
- Cube spawners:

    - Subtypes: audio spheres and synth spheres.
- Floor tiles:
    - Subtypes: time dilation, character gravity, character speed, sphere mass, and floor movement.

Dropdown menus are provided to streamline the setup process. There is no minimum or maximum complexity level of starting complexity, thereby enabling a wide range of starting conditions, for example to encourage or restrict emergent player behaviour.

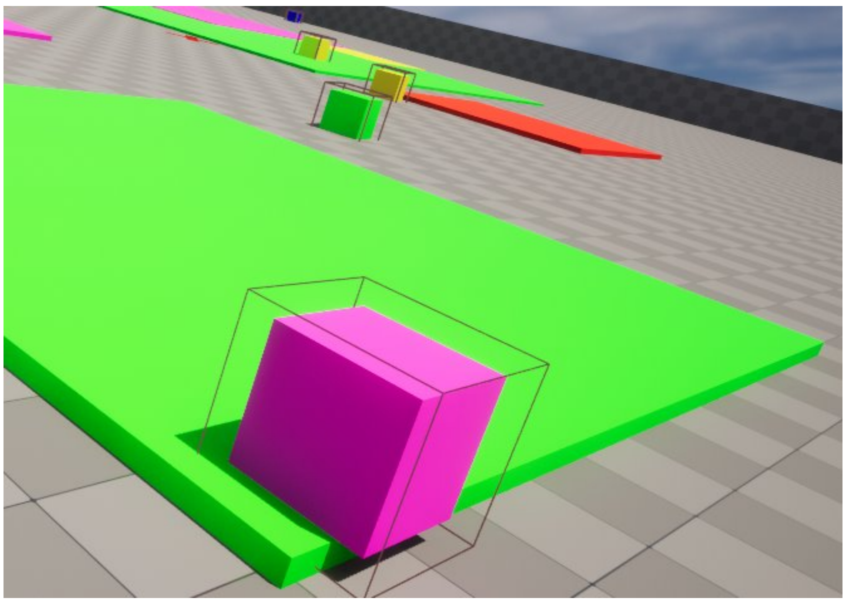

Figure 1. A series of cube spawners (highlighted) in the prototype level.

Performance mode provides split, shared screen play (SSP) and operates only in real-time. The use of game pads by all players is assumed, but it's possible for one or more players to use a custom controller via emulation. A typical third person control scheme is used by default but is customisable by the player. As a local multiplayer game, communication is expected to be in person and no in-game aids to player communication are provided.

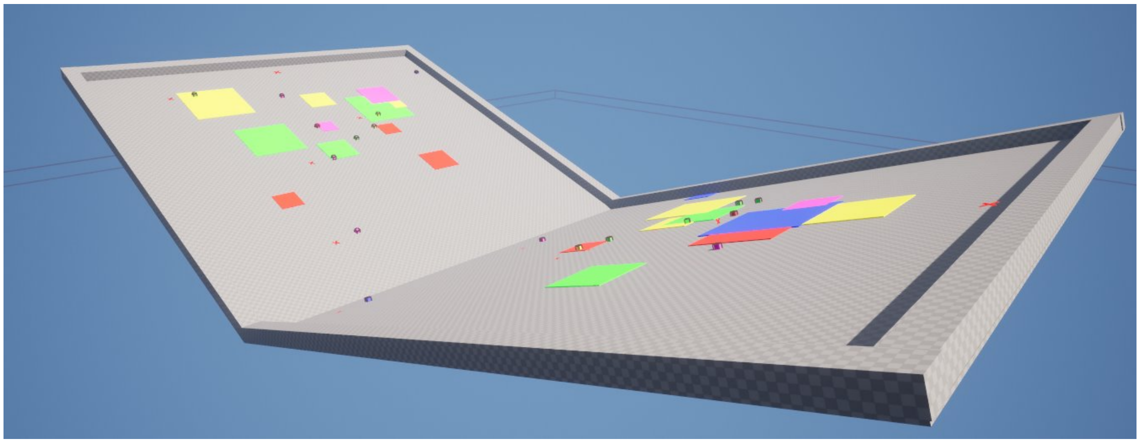

Figure 2. The prototype level.

Prototype Level

A prototype level (Fig. 2) acts as an example composition. Inspired by childhood games of Bulldog, the level consists of two slopes that meet at their lowest vertices. The geometry of the level is not fixed, and can be altered by the player via the use of floor tiles.

Preliminary Playtesting

Testing has so far been brief and informal. Nevertheless, with colleagues acting as play testers and a brief introduction to the system and the standard controls, some interesting player behaviours have already been observed:

Table 1. Results of initial, informal playtesting.

Setup	Observed Behaviours	Verbal Comments
Players must play the spheres themselves to produce any sound (no sphere-to-sphere triggering).	An example of player cooperation to build a composition on-the-fly.	"I enjoy it." "Lots of possibilities." "Making sound was easy, making meaningful sound was a bit harder."
The spheres trigger each other upon contact.	An example of player cooperation to build a composition on-the-fly.	"Music and sound makes it engaging." "may take some time to master."
Players must play the spheres themselves to produce any sound (no sphere-to-sphere triggering).	The players chose not to cooperate.	"I like how you can play against each other or cooperate." "making meaningful sound was not easy."
The spheres trigger each other upon collision.	The players chose not to cooperate or collaborate.	"TYG is somewhat expressive."

		"TYG is interesting."

Discussion

At this prototype stage, it is already apparent that the lively and surprising social interactions and behaviours of players desired by Perkis (1989) of The Hub are a significant part of TYG. If some of these collective behaviours might be considered usual in a musical context, for instance, players working together to create a semi-improvised composition in real-time, we found it curious that other observed behaviours, notably sabotage, are more typical of local multiplayer video games. If this could relate to player prior experience or background, it might also relate to the perceived affordances of the TYG protype. For example, we are not game artists, and player avatars are currently placeholder assets that are likely more suggestive of video game than musical instrument for most people.

The divergent behaviours seen so far also complicate conceptualisation of the instrument. For instance, if half of the behaviours observed to date fit with the idea of working together as single entity that can't be readily divided, the other half are not a good fit for this. Indeed, some of the latter behaviours, for example one player jumping into the ether, challenge even Kuivila and Behrman's (1998) broad definition of composition that they describe in terms of "everything done with a surfboard in the surf is a part of surfing."

At the same time, although the manner of expression is not necessarily completely like that discussed in the NIME literature, this could be seen as another form of freedom for players to express themselves, and a significant positive aspect of the TYG instrument to date. Moreover, for at least one of the play testers, there was also felt to be a connection between difficulty and expression, thereby recalling Ryan's (1991) idea that, even when the kind of player effort is changed (compared to a traditional instrument), expressive potential is diminished if an instrument is too easy to play.

Nonlinearity is present in the interactions between players and audio spheres and audio spheres and other audio spheres: there is clear causality when an audio sphere is struck, with details of the interactions being determined by a (player variable) physics simulation. If a lack of haptic feedback is a defining characteristic of DMIs compared to their acoustic predecessors, it is not yet clear if this is missed by players in the context of TYG. Acoustic instruments tend to have a strong and direct relationship between input gesture and sound output, based on reliable many-to-many mappings, and that manifests in clear causality of sound. Thus, speculatively, it perhaps it is that causal haptic feedback is less useful (and therefore less of a 'loss') in the TYG case, where mapping types are more variable (including dynamically variable) and can extend into the extreme one-to-many.

Future Work

We plan to shortly implement live looper (temporal looping) functionality. This will be based around players being able to insert loop points and then (re)call these for individual or collective effect, thereby enabling sequences to be replayed as a compositional device. In the slightly longer term we will undertake a formal design study to help guide the further development of the TYG instrument. Other goals include enabling input from a wider range of controllers, including dedicated music controllers.

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