Portfolio of Compositions and Exegesis:

Conflict and Resolution -

modelling emergent ensemble dynamics

by

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1 Introduction

Since the 1980s, with the rapid advancement of computer technologies, many composers have looked towards computer science for novel approaches to the generation of music. With the popularisation of scientific endeavours such as Chaos and the Artificial Sciences (Artificial Life, Artificial Intelligence and Cybernetics), a number of impressive algorithmic systems have been developed (see Miranda 2001). These approaches have strong links to experimental practice in the 20th century (Johnson 2003).

While biologically inspired models have proven popular, particularly Cellular Automata, (Bilotta et al. 2001, Harrald 2003, Burraston et al. 2005) and Genetic Algorithms (Jacob 1995, Todd and Werner 1999, Wascha II 2001), recently, a number of composers have begun to focus on models that offer stronger musical analogies. Miranda has conducted ambitious work in this area through the use of 'Mimetic Models'. This work aims to model the emergence of culture, and the origins of music through computer modelling and simulation, drawing inspiration from linguistics (Miranda 2002).

This portfolio is inspired by this more musical approach to generative composition, as it focuses on the development of a software model that simulates the dynamical systems of music, particularly the social dynamics of music performance. The model's roots stem from the notion of Performance Indeterminacy, pioneered by the New York School in the 1950s (Morgan 1991: 365-370), although as the research has progressed, it has become increasingly clear that it has much in common with the more open scenarios of free improvisation.

As a composer, I have long been interested in the way in which performers interact with one another when performing, particularly the differences in musical tension when performers are making decisions 'on the fly' as opposed to reading from a musical score. As such, my works are often about action, creating scenarios that allow musical situations to arise, as opposed to creating fixed musical artefacts. This approach has influenced not only my acoustic music, but also my installation work, and has spawned my interests in interactive computer music.

1.1 Problems & Research Methodology

Much of the existing work in generative computer music simplifies the musical problem by exploring only particular aspects of composition. This often involves a focus on the creation of rhythm and melody (see Cope 1992, Bilotta and Pantano 2001, Todd and Werner 1999), or on specific musical problems such as the harmonization of chorales in the style of Bach (Horner and Ayres 1995), or the creation of traditional Jazz solos (Biles 1994 and 2001). A reason for this, brought to light by Waschka, is that when using generative computer systems, music is an incredibly flexible problem, far less defined by external constraints which may define other non-musical problems such as “safety considerations (a building must stand), functionality (the car must move efficiently) and budget (a bridge cannot cost more than X)” (Waschka II 2001: 83). As such, composers have applied their own limitations to their systems in order to restrict the act of composing down to a more manageable problem. This approach has left many aspects of composition unexplored through generative process. One such aspect is performance practice.

The generation of higher-level musical forms is another well-documented problem in algorithmic composition (see Mozer 1995). A common criticism is that computational methods that lead to novelty at the micro level of music often fail to maintain interest in compositional structures across a range of scales (Hooper 2005). A number of solutions have been suggested to this problem, including the use of hierarchically related algorithms (Biles 1995).

A third problem addressed through the portfolio is the question of interactivity, and its relationship with improvisation. Since this research began in 2003, the field of generative computer music systems that allow for interactivity with musicians in live performance has gained renewed impetus through the rise of the ‘Live Algorithms for Music’ research network (Lewis 2007). Live Algorithms (see http://www.livealgorithms.org), combine non-linear generative composition techniques with live electronics and a sense of ‘strong interactivity’ exemplified through the practices of free improvisation (Blackwell and Young 2005). Previous examples of Live Algorithms include: George Lewis’ ‘Voyager’ system created in the late 1980’s (Lewis 2000); Al Biles’ ‘GenJam’ system, early 1990’s (Biles 2002); and Tim Blackwell’s ‘Swarm Music’, early 2000’s (Blackwell and Bentley 2002). Blackwell’s work, with its particular focus on behavioural models using swarming algorithms (Blackwell 2007), has strong resonance with the research presented here.

These problems are explored and addressed through reflective practice. This portfolio of compositions explores Game Theory[1] as an approach to generative composition and interactive computer music. Software has been developed that attempts to simulate the interactions of a group of improvising performers using a multi-agent system based on the Iterated Prisoner's Dilemma (IPD). The reasoning behind this choice of model, and links between the IPD and music will be established through the remainder of Chapter 1. Through this reflective approach, over the duration of the project, composition activities and programming activities have formed a symbiotic relationship to the point where by the composition of *fr@gm3nT* (Chapter 6) programming activities and composition activities are one and the same. Reflecting the close relationship between the works and the overarching research, the Portfolio of Compositions, and Exegesis are presented as a unified document.

The works presented systematically work towards the creation of an interactive improvisation environment known as *ENSEMBLE*. They address a series of research goals, including exploring the IPD as an approach to performance practice and incorporating the IPD into the practice of composition (Testing the Waters - Chapter 2), developing generative IPD computer software that allows the output to be pinned down and analysed (Software and Scores - Chapter 4), developing real-time generative IPD systems (Installations and Films - Chapter 5), and finally the development of real-time interactive systems (Chapter 6). The works are split between chapters highlighting their contribution to the overarching research, and as such, do not appear in strict chronological order. At the conclusion of each chapter, the works are reflected upon both in regards to their impact on the overarching research, and their reception in performance. The reflection on performances is seen as important, as the works extend beyond mere experimentation, with a strong emphasis on practical music making. This has not always been the case in experimental computer music practice (Burt, 2007). Individually, the works address a wide range of goals, meeting the requirements for various commissions, and performance situations. This is discussed in the context of each work.

Overall, the sense of form evident in the works presented raises further questions about improvisation. While the question as to whether real-life improvisers are caught up in a perpetual Iterated Prisoner's Dilemma is not answered, it is hoped that this work will spawn interest in a wider interdisciplinary audience, leading to further investigation into the nature of improvisation and interactivity. Certainly, the portfolio points towards a possible next generation of interactive computer applications, and adds to the emerging field of Live Algorithms for Music.

[1] Brought to prominence by John von Neuman through his book *Theory of Games and Economic Behaviour* (Neuman and Morgenstern 1944), the roots of Game theory stretch back to the 1920s (Poundstone 1992: 40-41).

1.2 Performance Indeterminacy

The term 'improvisation' holds many connotations for different people, particularly regarding notions of deep personal expression, and of course, cultural background. As such, at the beginning of this project it was felt that notion of Performance Indeterminacy, championed by the American Avant Garde in the 1950s, offered a more tangible starting point for the creation of a generative computer model. The underlying principles for the subsequent software development and portfolio stemmed from this concept, although as the work progressed, it became clear that many of the concepts developed could likely be applied to more open scenarios.

After composing 'Music of Changes' in 1951, an early work using chance operations, John Cage faced a dilemma. Through using chance, and consequently removing intention from his work, he had reduced the performer to "what you might call an automaton" (Cage, in Corbett 1994: 185). The performer had been left with limited room for interpretation. In order to fix this imbalance, Cage redefined the role of the performer through using Performance Indeterminacy.

The works of all the New York School composers used Performance Indeterminacy through the 1950's (see Watkins 1995: 565-570). While Brown, Cage, Feldman and Wolff all incorporated indeterminacy into their works in different ways, and had quite different views on its role, there are a number of characteristics that are common to all indeterminate works. Generally, the composer gives the performer freedoms either to make choices about how they will play given material, or choose the material they will play within a given framework. Through these freedoms, the performer makes choices spontaneously while performing the piece. Of course when these types of works are performed, no two performances are alike, and as such no individual performance of a work is definitive, just an example of how the work could sound. In describing this situation, Cage points out "the function of the performer is that of a photographer who on obtaining a camera uses it to take a picture. The composition permits an infinite number of these, and, not being mechanically constructed, it will not wear out, it can only suffer disuse, or loss" (Cage 1961: 36).

The indeterminate works with the most relevance to this research are those by Christian Wolff. From later in the 1950s, Wolff began to explore indeterminacy that through the act of performing allowed an unpredictable chain of performance situations to emerge. These works present each performer with a set of precise rules triggered by the actions of the other performers. While his early works of this type, for example 'Duo for Pianists II' (1958), are very complex and require virtuosity on the part of the performers, by the end of the 1960s he had devised a more conceptual style, which while still meeting all the same goals as his earlier works expressed his ideas in plain English.

> For an orchestra made up of at least 15 players, each of whom chooses one to three sounds, fairly quiet. Using one of these each time, you have to play as simultaneously as possible with the next sound of the player nearest to you; then with the next sound of the next nearest player; then with the next nearest after him, and so forth until you have played with all the other players present.
>
> (score excerpt from ‘Burdocks’, Wolff 1971, in Nyman 1999: 7).

Wolff’s work ‘Burdocks’ for one or more orchestras (1971) is interesting as it meets many criteria that would appear relevant to complex systems research, and particularly the notion of emergence. In complex systems, emergent structures and behaviours arise through the interactions of a system’s components, often revealing properties that are not evident in the components themselves. For example, a company is more than the sum of its assets and personnel, while the complexity of a city arises through the interactions of millions of people (Coveney and Highfield 1995: 330). These situations are difficult to explain through reductionist science, as breaking a system down and examining its parts actually reveals little about the whole. Emergence is taken a step further in Artificial Life, where the concept is used to describe “the crucial leap it takes between nonlife and life” (Whitelaw 2004: 207).

If we explore Burdocks in this light, firstly: the work is non-linear. Its construction is impossible to derive by analysing a recording of the work, and working back in a musicological sense. Secondly, the performers of the work are given autonomy. Once Wolff has outlined the process that governs the performance of the piece, he relinquishes control of the way it plays out. Finally, bound by simple local rules that govern their interactions, the performers produce a highly complex extended musical form, producing emergent global behaviours similar in many respects to those found in various flocking and schooling experiments (for example Reynolds 1987).

While works such as this have not been widely considered in this light previously, Johnson (2003) suggested that Cornelius Cardew’s work from the 1960s offered a forerunner to the use of evolutionary and adaptive computation in music (techniques central to Artificial Life), and certainly, the game pieces of John Zorn could offer more recent examples; for example, ‘Cobra’ completed in 1984 (Zorn 2002). The exploration and computer modelling of the emergent dynamics evident in these types of musical works are the main premise under which the software presented in this portfolio has been developed.

1.3 The Prisoner's Dilemma Game

As the main aim was to simulate what is essentially a social interaction problem, it was suspected that the Iterated Prisoner's Dilemma could offer a framework for further exploration and development. The Prisoner's Dilemma has been found useful in a wide range of interaction problems ranging from understanding the dynamics between foraging fish and divorcing people (Axelrod 1997: 6). As this single model is able to capture the fundamental features of such disparate situations without the need for representing the details, it stands to reason that it could also offer insight into the social interactions of music. Further weight is added to this argument through the writings of renowned American improviser George Lewis, who suggests that the emergence of structure in improvised music occurs in much the same way as structure emerges in our every day lives: "We interact with our environment, navigating through time, place and situation, both creating and discovering form" (Lewis 2004: 282). A description of Zorn's 'Cobra' also offered inspiration as he described the work as "just a series of instructions about how to relate and how to structure. It's a series of on/off switches, really: when to play, and when not to play" (Zorn, in Duckworth 1999: 462). This appeared to point towards a binary system that could be accommodated by the Prisoner's Dilemma.

A typical Prisoner's Dilemma scenario based on the original dilemma outlined by Albert Tucker (Campbell & Snowden 1985: 3-8) is as follows:

Two drug dealers are caught by police and placed in separate rooms to be interrogated. While the police have the prisoners on possession charges which carry a possible sentence of one year in jail, they suspect that they are dealers but have no proof of this. The public prosecutor then offers both prisoners a deal. Confess to being a drug dealer and give evidence against your partner and you can go free while your partner serves five years in jail, if you both confess you will receive three years in jail for your guilty plea. The dilemma for the prisoners here is that: if neither confesses to dealing, they will go to jail for a year; but they can not guarantee that the other will not confess and take the plea-bargain; so the only rational thing to do is confess, as a three year sentence is a better outcome than a possible five years in jail.

In a one-off situation like the one outlined, the Prisoner's Dilemma suggests that whenever there is uncertainty on what your opponent is about to do, the only rational option is non-cooperation. This idea led several of the US government's advisors, including members of the RAND Corporation (Poundstone 1992: 4) and British pacifist Bertrand Russell (1946: 21), to advocate a pre-emptive nuclear strike against the Soviet Union in the late 1940's.

Fortunately this bleak scenario changes somewhat if the process is iterated allowing for multiple encounters between the participants. Suddenly a whole myriad of strategies are possible as the participants are able to take into account previous interactions in order to shape their response in future interactions.

Robert Axelrod, a political scientist, approached the question of what was the 'best' strategy in this situation through the organisation of two computer tournaments in the early 1980s. Experts in game theory were invited to submit strategies for the Iterated Prisoner's Dilemma that were played off against each other in a round robin tournament. The winning strategy in both tournaments was the 'TIT FOR TAT' rule by Anatol Rapoport, although Axelrod suggests that, much like in real life, there is often no best strategy. The strength of each strategy lies in the environment in which it functions (Axelrod 1984: 27-54).

1.4 The Prisoner's Dilemma and the Arts

While the Prisoner's Dilemma has captured the imagination of philosophers through the rather bleak outlook it presents about basic human nature, it has been somewhat of a rarity in the arts. Aside from the some of the classic films dealing with the madness of the nuclear arms race, for example Stanley Kubrick's 'Dr Strangelove' (1964) (whose main character would appear to be a caricatured blend of several of RAND's key figures), art dealing more directly with the Prisoner's Dilemma is fairly scarce.

Nick Didkovsky put forward a notable musical example in the early 1990s. Based on Douglas Hofstadter's 'Luring Lottery' (Hofstadter 1983) Didkovsky's work allowed performers to compete for control of musical events via a network of Commodore Amiga 1000 computers (Didkovsky 1992). Through performing the work, Didkovsky noted that while many interesting behaviours emerged among the performers in rehearsal as they attempted to understand how the system worked, once they understood the system, the performance was actually rather tame; the performers would simply take control of the musical events in turn.

A recent theatrical example that premiered during 2007 was Bohemian Productions' innovative play 'A Prisoner's Dilemma'. Featuring a series of interactive scenes, the actors portrayed various Prisoner's Dilemma scenarios under the control of the audience. The outcome of each game altered the plot so that each performance was different, and how the audience fared in each scenario was recorded. The results were posted on their website for the duration of the season, allowing the audiences to log in, and see how they fared against other audiences (Bohemian Productions 2007).

If the net is thrown more broadly to incorporate Game Theory, then Iannis Xenakis offers three works: 'Duel' (1959), 'Strategie' (1962) and 'Linaia-Agon' (1972); (Varga 1996: 107-109). These works offer an interesting performance situation where ensembles are pitted against one another in a musical game. There is a referee who awards points to the ensembles according to a 'game matrix', the composer defines the tactics for the ensembles and at the conclusion of the work a winner is announced. The winner is determined by which ensemble is most skilled at executing the composer's tactics for the game, leading to the most interesting solution.

A 1962 performance of 'Strategie' in Paris, for two conductors and two orchestras, took the competitive nature of the game a step further, featuring Konstantin Simonovitch who liked Xenakis' music and Bruno Maderna who hated it. The performance was controversial as the tension spilled over into the audience, with disagreeing audience members attacking one another. Ironically, Maderna (who hated Xenakis' music) 'won' this performance (Xenakis, in Varga 1996: 41)

2 Two Creative Works: testing the waters

Prior to attempting to write any software relating to the Iterated Prisoner's Dilemma, two works were written to test the musical suitability of the model and to inform how to approach creating a musical IPD.

There were three main concepts behind these works:

1. to experiment with the IPD as an approach to performance;
2. to incorporate the IPD into the composition process;

and

3. to develop strategies for sonifying the IPD.

These concepts resulted the following two works, *Fight or Flight: the Prisoner's Dilemma* for percussion ensemble and *PARADOX eleven* for guitar trio, violin, cello and percussion. As no software for sonifying the model's output to music had been written at this point (indeed, no programming had even been attempted), these works drew heavily on my previous complex systems work that incorporated Cellular Automata, and were sonified by hand. *Fight or Flight: the Prisoner's Dilemma* uses the IPD purely as a conceptual idea for performance, and asks the performers to bind their interactions through predefined rules. In contrast the IPD is bound to the composition process of *PARADOX eleven*, defining the work without asking the performer to take it into consideration. Both works draw on indeterminacy in performance, and have made a valuable contribution to the software development that resulted in the other works of the portfolio.

2.1

Fight or Flight: the Prisoner's Dilemma

for percussion ensemble: 27 un-tuned instruments and 2 marimbas

by

Luke Harrald

2003

Fight or Flight

The Prisoner's Dilemma

PERFORMANCE NOTES

The Prisoner's Dilemma: an overview

The *Prisoner's Dilemma Game* can be briefly summarised as follows:

Two drug dealers are caught by police and placed in separate rooms to be interrogated.

While the police have the prisoners on possession charges which carry a possible sentence of one year in jail, they suspect that they are dealers but have no proof of this. The public prosecutor then offers both prisoners a deal. Confess to being a drug dealer and give evidence against your partner and you can go free while your partner serves five years in jail, if you both confess you will receive three years in jail for your guilty plea. The dilemma for the prisoners here is that while if neither confesses to dealing, they will go to jail for a year, they can't guarantee that the other won't confess and take the plea-bargain, so the only rational thing to do is confess as a three year sentence is a better outcome than a possible five years in jail.

In a one-off situation like the one outlined, the Prisoner's Dilemma suggests that whenever there is uncertainty on what your opponent is about to do, the only rational option is non-cooperation. This idea led several of the US government's advisors to advocate a pre-emptive nuclear strike against the Soviet Union in the late 1940's.

This work explores the *Iterated* Prisoner's Dilemma. In this situation players interact with each other a number of times (rather than just once like in the example above). This allows each player to devise strategies on how they will interact with the other players based on previous moves in the game.

The Iterated Prisoner's Dilemma has been used to model various decision-making processes, finding use in many fields ranging from biology to warfare. The most interesting aspect of this model is that the safest or most rational choice in the short term is not always the most productive long-term strategy, and that the strength of any strategy is always relative to the other strategies in play.

Approaches to Performance

This work explores the Prisoner's Dilemma through the use of performance indeterminacy. The work is constructed from a number of 24 second periods, each of which constitutes a turn in the game. All of the musical material within each turn must be played between the times specified.

a typical 'turn' from the percussion 1 part. The semi-improvised accompaniment can be seen either side of the metered material in the central three bars.

Each performer playing an un-tuned part must select a strategy for how they are going to interact with the other performers prior to the commencement of the piece. This strategy must be adhered to throughout the performance of the work. Some possible strategies are listed below (of course the performer is also free to come up with their own):

Always Cooperate OR **Always Defect**.
Random: randomly cooperate or defect
Tit-for-Tat: cooperate in the first round, then do whatever the other player did in the previous round.
Spiteful: cooperate until the other player defects, then always defect.
Mistrust: defect in the first round, then do whatever the other player did in the previous round.
Tit-for-Two Tats: Cooperate, except when the other player has defected in the two previous rounds.
Pavlov: Cooperate only if both players opt for the same choice in the previous round.

Performers interact through the metered material that occurs in each turn. The metered material can be played at any dynamic and at any tempo the performer chooses, although on hearing another performer playing metered material, cooperation may take place through picking up on their tempo and dynamic, while defection takes place through ignoring their lead, and playing a different tempo and dynamic. The main aim for the performers in the work is to create an interesting performance. As previously mentioned with regards to the prisoner's dilemma, strategies that prove fruitful in the short term may not achieve longer-term success. For example, if all three performers chose to always defect, in the short term the results may be interesting, probably even humorous, as the three performers keep putting each other off, or sound like they are fighting, but over the entire 15 minutes of the work this is likely to become tedious.

Other Performance Issues

In addition to the metered material, which is vital to the interactions of the game, each turn also includes semi-improvised material where each sound can be played as long or as short as the performer chooses within the times specified. The semi-improvised material is accompaniment, creating a backdrop for the interactions of the game. As such, the marimba parts take on an accompanying role throughout the piece. Like the metered material, the dynamics for the semi-improvised material are open, although performers should always keep in mind that this material is accompaniment.

The semi-improvised material occurs in two types; with or without attack. Material with attack is marked with an accent and this material is to be played with hard mallets. Each note may be played as either a single strike of the instrument, or a roll. The material without attack is either played as a roll with soft mallets (where a roll is specified), or by rubbing a super-ball against the instrument creating a kind of bowed effect; this is specified by a note surrounded by a circular arrow and can be seen in the score example on the previous page.

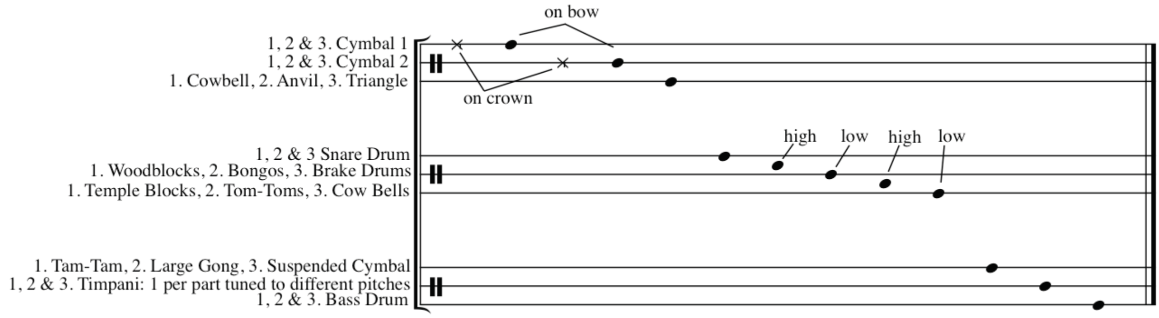
Within each turn of the game, the metered material is presented in the centre of each time bracket. Similarly, the semi-improvised material is evenly spaced around the metered material. This is to avoid suggesting any kind of placement of the material within the times specified. The metered material can be considered mobile, and can be played at any point within the bracket. Using the example to demonstrate, a performer could play a single strike of the timpani, then play the metered material, followed by the remaining thirteen semi-improvised sounds, or the performer couls play all the semi-improvised material first, followed by the metered material. Either would be a valid interpretation of the material presented. The semi-improvised material may also be played as long or as short as the performer chooses, and although the material is evenly spaced over the bracket, the performer is under no obligation to fill the entire bracket with sound.

As the marimba parts are semi-improvised throughout, the material can be played as the performer chooses. Each sound may be played as a single strike or a roll.

Between 7'12" and around 9'26" there is a section where the three un-tuned parts are locked together in a period of 'forced cooperation'. All the material is metered through this section, and a conductor may be used if needed. The dynamics of this section should reflect the metered material that has come before, and as the section is cooperative, all performers should play the same dynamic. If dynamic gestures are added, they should be reflected by all performers.

Notation Key

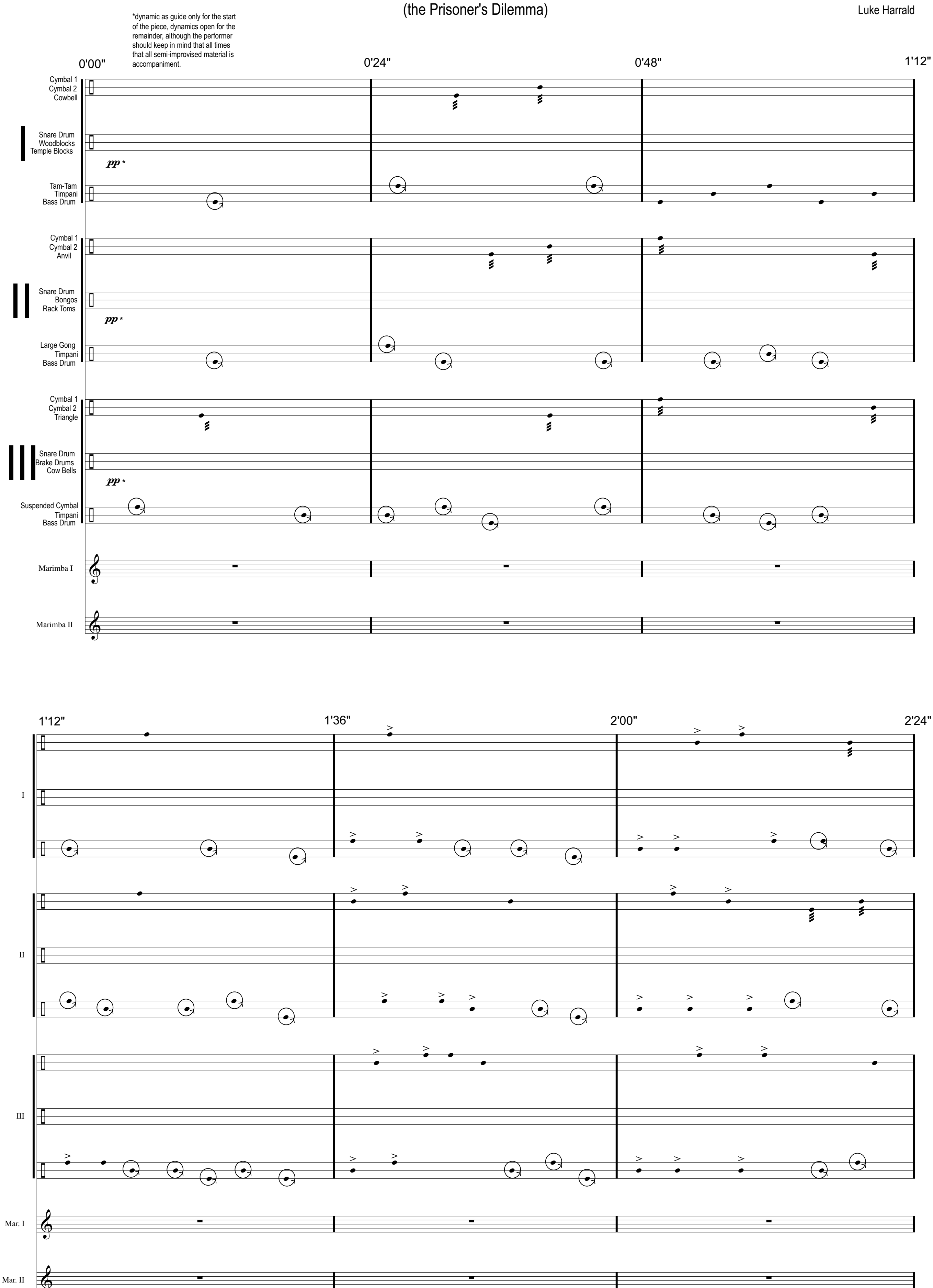
Note that any of the instruments may be substituted for other instruments available provided the substitutes have similar attack and decay characteristics to the specified instruments. The similarities and differences between parts should be maintained, for example, the contrasts in timbre through using wood, metal or skin instruments. Where the same instrument is specified in all three parts, performers should aim for subtle differences in timbre between the instruments to identify the parts.



Fight or Flight

(the Prisoner's Dilemma)

Luke Harrald

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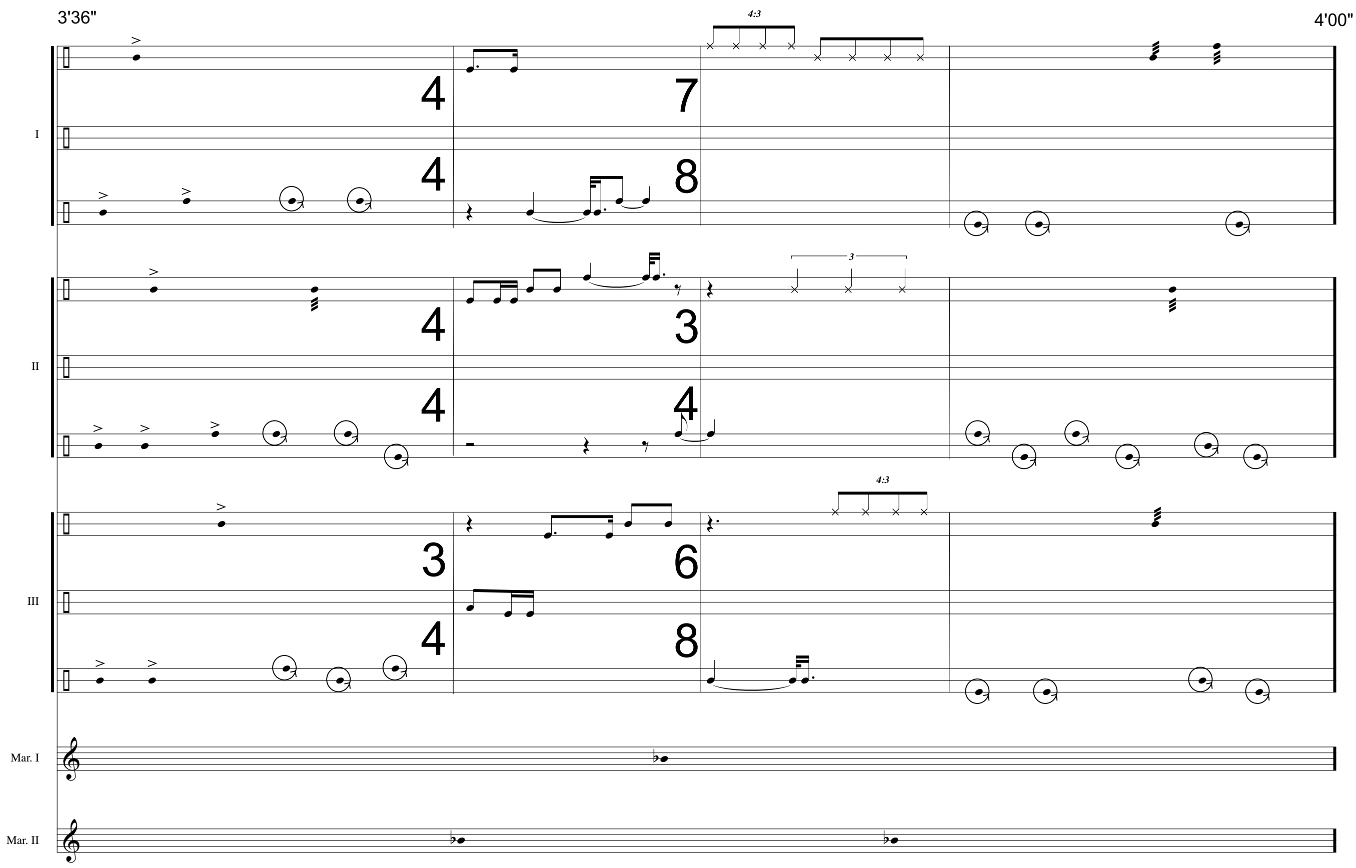
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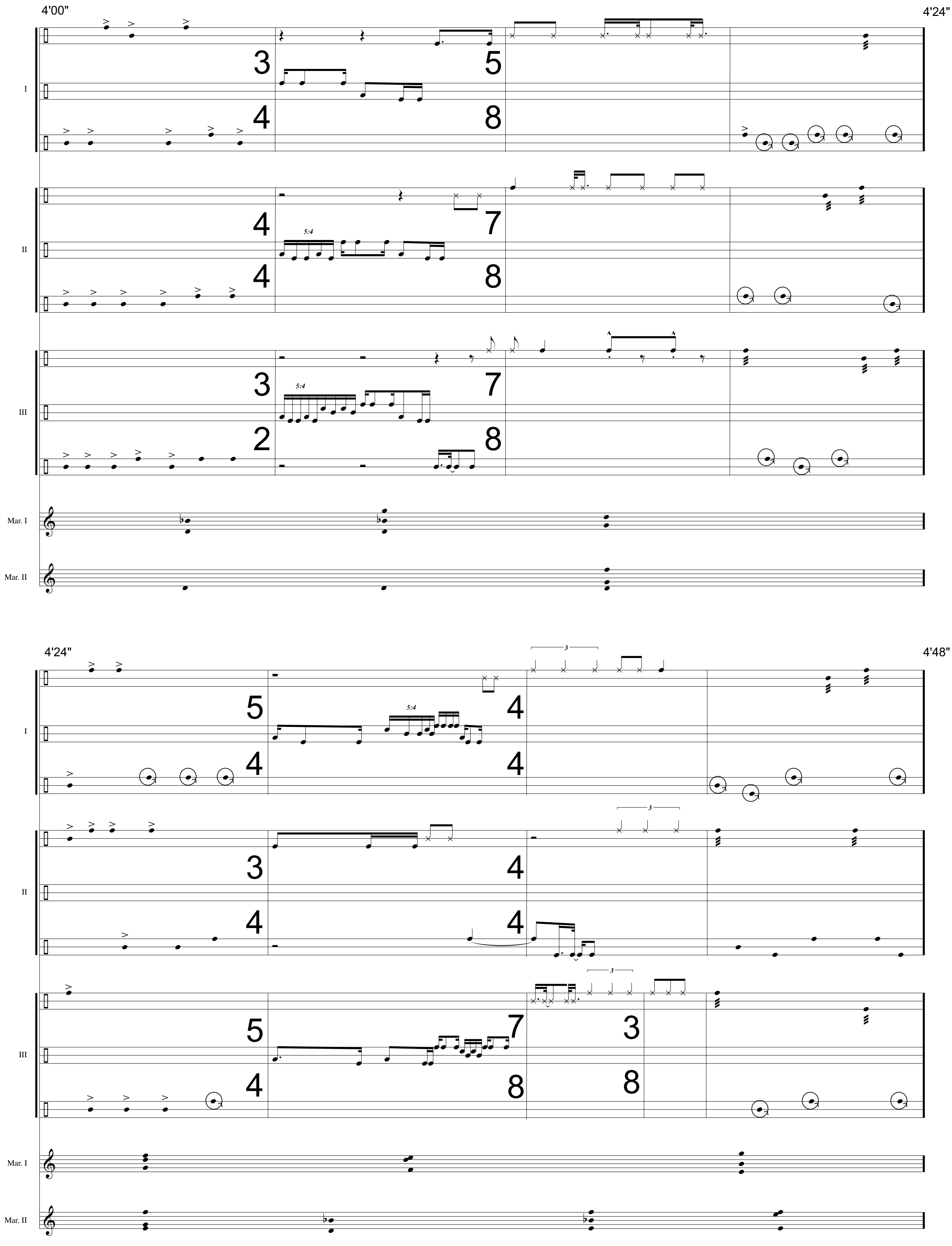
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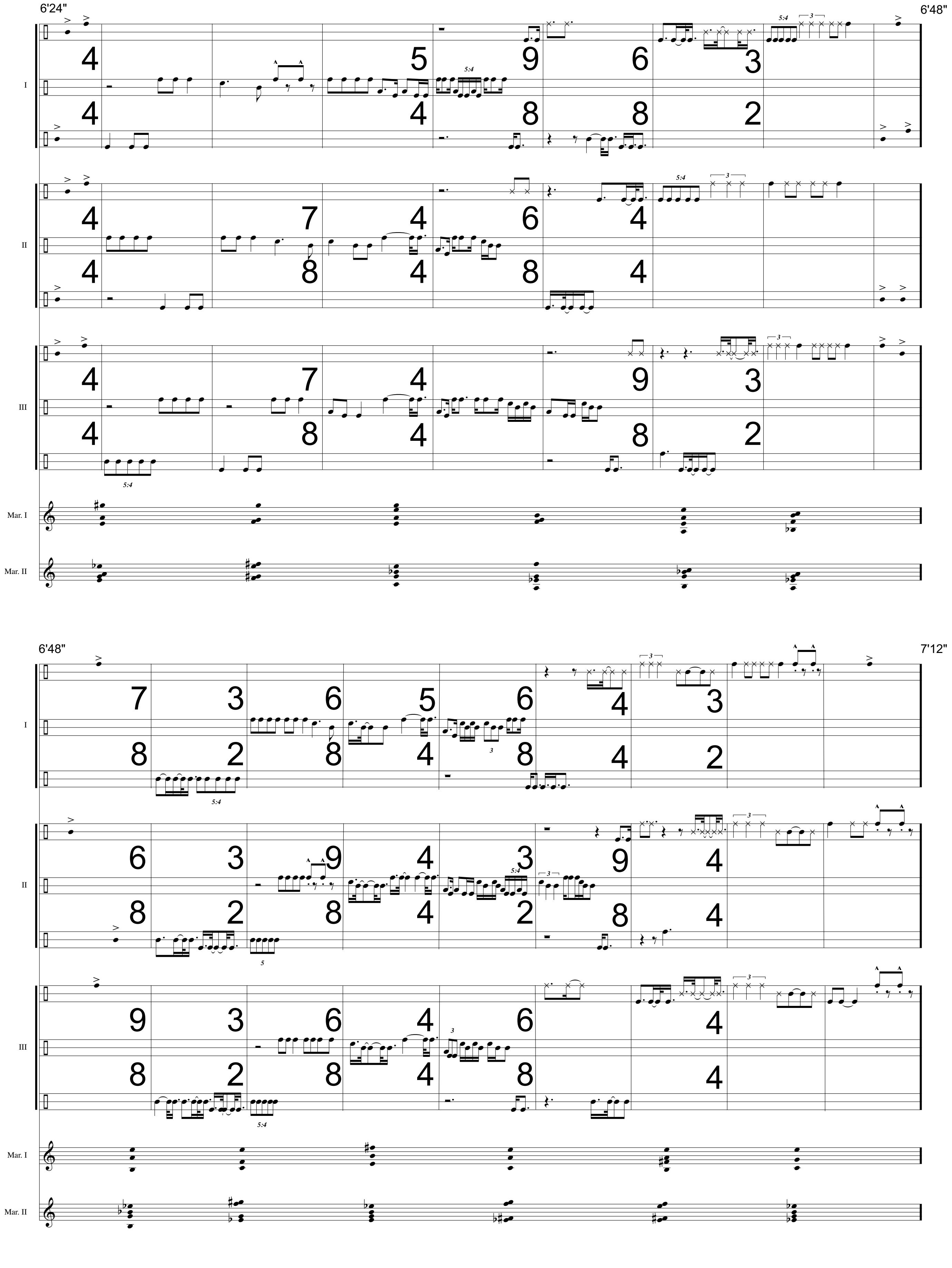
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9'24"- 9'28"
9'26"


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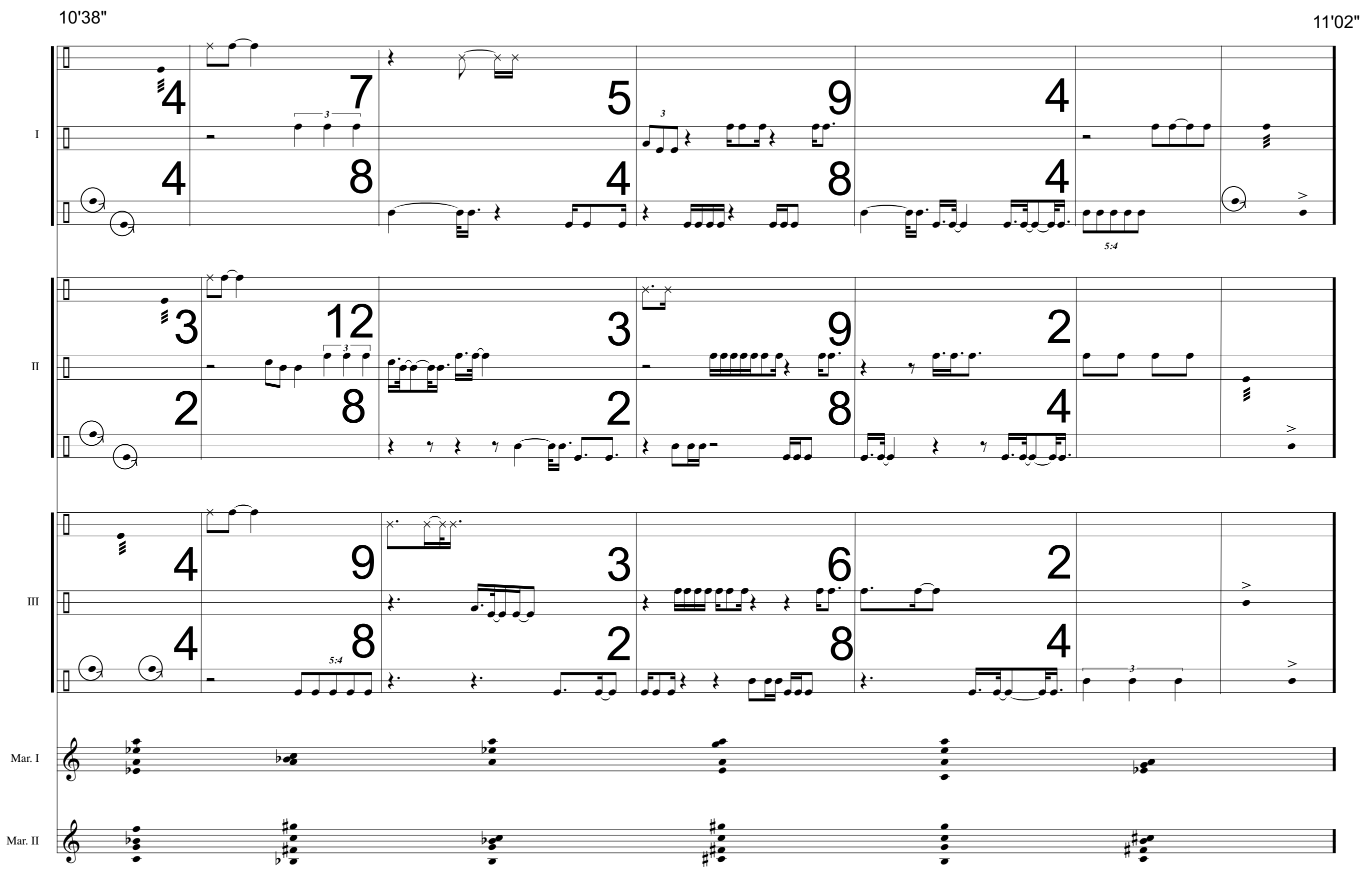
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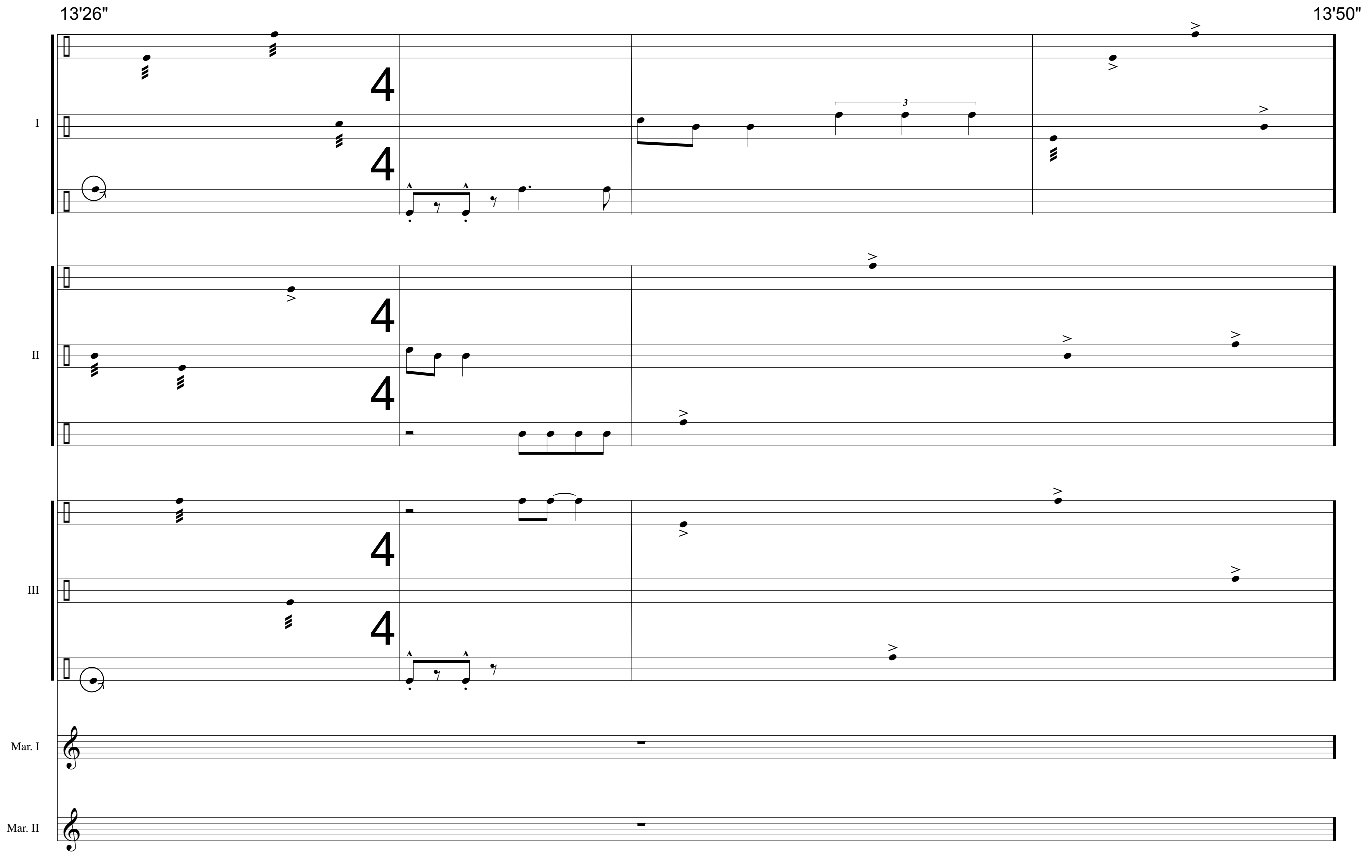
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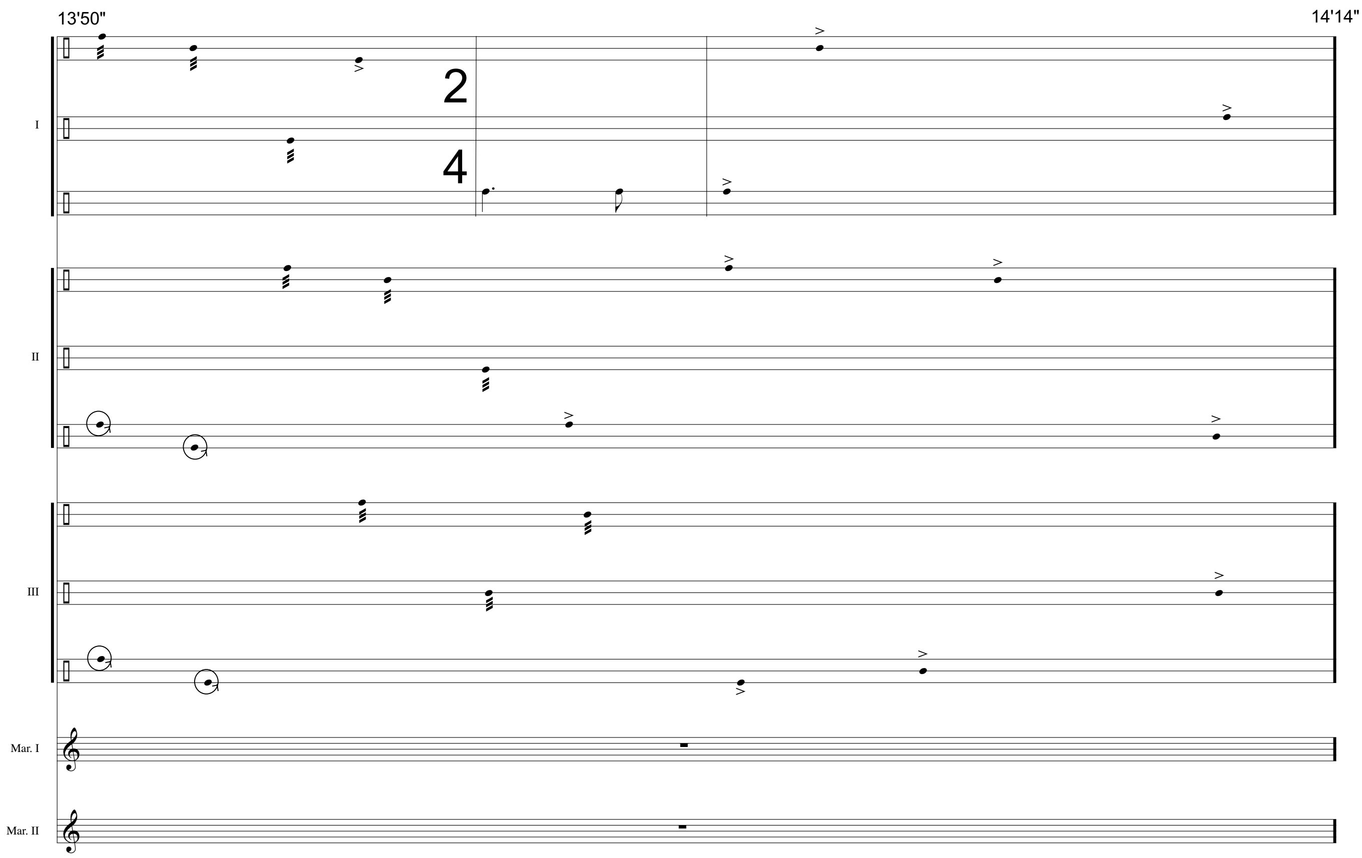
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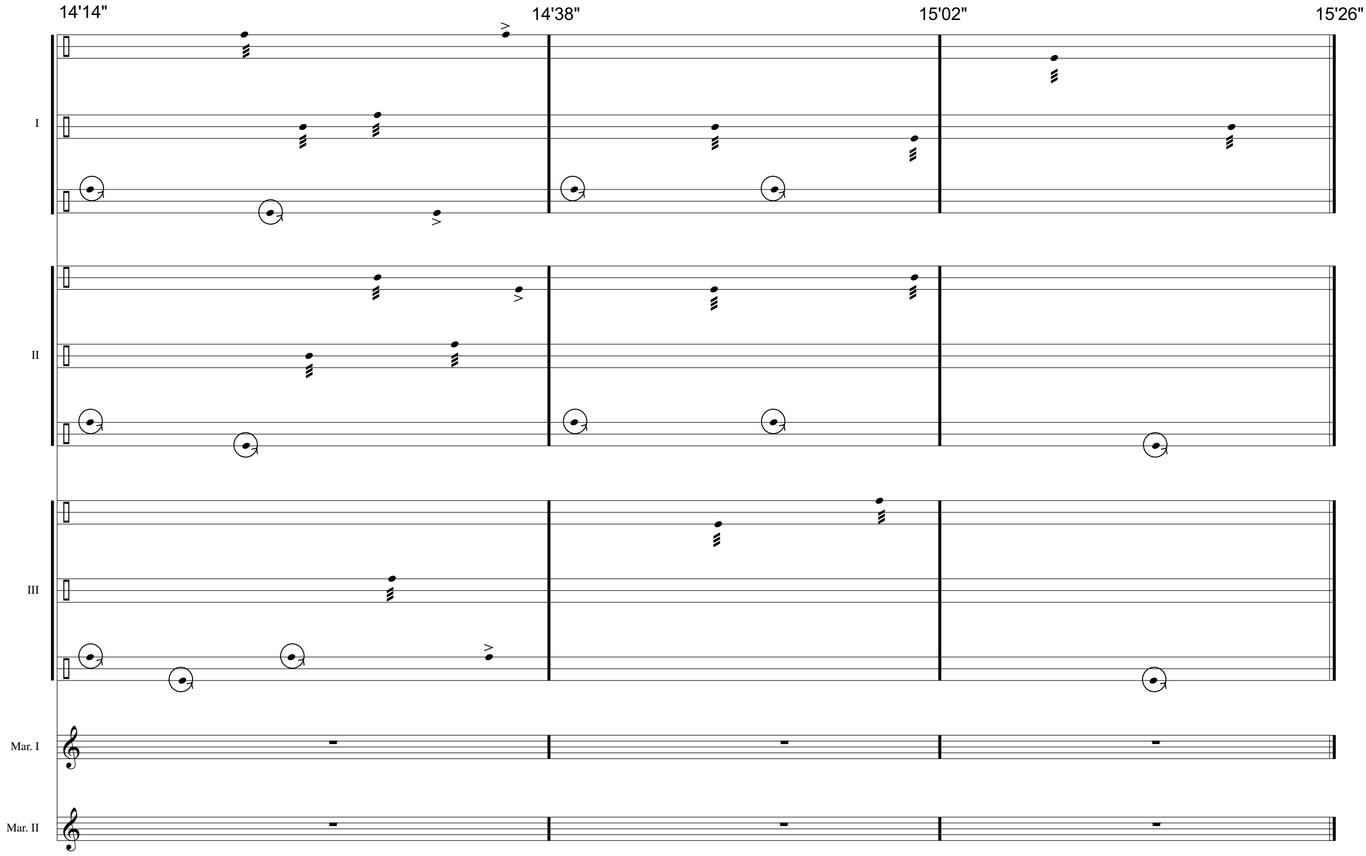

14'14"
14'38"
15'02"
15'26"
I
II
III
Mar. I
Mar. II

Fight or Flight: the Prisoner's Dilemma (2003) for percussion ensemble

Fight or Flight, examines the Iterated Prisoner's Dilemma as an approach to performance practice. The performers are presented with musical material that is played within a series of 'turns' that last 24 seconds each. Within each turn the performers are presented with two types of musical material, that is, material of indeterminate length, and traditionally notated (metred) material. The indeterminate material effectively is accompaniment, and creates a backdrop over which the interactions of the game can take place. The metred sections have specific rules for performance, and while they always appear in the centre of each round in the score, they are actually mobile and may be played at any point within the 24 seconds (Figure 2.1.1).

Prior to performing the work, each performer is asked to create a strategy that governs how they are going interact with the other performers. This strategy must be adhered to throughout the performance of the work. 'Interactions' are achieved through the performance of the metred material within each round. The metred material may be played at any tempo, and dynamic the performers chooses, although on hearing another performer playing metred material, co-operation can take place by picking up on their tempo and dynamic, and joining in, while defection takes place through ignoring their lead, and playing at a different tempo, and/or dynamic. The performers are asked to choose strategies that lead to an interesting performance. The main aim of this instruction was to try and encourage the performers to adopt reasonably complex strategies, as if all the performers were to adopt simple always co-operate, or always defect strategies, the resulting performance certainly would not meet this criteria.

Aesthetically, the work brings together what may appear to be diametrically opposed ideas, combining indeterminate materials with complex precisely notated materials. This distinction of materials is mostly aimed at the performer, allowing the IPD concepts of the work to occur, and also explores the different mental states of the performer when faced with precisely notated and indeterminate materials.

The musical material used in *Fight or Flight* grew out of an interest in exploring the musical potential of the oscillators that occur in the 2D cellular automata 'Life' (Gardiner 1970). After considering a number of different oscillators, it was decided that some kind of glider would be best suited to the task as rather than simply repeating itself after a certain number of steps, the movement of the glider could cause the musical material within the work to evolve over time. A large 'glider' was chosen for the task that reproduces itself every five steps.

Figure 2.1.1 Extract from *Fight or Flight* (the Prisoner's Dilemma) percussion 1 part showing one round of the game. The central bars contain the material vital to the interaction for this round, while the indeterminate material either side of this provides accompaniment.

Like all gliders, this automaton moves infinitely through the universe. In order to highlight and take advantage this attribute, a matrix of musical events was constructed for the work that corresponds with the 'flight path' of the automaton. Musical events are triggered over time as each cell comes to 'life' and subsequently 'dies'. The structure of the work is created by the automation passing through the matrix, much like a bird flying past a window (Figure 2.1.2).

The matrix used in *Fight or Flight* is divided into three sections (Figure 2.1.4), with the outer sections forming the two marimba parts, and the central section forming the three un-tuned percussion parts. One of the main aims in the construction of the matrix was to reflect the automaton at a number of levels. This was achieved through the use of symmetry in the central section, reflecting the symmetrical formations common to all oscillators in Conway's 'Life'. The pitch material in the outer sections meanwhile is gradually transposed throughout the matrix to reflect the automaton's constant movement.

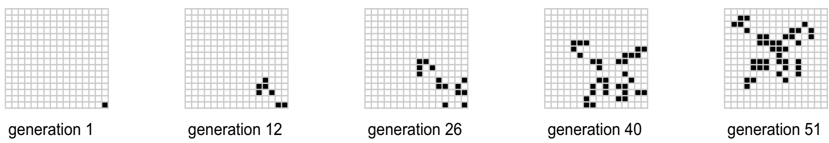


Figure 2.1.2 Five generations of the glider automaton highlighting the window effect.

The sonification of the automation is handled differently between the marimba, and untuned percussion parts. The outer sections of the matrix are mapped sequentially to the marimba parts, while the central section is mapped to the un-tuned parts in parallel. As such, in each round, three generations of the automaton are realised in sequence in the marimba parts, while the three generations of the automaton are split between the un-tuned parts. To keep the music syncronised, a generation effectively lasts 24 seconds in the un-tuned parts, and 8 seconds in the marimbas.

The rhythmic structure of the work is created through live cells triggering small rhythmic units. The rhythmic units are based on beat divisions of increasing complexity (Figure 2.1.3). While all of the units effectively have the same internal proportions, different densities of rhythm are achieved through utilising different length beats; in this case, 2, 3 or 4 quavers. The different beat lengths are cycled throughout the matrix to create areas with increasing and decreasing densities of rhythm. Overall, this process creates a symmetrical structure.

Indeterminacy is another important rhythmic aspect of the work, and is vital in allowing the social interactions between the performers to occur. The indeterminate material occurs in two types, either with, or without attack. Material without attack is achieved through the performer either playing a roll with soft mallets which is begun as quietly and smoothly as possible, or through the performer rubbing a super-ball against the instrument. Conversely, material with attack is played with hard mallets, and can either constitute a single strike of an instrument, or a roll. All indeterminate material can be played as the performer chooses, and the performer is under no obligation to fill each round with sound. Silence is both allowed, and encouraged as an area of experimentation within the work.

Figure 2.1.3. Beat divisions used in *Fight or Flight*

In performance, *Fight or Flight* has thrown up several challenges that have ultimately led to the work not being performed publicly. The first attempt at rehearsing the work was by the Griffith University Percussion Ensemble in Brisbane under the direction of Vanessa Tomlinson. The ensemble was excited about the different approach to performance that the work suggested. Unfortunately, due to the complexity of the musical material, implementing the strategies for performance was difficult and perhaps impossible. From the performer's perspective, it was often ambiguous whether another performer had co-operated with, or defected against their actions. This in turn, made the choice about their next action impossible. While further rehearsal (and perhaps using virtuosic performers) may have improved this situation through familiarity with the material, it was none the less a situation that was difficult to overcome. While these problems were disappointing, *Fight or Flight* certainly helped shape my ideas for future work, and indeed, the ambiguities of live performance are easily overcome in the synthetic, logical environment of a computer program.

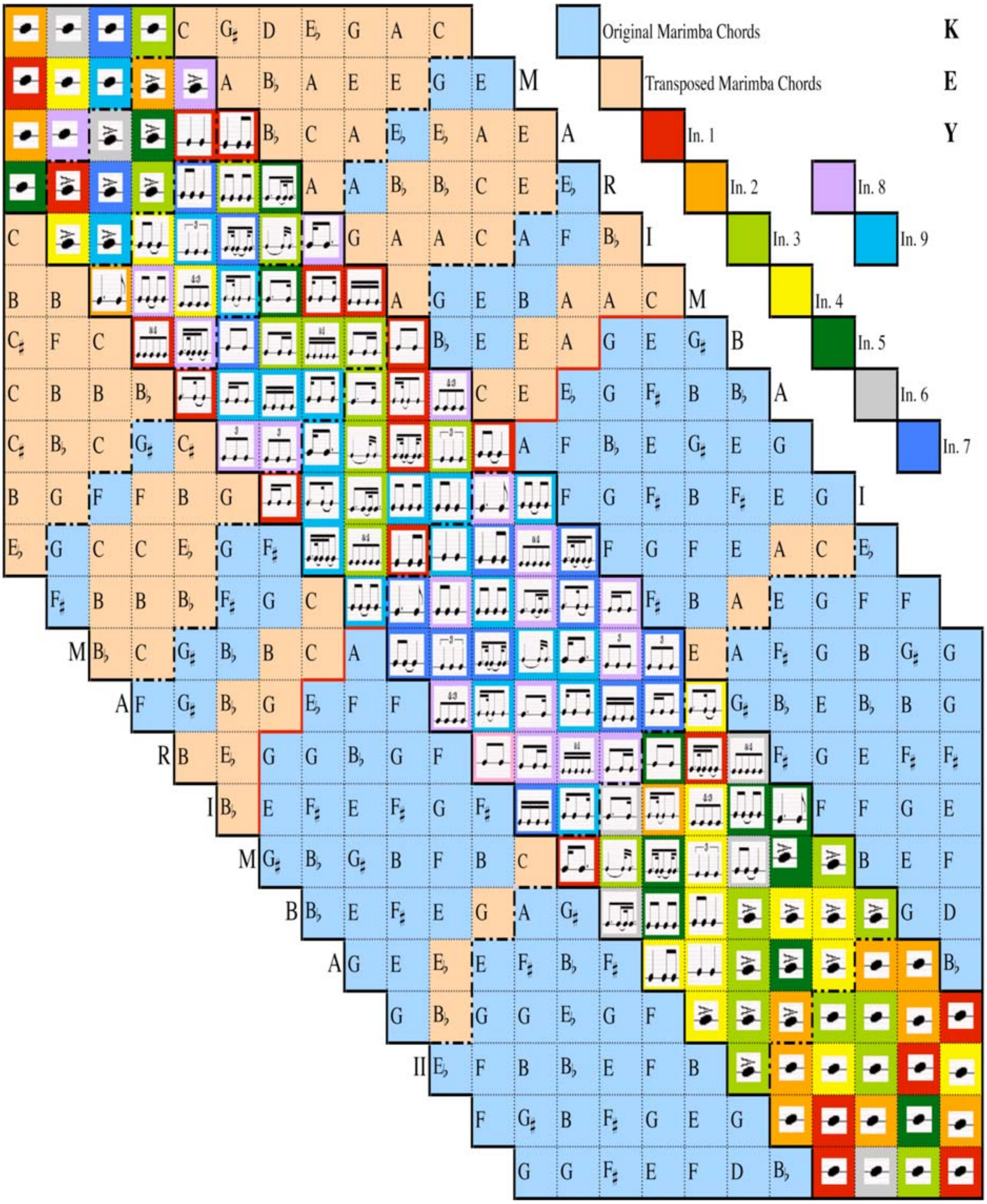


Figure 2.1.4. The matrix used to create *Fight or Flight*

2.2

PARADOX eleven

for three acoustic guitars, violin, cello and percussion

by

Luke Harrald

2004

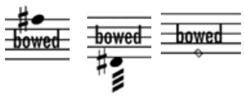
PARADOX eleven

Performance Notes

- All material must be played within the time brackets specified.
- All durations can be as long or as short as the performer chooses;
  ie. the material does not have to fill the entire bracket.
- Where repeats are specified, the performer should repeat the material to fill the bracket.

Notation Key

Guitars



bow the pitch indicated: can be straight or tremolo. All harmonics are open, with the note position on the staff indicating neck position. Higher pitches = higher up the neck

play a tremolo, and gliss from the pitch indicated in the direction of the arrow. Half depress the string so that microtones can be achieved and notes abve the fretboard can be played

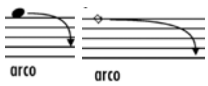
harmonic tremolos are once again approximate. Start from the neck position indicated and gliss in the direction of the arrow.

in two part writing, allow the pitch with the arrow to ring on

play a pulse on two harmonics as fast as possible in the rhythm indicated

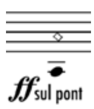
loudly strike the body of the guitar

Strings



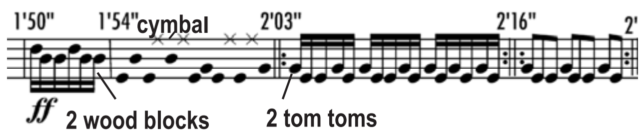
Glissandi: start at the pitch indicated and gliss in the direction of the arrow. Diamonds indicate harmonic glissandi. All harmonics are precicely notated in the string parts, unlike the guitars. Glissandi may be with a normal tone, or tremolo.

natural harmonic.

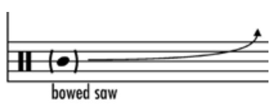


make a scraping noise by lightly placing a finger on the string to dampen it and bowing on the bridge. Sould be very short and loud.

Percussion: Bowed saw, 2 wood blocks, 2 tom toms and 1 cymbal



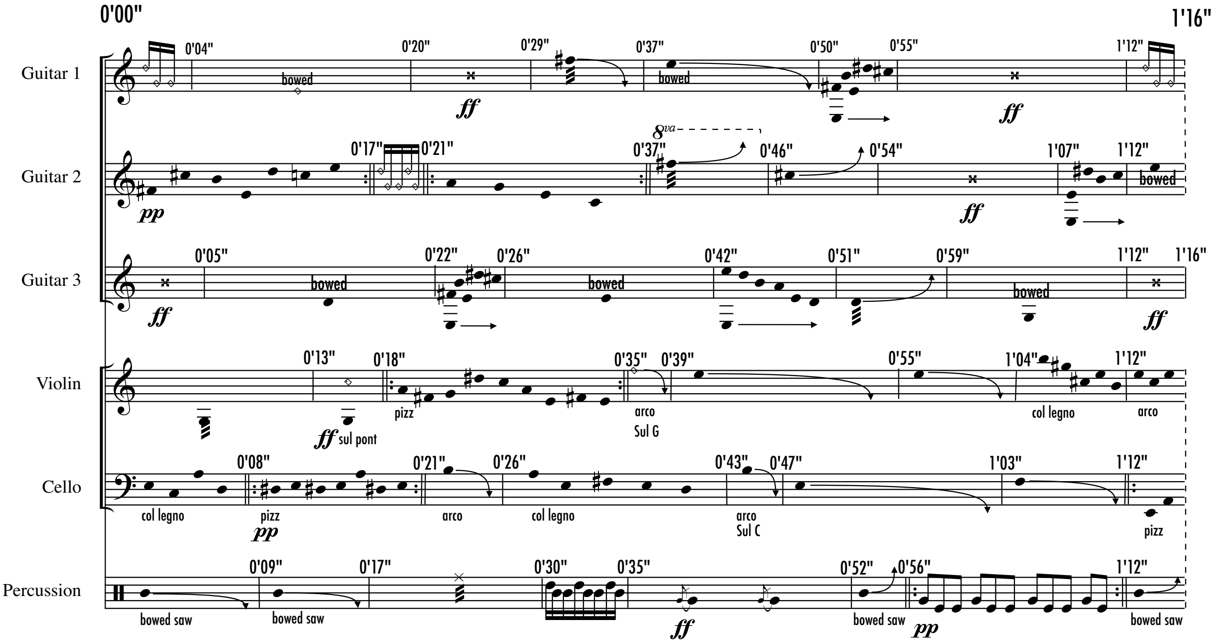
any material without stems is rhythmically free. Rhythmic units marked in semiquavers should be played as fast as possible, while quavers indicate that the percussionist should create a rhythmic pulse at a tempo of their choosing.

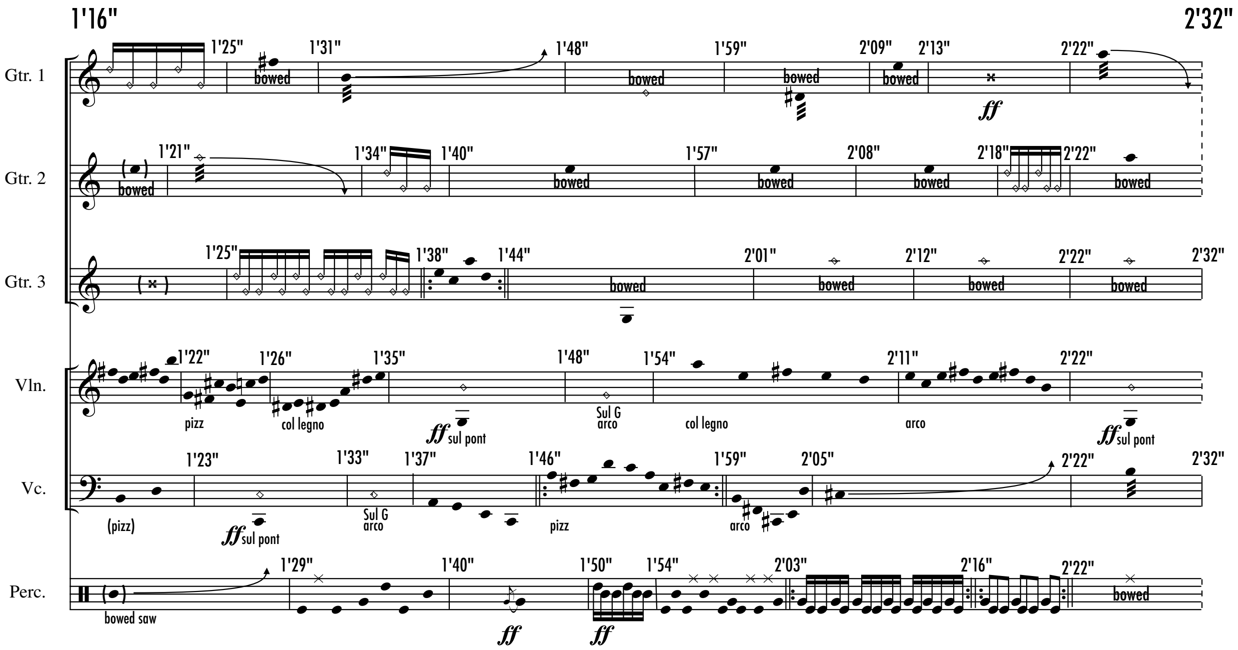


The pitches indicated in the bowed saw part are approximate. A pitch in the middle of the staff indicates a pitch around the middle of the range of the instrument. Gliss in the direction of the arrow.

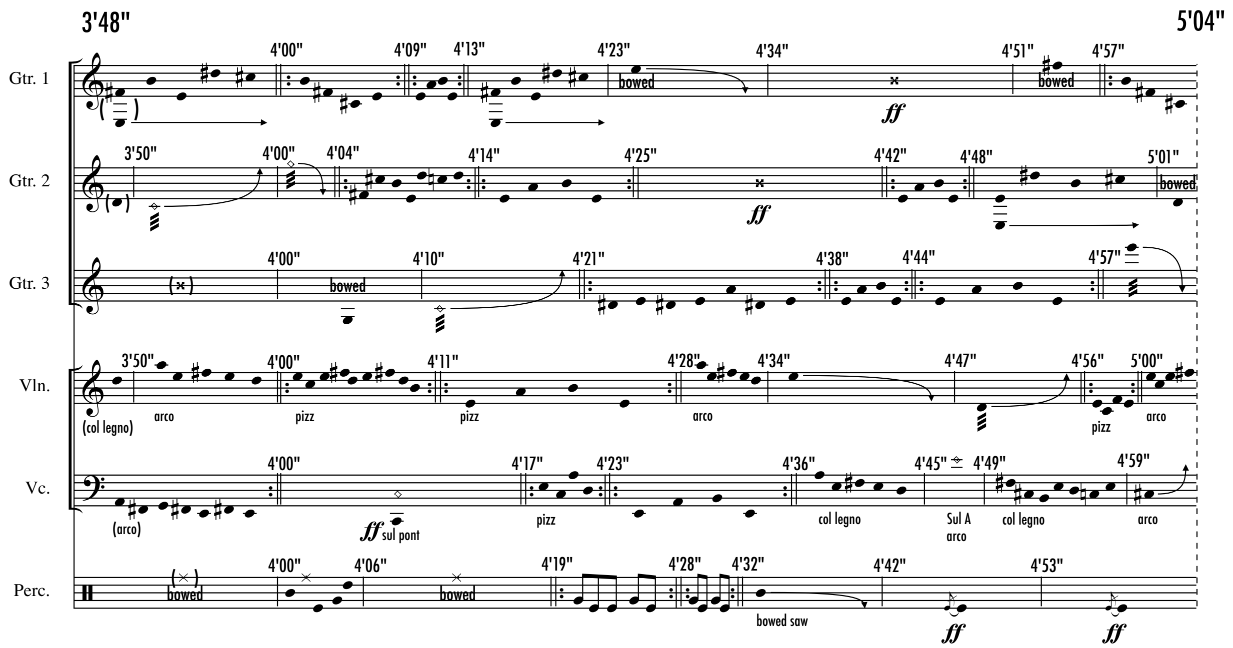
PARADOX eleven

Luke Harrald






2'32"
3'48"
Gtr. 1
Gtr. 2
Gtr. 3
Vln.
Vc.
Perc.
2'38"
2'54"
3'08"
3'18"
3'36"
3'46"
bowed
2'36"
2'52"
3'22"
3'32"
ff
2'46"
3'02"
3'42"
2'40"
2'50"
3'04"
3'20"
ff sul pont
arco
Sul E
col legno
3'00"
3'14"
3'30"
Sul A
2'36"
bowed saw
3'28"
3'44"


3'48"
5'04"
Gtr. 1
Gtr. 2
Gtr. 3
Vln.
Vc.
Perc.
4'00"
4'09"
4'13"
4'23"
4'34"
4'51"
4'57"
bowed
ff
3'50"
4'04"
4'14"
4'25"
4'42"
4'48"
5'01"
4'10"
4'21"
4'38"
4'44"
4'11"
4'28"
4'47"
4'56"
5'00"
(col legno)
arco
pizz
4'17"
4'36"
4'45"
4'49"
4'59"
(arco)
ff sul pont
Sul A
col legno
4'06"
4'19"
4'32"
4'42"
4'53"
bowed saw


5'04"
6'22"
Gtr. 1
5'10" 5'27" 5'32" 5'45" 5'53" 6'02" 6'18"
ff ff
Gtr. 2
bowed
5'10" 5'15" 5'28" 5'36" 5'45" 6'01" 6'05"
bowed
ff ff
Gtr. 3
5'06" 5'10" 5'23" 5'31" 5'40" 5'56" 6'00" 6'17"
bowed
ff ff ff
Vln.
(arco)
5'10" 5'18" 5'27" 5'43" 5'47" 6'04" 6'09"
col legno
arco
ff sul pont
arco
ff sul pont
Vc.
arco
5'10" 5'19" 5'35" 5'39" 5'56" 6'01" 6'14"
ff sul pont
arco
Sul A
ff sul pont
ff ff ff ff
Perc.
5'10" 5'26" 5'30" 5'47" 5'52" 6'05" 6'13"
ff ff ff ff ff ff

PARADOX eleven (2004) for 3 acoustic guitars, violin, cello and percussion

Following the difficulties of implementing the IPD as an approach to performance, a work was attempted that confined the IPD to a composition activity rather than a performance activity. *PARADOX eleven* is the third work in the PARADOX series that started with *PARADOX 9* in 1999. This series of works is defined through a copious use of extended techniques, a common instrument in the guitar, and indeterminacy in performance. Besides the main research goals for the work, which were to develop strategies for sonifying the IPD to use in the planned computer models, other concepts were explored that revolved around incorporating pop music materials into an experimental, indeterminate setting; particularly 'riffs'. In this area, the revelation was a rather simple one that involved repeats. Certain materials within the work were repeated continuously to fill a time bracket, rather than played once. This transformed the work and gave it occasional bluesy overtones.

In order to incorporate the IPD into the composition process, a suitable Prisoner's Dilemma application was needed. As the Spatial Prisoner's Dilemma (Nowak and May 1995) is essentially a four state Cellular Automaton, it was decided that this was a likely starting point as there would be connections with my previous CA based composition techniques, and the Spatial Prisoner's Dilemma provides a graphical representation of the interactions in each round (Figure 2.2.1). An Internet search produced a Java applet by Serge Helfrich (2002). This particular applet is based on the work of A.L. Lloyd (Lloyd 1995). The 35 generations of the Spatial Prisoner's Dilemma used in *PARADOX eleven* can be seen over the page.

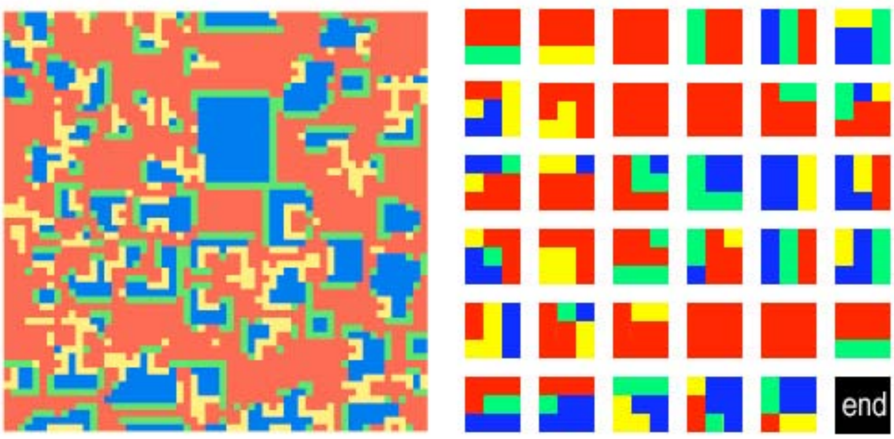


Figure 2.2.1 Left: a single generation of the complete lattice produced by Helfrich's Java applet. Right: 35 generations of the neighbourhood used to create *PARADOX eleven*. The colour of each cell above indicates its behaviour in the current and previous rounds. Blue= cooperated in the current round and the previous round, Yellow = defected in the current round and cooperated in the previous round, Green = cooperated in the current round and defected in the previous round, Red = defected in the current round and the previous round.

In the Spatial Prisoner's Dilemma, cells on a lattice change their states according to the behaviour of their eight surrounding neighbours; this is effectively a 2D Cellular Automaton. As can be seen above (Figure 2.2.1), for *PARADOX eleven*, only the interactions of a single 'neighbourhood' of nine cells were used to create the work. This approach draws obvious inspiration from the method used in *Fight or Flight*, as the entire lattice is not sonified, although this is where the similarities between the techniques used in the two works end.

Essentially, for this work, the interactions between the cells in the Spatial Prisoner's Dilemma were used to guide selections from randomly generated musical material. This is quite a departure from the idea of directly 'triggering' musical events through matrixes like the previous Cellular Automata based works, and was to have profound influence over the approach to both software development and to the works produced later in the portfolio. These selections 'filled in the details' of an externally derived temporal structure.

The temporal structure of *PARADOX eleven* is divided into 5 sections, each defined by a 'Vertical Isorhythm' (Figure 2.2.2). While Isorhythms traditionally involve the cycling of differing numbers of pitches and durations to create melodic variation, here a series of durations are cycled through different timbres (that is, vertically through the parts). The durations are cycled through the timbres until all parts have included all durations, completing a section. Three sets of durations are used in the first three sections of the work and the first two sections are reversed to complete the 5 sections of the form. This creates quite an obvious temporal arch, although due to the treatment of the musical material, the arch is obscured in performance.

1	14	16	9	8	13	5	17	13	6	17	11	10	4	9	16	16	14	10	18	10	14
2	17	14	16	9	8	13	5	9	13	6	17	11	10	4	14	16	16	14	10	18	10
3	5	17	14	16	9	8	13	4	9	13	6	17	11	10	10	14	16	16	14	10	18
4	13	5	17	14	16	9	8	10	4	9	13	6	17	11	18	10	14	16	16	14	10
5	8	13	5	17	14	16	9	11	10	4	9	13	6	17	10	18	10	14	16	16	14
6	9	8	13	5	17	14	16	17	11	10	4	9	13	6	14	10	18	10	14	16	16

9	4	10	11	17	6	13	17	5	13	8	9	16	14
4	10	11	17	6	13	9	5	13	8	9	16	14	17
10	11	17	6	13	9	4	13	8	9	16	14	17	5
11	17	3	13	9	4	10	8	9	16	14	17	5	13
17	6	13	9	4	10	11	9	16	14	17	5	13	8
6	13	9	4	10	11	17	16	14	17	5	13	8	9

Figure 2.2.2 Outline of the temporal structure of *PARADOX eleven* showing the 5 sections. All durations are in seconds, and the isorhythms of the first three sections are as follows:
Section 1: 14", 17", 5", 13", 8", 9", 16"
Section 2: 13", 9", 4", 10", 11", 17", 6"
Section 3: 16", 14", 10", 18", 10", 14", 16"

In order to sonify the interactions between the cells in the automaton, six types of musical material are manipulated. These range from extended techniques, to small rhythmic motifs and repeated materials of open duration. Each of the five sections has one particular type of musical material that is triggered through cooperation. Cooperating cells trigger the same type of musical material if they cooperate for one generation, while if they cooperate for two consecutive generations they trigger exactly the same musical material. Defection results in a random selection of new material from any of the other 5 types of musical material. The notion of cooperation consolidating musical events, and defection introducing new material has persisted throughout the subsequent software development and works, although various schemes for implementing this idea have evolved with subsequent development. This work applies this idea in the most restrictive way of all the works in the portfolio, and is the only work where cooperation results in set types of musical material.

In performance, *PARADOX eleven* was far more successful than *Fight or Flight*, and premiered as part of the 2004 Adelaide Fringe Festival. A recording of this performance is included on track 1 of the CD in Volume 2. Through incorporating the IPD into the composition process, the work was a much better indicator of the IPD's musical potential. Although the use of the IPD is restricted in many ways, the pleasing aspect of the work was the way that through cooperation and defection the musical materials seem to float across the musical surface as different materials are reinforced and abandoned.

2.3 Discussion: research outcomes

As early, formative works, *Fight or Flight* and *PARADOX eleven* established several key concepts that informed both the software development and the composition of future works included in the portfolio. From a procedural viewpoint, both works drew heavily on my previous approaches to algorithmic composition. For example, both works use quasi-arch forms. The Vertical Isorhythms used in *PARADOX eleven* were also intended to combat the discrete nature that affects all iterated systems. To avoid creating vertical 'blocks' of materials, the isorhythm offset the sequence of the automaton's generations. Future software based systems adopted various strategies to mask the discrete nature of the IPD, but overall it was found that breaking up the sequence of generations was not required.

While *Fight or Flight* was not successfully performed, it had an important role in shaping my ideas on the function of future software models. Essentially, the performers took on the roles of agents, and this was an important step in formulating strategies for software development. Equally, through *PARADOX eleven*, the notion of cooperation consolidating established musical materials, and defection leading to the introduction of new materials was another important step. While this idea was executed in quite a contrived way through the composition process used in *PARADOX eleven*, the idea lead to far more open models in future work. Certainly, the way in which the musical materials were established, and subsequently dissolved through the interactions of the cells in the Spatial Prisoner's Dilemma suggested that the Prisoner's Dilemma could offer a promising approach to form.

3. Software Development

Throughout the software development for this project, many applications were written to meet the requirements of different compositions and performance situations. As such, although the compositions and software are split up through the subsequent sections of the portfolio into Non-Real-Time Applications (Scored Works), Real-Time Applications (Installations and Films), and interactive applications (Live Collaborative Work), in actual fact most of these systems were developed simultaneously, and do not fit in the sequential order that the portfolio suggests. As such, the portfolio does not appear in strict chronological order.

All software was developed in Cycling 74's Max/MSP programming environment (Puckette et al. 1990-2005). As the software was developed over a period of almost three years (2004 to 2007), there are many different versions; various screenshots appear in Figure 3.2.2. Two of the applications used to create the compositions of the portfolio are included on the Data DVD in Volume 2.

3.1 System Design and Implementation

In order to allow for easy modification for different compositions and for ongoing development, a modular approach was taken to system design and implementation. All applications built for the compositions of the portfolio are based around two main components, these being a processing module that incorporates the IPD model, and a time module that provides the IPD with an external clock. These two components form an IPD engine to which various other graphic user interfaces, input and output components are added to allow for user interaction with the system, and a variety of musical and visual input and output.

The following section will discuss the conceptual and practical development of the IPD engine. The development of all other components will be discussed in conjunction with the various compositions for which they were developed.

3.2 The IPD Engine

While the Spatial Prisoner's Dilemma had proven useful in the composition of *PARADOX eleven*, it was never my intention to use it specifically as the basis for my own system. The main aim for the system was to draw a much closer musical analogy than the Spatial Prisoner's Dilemma could provide. The final engine incorporates a virtual ensemble of eight interacting agents, although initial models incorporating four agents were developed, drawing on a quartet model, and a model based around 24 agents, drawing on the orchestra, was also attempted. While the original model incorporating four agents was expanded to eight agents, the orchestral model was never completed due to a lack of computing power. One of the limitations of the system defined from the outset was that it should run on a single laptop computer, specifically, an Apple G4 PowerBook running at a speed of 1.33 Ghz, which was the top of the range Apple Laptop in 2004. This was seen as necessary to allow for ease of use in live performance with the interactive versions of the system. This approach ultimately proved problematic, as the G4 did not produce the computing power required for the interactive systems, and as such this limitation was abandoned, with interactive versions of the software requiring a G5 desktop system as a minimum requirement. Several performances have taken place using the current (as of 2007) crop of Intel based Apple laptops without issue.

The IPD engine is a deterministic Prisoner's Dilemma tournament that draws inspiration from the work of Robert Axelrod, although it has some clear distinctions enabling the agents in the system to more closely model a group of interacting musicians. The agents are faced with an environment that is solely made up from their interactions and the only way they can communicate with each other is through the sequence of their own behaviour. While the agents have the facilities to implement all of the strategies in the system, each agent is preset to a particular strategy prior to the first round of interactions. This was an intentional limitation placed on the system for two reasons, firstly to allow for clarity in the interactions between agents, and secondly to allow for an exploration of the effect that different combinations of strategies had on the system's musical output.

Typically, strategies are randomly assigned to the agents, although the user may also choose their own combinations. Most of the rule sets implemented have been well established through Axelrod's original tournaments, although the 'Pavlov' rule was developed by Nowak (1995) and represents more recent research. The rule sets represent a variety of rule types, including those that are passive, responsive and aggressive. The musical implications of the selection of rule types will be discussed in Chapter 4.

Currently, seven rule sets are implemented, including:

TIT FOR TAT: co-operate in the first round, do whatever the current opponent did in the previous round in all subsequent rounds;

RANDOM: a random or irrational selection;

VENGEFUL: cooperate until defected against, and then defect for the next five rounds regardless of the opponent's response;

COPYCAT: do whatever the player with the highest score did in the previous round;

PAVLOV: win stay the same, lose change (currently the system implements two variations of this rule, one is aggressive and counts a cooperate/ cooperate rule as a loss- just like the classic version of this rule, while the other is passive and counts this situation as a win);

and

DOWNING: do what the most players in the previous round did.

In a typical run of the system, the agents interact through a number of rounds, the length of which is defined randomly by an external clock. The user is able to exercise some control over the density of the musical material produced through setting the range of round lengths. Through each round of interactions, the agents encounter each other in randomly selected pairs. There is an equal chance that an agent will encounter the same opponent in the subsequent round as a new opponent. One important difference between the model used here and Axelrod's tournament is that all agents interact in pairs simultaneously, and can 'see' all of the other interactions that are occurring, not only the interaction with their current opponent. This means that if an agent 'suckers' an opponent in the current round, it may receive retribution for that defection even if it encounters a new opponent.

Another key difference between this model and that of Axelrod is in the length of an agent's memory. Rather than containing a history of encounters with particular agents, in this instance, each agent's memory is limited to only the previous round of interactions. In this sense, the model is similar in some ways to the Spatial Prisoner's Dilemma used previously, although space is unimportant; each agent has an equal chance of encountering any other agent in each round of interactions. Also unlike a typical Cellular Automaton, all members of the system do not interact with each other using the same strategy.

At the conclusion of each round of interactions points are awarded to each agent according to a typical IPD points matrix (see below) and tallied depending on the out-come of the interaction. These results along with the responses from the other agents are stored in the agent's memory to determine their response in the next round.

The Prisoner's Dilemma payoff matrix

Note: the payoffs to the row chooser are listed first

		Column Player	
		Co-operate	Defect
Row Player	Co-operate	R=3, R=3 Reward for Mutual Co-operation	S=0, T=5 Row: Sucker's payoff, Column: Temptation to defect
	Defect	T=5, S=0 Row: Temptation to defect Column: Sucker's payoff	P=1, P=1 Punishment for mutual Defection

Figure 3.2.1 A typical Prisoner's Dilemma points matrix outlining the payoffs for players according to the outcomes of their interactions. (Axelrod 1984: 8). P= Punishment Payoff for Mutual Defection between players (1 point), R= Reward Payoff for Mutual Co-operation between players (3 points), S= Sucker's Payoff (0 points) and T= Temptation to Defect payoff (5 points).

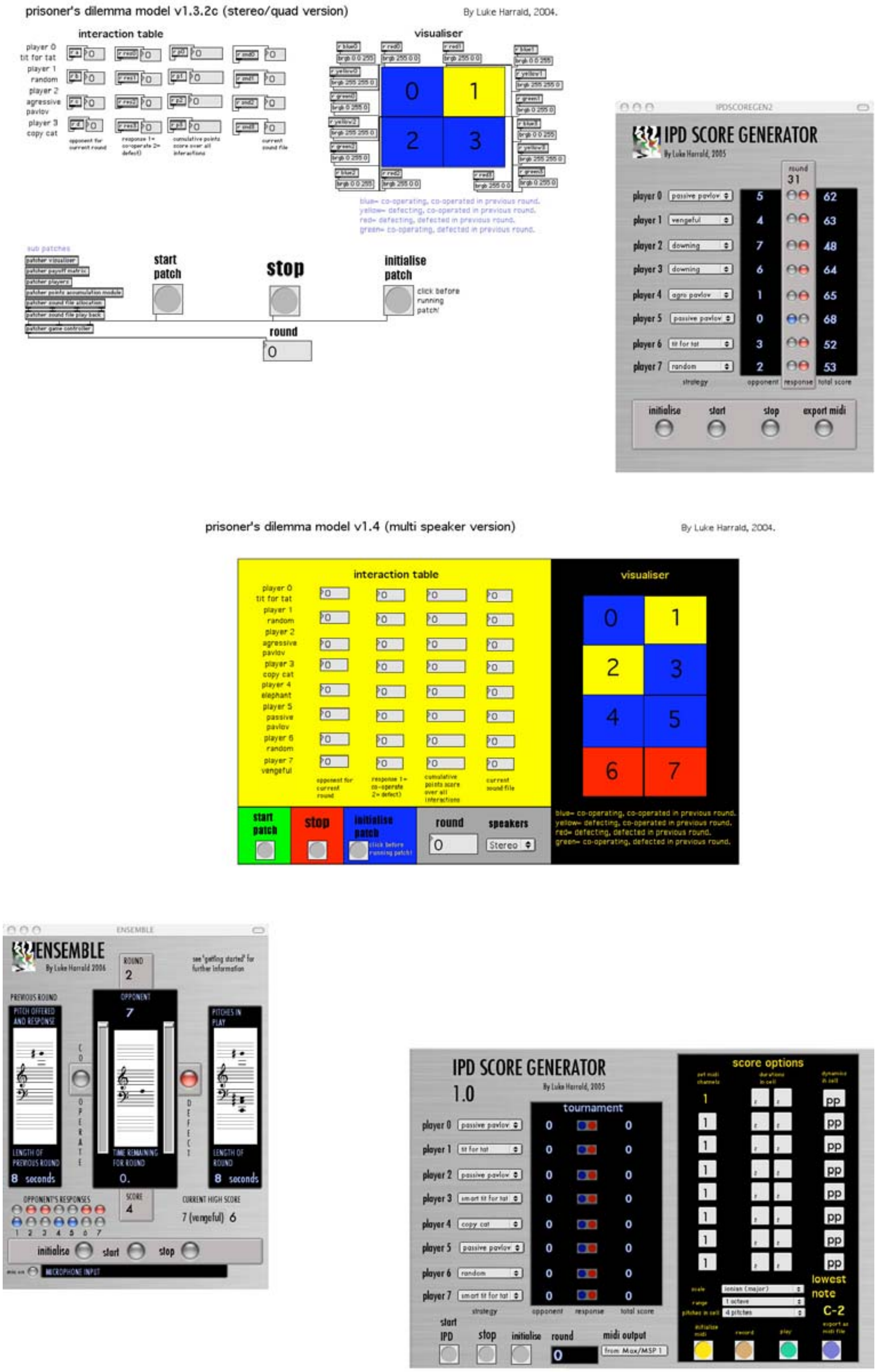


Figure 3.2.2: Screenshots of some of the applications developed throughout creation of the portfolio. Top left: an early version of the Iterated Prisoner's Dilemma model with only four agents. Top right: The final version of the *IPD Score Generator* application. Middle: The completed Iterated Prisoner's Dilemma engine with eight agents. Bottom Left: An early version of the interactive *ENSEMBLE* application. Bottom Right: Version 1 of the *IPD Score Generator* application.

3.3 Anatomy of an Agent

Each agent consists of a behavioural engine, a memory, 'eyes' and 'ears'. The behavioural engine contains all the agent's cognitive abilities, effectively incorporating the strategies for interaction, outcome assessment, comparative functions to interpret musical and visual output and generative capabilities that allow the agent to produce new sonic and visual output as needed. This can be explored further in Appendix A where the Max patches for the applications are presented.

The memory of each agent, while being restricted to only the previous round of interactions, actually stores a substantial amount of information about its experience in the previous round and equally that of its opponents. The memory receives information from the behavioural engine, as well as the agent's 'eyes' and 'ears'. Effectively the eyes and ears give the agent feedback on the musical and visual output of the entire system that is occurring in the performance space. The behavioural engine monitors and assesses the interactions between agents. At the end of each round, the agent's memory is purged, and updated with new information from the current round. This information is then used to inform the agent's behaviour in the next round.

3.4 Time

As with most algorithmic systems, time in the IPD engine is discrete, and in this instance, is controlled by the 'time' module. Effectively providing a metronome for the system, the time module triggers each round of interactions, and also controls the random pairings of the agents. The time module effectively has two modes of operation aimed at real-time applications, or generative (score based) applications. In real-time mode, the module varies the length of each round randomly according to limits set by the user. These are generally set above four seconds if used in an interactive context as human performers generally struggle with decision-making processes shorter than two seconds so a four second round allows a buffer for this threshold. In generative mode, the rounds are triggered in a strict metronomic fashion at 500 millisecond intervals. In this instance, the length of the round is simply delivered to the agents as an integer, allowing for fast score generation in non-real time.

3.5 Musical Considerations

Reflecting the ideas developed through *PARADOX eleven*, and echoing one of the key concepts of this research, ‘modelling emergent ensemble dynamics’, the approach to sonifying the IPD is rather simple, drawing inspiration from the Wolff example outlined earlier. Much like the scenario of the Prisoner’s Dilemma itself, musically, the agents only have two choices:

1. Play the same material as the previous round;

or

2. Introduce new material through a random selection.

The agents are not programmed with any kind of expert knowledge relating to hierarchical musical structures, and any sense of form produced by the system is a result solely of the interactions between the agents. While the scenario leading to the creation of a musical surface is different from *PARADOX eleven*, it none the less draws on the notion of cooperation reinforcing musical material, while defection introduces renewal.

To create the musical surface, through each interaction, each agent confronts its opponent and issues a response. The overall point scores of the pair are compared and the agent with the highest score becomes the dominant player in the interaction. A mutual co-operation will result in the dominant player’s musical material from the previous round being continued in the current round by both players. If either player is ‘suckered’ they will take on their opponent’s musical material while the defector makes a random selection of new material. Mutual defection results in a random selection for both players (Figure 3.5.1)

Ensemble: possible musical outcomes for a single interaction	
Agent 1 Current Score: 246 Previous sound= 23	Agent 2 Current Score: 233 Previous sound= 2
Response: co-operate	Response: co-operate
Result: Both agents play sound 23.	
Response: Defect	Co-operate
Result: Agent 1 randomly selects a new sound, Agent 2 plays sound 23.	
Response: Co-operate	Defect
Result: Agent 1 plays sound 2, Agent 2 randomly selects a new sound.	
Response: Defect	Defect
Result: Both agents randomly select a new sound.	

Figure 3.5.1: An outline of the possible musical outcomes of an interaction between two agents in the IPD engine.

The audience hear the results of these musical choices on a global level, creating the resulting musical surface. The actual details of this transformation have been handled in a number of ways, and this will be explored further through discussion of the specific applications and compositions created based on the IPD engine. The system has been used to manipulate sound at a macro level, manipulating pallets of samples, the micro level through controlling the combination of sine tones and at the meso level through generating streams of MIDI note events to generate musical scores.

3.6 Discussion: implementation of strategies

The interpretation of the agent's actions in musical terms has heavily influenced the implementation of the IPD model used throughout this project. One example of this can be seen in the agent's memory. While the agents in the model have a short memory (one round), they are able to take in the global information from that particular round. In effect they 'see' all the other interactions that occur and 'hear' sounds played by the other agents. This global information allows the agents to survey the dynamic landscape as it unfolds, while each individual interaction allows them to focus their attention on a particular agent. This scenario draws inspiration from the types of interactions that occur in ensemble playing. Often musicians will tend to listen to the whole group of performers, but will also focus their attention towards individual performers throughout a performance. Of course, these interactions are heavily stylised in the IPD model as real-life instrumentalists make their decisions based on expert knowledge whereas the agents switch their focus through random selections.

The short memory of the agents, and their ability to survey the global interactions of the group has implications for the way in which the various IPD strategies are realised. For example, a typical DOWNING strategy surveys the history of its previous interactions with an opponent to determine the probability of its opponent's response in the current round. It then uses this information to determine its own response (Axelrod 1984: 34). In the model used here, DOWNING is tweaked somewhat as it has access to global information, but cannot refer back to interactions prior to the last round. Hence it looks at whether the majority of agents are co-operating or defecting, and uses this information to determine its response. In this sense it is able to assess whether it is experiencing a cooperative or hostile environment, and respond accordingly as opposed to assessing the behaviour of its direct opponent. If the majority of agents are behaving in a hostile fashion, it presumes that its opponent is likely to be hostile regardless of its individual behaviour in the previous round.

While the agents are able to consider global attributes through their strategies for interaction, the selection and transfer of musical material between agents is solely governed by the outcome of the local interaction between each pair of agents in a particular round. This creates the musical dilemma of sorts, in that, in order for an agent's material to be played by their opponent and indeed possibly be passed on to other agents in future rounds, cooperation is required. At the same time, if their musical material is to persist, they must either have a higher score than their opponent so that they are the dominant player in the encounter, or 'sucker' them which either way means defection must be risked at some point. Of course, because their actions can be seen by the other agents, they are always at the risk of swift retribution in the next round, which will obviously cause their musical material to be ignored through the introduction of new musical material by their opponent. Equally, through cooperation, they also run the risk of being 'suckered' causing them to be forced to take on their opponent's musical material regardless of their score.

This behaviour is reminiscent of the dilemma faced by performers in an indeterminate or improvisatory setting.

> Structure in improvised music derives from spontaneous (ie. unplanned) changes in musical direction… Each musician is faced with a constant dilemma: new expressive initiatives may be followed, or they may be ignored. The tension between expressive attraction and avoidance leads to the sudden, apparently orchestrated, changes that characterise this music.
>
> (Blackwell and Bentley 2002: 1462)

Through the IPD model, it is obvious that a 'best' strategy could be searched for, where-by a particular agent is able to dominate the others and basically impose its musical will in a kind of musical 'Core Wars' (Coveney and Highfield 1995: 240). This has not been the aim of this research, not to say such research would not produce interesting results, just that more emphasis has been placed on exploring the dynamics that arise from the interactions between the agents rather than searching for a 'best' strategy. Indeed, one of the main questions explored through the model is what combination of strategies can lead to the emergence of larger scale musical forms.

4. Non-Real-Time Applications: software and scores

The following section will discuss the development of the software application *IPD Score Generator* and the works associated with this application. As the name suggests, *IPD Score Generator* allows output from the IPD engine to be implemented in the MIDI domain, enabling direct transformation from IPD data to musical scores. The development of this application has been informed by, and informed, the works *Surroundings* (2004) for piano trio and electronics, *Irene's Myth 3* (2005) for solo cello and narrator, and a large scale work *Give in to Light* (2006) for orchestra.

4.1 IPD Score Generator

IPD Score Generator was an important step in this research, as unlike the real-time applications based around the IPD engine, *IPD Score Generator* is able to generate musical materials that are pinned down and can be more easily analysed and assessed. As the IPD model can be quite volatile, often the musical surface produced is very transitory in nature. Thinking back to Cage's comments that through indeterminate works, "the function of the performer is that of a photographer who on obtaining a camera uses it to take a picture. The composition permits an infinite number of these…" (Cage 1961: 36), in this instance, the agents of the IPD engine take the place of the performers, allowing *IPD Score Generator* to create an infinite number of 'pictures' of the indeterminate situation at hand.

The development of *IPD Score Generator* centred on the creation of two modules added to the IPD engine. These were an output module that was able to transform the agent's actions into musical scores, and a Graphic User Interface (GUI). Interestingly, the final version of *IPD Score Generator* presented here was intended to be a 'lite' version of the application with limited functionality to be distributed with conference proceedings and other publications. Variations of the simplified version of the application were actually used in the composition of two works included in the portfolio, showing that even with restricted functionality, the application was still very effective at producing a variety of musical outcomes.

4.2 GUI Design and Implementation

As GUI design is an entire field in itself, this aspect of the project was challenging, and the GUI went through many versions. For simplicity, the final version of the GUI incorporates two panels. The main panel includes a visual representation of the IPD tournament and controls, while the initialisation panel enables the user to set up a pallet of materials that is manipulated by the agents to generate the score (Figure 4.2.1).

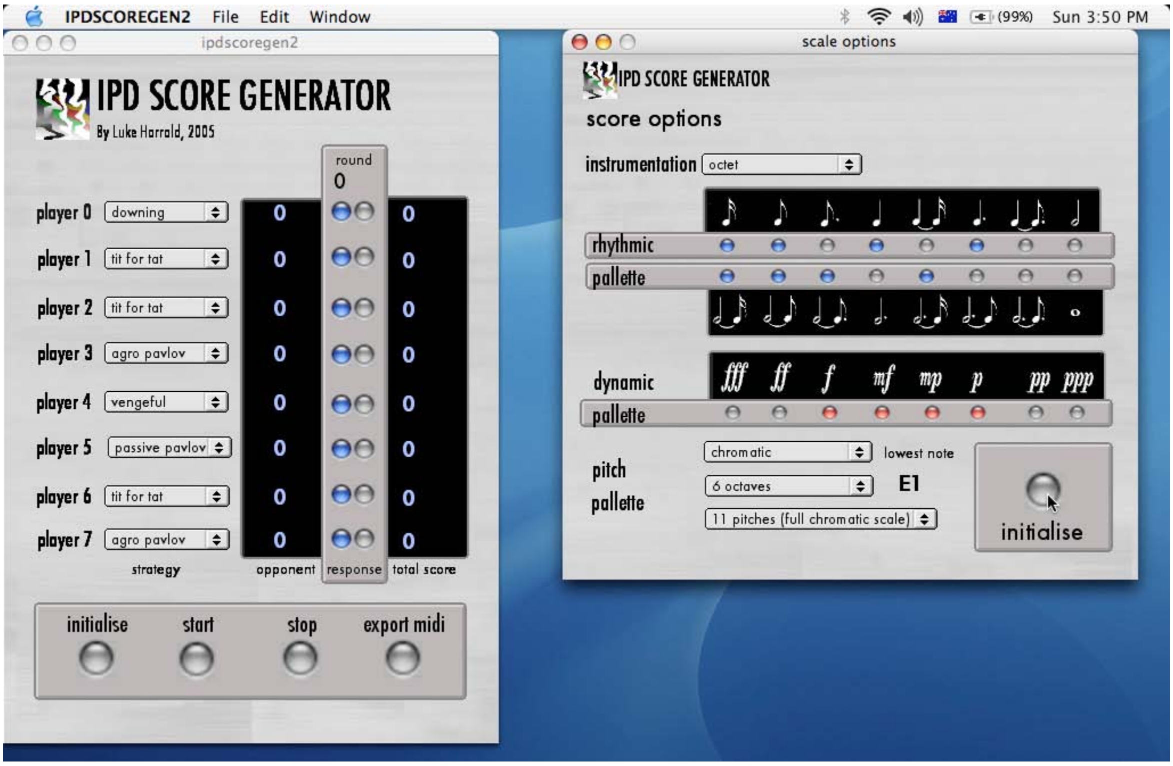


Figure 4.2.1 *IPD Score Generator* Graphic User Interface. Both panels are shown, with the main panel on the left, and the initialisation panel on the right. When the application is opened, only the main panel appears, the initialisation panel opens when the user initialises the system, ready to generate a score. As initialisation is completed, the panel automatically closes.

The controls on the main panel are quite simple, enabling the user to set the strategies for each agent through a series of drop down menus, initialise the system, start and stop the tournament, and export a MIDI file of the system output once the tournament is complete (Figure 4.2.2). On the right side of the panel, the user is able to see the actual IPD tournament unfold, with readouts indicating the round number and each agent's current opponent, response and total score. While the visual representation of the tournament is of interest to users unfamiliar with the IPD, and allows them to see how a change in the combination of strategies alters the global behaviour of the system, in early systems it also played an important role in troubleshooting. If agents were not behaving as they should, the situation was easily found and rectified. Some of the early systems were also able to print lists of the agent's responses in each round for checking.

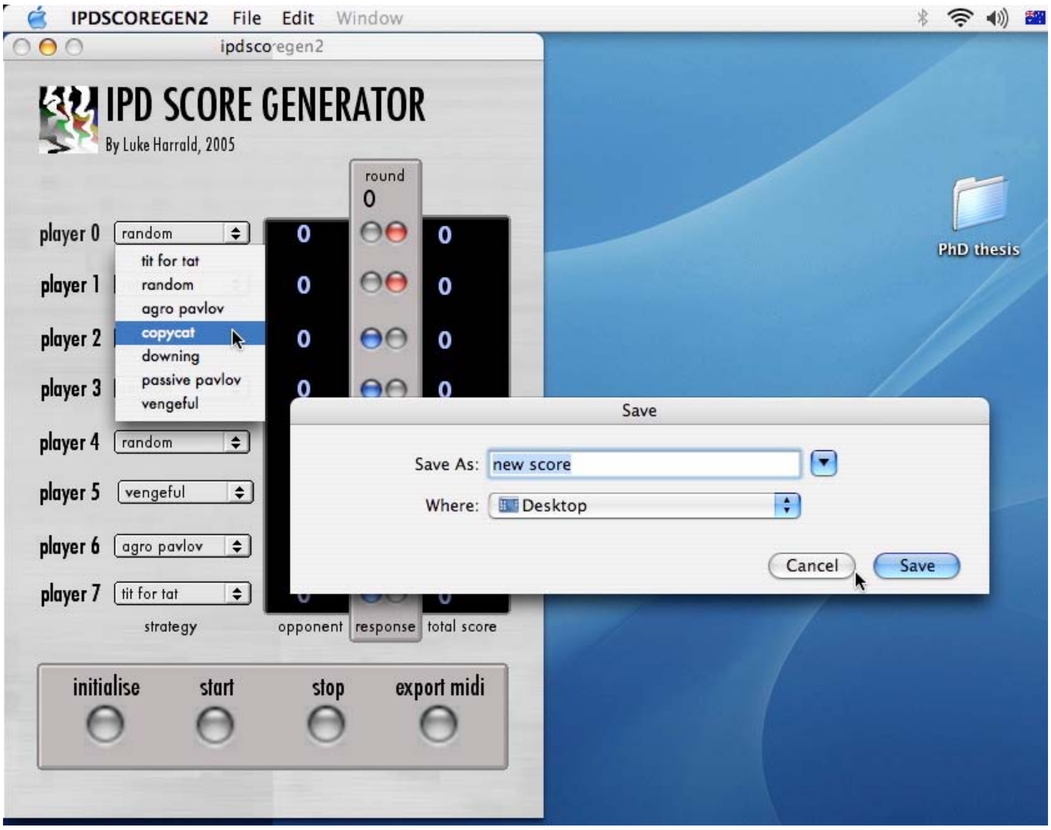


Figure 4.2.2 GUI detail, showing a drop down menu for setting the strategy of one of the agents and the save dialogue instigated by hitting the export MIDI button.

The initialisation panel serves a dual purpose in the application. On the one hand, it allows the user to set the palette of sounds they want to use for their particular work, but on the other, it also gives the system some time to initialise certain parts of the IPD engine while the user is setting up their preferences. This feature allows the user to begin generating a score as soon as they have set their preferences, rather than having to wait for the system to initialise. The panel enables the user to set various limits on the material that the agents will use to generate their score. This material is divided up into several palettes that are set through either drop down menus or buttons that can be switched on or off (Figure 4.2.3). The palettes include an instrumentation palette, a rhythm palette, a dynamics palette and a pitch palette. As this version of the software was intended to be the 'lite' version, these choices are in some ways restricted, for example, there are only four types of instrumentation to choose from, piano (solo), duo, quartet and octet. Equally, complex rhythms are not possible, with the user restricted to the simple beat divisions between a semiquaver and a semibreve, while the pitch is restricted to 12-tone equal temperament. Despite these limitations, the application is still able to generate a very wide variety of musical material.

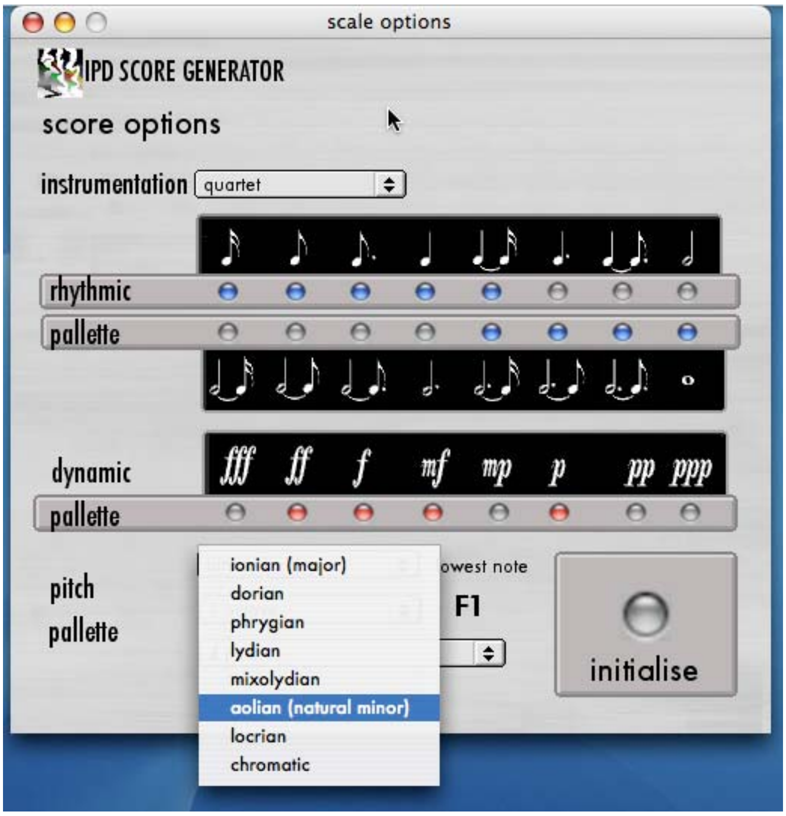


Figure 4.2.3 Initialisation panel detail with the 'scale' drop down menu open. Note the buttons that are used to turn the various durations and dynamics on and off. Once the user is satisfied with their choices they hit initialise to load their sound palette into the IPD engine.

4.3 Output Module (IPD data to MIDI file conversion)

The output module of *IPD Score Generator* allows the IPD engine to create a MIDI file that can then be opened in a score editor to create musical scores. The MIDI file itself is created through the use of the MaxMSP 'Detonate' object; a variation on Miller Puckette's 'Explode' (Puckette 1990). The Detonate object is quite a powerful MIDI sequencer and a MIDI file reader, although the use of the object has had several drawbacks that have required workarounds that ultimately mean that while *IPD Score Generator* has the appearance of user friendliness close to a commercial application, in reality it has limited use outside of my own composition process. On a more positive note, moving *IPD Score Generator* away from being a real-time application made the program far more efficient, and allowed for a more complex sonification of the agent's interactions. Effectively, working in non real-time, and the MIDI domain, the agents have far greater control over the musical material they produce than in the real-time applications.

As outlined in the description of the IPD engine, cooperation between agents results in material from the previous round being reinforced, while defection leads to the random selection of new materials. In *IPD Score Generator*, these materials include, pitch, velocity, offset (the how far in to the round the musical event occurs) and duration.

In some ways, the scenario faced by the agents in *IPD Score Generator* is similar to Cage's late 'Number' pieces (Pritchett 1993: 199-204); for example '101' for Orchestra (1988). The agents are presented with a round length (much like Cage's 'Time Brackets'), and they can control how far into the round they begin to play and how long they play for. Unlike the Cage Number pieces, the length of the round only controls the range of attacks, the ends of the notes are not bound by the length of the round, allowing agents to overlap their material into the next round. Like the use of the isorhythms in *PARADOX eleven*, this aspect of the application was to combat the blocky nature of discrete systems; giving the material generated a more continuous feel. The agents control the pitch, dynamics and tessitura of each note. Generally, the agents are assigned to independent MIDI channels, so that each agent is effectively 'playing an instrument', although in a variation of the system used in the composition *Give in to Light*, the agents also control MIDI channel information, allowing for the control of timbre.

One of the biggest challenges to overcome when converting the information from the agent model into MIDI data was the issue of silence. It was felt that allowing the agents to 'choose' not to play was just as important as when they chose to play as this would allow for the generation of different densities of musical material. Through using the 'detonate' object this was problematic because rather than using 'Note-off' events to end notes, detonate uses a 'Note-on' event with a velocity of zero. This meant that when an agent chose silence, that is, material with a velocity of zero, detonate would effectively see a Note-off, and not register the event in the MIDI timeline as it did not follow a Note-on.

As my works are generally scored in Make Music's 'Finale' scoring application (Make Music 2007), the workaround for this problem came through the MIDI import functions of Finale. The agents choose to stay silent in a round by choosing a note with a velocity of 1, these notes are then filtered out through Finale's MIDI import filtering functions and turned into rests. While notes with such low velocities would generally not be heard if the file was played through a MIDI sequencer, they do appear in scoring applications (if they are unfiltered) as note, not rests. The MIDI files produced *by IPD Score Generator* have also been found to be quite sensitive to quantisation settings when the file is imported, and as such, the application relies fairly heavily on the filtering functions of Finale. This is one of the main reasons the application has not been distributed as planned, and it is hoped that more suitable solutions can be developed in the future. The software is included in Volume 2 on the Data DVD as an OS X application. The results from using the software may be varied as it has not been widely tested outside the computer systems used to produce this portfolio and support will not be offered.

4.4

Surroundings

Inspired by the work of Peter Atkins

for piano trio and electronics

by

Luke Harrald

2004

Surroundings

Inspired by the work of Peter Atkins

First Movement

Luke Harrald


Vln.
Vc.
Pno.
pizz.
arco.
pizz.


41
Vln.
Vc.
arco.
Pno.
46
pizz.
51
56


61
Vln.
Vc.
Pno.
arco.
pizz.
arco.
66
71
76

Vln.
Vc.
Pno.
pizz.
arco.
pizz.
arco


101
Vln.
Vc.
101
Pno.
106
Vln.
Vc.
106
Pno.
111
Vln.
Vc.
111
Pno.
116
Vln.
pizz.
arco.
Vc.
pizz.
arco.
116
Pno.


Vln.
Vc.
Pno.
121
pizz.
126
arco.
131
pizz. (let ring)
pizz. (let ring)

Surroundings

Second Movement

Luke Harrald


21
Vln.
Vc.
21
Pno.
26
Vln.
Vc.
26
Pno.
31
Vln.
8va
Vc.
31
Pno.
36
Vln.
Vc.
36
Pno.


41
Vln.
Vc.
41
Pno.
46
Vln.
Vc.
46
Pno.
51
Vln.
Vc.
8va
51
Pno.
56
Vln.
Vc.
8va
8va
56
Pno.

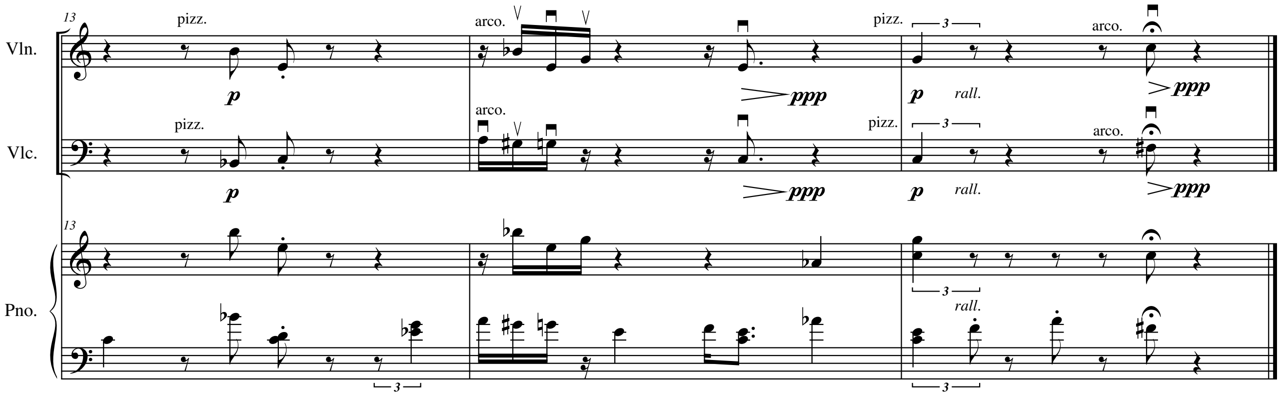

61
Vln.
Vc.
61
Pno.
66
Vln.
Vc.
66
Pno.
71
Vln.
Vc.
71
Pno.
76
Vln.
Vc.
8va
76
Pno.

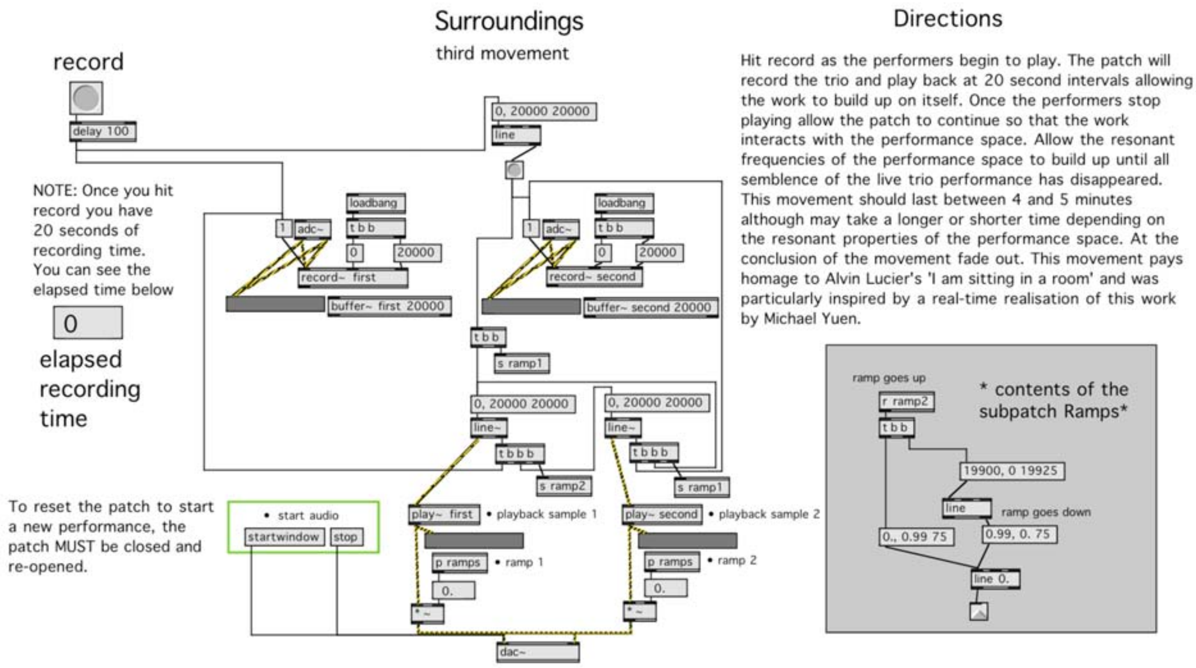

81
Vln.
Vc.
8va
8va
81
Pno.
86
Vln.
Vc.
(8va)
8va
86
Pno.

Surroundings

Third Movement

Luke Harrald


13
Vln.
pizz.
arco.
pizz.
arco.
p
ppp
p
rall.
ppp
Vlc.
Pno.
rall.


Surroundings
third movement
Directions
Hit record as the performers begin to play. The patch will record the trio and play back at 20 second intervals allowing the work to build up on itself. Once the performers stop playing allow the patch to continue so that the work interacts with the performance space. Allow the resonant frequencies of the performance space to build up until all semblence of the live trio performance has disappeared. This movement should last between 4 and 5 minutes although may take a longer or shorter time depending on the resonant properties of the performance space. At the conclusion of the movement fade out. This movement pays homage to Alvin Lucier's 'I am sitting in a room' and was particularly inspired by a real-time realisation of this work by Michael Yuen.
record
delay 100
NOTE: Once you hit record you have 20 seconds of recording time. You can see the elapsed time below
0
elapsed recording time
0, 20000 20000
line
loadbang
t b b
1
adc~
0
20000
record~ first
buffer~ first 20000
record~ second
buffer~ second 20000
s ramp1
s ramp2
line~
t b b b
To reset the patch to start a new performance, the patch MUST be closed and re-opened.
• start audio
startwindow
stop
play~ first
• playback sample 1
play~ second
• playback sample 2
p ramps
• ramp 1
• ramp 2
0.
*~
dac~
ramp goes up
r ramp2
* contents of the subpatch Ramps*
19900, 0 19925
ramp goes down
0., 0.99 75
0.99, 0. 75
line 0.

Surroundings (2004) for piano trio and electronics

Surroundings was commissioned through Arts SA as part of the Sight Specific Music project at the Greenaway Art Gallery. The premiere performance was presented by Recitals Australia, and subsequently the work was recorded by Radio Adelaide and released on the compilation CD 'Sight Specific Music volume 1'. Two versions of the work appear in Volume 2. The full work appears on the CD (tracks 2, 3 and 4 recorded by Trio Typology) and the third movement on the DVD (performed at ACMC05 by Topology at Queensland University of Technology). For the performance at QUT, the Double Bass was used as a substitute for the Cello to suit the requirements of the Topology ensemble. The Cello part sounds an octave lower in this performance.

The Sight Specific Music project aimed to bring visual artists and composers together to create new work. The new compositions were performed alongside exhibitions of the visual artist's work in the gallery space. *Surroundings* was performed with, and inspired by the work of Melbourne artist Peter Atkins, particularly his 'Big Paintings' exhibition in 2003. This work offers an excellent introduction to some of the music able to be generated through *IPD Score Generator*, as the work is virtually un-altered from the musical material generated by the application. This was a conscious aesthetic choice as Atkins' work centres on found objects, and as such, I aimed to create a work that was *found* rather than *composed*.

Atkins' work consists of montages of non-art objects that are reworked into paintings, generally focusing on objects that carry the traces of human use. Small objects become large, large objects become small, and everyday objects that would not make it into canon of high art are included; for example, toe separators (Figure 4.4.1) or a torn handle from a paper cup found on an airport floor (Thomas 2003).

The initial thought was to collect field recordings for this work and use them as a basis, although this was considered a little too close to Atkins' approach, too obvious, and ran the risk of creating a 'spoof' rather than a tribute. A more abstract approach was needed. Picking up on the themes of human intervention apparent in Atkins' work, in approaching *Surroundings*, I began to think about some of the other applications of the IPD that relate to the modelling and interpretation of the social dynamics that constantly take place around us, shaping our perceptions and experience.

Figure 4.4.1 Toe Separator (2005) by Peter Atkins (Reproduced by Permission).

The other aspect of the project that had a heavy influence on the work was the performance space used for the premiere. The Greenaway Gallery was formerly a factory and as such is very resonant. The third movement of the work takes advantage of this resonance, another found object, and pays homage to Alvin Lucier's 1969 work 'I am sitting in a room' (see Lucier and Simon 1980: 30). The generated musical material is at first reinforced, and subsequently destroyed by the resonant frequencies of the performance space through a process of constant recording and playback. The tape recorders from Lucier's work were reproduced in Max/MSP for live performance. The layering effects of the tape loops and subsequent decay of the composed material closely mirrors Atkin's painting techniques where printed motifs are layered until each individual motif is obscured; Figure 4.4.2.

Several combinations of strategies were tried in 'finding' *Surroundings*. The implications for form through implementing different strategy types will be discussed later in the chapter. The sound palette used was quite open, with three octaves of the full chromatic scale and a full palette of durations (including triplets that were omitted from the later 'lite' version of the software) used throughout the parts. The ensemble of agents was split up through the trio, with four agents' material being mapped to the Piano part, while the Violin and Cello parts were each generated by two agents. The final movement is the only exception to this, where all eight agents were mapped to the piano part and the violin and cello parts were added to reinforce the material used in the piano. The generated materials were used in the work with little revision, the only intervention was the occasional octave transposition to avoid instrumental impossibilities.

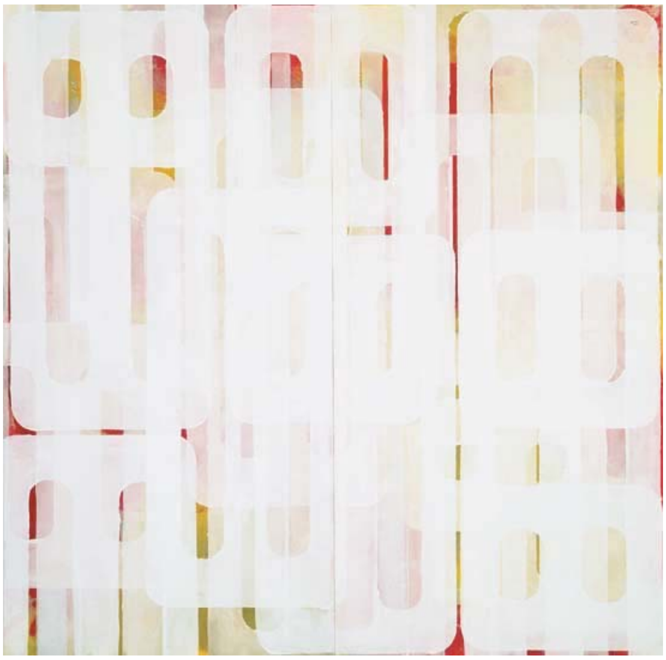


Figure 4.4.2 Buckle (2002) by Peter Atkins (Reproduced by Permission)

In performance, this work was well received, with the final movement being described as “the highlight of the concert series” at the 2005 Australasian Computer Music Conference in a RealTime magazine review, (Hooper 2005). Not surprisingly, this is the movement that also ties in most closely with Atkin’s work.

4.5

Irene's Myth

Inspired by the work of Annette Bezor

for narrator and cello

by

Luke Harrald

2005

Irene's Myth 3

* Please note that the alignment of the narration and the cello part is approximate. There is no need for strict synchronisation between the parts.

Luke Harrald


22
Narr.
blondes on the covers of magazines be your entertainment
Thousands of fans found
Vc.
mp
25
themselves redirected to the site of a D-sized American porn star
Thousands of fans found themselves redirected to the site of a D-Sized American
p
28
porn star
I don't know what I am yet, or what I'll be in the future
Was it marketing genius, experimental art or a
mp
31
desperate ploy for attention
Let all the other over exposed blondes on the covers of magazines be your entertainment
mf
34
Thousands of fans found themselves redirected to the site of a D-sized American porn star
Thousands of fans found themselves
sim.
f
37
redirected to the site of a D-sized American porn star
Let all the other over exposed blondes on the covers of magazines be your
rall.
p
40
entertainment
A tasteful sex symbol giving you middle of the road pop hits
I don't know what I am yet or what I'll be in the future
Thousands of fans
a tempo
mf


43
Narr.
themselves redirected to the site of a D-sized American porn star
Thousands of fans found themselves redirected to the site of a D-sized American porn star
Vc.
46
Thousands of fans found themselves redirected to the site of a D-sized American porn star
A tasteful sex symbol giving you middle
49
of the road pop hits
He started swearing at her, she asked him why he always had to be so horrible
I don't know what I am
sim.
52
yet, or what I'll be in the future
Thousands of fans found themselves redirected to the site of a D-sized American porn star
Thousands of fans found
55
themselves redirected to the site of a D-sized American porn star
Despite dumping her, he still believed he could pester her for sex
58
He started swearing at her, she asked him why he always had to be so horrible
I don't know what I am yet, or what I'll be in the
rall.
61
future A tasteful sex symbol giving you middle of the road pop hits A tasteful sex symbol giving you middle of the road pop hits I don't always feel sexy

Irene's Myth 3 (2005) for solo cello and narrator

Irene's Myth was also commissioned through the Sight Specific Music project, and was written in response to the work of Annette Bezor. The complete commission was 17 minutes long, and scored for hand bells (6 octaves), cello, percussion, choir and narrator. The complete work has four sections, although only part three has been included in the portfolio. This is mainly due to the fact that only part three has been adequately documented, and unfortunately, the South Australia Handbell Society used in the premiere performance has since disbanded. Through this work, *IPD Score Generator* very much took on the role of 'algorithmic composer's assistant' and various IPD materials were manipulated into different hierarchical forms through the four sections of the work. Part three represents the least manipulated example and demonstrates several key aspects of materials generated through the IPD.

Bezor is primarily a painter, whose work draws together many themes, especially the iconisation of image and the depiction and objectification of women in the popular media and in art. Bezor's images "idealise female beauty, filling the canvas with women's faces, stylising their features, hair and colouring, without setting" (Reid 2001).

Influenced by contemporary media forms and values, Bezor uses the computer to take images and alter them before rendering them in paint. She will often paint multiple versions of the same image, mirroring the endless replication and manipulation of images proliferated through digital media and raising questions about authenticity, and commodification of both the image, and the art object itself. While the mass media uses similar manipulation techniques to pull the female image towards a perceived ideal, Bezor's work pulls in the opposite direction, asking how far you can take something outside the norm, while retaining an image of beauty.

Several of Bezor's techniques and ideals were drawn on in the creation of *Irene's Myth*, although as one would expect, the work puts quite a musical slant on these ideas. *Irene's Myth* was particularly influenced by the Bezor work 'Ego Moon 2' (Figure 4.5.1) which is one of a series of portraits of pop star Sophie Monk that were influenced by the sexploitation of her image following her success in the reality TV series 'Pop Stars' (Adamson 2000). Interestingly, Pop Stars was an Australian concept, which predated the current worldwide 'Idol' phenomena, spawning spin offs in New Zealand, the UK and the USA, and setting the template for the Idol series that followed.

Figure 4.5.1 'Ego Moon 2' (2005) by Annette Bezor (Reproduced by Permission)

The text for the work was created through chopping up a number of 'celebrity gossip' magazines, and feeding randomly selected sentences through a randomising patch in Max/MSP. This was done several times to remove any reference to the original material, creating a nameless, faceless, stylised 'pop-diva' scenario that upon reading, could be generically applied to many of the current crop of divas as they are portrayed through the media, and was perhaps more successful at highlighting the commodification and exploitation of their images than I had imagined. In addition to the gossip magazines, several dictionary definitions were used in the text including definitions for advertising, commodificaiton, copy, high art and original.

Throughout the text and the musical structure of *Irene's Myth*, there is a heavy use of repetition, drawing on ideas of commodification in art and drawing fairly obvious 'Pop' music connections. Indeed, through composing this work, and exploring the underlying concepts in that of Bezor, I once again began to reshape my approach to algorithmic composition, considering concepts such as 'junk music' and 'muzak' and how algorithmic composition may apply to these areas. Simply using the computer to generate materials for the work also raises questions about authenticity and authorship, which may be addressed differently depending on whether the composer is using software of their own creation, or software by others.

In composing this work, a number of constraints were placed on the musical materials that were manipulated by the agents of the IPD, and these, revolved around giving the work Pop overtones, simplifying the kinds of musical material produced. Pitch wise, modal materials were used, while the durations were restricted to only multiples of quaver values and the dynamic and tessitura ranges were similarly restricted. All the musical material for the work was generated in a single run of *IPD Score Generator*, although throughout its four sections, the material is treated a number of ways.

The Cello part featured in part 3 combined the output of all eight agents, and is presented with little editing, although impossibilities were once again removed; for example there were several impossible quadruple stops that were reduced down to double stops. Large sections of the generated material have also been cut up, and placed into a simple binary form, with repetitions, creating an A A B B form. The repeat of A, and the first appearance of B are essentially the single run of material generated for the movement, with the repeats added in to fill out the form. The iterative nature of the IPD allows melodic motifs to emerge and dissolve as materials are reinforced and abandoned, lending the generated material to this kind of treatment. The most interesting aspect of the material generated for this movement is the sense of phrase that is immediately apparent, and also the contour and movement of the material leading to prominent highpoints and troughs.

Sitting low in the Cello's register, with only subtle variation in dynamic range, the work sits squarely within the restricted tessitura and dynamic ranges of popular music. Two versions of this work appear in Volume 2. A video of the premiere performance at the Greenaway Art Gallery appears on the DVD, while a generated MIDI mock-up of the work appears as track 5 on the CD.

4.6

Give in to Light

for orchestra

by

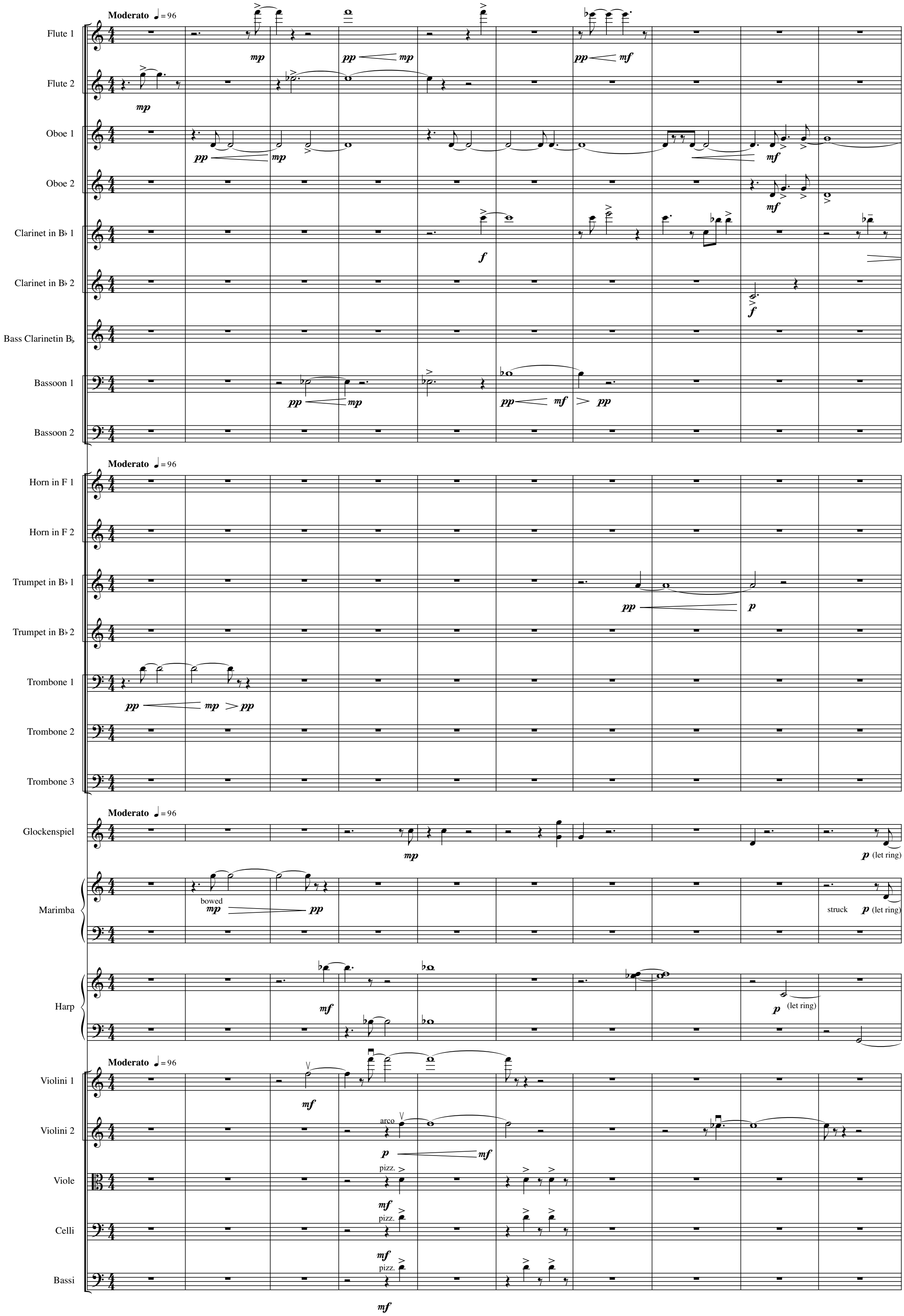
Luke Harrald

2006 - 2008

Score

Give in to Light

Luke Harrald




Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
arco
pizz.


23
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
struck
Mrb.
Hp.
Vln. 1
Vln. 2
pizz.
arco
Vla.
Vc.
D.B.


35
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.


47
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.


59
A
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
bowed
Mrb.
Hp.
Vln. 1
pizz.
U.H
arco
Vln. 2
Vla.
pizz.
arco
Vc.
D.B.
(let ring)
pizz.


71
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
struck
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
arco
D.B.


83
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
pizz.
(let ring)
arco


95
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
mp
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
ppp
pp
ppp
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
bowed
p
struck
Mrb.
bowed
p
Hp.
mp
Vln. 1
pp
ppp
Vln. 2
pp
div.
non div
Vla.
pp
Vc.
pp
pizz.
D.B.
pp


107
B
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
struck
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
arco
pizz.
arco
pizz.
arco
pp
p
mp
f
fp
ppp
mf
pp
mp
pp
ppp
pp
ppp
pp
mf
p
ppp


119
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
bowed
Mrb.
bowed
Hp.
Vln. 1
Vln. 2
Vla.
pizz.
Vc.
D.B.


131
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
(bowed)
struck
Mrb.
(bowed)
struck
Hp.
Vln. 1
Vln. 2
pizz.
arco
Vla.
arco
Vc.
D.B.


143
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
pizz.


155
C
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
bowed
Hp.
Vln. 1
arco
U.H.
pizz.
Vln. 2
pizz.
Vla.
arco
Vc.
D.B.


167
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
struck
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
arco
pizz.


179
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
bowed
pizz.
arco
div


191
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
struck
Mrb.
Hp.
Vln. 1
Vln. 2
non div
sul D
sul A
normale
Vla.
arco
Vc.
arco
D.B.
arco


203
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
bowed
Mrb.
bowed
Hp.
Vln. 1
pizz.
Vln. 2
pizz.
Vla.
Vc.
pizz.
D.B.


215
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
(bowed)
struck
bowed
struck
Mrb.
struck
Hp.
Vln. 1
arco
Vln. 2
arco
pizz.
Vla.
pizz.
arco
Vc.
arco
D.B.


D
227
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
arco
pizz.
mp
f
p
pp
mf


239
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
struck
Mrb.
bowed
Hp.
Vln. 1
pizz.
Vln. 2
Vla.
Vc.
D.B.


251
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
struck
Hp.
Vln. 1
arco
Vln. 2
Vla.
pizz.
arco
Vc.
pizz.
arco
D.B.
pizz.


263
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
U.H
pizz.
arco
Vln. 1
Vln. 2
Vla.
Vc.
D.B.


275
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
E
bowed
struck
arco
f
mf
mp
p
pp
ppp


287
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
struck
Hp.
Vln. 1
Vln. 2
arco
Vla.
pizz.
U.H
arco
Vc.
D.B.


299
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
arco
pizz.


311
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
pizz.
arco


323
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
bowed
Mrb.
bowed
Hp.
sul A
Vln. 1
Vln. 2
Vla.
Vc.
D.B.


335
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
struck
bowed
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
pizz.
normale
arco
div


347
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
con sordino
Glk.
(bowed)
struck
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
pizz.
arco
non div

359
F
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
senza sordino
pizz.
arco
U.H


371
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
senza sordino
pizz.
arco


383
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
bowed
Mrb.
bowed
struck
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
pizz.
arco


395
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
senza sordino
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
struck
bowed
Mrb.
bowed
Hp.
Vln. 1
arco
Vln. 2
arco
div
Vla.
arco
pizz
Vc.
arco
D.B.


407
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
non div
Vln. 2
Vla.
Vc.
D.B.


419
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
pizz.
arco


431
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
bowed
Hp.
Vln. 1
U.H
pizz.
arco
Vln. 2
Vla.
Vc.
D.B.


443
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
Mrb.
Hp.
Vln. 1
Vln. 2
Vla.
Vc.
D.B.
sul A
normale
arco


455
G
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
bowed
Mrb.
bowed
Hp.
Vln. 1
pizz.
arco
div
Vln. 2
arco
Vla.
pizz.
Vc.
pizz.
arco
D.B.
pizz.


467
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
struck
(bowed) Mrb.
struck
Hp.
Vln. 1
non div
Vln. 2
arco
Vla.
arco
Vc.
pizz.
D.B.
arco
pizz.


479
Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
bowed
Mrb.
bowed
Hp.
Vln. 1
pizz.
Vln. 2
pizz.
arco
Vla.
pizz.
arco
Vc.
arco
D.B.


Fl. 1
Fl. 2
Ob. 1
Ob. 2
B♭ Cl. 1
B♭ Cl. 2
B. Cl.
Bsn. 1
Bsn. 2
Hn. 1
Hn. 2
B♭ Tpt. 1
B♭ Tpt. 2
Tbn. 1
Tbn. 2
Tbn. 3
Glk.
BULLROARER
Mrb.
struck
Hp.
Vln. 1
arco
Vln. 2
pizz.
Vla.
Vc.
D.B.
arco

Five bullroarers are heard alone for 90 seconds at the conclusion of this work. A player from the back of the first violins and basses should be selected to play the bullroarers, along with the harpist and the two percussionists. Starting at the points indicated, the players should stand - clear of the other orchestra members - and swing the bullroarers loudly. Due to their positions while performing their instruments, the players should be well spread around the outside of the orchestra. While performing, the players should aim to avoid falling into synchronisation with one another as much as possible. Alternatively, 5 bullroarer players could be used specifically for this part of the work. In this instance, the performers should be spread out around the outside of the orchestra.

Give in to Light (2006 - 2008) for orchestra

Give in to Light expanded on the ideas of *Irene's Myth* as it incorporated similarly restricted musical materials, but focused more specifically on the IPD and the generation of bottom-up musical forms, exploring much larger musical forces and time scales. The main concept that formed the basis for the work and its aesthetic was a vision of the entire orchestra placing down their instruments, and swinging 'Bullroarers' around their heads. While this was impractical in execution, with the Bullroarers being eventually restricted down to five players, it was a lasting vision throughout the creation of the work. One of the interesting aspects of the Bullroarer is that it has arisen independently in many cultures around the world as an instrument of ritual (Dundes 1976: 220-222), with the voice of god, or the summonsing of spirits being a common theme, as well as being linked with wind and thunder. The use of the Bullroarer in *Give in to Light* aims to pick up on this cultural commonality, and certainly falls outside any specific cultural reference.

It has been suggested that our fascination with Bullroarers can be put down to the spectra they produce, which are rich in infrasonics (Turzin 1984). Most people are familiar with the uneasy 'calm-before-the-storm' feeling we get as a distant storm approaches. Although the thunder cannot be heard, we can still perceive the infrasonic components of the sound, which through their long wavelength can travel much further than the audible components. Turzin suggests that this experience arises through "the fact that its source lies just beyond the workings of our psychosensory apparatus", (ibid: 586) and that through the same physiological mechanisms, the Bullroarer creates a similar anxious response in listeners.

While this may offer some kind of physical explanation of their mystique and universality, certainly, the power of human experience through the rituals in which the instruments are used cannot be ignored. Through its reflective, contemplative aesthetic, *Give in to Light* aims to pick up on some of the universal themes of the Bullroarer, including death and ancestry, aiming for a sense of reverie. This state is heightened by the musical material dissolving down into the whir of the Bullroarers at the conclusion of the work. Unfortunately at this point in time, there has been no performance of this work and it is hoped that it will be performed in the future. A generated MIDI mock-up appears on track 6 of the CD in Volume 2.

The musical materials for *Give in to Light* were once again generated in a single run, using a variation of *IPD Score Generator.* Throughout the previous works, each agent's output was mapped to a specific part, effectively allowing the agents to 'play' an instrument. Through this work, agents were also given control of timbre, allowing their output to be spread across the orchestra. This allowed generated motifs and melodic fragments to float across different instrumental timbres, leading to an interesting 'Klangfabenmelodie' (Shoenberg 1975: 485) effect. The editing process that lead to the final work aimed to heighten this sense of a 'melody of timbres', with dynamics and articulations added to the parts to accentuate both horizontal melodic lines that emerged within individual parts, and more importantly, lines that spread across parts. The approach to dynamics and phrasing throughout the work also drew inspiration from electronic music editing techniques such as cross fades, and timbral modulation. A simple example of this can be seen in Figure 4.6.1.

Utilising a modal palette, the agent's pitch selections were treated as pitch classes rather than being absolute throughout editing. Much like the previous works, this generally lead to octave transpositions to avoid impossibilities and to aid playability, although in this instance special consideration was given to the generated phrase shapes, and melodic contours as one of the key aims of the work was to demonstrate the structuring properties of the IPD model. A particular focus was on highlighting the way in which the agents could generate materials that transcended different musical time scales, creating motifs, phrases and an overall sense of form simply through local interactions. This resulted in some manipulation of the agent's original orchestration selections, for example, if multiple voices appeared in a monophonic instrument, then these would be split between two parts (for example, Flutes 1 & 2) or played by another instrument in the same instrument group (for example, Winds, Brass or Strings) to avoid omitting the material. These adjustments were used as sparingly as possible, and through this approach, little of the generated material was omitted from the final score.

Rhythmically, the work makes use of a simple palette, incorporating a base rhythmic unit of a quaver, with all multiples out to a breve being put into use. This choice of palette was found through experimentation with the software over several runs, giving the generated materials the sense of space needed for the work's contemplative aesthetic. Through the work's pointillistic overtones, a sense of rhythmic pulse is generally avoided, although a pulse occasionally emerges.

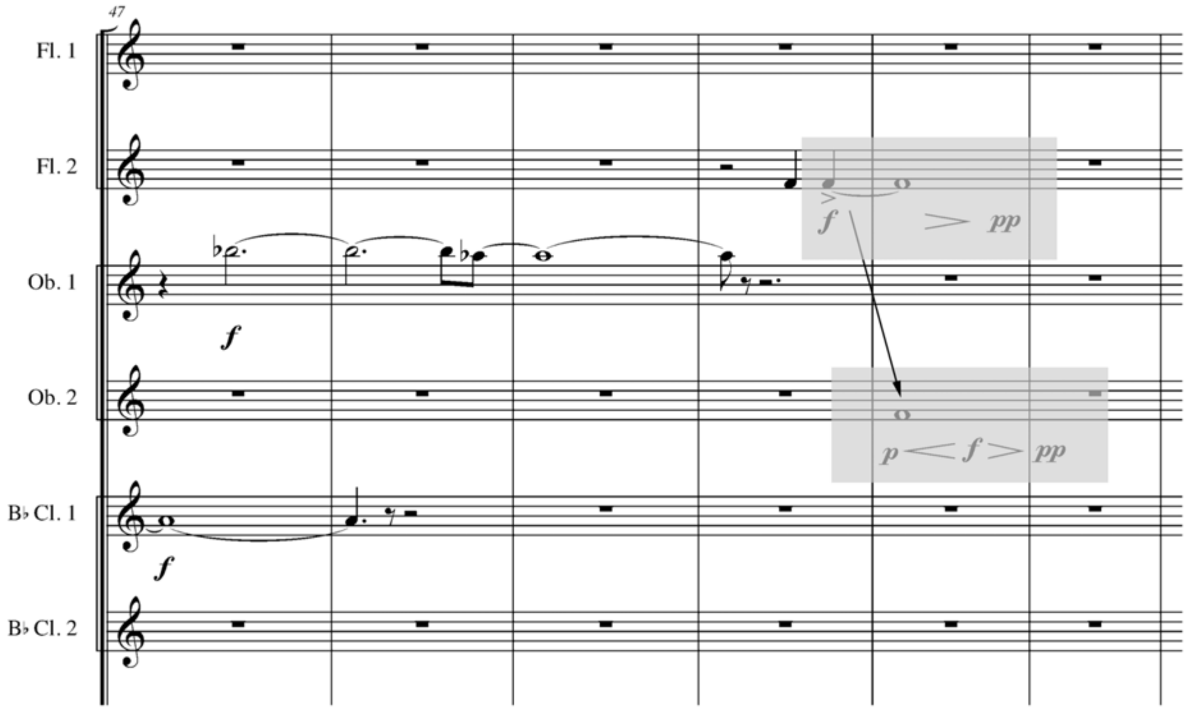


Figure 4.6.1 Extract from bars 47 - 52 *of Give in to Light*, highlighting a timbral transition between the Flute 2 and Oboe 2 parts. The aim here is that once the F pitch is established in the Flute it should cross-fade as seamlessly as possible into an Oboe sonority.

4.7 Discussion: the implications of strategy

The most striking aspect of the works presented through this chapter is their immediate sense of phrase and directed motion, without any reference to traditional composition methods such as thematic development or functional harmony. This sense of phrase occurs solely through the agent's interactions as they reinforce and abandon different musical materials. As these interactions occur at the meso (or note) level in these works, without hierarchical operators to control other aspects of the form, the key research question raised here is: what combinations of strategies for interaction between agents can lead to the emergence of interesting musical structures? This is different in many ways to typical IPD research in that the main emphasis here is not on finding a 'best' strategy, but rather looking at the roles that different strategies can play in changing the dynamic musical state of the system. With this in mind, the seven rule sets implemented in the IPD engine (page 45) can be classified according to both their descriptors typically used in game theory and their musical role. This is both helpful in predicting the kinds of music that a particular combination of rules might produce, and in ascertaining what other IPD rules might prove musically useful in the future (Figure 4.7.1).

Following his first IPD tournament, Axelrod broadly described the submitted strategies as 'nice', or 'not nice' (nasty), 'responsive' or 'unresponsive'. Nice strategies will never be the first to defect, while nasty strategies see cooperation as an opportunity to exploit their opponent in the next round; or assume their opponent is hostile and defect from the first round. Similarly, responsive strategies will react to the actions of their opponent, while unresponsive strategies ignore their opponent's responses. A strategy's level of forgiveness refers to how quickly it will return to cooperation once its opponent has resumed cooperating (Axelrod 1984: 33-36).

In a musical context, bearing in mind that through *IPD Score Generator*, cooperation reinforces existing musical materials, while defection results in a random selection of new materials, the rule sets can also be defined according to the roles they tend to play within the virtual ensemble. For example, nice rules can be thought of as 'passive', maintaining a state of equilibrium within the initial musical state, while nasty rules can be thought of as 'agitators' which push the musical state forward by introducing new materials. 'Responsive' rules tend to reinforce this push towards new states instigated by the agitators, while 'forgiving' rules can be considered 'dampeners', coaxing the responsive rules back towards cooperation and the reinforcement of the newly introduced musical materials. Combinations of these musical behaviours are what give the music produced by *IPD Score Generator* its sense of phrase, and musical flow.

Name	Strategy	Attributes	Musical Role in the ensemble
TIT FOR TAT	Cooperate in the first round, mimic the opponent's response from the previous round in all subsequent rounds.	Nice Responsive Forgiving- once others cooperate	**Passive**- will maintain a stable cooperative musical surface. Once change begins to occur, it's responsiveness helps introduce new musical materials and consolidate these through cooperating with opponents once others begin to cooperate.
RANDOM	a random or irrational selection.	Unresponsive	Can play an important role as either an **Agitator** for the musical surface (in concert with nice, responsive rules) or a **Dampener** to pull the ensemble back towards more cooperative situations if there is a high level of defection.
VENGEFUL	co-operate until defected against , then defect for the next 5 rounds regardless of opponent's response.	Responsive Nice relatively Unforgiving	**Passive** until defected against, then major **Agitator**- spreads defection quickly through the ensemble, as the 5 rounds of retaliation effect multiple opponents. Can create a very chaotic musical surface punctuated by short cooperative periods.
COPYCAT	do whatever the player with the highest score did in the previous round.	Unresponsive tends to follow 1 round behind others	**Stabiliser**- tends to lag a round behind the other players. As such will allow sounds periods of mass cooperation and defection to linger a little longer than they otherwise would have.
PAVLOV	(traditional) win stay the same, lose change. counts a cooperate/ cooperate response as a loss (ie. opportunity to exploit, so will defect in the next round).	Responsive Nasty Forgiveness in order to exploit	Works well as an **Agitator**, cooperation is an opportunity to exploit! Also takes on the **Dampening** role will pull the musical surface back towards more cooperative states (before exploiting again).
PAVLOV	(passive) as above, but counts the cooperate cooperate result as a win and will not defect until defected against. Unlike TIT FOR TAT, a defect/ defect result will cause cooperation.	Responsive Nice, Forgiving- will hold out the olive branch	**Passive + Dampening-** tends towards cooperative states, and promotes them through holding out the olive branch in periods of high defection. Will retaliate on the first defection though, and continue to do so until it gets a defect/ defect result.
DOWNING	do what the most players in the previous round did.	Unresponsive to specific players, but responds to the overall state	**Stabiliser**- holds the musical state towards either mass cooperation or defection depending on the majority. The downing strategy can play an important role in pushing players towards one state or the other. Use with care- too many Downing's cause the system to get stuck!

Figure 4.7.1 Table of currently implemented rule sets and their roles as musical agitators, pushing the musical surface towards new states, consolidators, pulling the musical surface towards previous states and stabilisers, holding the ensemble's behaviour towards either cooperation or defection en masse.

The sense of form evident in the generated works emerges through using combinations of strategies that promote global behaviours that oscillate between high levels of cooperation and high levels of defection. During periods featuring high levels of cooperation, the agent's musical choices converge towards a single sonic event, (or pull towards equilibrium) while high levels of defection lead to randomness and a rapid introduction of new musical materials (or push towards entropy). The speed that the system oscillates between these two states affects the volatility of the music produced. The key to producing a fluid sense of form would appear to lie in maintaining the global dynamics of the ensemble between ordered and random states, suggesting behaviours that conceptually tie in with Wolfram's 'Type 4' Cellular Automata. These Automata exhibit complex behaviour that hovers on the border between order and chaos. Interestingly, in the field of Artificial Life, founder Christopher Langton suggests that life itself exists in this state, on the 'Edge of Chaos' (see Coveney and Highfield 1995: 271- 278). After studying a wide range of Cellular Automata, he concluded that:

> 'interesting' complexity arises only within a very narrow range. Only then is life possible. Outside those values, the system's behaviour is boringly homogenous, rigidly periodic, or uselessly chaotic.
>
> (Langton, in Bowden 1996: 10)

5. Real-Time Applications (installations and film work)

The real-time applications based on the IPD engine are in many ways more simplistic than *IPD Score Generator*, and the applications themselves were built to meet the requirements for specific installations. Part of this simplicity stems from computational limitations, although in most instances, ultimately came down to aesthetic choice as the installations tend to conform to a more minimalist aesthetic than the scored works. This section also includes film work that does not use real-time computation, but utilises the same applications as the installations to generate musical materials that were subsequently recorded and transformed into completed works.

Four works are discussed through this section; *CONflict* (2004), *Drowning* (2006) and *Monuments* (2006) are installations, while *The 9:13* (2005) is a film. Real-time process is of vital importance to the installations presented, and underpins my entire outlook on installation art in general. In much the same way that Alexander Calder's mobiles revolutionised sculpture through being able to subtly change configuration, inviting the viewer to visit the work anew with each encounter, the live processes used here allow the works to undergo a constant process of transformation, evolution and renewal. While this concept was challenged through a review of the work *CONflict* (Mitchell 2006) as to whether this process was obvious or even noticeable to the casual observer, the point here is a conceptual one in that the work *CAN* change whether it does so in the particular timeframe an individual encounters the work or not.

The commercial release of *The 9:13* has been included in Volume 2, while the other works in this section appear on the Video DVD.

5.1 CONflict (2004) installation for projection and speakers

CONflict was the result of collaboration with filmmaker Hugh McLean. Inspired by the McLean short film 'World without End' (2003), in creating *CONflict*, fourteen still images were extracted (Figure 5.1.1) from the film, and used these as a palette of material to be manipulated by the IPD engine. From the outset, the impetus for this installation was visual, and drew heavily on the aesthetics of late abstract expressionism.

The original film was quite painterly in appearance, an effect created through first shooting the film on 'Super 8' and then digitising the footage at very low resolution (at times as low as 8 pixels by 6 pixels). McLean found that when digitising the Super 8 footage, once the resolution fell below a certain threshold, the pixelation of the image actually disappeared, creating a highly stylised, lo-fi effect. The main visual idea for the installation was to draw on this effect and create a projected 'painting' that could evolve and change appearance over time. Combined with sound, the installation aimed to create a reflective, meditative space.

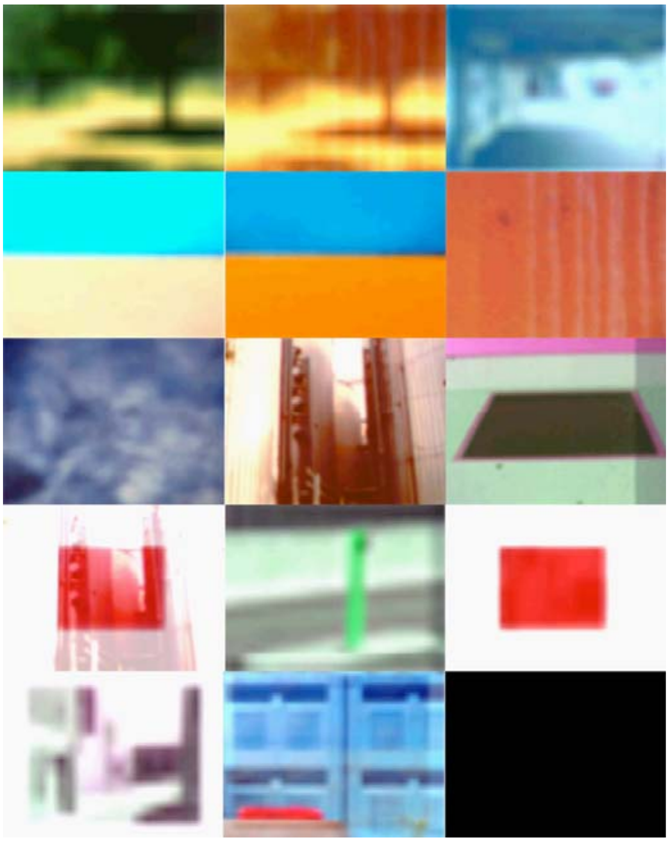


Figure 5.1.1 The 14 images taken from the McLean short film “World without End”. These images were used as a visual palette to be manipulated by the IPD engine. The 15th black image was used to fade out the end of the installation if used as a ‘performance’.

Sonically, the work adopts a minimalist aesthetic, with the agents manipulating a palette of justly tuned sine tones, splitting the octave into 18. Based around a scale used by 17th Century composer and harpsichord maker, Joan Albert Ban (1597/8 - 1644), the scale is constructed through creating a Pythagorean chromatic scale and adding 6 extra tones a syntonic comma higher than the 12 initial tones (see Rasch 1983: 78). This tuning allows for three perfectly tuned tetrachords, and offers a much higher level of consonance than equal temperament, as well as an interesting variety of dissonances when not used as Ban intended. As the agents in the IPD engine have no understanding of harmony, the work moves through various unpredictable harmonic states. An approximation of the scale can be seen in Figure 5.1.2.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18

C [C# Db] [D D*] [D# Eb] E F [F# F#*] G [G# Ab] A [Bb Bb*] B (C)

Figure 5.1.2: Approximation of the 18-tone scale used in *CONflict*. Scale degrees 1, 2, 4, 6, 8, 9, 10, 12, 13, 15, 16, and18 are the initial Pythagorean scale, with degrees 3, 5, 7, 11, 14 and 17 added a syntonic comma (approximately 22 cents) higher. Note, an asterisk indicates the pitch is a comma higher than the previous pitch. Intervallic relationships of a comma are indicated in square brackets.

From a programming perspective, the main element added to the IPD engine for *CONflict* was an output module that allowed for the handling of both visual and sonic output. The agents have less control over their material than in *IPD Score Generator*. This is partly due to the fact that this work actually represents the first serious attempt at sonifying the IPD engine's output and predates it, although *CONflict* pushes the G4 CPU to 100% at the start of each round of interactions during cross-fades from one round to the next so there was little headroom for added complexity in any case. In each round of interactions, the agents select a pitch and an image to be output for the entire length of the round, and the only parameter they can manipulate outside of this is the cross-fade time from one event to the next. The pitches in this instance are generated through a bank of sine wave oscillators.

The final output experienced by the audience is the global result of the agent's interactions. As such, the choices of the agents are combined, with the eight images overlayed (Figure 5.1.3) and the sine waves spatialised through stereo, quad, or a cube of eight speakers. Like *IPD Score Generator*, agent's cooperation leads to the reinforcement of material and defection leads to a new random selection. In the visual domain, this simply implies that cooperating agents will display the same image, while defecting agents will randomly select a new one. As higher levels of cooperation emerge, one particular image will become dominant in the combined image.

This installation has been re-worked for a number of settings (Figure 5.1.4), and has been presented both as an installation and as a performance; in a performance, the agents are the performers. One of the most interesting aspects of work is that while the same process manipulates both the visuals and audio, there is no obvious direct causal relationship between the image and sound. This aspect of the work was reinforced through a review of the work for RealTime magagazine:

> "The slowly evolving, richly coloured, abstract visuals were accompanied by monochrome sound developing through unpredictable harmonic fields. Although both were controlled by the same process there was no mickey-mousing of sound and image."
>
> (Whittington, 2005).

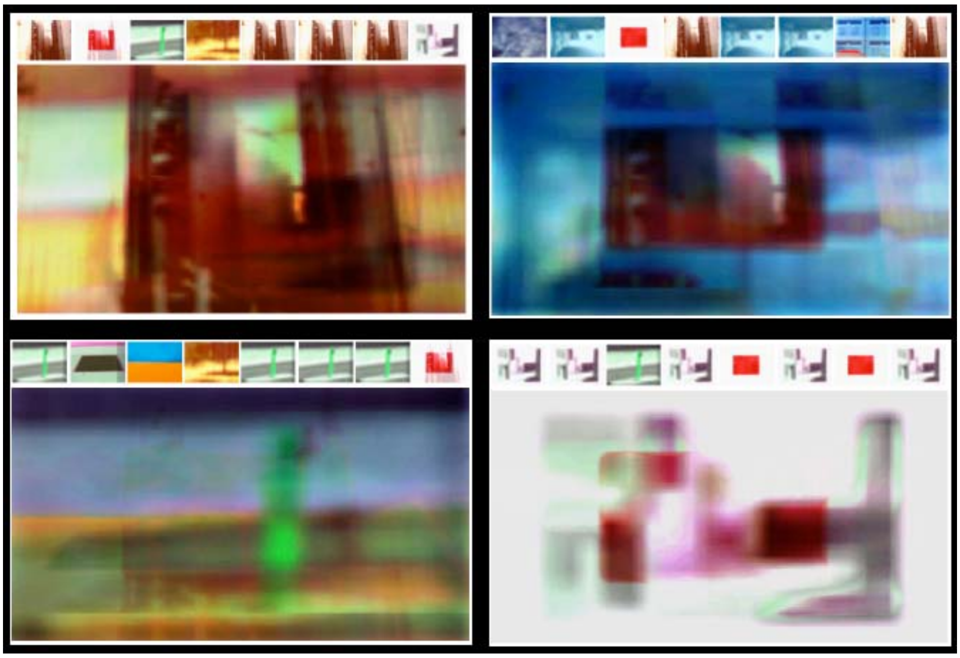


Figure 5.1.3: Four rounds of *CONflict*, showing the combined image seen by the audience with the agents individual choices displayed above. In performance, the agent's choices are not displayed.

Figure 5.1.4 Two instances of *CONflict*. Left: as part of Project 2 in 2005; projected onto two ornate mirrors, this version most closely reflects the concept of the 'evolving painting'. Right: as part of the Project 3 Street Cinema in the Adelaide Festival of Arts in 2006. Reproduced by Permission.

5.2 Drowning (2006) installation for submerged piano

Although *Drowning* uses software very similar to *CONflict*, with the bank of sine waves replaced by a palette of samples, the two works are presented very differently with *Drowning* drawing on a far more sculptural approach. Showing the influence of Annea Lockwood's 'Piano Transplants' (1969-2005)[2], Lockwood's work re-contextualises the piano through placing it in various outdoor environments, leading to the instrument's destruction, *Drowning* aims for a similar scenario through stripping the piano to its key elements (soundboard and strings) and presenting it in the gallery, submerged in a clear Perspex tank (Figure 5.2.1).

The work also responded to current events, which revolved around the 2005 destruction of New Orleans. Although many tragic events unfolded through the destruction of the city and subsequent rescue effort that certainly should not be understated, as a composer, one of the compelling aspects of the disaster was the loss of music and particularly, the loss of musical instruments. What did the thousands of instruments submerged beneath the floodwaters sound like? With this in mind, all the sound samples used through the work were created through exciting the submerged piano in various ways, either through jets of water, or through striking it with various objects. These sounds were developed through improvisation, recorded with hydrophones, and subsequently split up into a sound palette to be manipulated by the IPD engine.

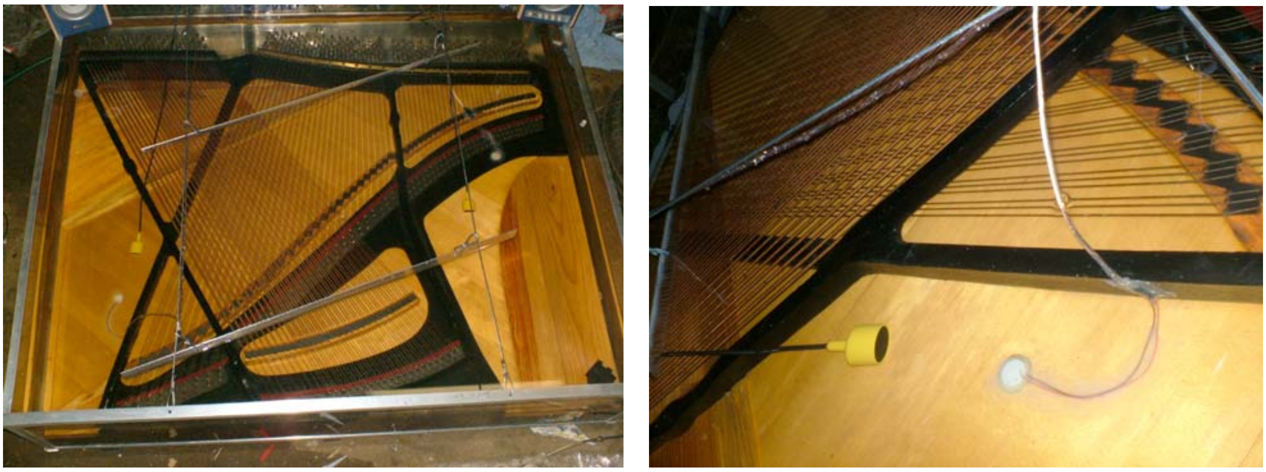


Figure 5.2.1 Left: overhead shot of *Drowning* shortly after completion. Right: close-up of a piezo and a hydrophone.

The set-up for *Drowning* is reasonably complex and there are two alternate set-ups for the work depending on resources available (Figure 5.2.2). The output from the IPD engine is used to resonate both the soundboard of the submerged piano, and two aluminium plates that are suspended in the water. Through the use of hydrophones, the entire work becomes microphonic, picking up the sounds

[2] 'Piano Burning' is probably the most well known work of the series through its infamous inclusion on the cover of Issue 9 of Source Magazine (Lockwood 1971: 48).

of the audience viewing the work (mediated through the water), and the resonance of the soundboard and plates. The sounds from both sources are mixed, and projected through speakers into the audience space. A small amount of the sound from the speakers is also transferred back to the hydrophones, creating a subtle feedback loop somewhat akin to the loops used in *Surroundings*.

Although the placement of the piano in a tank, in a gallery, is somewhat reminiscent of the work of the British artist Damien Hirst, here the placement is more about destruction than preservation[3] , and in contrast to his work, is more about action than the object itself. Conceived as a temporary work from the outset, in the configuration presented here, *Drowning* lasted approximately six days. As the piano resists a process of gradual degradation, the electronics serve to keep the fading musical function of the instrument intact as both a performance medium for the ensemble of agents of the IPD engine and as a device of human interaction through the submerged structure becoming microphonic; the piezo drivers used to drive the soundboard even look somewhat like the sensors placed on cardiac patients (Figure 5.2.1). While the audience's interaction with the work is a shadow of the piano's traditional function, it also further alters the audience experience as their footsteps are amplified giving the impression of walking on the deck of a boat, adding to the illusion and feeling of an expanse of water.

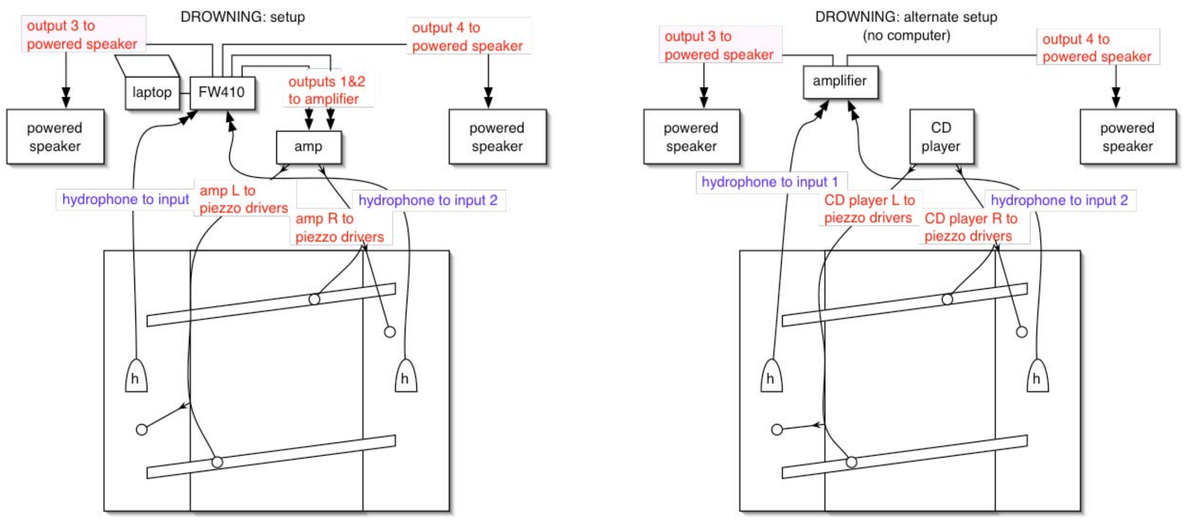


Figure 5.2.2: Alternate set-ups for *Drowning*. The generative version on the left incorporates real-time generation through an application run on the laptop, while the loop-based version on the right drives the soundboard of the piano and aluminium plates with a pre-recorded loop. Conceptually, the generative version is the most authentic realisation of the installation.

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[3] although rather famously the tiger shark in Hirst's 1991 work *The Physical Impossibility of Death in the Mind of Someone Living* indeed decayed from the inside out due to ineffective preservation, prompting him to rebuild the work after it sold to a US collector in 2004 (Vogel 2006).

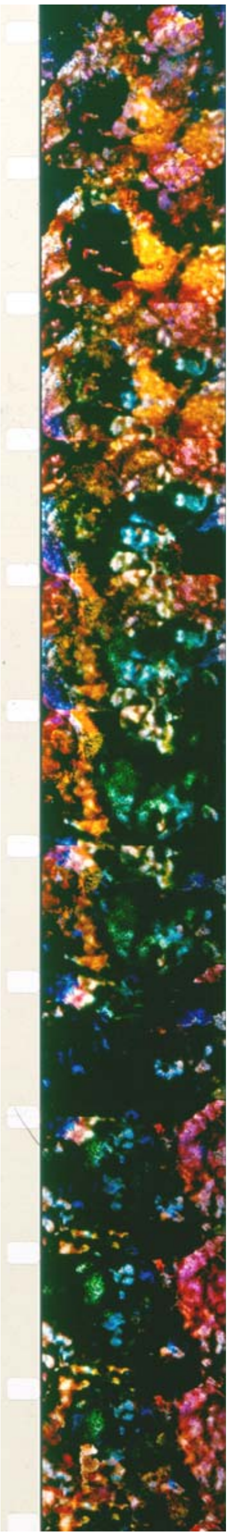
5.3 The 9:13 (2005) film soundtrack

Commissioned through Sacred Cow Films, the soundtrack for the short film *The 9:13* was an interesting experiment using IPD output to assist in the composition of a work very much in a commercial vein. As *The 9:13* is a thriller, director Matthew Phipps was really looking for an edgy, experimental soundtrack for the film in any case, but as a project, it was quite radically different to the other works included in the portfolio. Budget was an important factor, and due to budget constraints, there was no way live performers could be hired to record music for the film. As such, the entire soundtrack used electronics, and was generally sample based. The soundtrack was composed around the final cut of the film using a range of musical materials, in a subtle leitmotif style. The IPD generated materials typically underpin the relationship between the characters 'Thunder' and 'Joe', and the 'black dog', all of whom are interlinked through the plot.

This particular leitmotif was influenced by the way in which 'Thunder' would go into a trance-like state any time he mentioned or thought about the black dog. This state would also accompany his unpredictable acts of violence, which were in some ways out of character with his 'likable-larrikin', working class persona. From a technical viewpoint, to create the leitmotif, output from the *IPD Score Generator* was streamed through Garritan Personal Orchestra (Garritan 2006) into an audio file. This audio file was then re-manipulated by the agents in the audio domain through the use of a bank of delay lines. This was quite simply handled, with the agents controlling delay length; which in turn also allowed the control of octave transpositions through using long delays. This doubling up of the process was an interesting idea, suggesting the possibility of using hierarchically related 'ensembles', where one group of agents produced musical materials that could be dissected and further manipulated at the motif level by a second group of agents. This idea was explored further in the visual domain for the work *Monuments*; although has not been the subject of much experimentation at this point.

Through using the delay lines, the material was far removed from the original source material, and gave it a metallic ambient quality that reinforced the dramatic tension between the characters of the film. It was important to move the generated material as far as possible from sounding MIDI generated, to achieve a blend between the IPD generated materials and the other samples used throughout the film. This was quite successfully achieved, with the overall audio quality of the generated and non-generated samples being very consistent. As an approach to film composing, the iterative nature of the IPD proved useful as the constantly shifting but similar timbral motifs that were generated allowed for variation through different scenes, while still maintaining a connection between events in the narrative without actual repetition of material.

5.4 Monuments (2006) installation for projection and quad surround



Contrary to the opening statement of this chapter about my views of installation as a real-time process, *Monuments* is a loop. The main reason for this revolves around the fact that the premiere was a performance and the original concept for the work was cinematic. The main aim for the work was to offer the audience an experience somewhere between installation and cinema. Many people who have viewed the work have pointed out that it would be a successful installation, so it is listed here as such. *Monuments* was written in the studios at the Centre de Creation Musicale Iannis Xenakis (CCMIX) in Paris. Several aspects of this experience, and composers whom have worked at CCMIX had an influence on this work.

Inspired by the many fantastic cathedrals in Paris, particularly Notre Dame, and Parisian night life, the images used aim to conjure a feeling of darkness being illuminated by various sources, for example stained glass, the bright lights that illuminate the many Parisian monuments at night or dawn through the pyramid at Muse de Louvre (Figure 5.4.2). Certainly the influence of the Stan Brakhage's Chartres Series (1994), which was inspired by a trip to Chartres Cathedral, cannot be denied and the concept for the work emerged after attending a screening of the Chartres Series accompanied by a lecture given by the late filmmaker's wife, Marilyn Brakhage (Figure 5.4.1)

From a process perspective, *Monuments* incorporated techniques that draw on many of the previous works, and in some ways, represents the culmination of these ideas prior to the implementation of interactive work. The film was generated through using the software from *CONflict.* A palette of photographs taken around Paris during July 2006 was run through the system, and from the output of this first run, a second set of images was extracted. These composite images were run through the system again, further exploring the 'doubling-up' process used in *the 9:13* soundtrack. Through this process, a low-fi stylised effect is created, drawing on a similar visual aesthetic to *CONflict*, although in this instance the effect is achieved through image overlay, with up to 64 images being overlayed at any one time.

Figure 5.4.1: A hand painted film strip from Stan Brakhage's Chartres Series (1994). Reproduced courtesy of the Estate of Stan Brakhage and www.fredcamper.com

Figure 5.4.2 A screenshot from *Monuments*. This is one of the moments of illumination that occur throughout the work, in this case marking the end of section one.

The sonic material was also generated through the *CONflict* software, although granular synthesis was used for the generation of tones, rather than sine waves. ‘Cloud Generator’ by Curtis Roads[4] and John Alexander (Roads 1996) was used for tone generation, with a grain size of 5 to 50 milliseconds and a density of 500 to 5000 grains per second. The tones were implemented as a palette of samples in the *CONflict* software, and a single run of the system was recorded with the agents’ output split between four tracks. These raw materials were further manipulated intuitively to create the final work. Much like the processes used in *Irene’s Myth*, the IPD materials were quite heavily manipulated, with the editing at times aiming for a tight sense of synchronisation with the visuals, while at other times, a looser association was aimed for, in keeping with the cinematic aims of the work.

5.5 Installations and Screenings

When presented publicly, the works through this chapter were in some cases, very successful, and in others disastrous. *CONflict* represented one of the successes with repeat showings in the Electrofringe (Newcastle, NSW, 2004), Project 2 (Adelaide, 2005), and the Project 3 Street Cinema as part of the Adelaide Festival of Arts in 2006. Receiving critical acclaim as part of the Project 3 Street Cinema, described as a “stunning synthesis of abstract sound and vision” (Mitchell 2006), *CONflict* has been very well received each time it has been shown. Similarly, *The 9:13* was nominated for Best Short Fiction Film in the Australian Film Institute Awards, and has subsequently toured Australia several times since its release in 2006, as well as screening in Los Angeles, Toyko, Venice and many other international short film festivals. *Monuments* was also enthusiastically received at its premiere at the CCMIX studios in Paris.

4 Roads has had a close association with the studios at CCMIX since 1994.

By contrast, *Drowning* did not even make it to its premiere. From the outset the curators of the event knew it was a temporary work, and the original brief was for it to last for three days. The work actually achieved this mark reasonably comfortably, but unfortunately as I was in the United Kingdom for the installation, the work was installed four days prior to the opening of the gallery. Through the extended time period, the tank actually cracked from the soundboard of the piano warping and placing pressure on the Perspex, meaning that the installation had to be hastily removed on the day of the opening. This was quite a disaster, although on the upside, the few people who saw the work installed in the gallery prior to its demise were positive about it, and this will likely lead to a new 'structurally sound' version of *Drowning* being shown sometime in the future.

5.6 Discussion: research outcomes

The main research objectives explored through the four works featured in this chapter revolved around the development of real-time sonification and visualisation strategies for the IPD engine leading to output modules that could be incorporated into the interactive system introduced in Chapter 7. Although all the works presented are based around variations on the software developed for *CONflict*, much like the *IPD Score Generator* application there were several earlier versions of the software developed leading up to *CONflict*. These early versions were far from optimised, and pushed the CPU of the laptop to a constant 100% leading to the expected glitches and application crashes. The main optimisation techniques developed to reduce CPU loading revolved around switching off as many processes as possible in the output module once the agent's choices for the round had been completed. This allowed the CPU load to spike up to 100% briefly, which was followed by a lull in CPU load as the round played out. This approach created stable systems for the installation works, but later proved problematic in the interactive system. The only solution to these problems was to abandon the original brief of making all work executable on the G4 PowerBook, and making a G5 desktop the minimum specification for the interactive work. The subsequent interactive system has also been successfully used with the current (as of 2007) crop of Intel based Macbook and iMac systems using 2Ghz Core 2 Duo chipsets.

While the score based works were important in pinning down the behaviours of the IPD engine for analysis and the exploration of the impact of different combinations of strategies, in many ways, the real-time works underpin the robustness of the IPD concept in a far more generalised fashion. Although the motivation for developing the software and works to incorporate different media stemmed from a desire to allow live performers to interact with a variety of sonic and visual media through the interactive software, these works have shown that the IPD is a useful tool in organising musical materials at the micro, meso and macro levels of music. That the IPD is also able to create interesting longer-term temporal structures in the visual domain further highlights its organisational capabilities in an aesthetic context.

6. Interactive work

From the outset of this project the interactive work was always the end goal, although once underway it became obvious that rather than being the end, this aspect of the portfolio was only the beginning of an entire area of research into the IPD and its relationship to music, and particularly improvisation. Interaction with live performers has always been seen as important, as while the agents are able to organise musical materials into quite surprising musical structures considering the simplicity of the rules under which they operate, certainly, their interactions are very stylised, and lack many of the subtleties of real life performers. At the Australasian Computer Music Conference in 2005, after demonstrating some musical examples generated with one of the early versions of *IPD Score Generator*, I was asked why I wanted to incorporate live performers into the system, when it was quite obvious that I had developed a successful generative composition system, able to create interesting musical structures autonomously. The main reasoning behind 'plugging' a live performer into the system was that it was hoped that, through responding to the performer's input, the agents' musical output could be pushed farther, leading to more complex forms than those that could be created by the agents alone.

The following section discusses the development of the *ENSEMBLE* interactive application and its use, leading to the work *fr@gm3nT [fragment]* written for saxophonist Derek Pascoe. The *ENSEMBLE* application draws further inspiration from the notions of performance indeterminacy pioneered by the New York School, in that, it aims to push the performer outside their normal processes, to create new musical experiences rather than drawing on what they already know. As such, there is a heavy emphasis on game play, and a strong connection to 'gaming'. Initial experiments revolved around the development and use of a GUI, creating the *ENSEMBLE* 'video game' (Figure 6.1). Through the game, the performer competes with the agents in a musical IPD tournament.

6.1 ENSEMBLE: software development (2006 - 2007)

Asides from the GUI, the main software development for *ENSEMBLE* revolved around the modification of the IPD engine to incorporate pitch recognition, enabling the ensemble of agents to interpret the actions of the live performer. The output module of *ENSEMBLE* is most closely related to the module developed for *Drowning*, in that the IPD Engine (and the performer) manipulates a palette of samples. Moving the application away from MIDI sounds was seen as important as it was the traditional medium of many interactive music systems developed through the 1980s and 90s, and current technologies allow for development without these kinds of restrictions. None-the-less, MIDI is still used as a messaging protocol in the system, used to trigger the sample palette.

6.2 Incorporating the performer's actions into the IPD engine

In order to incorporate the performer's actions into *ENSEMBLE*, one of the agents was removed from the system, and the performer effectively 'wired' into the agent's place in the IPD tournament. As such, the performer collaborates with (or competes against) an ensemble of seven agents. The modular structure of the interactive application can be seen below:

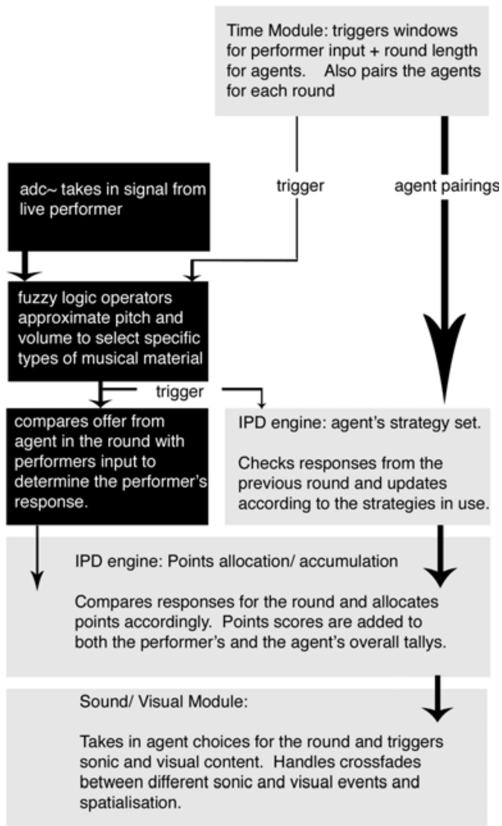


Figure 6.2.1 The modular structure of the interactive application *ENSEMBLE*. Note: the input modules used to incorporate the actions of the performer are highlighted in black. This represents the final version of the application used in the work *fr@gm3nT [fragment].* This version was extended from the earlier versions through incorporating fuzzy logic operators to assess the pitch tracking. This increased the accuracy of the pitch tracking substantially.

Through removing an agent from the system, incorporating the performer's input was simplified somewhat, as it was an addition to the existing IPD engine, rather than having to modify the whole application to incorporate an extra player. The main additions to the IPD engine revolved around pitch recognition, and a number of comparative functions that could transform the tracked pitch information into a form that could be understood as a cooperate or defect response by the agents. The pitch recognition was based around Tristan Jehan's 'pitch~' object (2001), and several different strategies for interpreting the objects output were devised.

In the initial *ENSEMBLE* 'video game', this was handled in quite a simple fashion, with all the tracked pitches occurring within a round being stored as a list, and at the conclusion of a round, the list would be checked for the most common member, and this would be compared to the agent's offer for the round determining the performer's response. Several timers were also developed to measure how far into a round the performer played, and how long they played for. This system really only allowed the performer to play one pitch per round, and was quite limited, although it was reasonably accurate for individual notes played with a normal tone. The pitch information was most important here, as it solely determined whether the agents saw the performer as cooperating or defecting. Other information such as round offset, note length and velocity were stored to determine the sound the performer's next opponent would play if it either cooperated or was suckered.

The complexity of tracking the performer's input was compounded somewhat for Fragment as the work incorporated saxophone multi-phonics and extended techniques. The solution lay in the development of several fuzzy logic operators that allowed different aspects of the sound to be tracked, and categorised so that rather than attempting to precisely track individual sonic events, as was the case in the initial version, snapshots of the performer's actions were taken, and then a higher level 'type' of musical material was approximated. Although it may seem counter intuitive, this actually led to a far greater accuracy in recognising different sonic events, and also simplified the system considerably.

6.3 GUI Design: *ENSEMBLE* video game

The *ENSEMBLE* GUI design followed on from the notepad style interface created for *IPD Score Generator*, and once again aimed to be as simple as possible to use. This was achieved through a strip of user controls across the bottom of the interface, controlling initialisation of the IPD engine, the number of speakers in use, microphone input, and starting or stopping the game. For the sake of simplicity, several of the user-defined features of *IPD Score Generator* were dropped, for example, user control of the agent's strategies, and the sound palette.

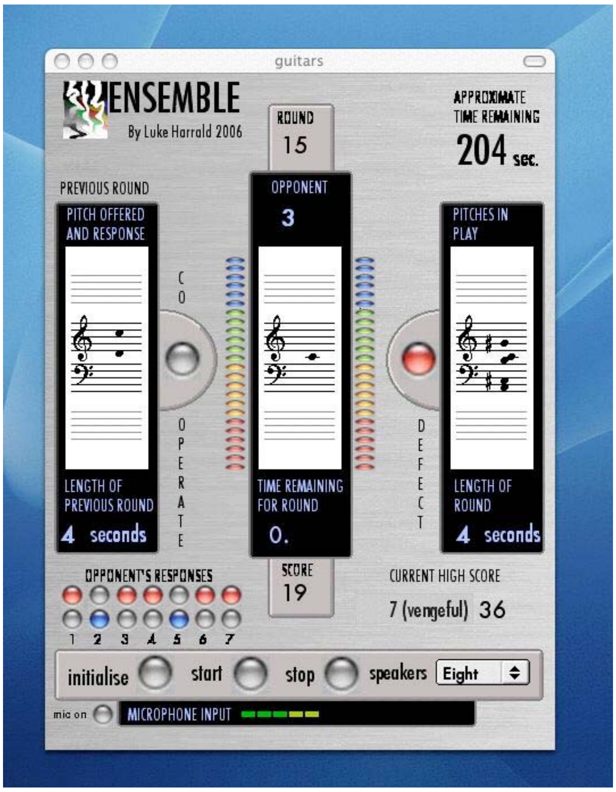


Figure 6.3.1 The initial version of the interactive *ENSEMBLE* video game. The performer takes on the ensemble of agents in a five-minute battle to see who can get the highest score; the game-play generates a new composition at the same time (May, 2006).

As the main emphasis here was on game-play, with the performer effectively taking on the ensemble of agents in a competitive, musical Prisoner's Dilemma tournament, there was a lot of information to display as it was felt that both the performer and the agents should have the same information available to them. Due to the complexity of this information it dominates the interface, and includes: the total time remaining in the game, the response (as the registered by the game) of the performer and each agent in the previous round, the performer's current score, the current high score and three panels of more specific musical and round information.

The three panels in the middle of the GUI display musical information relating to the current and previous rounds of the game, with the global information relating to pitches in play and the length of the current round appearing on the right, information about the performer's current opponent and the length of time remaining in the round appearing in the centre, and information from the previous round appearing on the left. This horizontal arrangement was devised so that the passing of time is handled in a similar way to traditional music notation. Due to the fact that western music notation is read from left to right, current musical events typically appear in the centre of the performer's focus, while future events are to the right of this, and past events to the left. While this arrangement was designed to tie in with the traditional reading skills of the performer, through using the interface, it would appear that perhaps this is less intuitive than first imagined as multiple staves used in scores typically appear in a vertical arrangement, and this may actually be easier to read.

Experiments with the *ENSEMBLE* video game revolved around playing the game with an electric guitar and e-bow (Figure 6.3.2). This generated some interesting musical results, and certainly met the brief for a system that was quite a departure from the normal experience of improvising. Playing the game took quite a bit of practice, as there was quite an overwhelming amount of information to take in as a 'player' and ultimately, the interface was dropped for the work *fragment* for reasons that will be discussed in the next section.

Figure 6.3.2 The *ENSEMBLE* video game in action with electric guitar, e-bow and the seven agents performing through an array of Marshall MS-2 amplifiers. This system worked with the PowerBook G4, although the later systems require a G5 minimum.

6.4 fr@gm3nT (2007) for Derek Pascoe

Fr@gm3nT [fragment] was a close collaboration with Derek Pascoe, a virtuosic saxophone player and improviser with some 30 years experience. Although the main aim throughout *ENSEMBLE*'s development was the creation of a universal interactive environment that could be responsive to anything the performer chose to play, *fragment* has very much grown into a recognisable work, offering a framework for interaction between the live performer and the virtual ensemble with restricted sonic materials. In some ways this is reminiscent of Cage's 'Gamut' technique (Pritchett 1993: 48- 50), although rather than being involved in the act of composition, here the manipulation of the gamut occurs in real-time during performance. Like other indeterminate works, *fr@gm3nT* remains instantly recognisable while allowing for a vast variation in detail. Developed over a period of several months, there were many interesting discoveries made about how a performer might interact with the computer model, and indeed, what may lead to a successful strategy for a live performer playing the IPD.

The title of the work was a response to my frustrations at the many encrypted passwords that seem to dominate our lives in the digital age, and also from the rise of the use of 'l33t' in the English language; (leet: short for 'elite', a hacker language the mainstay of online gamers where the vowels of words are replaced with numbers). This turned out to be timely by the end of 2007, with the Merrian-Webster's dictionary naming 'w00t' (woot: a cheer used in online gaming or chat) the word of the year for 2007 (Ward 2007); it was subsequently added to their online dictionary. 'Hacking' has remained a constant theme throughout the collaboration with Pascoe, as he often describes my role in live performances as 'hacking into and subverting his endeavours with my agents'. This concept has been expanded in subsequent work to incorporate audience participation, allowing four audience members to play the IPD against the ensemble of agents across a wireless network, manipulating the sonic materials I have at my disposal as I mix live on stage (see Figure 7.0.1).

The sonic palette for fragment is a set of 28 samples that consists of a number of extended saxophone techniques including multi-phonics, harmonics, key slaps, screams and several short looped motifs with a normal tone. The samples are essentially short fragments from recordings of Pascoe's improvisations over two sessions during the development phase of the work, where performing, programming and recording all combined into the composition process, shaping both concept and aesthetic. This has been an interesting process, with Pascoe commenting that in some ways, he gets a strange feeling of déjà vu, where a motif or sound created off-the-cuff a week, or even several months previously, rises to prominence and becomes central to a subsequent performance.

To aid in pitch tracking, the samples are divided into eight high level sound-types that allow the process to be greatly simplified through the use of fuzzy logic operators; this use of sound-types stretches right back to *PARADOX eleven*, the first work in the portfolio written using the IPD as part of the composition process. During each round of interactions, the performers input is pitch tracked, leading to the selection of one of the sound-types. This is compared to the type of sound offered by the performer's opponent for the round to determine whether the performer cooperated with, or defected against the agent's offer. The specific sample is then selected randomly from the samples available in the type of sound selected; typically between 2 and 5 sounds. This sound is then fed back to the agents as the current sound being played by the performer. Curiously, by approximating the type of sound and then performing a random selection from the available possibilities, the pitch tracker was far more accurate than the more precise methods attempted in earlier versions of the system. The accuracy for type was very robust, while more often than seemed feasible, the sample closest to what the performer had just played would actually be selected. Of course, aiming to select from a specific palette of known sounds is a much simpler problem than the pitch tracking required in a more open interactive system, and spectral tracking and mapping are certainly areas of much current research.

One of the interesting observations through the development phase of fragment surrounded using the graphic interface. Initial experiments for the work revolved around Pascoe playing against the agents through the *ENSEMBLE* GUI, which was found to be overly cumbersome, and generally presented too much information for him to follow with any real accuracy. This was reflected in Pascoe's generally low scores playing the game (he was often beaten by the agents) affecting how much influence he could exert over the system. As Pascoe generally uses a strategic approach to his own improvisations, and has a keen sense of strategy when interacting with fellow (human) improvisers, it was felt that he may fair better if he ignored the GUI, and simply responded to the agents by listening to them just as he normally would when performing. Despite the ambiguities of which particular agent Pascoe was interacting with in each round, by removing the GUI, this proved to be an improvement, allowing him to soundly beat the agents' scores in the tournament most of the time, and dramatically increasing the quality of the performance. While it comes as no surprise that improviser's listening skills are more keenly developed than their reading, this aptly demonstrated that when working with experienced improvisers the GUI was unnecessary and it was dropped from the final version of *ENSEMBLE* used in performance of the work. The MaxMSP application used in the performance of *fr@gm3nT* at the 2007 Australasian Computer Music Conference is included in Volume 2 on the Data DVD. This application is not locked beneath a GUI, so all the sub-patches may be opened.

When working interactively, the combination of strategies selected for the agents in *ENSEMBLE* are slightly different to those used when generating a work using *IPD Score Generator*, as with the input of the live performer, there is little chance of the system getting stuck in a state of total cooperation, but a high chance of the system being stuck in a state of total defection. As the performer can easily take on the agitating role, less aggressive strategies can be used, and generally, responsive strategies were focused on, so that the system would quite clearly respond to the performer's input, making the interactions more transparent for both the performer and the audience, while still allowing for complex modes of interaction. As such, 'Vengeful' was not used at all, being replaced with an extra 'Tit for Tat': the strategies used for Fragment were two Tit for Tats, Random, Aggressive and Passive Pavlov, Copycat and Downing. This combination was quite effective as following the premiere performance of the work at the 2007 Australasian Computer Music Conference, Pascoe pointed out that through performing with the system, he felt as though it would at times reinforce his musical directions and at others work against him much like a real ensemble, and that in fact the system was often "more responsive than a human ensemble ever could be" (2007 pers. comm. 19 June). This also appeared clear to the audience, as a review of the performance commented, "*fr@gm3nT*, for computer and saxophone, had Pascoe's saxophone sometimes accompanied, sometimes attacked by computer-selected samples of itself" (Burt 2007).

Fr@gm3nT has been performed three times during 2007, and the differences between performances have been striking, as the work has been adapted to different settings and performance environments. The premiere at ACMC07 was spatialised through a cube of eight speakers in a large auditorium. The audio spatialisation in this instance (with an agent's output in each speaker) was quite spectacular, with the height of the cube allowing the agents responses to whirl around the auditorium, responding to Pascoe's quite aggressive performance which was possible through the size of the space and PA system; prompting Burt's apt summary above.

The second performance was as part of the Tyndall Assembly series at the Gallery De La Catessen, a small venue, prompting Pascoe to introduce the work by commenting that he 'would not be leaving third gear this evening for the sake of peoples ears'. Performed in quad surround, this performance showed the work's subtler side, with Pascoe at times interacting closely with the agents, while at others branching off into solo territory with the agents providing an ambient accompaniment. This version of the work received positive reviews in local Adelaide newspaper 'the Advertiser', where the work's process was described as "resulting in sonic felicities of shape, strength, purpose and some delicacy" (Smith 2007). The recording of this performance appears in Volume 2, on track 7 of the CD.

The third performance took place at a bar (Figure 6.4.1), through a large stereo PA system. As this was a very noisy performance environment, Pascoe decided that this performance needed a different approach, both in performance and strategy, in order to create a connection with the audience. While he had carefully interacted with the agents in the previous performances, this performance was quite different as he basically beat them into submission with an 'Always-Defect' strategy. This was an explosive performance, the conclusion of which resulted in most of the agents joining Pascoe in 'primal screams' that were reminiscent of Robert Ashley's 'the Wolfman' (1964) . A short video extract from towards the end of this performance appears in Volume 2 on the Video DVD.

Figure 6.4.1 Luke Harrald and Derek Pascoe perform *fr@gm3nT* at EARPOKE, 22/11/2007.

6.5 Discussion: ENSEMBLE and game-play

Although the improvising ensemble is a mode of music making that *ENSEMBLE* draws inspiration from, it was never intended as a replacement for a human ensemble, but rather as something that offers the performer a similar collaborative experience, with an aim of opening up new possibilities for collaborative music making. Here, the role of the computer goes beyond simply following the performer's input, or signal processing, to take an active part in shaping both the structure and overall form of the performance; essentially creating a virtual collaborator. Exploring the system from the perspective of game-play, two aspects would appear critical in creating this sense of collaboration, these being: randomness, and the competitive nature of the IPD tournament.

Typically, games fall into two categories, these being 'open', where all the pieces in play can be seen by all players, such as Chess or Go, and 'closed' such as card games (Eigen and Winkler 1981: 16-17). Open games tend to have complex rules that create uncertainty about the outcome through it being impossible for the players to conceive all possible combinations of moves, placing an emphasis on rationality and abstract thought; that is, the game is self contained, creating its own world governed by its own rules. Closed games on the other hand, have simple rules (often the highest card or hand wins), but through uncertainty about what hand their opponent has, or what their actions will be, the emphasis is shifted to understanding the psychology of the opponent rather than rational decision making; for example, the best Poker players are both good at bluffing and knowing when their opponent is doing the same. It is the combination of simple rules, and chance, that gives closed games their uncertain outcome, adding an extra dimension to the game that creates their widespread appeal.

With its combination of simple rules, and chance, *ENSEMBLE* would appear closely related to the card games outlined above through randomness giving the system an added dimension that is perhaps not readily apparent in the IPD itself. This may explain why the IPD has generally failed to capture the imagination of artists at a time when there is much interest in other areas of complex systems research.

If the performer knew prior to beginning a performance the order of the agents they were paired with, or they competed against a single agent, then the outcomes for all interactions would be predetermined killing off any novelty the game has to offer. The parallel random pairings of the agents adds unpredictable behaviour to the game, as the performer can not be sure which agent they will face in the subsequent round. In a musical sense, the simple binary behaviour of the agents is again made unpredictable through defection resulting in random musical choices, pulling the global musical state of the system in many unpredictable musical directions. These elements of chance continue to exert influence throughout a performance, with the combination of rules and chance generating a sense of coherence while creating an outcome that is inherently unpredictable.

The aspect of competition is equally important here, as the performer must fair well enough in the tournament to have any influence on the system at all. This aspect highlights the autonomy of the agents, and heightens the sense of collaboration that is evident in *ENSEMBLE*, as it at times reinforces, and at others works against the performer's input. While the competitive aspect of the system is vital from the perspective of game-play, it is also reminiscent of the rivalries between performers that sometimes arise within improvising ensembles, pushing the performers to ever-greater heights.

> The ambivalent feelings Charlie had developed toward Dizzy Gilespie were displayed at a concert in Carnegie Hall the night of September 29… The Parker-Gillespie set at once exploded into a duel, the weapons being trumpet and saxophone… Despite the bristling hostility that surrounded the two performers, Parker's solos retained that continuity and completeness of form that marked his best work… It was one of his fire-eating nights, a display of astonishing musical powers.
>
> (Russell 1972: 247-248)

The current strategies used in *ENSEMBLE* are deterministic: once the game begins the agents are unable to modify their behaviour to improve their performance in the IPD tournament. This was considered important to allow clarity in the interactions between the live performer and the agents, allowing the performer to become familiar with how different agents behave and how different combinations of strategy affect the global dynamics of the ensemble over time. As *fr@gm3nT* made use of the same strategy set over several performances, it was interesting to note that Pascoe did indeed become accustomed to the global dynamics of the system, realising that he could beat the combination of strategies in play by always defecting.

Systems have been considered that allow the agents to switch strategies to increase their performance in the tournament, as well as evolving systems that allow the agents to evolve new strategies over time. Didkovsky's work with the 'Luring Lottery' suggests that modifying the agent's behaviour to improve their overall performance in the tournament may not prove to be as desirable as it seems.

Didkovsky found through his system that in a group of human performers, several behaviours developed in rehearsal prior to the performers having a full understanding of his system that did not occur in the actual performance of the work. These included 'arms escalation', as performers defected against one another to try and gain control of the musical events; 'de-escalation', as they realised that this method did not actually enable anyone make significant changes to the musical events; 'peace', as performers basically gave each other an equal chance of control; and 'destabilisation', as once peace was established, performers would try to take control through defecting from time to time. Unfortunately, the performance was rather tame as once the performers understood how the system worked they tended to work cooperatively as a group without any of the 'social storminess' of the rehearsal. (Divkovsky 1992: 7).

As *ENSEMBLE* relies on these kinds of retaliatory behaviours to generate structure, changing the agent's strategies to improve their performance during the tournament would appear likely to lead to the production homogenous global behaviours, and static music.

7. Conclusions

Over the last 50 years, computer music composition has established its own set of norms and traditions, many of which focus on the abstract, logical aspects of composition, incorporating extra-musical influences to create novelty. This approach has been very effective, spawning many new sounds and structures, but is often criticised for an obsession with micro details that do not transcend musical time scales, making the generation of higher-level form problematic. While the methods used throughout this portfolio are not about to autonomously generate a Fugue, or Sonata (and nor was this my intention), the works do demonstrate a coherence and sense of form that belie the simplicity of the rules that under-pin them. It is interesting that in search of musical novelty, many composers have looked towards biologically inspired, non-linear computational methods such as Cellular Automata and Genetic Algorithms, yet relatively few have turned the mirror around, adapting similar non-linear approaches to explore our own spontaneous musical behaviour in new ways.

The Iterated Prisoner's Dilemma has proven itself to be a rich resource for musical application, creating complex forms and interactive situations through a very simple question: shall we cooperate, or not? While this question has preoccupied philosophers and researchers across many disciplines, it is surprising that in artistic practice it has received very little attention. With the recent interest in interactive computer systems, as the pre-eminent model for simulating social interaction, the Iterated Prisoner's Dilemma would seem an obvious choice.

The compositions presented through this portfolio have established that the Iterated Prisoner's Dilemma is a viable strategy for generative composition. The works themselves have been well received in live performance, in a range of settings, often with little to no explanation of the underlying processes at work. The fact that the works themselves can connect with an audience purely at an aesthetic level certainly points towards the robustness of the concepts presented.

The sense of musical phrase and form created through the agents' interactions as they reinforce and abandon different musical materials mirrors the way in which form emerges in the indeterminate works of the 1950's American Avant Garde, and would appear highly suggestive of the way in which form emerges in free improvisation where there are no pre-determined structures. These concepts have transferred very successfully to the interactive environment, allowing the virtual ensemble to reinforce or work against the input of a live performer. This is an exciting development for future work as it suggests that the Iterated Prisoner's Dilemma offers a vehicle for modelling the interactions between improvisers without the complexity of incorporating a performer's musical training or cultural background. It is hoped that this aspect of the work presented will capture an interdisciplinary audience, and lead to further exploration of the relationship between improvisation and the IPD.

There are many avenues for further exploration of musical applications of the IPD, both in the fields of generative music and as a platform for interactive music applications. Certainly more complex models that move beyond the deterministic IPD used here may offer further insight, and to this end, Axelrod's 'Cultural Models' that "explore how we become who we are through our interactions with others" (Axelrod 1997: 145) would appear promising.

From the perspective of the system presented here, development is ongoing and at the time of writing. One new direction has been the creation of an application that allows audience members to interact with the virtual ensemble during live performances across a wireless network. Called *Hackers* (Figure 7.0.1), this musical game allows four audience members to compete with the virtual ensemble (and each other), affecting the sounds I have at my disposal as I mix live on stage; effectively hacking in to my performance. This application has been used live with quite unexpected results, and will no doubt spawn further research into the nature of game-play and interactive music. Certainly, the exploration of these types of systems with a strong emphasis on practical music making as both a composition activity, and in live performance points towards my own approach to future work.

Figure 7.0.1 *Hackers* GUI: a recent application extending the concepts of this portfolio to incorporate audience participation.

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