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Algorithmic Improvisers

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ABSTRACT OF THE THESIS

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Professor Christopher Dobrian, Chair

In this essay I explore the creation of interactive, improvising computer partners. I consider different forms of interaction with computer musical collaborators, be it through traditional musical instruments or alternative controllers. I discuss the work of David Cope, particularly his musical analysis and composition program *Experiments in Musical Intelligence*, George E. Lewis and his musical improviser *Voyager*, and finally Eduardo Reck Miranda's work in algorithmic composition and alternative controllers. The ideas of each of these artists have significant implications for the design of interactive music systems and form the basis of my model of computer improvisation. My approach to improvisation is informed by various styles of the Western tradition—primarily jazz—from very open improvisation (free jazz) to highly structured improvisation.

I begin by analysing key ideas behind interactive music systems, such as creating dialogue and reactivity compared to compliance. I then discuss how Cope's EMI can be utilised as a framework for analysis and improvisation, and discuss other ways of listening and understanding incoming music. This is followed by a comparison of some forms of interaction and algorithmic composition, which comprises the main component of musical generation used by these computer systems. I conclude by discussing my own implementations of these concepts in the piece *Henonistic*.

The Consequences of Computer Interaction

The systems I am interested in studying and creating are based on interactivity. For the purpose of this paper, I consider interactivity an exchange between multiple autonomous agents, such as a human and a computer, where each agent is able to dictate varying levels of control over the combined output as well as over the other agent. Both agents must not only respond, but also contribute their own musical elements. In relation to discussions on computer music interactivity, George Lewis states 'interactivity has gradually become a metonym for information retrieval rather than dialogue'.[1] Lewis also describes the difference between systems that are compliant as opposed to interactive, and that simply retrieve information rather than engage in a dialogue. In discussing reactivity and interactivity Christopher Dobrian states 'inter- in the word "interactivity" implies mutual influence between agents that are also in some way autonomous decision makers'.[2] This ability to create dialogue, mutual influence, autonomous decisions and interaction is central to the systems I wish to create. Referring to Robert Rowe's taxonomy for interactive music systems,[3] the systems I will discuss are firmly in the 'player' category; that is, they are not an extension of a human performer and are instead an artificial performer. These systems are autonomous agents, operating independently of human control. Applying Russell and Norvig's[4] definitions for artificial intelligence, the systems are intelligent model-based reflex agents, capable of tracking and storing their environment and altering their perceived

[1] George E Lewis *Too many notes: Computers, complexity and culture in voyager.* (Leonardo Music Journal 10 (2000): 33-39.) p.36
[2] Christopher Dobrian, *Strategies for Continuous Pitch and Amplitude Tracking in Real Time Interactive Improvisation Software* Proceedings of the 2004 Sound and Music Computing conference, Paris, France, p.1.
[3] Robert Rowe. *Interactive music systems: machine listening and composing*. (Massachusetts: MIT press, 1992)
[4] Stuart Russell and Peter Norvig *Artificial Intelligence. "A modern approach."* (Prentice-Hall, Egnlewood Cliffs 1995) p.51.

environment. The music systems I am studying are also capable of actively changing their environment, responding to their environment or ignoring environmental input.

There are advantages for both computer and human performers that can be exploited through a collaborative form of music making. Miranda describes a computer's ability to follow 'extremely detailed instructions quickly and accurately'[5] as an advantage of computer performers. It is much more difficult for computer performers to create human-like musical inflections and expression.[6] Dobrian proposes one method to achieve computer expressivity, by capturing characteristics of a performance, or 'stealing' from a human performer.[7] In my research, the ultimate goal is not necessarily to replicate, or be as expressive as a human performer. Instead, expressivity is one of the many musical elements that can be explored and invoked through human and computer improvisation.

The interactive systems I am studying isolate design into multiple components. Each system begins with a perception component that listens to and analyses incoming musical information. This is followed by a musical generator, which can take many forms, and then a performative component that decides how to handle the generated and perceived information and finally creates the audible output. This use of input to processing to output stems from the work of John von Neumann, whose own work is based on earlier understandings of human perception. This is far from the only model for an interactive system, however this paper will primarily deal with systems using this model.

My approach to improvisation is informed by various styles of the Western tradition from very open improvisation (free jazz) to highly structured improvisation. In general I

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[5] Eduardo Reck Miranda and Marcelo M. Wanderley,*New digital musical instruments: control and interaction beyond the keyboard.* (Middleton, Wisconsin: AR Editions, Inc., 2006) p. 227.
[6] Christopher Dobrian and Daniel Koppelman, *The E in NIME: Musical Expression with New Computer Interfaces* In Proceedings of the International Conference on New Interfaces for Musical Expression (Norbert Schnell, Frédéric Bevilacqua, Michael Lyons, Atau Tanaka, eds.), 2006.
[7] Dobrian, *Strategies for Continuous Pitch*

approach improvisation from a jazz background. To quote Derek Bailey, 'There is no doubt that the single most important contribution to the revitalisation of improvisation in Western music in the 20th century is jazz'.[8]

Computer improvisers and electronic music in general allow for musical outcomes that would not be possible otherwise. Part of the original imperative for *Voyager* was to create an improvising orchestra, something that Lewis felt was impossible at the time. Improvising computers offer a range of musical possibilities that are not available without them, as stated by Miranda: 'An artificial intelligence-based interactive music system should promote the exploration and discovery of new outcomes'.[9]

Musical Analysis, Knowledge and Influence

David Cope's computer program *Experiments in Musical Intelligence* (EMI) explores the emulation of music in the styles of various western composers. EMI uses a diverse method of analysis on multiple structural levels and then utilises this analysis to recombine (the process is named *recombinancy* by Cope) works into new music that is stylistically similar to the works analysed. EMI's musical database can be chosen from any work and is input through MIDI files. EMI can analyse and retain essentially unlimited quantities of material in seconds. As a musical system EMI has capabilities, such as virtually limitless storage of musical material, that would seem impossible for a human to ever hope to achieve.

While EMI is not designed for real-time interaction and instead creates musical compositions, it does have significant implications for the design of improvising systems.

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[8] Bailey, Derek. *Improvisation: its nature and practice in music* (Ashbourne: Da Capo Press, 1993) p48.

[9] Miranda and Wanderley, *New Digital Instruments* p. 244.

The ability of a system to engage the musical language of many different composers and styles could have a range of use for an improvising system. In addition, Cope has created a highly effective and unique method of analysing music; elements of which could foreseeably be used in real-time analysis. There are examples of other systems that employ a similar environment of utilising or exploring a harmonic understanding, one of which is GenJam (created by John Al Biles),[10] which utilises genetic algorithms to create melodic ideas over jazz chord progressions. EMI however creates a noteworthy method of approximating a musical style, through an innovative form of representation which creates a comprehensive knowledge base.

EMI is an example of data-driven programming, meaning the decisions and model of the software are all directly controlled by the data. In the case of EMI this data is drawn from a stored database of MIDI files. EMI's theoretical basis has a diverse range of potential for the live analysis of improvisations. An improviser must listen (including analysis and removing unneeded information), make decisions on important musical information and then perform based on this data. An improviser should also have an understanding of the ongoing musical structure, both on a micro and macro level. While EMI contains the tools to create this analysis and make greater structural decisions, the challenge is implementing a new form of database that can change in real time and not solely depend on information created offline. Through an integration of approaches to machine listening, I believe EMI could become a useful tool in interactive musical settings.

One of EMI's techniques, allusion, allows for recognition of relationships between passages of music that occur in different works. Allusion allows relationships to be built not just within one composer's works, but between the works of multiple composers, providing

[10] Eduardo R Miranda and John Al Biles eds. *Evolutionary computer music*. (London: Springer, 2007) p. 137-170

the ability to place music in a specific stylistic era. Cope separates allusions into different categories including quotations, paraphrases, likenesses, frameworks, and commonalities. As a live analysis tool this can be used to understand other improvisers' harmonic language, and can also place harmonic and rhythmic ideas within the context of other music. While not necessarily always responding in a predetermined way, this musical analysis can allow a program to view how others have previously responded and allow the information to inform future decisions.

EMI's most beneficial feature to interactive music is its highly developed approach to comprehending musical structure. Miranda states in relation to 'interactive computer-based music ... The main difficulty is organizing musical materials in real time into coherent musical forms with a clear sense of direction and purpose'.[11] This directly corresponds to the ideas formed by Cope around structural analysis, including SPEAC (see below) and other general concepts.

EMI detects new thematic boundaries by tracking musical patterns and identifying when there are no recurring patterns. In the absence of those, it uses contrasts in timbre, phrase or length. Importantly it can also reference its database of works to predict what qualifies as a new section. As a tool for an improvising computer this ability to identify structures purely based on musical input is crucial to creating a system that doesn't appear random and has a higher level awareness.

SPEAC (Statement, Preparation, Extension, Antecedent, Consequent) is a powerful tool used by EMI to control the development and release of musical tension; although it should be noted it has a strong bias to analysing Western classical music. SPEAC places

[11] Eduardo Reck Miranda, *Composing Music with Computers* (Oxford: Focal Press, 2001) p. 238.

musical parameters into a context derived from the work of Heinrich Schenker.[12] It analyses each note or phrase as either S, P, E, A or C and places each idea in a context of tension and its musical role, with the goal of understanding musical direction. This level of analysis could be used to help create coherent musical statements as well as to recognise other improvisers' language.

As well as being potentially applicable to live analysis, EMI creates a conceptual base that could be used to teach improvising computers knowledge of any musical style and allow them to draw on this information. EMI presents a vocabulary that can essentially be used as an educational course for computer improvisers. A standard method of jazz education revolves around three stages of learning, 'imitate, assimilate, innovate'.[13] This process has been most formally asserted by jazz trumpeter Clark Terry, although similar ideas appear in many methods of jazz pedagogy, in slightly varied forms. Derek Bailey describes the process as, 'choosing a master', 'absorbing his skills' and 'developing an individual style'.[14]

In Terry's definition, imitation involves copying stylistically the model of a master musician. Assimilation is then the act of 'ingraining these stylistic nuances' and 'truly connecting them to your ear and body'.[15] EMI to my mind fulfills both imitation and assimilation of the compositions it is given, and the process of recombinancy represents an approach to achieve the ideas of Terry. Whether or not EMI's work stands up to the actual works of the composers it imitates, it is my opinion that it can produce a very effective emulation. I believe EMI comes close to the imitation and assimilation skills of a human (or

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[12] Heinrich Schenker. *Das Meisterwerk in der Musik: ein Jahrbuch von Heinrich Schenker. Drei Masken Verlag.,* 1926.
[13] Mark Graban. *"Learning Jazz (and Lean?): Imitate, Integrate, Innovate"* (2012. ret: 18 Sep. 2014)
[14] Bailey, *Improvisation*, p. 53.
[15] Graban, *Learning Jazz*

possibly beyond), and does so in a fraction of a second and with the ability to imitate any number of composers.

Cope's recombinancy outlines Terry's model of assimilation and applies to many improvisers' development of musical language. I understand assimilation to mean the process of intertwining other performers' musical language within one's own musical creations. Cope describes that creativity 'synthesizes the work of others, no matter how original the results may seem'.[16] All improvisation draws on a musical and cultural heritage, even completely free improvisation draws on past paradigms. In this way improvisation can be seen as a combination of many previous works, recombined to create new improvised ideas.

The final stage of Terry's model - innovate - is inevitably the hardest to justify and perceive, not only for the computer improviser. Arguably, EMI as a composer does innovate through its manner of recombining previous works. Cope argues that all innovation and creativity is the result of connecting 'differing but viable ideas in unique and unexpected ways';[17] an argument that is openly favourable to his own creation EMI. Discussions on artificial creativity extend far beyond interactive music systems; whether or not a computer program can be creative is contested and raises many further philosophical questions.

Direct imitation without innovation in improvisation is a considerable issue not just for computer programs. Many improvisers draw on licks (previously created material) as part of their language. This lick based method of imitation and assimilation works as a method of addition to an improvisers vocabulary, much in the same way EMI rephrases classical music. This method of incorporating musical language is however not without contention and

[16] David Cope, *Computer Models of Musical Creativity.* (Cambridge: MIT Press, 2005) p. 87
[17] Ibid., p. 12.

players are often accused of direct imitation. Strinavasan describes: ‘The enemy is mere imitation without imbibing the inspiration which makes the art a living thing’.[18]

Regardless of EMI’s ability to innovate, it has the potential to the create a strong platform for a computer improviser. The ability to have an incredibly extensive (essentially infinite) knowledge of composer’s style and the ability to create in these styles can only broaden improvisational abilities. Even the most ardent musician cannot hope to retain a fraction of the database that a program such as EMI contains and it is these skills that are unique to a computer improviser that build its musical relevance.

Alternate Forms of Listening

While Cope’s program EMI provides a model of analysing and composing music based on works by classical composers, there are many other ways to approach musical understanding in real-time improvisation. Key elements of improvisation - especially more open free improvisation - are lost in an EMI analysis of MIDI information. MIDI fails to capture information on timbre, variations of which can play a key part in an improvisers language. Rowe describes musical information transformed to MIDI as ‘not so much lost as it is incomplete’[19] and mentions that MIDI’s orientation reflects a development around keyboard instruments. MIDI also contains no information about parameters such as bowing on string instruments.

[18] Bailey, *Improvisation*, p. 52.
[19] Robert, Rowe. *Machine musicianship.* Massachusetts: MIT press, 2004. p. 32.

Miranda relates his own ideas on computer listening:[20]

> It would be impractical to implement a fully comprehensive model of musical listening in an interactive system. A practical solution is to focus on modeling those aspects that are believed to be most important for delivering the tasks the system will be required to perform.

This statement raises the question, if there were a 'fully comprehensive model of musical listening' what would that model contain? As Rowe flatly states, 'I do not believe that a general music representation exists'.[21] While Rowe is referring to notated musical forms, the same exists for forms of listening; there is no comprehensive model available. Instead, human performers listen to aspects that are most important for their current musical situation, with listening choices informed by a performer's musical and cultural background. At the same time, in the same piece, multiple improvisers can be focused on different musical elements. Even in the same situation, different improvisers will have different mechanisms for listening.

With all this in mind the challenge then becomes to decide what musical aspects a computer improviser will listen to. While EMI presents a model to analyse music, this is not always needed or even relevant to some forms of improvised music. Rowe instead describes drawing 'plausible inferences about the obvious'[22] from computer listening. These inferences are closer to the knowledge that a group of musicians may hear when listening to improvisers. Rowe likens the process to readers of a novel all concurring on characters and certain main events, but not on more subtle emotional layers. For live computer improvisations full analysis of all musical content can be highly system demanding, and if much of this information goes unused it presents a hurdle that can be avoided.

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[20] Miranda, *Composing Music with Computers*, p. 225.
[21] Rowe, *Machine Musicianship*, p. 31.
[22] Ibid., p. 236.

Lewis' program Voyager uses a complex method of listening based on 'at least thirty different musical parameters' including 'Volume, sounding duration, octave, register, interval width, pitches used, volume range, frequency of silence, and articulation'.[23] This raw information is then analysed and stored in a block of variables that describe the incoming information at the current time. Voyager's method of listening directly corresponds to its output; the same parameters are used to describe the output, although there is a high level of complexity and decision making between input and output. In this way Lewis has created a listening system clearly based on the desired musical outcomes of the program.

Lewis states that *Voyager*, explores the 'bidirectional transfer of intentionality through sound - or 'emotional transduction'.[24] Lewis elaborates that the emotional state and meaning of the improviser is embodied within the sound and therefore any analysis of the musical material contains this embodiment. I understand Lewis to be describing that the emotional content of a musical statement is tied to any reiteration of the original material, including when the transfer of musical information distorts and removes part of the signal. Lewis infers that any improviser, human or computer, can carry and reinterpret the emotional state of another improviser 'even if the actual material played by the computer does not necessarily preserve the pitch, duration or morphological structures found in the input'.[25]

Lewis' conclusion that sound carries the same emotional state even after musical content has been removed, does require further examination. As is discussed in this paper, no transfer of a musical performance to a computer domain will be lossless. Musical and physical information such as gesture will be lost and cannot easily be transferred to a digital

[23] Lewis, *Voyager*, 1993, Tzadik, CD
[24] Lewis, *Too Many Notes*, p. 37.
[25] Lewis, *Too Many Notes*, p. 37.

domain. This cross-domain transfer also alters the information, adding distortion, unintended noise and potentially changing the information.

I believe it is possible to retain much of the emotional state of the music even when parameters are removed. Western classical sheet music features an extremely high loss of information, yet is capable of containing the original musical intentionality of the composer. This intentionality is only available to musicians with a background in the style of music that is being represented, however, through their already existing database of stylistic and cultural references. As musical information is transferred to a digital domain it can likewise be stored in a manner that can be reinterpreted with at least part of its original emotional state. Like the Western classical musician reading sheet music, the performative component of a computer improviser requires its own form of database of references to interpet the original musical intention.

Forms of Interaction

In the choice of musical instruments to be used with interactive music systems there is no reason to be limited only to traditional instruments, although they are certainly viable options. Both traditional musical instruments and other forms of musical controllers carry with them their own benefits and problems. In addition to traditional instruments, other categories of alternate musical interfaces as described by Miranda and Wanderley[26] include: acoustic instruments with sensors, new instruments based on old designs (such as an electronic keyboard), instrument inspired designs, and alternate controllers (new designs).

[26] Miranda and Wanderley. *New Digital Instruments* p. 20.

Traditional musical instruments allow for musicians to use established performance practices in musical interactions with interactive systems. This virtuosity carries significant musical advantage although instrumental virtuosity is inevitably tied to a style of music. Derek Bailey argues 'There is no generalised technique for playing any musical instrument'[27] and instead all instrumental technique is directed towards certain musical goals. This is no different than any interactive music system which will always be forced to draw on the background and musical direction of the creator to some extent. This reliance on a style or genre of music can be a benefit for music systems.

George Lewis's 1993 album *Voyager* features Roscoe Mitchell on alto saxophone and George Lewis on trombone interacting with the system Voyager, which uses only the sounds of sampled/synthesized orchestral instruments. For Lewis this choice represents the goal of his system, to explore 'interaction and behaviour as carriers for meaning' and not 'novel timbres'.[28] In this way *Voyager* is tied to and embodies 'African-American cultural practice'.[29] Discussing computer music Miranda and Wanderley point out 'it also requires careful thinking about how such algorithms will be controlled by the performers'.[30] Alternate controllers offer direct ways to communicate without the need for complicated forms of audio analysis. It is possible to gradually remove some of the barriers between human and computer interaction, although all systems still involve a loss of information arising from the transfer of the gestures and thoughts of a human to their interpretation by a computer.

Many of Miranda's composition and technological projects explore the human mind, neural networks and biosignal interfaces. Recent works have also focused on BCMI (Brain Computer Music Interface) which involves a person 'wearing a brain cap furnished with

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[27] Bailey, *Improvising.*, p. 99.
[28] Lewis, *Voyager*
[29] Lewis, *Too Many Notes*, p. 33.
[30] Miranda and Wanderley *New Digital Instruments* p. xix.

electrodes'.[31] *Activating Memory* - recorded in February 2014 - allows four human performers to control sheet music that is shown to a string quartet. This type of technology has potential for use in interactive systems either as a sole form of interaction or as an addition to acoustic instruments or other alternate controllers. Any new interface will carry its own limitations and definitions of input, however there is no reason to restrict work with computer improvisers to traditional understandings of musical instruments.

Algorithmic Composition

A distinct advantage of an interactive music system is the simultaneous ability to have some form of knowledge of a musical style (through concepts such as those created for EMI), while also having access to computer centric forms of musical composition. An improvising computer should be able to create music without an input from the performer. Lewis regularly describes *Voyager's*[32] ability to perform solo as key to its power as an improviser. Cope breaks algorithmic composition into eight categories: rules-based programming, data-driven programming (EMI falls into this category), genetic algorithms, neural networks, fuzzy logic, mathematical modeling, sonification, and human models.[33] Each of those categories has a range of potential for interactive computer performance, although they share the same challenge of creating a system that interacts and responds but doesn't blindly create.

Iterative algorithms are an example of mathematical modelling and can be employed in a range of algorithmic composition. An iterative process is a mathematical procedure that is self-referential and repeated; that is, the next step of the procedure uses the previous

[31] "Activating Memory on Vimeo." 2014. 5min. 38 sec.
[32] Lewis *Voyager* and *Too Many Notes*
[33] Cope *Computer Models* p.175.

result. A simple representation of an iterative process is $x_{(n+1)} = x + 1$ where $x_{(n+1)}$ is the next iteration of the procedure. These processes can have three types of orbits (projected range of numbers): moving towards a stable value, oscillating between specific areas, or falling into chaos. Fractals - including the Mandelbrot set - are among the most known versions of iterative algorithms although many different forms can be used musically.

Iterative processes have musical implications because they have an internal structure that can be translated to a musical idea. Due to their internal orbits these processes can create a coherent musical language; even when not based strictly in a harmonic system, they can create systematic and controlled musical ideas. Miranda states: 'our ears tend to enjoy music that presents a good balance between repetition of musical elements and novelty within the scope of the piece itself and in relation to other pieces'.[34] Miranda outlines that the challenge when using these formulas comes down to the ability to map certain parameters to musical events. Overly simplistic mappings can be 'uninteresting',[35] while mappings that are overly complex may hide the behaviour of the orbit and essentially remove its usefulness. These issues involving cross-domain mapping - where information is transferred from one domain to another - are a core design issue for interactivity in general, extending beyond only musical applications.

Regardless of the mappings, when applied musically these ideas will inevitably be centred in a certain musical language. In relation to musical composition Cope states: 'Every work of music, unless it has been composed entirely by a formalism (and possibly even then), contains within it many pointers to the musical culture that helped create it'.[36] When mapping parameters from iterative processes musical idioms are evoked; mapping data to

[34] Miranda,*Composing Music with Computers*, p. 88.
[35] Ibid op. cit., p. 88
[36] Cope *Computer Models,* p. 175.

pitch instantly declares that choices are being characterised around a particular pitch system, and even the very concept of having pitches that can be mapped is rooted in a certain musical styles.

Henonistic

In my own work I have used the Hénon map (created by Michel Hénon) to create a musical improvisation partner, utilising the orbit of the Hénon map to create every musical component. Additionally, I use the Hénon map to decide musical directions and impact the overall structure. The Hénon map is a two-dimensional map that takes a point and moves it to to a new location using the algorithm below.

$$\begin{cases} x_{n+1} = 1 - ax_n^2 + y_n \\ y_{n+1} = bx_n. \end{cases}$$

Figure 1: Henon Map
In my version a = 1.303 and b = 0.21;
The diagram shown is the classical Hénon map, with values a = 1.4 and b = 0.3

The Hénon map is an example of an iterative process and is a discrete dynamical system that shows chaotic results. A discrete dynamical system moves at chosen time intervals, and continually uses the same formula to move to new locations. Chaos within mathematics applies to systems that through slight variations in their initial conditions can show drastic changes. More importantly to my own use is the tendency of chaotic systems to create highly structured orbits, with a logic that is not often easily discernable. The Hénon map is particularly effective for musical patterns because it displays a regular orbit, albeit with chaotic results that contain intermittent outliers. By using an underlying formula such as this, I believe it is possible to create the illusion of an intelligent organised system that has somewhat predictable results, but does show occasional creativity through the chaotic movements, reaching beyond the more predictable patterns.

I would argue that developing a balance between predictability (the regular orbit) and unpredictably (the chaotic results) is key a part of Western music, assuming repetition itself is not the aesthetic basis of the piece. Pierre Boulez describes all Western music as 'caught up in a "dilemma" involving repetition, variation, recognition and the unknown'.[37] Iterative processes can be considered a form of musical composition through their internal repeating process which creates recognisable patterns. With the addition of chaotic results as the 'unknown' these formulas can be used to create musically effective output.

Through experiments substituting the Hénon Map with alternate formulas or with random values, it became apparent that this use of an iterative formula did contain musical significance. While my use of the Hénon map does produce defined harmonic and rhythmic characteristics, this sound is never identical in subsequent performances. I would liken its output to that of a performer reinterpreting improvisational guidelines in each performance. I use multiple iterations of the Hénon map in my composition, with each version operating at a different speed of output. This has the effect of parameters (such as harmony, rhythm and structure) moving at different speeds. I intend for this to allow for very direct mappings from the variables created by the Hénon map to musical parameters, without sacrificing musical interest.

[37] Edward Campbell. *Boulez, music and philosophy*. (Cambridge university press, 2010) p. 154.

My piece uses three conceptual instruments (drums, bass, and guitar) performed by the computer with a bass clarinet performed by the human player. I divide the piece into three layers (demonstrated in Figure 2), although the layers communicate between each other and they are all highly intertwined. The bottom layer creates the decisions of each instrument using musical ideas generated from the Hénon map and an interactive component from the bass clarinet part. The middle layer decides how each instrument will interact, using a game-like system developed for the piece; this is the only section that doesn't rely on the Hénon map. The top layer acts as a greater structural conductor and decides on instrument combinations (solos, duets, trios or quartets) and when key moments of melodic unison should begin. The top layer combines the output of a Hénon map with the input from each instrument to decide the overall direction.

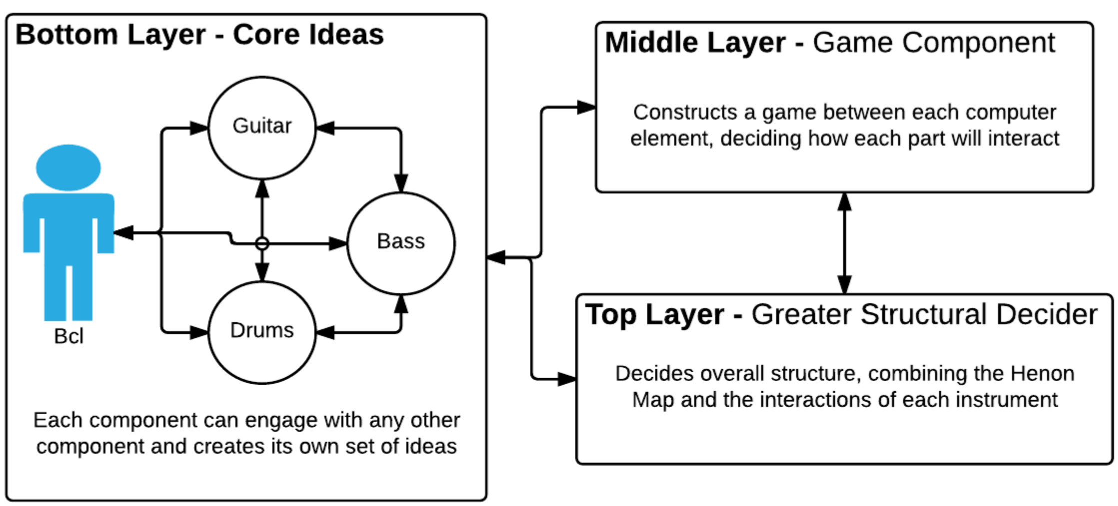

Figure 2: The Multilayered Approach in Henonistic

I also have a global harmonic foundation underpinning the work based on the scaling of both the x and y values of the Hénon map to a note in the Western chromatic scale. I then divide the distance between these two notes and add a note halfway between (creating a triad) before adding a 7th on the chord using the distance between each note. This creates a sequence of four note chords that each run for 16 beats, which defines the harmonic progression for each improviser. The choice of 16 beats is arbitrary in nature; as rhythmic ideas cross and accents are articulated with different placements, no meter is ever perceived.

Each instrument uses the Hénon map in a slightly different way, but one common characteristic is to use the x and y values to create rhythmic lengths. As a basic variation each value of x and y could be multiplied by 100 to create a note length (in ms) and once these notes end the next point in the map is created to output the new note lengths. By using this internal structure from the Hénon map across multiple iterations, combined with the input of a live performer, it is possible to create many unique and changing improvising environments.

Conclusion

As demonstrated in the work of Miranda and Cope, there already exist computer programs and concepts that can be repurposed to create computer improvisers, capable of being truly interactive. *Voyager* represents one of the possible voices of a computer improviser and importantly Lewis' work explores the implications of a computer improviser and the *'emotional transduction'*[38] of meaning from human to computer. This transfer of

[38] Lewis, *Too Many Notes*, p37.

information and meaning between domains extends beyond musical studies and relates to wider work in the field of interactivity.

Computer improvisers' musical language can be based on any combination of musical material, including Western classical music and jazz. They can also use methods of algorithmic composition to create new musical concepts not available to human improvisers, such as iterative processes. The concepts of computer interactivity and artificial creativity have much broader implications beyond music. Whether a computer is theoretically capable of artistic actions raises many further theoretical and philosophical issues. Regardless of these issues, in performance computer improvisers will always be an extension of human musicality, implicit in the decisions made by the programmer and through her/his inherent link to centuries of musical development. Computer improvisers offer a different form of live musical creation, capable of creating new musical environments for both computer and human performer.

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