Nonlinear Dynamical Systems as Enablers of Exploratory Engagement with Musical Instruments

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Abstract.
This paper presents a small scale study that examined links between the inclusion of nonlinear dynamical processes in musical tools and particular kinds of engagement. Communication-oriented attitudes to engagement that view the tool as a medium for transmission of ideas are contrasted with material-oriented attitudes that focus on the specific sonic properties and behaviours of a given tool, and the latter are linked to the inclusion of nonlinear dynamical elements. Methodological issues are raised and discussed, particularly with regard to the holistic nature of musical instruments, the difficulties of independently testing isolated design elements, and potential methods for addressing these difficulties.

Keywords: Nonlinear dynamical systems, engagement, exploration, mapping, free improvisation

1 Introduction

This paper examines the use of nonlinear dynamical systems as elements within the design of digital musical tools, and the effects they can have on how musicians approach using such tools. A short study is presented alongside the preliminary results.

Worth (2011) distinguishes between two contrasting approaches to engaging with musical tools. The first – referred to as *idealist* - views the tool as an ideally transparent medium through which the musician's ideas pass from thought to sound. The second perspective – referred to as *literalist* - is more material-oriented, and views the tool as something to be engaged with and experimented with, and as a source of ideas. Worth traces this latter attitude in the work of artists associated with the Mego label, but similar attitudes can be found in other fields, notably free improvisation where the instrument is variously referred to as an "ally" (Bailey 1992), something to have a "relationship" with (Unami 2005), something with it's own "intentions" (Hopkins 2012), and where the performer may be "played by" the instrument (Borgo 2007, p 57). Keep (2009) discusses similar attitudes in experimental music, where the exploration of inherent sonic properties plays a significant role. Gurevich and Treviño (2007) discuss the tendency towards the former idealist approach in the NIME community, noting that the term *expression* seems to include a tacit assumption that the performer's role is to communicate something "extramusical", and that this assumption risks excluding alternative modes of engagement such as those found in experimental musical practices. Musicians concerned with a more literalist approach often seem to value instabilities and unpredictable elements in their engagement with a given tool (Keep 2009, Unami 2005, Prévost 2007, Warburton 2001).

This paper links these elements to the properties of nonlinear dynamical systems, and examines potential links between the inclusion of such processes in musical tools, and particular approaches to engaging with these tools. A study was conducted in which participants engaged with a range of different digital musical interfaces, some of which included nonlinear dynamical elements and some of which did not. Although concrete conclusions are difficult to draw from this initial small-scale

study, the findings suggest links between specific design decisions taken in creating musical tools and the approaches taken by musicians to engaging with these tools, particularly a link between the nonlinear dynamical elements and more open exploratory engagement as opposed to communicating pre-established ideas. This research has relevance for considerations of musical instrument design, and for considering the relationships between contemporary musical practices and contemporary musical tools. It may also be relevant to HCI more broadly, particularly in situations where designers wish to foster creative engagement and exploration, for example in interactive drawing tools or in computer games (physics based games already provide interesting examples of exploratory engagement with dynamical systems).

Nonlinear dynamical systems and their relation to musical practice are considered in more detail below in section 2 and an overview of past work is given in section 3. This is followed by description of the methodology used in the study, initial findings, and discussion contextualising these results and highlighting interesting aspects of the methodology.

2 Nonlinear Dynamical Systems and Music

Chaos, instability, unpredictability, and complex behaviours are all closely associated with nonlinear dynamical systems (Strogatz 1994). Links between such systems and musical behaviours have been noted and explored in a variety of contexts. Pressing (1988) describes the links between their properties and approaches to composition. Many composers have worked explicitly with such systems: e.g. David Tudor, Insook Choi, David Dunn, Ryo Ikeshiro, Dan Slater, and countless others. Microphone-loudspeaker feedback provides a simple example of a nonlinear dynamical system affording a complex range of musical behaviours: the system may change over time with fixed input (e.g. swelling or fading away), there are abrupt transition points where the system will jump from one relatively stable state to another (e.g. abrupt changes in register to different harmonics), it is chaotic in that it is highly sensitive to initial conditions, and it exhibits hysteresis, such that the state of the system depends not only on the present input, but on the history of the input, enabling properties such as mode locking (e.g. placing the microphone in exactly the same place may not produce the same pitch every time).

Nonlinear dynamical systems can be found in the workings of many acoustic instruments: governing airflow in wind instruments, in the relationship between reed movement and airflow in the bore of reed instruments, bowing interactions in string and percussion instruments, and in more subtle aspects of many other instruments (Smith 2010). Free improvising and experimental musicians often seem drawn to these elements: bowing objects, using feedback (acoustic or electronic), working directly with piano strings rather than the keys, exploring multiphonics and unstable areas in reed instruments, etc.

3 Related Work

Hunt and Kirk (2000) studied the effect that complex mappings could have on engagement with musical systems and observed that interfaces incorporating complex mappings were often seen as more fun, and helped to facilitate complex musical gestures. A similar result may be expected from nonlinear dynamical systems as they interrelate inputs and outputs in a similar manner, but add further complexities in the form of time dependence and nonlinearity. Extending the complexities of the interaction in this way may therefore yield a similar alteration in engagement and affordances. The language used by many researchers working with nonlinear dynamical systems in music seems to support this claim. Burns and Burtner (2004) describe interaction with their feedback networks as “engaging” with a system rather than “commanding” a system. Kiefer (2014) talks of the “compelling, unpredictable, and strangely lifelike behaviours” encountered in perturbing musical systems based on echo state networks. Bowers and Hellström (2000) describe how the inclusion of nonlinear

dynamical aspects in their instruments goes beyond merely supporting exploration, and actively "incites" it.

Precedent for attempting to investigate the effect of nonlinear dynamical instruments on creative and exploratory engagement can be found in the longitudinal study conducted by Gelineck and Serafin (2012). Modular devices that incorporated physical modelling elements were given to three experimental composers for a period of several weeks. A common response from the participants that the instruments were unpredictable and too difficult to control, and that they would be impractical in a live environment. The definition of the term experimental in this context appears to be much broader than the specific meaning used by Nyman (1974) and Saunders (2009) and referred to in section 1 in relation to a literalist model of engagement; almost all the participants appeared to be attempting to pass their ideas transparently through the tools, as opposed to engaging with and exploring their specific sonic properties. An important distinction between the present study and the study conducted by Gelineck and Serafin is that free improvisation plays a significant role in the practice of several participants of the present study, allowing for a comparison between the attitudes of musicians working with a more material-oriented approach with those engaged in communication-oriented practices.

4. Methodology

Four interfaces were created for the purposes of this study: two based around nonlinear dynamical processes, and two that did not include such processes. The four systems are described in more depth later in this section, and an overview is provided in table 1. Each system took the same input: two dials and a slider from a MIDI controller. Four participants were asked to engage with each of the four interfaces for 5-10 minutes, to create a short 1-4 minute recording, and to complete a questionnaire for each interface. Short interviews were then conducted at the end of the session. The order in which the interfaces were presented was randomised for each participant.

4.1 Comparable Interfaces

A wide range of factors may affect a musician's experience and engagement with a particular musical system, making it difficult to establish the significance of a specific element. The inputs, mappings, and available sound world may all contribute to the nature of a musician's (or non-musician's) engagement. The specific designs of the four interfaces attempt to address some of these considerations (leaving aside the influence of the input controller for the purposes of this study). In particular, these four interfaces attempt to distinguish the influence on participant engagement of the nonlinear dynamical elements as distinct from both nonlinearities in static mappings, and from the particular sound world afforded by each interface.

Table 1. The four interfaces used in the study

Interface	Nonlinear Dynamical	Mapping	Audio Engine
1	Yes	Continuous	Resonated Duffing oscillator
2	Yes	Discontinuous	Resonated Duffing oscillator
3	No	Discontinuous	Resonated oscillator
4	No	Continuous	Granulated sample player

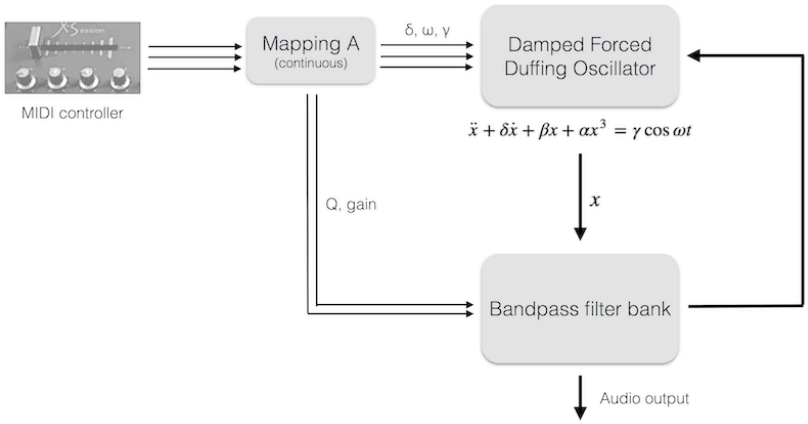

Fig. 1. Interface 1. A damped forced Duffing oscillator coupled with a bank of linear resonators. The user interacts with the system via three MIDI controls.

Interface 1 – Nonlinear dynamical system with mapping A

Both interfaces 1 and 2 are based on a damped forced Duffing oscillator (Guckenheimer and Holmes 1983), shown below as a discrete map. This is a nonlinear dynamical system that models the

$$x_{n+1} = y_n$$
$$y_{n+1} = -\delta y_n - \beta x_n - \alpha x_n^3 - \gamma sin(\omega t)$$

forced vibrations of a beam that is fixed at one end.

This equation is implemented at sample rate and coupled with a set of resonators such that the x_n term is passed through the filter bank, and the output of the filter bank is used in its place in the above equation. This combination of a nonlinear function coupled with a linear resonator bears a close resemblance to the structure of many acoustic instruments (McIntyre et al. 1983) and hence to many physical models (Smith 2010). The specific structure of interface 1 is shown in figure 1.

Interface 2 – Nonlinear dynamical system with mapping B

Interface 2 differs from interface 1 only in terms of the mapping from the MIDI controls to the system parameters: interface 1 uses continuous linear changes (mapping A), whilst interface 2 uses discontinuous mappings that cause jumps in the parameters at particular points (mapping B). This distinction was included to assess how significant the nonlinear dynamical component was in comparison with the static discontinuities in the mapping. In other respects this interface is the same as interface 1.

Interface 3 – Static system with mapping B

Interface 3 is very similar to interface 2, but with the Duffing system removed as shown in figure 2, rendering the interface non-dynamical and linear. The discontinuous mapping is retained however. Although the system is similar to interface 2 and to a lesser extent interface 1 in terms of the processes involved, the range of possible sounds is very different.

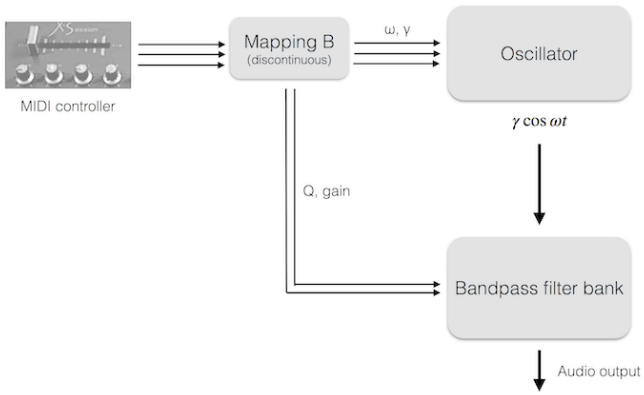

Fig. 2. Interface 3. Duffing system and the feedback are removed, leaving an oscillator and resonant filter bank. Discontinuous mapping B is otherwise preserved from interface 2.

Interface 4 – Static System based on audio recording of interface 1

Interface 4 attempts to preserve the sound world of the Duffing systems by basing the interface around a two minute audio file recorded from interface 1. The system is therefore not a nonlinear dynamical system, but retains a very similar sound world to interfaces 1 and 2. The inputs are mapped to position in the sample, granular pitch and overall volume.

4.2 Participants and data collection

All recruited participants had a significant background in music, but varied considerably according to how significant they felt that free improvisation was in their own practice. The questionnaires asked participants to use Likert scales to measure their agreement with statements relating to: how unpredictable they found each interface, to what extent they could repeat an action, how much they felt they understood each interface, to what extent they felt that there was more to discover, and whether they felt that the interface fitted in with their own practice. In addition, participants were asked to rank the interfaces according to how satisfying they found their experience. Data was logged from the systems themselves, allowing concrete differences in engagement to be examined in the participants' recordings and practice sessions.

5. Preliminary Results

As mentioned above, this is a preliminary study where refinements to the methodology are as relevant as findings from the data. As the sample size is small, the numerical data is not strong enough to produce concrete evidence of any particular hypothesis, but helps to provide broader pictures of user engagement when combined with questionnaire and interview responses. The results shown below therefore highlight potential areas for more detailed study.

5.1 Differences in attitude between self-professed improvisers and non-improvisers

The four participants – A, B, C and D - varied in terms of their engagement with free improvisation, rating themselves respectively as 1, 5, 7 and 8 on a scale from 0 (no engagement) to 10 (entire practice). The three participants that professed an interest in improvisation all felt most 'satisfied' by interface 1. The interviews highlighted a range of justifications for this, such as:

- "[interface 1] was really fun [...] much more enjoyable" [compared to interface 2] – participant C
- "I felt I could explore, the unpredictability was nice" - participant D
- "I felt like it changed more, it was more variable" - participant B

Participant D linked interfaces 1 and 2 closely however and referred to both as being open to exploration. Participants B and C differed in how unpredictable they found interface 1 however, with some rating interface 4 and interface 2 as equally or more difficult to predict. Participants B and D both felt that the interface fitted in best with their existing practice compared with the other interfaces.

By contrast, participant A, who did not identify as an improviser (1/10) ranked interface 1 as the least satisfying of the set. Interfaces 1 and 2 were grouped together as being more unpredictable than interfaces 3 and 4, and despite describing the unpredictable elements as fun, preferred interface 3:

> [...] it was easier to [...] get somewhere I had in my mind. The other ones were more noisy [...] so I couldn't control [them] that much. (participant A)

5.2 Influence of the specific sounds afforded by each interface

The available sound worlds in the various interfaces appeared to play a key role in the participants' preferences and their approach to engaging with the interfaces. Participant A's preference for interface 3 over interface 1 was due at least in part to the scope for "Stockhausen-like" staccato sounds in interface 3 that the participant preferred to the "droney" sounds of interface 1.

Participant B was similarly influenced by the sound world and felt as though preference for a particular interface's sound combined with the potential for variety were the chief factors in determining their preference.

5.3 Significance of the mapping

Given the similarities at the core of interfaces 1 and 2, there were some surprising differences in the participant's attitudes towards them. Participant C saw interface 2 as significantly more unpredictable, and "a bit of a wilderness", worrying that it would be a problem in live performance, and as noted above, was consequently less enjoyable. The participant ranked it as the least satisfying despite ranking interface 1 as the most satisfying. Participant B preferred the continuous nature of interfaces 1 and 4 as they allowed for small, incremental adjustments, as opposed to interface 2 where "the margin seemed to be quite fine".

5.4 Exploratory engagement

As mentioned in several of the quotes above, interfaces 1 and 2 were generally linked to an exploratory approach, whether participants saw this as something that suited their own practice or not. Participants' Likert scale responses tended to agree with the statement "I feel that there are many areas that I could still explore and discover" in relation to interfaces 1 and 2. Participant A and participant C both seemed less inclined to explore freely and both expressed some frustration with trying to achieve ideas that they had in their head through the interfaces that they perceived as more unpredictable. This is illustrated in the quote from participant A given in section 5.1. Participant C sees the unpredictability as a problem under particular circumstances (notably in interface 2):

> when something has happened that might have been a bit unpredictable [...] there's a certain couple of things that you can do that will get you to where you want to go [...] an overall idea that you have in mind, but obviously if it's too unpredictable then you can't even do that. (participant C)

Participant D felt that unpredictability was a problem in certain situations but not others: "in the ones that I felt that I could still explore, then the unpredictability was a good thing". Interfaces 3 and 4 were seen as frustrating to engage with in an exploratory manner and instead, were considered as something that might be more appropriate for them to use in a song based context. Participant C also made a distinction in the kinds of interaction they felt would be relevant for different areas of their practice, aspects that were too unpredictable were not seen as appropriate for song-based contexts.

6. Discussion

The results point at potential links between the nonlinear dynamical elements and a tendency for exploratory engagement, albeit with certain caveats relating to the methodology (discussed further below). A common thread across the four interviews was the appropriateness of different kinds of interaction for different musical contexts, which is consistent with the distinctions in how people with differing musical practices and backgrounds responded to the different elements. Examining participant's responses in terms of the communication and material oriented approaches outlined in section 1 appears to be a useful approach, and provides a framework for considering differences in attitude across the different participants. These results can be compared with Hunt and Kirk (2000) who also concluded that whilst some saw complex interactions as being more fun, some users preferred interfaces that provided more simple controls for individual sonic parameters. The present study suggests however that participants may actually alter their attitude towards complexity - and particularly unpredictability - given the specific nature of the interface, and the musical style that is suggested by a particular interface.

The methodological insights encountered through conducting this study are also of interest. The instruments could be stripped back to just the elements under consideration and simplified in all other respects, but as Stowell and McLean (2013) point out, this may reduce the instrument to the point of being unmusical. This study takes the opposite approach in order to attempt to encourage rich musical interactions between participants and the tools. The interfaces are therefore complex and contain many aspects beyond those directly under consideration, making it more difficult to isolate the influence of the nonlinear dynamical systems. The differences in attitude that some participants had towards interfaces 1 and 2 seems to highlight this, as they use the same underlying system, and differ only in the nature of the mapping to the system. This study has attempted to get around such problems by including multiple mappings so these distinctions can at least be noted, and so that it may be possible to separate changes in engagement that relate to this mapping decision as opposed to the nonlinear dynamical system. The use of a system which generates sounds similar to the nonlinear dynamical interfaces (interface 4), and a system which is technically similar (interface 3) is likewise an attempt to separate the effect of the nonlinear dynamical elements from the influence of both the specific sounds available and from the other aspects of the sound engine beyond the nonlinear dynamical component. Using this approach, results that present distinctions between interfaces 1 and 2, compared with interfaces 3 and 4 are therefore more likely to relate to the influence of the nonlinear dynamical elements, and less likely to relate to the other elements.

7. Summary

The small scale study presented in this paper suggests links between the inclusion of nonlinear dynamical processes in musical tools and particular kinds of engagement. Distinctions are made between approaches that focus on communicating ideas that are formed independently of the tool and approaches that focus on exploring the specific sonic properties of the tool. Links are made between the latter mode of engagement and the use of nonlinear dynamical processes. Methodological issues are raised and discussed, particularly with regard to the holistic nature of musical instruments, the difficulties of independently testing isolated design elements, and potential methods for addressing these difficulties. The results at this stage are tentative, and further studies are proposed with greater participant numbers.

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