A Practical and Theoretical Introduction to Chaotic Musical Systems

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Abstract. This paper is an extended dialogue on the workshop themes of nonlinearity, feedback, and chaos in musical instrument and interaction design. Following a brief introduction to the area, perspectives are brought from the three authors on their practice and research in this field. Cross examination of these perspectives leads to the suggestion of some open research questions. The original workshop description is included as an Appendix.

Keywords: nonlinear dynamics, chaotic musical systems, interaction design, agency, autonomy, emergence, feedback, audible ecosystems.

Introduction

This paper emerged from a collaborative workshop proposal on the subject of chaotic musical systems. Behind the workshop was the desire to collide the various perspectives the authors bring from their engagement with chaotic and nonlinear systems in their research and musical practice. The intended aim of this three-headed approach is to illuminate the points of resonance and difference between the positions of the authors - with the hope that this knowledge sharing could be fruitful in theorising the overlap between musicality and unpredictability, and stand as a platform for further research in this area. At the heart of the workshop and this paper is a double articulation between theoretical and practical concerns, where multiple perspectives are brought into dialogue - with an emphasis on the challenges posed by these techniques to the various features of musicality as it relates to digital instrument design. Nonlinear and chaotic systems provide a distinct set of resistances and affordances in performance, cleaving a space for reassessing our categories in thinking human-machine interaction.

Background

A wide body of literature and practices have developed around the use of chaotic systems for musical ends over the past 50 years. Ranging from their deployment as structural processes for composition (Pressing 1988), to their use in digital and analogue synthesis methods (Choi 1994, Dunn 2007, Slater 1998, Tudor 1995). They may be used explicitly as named systems, such as Choi's use of Chua circuits, Dunn and Ikeshiro's use of the Lorenz attractor, Pressing's use of the Logistic map and predator-prey models, Di Scipio's sine map, Ian Fritz' implementation of a Jerk (Elwakil 2004) equation, or Andrew Fitch's implementation of coupled Wien Bridge oscillators (Yang and Li 2002) for analogue synthesis. They may also be explored more intuitively in feedback systems, whether with analogue electronics, microphones and loudspeakers, guitars and amplifiers, or in digital feedback systems. While a full literature review of the subject is beyond the scope of this paper (see Sanfilippo and Valle (2013) for a useful overview), it's important to note that chaotic systems have enabled a rich and diverse set of musical practices at multiple time scales - both at the level of sound generation, and at higher order structural levels - often with feedback and interdependency between the two. Without being overly deterministic, a theme that runs throughout this canon of practices is that systems which are iterative, structurally coupled internally and/or to their environment, and display some degree of self-organisation – all bear some resemblance to and have resonance with the loose and distinctly humanist category of 'musicality'.

Perspectives

Tom Mudd

My interest in nonlinear dynamical systems stems from wanting to improvise with digital tools. In particular wanting to create tools that I can explore over extended periods of time, finding and discovering sounds and behaviours that I couldn't have envisaged in creating those tools. Many free improvisers have described a sense of surprise with their instrument even after months, years or decades (Kopf 1986, Warburton 2001, Prévost 2008). How can instruments that may be relatively simple in construction be so endlessly unpredictable and explorable? My recent research has been investigating the role of nonlinear dynamical processes in musical interactions: iterative systems where the output is a nonlinear function of both the current inputs to the system (e.g. the musician's actions at a given point in time), and the previous output from the system. Although the abstract mathematical nature of these systems may seem distant from the concerns of saxophonists or violinists, acoustic instruments can be seen in very similar terms. Reed and bowed instruments in particular can be seen as nonlinear dynamical processes (Smith 2010), and physical models of such acoustic instrument necessarily involve nonlinear functions and feedback.

The result - whether implemented digitally or acoustically - may often produce situations where the interaction is confusing and difficult. While this may sound like a problem, particularly in the context of interaction design, in musical situations this can be a virtue: the instrument will throw things back at the performer that they may not have been able to predict, and allows room for an interaction in which the musician has a relationship with the instrument rather than commanding it (Unami, 2005). The mechanisms that create the "difficult" interactions may also be responsible for the richness of possibilities on those instruments. John Butcher provides an excellent example: through exploring the points where the reed ``seizes up and brakes down [...] on the edge of controllable sound'' (Warburton 2001) he finds a wealth of amazing resources which may be explored seemingly endlessly. A somewhat trite comparison might be to the infinite detail that may be found at the edges of a fractal structure, only in this case this is not an analogy at all, as fractals are, in general, also iterated nonlinear functions and the levels of detail found at these edge points are potentially connected in a very real way.

These ideas were explored in a recent study into how musician engage differently with digital systems that do and do not contain nonlinear dynamical components (Mudd et al, 2015). Participants of varying musical backgrounds engaged with a range of representative systems, and their behaviours, responses and attitudes were recorded and analysed. The study suggested potential links between the inclusion of such processes and the affordance of exploration and serendipitous discovery. The results are difficult to generalise from the specific systems considered to nonlinear dynamics more broadly however.

My musical practice has involved digital implementations of nonlinear dynamical processes to synthesise sound. Recent, fruitful work couples relatively `simple' nonlinear dynamical systems, such as the Duffing Oscillator, to banks of resonant filters. The output from the filters is fed back to the nonlinear equation at audio rate (currently implemented as an external in MaxMSP). This bears a resemblance to many physical models, where the reed or the bow behaviour represents the nonlinear function, and the resonant filters represent the linear response of the string or vibrating air column. The resonant filters serve to tame the chaotic nature of the nonlinear dynamical system to an extent, so that controlling the resonance controls the stability of the system. The systems are similar in kind to those described for the empirical study (Mudd et al 2014; 2015) and are described in more detail there.

Tristan Clutterbuck

My perspective on nonlinear and chaotic musical systems derives primarily from an interest in the provocation these tools provide in challenging our theorisations of what it means to be ‘social’ in musical practice. This provocation lies in the ways in which these kinds of systems tend to display complex behaviours over multiple orders and timescales - the question this poses is how can it be said that objects *do* things in the course of social action? In order to address this problematic I turn to the sociology of actor-network and material semiotics (Latour 2007, Law 2008, Suchman 2006). My background lies much closer to the social sciences than mathematics or physics - so whilst I’m interested in the various means of describing these systems mathematically and the aesthetics of their behaviour, my stake is not so much in carving out a partisan position on interaction / system design. I’m more interested in describing the ways in which these systems, and the various nebulous concepts which orbit them (agency, autonomy, etc.), collide with the rich social fabric of *musicking* - a concept which somehow brings together practices, rituals, genres, sounds, time, histories, amongst countless other ideas. My recent research has been involved in grappling with the difficulties of writing a longitudinal sociological analysis of musical practices which construct incredibly complex assemblages of ‘autonomous’ technologies, institutions, bodies, and identities. A strong focus is on trying to overcome simple anthropomorphisms in describing the agency of chaotic musical systems by widening the frame, or *unit of analysis* of these tools. In order that we might illuminate the *other* entities which transform, mediate, overcome, and dominate the ‘agencies’ of our musical systems. When our systems act, what else is acting?

The other side of my research which feeds these theoretical concerns, is musical practice based in free improvisation with chaotic and nonlinear systems. Engaging with explicitly ‘agentive’ musical systems, systems which display varying degrees of autonomy at micro and meso structural levels. This began with a close exploration of Rob Hordijk’s (Hordijk 2009) rungler circuit in both analogue and digital instantiations, but has been followed by engagement with the analogue circuits of Grant Richter, Ian Fritz, and Andrew Fitch. All of these designs share the emergent property through performance that they *feel* like you’re engaging with something which has it’s own sense of direction and agency. The instrument is in a complex play between equilibrium and instability, with myself interfering in order to push it in either direction. These tools *operate* on us in strange ways, through their seeming capacity to make 'musical' decisions – even if, when we open up the black box these behaviours are the emergent property of some incredibly simple processes. A concept of cognitive scientist Andy Clark’s (Clark 1998) which I find useful to employ to describe this relationship is that of continuous reciprocal causation. A double articulation is at the core of this interaction, it’s impossible to separate the movements of the performer and the movements of the instrument - these entities cannot be viewed under a strict ‘action - response’ paradigm.

Given these observations, one might propose to apply some thesis on objectural agency to musical practice in order to tie up these loose ends. But on closer examination things are not that simple, and what on face value looks like a singular agency displayed by this kind of system, turns out to be not as straightforward as it might seem. For one thing, they seem to play two roles at the same time, at once a straightforward musical instrument (nonlinear, chaotic, and multistable characteristics are displayed in a number of traditional musical instruments, and canonised experimental systems from the avant-garde onward), and at the same time acting as an instance of cultural memory, operating more in the capacity of a score than an instrument, (I’m referring to their meso structural capabilities, and larger scale structural decisions made by systems like George Lewis’ voyager (Lewis 2000)) where the designer reaches through time and space to ‘takeover’ and constrain a performer's agency during performance. Here agency is dislocal, and decontemporalised, and the dichotomy between designer and performer is often unclear - but again, could the same also be true of traditional musical instruments? Could the cello for example, also be viewed situatedly, and ecologically, as a meso-structural device based on the parameters of the length and speed of a human arm, and the size of the body of the instrument. A difference only of agential scale, not type. These multiple duplicities put a strain on traditional theorisations of instrument/performer relations. There’s a plurality at the heart of these objects, a kind of phasing between states, which makes it difficult to make any definitive truth claim about their being or capability to act, at once faced with something seemingly so singular, and unique in it’s ability to act, yet also strikingly familiar in their resemblance to traditional forms. It’s my contention that complex systems are no special case of objective agency, but rather act as a kind of compressor for musical agency *writ large*, a drawing into a single locale vast networks of relationships, threads of agency, transformations in the course of action. Entities which are normally so distributed in time and space as to have their effect written out of, or merely into the background of the course of social action. These systems are vast ecologies scaled to the everyday interaction space of the human mind that is locally and concurrently.

To focus on these as objects of a singular type with the capacity to act in musical interaction is to close down an analysis of how they are embedded in a complex web of social mediations at multiple scales (Born 2010).

Dario Sanfilippo

My research focuses on the exploration and study of topics that include complexity science (Mitchell 2006, Morin 2006, Kitto 2006), cybernetics and systems theory (Ashby 1956, Heylighen 2001), chaos theory, graph theory, interactivity and synergetics (Corning 2002), as well as their applications for the design of living and intelligent sonic systems for human-machine interaction performance, autonomous sound installations, and nonconventional sound synthesis and processing techniques (Sanfilippo 2013). Within this framework, concepts, technology and creative practices are interdependent and codetermine themselves with the goal to merge science and art by establishing a bidirectional communication between these two areas.

The implementation of systems which are capable of evolving autonomously and non-trivially (von Foerster 2003) is a fundamental aspect of my work, as a condition where both the human and the machine can generate actions and reactions is necessary in order to have mutual influence — interaction. These systems exhibit an individuality, organicity and expressivity characterising some sort of artificial life form that emerges from networks of recursive and nonlinear interdependencies, for which improvisation is the functional mechanism - aural feedback - that allows the cross-coupling of two entities which simultaneously perturb and adapt to each other. Even in the low-level, sound streams affect each other and shape themselves and interactivity becomes a structural characteristic distributed at all scales and domains. Time and frequency are indeed strictly interrelated and as a result the sonic quality (timbre) affects the quality of the dynamical behaviours (form) and vice versa (Di Scipio 2003).

Every component - analogue or digital - which is within a feedback loop (Sanfilippo et al. 2013) in the network becomes a unit with a systemic and fundamental role in the totality: something that contributes to the resulting global behaviour of the system. As a consequence, the quality of the single devices or algorithms used is meaningless in relation to the whole. Different components, regardless of their quality, will generate different emergent behaviours which are not to be considered as better or worse than others. The environment, too, can become structurally connected to the system by means of external feedback configurations - for example using aerial microphones and loudspeakers - so that the particular anti/resonances and all the possible perturbations of an environment will be essential for that specific sonic result. This way, there is no constraint as of what kind of equipment/technology is used and what the characteristics of an environment are, as every situation is potentially an interesting one.

Openings

Rather than provide conclusions from this brief overview, it seems more useful to cross examine the perspectives and histories provided to suggest some open questions, or areas of further research in this field. Chaotic and nonlinear systems in relation to musical practices weave together a complex set of threads from cognitive science, biology, physics, mathematics, the arts, social sciences, and philosophy. With obvious prospects for interdisciplinary work, and knowledge sharing between the arts and sciences. Open questions fall around the utility of 'simple' modelling techniques to describe a reduced version of incredibly complex 'real' systems of humans and non-humans. How can we mobilise our mathematical understanding of complex systems in the description and understanding of something as 'loose' and heterogeneous as musical practice? What role do these systems already play in our interactions with musical tools, and how are these systems understood by musicians that use them? What can qualitative methods tell us about the scale of nonlinearity required for a system to feel musically useful?

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Appendix

Workshop Description

Introduction

This one-day workshop explores iterative feedback processes in the design of musical tools, and the questions these types of processes pose for theorising agency, autonomy, interaction design, sociality, and causality. Participants will be introduced to three approaches to implementing chaotic, nonlinear systems in real-time signal processing environments (Max and Pd), each relating to the artistic practices and research interests of the workshop leaders - culminating in an open session where participants are encouraged to adapt these techniques in developing their own implementations. At the heart of this workshop is a double articulation between theoretical and practical concerns, where multiple perspectives are brought into dialogue across the three sessions - with an emphasis on the challenges posed by these techniques to the various features of musicality as it relates to digital instrument design. Nonlinear and chaotic systems provide a distinct set of resistances and affordances in performance, cleaving a space for reassessing our categories in thinking human-machine interaction.

Workshop Structure

The workshop will be divided into 6 parts as follows:

1. Introduction (30 mins)
2. Session A: Recursive signal processing with Dario Sanfilippo (1 hour)
3. Session B: Shift registers in Gen~ with Tristan Clutterbuck (1 hour)
4. Session C: Pseudo physical models with Tom Mudd (1 hour)
5. Participants implement and explore techniques introduced in the previous sessions with guidance from workshop leaders (1 hour)
6. Group discussion and demoing of participants’ projects (1 hour)

Workshop Outcomes

- Provide participants with an overview of the theoretical terrain of chaotic and nonlinear interaction as it relates to artistic practices: whether acoustic, electronic, or digital.
- Gain an introductory insight into the development of such processes in designing musical systems - a design paradigm where by necessity musical instruments and tools must be *collaborated* with. In opposition to a tool theory of top-down control, with a linear conception of action from performer - instrument. Chaotic and nonlinear systems instantiate a push-pull relationship between a performer and their tools.
- The implementation of participant's own nonlinear/chaotic system design based on the techniques introduced throughout the day, and following guidance from the workshop leaders.
- A group discussion / demonstration on the broader aesthetic ideas surrounding the design, development and use of such systems.

Part 1: Workshop Introduction (30 mins)

The notions of nonlinearity, circular causality and iteration will be introduced and related to the capacity for self-organisation and emergent behaviour. The term *chaos* will be explored in more detail and distinguished from other kinds of unpredictability that result from stochastic approaches. These ideas will be explored in relation to paradigms of instrument design, musicality, and the constitution of the units performer, instrument, environment - with a view to opening up questions of what it means to think systemically, or ecologically. The aim of this introduction is to lay out the possible topography of practice/theory that can be traversed through engagement with these kinds of tools, by bringing into dialogue the differing and frictional perspectives of the three workshop leaders.

Part 2: Session A: Recursive signal processing with Dario Sanfilippo (1 hour)

In this session, audio processing techniques will be explored within the framework of time-variant feedback delay networks. After a theoretical introduction regarding the properties and characteristics of feedback systems, some common algorithms will be described and implemented as self-oscillating and self-regulating units. The implementation of sound analysis techniques will also be described in order to provide the tools for the generation of control signals which will pilot the variables in the processing units so that variety and dynamical behaviours will be enhanced.

Part 3: Session B: Shift registers in Gen~ with Tristan Clutterbuck (1 hour)

This session focuses on the surprising and emergent musical properties of shift registers implemented in a feedback circuit - with some discussion on the issues posed by these simple, yet complex circuits in theorising the roles that all objects play in constructing the various threads of agency that comprise musical practices. Sample accurate processing in gen~ enables some level of emulation of the classic hardware bit shift circuits of Don Buchla (Source of Uncertainty), Grant Richter (Noisering), and Rob Hordijk (Rungler), whilst also allowing for arbitrary extension in various directions. Drawing inspiration from these designs, this session will focus on the implementation of an 8 bit shift register, where users have some influence over the level of entropy of recycled information. Participants will be provided with an initial max patch, walked through the signal flow of the circuit, and encouraged to experiment with feedback paths and modulation sources - the overall goal being that of demystification, opening up the black box, in order to question the aesthetics and behaviour of a circuit that on the surface displays some level of autonomy.

Part 4: Session C: Pseudo physical models with Tom Mudd (1 hour)

Tom Mudd will introduce his work on simple digital nonlinear dynamical systems constrained by resonant filter banks. The latter act to regulate the chaotic properties of the system, resulting in instruments that are directly analogous to acoustic systems: nonlinear systems (e.g. reeds or bow-string interactions) coupled with resonating bodies (e.g. vibrating strings or air columns). The resultant systems are not directly modelling any specific acoustic situation, but nevertheless incorporate sonic and behavioural elements as they might be encountered in physical acoustic situations. Participants will be provided with a starting example made in MaxMSP and encouraged to adapt and explore different approaches to resonance, nonlinear functions, and different approaches to controlling the whole system.This work is motivated by a desire to create tools for live performance that offer complex, often unpredictable responses to simple input and can thus become rich resources for sonic exploration. It draws on an examination of the incredibly complex nonlinear dynamical processes found in many seemingly simple acoustic systems.

Part 5: Participants further explore some of the above approaches with assistance from workshop leaders (1 hour)

Time is allocated for participants to develop their work from any of the three sessions. Expanding upon, and modifying the examples provided earlier in the day. Workshop leaders will be present to provide practical assistance and answer questions.

Part 6: Group discussion and demoing of workshopped projects (1 hour)

Group discussion between all participants and workshop leaders reflecting on theoretical, aesthetic and practical aspects that emerge from the workshop. Participants may demonstrate the projects they have developed over the course of the day, providing concrete practical examples to seed a discussion in broader terms.