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# Dynamical Interactions with Electronic Instruments

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## ABSTRACT

This paper examines electronic instruments that incorporate dynamical systems, where the behaviour of the instrument depends not only upon the immediate input to the instrument, but also on the past input. Five instruments are presented as case studies: Michel Waisvisz' *Cracklebox*, Dylan Menzies' *Spiro*, no-input mixing desk, the author's *Feedback Joypad*, and microphone-loudspeaker feedback. Links are suggested between the sonic affordances of each instrument and the dynamical mechanisms embedded in them. These affordances are contrasted with those of non-dynamical instruments such as the Theremin and sample-based instruments. This is discussed in the context of contemporary, material-oriented approaches to composition and particularly to free improvisation where elements such as unpredictability and instability are often of interest, and the process of exploration and discovery is an important part of the practice.

## Keywords

Dynamical systems, nonlinearity, free improvisation, affordance, mapping

## 1. INTRODUCTION

This paper examines electronic instruments with dynamical elements, where the audible output is dependent not only on the instantaneous state of a user's input - i.e. the current values of the various controllable parameters - but also on the history of the user's input. This examination is motivated by particular contemporary attitudes to musical tools in composition and improvisation where the acceptance that ideas are often formed through active engagement with such tools, and the recognition that the instrument is not a transparent medium, are deeply embedded ([14]; [1, p. 1]; [4, p. 276]; [2, p. 205, 286]; [23, p. 65]; [6]). It is hypothesised that the potential for *exploration* of musical territory afforded by the tool may be enriched through the inclusion of such dynamical elements.

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Free improvisation in particular provides an interesting perspective on the relationship between humans, tools and creativity. Although generalisations about free improvisation are difficult, one relatively consistent element is the focus on searching and exploration. In terms of engagement with tools, this presents a relatively unusual situation in that the tool is not a means to achieve a fixed end, but something that is actively investigated by the musician during the performance. The requirements that a musician will have of their instrument can therefore be very different from the requirements of everyday tools and of musical instruments in less exploratory contexts. Any method of eliciting sound from the instrument is as valid as any other, just as any sound is as potentially valid as any other: scratching the body of a violin, bowing with the wood of the bow, rubbing the body with a finger, extremely gentle bowing, extremely harsh bowing, etc.

Many free improvisors embrace chaotic or unstable elements in their instruments, whether electronic or acoustic. Saxophonist John Butcher has said of his practice that "a lot of the material I work with is right at the border of the instrument - the reed - seizing up and breaking down. It's on the edge of controllable sound." [21]. This attitude is perhaps an explanation for the widespread use of feedback in improvisation, as this is a useful way to achieve unstable, chaotic properties with simple systems.

A discussion of the properties and affordances of dynamical elements in musical instruments is followed by five case studies of instruments that include such elements, and for contrast, two that do not, linking each to specific musical proclivities and affordances.

## 2. AFFORDANCES IN ELECTRONIC AND ACOUSTIC INSTRUMENTS

It is useful here to consider the dynamical nature of acoustic instruments. Blown instruments, bowed instruments, plucked instruments and struck instruments have nonlinear dynamical properties which can be explored and exploited by performers [15, 19]. Although electronic instruments should not be relegated to simulating acoustic instruments, a common criticism of electronic instruments when comparing the two is a perceived lack of depth and expression [5, 16, 9]. The terms depth and expression can be problematic however as they are both relative to particular attitudes to music. Attempting to compare software such as Ableton Live with a saxophone in terms of expression or depth is relatively meaningless, as both allow different forms of depth

and expression, and each affords different kinds of musical activity. The frustration with expression and long-term engagement in electronic instruments can perhaps be viewed as a difference in affordances: in general, electronic and particularly digital instruments allow for the slow sculpting and crafting of sounds, while acoustic instruments allow for spontaneity and subtlety of gesture (although many exceptions can be found on either side). There have been many explicit attempts to develop electronic instruments with the kinds of affordances found in acoustic instruments [7, 8, 16, 12, 11].

Hunt and Kirk [7] frame the debate in terms of engagement, stating that many electronic instruments encourage an *analytical* approach to the instrument and the sounds produced rather than the more *holistic* approach suggested by acoustic instruments. Their experiments highlight a link between long term engagement with digital instruments and the use of cross-mapped parameters: mappings where multiple inputs may effect the same output, and multiple outputs may be affected by a single input. In experiments with such interfaces, although the inner workings were not so easily understood by the participants, many judged them to be more fun to engage with over longer periods than the other interfaces. By comparison, the simple one-to-one mappings were seen by the participants as being understandable but ultimately limited, less fun and not as capable of producing complex results. Kvitte [10] reaches similar conclusions, citing complex mappings as being “more interesting and rewarding to use than systems of simple one-to-one mappings.” Dynamical systems naturally incorporate this approach, as the output is a complex combination of a variety of inputs.

### 3. MUSICAL PROPERTIES OF DYNAMICAL INTERACTIONS

The nonlinear dynamical nature of certain acoustic instruments, such as the feedback relationship between the reed and the bore in saxophones and clarinets, and between bow movements and vibrating strings in string instrument [19] can be linked to their complexity, instability and unpredictability. Although these elements can be initially frustrating to users hoping to develop sufficient proficiency to be able to put the instrument to use towards a particular end, these unpredictable areas can be very rich areas to explore in the musical contexts described above, regardless of whether one has mastered the instrument beforehand.

Despite their potential complexity, nonlinear dynamical systems are essentially deterministic, which allows a particular series of events to be reproduced (although chaotic sensitivity to initial conditions and time-dependance may make this difficult). This points to a potentially important distinction between the nature of complexity and unpredictability in dynamical systems in comparison with stochastic systems, a difference which may be highly significant for musical interactions, and creative engagement with tools in general, but is beyond the scope of this paper.

### 4. FIVE DYNAMICAL ELECTRONIC INSTRUMENTS

The five instruments examined in this paper provide examples of dynamical electronic instruments, which is to say that through the use of feedback, they maintain a memory of past events which can affect the present interaction. Each instrument is described in an attempt to relate the dynamical mechanisms to the particular affordances of the instrument. They are selected to present a fairly wide range

of electronic instruments: they span a broad period of recent history, encompass both digital and analog approaches, include both linear and nonlinear systems, and utilise a variety of input and output methods. The properties of these instruments are then contrasted with examples of static (non-dynamical) instruments.

#### 4.1 Waisvisz’ Cracklebox

The Cracklebox (Kraakdoos) presents an interesting case study as it is comprised of a relatively basic circuit that makes use of touchpads to allow the user to connect together different parts of the circuit through their body (or through multiple bodies). The relationship between the user’s input and the sound produced can initially seem very unpredictable and unstable, and pressing the same pads at different points in time can produce different results. The touchpads are sensitive to very slight changes in finger position, and even when the fingers are kept completely still, the resultant sound is rarely stable (e.g. in pitch or volume) as the capacitors in the circuit are charging and discharging over time. In most cases the changes in output tend to be proportional to the changes in input, but chaotic points can be found where tiny adjustments in the input lead to very different trajectories in the resultant sound. In addition to this, the instrument’s behaviour begins to change as the battery power fades. This invites a certain kind of play and exploration, and although the instrument can be initially confusing it can retain interest by allowing for unexpected things to be found through longer term engagement. Musical events are repeatable, but the charging and discharging of capacitors must be taken into account to achieve this, meaning that an event cannot necessarily be repeated spontaneously.

Although the user has only six touchpads as controls, the position on each pad is of great importance, and more interestingly, the combination of pads and the timing of the presses affords a much greater range of possibilities than might be expected from a mere six controls.

#### 4.2 Menzies’ Spiro

*Spiro* represents a direct attempt by Dylan Menzies to explore the incorporation of dynamics into the control system of an instrument (see [12] for more detailed information). The instrument is deliberately simple in terms of the audio output, which consists of a modulated sine tone, inviting comparisons with Waisvisz’ *Cracklebox* described above. The result is consciously reminiscent of the cyclic sounds of birds and frogs, where patterns are repeated with subtle variations. The instrument is controlled via a MIDI keyboard using the keys, the modulation wheel and the pitch-bend control. Although the system is essentially deterministic, itself sensitivity to velocity makes it very difficult to exactly repeat a specific sound, as the velocity has an impact on the frequency of the output (see technical diagrams in [12]).

Different MIDI keys trigger enveloped oscillations with different parameters for frequency, attack, decay, waveform, mode (cycle/one-shot) and velocity sensitivity. These are combined together to determine the amplitude and frequency of a single oscillator. Different combinations of keys will create different patterns, and these combinations change over time as the envelopes for the different keys interact. In comparison to the other instruments discussed here, *Spiro* has relatively little scope for chaotic behaviour as the system is linear. Although it is tricky to repeat a sound exactly, a small change in the input parameters or the relative timing of events can only lead to a small change in the resultant sound. As such there are none of the drastic discontinuities

exhibited in the other instruments described here, and any unforeseeable emergent behaviour is largely confined to the subtleties of the sounds.

### 4.3 No-Input Mixing Desk

‘No-Input mixing desk’ has been used as a technique and as an instrument by a variety of practitioners, notably the Japanese improviser, Toshimaru Nakamura, who has become closely associated with the instrument. Mixer channels are fed back on themselves, or networked with other channels with sufficient gain for the noise in the system to feed back and produce a sound. Simple alterations to the volume and EQ can have a variety of effects on the sound: volume changes, frequency changes, rhythmic fluctuations (produced from very low frequencies) and timbral effects. While linear in places, the sound can jump dramatically at certain points with minimal adjustments to the controls (Nakamura notes [17] “It’s unpredictable and uncontrollable”). No-input mixing desk can be seen as a subcategory of audio feedback processes in general, although the system’s response is much faster than with is in the case of microphone-speaker feedback.

The simple addition of feedback to a regular mixing desk demonstrates very efficiently the power that feedback has in terms of affecting control, affordances and user engagement with a system. Mixing desks are usually examples of a one-to-one mapping *par excellence*, with each control having a very singular and separate function from the other controls, and surprises are unwanted and unlikely in such an interface. Introducing feedback into the system changes the nature of the interaction completely however, with the controls now interrelated as described above, producing sudden unexpected transitions in the sound at variable thresholds for any of the volume or EQ parameters.

### 4.4 Audio Feedback (Larsen Effect)

A wide spectrum of instruments and systems could be considered under the heading of audio feedback. The ‘audio’ prefix has been used here to denote microphone-loudspeaker feedback to separate it from other kinds of feedback, such as the no-input mixer described above, or instruments incorporating the feedback of control data. Audio feedback has a long history of use in many styles of music. Whilst it is generally employed in conjunction with a source sound (as with guitar feedback) it is often deployed as an instrument in itself both in compositions (e.g. Hugh Davies *Quintet* or Steve Reich’s *Pendulum Music*), and by a variety of improvising practitioners. The fact that feedback can be ‘explored’ has often been a key feature, and the chaotic behaviour of the feedback is embraced aesthetically ([3]; [20]; [17]; [18]). Audio feedback has interesting links with the harmonic series as feedback will often occur at integer multiples of a particular frequency based on the time taken for the sound to travel around the loop, and hence the distance between the microphone and the speaker. Although abrupt jumps in pitch occur, they are often related to a single fundamental frequency and therefore related harmonically.

The relationship therefore between the distance from microphone to speaker and the frequency of the sound produced sets up different interaction possibilities. One may move the microphone position or alter a setting that controls how the sound is passed from the microphone to the speaker (volume, EQ, delay setting, etc). Such changes may alter the frequency of the sound continuously producing smooth glissandi, but the frequency may also jump abruptly into a different register as described above. The speed of the system’s response to such changes is limited by the speed of sound. If for instance, the gain is set so that the

microphone-speaker coupling only just begins to feedback, it will take several recursions for the feedback to build up, and a change in the position of the microphone may temporarily halt the sound as the particular frequency that is feeding back is no longer reinforced by the system, and a new frequency may take time to appear. Varying the microphone gain therefore alters the rate at which the system can feedback and affords the musician some control over the behaviour. Such properties form both the character of the sound, and the nature of the interaction

### 4.5 Feedback Joypad

This instrument was created by the first author in 2008 to explore cross-mappings from a USB gamepad to a filtered digital feedback loop audio engine [13]. Resonant filters are used to pitch the feedback and various other filter, limiter, delay and feedback settings can be altered in a web of many-many mappings. The device was created for personal use, with the focus being on creating an instrument that could be used alongside acoustic performers in improvisational contexts.

The use of delay and feedback means that a user’s input may start a process which gradually tends in a particular direction over time (e.g. swelling, diminishing, shifting from one pitch to another). The state of the system at any given time is therefore dependent on the history of the user’s input. Although the instrument exhibits various discontinuities and instabilities, some of these are deliberately included through the specific parameter mappings (e.g. threshold-crossings from analog inputs), whilst some are due to the chaotic nature of the feedback system. Digital feedback loops can explore a wide range of delay times, affording different possibilities: very long delay times allow for slower and more clearly periodic phrases to be slowly evolved in different directions. Very short delay times allow for more spontaneous changes, and produce frequencies related to the inverse of the delay time. These frequencies can interfere with the frequencies selected for the resonant filters in the loop producing further instabilities. The ability to filter the feedback to specific fundamental frequencies using a three button system analogous to trumpet valves means that a continuity between stable, controllable pitches and unstable, unpredictable properties can be explored. A similar approach was employed by Menzies in his *Bird* instrument [12] allowing the instrument to play stable equal tempered pitches in a melodic fashion, or to be pushed to unstable regions that invite timbral exploration.

### 4.6 Comparisons with Static Instruments

The dynamical elements in the above instrument seem to relate to the following key tendencies:

1. one-to-one mappings between input parameters and sonic results are relatively rare; the parameters are generally interrelated in complex ways,
2. the instruments may be initially confusing and unpredictable,
3. the instruments may reward long term engagement by revealing new sounds or behaviours that are not immediately obvious.

The emergent properties of such instruments can be contrasted with the nature of a static (non-dynamical) instrument such as the Theremin. As the Theremin allows for control of only two separate parameters, frequency and volume, the instrument has essentially no hidden sonic or behavioural depths to explore, no emergent properties. Once

a user has experienced the instrument once, they are able in principle to infer all the possible states and sounds that the instrument may produce. This is not true of an instrument like the Cracklebox where the possible range of sounds and behaviours is enormously varied, and cannot be intuited without extended engagement with the instrument.

Another class of static approaches that is useful to consider is sample-based performance. In interfaces that allow for sample playback and manipulation through alterations to the segment of the sample that is currently playing (see “Scrubbing and its Variants” and “Dipping” in [22]), the relation between control and the resultant sound can be extremely nonlinear. If the content of the audio file is heterogeneous, the performer will be able to leap from one musical area to another at will and can explore the musical possibilities afforded by the particular sound file. It is however only explorable in one-dimension. Unlike the examples given above, setting the control to the same value twice will result in the same outcome (although sampling of a live audio source complicates this).

Whether the possibility for such exploration is of importance to a musician can perhaps be linked to the musician’s wider attitudes to music. The idea of music as communication from performer and/or composer to listener seems to necessitate transparent instruments that allow the musician to realise sounds that have already exist in the artists mind. This approach may be better served by static instruments. More material-oriented attitudes to music such as those cited in the introduction consider the interaction with the tool or instrument as fundamental to the musical material, and such practitioners are perhaps more inclined to explore systems that yield unexpected results.

## 5. CONCLUSIONS

The inclusions of dynamical systems in musical instruments appears to translate the properties of such systems into the musical domain, allowing for complexity of interaction, cross-mappings of parameters, chaotic points, difficulty of analysis and unpredictability of outcomes. This is not put forward as a model for all musical interaction, but rather as a mode of musical engagement that engenders specific types of affordances that can be linked to a range of current attitudes to contemporary music, and may be of particular relevance in free improvisation where many examples of dynamic instruments can be found. The properties of an instrument are viewed as a landscape of affordances to be explored by a musician that does not reveal itself all at once, as the behaviour of the system at any given point is determined not just by the instantaneous state of the inputs, but also by the history of the inputs to some degree. The deployment of dynamical elements in digital systems may have wider implications for HCI as a method of encouraging divergent responses to a given situation, and facilitating exploration and long-term engagement.

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