

# Grounded Yet Shifting: Shaping Hybrid Performance Ecologies With Dynamic Tonality

John Bowers  
john.m.bowers@gmail.com  
Independent artist-researcher  
UK

## Abstract

Rather than working with fixed scales and intervals, dynamic tonality explores the possibility that instruments and how they are tuned could dynamically change as a performance unfolds. While modulation between keys, for example, is a familiar feature of much Western music, dynamic tonality more radically extends the possibilities for tonal change in real-time. This paper examines how working with dynamic tonality can bring together instruments, interfaces, generative algorithms, sound synthesis, and processing methods to create coherent yet challenging performance ecologies. Rather than drill deep on one particular application, a variety of settings where dynamic tonality has a core role is explored. Five different methods are defined for generating scales, based on the commonality of detected pitches in a time interval, the confidence of detection, the range of alternative pitches required, amongst other considerations. Seven different performance systems are described which outline possibilities for dynamic tonality in hybrid performance environments with particular attention given to how dynamic tonality has enriched a room feedback system. The paper reflects on current performance experience before turning to possibilities for future work and speculations on the 'grounded yet shifting' aesthetic that such systems engender.

## Keywords

Dynamic tonality, performance ecology, practice-based research, artistic research, generative algorithms

## 1. Introduction

It is easy to write the history of Western music as a progressive expansion of tonal and timbral possibilities. From plainchant, through polyphony, to mixed ensembles, through music governed by single keys, to complex modulations, to twelve tone serialism, to microtonality, to atonality, to all sound having musical potential, including silence. It is equally easy to problematise nearly every term and step of this story [e.g. see 8], including the idea of progress as an ideological fiction that separates high culture from low, the dominance of imperial cultures over the primitive, what is new from what is out-moded. This paper takes a step into this complexity but tries to articulate its concerns so as to open up possibilities rather than close them down. In particular, I consider open, flexible, and dynamic understandings of tonality which are explored through a range of design possibilities, practical gigging experience, and aesthetic speculation. In this way, the paper sketches the beginnings of a practice that offers an oppositional stance to some ideologies of musical history, not just through critique, but by making, reflecting, and playing.

As a way in, let us acknowledge work that problematises the distinction between pitch and timbre. Very commonly we think of timbre as 'tone colour', the aural quality that can distinguish different instruments or musical sources independently of how they are pitched. In a series of works, Sethares and his colleagues [e.g. 23, 24, 18] have queried the robustness of this distinction. They point to examples such as gamelan music where the pitches in scales and the sound qualities of instruments are very closely intertwined. Examples can also be found in the recent history of electronic instruments. Sample-based instruments can often sound more consonant if they play scales which depart from the twelve tone equal temperament (12-ET) system that has been prominent in Western music for six centuries [23, p. V].

The separation of note specification from sound synthesis, that the MIDI standard incarnated in 1983 [16], reifies a problematic separation. Many computationally oriented



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*NIME '26, June 23–26, 2026, London, UK*

approaches to music see classic separations in software design (e.g. the model-controller-view distinctions [11]) as having a similar rationale. Accordingly, separations in computer music between, for example, 'score' and 'orchestra' as in Csound [9], seem natural and are often unquestionably reproduced. We can easily treat the design of our instruments, whether software, hardware or hybrid, and what exactly they might play as separable concerns.

However, there are many currents in the history of music which counter this picture. Harry Partch's neo-Pythagorean preoccupations led him to create instruments that were specifically designed to play the scales that he theorised [17]. For his part, Sethares explored a number of strategies, typically based around the minimisation of perceived dissonance, for defining scales that instruments could play by thinking through the interpenetration of tonality and timbre - including deriving scales for a bell, a rock, and a crystal [23].

This paper contends that such affairs are under explored in the NIME conferences - but for a few exceptions, see [14] and [20]. While it is beyond the scope of this paper to offer a full critical review, it is not controversial to claim that much research in NIME has inherited distinctions that are taken for granted in contemporary music making and which are further underwritten by common computing design wisdom. To help reorient research, I want to make three key remarks.

1) Let us take as our object of study not so much single instruments or interfaces but be sensitive to the 'performance ecology' [6] or 'performance ecosystem' [25] that they are part of. That is, we design with the hurly burly of performance in mind while acknowledging that musical resources are always plural, even if we are 'merely' talking about a single instrument in a resonant space. Such ecologies are commonly hybrid in that they bring together constituents of varied materiality: software, hardware, wood, wire, bodies of flesh and blood.

2) In addition to thinking through the mutual implication of tonality and timbre, let us consider tonality as 'performative assemblage'. That is, thinking of different tonalities (scales, intervals, and the rest) as performing a bringing-together of elements. There is an historical argument that agreement on the ratios associated with different scale degrees only became a prominent concern for musicians when international consorts were assembled and discrepancies became obvious, for example, in the King's Music as studied by [12]. This gives a different perspective on what we might take as consonance. To be sure, consonance can be defined in terms familiar from Sethares and Plomp and Levelt [19] but we can also consider consonance in terms of whatever practically, performatively is needed to 'bring it all together'.

3) These affairs become most conspicuous if we take 'non-idiomatic' [1] improvised music as our focus - that is, music which does not necessarily have any advanced fixed tonal

constraints and might be dedicated to techniques which extend what are commonly regarded as an instrument's familiar timbre.

As a contribution within this zone, I offer the results of artistic research concerned with what I am calling 'dynamic tonality'. I introduce this in contrast with the most prominent examples in Sethares' work of what he calls 'adaptive tunings'. Sethares [23] presents an algorithm for adaptively retuning during the course of performance to maximise sensory consonance while maintaining fidelity to a desired set of intervals. Sethares' research domain is different from the one sketched here. I am not stipulating any advanced set of desired intervals or an explicit criterion of sensory consonance (compare also with [20]). Rather, I am concerned with finding shifting latent tonalities in ongoing sound and making these available to the performer. This is a less normative approach and one suited to improvisational settings where adapting how the music is tuned lies in a feedback loop with the performer's tonal and timbral action.

## 2. Computing Tonalities in The Wild

Clearly, there is a vast design space in which algorithms for the identification of latent tonalities in ongoing sound could be formulated. The approach taken here has been to investigate options in close relationship to performance practice. That is, the work has been strongly shaped by the desire to make systems that are readily gigable 'in the wild'. Accordingly, I have avoided approaches that require extensive pre-training or set up time, or that need a complex computing infrastructure. All the work discussed here can be readily implemented on a recent laptop, taken to the gig, and expected to work first (or maybe second) time. In the spirit of artistic research (see, for example [3], [4] and [5]), it is through this practical performance experience that I hope to elicit knowledge that is useful for others. In this section, I discuss the algorithms for pitch detection and scale generation that I have used, hoping to make clear that the decisions I have taken are just a few amongst many alternatives but, through this, I hope to outline the kinds of considerations future work might also need to address.

### 2.1. FluCoMa

An early commitment was made to use the pitch detection algorithms in the FluCoMa Library [10], particularly as these are timbrally/spectrally informed, and develop performance software in Pure Data. FluCoMa's [-fluid.pitch] offers three different algorithms:

- Cepstrum which returns a pitch estimate as the location of the highest peak in the Cepstrum of the signal
- Harmonic Product Spectrum which implements the Harmonic Product Spectrum algorithm for pitch detection [15]

- YinFFT which implements the frequency domain version of the YIN algorithm [7]

I have mostly used the YinFFT as it seems to yield useful results over a wide range of input sound qualities (from harmonic to enharmonic to noisy). I set [~fluid.pitch] to report in Hz in the range 20Hz to 1000Hz. This means that fewer detections are made of close-to-DC signals or low frequency rumblings or high frequency hiss or overtones which will duplicate results under octave reduction (on octaving see below). It is not necessary to have full range pitch detection to identify scales in the manner I will describe.

## 2.2. Pitch and Confidence

An interesting feature of [~fluid.pitch] is that its output is a pair of numbers, one representing the detected pitch, the other representing the confidence of detection. A common use would be to filter the detected pitches by confidence so that only the most clearly identifiable pitches would be of influence. This would be useful for musics where the maintenance of clear pitch centres is important. However, the fact that [~fluid.pitch] streams its best detection each analysis frame anyway means that low confidence results, as might occur as the selected algorithm grapples with spectrally diffuse input, are also available. I preferred having this 'liberal' approach to pitch detection. Indeed, as we shall see, this makes it possible to create scales based on a confidence ordering.

## 2.3. Windowing

The extraction of a tonality from ongoing sound is a kind of discretisation imposed on a continuum - much like the identification of individual pitches within continuous analysis in [~fluid.pitch]. This raises the question of how large the windowing of the results of analysis should be. There are many possible options here. It would be possible to compute a scale every N identified pitches. Or report every S seconds. Or to have the window size dynamically change in the light of other analyses. Some kind of overlapping windowing might be interesting to implement too - for example, allowing half the scale degrees to change at the close of each window, thereby enabling partial modulations. I have crudely simplified this design space and explored to date only clock time defined windows. In most of the explorations I describe, new scales are computed every 2000ms. This seemed intuitively to be a window size that was tolerant of a variety of rates of change in different input materials without adding noticeable window size artefacts.

## 2.4. Octaving, Frequency Resolution, and Bins

Several of the methods for computing a latent tonality that I have explored involve identifying the most commonly detected pitch in the reporting window as a 'root' and ordering the others in terms of their frequency of occurrence. This requires some discretisation in the pitch domain. Again, many alternatives are

possible here. I followed a rounding to the nearest 1Hz with [~fluid.pitch] reporting in Hz. This seemed suited to the wide spectral variation in the input material I chose to investigate and perform with. Clearly, other ways of discretising the pitch detection results would be possible - for example, setting [~fluid.pitch] for MIDI-style reporting for more harmonically organised material.

Other scales take the confidence with which pitches are detected as primary. So, an alternative 'root' is identified with the most confidently detected pitch in the interval with all other detected pitches being ordered by confidence rather than a (binned) frequency of occurrence. This permits scales to emerge with microtonal intervals and pitch clusters.

## 2.5. Five Alternative Scales

On the basis of this [~fluid.pitch] informed analysis and its identification in the window of two alternative 'roots' (by commonality and by confidence), a frequency of occurrence histogram, and a confidence ranking, many alternative scales can be computed. I have explored five. In principle, my analysis and scale generation methods can support any number of scale degrees. The choice concerns what kind of music that one wishes to engender. A music based around slow moving drones might require only a small number of scale degrees. A microtonal music might benefit from 20 or more scale degrees being identified. In principle, the number of scale degrees could be dynamically changed during the course of performance. As a compromise between complexity and easy selection, I create scales with just 12 degrees. Obviously, the scales that dynamically emerge are very different from standard Western 12-ET and, depending on the nature of the ongoing material under analysis and the kinds of scales selected, it is quite possible that microtonal clusters can emerge. Accordingly, I describe the different scales I have explored on the assumption that 12 degrees are to be found, though this is not fixed in my software.

The reader is invited to view the video that accompanies this paper to see and hear examples of the scale creation algorithms in action.

### 2.5.1. Commonality Scale

In this, the 12 most common pitches are taken to compute the scale. They are frequency-of-occurrence ordered with the most common being the root (call it R), the second most common being the second degree, and so forth. The scale is 'octave reduced' so that all pitches other than the root are transposed to lie between R and 2R. The scale typically has a re-entrant character in that lower pitches can be found in degrees which follow higher pitches. This means that a sweep from root to higher degrees can go both up and down in pitch. While this is not a typical understanding of 'scale', it permits interesting tonal patterns to be available with simple gestures.

If fewer than 12 pitches are detected (a rare occurrence), duplicates are generated to fill all 12 scale degrees.

### 2.5.2. Stretched Commonality Scale

While the Commonality Scale contains the 12 most common pitches, the Stretched Commonality Scale enables access to both common and rare pitches. Again the root is the most commonly identified pitch in the reporting window. However, the 12th pitch in the scale is the rarest with the other 10 being taken from equally spaced bins. Again, the pitches are octave reduced and, similarly, the scale often has a re-entrant character. This scale has the advantage that selection of the higher degrees is more likely to provoke an overall shift in tonality than selecting from the Commonality Scale. Additionally, if one plays two part material generated using both the Commonality Scale and the Stretched Commonality together, the two parts will diverge as the scale degree increases from unison at root to maximally divergent at the 12th degree - even though all pitches will have some connection to the analysis of ongoing sound.

### 2.5.3. Confidence Scale

In this, the 12 pitches are the 12 most confidently detected pitches in the reporting window with the most confident pitch being the root and the following 11 appearing in decreasing order of confidence. Thus a sweep from root to 12th degree is a movement of decreasing confidence. Again, octave reduction is applied.

### 2.5.4. Generated Scales from Consecutive Commonality

This method of scale generation takes into account the relationship between consecutive reporting windows. Let us call the most commonly identified pitch in the current reporting window to be C (for current) and the most commonly identified pitch in the previous window to be P (for previous). Calculate C/P (in Hertz) whenever a new C is returned. This is a measure of how far the most common pitch has transposed up ( $> 1$ ) or down ( $< 1$ ) between the two reporting windows. The value of C/P is adjusted if it is less than 1 so as to symmetrise transpositions up and down. So, to give examples, an octave down becomes an octave up, a perfect fourth down becomes a perfect fifth up, a value of 0.4 becomes 1.25, and call this G. G by definition will be 1 or greater.

G is then used as a scale generator in the following iterative manner. Let f be the root. In a first iteration,  $f \cdot G$  and  $f/G$  are derived.  $f \cdot G$  is octave reduced if it is equal to or greater than 2. So, 2 or 4 would become 1, 3 would become 1.414, and so forth.  $f/G$  is given the symmetrical transposition discussed above so that it is brought in the range [1.0, 2.). After one iteration, we would then have three scale degrees (the root and the two derived). The next iteration repeats the multiplication and division by G on the most recently derived scale degrees, then bringing them in range, and removing

duplicates. Two iterations yields 5 scale degrees, 3 yields 7, 4 yields 9, 5 yields 11.

This method of deriving a scale is often exemplified using  $G=3/2$  to create scales which follow a circle of fifths. Here, by contrast, I am using a generator derived from a tonal change between reporting windows which, by its nature, will dynamically change. The intention though is strangely similar to traditions of using a perfect fifth as a generator - to provide for a range of plausible transpositional possibilities. In the current case, these are immanent to changes detected in the ongoing sound.

As noted, I have preferred using scales of 12 degrees, While 5 iterations of the generator algorithm yields 11 scale degrees, a 12th is added at the 'reflection point' in the octave, the geometrical mean between 1 and 2, that is, the square root 2. This can be regarded as the scale's tritone or diabolus in musica - a useful point of dissonance.

### 2.5.5. Generated Scales from Consecutive Confidence

This method is the same as Generated Scales from Consecutive Commonality except that the most confidently identified pitch in consecutive intervals is used to compute the generator for the scale. This is, of course, not necessarily identical to using consecutive commonality. Indeed, the similarity between these scales will likely diverge and will prominently diverge with consecutive iterations of the scale generation process. So, again, the coexistence of more than one scale and the derivation of more than one differently intoned part can create interesting tonal possibilities.

### 2.5.6. Mapping to MIDI

One of the reasons for accepting 12 scale intervals in each of the above scales was to facilitate an easy mapping to MIDI Continuous Control and MIDI Note data. Octave relationships are maintained as equal to a difference of 12 MIDI values. This means that conventional controllers can be used which at least honour that relationship even if their absolute values are unfamiliar. Five different MIDI to frequency maps are computed, one for each scale. The root notes for each scale can be mapped to MIDI in two obvious ways. Either a selected MIDI value is taken and the roots are associated with this or the roots are best approximated to their nearest conventional note value (e.g. a root of 355Hz is closest to 349Hz which is F4 alias MIDI note 65). In the former case, the mapping will be sensitive to changes in root value and small changes at the interface may produce large changes in output if the detected root has changed significantly since the last reporting window. Alternatively, in the latter case, the mapping is less sensitive to changes in root value and adjacent MIDI values will tend to be closer from one reporting window to another. Both options have musical uses.

### 3. Explorations

The author has over two years of experience working with dynamic tonality along the lines described, particularly in live improvised settings, both solo and with other musicians. These dynamic tonality techniques have made their way onto a number of released recordings - most notably *Machines of Mantic Stain* available at <https://unlanded.bandcamp.com/>.

I start this presentation of explorations with six concept demonstrators which show how dynamic tonality can work in a performance ecology organised around, respectively, traditional keyboards, string instruments, field recordings, modular synthesizers, continuously variable wind instruments, and vocal performance. Following these I give a more detailed presentation of how dynamic tonality has enhanced my performance system [4] where room feedback is dynamically returned or new material is generated interacting with feedback sounds. In each case, the intention is to show how heterogenous musical resources can be assembled around a dynamically changing tonal sense. Across these examples, we see acoustic, electronic, and digital musical resources intertwined to explore varied tonalities and spectro-morphological relationships.

The reader is invited again to view the video that accompanies this paper to see the demonstrators from this section and the more worked through system from the next.

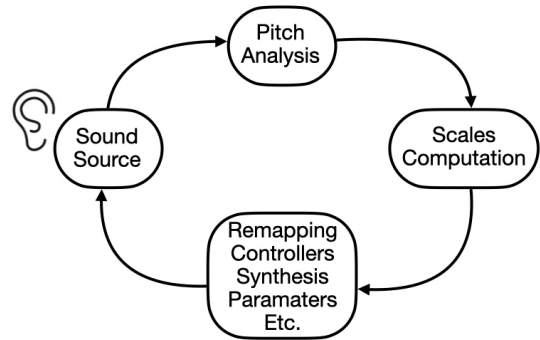
#### 3.1. Concept Demonstrators

##### 3.1.1. *The Very Ill-Tempered Klavier*

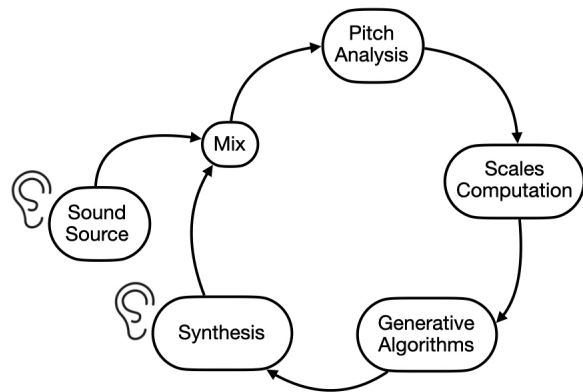
In *The Very Ill-Tempered Klavier* a conventional MIDI Controller Keyboard, the Arturia KeyLab Essential 61 Mk3, is dynamically retuned in response to an analysis of the sound it controls. While precise mappings between keys and pitches is uncertain, the keyboard is unconventionally playable. For example, if the performer pays careful attention to pitch selection and gives good examples of single pitches to the algorithms, the mappings may well stay intact or only be revealed as having changed when further exploration of the keyboard is undertaken. Alternatively, if dense cluster chords are played, the tuning of the instrument may dramatically change. By selecting a number of the scales to be heard simultaneously, dense polyphonic parts can be obtained which still can retain a harmonic sense and offer possibilities for complex parallel modulation.

A variety of behaviours have been explored using both traditional sampled keyboard sounds (retuned as required using MIDI pitch bend messages in conjunction with MIDI note values) and self-designed Pure Data synthesis patches. The *Variable Wavetable Vacillator Synthesizer (VWVS)* takes the interaction between timbre, tone, and tonality to an extreme. Live sound is micro-sampled to create wavetables which are played back in ensembles of three oscillators whose tuning

can be spread in a manner reminiscent of the ‘supersaw’ technique. The range of spread can be controlled. The oscillators can also be hard synched as well as phase modulated and pitch bent. In all these ways, the timbral content of the VWVS is radically variable. Working in conjunction with dynamic tonality, the player can move between relatively stable spectro-morphologies to an instrument seemingly with a life of its own. Hence *The Very Ill-Tempered Klavier* with apologies to J. S. Bach.



**The Figure 1: Dynamic tonality in a feedback loop remapping interaction with a sound source (see the main text discussion of *The Very Ill-Tempered Klavier* and *Quantising a Modular Synthesizer* for examples of this role for dynamic tonality)**



**Figure 2: Dynamic tonality in a feedback loop to shape generative algorithms for synthesis alongside a sound source (see the main text discussion of *Zitherrun*, *Ghosts Of The Field*, *How I Love You How I Love You*, and *Pulse Voice Shift* for examples of this role for dynamic tonality)**

##### 3.2. *Zitherrun*

In *Zitherrun* the sound from a 92 string Hopf guitarre-zither creates scales which are used by generative algorithms to stimulate noisy physical models for strings, as shown schematically in Figure 2. The physical models are based on the Karplus-Strong technique where a noise burst is injected

into a tunable delay and a low pass filter in a feedback loop. The low pass filter is adjustable so as to control the noisiness of the string, that is, how quickly the noise in the initial burst, the algorithm's simulated pluck, decays. This enables behaviour that varies from familiar Karplus-Strong sounds to pitched noise.

In *Zitherrun* all five scales are used in parallel with a Karplus-Strong inspired voice attached to each. Five generative algorithms set the pitches of the voices. These are five independent copies of an algorithm inspired by Estonian composer Arvo Pärt's tintinnabuli technique [13]. Pärt separates out the notes of a scale into (typically) a 1-3-5 triad and the rest. The triad is arpeggiated while the other notes of the scale play ascending or descending patterns which interact with the triad to create sensory consonances or dissonances. The effect is to vary the audible legibility of the triad from clear to implied and create a meditative effect.

There isn't space here to describe in detail my adaptation of tintinnabuli but the intention is to create patterns of tonal complexity which further interact with the mic-ed up sound of the zither, the generatively triggered physical models, and the layers of dynamic tonality tuning the models. By selecting different strings and chords, different dynamically computed scale types, and opening and closing the filters in the Karplus-Strong feedback loops, the player can effect tonality and timbre together in many different ways - even if the guitar-zither itself stays fixed in its tuning. *Zitherrun* with apologies to James Joyce.

### 3.3. Ghosts Of The Field

In *Ghosts Of The Field* a collection of field recordings are mixed. These are in five groups: recordings of a windmill, a train, wind blowing across the opening to bottles, traffic in a tunnel, and kites flying by the sea. The mix is analysed using the dynamic tonality techniques I have described to create the choice of five scales. The ribbon of a Haken Continuum Mini is used to specify up to two simultaneous pitches. These are rotated around the scales and retuned accordingly. These tunings are used to define filter pings and tuned delay lines. In this way, the latent tonalities in the field recordings are emphasised by the filter pings and the delay lines with the exact initiation of these sounds being triggered by the touches on the ribbon controller. The field recording mix can be matrixed to the scales so that the performer can vary the tonalities that affect the pings and delays.

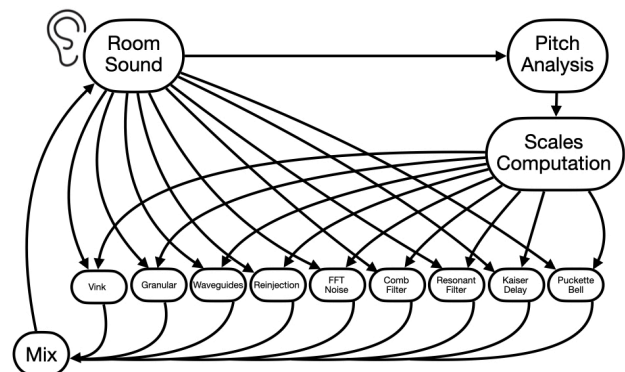
### 3.4. Quantising a Modular Synthesizer

A DC-coupled interface, the Presonus Quantum 2626, is used to convert the frequencies specified by the dynamic tonality Pure Data programs into control voltages for a Serge modular synthesizer. I confine myself to exploring two oscillators of the Serge (the New Timbral Oscillator and the Precision Oscillator). Each is in a feedback loop where their 1v/oct inputs

are fed by the DC-coupled interface. Arpeggiations, bursts of chaotic oscillation, drones which slowly destabilise, cascades of bifurcating tones, and mixes of these behaviours can be obtained in a manner reminiscent of the behaviour of Rob Hordijk's Benjolin circuits.

### 3.5. How I Love You, How I Love You and Pulse Voice Shift

In *How I Love You, How I Love You* a Swanee whistle is input to analysis and five granular delay lines are pitch shifted according to the the five scales so that the whistle as it glissandos is accompanied by five variably tuned shadows of itself. *How I Love You, How I Love You* with apologies to Iannis Xenakis and no apologies (because of the blackface) to Al Jolson. In *Pulse Voice Shift* an accompaniment is computed for a voice by driving pulsar synthesis configured to respond with quasi-vocal formants.



**Figure 3: A room feedback system in which dynamic tonality remaps multiple algorithms as they process room sound (see the main text discussion)**

## 4. Tuning Room Feedback

My major uses of the dynamic tonality approaches described in this paper have been in extensions of a room feedback system [4]. In this system, room microphones are used to drive multiple audio processes in a feedback loop, feeding back into the room. Over the years I have been working with this system many different algorithms have been explored in the loop programmed in Pure Data. Several of these benefit from having frequency-related parameters set by controllers mapped through the results of a dynamic tonality analysis. I typically use the scales generated from the consecutive commonality algorithm in this application as its sensitivity to changes in tonality and its offers of progressively more distant scale degrees (as the generator iterates) suits the shape of much feedback music while offering possibilities also for unexpected dynamic change - an extension of what is possible with room feedback that has been important to my research on this topic throughout [4].

At the time of writing, the following sound processing algorithms have controls which are remapped by consecutive commonality scales:

- pitch of the modulator ring modulating the room sound as in Jaap Vink's feedback technique
- pitch centre of 16 grain streams of room sound
- tuning of waveguides through which room sound passes
- tuning and spread of five delay lines following Georg Friedrich Haas' concept of 'reinjection loops' [2]
- pitch shift given to an FFT-based synthesis of noises which spectrally summate the room sound
- scaling of a comb filter
- scaling of a high-Q resonant filter
- transpositions up and down in an implementation of Henry Kaiser's square wave modulated delay line technique
- an algorithm adapted from Miller Puckette [21] which synthesises a triad of bell-like tones through tuned pitch shifting delays

For details of these algorithms, see [4]. It should be clear that this system has been majorly developed to accommodate dynamic tonality concepts. The next section discusses how this has impacted upon my performances and through this I begin a reflection on the ideas this research has embodied.

## 5. Reflections

I want to concentrate on two features of feedback music which have been enriched by dynamic tonality. *First*, when working with feedback, it is often desirable to find the points of instability where, for example, two feedback modes flicker between each other, perhaps resolving to a third mode, amongst related phenomena. The introduction of dynamic tonality techniques has enriched these possibilities. With many of the sound processing algorithms in the feedback loop being tunable, it is easier to find these points of instability and also, for that matter, regions of reinforcement. It is also possible reinject into the room material that is knowingly far removed from the tonality of the ongoing sound (e.g. by using the rare end of the stretched commonality scale). This enables layers of sound which have a relatively independent existence. In short, dynamic tonality has enriched the number of musically significant phenomena I can steer into existence in a feedback system. These possibilities are explored throughout the album *Machines of Mantic Stain* in which a Serge modular synthesizer is entwined with room feedback in solo improvisation.

*Secondly*, the introduction of dynamic tonality to tune the room feedback system has facilitated playing in group performances in a number of ways. In previous work [4], I have written about

how room feedback can enfold the contributions of multiple players into a common collectively steered texture. By letting the ongoing (collective) room sound inform how the feedback is tuned, it is possible to play with how integrated or diffuse this texture can be. For example, in several performances with the microtonal guitar playing of Hugh Metcalfe, I have been able to shadow the guitar with tuned feedback. That the analysis algorithms work continually throughout performance, rather than requiring calibration beforehand, makes for fluent responsiveness to microtonal playing even if, as in the work described here, my total tonal range might be a scale of 12 possibilities. Indeed, the commonality and confidence algorithms can cluster the 12 possibilities around what is live in the room making it easier to access pitches that relate to what is being played by my companion. In the modular synthesizer duo named *The Last Toadsmen Of The East* with Liam Wells, I can find pitches in his contributions whether they are pitched or noise based or in between. This can serve to reinforce an emerging pitched sense to the music or create tension between more than one pitch-centre depending on how scales and scale degrees in them are selected. These phenomena are especially important to improvised settings where tonalities might not be set in advance, where the musical machines are, by design, hard to control, and where the varied dynamic and tonal shaping of the whole performance is important.

Introducing techniques of dynamic tonality has given substance to the promise of feedback systems to provide a 'performance ecology/eco-system' in the senses of [6, 25] and sketched in the introduction to this paper. My room feedback systems can work with whatever sound is in the air to create an enfolding sonic environment. But this is not necessarily a flat-lined static convergent affair. The creation of different scales through an ongoing analysis enables further strategies for feedback manipulation and emergence. In this way, we can begin to see tonality as having a role in what I earlier called 'performative assemblage' by offering a form of consonance (con-sonance) around latent scales and intervals.

This experience, now at least two years deep, complements the concept demonstrators I wrote about earlier. *The Very Ill-Tempered Clavier*, *Zitherrun*, and the rest give a hint of the breadth of applicability of the techniques I have described. They serve as existence-proofs of principle. I hope my documentation of extensive live and recorded experience adds depth to this breadth that might inspire others to explore the domain of dynamic tonality.

## 6. Conclusions and Future Work

This paper has described artistic research interrogating the possibilities for dynamic tonality in shaping hybrid performance ecologies where varied musical resources intertwine. The work has the character of artistic research in that the development of techniques and systems has been in the light

of creative work with a variety of electronic, acoustic and digital technologies in solo and collective improvised performances. In addition, it offers research value in a variety of ways. I have described a number of algorithms by which ongoing, real-time analysis of tonality can take place - algorithms which could form the basis of future exploration. Along the way, some concepts for rethinking conventional notions such as tonality and timbre have been offered which situate them in a more extended technical, musical, social, 'ecological' context. Throughout, the intention has been to open out the 'design space' within which the development of musical interfaces and instruments takes place by presenting a series of concept demonstrators alongside a more detailed treatment of performance experience with a development of a particular system which has been presented to NIME previously.

Under the banner of dynamic tonality, a variety of algorithms and techniques has been explored for extracting latent scales from real-time, ongoing musical performance, without prior training or tonal constraint. As such, this work extends previous research in adaptive tonality [e.g. 14, 18, 24] which tends to concern itself with retuning performance in line with prior specified tonal constraints. This reciprocity between tonality and ongoing sound is particularly prominent in settings where a feedback loop exists between material generated using inferred scales and the analysis algorithms which create those scales.

In the presentation of the particular analysis algorithms, I have made clear the latitude for future experimentation: with different spectral and pitch analysis techniques, windowing, bin resolution, different scale computation algorithms, relaxing the assumption of octaves, exploring extremes of microtonality, and the coexistence of dynamic tonality with other scale types in complex polyphony (cf. the work of Wyschnegradsky [26] and Haas [2]).

It is clear that AI techniques for spectral analysis could also be applied in this domain. Of particular interest is the approach of Pultz Melbye [22] where a physical multi-string instrument is dynamically retuned as an AI-based learning process unfolds. Pultz Melbye deliberately slows the AI learning in part as a critique of AI in music. The applications I have discussed work on different timescales though a slowed approach would definitely be favoured in several feedback settings.

Pultz Melbye's work also has a physically retunable instrument at the heart of his installation. By contrast retuning in the current work has generally been accomplished digitally. Clearly, physically retunable instruments which operate in a time course that matches the tonality analyses is a concern that this research should go on to address. My research has currently concerned the use of conventional commercial controllers. There is much scope for the development of controllers and other interfaces which are specifically tailored

to working with dynamic tonality. Enhanced ribbon controllers, devices within the Theremin family [cf. 20], video analysis of free gesture, high resolution multi-touch devices combined with projections of tonal hints are all worthwhile avenues for exploration. At an early stage of development in the author's hands is the Derivational Tonnetz Keyboard designed to support scales created by iterating a generator, drawing on Leonhard Euler's Tonnetz of 1739. This is being built with over 60 Hall-effect keys arranged in an array such that the left-to-right position of the keys in each row reflects the order in which the scale degrees are iteratively calculated.

### 6.1. Afterword: A Grounded Yet Shifting Aesthetic

Let me close with some aesthetic speculations prompted by this research. Many of our metaphors for musical tonality are spatial ones. We refer to pitches rises and falling. We consider tonality to be rooted. Many traditional musical forms involve a return to the their ground to complete a musical closure, most notably sonata form. In this way, musical closure, while performing tonal return, brings about an ideological closure - a secure return to a status quo. These are perhaps not the times for such an aesthetic. But perhaps it is neither the time for a rejection of all senses of groundedness. The work here offers a potential alternative where grounds are situated in time, provisional, shifting, tentative, multiple, immanent, and playable. This strikes me as an aesthetic worthy of investigation.

## Ethical Standards

The research reported here was self-funded. No conflicts of interest are known. The author was the only human participant directly involved and no living non-humans were knowingly harmed in the work. As the main text notes, the research preferred to avoid approaches to computation which are known to be energy intensive. This, too, was an ethical choice.

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