A Microtonal Wind Controller
Building on Yamaha's Technology to Facilitate the Performance of Music based on the "19-EDO" scale.

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Abstract

We describe a project in which several collaborators adapted an existing instrument to make it capable of playing expressively in music based on the microtonal scale characterised by equal divsion of the octave into 19 tones ("19-EDO"). Our objective was not just to build this instrument, however, but also to produce a well-formed piece of music which would exploit it idiomatically, in a performance which would provide listeners with a pleasurable and satisfying musical experience. Hence, consideration of the extent and limits of the playing-techniques of the resulting instrument (a "Wind-Controller") and of appropriate approaches to the composition of music for it were an integral part of the project from the start. Moreover, the intention was also that the piece, though grounded in the musical characteristics of the 19-EDO scale, would nevertheless have a recognisable relationship with what Dimitri Tymoczko (2010) has called the "Extended Common Practice" of the last millennium. So the article goes on to consider these matters, and to present a score of the resulting new piece, annotated with comments documenting some of the performance issues which it raises. Thus, bringing the project to fruition involved elements of composition, performance, engineering and computing, and the article describes how such an inter-disciplinary, multi-disciplinary and cross-disciplinary collaboration was co-ordinated in a unified manner to achieve the envisaged outcome. Finally, we consider why the building of microtonal instruments is such a problematic issue in a contemporary ("high-tech") society like ours.

1: Background: Taking the Long View

To be sure, the desire to build new instruments to satisfy composers' needs for new forms of musical expression is, in principle, a perennial and widespread one: an "apple pie and motherhood" issue indeed (since no reasonable person could possibly be against it — in principle!)

Nevertheless, in the period since the mid-19th century, the *instrumentarium* of the orchestra has essentially remained fixed, except for some distinctive, but — in the broad context of the history of the orchestra — rather marginal developments. The constitution of the New York Philharmonic in 2016 is broadly and recognisably similar to that of the Leipzig Gewandhaus Orchestra when Mendelssohn conducted it in 1840. This may be partly due to the "globalisation" of the orchestra over the period 1840–2016 and the consequent need for standardisation across the Western — and increasingly the non-Western — world, providing a counter-force to developments in the regionalisation and individualisation of musical culture.

Certainly, since 1840, new instruments have appeared and existing ones undergone improvement in certain respects. For example, although the stringed instruments have remained the same as they were in 1840, the percussion section of the orchestra has undergone considerable expansion since then, reflecting the increased call for percussion instruments by composers, especially during the second half of the 20th century.

Furthermore, many instruments have benefited from new technologies which have improved them in some way — eg increasing their range, flexibility or efficiency — beginning with the Boehm clarinet-fingering system and the introduction of valves on brass instruments at or near the beginning of the period to which we are referring. Another example would be the timpani, which, although they have remained the centrepiece of the percussion section, have benefited from the universal introduction of pedal-tuning.

Of course, new instruments continue to appear outside of the orchestral domain. One of the most successful has been the introduction of the electric guitar in the mid-20th century. The Franco-American composer Edgard Varèse spent a large part of his career, beginning after the First World War, calling for new electronic instruments to realise his compositional ideas. One may perhaps interpret the gradual development of electro-acoustic music and computer-controlled instruments — including institution of the recent NIME (“New Interfaces for Musical Expression”) conference-series — as a response to similar creative impulses on the part of composers worldwide. However, the influence on — and interaction with — the *instrumentarium* of the orchestra has been rather marginal, albeit for reasons which have to do as much with the sociology and economics of the world of orchestral performance as with the constitution of the orchestral *instrumentarium* itself.

Yamaha’s WX11, WX7 and WX5 series of MIDI “Wind Controllers” were a particular manufacturer’s answer to a felt need for new wind instruments for musical expression. The WX7 was introduced in 1989, followed by the WX11 in 1993 and the WX5 in 1999. Though never as ubiquitous as the electric guitar, these Wind Controllers have, like some the inventions mentioned in the previous paragraph, been adopted to some extent in the worlds of jazz, popular, “roots” and “world” music. Although designed primarily to be played with Yamaha’s own synthesizers, the WT11 and VL70m “sound modules”, these Wind Controllers enable sound stored on any computer (taken from libraries of sound-samples or generated by physical modelling programs) to be disseminated using the fingering system of a flute or a saxophone and, to a limited extent, the embouchure of a particular player: ie they provide a many-to-one mapping between fingering-system and sound, and a compass larger than regular “acoustic” versions of the same instrument, while leaving dynamics and articulation under the control of the player. The outcome of our particular microtonal wind-controller project has been a kind of “adapted clarinet” because the clarinet is the principal instrument of co-author Alex South (of the *Scottish Clarinet Quartet*, amongst other ensembles) and the physical model which we are using produces “clarinet-like” sound, but Alex is using the fingering system of the saxophone (“adapted recorder fingering”: simpler than the cross-fingerings used by recorder players, but more complicated in its more extensive use of the little finger), albeit any sounds which can plausibly be controlled by breath and embouchure could in fact have been used.

However, one of the characteristics of almost all of the instruments mentioned is that they are (basically) tuned to the ubiquitous, “regular” 12-EDO scale (characterised by equal division of the octave into twelve parts). So Glasgow University’s Science and Music Research Group (SMRG) adopted the WX7, and later the WX5, and adapted it to the requirements of microtonal (specifically 19-EDO) performance.

2: Initial considerations

A number of reasons lay behind the choice of 19-EDO, mostly pragmatic rather than utopian or idealistic ones:

1. The practical dimension: the existence of the *Microfest UK* series of conferences in which a number of participants demonstrated particular interest in music based on the 19-EDO scale. One of these was trumpeter Stephen Altoft, who has had built, for his "acoustic" trumpet, a number of attachments which will enable it to play music in 19-EDO. In 2011, Stephen issued a CD recording, *The Yasser Collection* (Altoft 2011), of 19 short compositions by 19 different composers (in principle!: albeit, in the event, the planned 19 turned out to be 17) in 19-EDO tuning!

2. The theoretical dimension: the existence of long-standing theoretical work on 19-EDO tuning, beginning with the foundational work of Joseph Yasser in the 1930s and Joel Mandelbaum in the 1960s (see Yasser (1932, 1975) and Mandelbaum (1961)).

3. The historical and cultural dimensions: the possibility of viewing the structure of the 19-EDO scale as a superset of the 7-note diatonic scale (in contradistinction, to be sure, to Yasser's treatment of it as a superset of the 12-note chromatic scale), analogous to the use of microtonal elements as a superset of the 5-, 6- or 7-note scale in many cultures of the past and present.

As we shall see, these "microtonal WX7 and WX5" have not inconsiderable limits on control of speed and flexibility, as well as of dynamics and articulation, but they provide a reasonable and useful compromise: between utopian compositional desires and practicality under normal performance conditions.

Our "Adapted Wind Controller" involves plugging the WX7/WX5 into a computer rather than into the VL70m sound module, along with a double footpedal which works in conjuction with a "normal" fingering system. By "normal fingering", we just mean one of two alternative options, viz that the player may operate the WX7/WX5 using either flute or saxophone fingering. Figure 1 shows co-author Alex South demonstrating the setup.

In the context of the ongoing research on microtonality at SMRG, there is no intention to confine our focus solely to 19-EDO — or, for that matter, to the WX7/WX5 — in the long run. Several other issues must be considered. One of these is not to do with the *production* of microtonal music at all, but with the *perception* of such music and the effect of perception upon *reception.* Amongst other things, SMRG has been prosecuting a program of research and invention to help singers perform music based on the 19-EDO scale, which in essence is an "ear-training" programme, based on "machine-assisted" practice and rehearsal, using what SMRG has dubbed the *Rosegarden Codicil* along with two new keyboard-based accompanimental instruments, the *Ill-tempered Clavier* and the *SMRGygurdy.*The following section of this article provides an outline of how this has been done.

A notation system specific to 19-EDO is used. Most of the composers represented on Stephen Altoft's aforementioned CD of 19-EDO music also use this system. The 19-EDO ("hyper-chromatic") scale can be written down without recourse to novel notational signs of any kind. All that is required is a recognition that the sign for "sharp" simply indicates the raising of a given "natural" note by a "hyper-chromatic" step (1/19 of an octave) and the sign for "flat" indicates the *lowering* of a given "natural" note by the same interval (rather than by a semitone, as in 12-EDO).

Figure 1: Alex South playing the adapted WX5.

Figure 2 gives the notation for a 19-EDO scale on middle C by way of example.

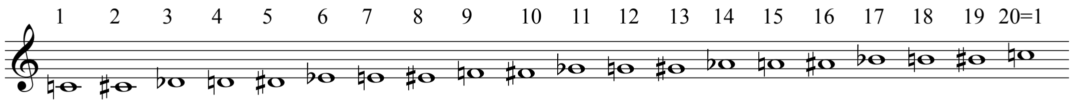


Figure 2: The notation of the 19-EDO ('hyper-chromatic') scale.

Familiar interval-categories such as the perfect fifth or the whole tone are contained within the 19-EDO scale, but in terms of precise distances (as measured in cents) these interval-categories are of only approximately the same size as those contained within the 12-EDO scale. Thus the perfect fifth, which in 12-EDO is comprised of 7 chromatic steps (7/12 of an octave), is, in 19-EDO, comprised of 11 "hyper-chromatic" steps (11/19ths of an octave). If we express these distances in cents, we see that the 19-EDO perfect fifth is 694 cents (11/19 of 1200 cents), which is slightly smaller than the 12-EDO perfect fifth (700 cents). Likewise the whole tone, which in 12-EDO is comprised of 2 chromatic steps (2/12 of an octave or 200 cents), is, in 19-EDO, also smaller, viz comprised of 3 hyper-chromatic steps (3/19 of an octave or 189 cents). Moreover, if we consider the intervals found in the harmonic series, then the perfect fifth (between partials 2 and 3) and the whole tone (between partials 8 and 9) provide examples of those intervals which are different again (702 cents for the perfect fifth, 214 cents for the whole tone). So the foregoing might lead us to ask "Exactly what is a second (or a third, a fourth, a fifth, a sixth, a seventh...) anyway"? The answer to that question takes us many centuries back into history: at least as far as Guido d'Arezzo (c 991 – 1050), and his system for learning and notating music based on the diatonic scale (or more precisely, the "natural" hexachord and its two intersecting transpositions, the "hard" and "soft" hexachords). Consideration of Guido's system draws to our attention the fact that both the 12-EDO scale and the 19-EDO one are, historically, offspring of the scale with 7 notes to the octave, and the interval of a perfect fifth from which that scale is *au fond* derived.

Indeed, we may even cast our net even further back into history, to the famous ancient Greek philosopher, Pythagoras of Samos (c 570 BC – 495 BC) and his observation that the perfect fifth is instantiated by the interval sounded by the plucking of two strings of identical material, thickness and tension whose lengths are in the proportion 3:2. We now know that this is the same instantiation as the aforementioned fifth between partials 2 and 3 of the harmonic series (702 cents: the so-called "just" perfect fifth). However, musical history since Pythagoras has found uses for quite a variety of instantiations, so we can't reasonably assert that one instantiation is "better" than the others in any absolute sense. As Easley Blackwood (2014) has shown, the minimum requirement for the 7-note scale to be "recognizably diatonic" is merely that it must be based on a perfect fifth which is greater than 685.714 cents but smaller than 720 cents (for reasons we shall not canvas again here).

Nevertheless, there lingers a certain "hankering after Pythagoras" in some quarters, notably with American composer Harry Partch (1901 – 1974), often regarded as the "Father of Contemporary Microtonal Music", and in some recent musicological texts (eg Duffin (2008)).

An important musical consequence of the fact that the major second is comprised of 3 hyper-chromatic steps is that the minor second in 19-EDO is 2/3 of a major second (2/19 of an octave, or 126 cents), so that one of the most familiar of all musical objects to those brought up to think of 12-EDO as "normal", namely the semitone, turns out not to exist at all in 19-EDO. But on the other hand, 19-EDO makes available to melodic progression a step even smaller than the minor second, viz the diminished second (1/3 of a whole tone or 1/19 of an octave, or 63 cents) which can scarcely be said to exist in 12-EDO, because in 12-EDO the diminished second is enharmonically equivalent to a unison.

This observation draws attention to the fact the enharmonic equivalences in 19-EDO are altogether different from those in 12-EDO. To take another example: the pitch enharmonically-equivalent to C♯ is not D♭ (as in 12-EDO) but D𝄫 (1/19 of an octave lower than D♭), and the pitch enharmonically-equivalent to D♭ is not C♯ but C𝄪 (1/19 of an octave higher than C♯), and so on.

The most frequently-used enharmonic equivalences can be noted by comparing the nomenclature of the notes in Figures 2, 3 and 4. Those which are required for almost all practical purposes can be observed by noting the pragmatic way of writing ascending and descending hyper-chromatic 19-EDO scales: pragmatic in the sense that it's easy for musicians with a regular musical education to read, because it's an extension of diatonic notation.

Only signs for naturals, sharps and double-sharps are used in ascending scales (cf Figure 3):

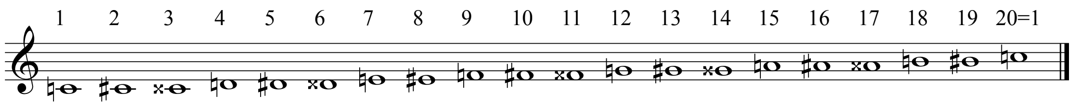


Figure 3: The normal notation of the ascending 19-ET scale.

Only signs for naturals, flats and double-flats are used in descending ones (cf Figure 4):

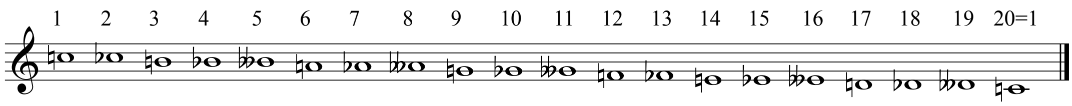


Figure 4: The normal notation of the descending 19-ET scale.

We may then proceed to characterise the whole repertoire of common intervals in terms of the 19-EDO scale, arriving at the following list, from which the repertoire of enharmonically equivalent intervals can be noted or deduced:

- unison (diminished, perfect and augmented) = -1, 0, 1 hyper-chromatic steps
- seconds (diminished, minor, major and augmented) = 1, 2, 3 and 4 hyper-chromatic steps
- thirds (diminished, minor, major and augmented) = 4, 5, 6 and 7 hyper-chromatic steps
- fourths (diminished, perfect and augmented) = 7, 8 and 9 hyper-chromatic steps

- fifths (diminished, perfect and augmented) = 10, 11 and 12 hyper-chromatic steps
- sixths (diminished, minor, major and augmented) = 12, 13, 14 and 15 hyper-chromatic steps
- sevenths (diminished, minor, major and augmented) = 15, 16, 17 and 18 hyper-chromatic steps
- octave (diminished, perfect and augmented) = 18, 19 and 20 hyper-chromatic steps

Comparisons between 19-EDO and 12-EDO also make clear the fact that the intervals of the two scales are best regarded as (a) *categories* and (b) *distances on a one-dimensional scale*, and that neither the 12-EDO nor the 19-EDO version of any given interval is more "correct" than the other. Indeed, when performed by voice or any instrument not pre-tuned to fixed frequencies, the categories are subject to considerable "elasticity" around the "theoretical" values of *whatever* system is implemented, so that, even when fifths or whole tones occur within chords, the tuning can vary by as much as ±30 cents from the intervals of 702 or 214 cents, emphasising the fact that there is *no* "correct" implementation of any interval in terms of cent values: it's the musical context which determines what the performers consider "in tune" or "out of tune".

3: Building a 19-EDO Performance Environment

The foregoing remarks outline the motivation for our "Adapted Wind Controller" and the character of the mictotonal materials which it was built to explore. We now proceed to describe in some detail how the instrument was built, what the issues involved in playing it are, and some features of a musical example designed expressly for it. We begin by describing various items of software which were designed to be driven by the instrument.

The software written to support rehearsal and performance of 19-EDO (and, in future, possibly other temperaments) was developed for Debian Linux and its derivatives, using the following components:

1. a PD patch enabling a foot pedal to modify the behaviour of a clarinet physical model thus enabling performances in 19-EDO using a Yamaha WX7/WX5 breath controller (Bristow 1991);
2. an addition to the Rosegarden MIDI sequencer program which permitted real-time pitch tracking against a score given in arbitrary temperament intended as a tool to support rehearsal by expert performers;
3. a script to invoke the software synthesiser *Fluidsynth* to enable 19-EDO "scodatura" performances on a MIDI keyboard; and
4. a real-time physical-model string instrument synthesiser based on Democron's modal model (see Demoucron (2008)) and developed at SMRG: the *SMRGyGurdy*. The *SMRGyGurdy* is based on the concept of a hurdy-gurdy with a wheel speed controlled by a volume pedal connected to the computer through a USB-DUX generic analogue/digital interface. See also Graham Percival's git repository.

Although the software is entirely open source and could (with more or less effort) be made to run on other Unix derivatives such as Apple's OS-X operating system, mindful of the ubiquity of "Wintel" (Windows™/Intel™ architecture) machines in the first two decades of the 21st century, a method was sought to allow the use of this software on them. The software architecture adopted by Microsoft™ is so fundamentally different from the Unix paradigm that it would be infeasible to pursue rewriting all of the applications and the libraries on which they rely to run on that platform. Consequently, SMRG has deployed a "Live Build" of Debian Linux which can be made into a DVD-ROM or used from a "flash drive" plugged into a USB port or, if the target machine supports it, a memory card of the kind normally associated with digital cameras.

Whatever medium is chosen, it will contain a copy of the GNU/Linux operating system including drivers for a wide variety of different hardware and all of the above-mentioned software. When configured for a flash drive or memory card, the device can be given two partitions. The first partition is made read-only and contains all of the system software and boot-loaders. The second is configured to allow reading and writing. Many Unices, GNU/Linux among them, support the concept of a "union mount". In this way it is contrived to use the read-only part of the memory card to store the system and essential configuration files, the "root partition". Simultaneously, the second partition is union-mounted with the root partition. By analogy, it is as if a sheet of glass (the second partition) were laid on top of a paper copy of this article (the root partition). If the reader wished to modify the text, it would be possible to write on to the glass, obscuring the original from view. When reading the article, it is the union of the original text and the additional material written on the glass sheet which is seen. In this way, we contrive to make it possible to store users' files and the changes they make to the configuration without either the necessity of re-constructing the entire operating system image or risking unintentional changes to the root partition compromising the operation of the live build. It is also a trivial matter for the author of the live build to apply alterations provided by users who customise their configurations to the root partition, should the alterations be considered generally beneficial.

When the memory card is inserted into a standard PC, the computer boots and runs from it without making any changes to the machine's installed operating system. Thus the machine is instantly converted to a GNU/Linux system for the duration that the SMRG software is used, reverting to its previous configuration entirely when the memory device is removed. No modifications whatsoever are made to the contents of the PC's internal disk drive.

In previous SMRG projects, laptops have been purchased specifically to distribute to musicians involved in the microtonal performances, but through the use of the live build, the cost of such projects has been significantly reduced. For example, co-author Alex South collaborated on a project to develop the 19-EDO wind controller software using the Live Boot system from a flash memory device inserted into his netbook.

4: 19Cl — A 19-EDO Wind Controller

4.1: Hardware Summary

We have used the WX7/WX5 wind-controllers, which employ saxophone-style fingering keys, to develop a microtonal instrument based on an acoustic clarinet sound. The controls have been augmented with two foot pedals, allowing the performer additional input mechanisms to access the full nineteen tones of the scale (while maintaining traditional fingering). One pedal shifts the current note up by one 19-EDO ("hyper-chromatic") step; the other, down. These pedals, the keys, and the performer's breath velocity are passed via MIDI (Musical Instrument Digital Interface) and USB (Universal Serial Bus) to the computer running the software.

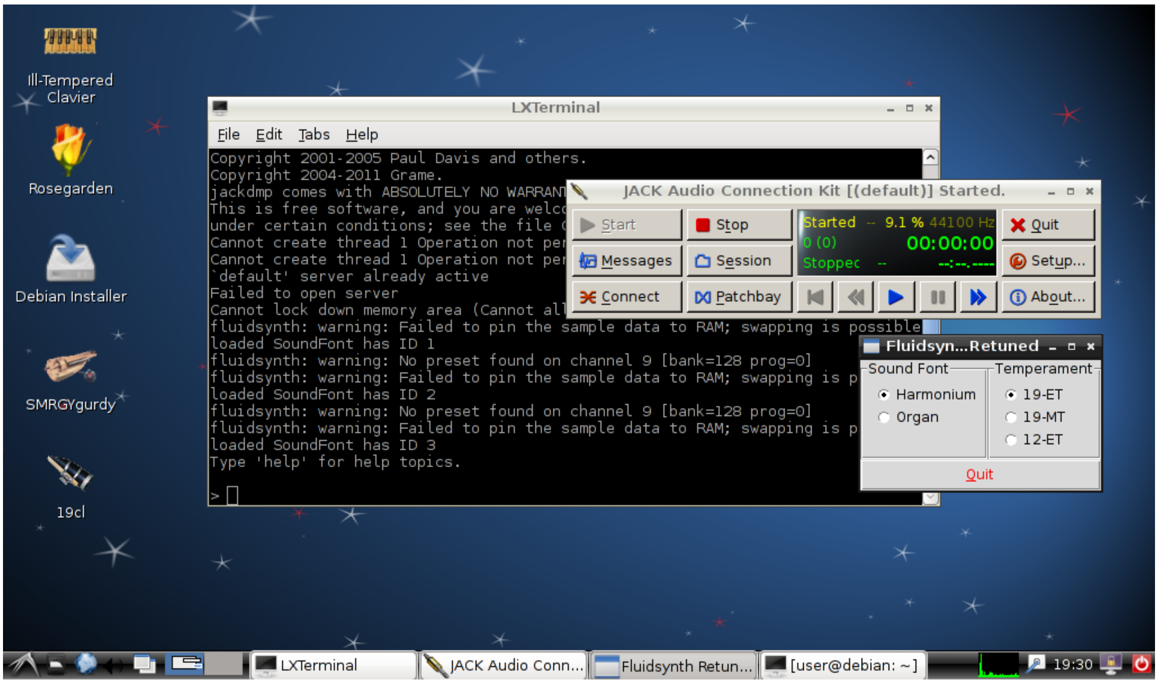


Figure 5: A Screen shot of the live-boot system running the *Ill-Tempered Clavier* (see page 17)

4.2: Software Overview

The software (*19Cl*) receives information from the wind controller and the foot-switches, and determines which note the performer intends to play. It then calculates the parameters required for the clarinet physical model and applies them in order to generate an audio signal. As well as the pitch and volume of the signal produced, control is exercised of the attack of the note in order to produce better and more controllable articulation.

19Cl is written in Miller Puckette's Pure Data (Pd) (Puckette et al. 1996), a visual programming language, and consists of five modules running on an Asus EEE-PC901 Netbook.

Main is the top-level module; it contains and controls the other modules, which are shown here in separate figures. Within each window, boxes represent specific instructions. Lines connect them together to form a signal path. The main module contains various boxes, also boxes that represent sub-modules; these are labelled *pd* followed by the name of the module (eg [pd PedalEvent]).

19Cl's top-level module makes use of the following sub-modules:

- FrequencyEngine: Determines what frequency should be produced by *19Cl*.
- PedalEvent: Tracks and stores the states of the foot pedals.
- ClarinetEngine: Produces the actual Clarinet tone.
- Articulation Processor: Manipulates the clarinet engine output to produce a more playable instrument.

Concave boxes, shown between concave brackets (like this(, represent messages emitting a value when an event is received; [square boxes] represent arbitrary objects which process data; Chamfered boxes are number boxes which, along with GUI objects, display data in real time as the program runs.

4.3: The Right Note

MIDI, the *de facto* standard for commercial digital musical instruments, is not a good choice when implementing a microtonal performance tool. Rather, it is imposed by the manufacturers of the chosen breath controller. MIDI represents pitch as a note number, which derives from a simplistic keyboard-centric mentality. C1 is note number 0, and the enharmonic equivalents of the 12-EDO scale are treated as identical. When a key is struck on a keyboard-style controller, the synthesiser receives a 3-tuple (Note-ON, note-number, velocity). When the key is released, a (Note-OFF, note-number, velocity) 3-tuple is issued, although some controllers confusingly issue a (Note-ON, note-number, 0) 3-tuple instead, associating the "velocity" of the currently sounding note with its loudness and setting it to zero. this can be a source of confusion on polyphonic music when the termination of a brief note, improperly processed, may result in premature silencing of a long note having the same pitch. The velocity parameter was originally intended to permit dynamic control of such keyboard instruments, and while the standard includes further articulation controls such as polyphonic and more specific "aftertouch" and pitch bending, the application of these controls is not precisely specified. Indeed, the type of control message used to send breath information changed in the decade between issuing of the WX7 and the WX5 controllers from the same manufacturer (1989 and 1999 respectively)! "Concert A" works out as note-number 69 in MIDI. To convert a MIDI note-number to a frequency in the 12-EDO scale, it is therefore simply necessary to evaluate (440Hz x 2^((note_number-69)/12)). However, we are combining the MIDI note number issued by the breath controller with A $\pm$ 1/19-octave bend generated by up- and down-pedals. This is done with the aid of two look-up tables which are stored as simple text files on the computer.

The first look-up table, *midi-to-index*, converts between MIDI note number and an internal 19-EDO note number. Whereas all of the sharp and flat accidentals have enharmonic duplicates in 12-EDO, all notes issuing from fingerings on the 19-EDO wind-controller are considered to have a sharp spelling which, with the exception of E♯ and B♯, differs from the flat associated enharmonically in conventional 12-EDO music. When it is desired to play a B♯, the performer has the choice of either fingering A♯ (which will be considered as such even when the piece is in F major) and sharpening the note a 19th of an octave to B♭ with the up-pedal, or fingering a B♮ and flattening to B♭ with the down-pedal. Using the MIDI note number system, it is impossible to distinguish between A♯ and B♭, but with the internal 19-EDO representation, the codes are quite distinct. The action of the inflexion pedals is simply to add $\pm$1 to the internal code.

The second lookup-table, *index-to-frequency*, permits the conversion of the internal note code for the 19-EDO wind-controller to a frequency in cycles per second for use by the clarinet synthesizer. The lowest note available to *19Cl* is D3, and this has index 1. A440 has index 31, being 30 19-EDO steps above D3.

The [FrequencyEngine] module converts incoming MIDI events to appropriate frequencies and this is shown in Figure 7. The module has two [col] objects which are initialised at load-time with the lookup-tables responsible for converting MIDI note number and foot pedal position to the desired frequency. The state of the pedals is stored internally as a number of 19-EDO steps, and this is set to 0 (both pedals up) when the module is loaded. The figure shows the state of the module after an A4

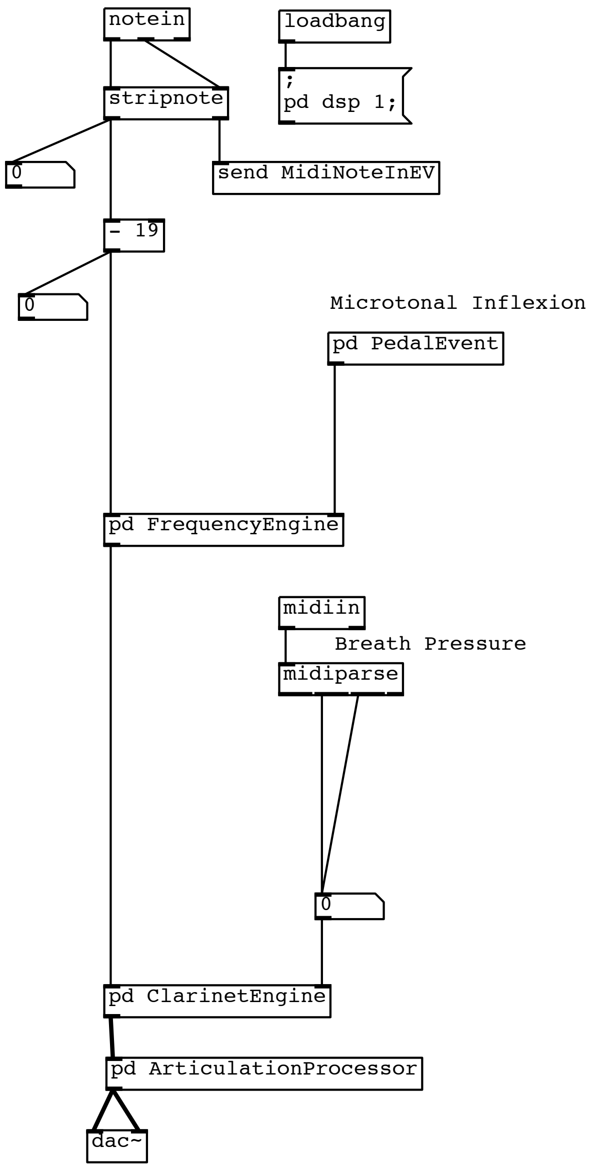


Figure 6: The Main module

has been played on the controller with no pedals pressed. Note number 69 has been received by the main module from the controller. The lowest pitch performable on the *19Cl* instrument corresponds to note-number 20, so 19 is subtracted from the received MIDI code by the main number before the message arrives at [FrequencyEngine] via the left inlet, and converted to 31 in the internal 19-EDO representation. Since both inflexion pedals are up, the pedal state is 0 and the 31 is propagated unchanged to the second [col] object. The second look-up table contains tuples of human-readable note names (for debugging purposes) and their associated frequencies, so the result of the lookup is unpacked into a symbol and a number. The former is simply displayed, while the latter, is in this case propagated to subsequent modules via the [outlet]. Our 19-EDO clarinet transposes down a whole tone (3/19ths of an octave), so the result is a "concert" G.

It is obviously important that changes in foot switch positions behave similarly to a new note fingering being applied to the controller. In Pd, it is usual practice for the left-most inlet to be the "hot" one. When a message is received at the hot inlet, a message is produced at the outlets. For example, the [+] object has two inlets, the left being "hot" and the right being "cold". Any number of messages can be sent to the cold inlet, but this only results in the value attached to the most recent being stored. Sending the sequence of messages [10; 11; 12(to the cold inlet of [+] yields no output, but if [100(is sent to the hot inlet, the message [112(is emitted (being the value sent to the hot inlet added to the value last sent to the cold inlet).

In [FrequencyEngine], the state of the pedals is applied to the cold inlet of the [+] object which calculates the index of the pitch in the 19-EDO scale to be sent to the outlet. However, this value is also applied to the "bang" object [O]. A "bang", or valueless message, is therefore sent to the hot input of the [+] object *whenever any pedal event is received* and this results in a new pitch being emitted from the [FrequencyEngine] whether the change is required as a result of a new fingering or a new pedal position. Accommodatingly, the [O] object also flashes whenever such an event is generated, which is an aid in debugging. If the "bang" were not propagated to the [+] object's hot inlet, the position of the pedals would only be taken into consideration when the wind controller generated a new "note-on" event. This permits ornaments to be achieved using the pedals, so that the performer can generate grace-notes, mordents, or with still more practice, trills.

4.4: Pedal Events

The Pd module responsible for processing pedal events is shown in Figure 8. The hardware used to provide the foot-switches is connected to the computer's USB interface, and simply emulates two keys on the keyboard being pressed and released as the pedals are operated. The key-codes generated by the left and right pedals are respectively 49 and 51, corresponding to the 1 and 3 keys appearing on the top row of the main keyboard on a standard English (US or UK) keyboard layout. Pd provides for the separate detection of keyboard (and hence foot-switch) presses and releases via the [key] and [keyup] objects. These emit the keycode of the switch respectively depressed or released.

[select] object is used to filter the foot-switch events. A [select object with n arguments tests its input against the values in the arguments list. It then performs the function of a multi-way switch. The incoming message is compared with each of the values in turn, and if a match is found, a "bang" is sent to the corresponding outlet. Events relating to the left pedal will therefore cause the first outlet to "bang", and those from the right the second. Other messages are passed to the final outlet, but since there are only two pedals, we expect none, and this outlet is left unconnected.

The structure of the module is complicated by the semantics of pedal depression. An early

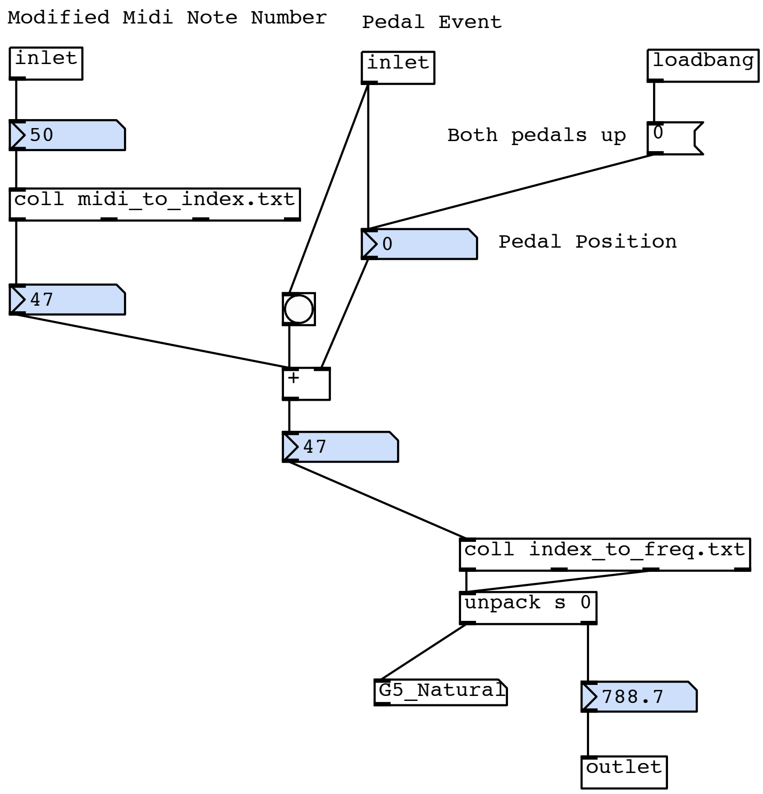


Figure 7: The Frequency Engine

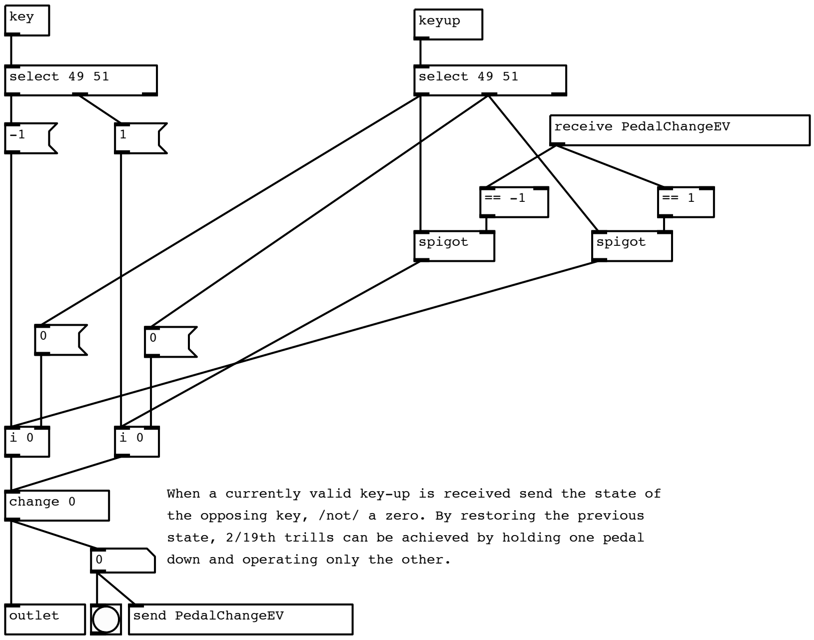


Figure 8: The PedalEvent Module

implementation simply generated a +1 when the sharpening pedal was depressed and a -1 for the flattening pedal. However, in performance, the expected behaviour was that a pedal release should cause a return to the inflexion pertaining before the most recent pedal depression. For example, if A♮ is fingered and the flattening pedal is depressed and held, a momentary depression of the sharpening pedal should cause the instrument to play the sequence A♭, A♯, A♭ and not A♭, A♯, A♮.

In order to achieve this, the state of the keys is stored in two distinct integers ([i] in Pd), both initially 0. Processing then proceeds as follows:

- Pedal-down events are converted to $\pm$ 1 and immediately set the state variable associated with the appropriate pedal. The new value propogates to the [change] object and also to the outlet,since two pedal-downs cannot happen on the same pedal consecutively.

- Similarly, if the pedal is released, the associated state variable is set to 0, but this time using the "cold" inlet.

- If and only if the last pedal event resulted in -1 (flatten) being emitted, the left-hand spigot (in current British usage, one would more commonly refer to a stopcock) is opened. If and only if the last pedal event was +1 (sharpen), the right-hand spigot is opened.

- The spigots regulate the passage of bangs from the pedal-up [select] object to the hot inputs of the pedals' state variables. Recalling that a bang is an empty message with no associated value, when applied to the "hot" inlet of the state variable, the variable's current value is passed to the [change] object.

- However (and this is the crucial point): a pedal-up on the right pedal opens the spigot associated with the left pedal's state variable and vice versa.

Now consider the pedalling sequence previously put forward. The left pedal is depressed: -1 is applied to the hot input of the state variable and thence to the change object and (since it was initialised to 0), generates a [-1(. The left-hand state variable is also set to -1.

As well as a -1 message appearing at the outlet, the message is broadcast to all listeners using [send pedalChangeEv]. Among the receivers is this submodule: the [receive pedalChangeEv] receives the change to value -1 and the left-hand spigot is opened. Pd defines the order of operation for the objects in a variable, so there is no risk of a race occuring.

With the left-hand pedal held down, the right-hand pedal is depressed. The right-hand state variable is set to 1, and the [change] object emits a message value 1. The left-hand spigot is closed and the right-hand spigot is opened.

When the right-hand pedal is released, a keyup message is passed to the [select 49 51] object, and the second outlet bangs. This causes the right-hand state variable to be reset to 0, and this is done via its "cold" input so no message is passed to the outlet. However, the right-hand spigot is currently open, so the bang caused by the pedal release is routed to the hot input of the left-hand state variable. Since the left pedal is still depressed, the left-hand state variable is still -1, so it is this value that that is passed to [change]. The result is that the sequence of messages emitted is [-1; 1; -1(and the desired functionality is achieved. If the left-hand pedal was released while the right was held down, the left-hand state variable would have been reset to zero (surreptitiously, via its "cold" input), so the message sequence appearing at the outlet would be [-1; 1; 0(which is again the desired functionality. The same logic applies *mutatis mutandis* if the order of the pedal depressions is reversed. The foregoing description of the state-machine is explained in the linked video 🎞

4.5: Computing the Sound

While the desired frequency has been established, the incoming breath pressure is captured from the WX7/WX5's MIDI input stream. *19Cl* employs a physical model object, *Clarinet˜,* to produce an approximation of a clarinet tone. *Clarinet˜* is a PD object based on the "Sound Toolkit" developed by Cook and Scavone (1999). The physical model is described in Scavone & Cook (Scavone and Cook 1998). The model directly computes the audio output using the physics of the oscillating air column within the instrument, taking into account the reed stiffness and applying certain parameters which affect the size and rate of vibrato. The advantage of a physical model it that, potentially, it produces more accurate transitions between notes and better-controlled breath/pitch inflections. The stiffness parameter is manually adjusted by the performer in the main window; it defaults to what we believe to be the most responsive and realistic value. The two real-time variables used by *19Cl* are frequency and breath pressure.

4.6: Preserving Articulation

The physical model necessarily makes an imperfect job of rendering a clarinet sound which could never fool an expert performer. There are known unknowns, such as simplifications of the model to enable it to be run in real-time on a modest computer, and unknown unknowns, arising from lacunae in the 20th-century mathematical descriptions of a real clarinet. The model used here is reasonably

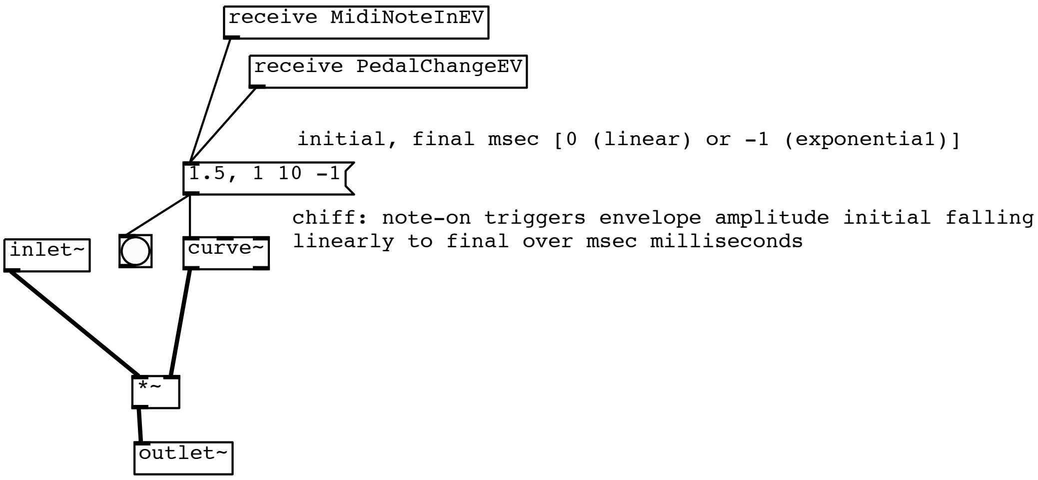


Figure 9: The Articulation Processor

simple and in computing terms virtually antique (it appears in the literature as early as 1983), but it is therefore very simple for a modern computer to execute. The clarinet engine contains parameters which can be set by the performer, so as best to accommodate the instrument to his or her own style and technique. We have also found empirically that adding an increasing amount of vibrato as breath pressure increases according to a quadratic law makes for a more natural-sounding result in performance (see Figure 9 on page 16).

In order to improve the responsiveness of the instrument the wind pressure is modified to add a "minumum usable pressure", so long as the instrument is being blown at all, allowing the instrument to "speak" more quickly. We have also have introduced an [ArticulationProcessor] sub-module, which takes audio input from the clarinet physical module, and applies a short "chiff" by momentarily increasing the rendered amplitude at the onset of each note. The values given are those preferred at an early stage of development by Alex South. In future, it may be possible to use the "pitch bend" data sent by the wind controller in response to changes in embouchure to modify the depth of articulation, permitting a wider variety of timbral variation.

Also available is a 17'19" video (*"Putting the Wind Up Pure Data"*) explaining and demonstrating the workings of this Pure Data patch.

4.7: The Rosegarden Codicil

Rosegarden is primarily a MIDI sequencer for Linux built on the JACK (JACK Audio Connection Kit) low-latency audio framework (Letz, Fober, Orlarey & Davis 2004; also `http://jackaudio.org`) and the Qt widget set (Blanchette and Summerfield 2008). It also has facility for editing audio and music score files, coupled with excellent quality score output via the Lilypond music typesetting system (Nienhuys and Nieuwenhuizen 2003).

The *Codicil* was written at SMRG and adds a real-time pitch-tracking facility to the score view of the sequencer. When playing back tracks, Rosegarden is able to display a cursor which moves over a common score notation display of a track. Where the track is monophonic, it is possible to display the deviation of a performed pitch from the notated pitch underneath the score. Furthermore, the expected pitch of the performance is calculated with reference to a temperament file, so that a variety of temperaments can be made available according to the application, including microtonal ones. This has proved a valuable rehearsal tool for musicians preparing a piece in an unfamiliar and/or non-standard temperament. While preparing composer and co-author Graham Hair's *Three Songs from the Turkish*, clarinettists Dr Alex South and Dr Ingrid Pearson (Royal College of Music) and singers Amanda Morrison (BBC Singers, Tallis Scholars, Scottish Voices et al) and Lisa Swayne (Royal Conservatoire of Scotland) had the system made available to them in order to rehearse the songs which were written with 19 equal divisions of the octave (Hair *et al* 2007). Ingrid Pearson devised an alternative fingering system and performed on an acoustic clarinet, combining it with inflexions produced by embouchure (see Hair et al. (2007)); Alex South has recorded the works for CD on acoustic clarinet before becoming involved in the project to develop the microtonal extensions for the WX7/WX5.

Initially, the *Codicil* incorporated the facility to analyse and display the pitch trajectory of an audio recording made with the Rosegarden sequencer. However, because more powerful and appropriate tools for pitch analysis are available which operate off-line, and because the authors of the Rosegarden program were keen that any additions to it did not make it harder for other contributing programmers to understand the source code, the current versions have only real-time functionality and are intended for use as rehearsal tools for highly competent musicians. Version 11.11 of *Rosegarden* (released November 5th, 2011) includes the *Codicil* as standard.

Because *Rosegarden* operates as a multi-track sequencer, it is possible to have the program accompany the rehearsal as well as analyse the pitch of the performance. When using 12-EDO, it is trivially easy to achieve this simply by having the sequencer play back the accompaniment track while simultaneously displaying and analysing the soloist's part. If the piece is in a different temperament, the easiest way to do this to obtain the accompaniment is to set up a (hardware or software) MIDI synthesiser which is tuned to the temperament required. If the temperament has more than 12 divisions of the octave, it will be necessary to provide a track in "scordatura" notation which, when played on the microtonal synthesiser, renders the desired pitches. This is the role of the Scordatura Keyboard, or as it has latterly become known, the *Ill-tempered Clavier*.

4.8: The Ill-Tempered Clavier

Fluidsynth is an open-source sound-font-based MIDI synthesiser for GNU/Linux. SMRG has used it mainly with a "harmonium-like" sound font.

Unlike many, if not most, commercial MIDI synthesisers, it honours the MIDI Tuning Standard (Scholz 1991) enabling all of the notes in its compass to be retuned to arbitrary pitches. By providing appropriate configuration files, it is possible to re-map the keys of the MIDI controller keyboard to produce notes of the 19-EDO scale (or others).

This implies that the only key which sounds as in conventional 12-EDO tuning is A4 (440 Hz). The physical distance associated with each interval increases; for example to play the interval of an octave required keys 19 keys apart to be pressed simultaneously, and even a perfect fifth involves keys 11 keys apart.

On an "ordinary" (12-EDO) keyboard, 19 keys span the interval of an octave and a fifth, and of course, an instrument which demands the reach of an octave and a fifth (in terms of keys) to sound an octave (in terms of pitches) can be counter-intuitive and physically demanding to play. Thus the *Ill-tempered Clavier* was intended as a secondary, accompanying instrument which could play the

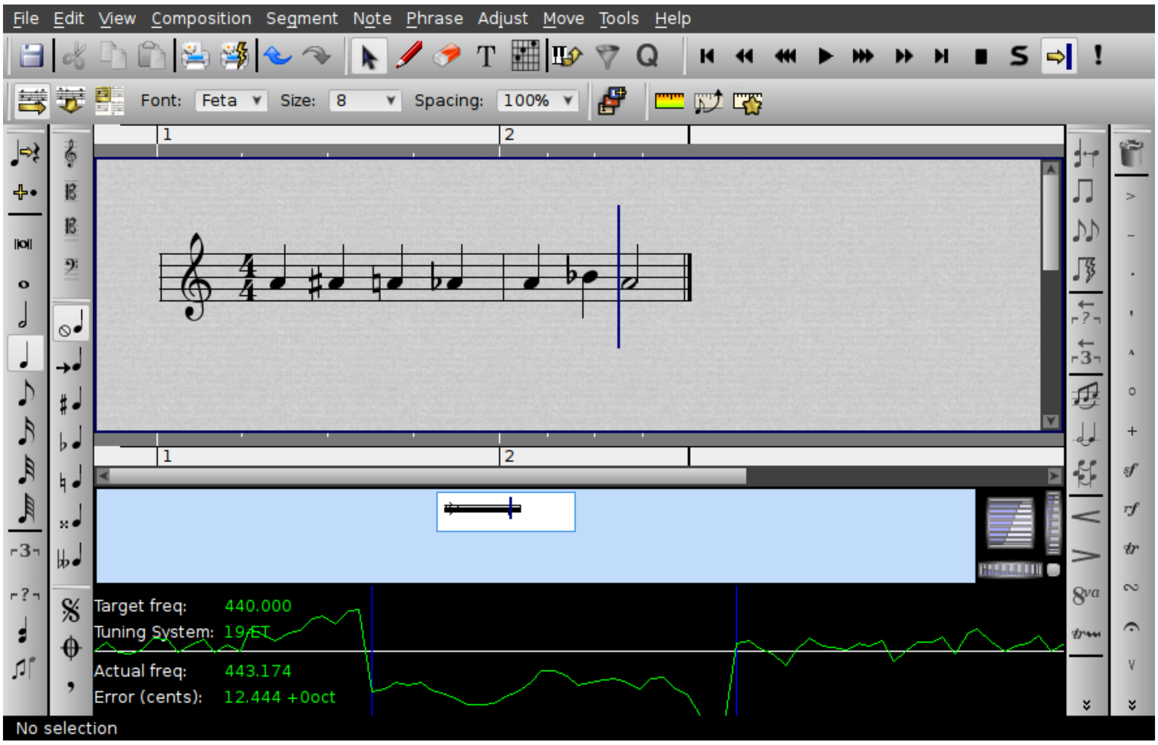


Figure 10: A pitch-tracking session. Blue vertical lines represent note boundaries, and the green line shows the deviation from the notated pitch. The graph is configured to show errors of up to ±50 cents, be 4 seconds wide and to ignore octave errors. In this attempt to perform the (19-EDO) score above, the singer is approximately 12 cents sharp at the instant shown. The penultimate note, a B♭, two hyper-chromatic steps above A, is rendered slightly flat in this performance.

simple, slow-moving harmonies which the second of co-author Graham Hair's 19-EDO songs (for voice with clarinet or Wind Controller, and Digital Harmonium) requires. However, it is in principle capable of performing a more elaborate role, and in the first and third of these songs (composed after the second) it does so, albeit it was never intended as a solo instrument.

A program designed to convert a 19-EDO score notated in Lilypond format has been written which produces two keyboard "Great Staves" as its output: the upper one contains the pitches are to be sounded (as with a conventional piano score); the lower one indicates which keys on the keyboard the performer must press to produce the sounding pitches given on the upper Great Stave.

For this reason, SMRG refers to the software as a "scordatura keyboard" (*scordatura*: "mistuning" (Italian)) in reference to the — predominately 17th and 18th century — practice of retuning the strings of a violin, and to the more recent (editorial) practice of publishing scores in a double-staff format (indicating both which pitches should be sounded, and what positions on the violin fingerboard must be pressed to produce those sounding pitches). Demands placed upon the keyboardist, both physical (by requiring unusual hand-positions for familiar chords) and cognitive (through the requirement to press the "wrong" keys in order to produce the correct sounds), has led to its more colloquial alternative title.

A very early 17th-century example, the opening two measures of John Bull's keyboard piece *Ut re mi fa sol la*, from *The Fitzwilliam Virginal Book,* is given. During the course of Bull's piece, about 18 of the 21 possible letter-names of notes (FCGDAEB, as naturals, sharps or flats) appear. Probably 12-EDO tuning — or possibly extended mean-tone tuning — was intended, but most of the piece (except for one measure!) can plausibly be played in 19-EDO, and the scordatura notation for this is given in Figure 11 (albeit the same notation will serve for 12-EDO or extended mean-tone tuning if the appropriate mapping of pitch to frequency is allocated).

Fluidsynth itself is a program designed to be used from the command line, and requires the user to have a fairly comprehensive grasp of the operation of MIDI synthesisers and the Linux sound system, as well as to provide the necessary sound fonts (banks of samples used to generate the output sound) and, if being used microtonally, pitch tables. To simplify its use, a GUI (grahic user interface) was constructed in a scripting language which provides simple push-button widgets to facilitate the selection of sound font and temperament. As well as providing this simple visual interface, the script runs the necessary software in the background in order to start *Fluidsynth* and allow the user to connect his/her chosen MIDI keyboard to its (virtual) MIDI input.

4.9: The SMRGygurdy

Like the *Ill-Tempered Clavier*, the *SMRGygurdy* is designed to be principally an accompanying instrument, so that the harmonic and contrapuntal possibilities of 19-tone and other temperaments can be explored.

The idea behind the *SMRGygurdy* was comparable in a general way to that of the accompanimental resources in some forms of Indian music, where instruments such as the *tampura* (and other less common ones) may provide a simple accompanimental drone on a single tone, which remains in place on the same pitch throughout (albeit often incorporating a rich palette of fluctuating timbral coloration of the drone pitch). Such an accompaniment functions as a counterfoil, highlighting the complexity and subtlety of nuance and ornamentation provided by the principal vocal or instrumental melody sung or played on other instruments. Some styles of music in the West — eg a particular form of minimalism, sometimes called "drone music" which appeared from about the 1960s — were influenced by such non-Western instruments and styles.

Ut, re, mi, fa, sol, la.

John Bull

Figure 11: 'Great Stave' notation of a 'scordatura' *Ill-tempered Clavier* score (showing sounding and written versions).

However, in place of a fixed drone, anchored to a single tone, the SMRG team wanted to diverge from the "traditional" functions of the *tampura* and other drone instruments in two ways:

1. by changing the pitch and register of the drone from time to time, effecting a change of tonal centre; and

2. by "augmenting" the drone to consist of 2, 3 or more notes, so that, effectively, the drone becomes a series of slowly changing chords.

The string sound is generated by a physical model of a vibrating string using the *artifastring* library (see (Percival et al. 2011)) The library models the behaviour of the string by considering each of its vibrational modes when open, then applying a force at the stopping point which is exactly that required to prevent any movement at that point. The bow is modelled as a frictional force which is greater when the hair is stuck to the string than when it is slipping. The model considers the velocity and pressure of the bow in calculating the force at the bridge which, combined with an acoustical representation of the instrument body, is used to generate the final audio output. In this implementation, the position of a volume pedal is read by a generic analogue interface and used to dictate the bow speed. The result is, as it were, an "electric hurdy gurdy", which has the wheel driven by a notional motor, the speed of which is controlled by the pedal.

The artifastring library has been highly optimised by the pre-computation and caching of as much of the necessary mathematical constants as possible, and the application is multi-threaded in order to take advantage of multiple CPU cores frequently found in contemporary computers, laptops and recently even tablets and mobile telephones. Consequently, even a modest machine is capable of five- or six-voice polyphony.

The supplied version is currently configured for 12-EDO, but SMRG intends also to provide for 19-EDO and other temperaments. Because the model of the string is entirely physical, it is simply a case of calculating the position at which the string should be stopped in order to produce the desired pitch, and sending this information to the model accordingly.

5: Technological Assessment

Our experience tends to suggest that orchestral musicians, accustomed to a repertoire which anchors so many assumptions on the 12-EDO scale (even though everyone knows this scale is no more than a kind of an "intonational average" around which the intonation of individual notes diverges considerably for expressive and other reasons), are often inclined to regard *any* formally-structured microtonal practice based as demonstrating — *ipso facto* — an "avant-garde" or "experimental" aesthetic orientation.

On the other hand, although the NIME ("New Interfaces for Musical Expression") conference-series is indubitably biased towards "avant-garde" and "experimental" mentalities and an interest in the unlimited repertoire of all the possible varieties of unmetered sound and noise which are at least potentially opened by techniques of elecro-acoustic composition, many of the projects reported there make use of traditional orchestral instruments to provide gestural input into, and control over, such sound-worlds: gestural aspects which are not easy to capture in computer-generated sound with other means.

The approach to microtonality in the present project adopted a "third way" between these two contrasting attitudes, combining aspects of both. We have tried to show that the exploration of 19-

EDO and the use of new instrument technology and computer software can be rooted in established practice but nevertheless still draw out new musical ideas from these resources.

An alternative to purchasing or building specialised microtonal musical instruments is to combine the advantages of available instrument technology and those of general purpose computers. A simple, low cost laptop PC or netbook can easily be converted to serve as microtonal rehearsal aid for instrumentalists and singers, using the Rosegarden Codicil. With the addition of a breath controller, a pair of foot-pedals and the 19Cl program, or a MIDI keyboard and the Ill-tempered Clavier, the computer can provide the means to perform 19-EDO or other microtonal ensemble music.

All of the necessary software has been assembled as a single collection in that it can be downloaded onto a DVD-ROM or an external memory device. The distribution medium optionally supports the use of two partitions so that changes made to the set-up by the user are persistent (which is to say they are not lost when the computer is shut down and restarted), yet no changes whatsoever are made to the host machine's installed software.

6: The 19-EDO Wind Controller in Performance

We now turn to a closer look at the possibilities and problems of the instrument from the performer's viewpoint.

In learning to play a new musical instrument, a performer inevitably brings his or her own history of engagement with any similar instruments already mastered. In the terminology of cognitive psychology, an instrument offers a set of affordances (Gibson 2014), which may elicit appropriate or inappropriate responses from the player depending on the degree of similarity. A mouthpiece affords blowing, a set of keys affords fingering, and so on. The responses initially elicited draw on the habits, skills, and know-how acquired by the player over thousands of hours of practice and performance. Such skills are exhibited by the more or less automatic patterns of neural, skeletal and muscular activity involving, at the least, breath, fingers and tongue (in the case of a wind player). In the case of the new instrument, these highly-specialized patterns must be modified to match the changed physical characteristics of the instrument (eg its weight, the dimensions of the keywork, shape of mouthpiece) and its response to playing (eg resistance to blowing, ease of movement of keys). The modification of these patterns requires the acquisition of a new set of bodily skills dedicated to the configuration and responses of the new instrument: in a word, learning. Such learning takes practice: patient repetition and conscious self-observation to recognize where old habits may be preventing a smooth performance, and to identify where completely new habits must be laid down. Over time the new instrument and its responses becomes incorporated within the body schema Gallagher (2008) of the performer, and tiny adjustments and corrections to the usual embouchure, blowing, articulation, fingering and posture, become automatic. The instrument becomes familiar to the player in the way that a new car becomes familiar to its driver.

This much will be readily recognized by anyone who has moved from one instrument to another related instrument. Clarinettists as a breed are quite used to such moves: they might have played recorder before taking up the clarinet, and after becoming skilled at the usual B♭ instrument will take up the slightly larger A clarinet with little difficulty. The clarinet family extends much further; professional players often specialize in playing one or other of the soprano E♭ or bass B♭ instruments, and in addition mayplay saxophone and even members of the flute family. Performers in symphony orchestras may occasionally find themselves with a rack of instruments in front of them (eg in

Mahler's *Fourth Symphony* the third clarinettist's part is scored for clarinets in C, B♭ and A, and bass clarinets in B♭ and A); while those in West End and Broadway shows are commonly "doublers" or "triplers" (perhaps playing clarinet in B♭, flute, and tenor saxophone, or clarinet in B♭, bass clarinet in B♭, and baritone saxophone). Co-author Graham Hair has followed in the footsteps of Babbitt, Henze and other twentieth-century composers in making such demands in *solo* works for the instrument, with his *Harmonice Mundi* in which the performer has to play the E♭, B♭, bass and contra-alto.

So, it is not unusual for a clarinettist to have to gain proficiency on an instrument related to the ordinary B♭ soprano: what is new is the possibility that this instrument be non-acoustic. The design and manufacture of electronic wind-synthesizers (as described in our introductory remarks), has gone hand in hand with their use by composers and performers: particularly in the studio but also in live settings. Saxophonist Michael Brecker (1949 – 2007) was a well-known jazz musician who used the Akai EWI in live performances and recordings (Including his first solo album *Michael Brecker* (Brecker 1987a) and his last, *Pilgrimage* (Brecker 1987b)), and Philip Glass's scores for wind-synthesizer in his *1000 Airplanes on the Roof.* Richard Ingham (personal communication) states that some different temperaments, such as quarter- and eighth-tone ones are, in principle, achievable through the use of the Yamaha TX81Z tone-generator. However, the present authors have not encountered investigations into the extent and limits of this potential, or implementation of actual performances using it. So, as far as the authors are aware, there has been little or no use of such instruments to perform microtonal music prior to our own adaptation of the Yamaha WX7/WX5. For co-author Alex South, a professional clarinettist with performing experience on the saxophone, coming to the WX7/WX5 wind-controller required two major initial sets of adjustments. The first was becoming familiar with the design and ergonomics of the instrument — its keywork, mouthpiece, etc., as mentioned above, and the second becoming familiar with reading music in the new 19-EDO scale, and selecting the fingerings required for the seven extra pitches per octave compared to the ordinary 12-EDO scale. These two adjustments interact because the increased number of subdivisions in the octave requires use of the foot-pedals to access those pitches written as flats, thus complicating the fingering patterns used to play passages containing these pitches. Beyond these adjustments there is also the issue of expressivity: a hard-to-quantify element of performance which for the clarinettist involves, at minimum, the precise and subtle control of instrument-specific factors such as dynamics, tone-colour (timbre), articulation, and intonation, as well as more general factors such as rubato and phrasing.

6.1: Design/Ergonomics

Taking the WX7/WX5 in hand, there are are a number of differences immediately noticeable to the player: it is much lighter and a little shorter than the B♭ clarinet, has a built-in plastic "reed", and keywork made of plastic rather than metal. In place of the register (speaker) key under the left thumb, there are a set of four buttons designed to shift the pitch up and down by one, two or three octaves. Under the right thumb is a springy rocker switch (the "pitch-wheel") which, like the reed, is designed to allow pitch-bending, that is, small deviations from the fingered note. Unlike the clarinet, but like the saxophone, there is no direct contact with tone-holes, and the fingerings used repeat at the octave (rather than the twelfth). However, unlike the saxophone there are no extra "palm keys" for high notes, or little finger keys for the written low B and B@ (immediately below middle C). This means that the ordinary chromatic fingerings within the 12-EDO scale are rather simpler than those of the clarinet, but also that passages which go outside of the two octave pitch range extending upwards from (written) middle C require the development of new fingering patterns. The use of octave buttons to access lower and higher notes requires much practice to become fluent (as is recognized on the useful webpage on Wind Controllers found at www.patchmanmusic.com/WindControllerFAQ.html), and initially interferes with the achieving of a smooth legato. Further differences between clarinet and WX7/WX5 become evident once the mouthpiece is put in the mouth and the instrument blown. Although the "blowing resistance" on clarinet and WX7/WX5 is comparable, articulation on the latter is, initially at least, much more difficult (the tongue feels "sluggish"). As the reed is not vibrating and contact between tongue and reed superfluous, the tonguing technique eventually settled on by Alex South is an adaptation of recorder tonguing, with the tongue contacting the roof of the mouth. Fast staccato may require the development of double-tonguing technique. However, articulation techniques developed by players as part of their normal training will stand them in good stead in fulfilling the expressive potential of the WX7/WX5 (Ingham 1998:185).

6.2: Score-reading

As described above and shown in Figures 2, 3 and 4 (page 5), nothing other than the ordinary symbols for flattened and sharpened notes need be employed in writing music for the 19-EDO scale, and this is the approach taken by co-author Graham Hair and other composers, including Ivor Darreg and Joel Mandelbaum. This notation has many advantages: it is easy to understand, aids the player to conceptualize the 19-EDO scale as an extension of the diatonic scale, and requires no learning of the meaning of additional symbols (such as those found in many "microtonal" works for which the symbols — eg for a quarter-tone sharp, an eighth-tone flat, etc. — are still not standardized: see Bok (1989,special english edition, 2004:6) for a comparison of the different sets of symbols in common use.). However, it is not without its own set of problems for the player of the customized WX7/WX5, partly arising from the very fact that that music written in this way looks misleadingly familiar. The chief reason that problems arise is that the 19-EDO WX7/WX5 player must learn a new way of dealing with notes written as flats. To play such notes requires not only the acquisition of new combinations of fingering and foot-presses (and the use of the pedal itself demands a new kind of coordination from the wind-player), but also — just as importantly — the inhibition of habitual responses. For example, a B♭ may be played by fingering B and pressing the left pedal, or fingering A♯ and pressing the right pedal, and must not be played with the accustomed fingering. The pitches between B and C, and between E and F, need special consideration as they too must be played with the pedal. B♯ may no longer simply be read as a C♮, etc. This makes new cognitive demands upon the player, and also has consequences for the joining of notes in smooth legato phrases. To play A–B♭–C requires good coordination between fingers and foot: achievable with practice but difficult to play smoothly. Of course, notes nearly always come in groups rather than individually, and the fluency of reading and playing scale fragments, broken chords, and the like is also much affected. In part this is a "fingering problem" – anything with a flat in it will require a novel fingering pattern (understanding "fingering" to include movements of the feet), but in addition it is a reading problem. In music written in a tonal idiom within 19-EDO there are now nineteen major keys rather than twelve. B♭ and A♯ majors are no longer enharmonic keys, and although musicians are used to performing in keys with two flats, they are not used to playing in keys with ten sharps! (major scale: A♯–B♯–C𝄪–D♯–E♯–F𝄪–G𝄪). A♯ major is now enharmonic with B𝄫 major: writing in this key will in fact reduce the load slightly to nine flats (major scale: B𝄫–C♭–D♭–E𝄫–F♭–G♭–A♭), although the player is unlikely to be much happier. The presence of double-sharps and double-flats offers further potential for confusion, once again resulting from the new enharmonicities. For example, F𝄪 may no longer be thought of and fingered as a G♮ — rather, it is enharmonic with G♭ and must be played with the pedal (either F♯ plus right pedal, or G plus left pedal). Passages in such keys will remain challenging until scales and arpeggios are mastered, and books of studies available for further practice.

6.3: New Fingering Strategies

As described above, the 19-EDO WX7/WX5 novice is faced with a host of new technical challenges to overcome, in order to become a fluent and expressive performer on the instrument. Here three tips may help the player devise new fingering strategies for certain passages likely to be encountered.

1. Notes written as naturals (excluding B and E) may be played with the ordinary saxophone fingerings, or in combination with the left pedal. For example, an "A" may be played with the A♯ fingering plus the left pedal (A♯+LP).

2. Notes written as flats may be played with either pedal. For example, a "B♭" may be played as B+LP or A♯+RP.

3. Notes written as sharps (excluding B♯ and E♯) may be played with the ordinary saxophone fingerings, or in combination with the right pedal. For example, an "A♯" may be played as A♯ or A+RP.

These new combinations may allow certain intervals to be played without moving the pedal, and thus negotiated more smoothly if legato is desirable. So, for instance the transition from A–B♭ can be played as A♯+LP to B+LP. The scale fragment A–B♭–C can be played as A♯+LP to B+LP to C♯+LP. There is a tradeoff, of course, for now notes which would otherwise be fingered "as normal" have a new fingering, but nonetheless this may well be useful in some situations.

Another use of this technique comes into its own in passages in extreme sharp and flat keys. For example, the scale of A♯ major used above to illustrate difficulties in score reading, can in fact be performed straightforwardly by playing an A major scale with the right pedal depressed. A scale in G♭ major can be performed as a G major scale with the left pedal held down. In fact, in these cases the fingering on the 19-EDO WX7/WX5 is much simpler than on the ordinary acoustic instrument.

Trills and tremolos deserve attention too, as these must be regular and fast, which the novice user may be unable to achieve with the pedal. In 19-EDO trills may be called for with an interval of one, two or three nineteenths of an octave, and study of these intervals shows that all may be played without moving the pedal, with the following exceptions: one nineteenth octave trills on E♭, E♮, B♭ and B♮. Composers take note!

7: Avvon d'Bishmaya: a Case Study

We conclude this documentation of the development of the "microtonal wind-controller" with a case study involving the performance of a musical example composed by our fourth author, Graham Hair: *Avvon d'bishmaya* (*The Lord's Prayer*) for soprano and digital sound (the latter incorporating Alex South's performance of the WX5 part). A complete piece, rather just a few measures, is chosen, in order to show not merely the presence of local 19-EDO features, but also possible approaches to medium- and larger-scale structures drawn from the 19-EDO scale, and to give at least an embryonic idea of some of the expressive possibilities of the 19-EDO scale: albeit accommodating the constraints of space available in a journal article dicates that the score be rather short. A recording of a performance is available on the internet[1] 🔊 . In this recording, the WX5 part is played by Alex South, and the "backing track" is generated by a combination of several computer programmes, including Lilypond, Frescobaldi, Fluidsynth, Rosegarden, Audacity, Sibelius, Wavepad and Csound. Score and recording enable readers and listeners to follow the use of the 19-EDO scale in an actual musical context.

It would probably be true to say that the General Public anticipates that compositions using the 19-EDO scale will, broadly speaking, fall into a stylistic category such as "contemporary avant-garde" or "contemporary experimental": what the *Soundcloud* website classifies as the "Contemporaryclassical" (all one word!) genre. By way of an example which does satisfy such conventional expectations, we nominate a prize-winning article, "The Microtonal Tuba" (cf Hayward (2011)), in which tuba-player Robin Hayward documents an interesting project in instrument-building and a repertoire of personal performance practices (based in particular on Just Intonation) which converge more with the aforementioned anticipated interests, or those of delegates to conference-series such as the Canada's "Sound Symposium" (see `soundsymposium.com`), where some of Hayward's work has also been presented, or to the related world of what is now often called, in Britain at least, "Sonic Arts". But despite such anticipation, the composer decided on this occasion to try something more closely related to the daily lives of the broad spectrum of clarinet, flute and saxophone players, teachers and students: ie contexts other than the "New Music Industry" or specialised events such as Aberdeen University's *Beyond the Semitone* conference, held in October 2013, where some of the composer's 19-EDO music was also presented.

Reception was an important factor in this choice: since the 19-EDO scale is unfamiliar to most listeners, the choice of that scale does not mean that listeners should obligatorially be challenged to interpret absolutely everything else about the piece from "a blank slate". Accessibility of the outcome suggests, on the contrary, that other aspects of the style and structure should aim at simplification, to achieve cognitive transparency.

From the standpoint of production, another factor in the choice of style was that it should, broadly speaking, be consistent with the stylistic orientation of the composer's other music: music which does not, for the most part, use the 19-EDO scale. All composers draw on past experience to create new music, and to deprive oneself of this possibility just because of the decision to use the 19-EDO scale would be a serious limitation. Indeed, when the composer presented other 19-EDO examples at an earlier conference in 2010, one of the delegates expressed surprise that her expectation (namely that use of the 19-EDO scale would cause the music to sound "totally perceptually opaque and alien") had been confounded.

But in addition to such pragmatic issues, more idealistic concerns regarding the historiography of 21st-century composition also played a role in the style adopted for *Avvon d'Bishmaya*. Some of these were articulated by sociologist Anthony Giddens (2013) in more generic terms, social and political as well as artistic: in particular the notion that the development of society in the second half of the 20th century has made more possible the development of artistic traditions "horizontally" rather than "vertically". "Vertically" refers to the linear historiographical narratives of the past two centuries (ie of 19th-century Romanticism and its intellectual child, 20th-century Modernism), as transmitted via the traditions of education in "classical music" taught in academic institutions. In contradistinction, "horizontally" refers to the non-narrative configurations of the virtually unlimited global musical repertoires available in the contemporary world via the jungle of recordings, internet downloads etc (including – of course – the music of the classical tradition from Adémar de Chabannes to Brian Ferneyhough). One feature of such "horizontal" transmission is that such attributes of the immediate past as the Emancipation of Dissonance (aka the Suppression of Consonance) and its linear descendent the Emancipation of Disorder (aka the Suppression of Categorical Perception, as embodied in scale-formations of all kinds, including 19-EDO) are by no means obligatorially transmitted to the twenty-first, being simply two of the near-limitless number of possibilities available in the contemporary global jungle.

As long ago as 1929, Ludwig Witgenstein identified the aforementioned "vertical" historical narratives as fallacies:

> When we think of the world's future, we always mean the destination it will reach if it keeps going in the direction we can see it going in now; it does not occur to us that its path is not a straight line but a curve, constantly changing direction
>
> — *(Wittgenstein 1929, 1998:5e)*

In more recent times, Leo Treitler has applied Wittgenstein's view to a more specifically musical context: "...the greatest works of all are achievements that in historical terms appear not probable, but improbable, even impossible" (cf Morgan & Sharshott in the *New Grove* 25: 714–715).

The literary scholar Lionel Trilling (referring to literature, albeit his remarks are surely equally applicable to music) proposed that the survival of such "vertical" historical narratives into the 21st century is an artefact of the tendency (exemplified by the Emancipation of Dissonance and of Disorder) of artists in 20th-century modernist cultures to self-identify as contrarian, transgressive dissenters (following such artists and critics as Schoenberg and Adorno): a view which has become progressively more anachronistic in the 21st century, when contrarian, transgressive dissent has become normative amongst artists, and thus only minimally contrarian, transgressive or dissenting, but rather something more conventional: a species of tribal, or even sectarian, conformity. Consequently, *Avvon d'bishmaya*'s "horizontal" approach finds a use for both tonal centricity, consonance and diatonicism and acentricity, dissonance and chromaticism, and its musical language allows for the inclusion of such materials as sensuous and ethereal harmonies, rather than restricting itself solely to "emancipated" dissonance and disorder. Individually, a good proportion of the harmonies in *Avvon d'bishmaya* are common to many forms of 20th-century jazz, popular and "world" music: eg the pentatonic collection and its subsets, and subsets of the whole-tone scale and the cycle of fifths. In his article about the compositional style of American composer Steve Reich, Richard Taruskin comments that "It sought no return to older styles. If it used consonant harmonies, it was ... not to reinstate traditional harmonic hierachies." (Taruskin 2008:100). *Avvon d'bishmaya* aims at a similar inclusive-but-not-retrospective approach, albeit the means used are totally different.

The structure of *Avvon d'bishmaya* is underpinned by a series of five chord-sequences (measures 1–39, 40–60, 61–76, 77–99 and 100–123A). Each sequence is based on common-tone connections: both between over-arching, medium-scale, structually-determining "maximally-even scales" such as diminished sevenths and augmented triads (constituent intervals in 19ths of an octave: 5554 and 667 respectively) and between immediately adjacent harmonies: procedures which constitute one of many possible exemplifications of "neo-Riemannian" principles. These principles will not be described in detail here, but see Cohn 2012; they differ considerably from those of "common-practice" tonality, albeit perhaps encompassable by Tymoczko's more recently-proposed generic concept, the "Extended Common Practice" (Tymoczko 2010). Accordingly, such "common-practice" functions as tonic, dominant, secondary dominant, pre-dominant, passing chord, neighbour chord, embellishing chord and so on, play no part. Five triads appear: C major (measures 1–3), B♭ major (40), E minor (61–62), D major (77–79) and A♭ major (100–101, 122–123): whose roots form the "maximally-even" scale A♭, B♭, C, D, E: a subset of the whole-tone scale (whose constituent intervals in 19ths of an octave are: 333334) as a large-scale structure, but none of these triads constitutes the "tonic" (of the piece as a whole). It would be more accurate to describe them as "points of maximum consonance" than as tone-centres.

In each of *Avvon d'bishmaya*'s five chord-sequences, each of the 19 tones of the 19-EDO scale appears at least once. In the choice of this design there was also an element of tongue-in-cheek "hommage" to Stephen Altoft's recent CD release (*The Yasser Collection*, see above), on which he plays 19 works by 19 (sic!: actually 17; see page 3) different composers on the 19-EDO trumpet.

Finally, it may be noted that the software to enable the "microtonal wind-controller" to be played by anyone in possession of a WX7 or WX5 Wind Controller, a computer, some foot pedals and a Flash Drive is available for download from `www.n-ism.org/People/graham.php`, from where the "backing track" for the "Electro-acoustic Orchestra" is also available for separate download.

Also available is a 52'04" film (*Making Music with Nineteen Tones*) describing and demonstrating the use of the 19-EDO tuning/intonation system, as it occurs in a performance of Graham Hair's *Three Songs from the Turkish* by soprano Katrina Nimmo, WX5-ist Alex South with the composer at the keyboard.

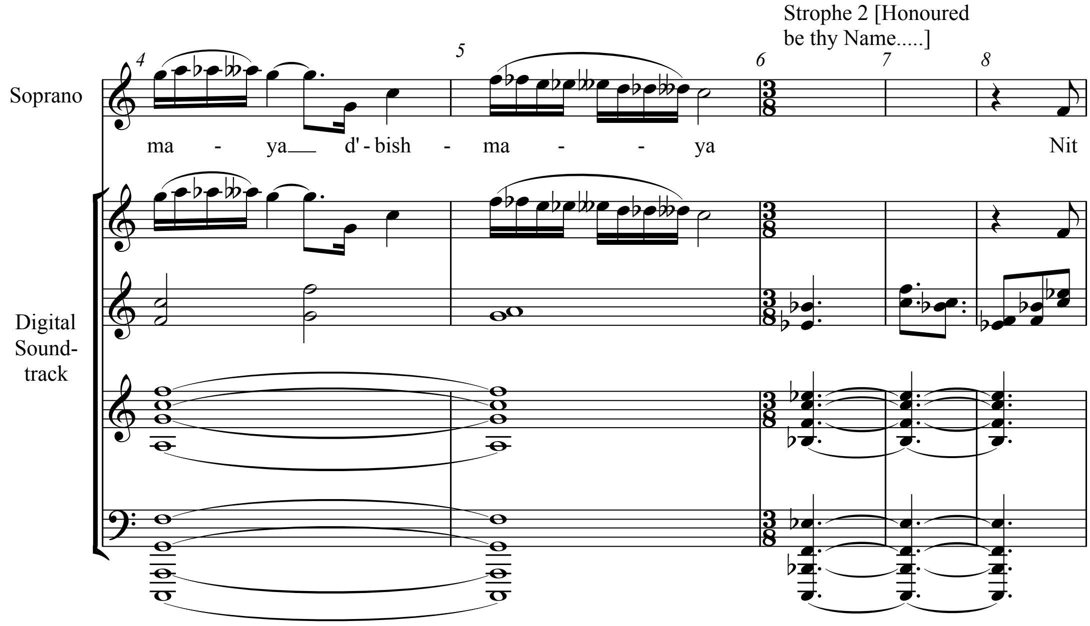
Avvon d'bishmaya

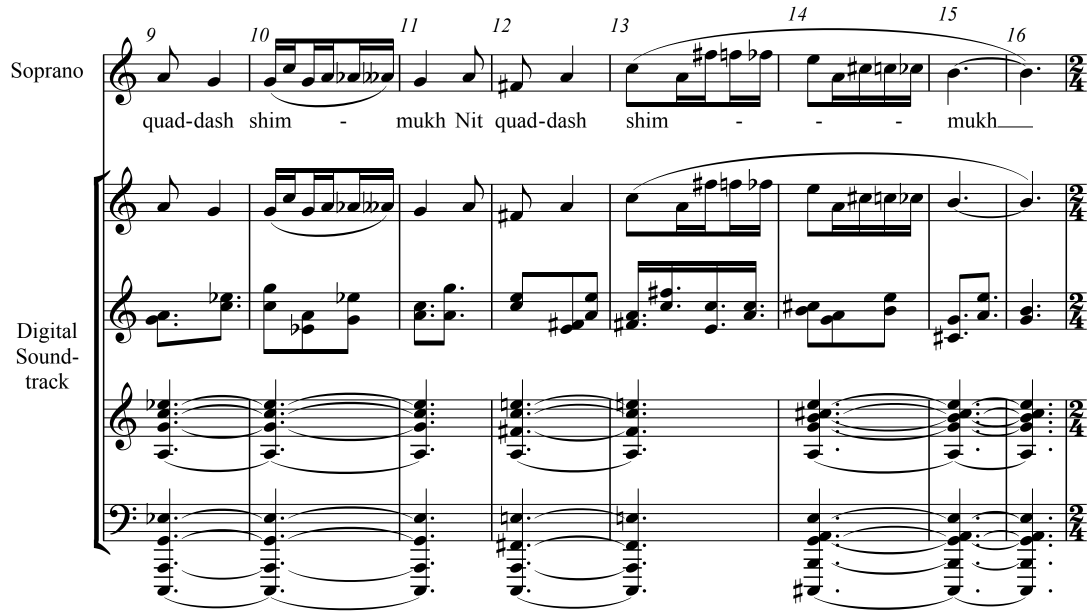
For Soprano and Digital Sound-track

Lento (♩ = MM 60)

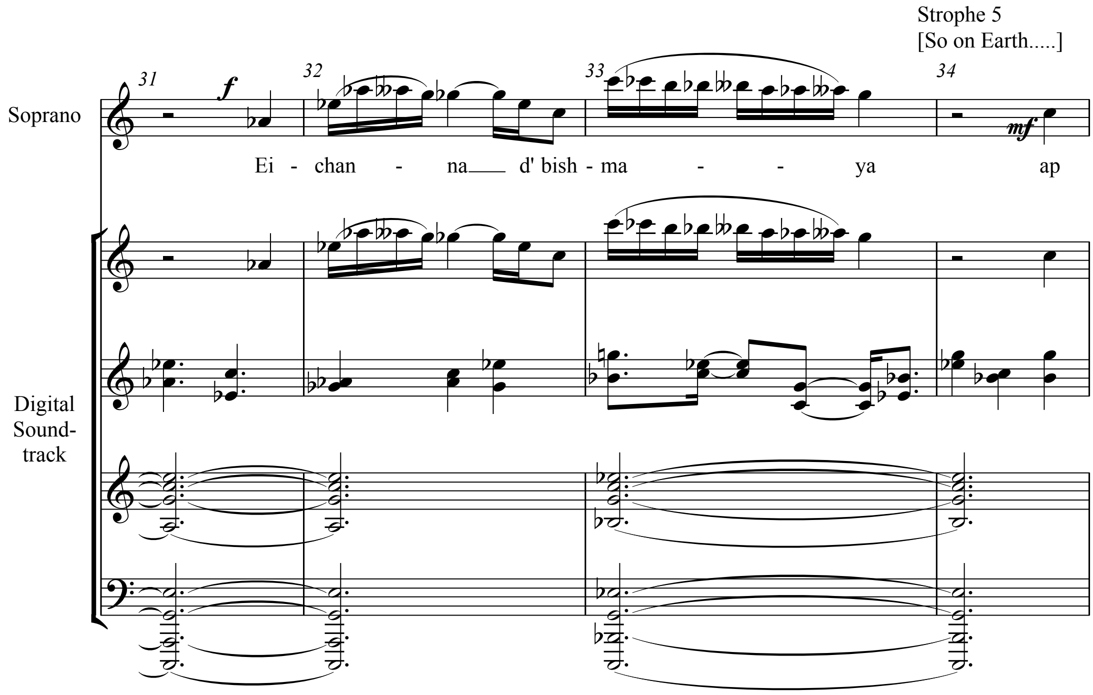
Strophe 1 [Our Father in Heaven.....]

Graham Hair


Strophe 2 [Honoured
be thy Name.....]
4
5
6
7
8
Soprano
ma - ya d'-bish - ma - - ya Nit
Digital
Sound-
track

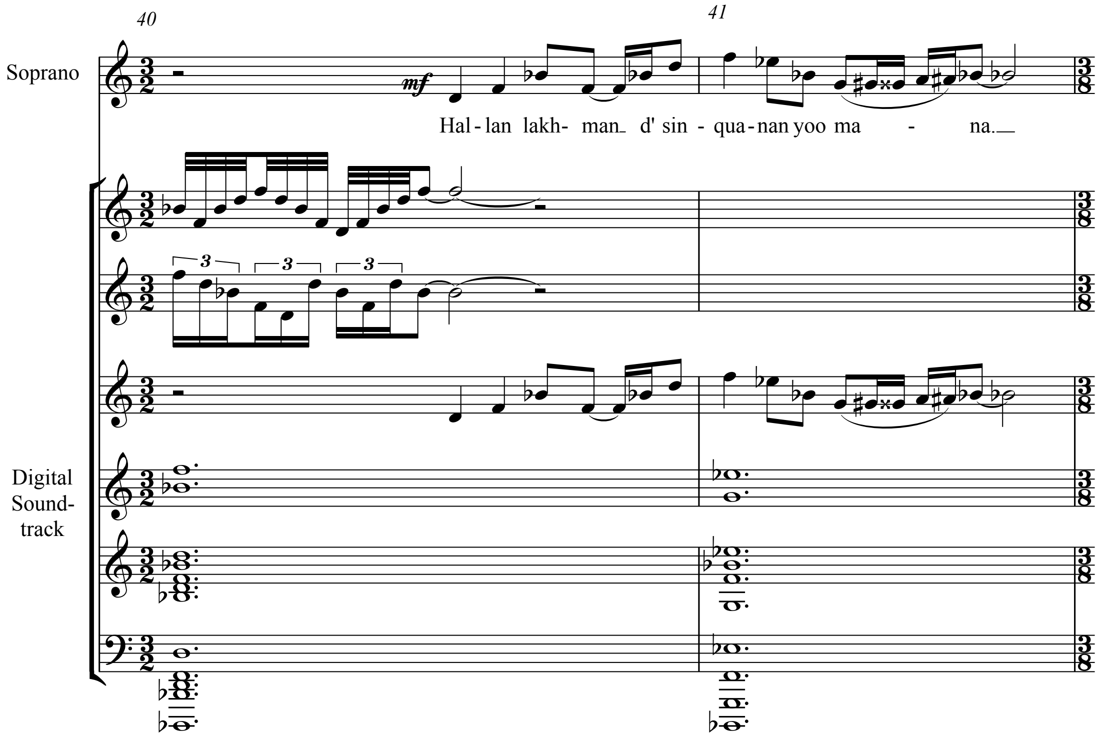

9
10
11
12
13
14
15
16
Soprano
quad-dash shim - mukh Nit quad-dash shim - - - mukh
Digital
Sound-
track


Strophe 3
[Thy Kingdom
come.....]
Soprano
Tie'-teh mal - choo - tokh
Nih weh siw - ya-nukh
Digital
Sound-
track
[Thy Will be done.....]
Strophe 4
[As in Heaven.....]
Soprano
Tie' - teh mal - choo - tokh
Nih weh siw - ya-nukh
Digital
Sound-
track


Strophe 5
[So on Earth.....]
31
32
33
34
Soprano
f
mf
Ei - chan - na d' bish - ma - - ya ap
Digital
Sound-
track


35
36
37
38
39
Soprano
b'a - - r'ah ap - b'a - r'ah
Digital
Sound-
track

Strophe 6 [Give us today our daily bread.....]



Strophe 7 [And leave us serene.....]

Strophe 8 [As we permit others to achieve.....]


Soprano
Digital Sound-track
49 50 51 52 53 54 55
na d'ap - akh - nan shwi - qan

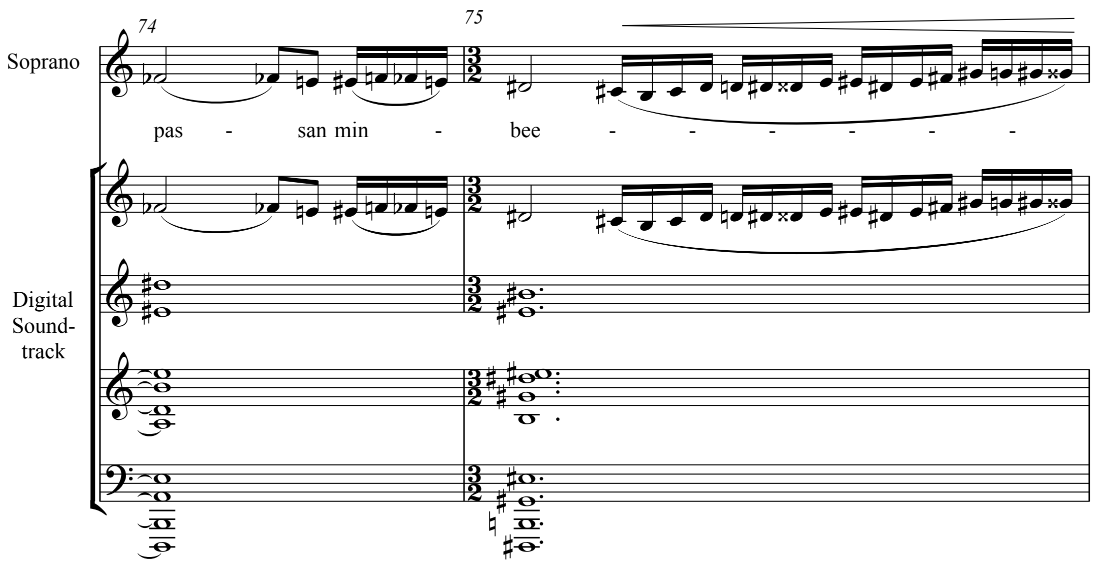

Strophe 9 [.....serenity]
Soprano
Digital Sound-track
56 57 58 59 60
p
l' kha - ya - ween l' kha - ya - ween

Strophe 10 [And do not bring us.....]

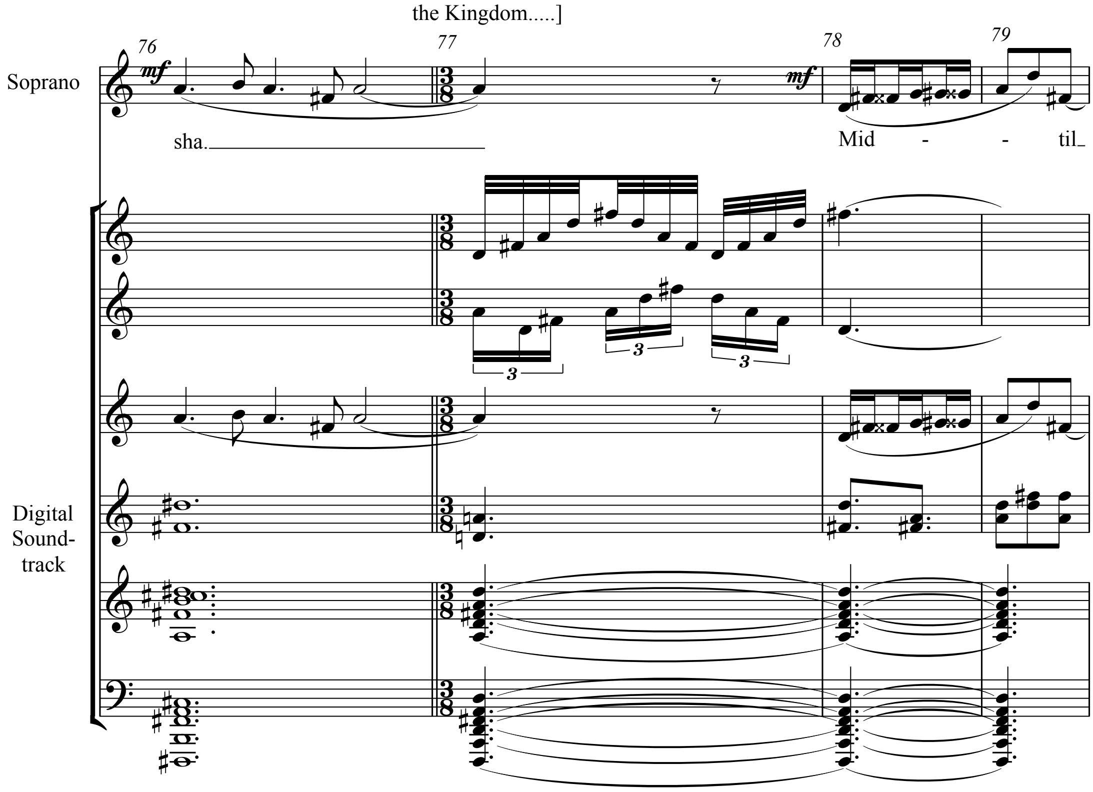
Strophe 11 [.....to trial]

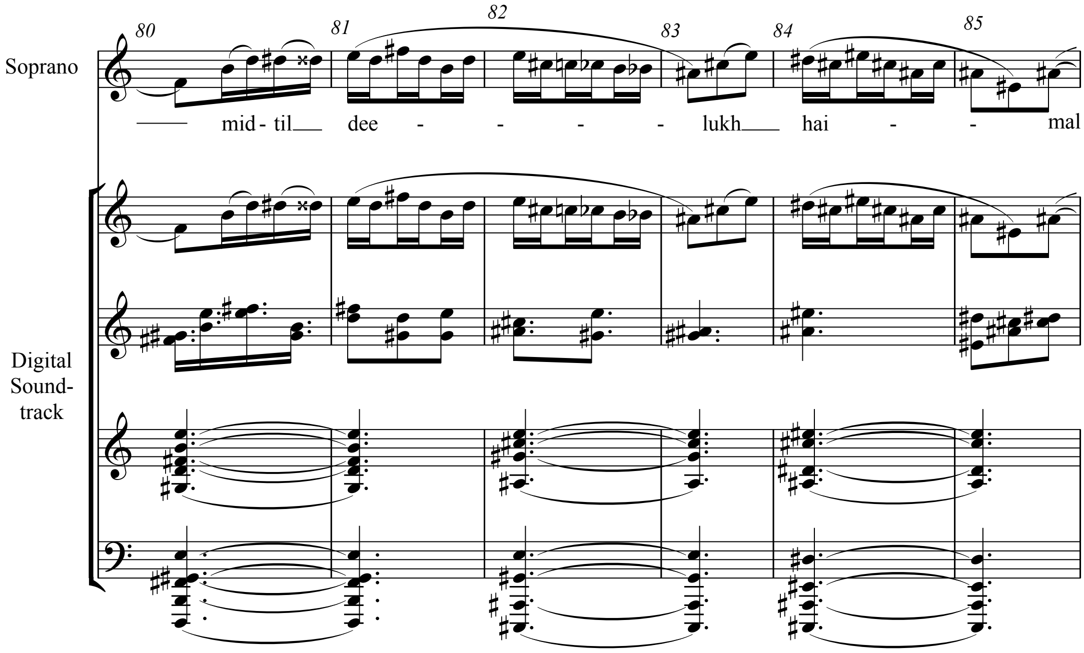
Strophe 12 [But deliver us.....]

Strophe 13 [.....from Evil]



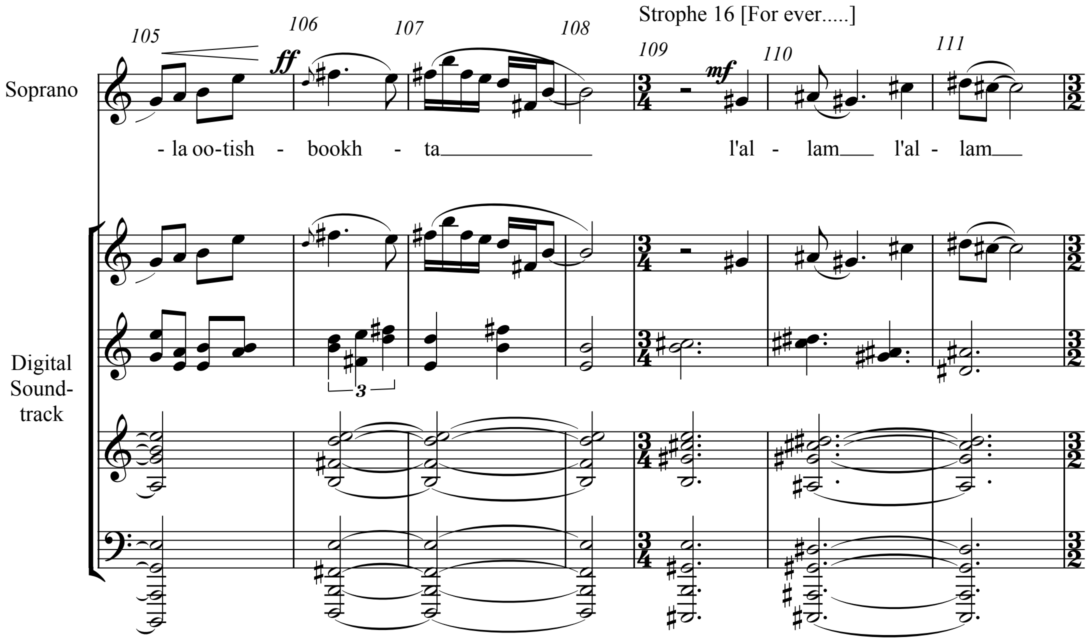
Strophe 14
[For Thine is
the Kingdom.....]

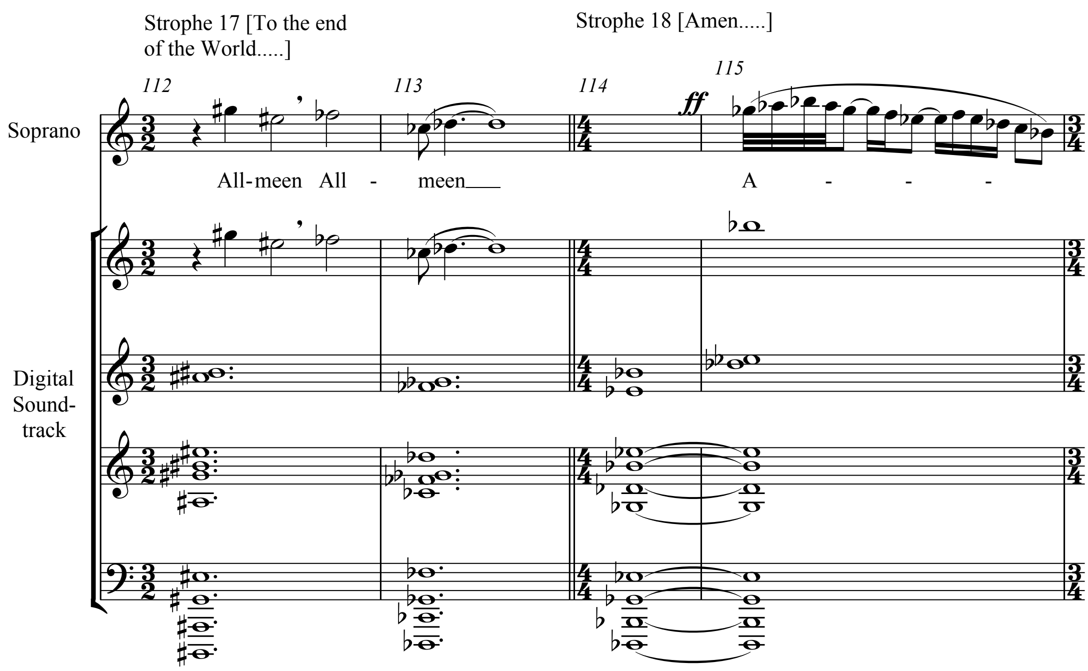



Soprano
Digital Sound-track
80
81
82
83
84
85
mid - til
dee - - - - -
lukh
hai - -
mal


Soprano
Digital Sound-track
86
87
88
89
90
91
f
choot - - -
ta
Mid - til
dee - lukh


Strophe 15 [And the Power and the Glory.....]
Soprano
hai - mal- choot - - ta Oo-khei-la Oo -khei - la
Digital Sound-track
Soprano
oo-tish - bookh - ta oo-tish- bookh- ta oo - khei -
Digital Sound-track


Strophe 16 [For ever.....]
105
106
107
108
109
110
111
Soprano
ff
mf
- la oo-tish - bookh - ta
l'al - lam l'al - lam
Digital
Sound-
track
3


Strophe 17 [To the end
of the World.....]
Strophe 18 [Amen.....]
112
113
114
115
Soprano
ff
All-meen All - meen
A - - -
Digital
Sound-
track


Strophe 19
[Amen.....]
Strophe 20 [Amen.....]
116
117
118
119
120
121
mf
Soprano
meen. A - - meen. A - - - - -
Digital
Sound-
track
Strophe 21 [Amen.....]
122
123
123A
pp
Soprano
- men A - - meen.
Digital
Sound-
track

8: Postscript: Why are there so many obstacles to the creation of microtonal instruments?

We conclude with some reflections on the future development of microtonal instruments in the light of our experiences during this project. We restrict our comments to 19-EDO, but consider that the situation with respect to microtonal instruments more generally is substantially the same.

Unfortunately, such future developments remain rather moot and problematic at the time of writing (August 2016) in our opinion. Despite the many composers who have worked with 19-EDO resources during the 20th century (and historic examples of 19-EDO going back to at least 1558), and despite the many person-years which music theorists have devoted to exploring the structure of the 19-EDO system of tuning, it remains quite difficult to locate instruments capable of playing "live" 19-EDO music (as opposed to computer realisations generated by Csound, PD, Supercollider or other software) and just as difficult to raise "live" performances. Why this is the case?

One illuminating comparison, from a quite different field, might be that of the "vested self-interest" involved in the writing of history. It has often been remarked that the way in which contemporary accounts of other times, places and societies are written reflect the attitudes of contemporary authors just as much as they reflect the events of those other times, places and societies which those authors are addressing. The centrality of self-interest in contemporary democratic societies deeply influences what factors are regarded as credible, mainstream or peripheral, even though we know that contrary attitudes have often been held in other times, places and societies, and may well be held again in future, so that the objectivity of contemporary attitudes is always open to doubt.

For example, twentieth-century writing on the First World War tended to marginalise the role of the Balkan civilizations until the Balkan Wars of the 1990s brought the state of those societies to world attention 75 years after 1918. Marxist histories of the English Civil War such as *Puritanism and Revolution: Studies in Interpretation of the English Revolution of the 17th Century* (1958) by Chritopher Hill (1958, 2011), studies written at a time of prominent contemporary Marxist theory and states and governments which claimed derivation from Marxist principles, were often dismissive of the role of religion in the conflict, but the rise of religion as an important historical force in the early twenty-first century lent additional weight to the traditional view.

We suggest that several forms of self-interested prejudice in contemporary society and institutions generally and contemporary musical society in particular are responsible for the state of play with respect to microtonal instruments. These include the suppression of inter-disciplinarity in musical and educational institutions which might provide the resources to build them and, more specifically, the disjunction of interest between instrument-builders and compositional practice, the hegemony of particular forms of latter-day Academic Modernism, especially electro-acoustic composition, in the groves of academia and the tying of research funding to anonymous peer-review.

For these reasons, amongst others, it is just very difficult to bring together the right combination of people, skills, funding and institutional support to build such instruments, given prevailing cultural attitudes. The aforementioned Harry Partch built his just-intonation *instrumentarium* himself (starting with his Adapted Viola in the period 1928 – 1930) from his own resources (describing himself as a "a philosophic music-man seduced into carpentry"), and our experience has been that it's not so very different in 2016, unless the instrument envisaged conforms to a rather specific, prescriptive conception of what a new instrument can or should be.

The educational institutions, especially the tertiary ones, which potentially have the resources — human, financial and organisational — to conduct research aimed at developing 19-EDO instruments, have also failed to bring this potential to actuality. There are at least two reasons for this. One of these is simply the result of institutional hypocrisy: the active suppression of inter-disciplinary work, despite the fact inter-disciplinarity is often explicity identified as a priority in the mission-statements of such institutions! It's quite easy to understand how this has come about. In hard financial times, there is often managerial pressure to designate "research-area priorities": usually determined by the monodisciplinary priorities of senior personnel in post, so that extra-ordinary measures are required to overturn institutional structures and practices with which they have been very comfortable for a long time. Another is that the mania for "research auditing" in recent decades has often resulted in very narrow definitions as to what actually constitutes research, and work on musical instruments of the kind we are considering is defined as falling outside current definitions of research in the disciplines individually and is "research" only from a cross-disciplinary perspective. Both of these practices are forms of *essentialisation*: that well-known process in political life, which involves the deliberate definition by powerful elites of particular characteristics as the "essence" of a person or a topic and the use of modes of thinking, speaking and acting which marginalise any persons or topics whose characteristics stray too far from that "essence".

In addition to such problems of "tertiary institution culture" generally, a particular practice — the regime of anonymous peer-review employed to distribute research funding to tertiary institutions — has come in for excoriating criticism from a number of senior figures involved in the allocation of research funding to tertiary instituions and in the administration and publication of research emanating from them. Anonymous peer-review may have a useful role to play in the preparation of research papers for publication, because there is a wide variety of publication outlets, and given that peer-review in such circumstances often results in helpful dialogue between authors and reviewers. But the relatively limited number of sources of funding can mean that anonymous peer-reviewing has a distorting effect on what research is carried out, and it has often been suggested that it is responsible for dumbing-down, and for the suppression of originality and innovation, following the well-known principle that a camel is what may result when a committee of self-identifiying experts with vested interests and barrows of their own to push is commisioned to design a horse.

For example, Richard Horton, editor of the British medical journal *The Lancet*, wrote that

> We portray peer review to the public as a quasi-sacred process that helps to make science our most objective truth teller. But we know that the system of peer review is biased, unjust, unaccountable, incomplete, easily fixed, often insulting, usually ignorant, occasionally foolish, and frequently wrong.
>
> — *(Horton 2000)*

More recently and more specifically, the celebrated development biologist Sir Lewis Wolpert, in highly critical articles in *The Observer* (Wolpert 2002) and *The Guardian* (Wolpert 2005), has written in a similarly trenchant way about the deleterious results of importing the concepts and intellectual paraphernalia of scientific research, including peer-review, into the practice and management of the arts, essentially because artistic practice changes, but does not progress, because scientific research is a collective endeavour which builds on the work of whole research communities, because artistic practice is constrained by imagination and invention, not by reality and truth and because scientific research searches for the single correct explanation for real-world phenomena, and is value-free up until the point where questions of its social implications are debated.

As a consequence of such opinions, several scientific journals started experimenting in the 1990s, with hybrid peer review processes, often allowing open peer reviews in parallel to the traditional model. These journals included the high-impact journal *Nature* in 2006. The initial evidence of the effect of open peer review upon the quality of reviews, the tone and the time spent on reviewing was mixed, although it does seem that under open peer review, more of those who are invited to review decline to do so! (see Van Rooyen et al. (1999) and Walsh et al. (2000)).

Those who followed the celebrated spat in 2006 in the pages of the *London Review of Books* between those two grandees of science and humanities Richard Dawkins and Terry Eagleton (see (Eagleton 2006), and the responses from the blogosphere), will certainly have no doubt that were either anonymously to peer-review the other, the result would certainly be the cutting-off of the other's research funding, as a result of which the wider disinterested community would be the poorer.

A typical modus operandi of peer-reviewing of artistic practice follows the pattern of a famous *dictum* on the workings of originality and innovation in science: a *dictum* usually attributed to 19th-century Harvard biologist Louis Agassiz (1807 – 1873), namely that every new compositional strategy which transgresses the world-view of those who are beneficiaries of the current presumptive *status quo* goes through four stages of peer-review obstruction:

1. peer-reviewers propose that their own discipline or profession has long since shown objectively that there's no point in pursuing topics which represent a challenge to the presumptive status-quo;
2. when someone of whom they disapprove undertakes to do it, they say it can"t be done;
3. when someone actually does it, they say that it's already been done;
4. when having been done, it receives a measure of interest from performers or audiences, they say it's trivial.

By such means, anonymous peer-review in the arts (and in practice, as opposed to principle) serves just as much to preserve the hegemony of the conventional wisdom of beneficiaries of the current presumptive status-quo, as to protect truth, ie is in reality often just a form of censorship, as Horton and Wolpert imply.

These situations are of course not peculiar to music, nor indeed are universities the only institutions which suffer from the syndrome. In the field of science and technology, one might consider the celebrated case of Shuji Nakamura, as recounted by Australian science journalist Bob Johnstone (2007). Working for the Nichia company in Japan, Nakamura invented the first high brightness Gallium Nitride LED whose brilliant blue light, when partially converted to yellow by a phosphor coating, is the key to white LED lighting. "Since lighting accounts for around a quarter of electricity usage, replacing conventional lights with LEDs would drastically cut our energy consumption" (Johnstone 2007: 10). But then the new company president ordered him to stop work on Gallium Nitride, so Nakamura had to develop the blue LED on his own, without material company support, and in 1993 he succeeded.

Nakamura left Nichia in 1999 for the University of California, Santa Barbara. "In Japan, still very much the land of lifelong employment at one company, it was a shocking thing to do" (Johnstone

2007:15): 15. In 2001 he sued his former employer over his bonus for the discovery, which "had by then for Nichia become a business worth well over a billion dollars" (Johnstone 2007:15). He was awarded 20 billion yen (about US$180 million). Nichia appealed, and in 2005 Nakamura agreed to settle for a mere 843 million yen (about US$8 million), which was nevertheless the largest bonus ever paid by a Japanese company at that time. Nakamura remains at the University of California, and holds over 100 patents.

A different example of problematic institutional priorities is provided by the "NIME" conference-series (NIME: new interfaces for musical expression). This has been partly due to the fact that the mind-set of the community involved in NIME has in considerable part been derived from the backgrounds of so many of the participants in computing, electro-acoustic music and "sonic art" more generally. Indeed, the NIME conference started out in 2001 as a workshop at the *Conference on Human Factors in Computing Systems*.

Recalling that musicologist Karol Berger, in evaluating what he took to be hopeful changes of direction in composition during the last few years of the twentieth century, singled out widespread recognition of "the evident artistic (as opposed to commercial) banality of technology", we should no doubt view the rise of new interfaces such as those which have been presented at NIME events as a welcome intervention of gestural elements into the compositional language of electro-acoustic composition and performance. Despite this criticism, however, Berger is really merely cautioning against hubristic technological utopianism — when compared to other hopeful recent developments, such as "the gradual erosion of the Cold War between abstraction and mimesis" and "the reappearance of poetic imagery as integral to instrumental composition" — rather than taking a dismissive attitude to technological media *per se* (Berger 2002:150–151).

Nevertheless, although devoted to what are essentially new instruments, no 19-EDO instruments (or instruments designed to play music based on other microtonal scales) have emerged from NIME. For presentations which exemplify the general character of what might be termed "NIME culture", see the videos from a recent NIME conference (2011 in Oslo) uploaded to the NIME website at `http://vimeo.com/groups/nime2011/videos/`. Thus it seems to the present authors that, for a combination of reasons such as these, the invention of instruments designed to perform music based on microtonal scales, including 19-EDO, with timbral qualities or performance haptics comparable with those of existing musical instruments except for their tuning characteristics, have remained a negligible priority, not only in the NIME community, but in musical, academic and commercial communities more generally.

Notes

1. The audio recording featuring Katrina Nimmo (soprano), Alex South (Wind Controller) and digital sound file accompaniment may be heard at `www.n-ism.org/SMR/Bailey_South_Evans_Hair/audio-clips/Avvon_d_bishmaya.webm`

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