From Technological Investigation and Software Emulation to Music Analysis: An integrated approach to Barry Truax's *Riverrun*

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ABSTRACT

This paper presents an approach to studying Barry Truax's *Riverrun* as it is being carried out within the TaCEM project (Technology and Creativity in Electroacoustic Music), a collaboration between the Universities of Huddersfield and Durham funded for 30 months (2012-2015) by the Arts and Humanities Research Council in the United Kingdom. This approach aims at realising an Interactive Aural Analysis with which the user can explore the creative and technological environment used by the composer to build his oeuvre, as well as navigate aurally through the results of the musicological study. It involves an important technological investigation of Truax's GSX program for digital granular synthesis, leading to the implementation, in the Max environment, of emulation software allowing for the live recreation of each of *Riverrun*'s sequences, along with further tools dedicated to the musical analysis of the piece. This paper presents the technological investigation and its issues, the pieces of software for the Interactive Aural Analysis of the work, and musicological observations drawn from such an approach.

1. INTRODUCTION

Barry Truax's *Riverrun* (1986) stands in the history of electroacoustic music as the first work entirely created using a real-time implementation of granular synthesis. Over nearly twenty minutes[1], the listener is immersed in a continuously evolving digital soundscape composed as a metaphor of natural streams. The composer notes that *Riverrun* "[…] modeled itself, as the title suggests[2], on the flow of a river from the smallest droplets or grains, to the magnificence, particularly in British Columbia, of rivers that are sometimes very frightening – they cut through mountains, they have huge cataracts, and they eventually arrive at the sea. Well this is, broadly speaking, the progression of the piece, creating this huge sense of volume and magnificence from totally microscopic and trivial grains."[3] As a method of digital sound production, granular synthesis fits the metaphor of the river particularly well: its smallest element, the grain, can be regarded as a single drop which, when multiplied in large quantities, enables the generation of massive streams with an expressive range that relies on the intrinsic characteristics of the synthesis method.

The TaCEM project, funded for a duration of 30 months[4] by the United Kingdom's Arts and Humanities Research Council, based at the University of Huddersfield and Durham University and led by the three authors of this paper, aims at exploring the relationships between technology and creativity by detailed study of eight case studies from the electroacoustic repertoire[5]. For each of these both the composer and her or his oeuvre are subject to contextual research, a musical analysis, and a technical investigation. This research, as well as its dissemination, builds on an approach previously initiated and developed by the principal investigator, Michael Clarke: Interactive Aural Analysis (IAA), which is based on the idea that the study of works, especially those that exist primarily as sound as opposed to the visual support of the score, can be significantly enhanced by being presented aurally, through the means of interactive software[6]. Hence, the final outcomes of the TaCEM project are to be in the form of both printed text and software that allows the user to engage aurally with the results of the analyses. The eight case studies for the project were selected using a number of individual and contextual criteria, and so as to form a corpus that can within reason be regarded as being representative of the electroacoustic repertoire and constituted of works of historical significance, such as *Riverrun*, the approach of which is presented in this paper.

In order to establish a means to provide a thorough understanding of the relationship between Truax's compositional concerns and his technological environment, we

[1] 19'44" on the first commercial recording of *Riverrun* [1].

[2] "Riverrun" is also the first word in James Joyce's *Finnegan's Wake*.

[3] Barry Truax, quoted in [2], p. 23.

[4] From August 2012 to March 2015.

[5] "TaCEM" stands for "Technology and Creativity in Electroacoustic Music". The web page of the project is at the address: http://www.hud.ac.uk/research/researchcentres/tacem/ (last visited February 19th, 2014). For further details on the project and its associated issues, see [3].

[6] For further details on Interactive Aural Analysis, see [4]. For actual Interactive Aural Analyses of electroacoustic works realised prior to the TaCEM project, see [5, 6].

have targeted and realised the implementation of a piece of software emulating the composer's GSX program. While the original software is only running on the composer's own PDP 11/23 controlling a DMX-1000 digital signal processer, both of which are still in use[7] at his home in Burnaby (British Columbia, Canada), the emulation software will be made publicly and freely available by the end of the TaCEM project in 2015, thus enabling prospective users to familiarize themselves directly with this compositional environment and engage with some of the preservation issues associated with the creative use of the dedicated hardware and software that form part of the history of electroacoustic music. In the case of Truax's *Riverrun*, it is worth remarking that the development of emulation software has been usefully assisted by a significant amount of literature and publicly available sources: the composer wrote a number of papers on the development of the unique software that enabled the realisation of this work and several others [7, 8, 9]. Furthermore, some detailed documentation on the work itself has been published on a DVD by Truax's own record label, Cambridge Street Records [10]. It comprises recordings of the separate tracks that constituted the final mix of *Riverrun*, general explanations of the implementation of granular synthesis in this work and, more crucially for analysis purposes, parameter charts corresponding to each sequence. From a musicological standpoint, Mara Helmuth's reference analysis of *Riverrun* [11] also provides useful information on Truax's development and use of the GSX program, along with reproductions of first-hand records and direct exchanges with the composer. Nonetheless, the task of emulating such unique software requires additional research on much low-level information that is rarely available, even for a work that is so well documented and discussed as this is the case here. This paper describes the technological investigations that have been carried out from the existing literature and with direct discussions with Truax, the resulting pieces of software including a program that emulates GSX in the context of *Riverrun*, and contextual analyses that have been built from an interactive aural exploration of the work.

2. TECHNOLOGICAL INVESTIGATION

2.1 Preliminary documentation on Truax's GSX program

Nowadays, granular synthesis and granulation of recorded sounds is widely embedded in commercial and open-source software, and many forms of these methods can readily be found in common computer music dedicated environments such as Csound, Max, Pure Data, or SuperCollider. However, at the time Barry Truax composed *Riverrun*, only a few composers had engaged with the technique, most notably Curtis Roads [12], and indeed the GSX program constituted the very first real-time digital implementation of granular synthesis. Mara Helmuth provides in her analysis [11] several key components that help us understand the overall behaviour of the software: "Looking at the computer code, one is struck by its efficiency compared to the numerous levels and complex object-oriented constructions often used today: only 256 assembler instructions of controller code generated the grains themselves."[8] She quotes Truax after an email exchange: "Since 12 lines of microcode defined a 'voice' or grainstream layer with a fixed waveform, 20 such layers could be generated in real time; in the case of FM [Frequency Modulation] grains, 30 lines of code generated each of the 8 layers. Precise timing of events was handled every 1 ms with an interrupt routine on the PDP-11 involving a few hundred lines of assembler code, with the remaining code handling user commands, printouts to the screen, generation of grain parameters, and managing presets and ramps."[9] Several concordant sources, including Helmuth's chapter, Truax's article "Real-time Granular Synthesis with a Digital Signal Processor", and the contents of the DVD documenting *Riverrun* give useful details on GSX and its range of user controls, usefully summarized as follows by Helmuth: "Grains were composed of additive synthesis [AS] or frequency-modulated (FM) sound, with three-part straight-line envelopes. The attack and the decay portions of the envelope ranged from 1/2 to 1/16 of the grain duration, and defaulted to 1/4[10]. With FM-based grains, the same envelope controlled amplitude of both the carrier and the modulator frequencies, producing palendromic grains with the highest modulation index and, therefore, richest timbre in the sustained portion of the grain. […] Half of the voices were assigned to each of two channels, producing stereo output. A variable delay time might occur between grains. The shortest grains produced by the scheduler were eight milliseconds (ms) in duration, generating 125 grains per second (gps) per voice. […] Truax used uniform random distribution to control the grain parameters, producing a stochastic music based on probabilities […]. The following control variables specified grain parameters for *Riverrun*: (1) center frequency and frequency range; (2) grain duration and duration range; and (3) delay time between grains. For additive synthesis, the number of voices with each of three waveforms and the total number of voices were also under use control. With FM, average modulation index, index range, and total number of voices were also available. These control parameters for the granular objects, also called presets, were under individual keystroke control. Ramps, or patterns of change in the parameters of the presets, were also stored and combined with the presets to elicit transformations, and initiated with keystrokes."[11] In the DVD, Truax adds further information on the implementation of ramps: "Most the dynamic interest in each of the [tracks] is obtained by using a ramp on the starting variables indicated in the tables. The speed of the ramp is controlled by the 'Ramp' parameter in [milliseconds] which indicates the time between increments or decrements. The amount of

[7] In February 2014.

[8] [11], p. 192.

[9] Barry Truax, quoted from an e-mail to Mara Helmuth, August 26th, 2004. [11], p. 192.

[10] From the parameter description of all the sequences of *Riverrun* in the DVD, it appears that only the ratios 1/2 and 1/4 have actually been used in the work, although 1/8 and 1/16 were technically possible.

[11] [11], p. 191.

the increment or decrement is the INC variable (which is 1 unless otherwise indicated) multiplied by a scaling factor, e.g. Freq.+2. Ramps can be ascending or descending, and in order to produce an imperceptibly slow ramp, a ‘random ramp’ is used where at each update point a random value of INC is added or subtracted. Hence for INC = 2, the values 0 or [2] will be randomly chosen, eliminating any obvious regular steps. In the table, the number of parameters being ramped and their individual scaling factors are indicated, such that multiple parameters can be simultaneously ramped, in similar motion (+,+) or contrary motion (+,-). A keyboard command (A, D) allowed ramps to change directions quickly, as well as to pause and then continue under manual control.”[12] As the above quotations demonstrate the information documented in available textual resources is enough to produce a software prototype that emulates the key features thus described. However, as will become clear shortly, it is not sufficient in itself to achieve complete authenticity.

2.2 Implementation of a first model and limits of existing documentation

Within the TaCEM project various software components have been developed, including T*IAA*LS, a generic set of tools for musicological analysis of electroacoustic works, and specific tools for each of the eight case studies, all of which are built using Cycling’74’s Max. Such an environment enables quick prototype implementation, advanced audio design and the production of powerful graphical interfaces. Being well embedded within the electroacoustic music field the Max environment also provides good prospects of long term accessibility. Where additional functionality is required, the Max environment is open enough to the use of extrinsic languages (C, Java, JavaScript, Lua) to embrace advanced developments in text-based coding.

After accessing the available information on granular synthesis as implemented in the GSX program and *Riverrun* itself (as presented above), the implementation in Max of a first global model for an acceptable emulation has proved reasonably straightforward. Two DSP modules, one for the additive synthesis grains and the other for frequency modulation-based grains, can be dynamically loaded within poly~ objects. Each of these modules has the same general architecture: an audio core generating, respectively, a maximum of 19 or 8 parallel streams of grains, controlled with appropriate parameters set by the user via number boxes, themselves being optionally driven by increments or decrements at scheduled ticks of a metro object representing the concept of ramp as established by Truax. The interaction between the user and the prototype is made from the keyboard for starting and stopping a stream, setting the values of all parameters, and triggering ascending, descending, or random ramps. Preset values of the grain and ramp parameters corresponding to the specific sequences of *Riverrun* can also be loaded by the user. The only aspect of the first prototype that could not be designed by patching in the standard Max paradigm has been a sub-sample accurate synchronizer for triggering successive grains of one single voice independently from imprecisions of the Max scheduler: a phasor~ object would be enough for driving successive grains with no delay between grains (figure 1), but an extension of phasor~ that enables both a zero period between two ramps and the guarantee of unchanged ramp and delay times during a given pseudo-period (figure 2) required a lower-level approach.

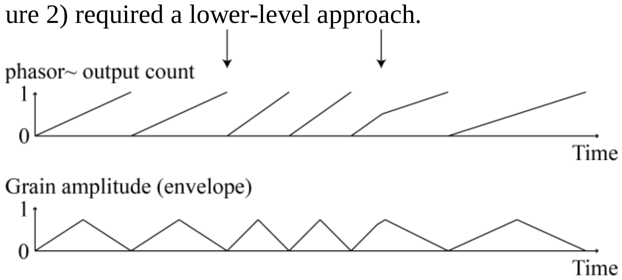

Figure 1. Control of grain envelopes from a phasor~ object. Arrows point user-changed parameters for period, which may happen during a ramp and are taking effect immediately. No delay is possible between successive grains.

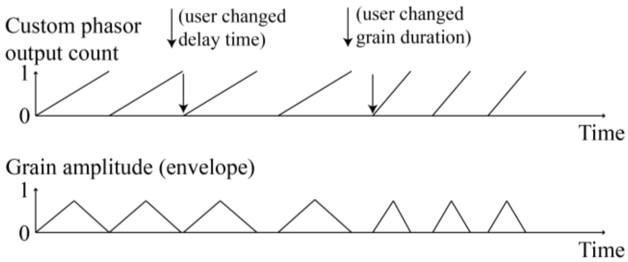

Figure 2. Control of grain envelopes from a custom phasor object. Top-level arrows point user-changed parameters for pseudo-period (duration and/or delay time). Bottom-level arrows point the time at which the parameter change actually takes effect, at the beginning of each pseudo-period. Delay is possible between grains.

The custom phasor object has been prototyped using the Gen environment in Max, and then implemented as an MSP external in C.

The first prototype model led to a flexible environment enabling the generation of both additive synthesis and frequency modulation grain streams, controllable with simple parameter access or evolving ramp processes. However, some local though important aspects of the GSX program are unclear or absent from the aforementioned literature, making the model limited as regards its primary aim: emulating in full the creative tool from which Truax composed his work. First listening tests proved the model a convincing first step in approaching the overall behaviour of granular synthesis as it is heard in *Riverrun*, but the prototype failed in genuinely replicating the actual sonic outcomes of the original program. Essentially, details of the harmonic components of the seven different waveforms used in both additive synthesis and frequency modulation are not provided in the literature, while obviously crucial in the sound rendering; furthermore, several details of the implementation had to be chosen arbitrarily from a number of possibilities, leading to unsatisfactory outcomes when the results were compared against the individual audio tracks as found in the reference DVD.

[12] [10], /Riverrun/structure.html

To address these issues, the members of the TaCEM project requested Truax's direct assistance in these matters, and met him on two occasions in 2013[13]. The outcomes of these meetings were very productive. For example the composer was able to provide the detailed numeric, visual and aural information we required on the seven waveforms used for *Riverrun*. This enabled the revised emulation to model the work's sound results with far greater accuracy – in the event the numeric information (for each waveform, one pair of harmonic rank and relative amplitude per partial) proved to be less helpful than expected, but the sonogram and audio information allowed for a satisfying reconstruction and calibration of the waveforms. On the occasion of the second encounter in Truax's studio, the two first authors of this paper spent three days discussing as yet unclear points, comparing the emulation side by side with the original system, and recording a video of the composer commenting the genesis of *Riverrun* (figure 3) and also the detailed implementation of the GSX program (figure 4).

Figure 3. Screenshot of a TaCEM recorded footage of Barry Truax in his studio in Burnaby, commenting the composition of *Riverrun* on 16th October 2013.

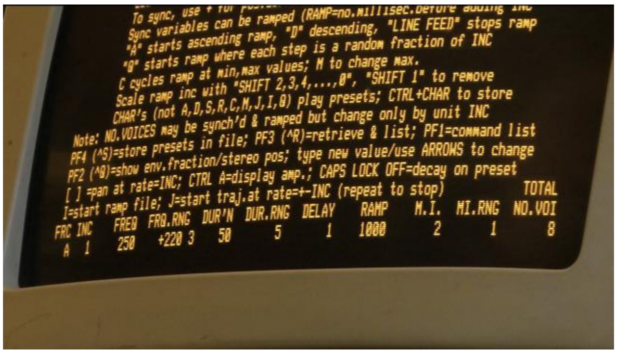

Figure 4. Detailed view of the teletypewriter screen with the GSX command lines for the control of the frequency modulation based grains.

The comparison sessions during the visit showed convincing results in some cases, but identified some important sound mismatches in both pitch and timbre for some sequences. After further investigation with Truax, these distortions appeared to be caused by a wrong assumption on our part concerning an undocumented detail of the GSX implementation. In the first model, granular synthesis had been implemented so that each grain initialises the phase of the waveform. In GSX, a voice is actually based on a continuous wave upon which successive amplitude envelopes are applied, without any re-initialisation of phase until the stream is stopped. While this difference of design is of almost no perceptual importance when grains are generated as a mass of sound objects with significant random variation, it becomes critical when generating steady streams of very short grains (less than 50 milliseconds) with all or most parameters being constant, as it happens in many sections of *Riverrun*. For instance, when changing continuously the frequency of a stream of 20 millisecond grains with all other parameters remaining identical results, if phases are reinitialised at each grain start, a sweeping effect in timbre rather than a pitch glissando is heard otherwise than in the case of the actual GSX program. As this implementation error was only detected by comparing some of the streams generated by the original emulation model in the first instance with the recorded tracks provided in the DVD and then directly with Truax's software itself, several hypotheses had to be considered regarding the origin of the problem: in particular differences between the low-level architecture of both programs and/or inaccurate emulations of key aspects of the synthesis process. Such a situation shows the important role that a composer's knowledge can directly have in addressing issues that cannot easily be resolved in the processes of reconstructing a tool both for studying an existing work and also creating new works.

3. A SET OF SOFTWARE TOOLS FOR ENGAGING IN AND ANALYSING THE CREATIVE PROCESS OF *RIVERRUN*

3.1 Exploring granular synthesis in the context of Truax's approach

As it will be distributed by the end of the TaCEM project[14], the emulation software runs in three main modes: the GSX emulation mode, the sequence mode, and the section mode. The GSX emulation mode gives an access to an interface simulating Barry Truax's terminal as visible in figures 1 and 2, along with a more developed panel integrating the same controls accessible with a mouse (figure 5). From the terminal emulation, the user can play strands of grains either from the additive synthesis model or from the frequency modulation models, with the following controls replicating Truax's environment: play and stop streams, moving the cursor through parameters, changing the value of the current parameter (by typing on the alphanumeric keyboard or incrementing and decrementing with arrows), changing the ramp scaler of the current parameter (by shift-typing on the alphanumeric keyboard), changing the ramp status of the current parameter (not ramped, ramped in the same (+), or opposite

[13] On the 29th of April at the University of Huddersfield, and from the 14th to the 16th of October in the Vancouver area, at his home studio in Burnaby and at the Simon Fraser University.

[14] In March 2015.

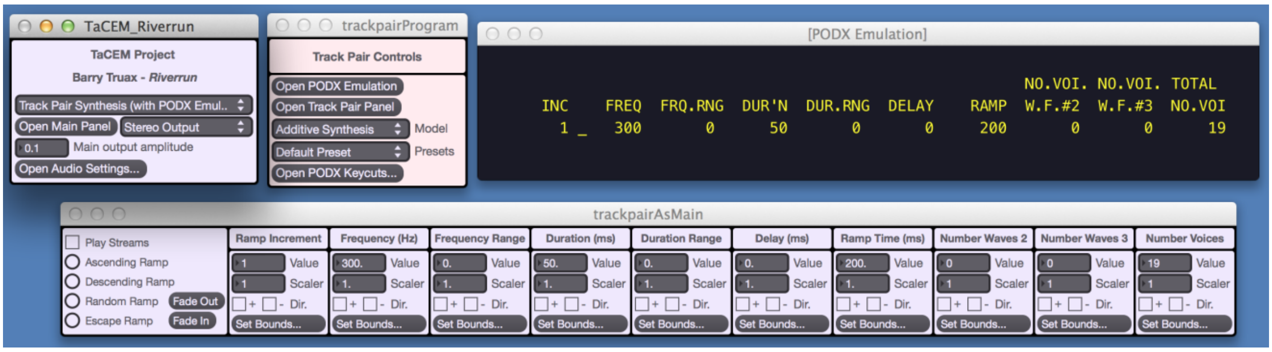

Figure 5. Overview of the TaCEM software for the resynthesis of *Riverrun*, in GSX emulation mode.

direction (-)), and launching or stopping ramps (ascending ramp (A), descending ramp (D), ascending random ramp (Q)).

Additive synthesis and frequency modulation models have specific sets of parameters. With the additive synthesis model, from left to right (as visible in figure 5), the parameters are: ramp increment (INC), frequency in Hertz (FREQ), frequency range in Hertz (FREQ.RNG), grain duration in milliseconds (DUR'N), grain duration range in milliseconds (DUR.RNG), delay between grains in milliseconds (DELAY), ramp period in milliseconds (RAMP), number of voices running the second waveform (W.F.#2), number of voices running the third waveform (W.F.#3), total number of voices from 0 to 19 (NO.VOI). With the frequency modulation model, from left to right (as visible in figure 4), are: ramp increment (INC), frequency in Hertz (FREQ), frequency range in Hertz (FREQ.RNG), grain duration in milliseconds (DUR'N), grain duration range in milliseconds (DUR.RNG), delay between grains in milliseconds (DELAY), ramp period in milliseconds (RAMP), modulation index (M.I.), modulation index range (MI.RNG), and total number of voices from 0 to 8 (NO.VOI). From the track pair control window, the user can load both models for synthesis, initialised with a default set of parameter presets. Immediately below the model selector menu another menu enables the user to recall parameter presets for all the strands of *Riverrun* using the loaded model (19 for additive synthesis, 37 for frequency modulation). In such an implementation, the user can explore freely the environment from which Truax composed his work, and also simulate the settings eventually chosen by the composer.

In addition to providing the emulation of the GSX program which, like the original, only enables the generation of one strand of grains at a time, the TaCEM resynthesis software offers two other main operational modes. In the sequence mode, the user can resynthesize four strands at the same time, which correspond to one of the 14 sequences (numbered A to N) from which *Riverrun* was built (figure 6).

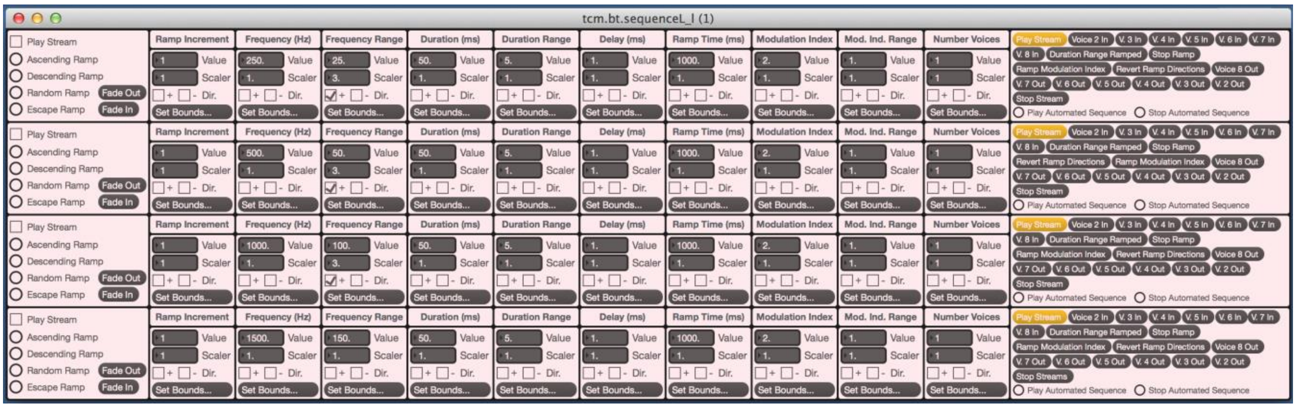

Figure 6. Sequence mode of the TaCEM resynthesis software (view of the L sequence, used in section 1 of *Riverrun*).

In addition to combining four instances of strand simulations enabled in the GSX mode, the sequence panel displays, on the right side, buttons corresponding to the sequential instructions that Truax defined for the performance of each strand, and also individually recorded in successive pages of his documentation DVD. This allows for either a manual triggering of successive steps (parameter changes, ramp settings, increasing or decreasing the number of voices) or an automated playback in which all instructions are triggered via a built-in sequencer. In the third mode, the same multiplication is applied: a simplified view of panel controls enables the user to resynthesize several sequences at a time, for each section of the piece (figure 7). Hence, the emulation software allows for musicological investigations ranging from a study of Truax's compositional environment to a reconstruction of *Riverrun* including the post synthesis treatments applied to certain sequences (reversing, speed doubling), each dimensional layer giving access to the granular synthesis controls that enable a thorough understanding of the musical consequences of decisions made on available parameters.

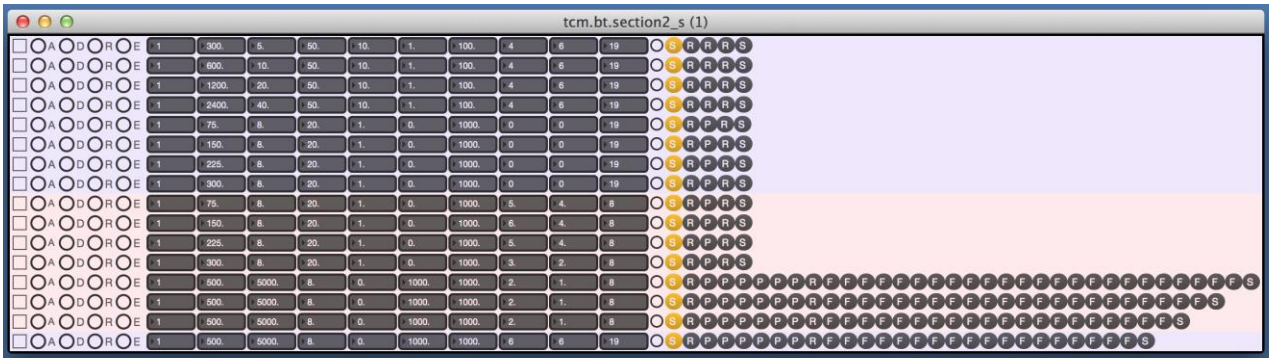

Figure 7. Section mode of the resynthesis software (view of section 2, including sequences F, D, E and N).

3.2 A sequencer and mixing board for the exploration of the individual tracks

In order both to compare the results of the emulation with the original tracks recorded for *Riverrun* and to explore the latter as they have been assembled and mixed in the final work, another software tool has been implemented, which includes a sequencer window (figure 8) and a mixer window (figure 9). As a complement to the resynthesis program, this tool built in Max and also inspired by standard digital audio workstations offers an efficient way of listening to the original source tracks individually or all-together. In particular, the solo and mute is not only implemented per track, but allows for the interrogation of each dimension of *Riverrun*, i.e., from bottom to top: channel (left or right), 2-channel strand (as generated by the GSX), sequence (four 2-channel strands) and section (two to four sequences depending on the section).

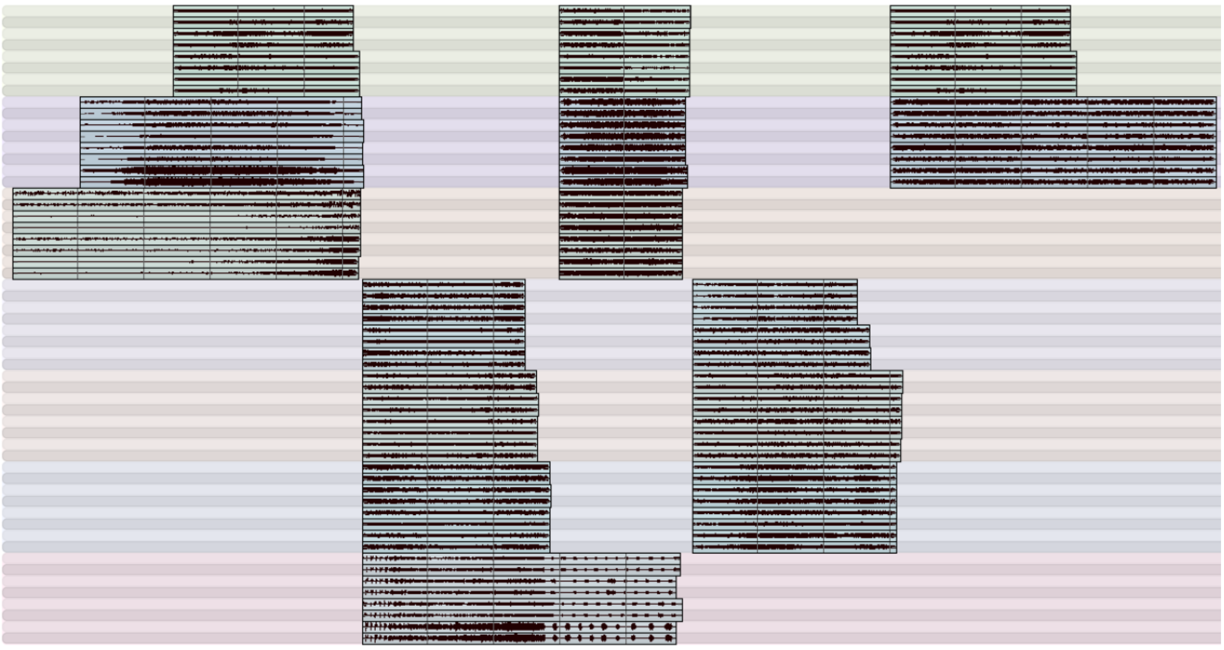

Figure 8. Sequencer window of the TaCEM multitrack software, showing the arrangement of all individual tracks within the 5 sections of *Riverrun*.

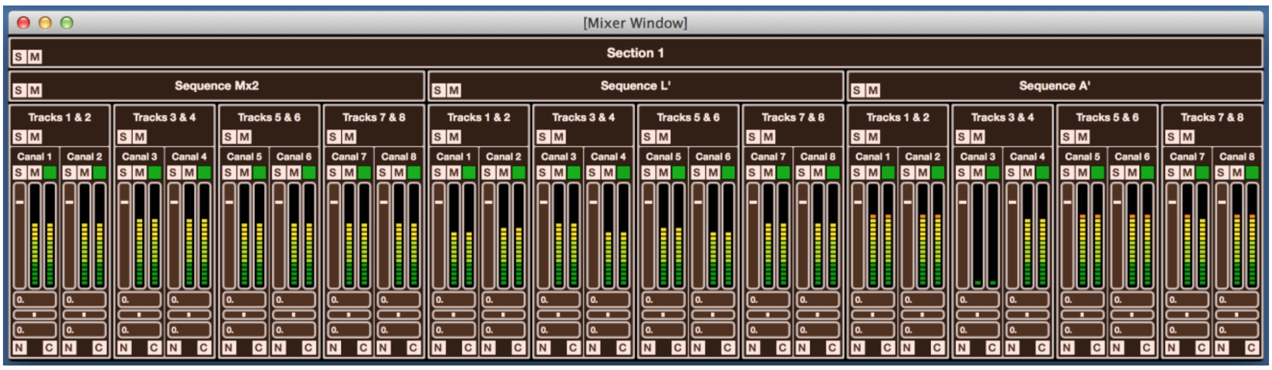

Figure 9. Mixer window of the multitrack software. Each dimension has an independent solo-mute system.

4. ANALYTICAL ELEMENTS FROM THE SOFTWARE-BASED INVESTIGATION

Bringing together our study of the context, the technology and the music, what conclusions might we come to about the relationship between technology and creative process in *Riverrun*? How far did technical innovation enable, or even inspire, certain musical possibilities? To what extent did the limitations of the technical system perhaps restrict the composer's options? First we should say that it is a two-way process: the technology and the musical creativity influenced each other. Barry Truax created his own unique software to suit his musical requirements. But working with technology also shaped his musical thinking for this (and later) works. It is a key example of a genuine interaction.

The most obvious way in which the technology facilitated this work is through the use of granular synthesis and in particular Truax's implementation of the technique. The construction of music out of thousands of tiny fragments of sound, often lasting only a few milliseconds, is something that cannot be done effectively with traditional acoustic instruments, it requires digital technology. The concept of the 'note' as the basic building block of a work, or even of the sound object or sonic event as in much acousmatic music, is completely absent. So the very starting point for musical composition has been redefined. The fundamental element here is no longer something that can be meaningfully heard or shaped in its own right. The significance of a grain is the part it plays within the process of an evolving grain stream and it would not make sense, either practically or aesthetically, within this context to attempt to shape each grain independently. Compositional thinking here is thus articulated in terms of process rather than event. Furthermore, the GSX software offers a distinctive approach to granular synthesis, with particular compositional features that merit further exploration. Back in 1986 it was also unique in offering granular synthesis in real-time. So he was able to shape strands of music as he listened to them, performing them live and responding to the sound. Performing the system is an essential part of Truax's creative interaction with technology in *Riverrun*, even though the final work is not live but a pre-recorded, fixed media piece.

However, the constraints of the technology available to him allowed only the production of a single stereo strand in real time. In order to build the rich and complex textures of *Riverrun* he thus needed to superpose multiple layers using an analogue multi-track tape machine. This method of working imposed some restrictions on what he could do in terms of creative flexibility, certainly compared with how one might work today. Nonetheless, Truax's technical setup, including the analogue recorder is key to the understanding of the way the work is shaped using many superposed layers of sound: the work has five distinct sections and these sections are constructed from individual sequences. Each section comprises between two and four superposed sequences and each of these sequences is in itself made up of four stereo strands, again superimposed. Often, two or more strands within a sequence use very similar parameter settings and follow similar transformational paths. The purpose is not to create counterpoint between these strands but to enrich the texture by overlaying related material. For example, in sequence A, there are two pairs of strands. The two strands in each pair are identical, apart from the fact that one uses frequency modulation grains, whilst the other uses additive synthesis grains. We are thus presented with two different timbral perspectives on the same material. In addition, the fact that each strand was created separately as a live, interactively controlled studio process leads to further small but highly enriching differences.

Another musically significant feature of Truax's granular system is that it is based on streams of grains and these streams have a potential for regularity, even if this characteristic is often hidden by random variation. Unlike some systems, which generate random grains within prescribed boundaries, with GSX randomness is presented to the user as a deviation from a central value. This applies to all the randomized parameters. With duration, for example, the user specifies a central value and then a range within which grains can deviate randomly. In the case of frequency, the range can be set to zero in which case there is no random variation and the values are as specified and predictable. In part at least, this is simply about the way in which the parameters are presented to the composer. But the musical significance of this is that there is a sense of underlying order, and the software facilitates, indeed encourages, movement between fixed order and random fields. This is a key compositional process that Truax makes productive use of throughout the work. In particular, one of the main ways in which *Riverrun* is shaped is through use of passages that feature movement towards or away from order in one or more of the contributing parameters.

As we have seen, granular synthesis is not so much about the intrinsic characteristics of individual grains but about the patterns and shapes that can be formed by manipulating large groups of grains. Truax's software is primarily designed to facilitate the shaping of sound in long evolving processes. Indeed with GSX it is probably easier to work in this manner rather than to create short gestures or events. The synthesis algorithm and the user interface thus encourages users to set up initial parameter settings and then transform the texture using ramps that progressively increment or decrement one or more parameters over time. The musical result is a piece that is about large-scale process. It is music of slow, subtle, textural changes, sometimes arriving at or departing from distinctive landmarks (for example, frequency unisons or rhythmic pulses) but otherwise more concerned with transformational process than individual sonic objects. This is compounded by the superposition, at any one time, of several similar processes, as we've already seen. It is, therefore, a form of "process music", but very different in sound and aesthetic from minimalism and with the processes being applied, not to the pitches and rhythms of notes, but to parameters of grains of sound. An example of this can be found in strands 1 and 2 of sequence A, which is part of the section 1 of *Riverrun*. As performed in the studio, these strands both begin with a grain duration of 8 ms and no duration range, so the grains are all the same length, 8 ms, and the delay is set at 250 ms. So a new grain is produced every 258 ms (duration + delay). Since no randomness has yet been introduced at this point the grains are not only all regular and periodic they also are generated in sync. Two processes then follow: firstly, the duration range is gradually increased to 24 ms with the result that small variations in length and timing of the grains are introduced and as a result synchronicity is lost between the grain streams: what was a simple regular pulse evolves into a more complex texture. Secondly, the delay between grains then increases. This gradually thins out the texture, there being more silence between grains and overall, therefore, a lower density of texture. Once recorded onto tape this whole passage was in fact played in reverse in the final composition. The main reason for doing this was to make the regular pulse of the synchronized grains the end goal of this layer of the section. It is important to remember that this process is only one of several that occur simultaneously within this section, so it is heard in counterpoint with other processes following different trajectories.

5. CONCLUSION

As the first out of eight case studies of the electroacoustic repertoire investigated within the TaCEM project, Barry Truax's *Riverrun* has been the object of a thorough investigation leading, with the help of the composer, to a successful emulation of the compositional environment, constituting both a powerful basis for the musicological analysis by the members of the project and a way of preserving and transmitting knowledge on an approach in which technological innovation is closely linked with the creative activity. As Truax has developed, thanks to his own skills as a computer software designer, a program to serve his aesthetical concerns and aims, he belongs to a category of composers whose engagement in the development of new technologies for artistic creation is as strong as their musical ambitions.

Assisted by an important existing literature and documentation on *Riverrun*, the software designed to emulate the GSX program aims at constituting a useful complement to earlier studies of this important work of the electroacoustic repertoire, in giving users access to an environment in which they can explore the expressive potential, but also the inherent limitations, of granular synthesis as it had been implemented by Truax for his own creative needs. Thus, having a concrete idea of the possibilities opened by his own environment may help an understanding of the composer's aesthetic approach, by an interactive study of both the general behavior of the tool and the settings decided for this work.

Acknowledgments

The authors would like to thank Barry Truax for his support in this research and his invaluable help in the investigation of *Riverrun* and his GSX program.

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