Abstract

The thesis is concerned with experimental electronic music composition techniques. It discusses methods used in early live electronics from the 1960s, demonstrating a unique approach to early live electronic music. The studies explore composition methods used in David Tudor's electronic music. Research materials are examined to show how Tudor's processes can provide a plethora of different musical outcomes. A series of practical experiments are carried out, based on the original circuit diagrams, texts and other materials surrounding Tudor's compositions. The experiments give a clearer understanding of composition techniques involving electrical feedback, mutual modulation, output processing and other related processes found in Tudor's electronic music. This research is carried out in order to broaden my own set of processes whilst gaining a greater appreciation of the methods used in early live electronic music. The accompanying compositions in this project experiment with various systems that avoid any editing or post production treatment, enabling a piece of music to be fully realised in the performance stage. The project shows how an independent electronic music maker may organise basic tools in order to produce different types of instruments, extending the limits of device functionality and composition output. This document can also be found in website format at www.roomforest.wordpress.com, along with all accompanying media and audio compositions.

A Study into the Working Methods of David Tudor and Live Electronics

Robert Kinder

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Project Outline

This project explores compositional techniques discovered in the early developments of live electronic music, focusing on the work of David Tudor from 1960 onwards. The research is concerned primarily with practical aspects of his compositional processes, with an aim to understand the electronic systems constructed for his music along with the functions they provide as expressive musical instruments. Tudor's concept of live electronics represented a "profound shift in electronic music" (Collins, 2004, p.1). The techniques used are fundamental to the characteristics of his work, setting him apart from many other contemporary early experimental electronic composers. His creative ideas exploring feedback, modulation and amplification have been recognised for contributing to the development of many modern electronic music applications and sound generation techniques, which are now found in a wide range of music styles.

Today, analogue and digital technology provide an abundance of tools that enable a wide range of different approaches to electronic music production. With little or no experience, it is now possible to create a system designed for any kind of music production with ease. The modern home studio is constantly developing, changing tools and updating applications that help make up the system. Amongst the various ways different electronic music systems can be constructed, there is an underlying requirement that must be considered in all: the configuration. This is essential as the configuration of a "system shapes how you work" (Brett, 2021, p.21). This study will investigate how Tudor's configurations can act as a stimulus for my own musical output in a modern electronic music studio environment with alternative tools.

Recent developments in technology allow an ever more detailed control of sound generation. Feedback has played a large role in signal processing. For example, the self-modulating oscillator, a technique that uses the output signal to control the modulation index (amplitude modulation) (Sanfilippo, & Valle, p.13).

The notion of feedback has been explored since the early 1940s, a phenomena that uses “closed information loops in organised structures” (Sanfilippo, & Valle, 2013, p.2). Some of the earliest composers to implement feedback into their work include “Robert Ashley (*Wolfman*, 1964), John Cage (*Electronic Music for Piano*, 1964), Steve Reich (*Pendulum Music*, 1968), Alvin Lucier (*I Am Sitting In a Room*, 1969), as well as Gordon Mumma (*Hornpipe*, 1967) who worked extensively with self-constructed circuits, and David Tudor (*Toneburst*, 1975), who was particularly relevant, basing many of his practices exclusively on feedback (*Microphone*, 1973)” (Sanfilippo, & Valle, 2013, p.2). A system that uses feedback can be generally summarised by its configuration, where an output is fed back to an input of the same system. An underlying feature of feedback systems is that components are connected in a way that causes them to mutually affect one another (Sanfilippo, & Valle, 2012, p.15).

Case studies have been carried out on compositions selected from Tudor’s output, with two additional studies on pieces written by colleagues who appear to have influenced his developments in electronic music composition. The pieces researched either exhibit a particular technological phenomenon or signify a notable point in the evolution of his career in electronics. Each analysis is followed by a practical experiment using original circuit diagrams, texts, images, and other available items concerning the compositions in hand. These are accompanied by a description of how techniques have been transposed to an alternative set of tools to create an original piece of music. Although all experiments in this project are carried out with a specific set of devices, the studies have been unpacked in a way that allows techniques to be applied to different devices and components. By researching the origins of feedback experimentation in a musical context, a deeper understanding emerges of how the potential uses of my systems can inform the way in which I work.

The following research experiments are presented as audio pieces, which explore the performative nature of Tudor’s systems and their potential as expressive musical instruments. All submitted compositions are captured as live performances; no editing, processing or post-production treatment has been applied to the final recordings. The main objective of this project is to discuss the construction of Tudor's music systems and their operational features within the context of live performance. All sound materials used in the submitted audio pieces are original. Research into David Tudor's work allowed me to discover different composition methods that extend my current skill set in electronic music production. The processes I have commonly used in my first ten years of creating electronic music have revolved around digital audio tools and commercial DAWs, such as Logic Pro and Ableton Live. Although I have used analogue devices in my own music, these mainly act as source sound material, often edited and processed after the recording stage. This project has enabled me to recontextualise my tools to create electronic instruments that give alternative methods in producing electronic music compositions.

An Introduction to David Tudor and Live Electronics

David Tudor's use of electronics has been described as legendary; his home made circuits and adapted devices have produced systems that provide a wide range of rich musical output. His music is often the result of much experimentation, using circuit diagrams and sketches to document the development of his systems (Adams, 2004). Tudor was born in 1926, Philadelphia, Pennsylvania. He was first introduced to playing music at the age of six when he was taught piano before following in his father's footsteps by learning the organ five years later. Tudor became a member of the American Guild of Organists and was eventually offered the role of resident organist at the Trinity Church of Swarthmore along with Swarthmore College in 1943. He started piano lessons with Irma Wolpe, where his skills with the instrument increased rapidly and began learning the technically advanced work of her husband, Stephan Wolpe, whose compositions were renowned for being extremely difficult to perform. In 1945, Tudor went on to perform a series of concerts showcasing works by Igor Stravinsky, Stephan Wolpe and Arnold Schoenberg along with others. After premiering Pierre Boulez's notoriously challenging *Deuxième Sonata* in New York in 1950, Tudor became recognized internationally as a master of his instrument. As a pianist he performed the music of composers such as Karlheinz Stockhausen's *Kontakte* (1964) and John Cage's *Indeterminacy* (1959). He started working with John Cage and other experimental composers such as Earle Brown, Morton Feldman and Christian Wolff, who would make use of his piano skills in order to realise their technically demanding compositions (Perloff, 2001).

Whilst working with John Cage, Tudor's work would focus on experimentation with electronic technology, where he would eventually find a new musical voice as an electronic music composer, abandoning the piano entirely (Collins, 2004). Cage was known for implementing electronic technology into his compositions, such as FM radios, contact microphones and amplifiers. He would often require Tudor to configure the circuitry and control the electronics throughout many of his performances, giving Tudor a fresh perspective as a performer along with vital experience with audio technology. He became Cage's right hand man, taking the role of co-composer and engineer, helping Cage to realise many of his works (Hultberg, 1988). Notably Cage's *Variations II,* (1961), a piece written for Tudor as a birthday gift, used a scoring system that allowed the performance to be rather sonically open. Musical parameters are applied to lines between various points on a graphic score. Tudor matched the instructions on the score to parameters of electronic devices that could be measured over time. "Cage used chanced operations in preparing the *Variation* scores*,* but did not always instruct performers to doing so when realizing them." (Miller, 2009, p.61). This allowed Tudor to make crucial decisions on the sonic output of Cage's composition, signifying the beginning of his gradual transition from performer, interpreter to composer in his own right (Pritchett, 2004). Cage's use of chance and indeterminacy was a huge influence to Tudor's music, he would eventually apply his own indeterminate composition techniques to a new electronic landscape.

Tudor went on to design his own homemade electronic circuits, revealing a new approach to artistic expression with the use of electronics. His systems somewhat differed from many other contemporary electronic instruments. The notion of live electronics set his work apart from the traditional workflow of electronic music and fixed mediums such as magnetic tape. “The complex feedback paths built into Tudor’s circuits courted instability and unpredictability: The performer could only exert loose influence – not precise control – over a precariously drifting system, and the same input could produce different results each time.” (Dalgleish, 2016, p.73). Many of Tudor’s electronic music processes have been mystified through his reluctance to explain or promote methods used in the production of his work. Although there are composition materials from Tudor available today, many details surrounding the technological aspects of his systems have been difficult to attain since his death in 1996 (Nakai, 2014, p.1) making his work rather difficult to reproduce.

A New Music Philosophy: David Tudor’s *Untitled*

(https://www.youtube.com/watch?v=2TgHFISt7HE&t=346s)

Untitled (1972), is an appropriate entry point to understanding the philosophy of Tudor’s approach to composition, as it appears to be part of a larger series of works that explore a particular configuration of signal interactions (Nakai, 2021, p.390). It marked the beginning of a new chapter in his music career, where his close working relationship with Cage ended through a divergence in aesthetic and musical motivation. Tudor's interests were in the sonic capabilities of electronics. He would continue to explore the functionality of technology as a primary instrument for his work. The concept of introducing forms of control back into indeterminate musical systems in order to discover particular sound worlds would take precedence over his previous engagements as performer, often of other composers’ works (Kotz, 2001, p.5). This contrasted with Cage’s ideas as, “a composer whose goal was a completely dissociated experience of sound that would make any sound and all sounds fascinating” (Kuivila, 2004, p.20). Cage was not always interested in developing particular sonic features, nor committing to specific techniques to achieve a certain type of sound world. Many compositions were made with the absence of personal musical preferences. Tudor would go on to produce his own compositions with scores in the form of circuit diagrams. By composing scores in quite a systematic manner and making specific choices in the preparation of a composition, he could create a particular type of system where the conditions of indeterminate activity could be exploited specifically in the performance stage. Tudor's goal was to explore particular sound worlds, which were dependent on the organisation of certain configurations.

The first existing schematic of *Untitled* is dated January, 1972, and was first presented to an audience in a series of concerts showcasing works of Tudor and Cage in the same year. The diagram (figure 1) shows the signal routing with all components and their position in the circuit. Although there are details available on specific tools, it is documented that many of these were replaced with different devices from performance to performance, as constant refinements were made (Kuivila, 2004, p.21). This version of *Untitled* appears to be part of a larger series of works that explore a particular configuration of signal interactions (Nakai, 2021, p.390).

Unlike many of Tudor's circuits designed for pieces prior to *Untitled*, this was a self-regulating system that did not depend on any external cause in order for it to become active and could produce modulation of its own accord. An earlier version of this instrument was realized at the Expo Pepsi Pavilion concert in Osaka, 1970. Two of the four pieces recorded at this concert, *PepsiAnima* and *Microphone,* used instruments that deployed this type of autonomous self-regulating operation within a feedback network as a primary feature (Nakai, 2021). The original version of the system designed for *Untitled* was too large and complex to carry to different performances. Tudor decided to use pre-recorded material of the original system being performed as input material (along with other recordings) with a scaled down version that would afford for mobility, yet still exhibit the aural results of the system he originally intended to showcase. He went on to compose an entirely live version titled *Toneburst,* in 1975 for the Merce Cunningham Dance Company (Kuivila, 2004, p.9).

The diagram begins with three tape machines, each routed to a signal switch. The device annotated with "(2 X 4) X 2", symbolises two separate devices each with 2 inputs and 4 outputs. Its function is similar to that of a matrix console, where an input can be directed to different outputs. It was more effective at carrying audio signals through multiple channels without interference or impedance issues when channel outputs are changed, a common studio problem at this point in electronics. This device named the 'Audio Multi Coupler', was built by Tudor using instructions from a publicly available schematic released in a 1970 issue of the *Popular Electronics* Magazine (Figure 2). Tudor adapted this design by duplicating the number of ports and adding gain stages to each output, giving it the name 'Dual Multi Coupler' (Nakai, 2021). Condensing these into a single device with 4 inputs and 8 outputs, demonstrates Tudor's ability to reconstruct electronic devices. The two output channels from the stereo signal switch each enter an input on the 'Multi Coupler', where signals are routed to different outputs leading to independent processing chains.

Signals are essentially subjected to two different sections of routing. The lower part of the system uses filters and gain staging, where signals are summed together then output to loudspeakers. One filter has its output returning to the 'Multi Coupler', producing a feedback loop. The upper section deals with two more feedback paths, consisting of a 'phase shift network' which is output to a series of filters, gain stages and two ring modulators, providing two extra parallel processing chains. Tudor built numerous phase shifting devices throughout his career. His creative use of phase shifting within feedback networks "lead to very unpredictable results" (Adams, 2004). The boxes labelled "X" with inputs "Y" &

“Z”, show the ring modulators and their respective inputs (highlighted green). One receives unfiltered signals of various phased degrees and directs the audio through a low pass filter. The second receives signals from a high and low pass filter. This produces sub audible frequency content caused by the frequency difference of each filter applied to the ring modulator’s “X” & “Y” inputs. These low frequency oscillations create additional characteristics that influence the modulation activity of the feedback. The output of each ring modulator is routed back into two separate inputs on the ‘Dual Multi Coupler’, producing two additional feedback loops to be redistributed around the system (Kuivila, 2004). Creating a number of interacting feedback paths this way causes signals to influence one another, providing constant sonic movement and preventing the feedback from becoming static or latching onto a fixed frequency. Summing these feedback paths together forms elements of pitch and rhythmic counter point. This contrasting feedback frequency relation is used to generate the indeterminate activity heard in the output stage. Performing identical versions of *Untitled* was near impossible due to the nature of the system design.

Many of the other devices used were commercial effects. The filters were made by Electro-Harmonix - 'The Screaming Bird’ was used as a high pass filter and ‘The Mole’ as a low pass. These two effects boosted a particular range of frequencies, which Tudor used to accentuate a particular range of the feedback frequency content (Nakai, 2021, p.453). The two separate processing chains are summed together before being output to the loudspeakers. Tudor would often shift the identity of *Toneburst* and *Untitled* in different performances to suit the technological situation of various concert spaces. The system becomes the tool for both sound generation and sound modulation.

Caryatid: Transposing Tudor's Analogue Feedback System to the Digital Realm

(https://soundcloud.com/user-128065381/caryatid)

Caryatid was produced through an experiment which explores routing techniques found in Tudor's feedback system designed for *Untitled.* The piece focuses on two techniques in particular, the generation of feedback, along with the manipulation of signals through routing and processing arrangements to form a unique set of compositional features. In order to examine the potential of feedback as a primary sonic feature, no other sound sources or external input materials (with the exception of one impulse to initiate the feedback) are used in the system. This experiment was transposed to the DAW environment Ableton Live but the same process can be applied to other digital tools such as MaxMSP, or Reaktor.

Ableton uses a series of return tracks, which are sent back to themselves to produce a number of independent feedback loops. These were processed differently with effects and modulation tools. The first send used for feedback consists of an equalizer, limiter and filter. With a limiter the send output could be routed back to the input of the same track, where a combination of track volume and return send amount allow feedback signals to be tamed. By using an equalizer, parameters can be used to manipulate the pitch of the feedback; the frequency, gain amount and equalization curve all contribute to the pitch characteristics. Figure 4 shows the settings for the first feedback channel. A filter using the low frequency oscillator as the modulation source was used to mimic the sub audible frequency content in *Untitled,* produced by the opposing filter outputs entering the ring modulators. Using lower frequencies allows the modulation envelopes to evolve over a longer period of time, rather than at the audio rate of the material passing through. In this arrangement, modulation frequency cycles act independently to the audio signal passing through, which provides an additional dimension of timing characteristics. With a square wave oscillator as a modulation source, two stable pitches are produced as the wave position shifts between the frequencies.

The principle here is simple, but detailed attention to the parameters is required for controlled pitch or imposing a specific musical outline. By fine-tuning these parameters, feedback signals can be tuned harmonically to taste, although accurate pitch control is not always easily achieved. This process is repeated on the next two return tracks creating a total of three feedback loops, each activating a different frequency. These were situated in a particular range of frequencies, providing an harmonic foundation that determined the frequency choices made to the rest of the feedback loops. The fourth feedback channel repeats this process with some additional effects. A reverb with the spin function deactivated is added to change timing characteristics of the filter's envelopes and gives a contrasting spatial quality against the previous signals. Another filter is used to create additional pitch information; two separate filters using a square wave oscillator as a frequency modulator will produce up to four stable pitches depending on the range of each filter frequency setting.

A mixture of high pass and low pass filters are used on the rest of the channels with a maximum of three used to create six stable pitches. The fifth return channel repeats the processing arrangement of the fourth, only this instance of reverb has the spin activation switch assigned to a MIDI controller. Saturation is used to add harmonic content to the feedback signal, which would usually only activate a single frequency, much like a sine wave. The spin function modulates the reverb reflections causing the feedback frequency to sweep between the pitches produced by the filters. This combination of settings creates a situation where feedback loops exist in a type of equilibrium, where signals are persistently cut and reactivated through the motion of each filter modulation. This happens at a rate where signals neither exponentially increase, nor cut long enough to deactivate the feedback. As the return track volume faders play a crucial role in the feedback characteristics, engaging with these particular faders would not be practical in a live performance, these parameters needed to be fixed at a particular value in order to produce a consistent feedback signal. To achieve flexible volume control, each of the return tracks are sent to their own dedicated audio input channel, where signals can be mixed in volume without interfering with the feedback characteristics (Figure 3).

Each audio input channel is routed to another single audio channel, where all feedback signals are summed together before reaching the master output. This allows the feedback signals to be processed globally through a Lexicon Reverb, giving a unified sense of space. From the reverb the signal is sent to another audio channel, which uses an equaliser to treat the feedback. From here, the signal is sent to a channel with a low pass filter and a separate channel using a high pass. The channel holding the high pass filter uses the return send to route the signal back to the fifth return channel, extending the feedback loop which adds more harmonic and pitch characteristics. The send value for this channel was assigned to a button on the midi controller to be used as a performance tool. Although this system is autonomous, it requires an input source in order to initiate the feedback. This was achieved by using a noise wave from Ableton's Operator, which is sent to all the return channels simultaneously. Although the experiment uses eight channels of feedback, only five were used in the final version of the piece. The only parameters used as performance tools were channel volume faders along with the send amount of the summing channel using the high pass filter and reverb spin function.

By using the post fader mode on the return channels, any signals received (in this case the noise wave used for feedback initiation) bypass the master output stage. An additional limiter is added after any gain parameter boosts the signal above 0dB, keeping signal clipping to a minimum.

Circuit Diagram – Figure 6 and 6.1

By comparing Tudor's original schematic with the *Caryatid* diagram, techniques that have been transposed directly from *Untitled* can be observed. Each device can be decoded with the diagram key.

The outputs from the four processing chains fed directly back into the 'Dual Multi Coupler', highlighted red; This series of feedback loops uses different processes distributed across the system, causing both sound generation and signal modulation. The *Caryatid* version condenses these into a single signal, which is directed from the 'channel send output' back to a feedback generation channel at the initial point in the signal path. This technique appears to modulate the sonic output of the instrument, creating additional expressive features from the existing feedback material.

The feedback network with ring modulators and filters in Tudor's schematic, highlighted green; The modulated filters used on this feedback loop cause the frequencies to continuously change pitch. The shifting modulation characteristics produced by the ring modulators in *Untitled* creates autonomous processing features, which are influenced by the audio signal output from the phase network. The phase network output material is determined by the 'Dual Multi Coupler' changeable output signals. *Caryatid* uses this technique with multiple return channels to generate a range of sound material, seen in parallel rows on the diagram. The filters are placed on these feedback channels and have been modulated with their internal LFOs, imitating the function of the ring modulators used in *Untitled*. Although these modulation signals are not influenced by the audio signal activity, they provided the same function in producing autonomous modulation as the ring modulators. The phase network was not used in this study, as the techniques mentioned above provided a vast amount of output material, making these particular techniques the focus of this experiment.
The following video demonstrates these processes in Ableton:
https://www.youtube.com/watch?v=pJcr8fvhlGc

David Tudor – *Weatherings*

(https://www.youtube.com/watch?v=0fPioj_G7Yo&t=89s)

Composed in 1978 for the Merce Cunningham Dance Company, the system used in *Weatherings* was built up from a collection of commercially available tools and custom designed devices, some of which were revived from the Pepsi Pavilion concert in Osaka, 1970 (Nakai, 2021, p.457). The development of this instrument revealed a fresh approach to processing, providing a new role for pre-recorded sound material within the context of a live electronic performance. *Weatherings* is a work that takes an alternative approach to modulation, as this system takes advantage of a particular parallel processing arrangement which is crucial to the sonic identity of the piece.

Tudor often refers to observing his processing chains in a reversed manner, by thinking about what signals are doing at the output stages. Many earlier concerts of *musique concrète* and live electronics in the 1950s would use edited tapes from the studio to playback electronic sounds. The tapes would merely accompany the traditional instrument activity on stage, producing the same order of sound materials fixed in every instance of playback. Tudor's objective was to transform the fixed sounds on tape themselves. Through live processing he could turn these into something unrecognizable from their original form, turning what was typically a studio process into a live performance. The system allowed a multitude of different sonic results to be produced from the same input material, with Tudor interacting with parameters or replacing processors within the same circuit framework from performance to performance. Although the choice of processors would have given some indication of the sonic outline, the sheer complexity of the signal path networks extended the limitation of each processor beyond their preconceived personality, providing an endless option of unexpected processing characteristics. This plethora of live processing results was explored to produce an indeterminate realisation at each performance.

This system had been adapted from an idea used in two earlier pieces titled *Pulsers* and *Toneburst,* realised in 1974, where the concept of 'output processing' was applied to form a new type of instrument. Each of these explored the processing characteristics of output signals used as input material for the instrument. Rather than using modulation tools at the end of the signal path, Tudor would feed modulated signals back into the mixing stage of the system. This inverted order of signal processing allowed Tudor to focus on the sonic output of the system in its entirety through performances. Allowing the human performer to explore sonic mutations through physical interaction with the different processors. It was important to Tudor that sound transformations happened in the performance stage, where the audience could experience the presence of a live musician (Duffie, 1986). The circuit diagram for *Weatherings* taken from You Nakai's study (figure 7), *Here After: Matters of Life and Death in David Tudor's Electronic Music* (Nakai, 2014), illustrates how 'output processing' has been implemented with a series of parallel modulation signals.
The signal originates from four tape recorders, which are routed to the first 'matrix switcher' with a total of 20 inputs and 10 outputs. An earlier version of this matrix switcher, the *Pepsi Modifier,* was designed by Gordon Mumma for the Pepsi Pavilion and was eventually given to Tudor after he requested to borrow it some years later. He recalls having a positive experience with the system in Osaka, where he was able to realise a number of works known as the *Pepsi Pieces.* The *Pepsi Modifier* had unique routing features, it allowed input signals to be routed to any of the 10 outputs instantly, and with its intuitive interface the channel select sliders could be used as an effective performance tool (http://remindedbytheinstruments.info/matrix.html). Tudor modified this by adding extra outputs. Each output signal from the matrix is directed into its own processing module. The 9th and 10th output appear to be connected to the same equalizer, annotated as 'EQ', while channel one uses a Maestro Envelope Modifier ("EM") followed by the Electro-Harmonix Silencer ("SL"). The rest of the outputs go to one of the following devices, which have been decoded by You Nakai from Tudor's original equipment list, archived at the Getty Research Institute; Electro-Harmonix Octave Multiplexer ("OM"), Paia Synthespins

(“S1/S2”) Electro-Harmonix Clone Theory (“CT”), Electro-Harmonix Talking Pedal (“TP”), Phasor/Flanger (“P/F”), and a Phased Locked Loop (“PLL”). (Nakai, 2014, p.14)

The Phasor/Flanger (http://remindedbytheinstruments.info/0039.html) was built by Tudor, with the help from a publicly available schematic released in 1970. This device duplicated the input signal to two outputs, which he used to produce a stereo signal from a single mono source. The outputs from each processor are routed to their own input on a second matrix switcher, with 10 inputs and 30 outputs. The remaining 20 outputs are connected to three mixing consoles, which carry the signals to six loudspeakers. This arrangement allows the output signals of each processor to be used as input material to be further processed, as defined by Tudor’s concept of output processing.

One of the three mixers has four of its outputs panned and routed back into the first matrix, indicated by "(20 x 10)", but details of the panning properties are unclear in this diagram. It would appear that the pan function resembled the matrix, acting like a switch for the different feedback loops entering the first matrix. The diagram shows two signals that go from the mixer output to the first matrix.

The library of pre-recorded tapes consisted of a number of recordings collected from various locations such as, “Demodulated Alpha”, “Wasp Chewing Slow”, “Wasp Chewing Normal”, “Brooklyn Kids”, & “A Mosquito in Test Tube”. Many of these were edited to produce longer versions to suit a live situation. This seems practical for a performance with a system of this nature, for example, the original 38 second long recording of a “Mosquito in Test Tube” would not be suitable for creating textures with longer durations. By increasing these recordings to a longer form, their presence could exist if not for the entirety of the piece, for a good amount of time for the performer to explore the modulation characteristics with a sense of musical continuity. “Demodulated Alpha”, was a recording of neural activity of animals; as this activity only produces low frequency content, laboratories would modulate the recording with a higher frequency, making it audible for scientific research. These modulation signals were applied to a separate channel on the tape. Tudor could easily ‘demodulate’ them by simply removing the modulation channel, reverting the recording to its original form. This low frequency content could influence the processing characteristics with slower rates of modulation to the other sound materials (Nakai, 2021, p.444).

The same input material was used repeatedly and often followed the same order in many different performances. The tapes could be viewed as a point of reference, using the same input material allowed the processing characteristics to be examined in comparison to the original form of these recordings. Although this system uses repeating circuit framework, a wide variety of sonic characteristics can be summoned through the choice of different signal path routings performed with the ‘matrix switcher’. The circuitry used in *Weatherings* remained the same in every performance, in order to cause variable mutations to the fixed sound materials. Tudor often refers to observing his processing chains in a reversed manner, by thinking about what signals are doing at the output stages.

Weathered

(https://soundcloud.com/user-128065381/weathered)

Weathered explores the concept of ‘output processing’ found in *Weatherings*. The experiment incorporates pre-recorded material into a system that uses parallel modulation chains along with feedback signals, where abstractions of output material become the dominant feature of the piece.

Six sources of input material are used, three of which were pre-recorded mono signals from tracks 1, 2 and 3 of an extended cassette tape loop, played back from a Tascam 414 MKII (figure 9). Channel 4 of the Tascam machine is reserved for the final panned output signal from the second matrix, which we will look at later. Input signals 5 and 6 double up as a single stereo source from a cassette played back using a Yamaha KX-230, which is routed straight to the second input of the second matrix. The routing options of the Tascam are flexible enough to function as a matrix for the input material. Outputs can be separated allowing independent processing to each of the signals. The stereo outputs are divided into two mono channels, where the pan controls determine the output of each signal. The third output uses 'tape cue/effect send 2'. The highlighted circles match each output to their respective control on the interface. Each channel can be sent to any of the three outputs simultaneously or independently. If the pan control is set to the centre position, signals will pass through both channels together, whereas the tape cue can output signals irrespective of the channel volume information with its own control. These were used as performance tools along with the pitch control, volume faders and equalization parameters.

The first output (left stereo) channel from the Tascam is routed into a Yamaha PS-023 Chorus/Flanger, followed by an Electro-Harmonix Oceans 11 reverb pedal (figure 10), which uses a reversed reverb (this is why some of the audio is delayed from some actions in the performance video). This was routed to the first input of the second matrix, which uses a Mackie 1202 VLZPRO. Here, the concept of output processing presents itself, enabling the raw input materials to be treated *before* the mixing stage by using these output signals as input sources.

The second (right stereo) output channel is routed to a Boss Chorus/Ensemble. This tool was used to imitate Tudor’s custom phasing device, which utilizes the two outputs to produce a stereo signal from a single mono source. Each of these outputs are routed into their own input on the second matrix, allowing each signal to be processed independently (figure 11). The third output channel, tape cue, uses a Boss DD-3 delay directed to the third input of the second matrix (figure

12). As auxiliary send one is post fader, audio signals depend on channel volume information, meaning these two outputs cannot be separated and would not be used in the experiment.

Once signals arrive at the second matrix switcher, they are subject to some additional processing, using an Electro-Harmonix Deluxe Big Muff distortion pedal on the first auxiliary (figure 13), which is sent to the input of channel 4 on the second matrix rather than an auxiliary return. This is the same for the second auxiliary, where the RFX-1000 adds some stereo reverb (figure 14). By sending each auxiliary to their own input channel, equalisation can be applied to the processed signals, but this also provides more routing options enabling these signals to either create additional feedback loops (by increasing the send value of the channel that receives the corresponding auxiliary signal), or sending signals to each other, where the distorted signal can be processed by the reverb and vice versa. The four signals arriving at the second matrix have the option to be mixed and processed independently.

The pan function at the end of the processing chain is set up in the following way to explore Tudor's original panning technique (figure 15 / 15.1). As master panning options are limited on the Mackie 1202VLZ, the 2nd pair of master outputs are fed directly back into channel eight. This duplicates a version of the master signal that can be panned before being sent to the fourth input of the first matrix. The mute function automatically sends the signal to alternate stereo outputs 3 and 4 on the rear of the machine. Since only channel 3 (left/mono) was used, the pan control functions more like a switch for the feedback loop passing through the whole system, closing the loop with the pan position to the left, and opening the loop with the pan positioned to the right where there is no signal. Although this is not entirely the same as Tudor's panning technique, it would have produced a similar type of function. As the volume fader of the fourth channel on the first matrix has to be raised to reveal the feedback, this was used in the performance with the final pan positioned to the left throughout the piece.

This enables one hand to engage in mixing input material, along with switching the feedback signal at the same point in the system intuitively.

The audio material plays a crucial role in the musical identity of the piece. The tape loop was made from a selection of pre-recorded material; a recording session from St Mary's Church, Mirfield, a custom Reaktor patch, and an acoustic guitar recording, processed and layered in Ableton. The stereo recording played back from the Yamaha machine is a series of pre-prepared stems consisting of continuous loops created from guitar and Ableton's Operator. Although these recordings were typically chosen for their musical characteristics, it is the physical engagement with system parameters that produces expressive qualities and structural developments over time. The extended tape loop used in this experiment also resembles Tudor's extended recordings, giving some continuity where processing can be explored consistently. Details on the preparation of these input sound materials are not covered here, as they were not created specially for the piece, but selected for their contribution to the pre-established sonic outline.

Instructions on Making the Extended Cassette Tape Loop:
https://www.youtube.com/watch?v=HAA_uxioqL8

By removing the side of the cassette shell, the tape loop can be extended to any length. A piece of cello tape was used to protect the magnetic tape from the sharp edges of the broken shell. The tape is lead around a bottle, lasting around 30 seconds per cycle. This can be achieved due to the available space at the side of the cassette housing on the Tascam machine (figure 16, 16.1).

Circuit Diagram

Tudor's concept of 'output processing' has been the main focus of this experiment. By comparing the original *Weatherings* schematic with the diagram for Weathered we can see how this technique has been applied to produce an instrument that uses multiple processing chain outputs as input material (figures 17 / 17.1 / 17.2 / 17.3).

The parallel 'output processing' chains between the first and second matrix used in *Weatherings*;

The *Weathered* diagram reduces these to three parallel 'output processing' chains, as this was the maximum number of independent outputs on the Tascam 414 used as the matrix. The optional fourth output diagram for the first matrix shows how the sync channel can be used as an additional output, although this is not an independent signal to the other channels. The variable signal paths are indicated by coloured 'cables', showing which outputs can be directed to different processors with their respective parameter. Parameters indicated in blue symbolise physical interaction in performance

The feedback signal through the panned master outputs on the final mixer routed back to the first matrix inputs;

This feature functions similar to the matrices, in that the pan position acts like a switch for signals entering the feedback loop. A similar type of routing arrangement can be seen in the *Weathered* diagram. This feedback loop uses only the left master output. The feedback can be redistributed across variable processors, demonstrated in the following video.

https://www.youtube.com/watch?v=ov0hn4QWBoM

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David Tudor & Gordon Mumma - *Mesa: Two Source Duo*

(https://www.youtube.com/watch?v=ulLt7_WB50s)

Through the 1960s, Tudor became fascinated with the Bandoneon, an instrument originating in Germany that had become popular in traditional Argentinian music. He was first introduced to the instrument through Mauricio Kagel, who composed *Pandorasbox, bandoneonpiece,* for him in 1960. Tudor went on to use the instrument extensively for the next five years and composed a series of works for it exclusively. The bandoneon is similar to the accordion, consisting of a large number of keys, bellows and buttons. It relies on air passing through the bellows in order to resonate reeds assigned to the different keys, and is capable of producing a vast range of sonic characteristics from each of the two sides of the instrument. The fact that the bandoneon is notoriously difficult to play appears to be one of the reasons Tudor was attracted to it (Goldman, 2012).

The idea for *Mesa* originated from an earlier piece that signified Tudor's transition from performer to composer in his own right. In 1966, Tudor wrote his first electronic composition, *Bandoneon! (A Combine),* for the famous event, 9 Evenings of Theatre & Engineering (Kuivila, 2001, p.2). This was a series of concerts organized by Robert Rauschenberg and Billy Klüver, where a collaboration of experimental composers, visual artists, dancers, along with scientists and engineers from Bell Telephone Laboratories formed a multi-media installation, which was to be the first of its kind. 9 Evenings of Theatre and Engineering marked a crucial point in the history of live electronic music performance, as it demonstrated the latest technological innovations with fresh approaches to artistic expression. The concert promoted the notion of technology being a focal element of the performances (Holmes, 2020, p.529). This event gave birth to the E.A.T (Experiments in Art and Technology) group, a non-profit organisation started by engineers Billy Klüver and Fred Waldhuer, along with artists Robert Rauschenberg and Robert Witman. The goal of E.A.T was to promote artistic experiments to the wider technology industry (Martin, 2015, p16).

Tudor worked closely with the engineers in the preparation of 9 Evenings and had a large role in designing aspects of the sound system to be used by the other artists. He recalls in an interview, “In order to make the whole thing sonically work, we had to have a generalized sound system. But programs had to be made so that it was adjustable to all the works that had to be presented…”. He goes on to state “I noticed that nobody was really using a lot of the features of the system, so I set out to put everything into this. So I made *Bandoneon!”* (Duffie, 1986). Tudor’s performance would take advantage of the engineer’s technical knowledge and make full use of the devices brought by Bell Labs, many of which were experimental prototypes specifically designed for the concert. Tudor connected the different media formats used by the other artists, using the bandoneon as a modulation source for audio signal processing, lighting and visual media. Using only the instrument in the title as audio material, *Bandoneon!* revealed the concept of ‘mutual modulation’, by using one side of the instrument to modulate the other, all within a single gesture (Goldman, 2012). This allowed the output of the bandoneon to be modulated by its own signal, combining sound generation with sound manipulation in a single performance action.

Ten contact microphones were attached to the bandoneon reeds, which would resonate depending on which keys and buttons were pressed, each of the ten signals were used to modulate processors placed at each side of the instrument. *Bandoneon!* clearly demonstrates Tudor’s ability to reorganize available devices to produce a new type of instrument, driven by his own artistic ideas. As Mumma recalls, *“*He studied them, took them apart, he redid things [. . .] It’s how he reassembled existing material that was the creative part of his work*”* (Tudor, 2010).

Mesa: For Two Source Duo, could be viewed as a reduction of *Bandoneon,* which focuses on the modulation of audio signals through electronic processing, produced by the instrument entirely. It was originally composed for colleague Gordon Mumma, commissioned by the Merce Cunningham Dance Company to produce the soundtrack for a dance called *Place* (1966). Mumma was already a respected engineer and electronic music composer, known for publishing his ground-breaking article ‘An Electronic Music Studio for the Independent Composer*’,*(Mumma, 1964). This document gave details on constructing a DIY home studio, and was one of the earliest available texts on the topic at the time. It provided a unique insight into how available audio technology could be utilised to produce a custom electronic music studio, at a much lower cost than traditional specialist studio equipment (Mumma, 1964). Mumma had already worked closely with Tudor on *9 Evenings* amongst various other performances since their first meeting at the ONCE festival, an electronic music event organized by Mumma from 1961-1964.

The duo consisted of Tudor playing the bandoneon whilst Mumma constructed and performed the electronic outboard processing. The bandoneon provided the only sound and modulation source for the entire piece. Electronic processing was used to produce cyber abstractions of the acoustic input material. Mumma coined the term ‘Cybersonics’ for describing live electronic processing of typically acoustic sounds. Cybersonics takes into account the interaction between the electronic processing characteristics of sounds and the sound materials themselves (Fillion, 2015, p.40). This idea was often expressed in Mumma’s work particularly *Hornpipe* (1967) and *Cybersonic Cantilevers* (1973). In essence Mumma had extended the stereophonic characteristics of the instrument into an augmentation of electronic circuitry. Signals from one side of the bandoneon are extracted and applied as a frequency modulation source for a ring modulator placed on the channel at the other side. Three microphones were placed at each side of the instrument, which were dedicated to a particular frequency band (three bands on each side). From here the six channels (three audio and three modulation) are sent to different parts of the system. The processing configuration was made up of four parallel chains arranged in two pairs, a pair of modulation signals and a pair of outputs. The processing chain was made up from three modulation devices. Mumma’s custom ‘Cybersonic spectrum transfer’, “a frequency shifter with equalization” (Mumma, 2015), output signals that were split into two modulation paths, one using a voltage controlled comb filter, and the other sent to the other pair of outputs. A voltage-controlled amplifier (VCA) was placed at the end of each chain, from which signals are sent to four loudspeakers (Nakai, 2021, p.230-243).

Low frequency content could be generated when two different notes in close proximity on the bandoneon were played simultaneously, which would be one of the features that inspired Mumma to explore the nuances of its modulation attributes. This extremely rich and chaotic mixture of frequencies was a result of the ring modulator being influenced by actions performed on the bandoneon, creating equal portions of interactive signal processing and sound projection. This electronic system mirrors the physical aspects of the acoustic instrument, producing its own range of dynamics and frequency content.

Mesa II

(https://www.youtube.com/watch?v=j7mG6PesdSc)

Mesa II was composed with a mixture of analogue and digital tools to produce a hybrid system that explores the idea of 'mutual modulation'. The principle of this system is based on the original *Mesa*, where one channel of audio is used to modulate the processing parameters applied to another audio signal. The computer was used to extend analogue signals to digital processing chains, where modulation attributes are dependent on incoming audio signals - actions performed in the analogue domain become the cause of digital processing characteristics. The schematic (figure 25) shows how audio signals have been organised to form a self-modulating system. Essentially, the bandoneon used in *Mesa* has been replaced with an electronic instrument, which uses a number of signal processing techniques involving feedback to produce a range of input material. A manipulated taped loop, synthesizer and feedback signals are used as both audio material and carrier signals for the processors. A spring reverb tank (Figure 19) taken from a Peavey Bandit amplifier is also used as a modulation source; as well as passing audio through the spring, it is struck physically through the performance, which modulates parameters of processers in the digital domain rather than being used to apply reverb.

A blank cassette tape loop (figure 20) of around 4 seconds is played back from the Yamaha KX-230. This piece of tape was modified, by removing much of the magnetic material that holds the audio information. As the imperfections pass over the play head, sonic artefacts are produced. These were used primarily as a modulation source but are heard in the piece occasionally. A custom arpeggiated MicroKorg Vocoder patch is used to produce a sustained harmonic drone. The cutoff frequency for the filter was used occasionally in performance to create dynamic shapes through the drawn out textures. As for the analogue mixer, the auxiliary outputs are routed into input channels rather than the auxiliary returns, providing the option of producing individual feedback loops or applying effects to input material in the traditional way. The first auxiliary uses a Boss DD3 followed by the Electro-Harmonix Oceans 11 reverb, the second holds the Zoom RFX1000, which uses a mixture of pitch, tremolo and rotary effect settings. Each feedback loop is processed through its respective modules, but can also switch signal paths in a parallel arrangement by interacting with the corresponding auxiliary output values.

This creates a network of feedback path options that provide a number of complex waveforms. The sound sources are routed to their own input on the Mackie 1202, which allows signals to be processed before being subjected to different paths in the digital domain. Signals are directed to one of two outputs from the Mackie mixer, either the left (mono) master output, which is used for sound material, or the left (mono) ‘alt 3’ output used for the carrier signal. These two signals arrive at Native Instruments’ Reaktor; input 1 receives the sound material signal, which is routed through an X-Fade module and CV Processor, followed by the Toy Box Audio Granular Sampler. With the record function set to FX, real time granular processing of the input material can be achieved. The signal is then sent to a Monark filter and Rounds reverb before entering the first channel of the final mixer, which outputs the signal to an Ableton audio channel (figure 21).

Input 2 of Reaktor receives the modulation signal, which is also sent to its own X-Fade and CV Processor, before being directed to modulation inputs of processors placed on the first channel. The pitch of the sampler, along with the FM, pitch, and frequency cut off inputs on the Monark filter, all receive the same carrier signal. The CV Processor gives control over signal values sent to the modulation inputs, whereas each X-Fade acts like a matrix for the two input signals. This enables both the audio and modulation signal to switch identity by inverting their paths. Each X-Fade and CV Processor is assigned to rotary encoders on the Behringer BRC2000 (figure 22). The Carrier path also uses a clock divider to produce a series of triggers in divisions of the incoming audio information. This was set up to imitate the low frequency content produced in Mumma's original system, but was not used in this particular version of the performance. Figure 23 shows a sine wave at 265hz as the gate input for the clock divider, giving a stable signal for the purpose of this demonstration. Although this does not produce sub-harmonics, the output results are still dependent on the incoming audio activity. A number for the input signal to be divided by is used instead of an audio signal – producing a gate trigger in relation to the signal entering the clock divider, not low frequency content.

Although the Cybersonic matrix in Reaktor is the primary cause for modulation attributes to the output stage, there are techniques used in the analogue domain that utilize 'mutual modulation' within the feedback networks previously mentioned. The stereo output signal from Ableton is routed to two channels on the Tascam 414, this was done to evaluate the qualities of tape as a recording medium. It is important to note that original recordings analysed in this project were traditionally recorded to this medium, which impacts on the overall sonic characteristics of the pieces greatly. Witnessing a live performance would provide a rather different aural experience from listening to a tape recording of the same performance.

A system that uses ‘mutual modulation’ techniques can provide a plethora of complex processing characteristics, with a distinct appearance from the, perhaps, limited operations available through any physical bodily engagement. By replacing human hands with audio signals, parameter values can not only be modulated at much higher rates, but envelopes can be produced which imitate shapes relating directly to physical aspects of the source material. Sounds can present themselves in a disguise of modulated processes unique to the input material properties. Indeterminacy appears in the range of processing behaviours determined by the modulation processors and their configuration.

Circuit Diagram

The following diagrams shows how devices have been arranged with signal routing to create a system that is capable of producing 'mutual modulation' techniques found in the original *Mesa* (figures 25, 26, 27 and 28) .

The stereophonic nature of the bandoneon used in the original has been replicated with an analogue electronic system that uses the left output to modulate the right or vice versa. The Cybersonic matrix is used as the primary modulation module.

The coloured cables indicate the different routing options for both the analogue feedback network along with modulation carrier signal outputs. The blue 'U' icon symbolises the input gain parameter on channel 4 dealing with the MicroKorg Vocoder signal. This is increased when the MicroKorg cutoff frequency is reduced in performance, producing distortion and additional dynamics to the audio material.

This system reveals a unique form of processing characteristics, which are influenced directly by musical gestures performed on the instrument. This enables the modulation signal to mirror physical aspects of the audio material passing through. The following video gives instructions on building the system. https://www.youtube.com/watch?v=qHoERY58S8E

Toshi Ichyanagi – *Appearance*

(https://www.youtube.com/watch?v=VQ4TmijOPV8)

Appearance (1967), directs us to another influential figure that helped form an integral part of Tudor's approach to electronic music composition. Japanese Composer, Toshi Ichiyanagi, was a young pianist and composer who had studied with Hiroa Kishio as well as Tomojiro Ikenouchi from 1946. He won the chamber music composition award at the Mainichi competition four years consecutively at sixteen before moving to America, where he studied composition with Vincent Persichetti and piano with Beveridge Webster in 1954 at the Julliard School of Music. He became fascinated by the work of Cage after witnessing a lecture, which lead him down a new path in search of his own position in the avant-garde music landscape. Ichiyanagi was soon commissioned to write various compositions due to the expanding recognition of his piano skills, which were increasing parallel to his social networks in the New York avant-garde scene. He quickly became a close colleague of both Cage and Tudor, where he was a frequent participant of various concerts across America and Europe. Whilst working in America and Europe, electronics had become a popular feature of Japanese experimental music. This ultimately encouraged him further to implement electronic technology into his music after returning to Japan in 1962. In the same year Tudor and Cage performed several concerts in Kyoto, Osaka, Sapporo and Tokyo, presenting works by Western composers such as Christian Wolff, Morton Feldman, Karlheinz Stockhausen and Toshi Ichiyanagi. Experienced musicians from the Japanese experimental music scene were heavily involved in the performances (Yang, 2021, p.351). Ichiyanagi's pieces *Cage Shock* (1961), and *Parallel Music* (1962), demonstrate the influence of Cage's composition techniques. *Kuu* (1965), is another work that shows the "sociomusical changes taking place in the early 1960s" (Loubet, et al, 1997, p.19). The 61-minute cassette recording consists of a calligraphy writing session, with office sounds, paper noises and other daily sounds heard throughout the piece. A number of works had been dedicated to Ichiyanagi through his involvement in the Western avant-garde scene, such as Cage's *0'00"* (1962), along with Tudor's 1972 piece *Untitled.* Whilst working in America and Europe, Ichiyanagi had brought with him a new aesthetic, which extended the circumference of his composition strategies (Galliano, 2006). Like Tudor, Ichiyanagi was a virtuoso pianist, who had found a new musical voice with the use of electronics in his work.

Due to the impact of the Second World War, the people of a post-war Japan were left in search of a new identity as they reassembled their nation after years of hardship and trauma through the fallout. Eastern philosophies such as Buddhism were increasing in popularity and spiritual awareness was becoming a largely popularised concept in Japanese mainstream society. Meditation sessions for businessmen were apparently even designed by Dr Suzuki in order to recalibrate the country's morale. Through the development of Japanese electronic music in the 1950s, a new type of scoring system was required to suit the change of musical features and new technology used. Traditional notation did not have much relevance (if any) to the aural characteristics of electronics, nor the performative aspects of electronic sound production. Scales of pitch, timing instructions, timbre and dynamic range were all rematerialized in a new complex sonic form. The traditional music language could not describe electronic music gestures accurately. A new type of scoring system based on graphic representations became the main tool for providing instructions on performance actions. Although it is stated that many Japanese electronic compositions were produced with these types of graphic scores, there are practically none available from this period today (Mizuno, 2019, p.104). Eastern philosophy was also becoming popular in western culture, with many concepts relating to the aesthetics of experimental electronic music, as Demers states, "All electronic music is a meditation on the act of listening to sounds both old and new, therefore a meditation on the cognitive processes that accompany listening" (Demers, J. 2005 p.22). Alan Watts was an English philosopher and writer who has been recognised for popularising Eastern philosophies such as Buddhism along with Japanese, Chinese and Indian traditions to the Western world. It is interesting to note that Watts and Cage were friends. Watts talked about Cage's music in his lectures, often referring to his work in order accentuate some of the philosophical ideas found in Buddhism. He also expressed his thoughts on the relationship between deep listening and consciousness in *Still The Mind* (Watts, 2000). It was amusing to read in Watts' autobiography about a memory he had of Cage at party at his home:

> John slept that night […] in the living room, where we kept a hamster in a cage [...] this particular wheel squeaked abominably as the hamster ran, so I told John to put the cage out in the passage if it bothered him. Oh no, not at all! John Said. It's the most fascinating sound, and I shall use it as a lullaby. (Watts, 1973).

Score as Process

As the composition documents show in *Source [Electronic Resource]: music of the avant-garde* (Boyd, 2013), the notation for *Appearance* is made up from a series of scores dedicated to each instrument independently; "Brass", "Organ or Bandoneon", "String Instrument", "Oscillator 1", "Oscillator 2" and "Ring Modulators", (Ichiyanagi, 1967). All instruments have a set of two scores using a number of symbols that represent a specific type of performance instruction. Musical gestures are matched to general instructions for sonic characteristics, such as "produce a lower sound", "produce a stronger sound", "produce a sound of the same length", or "produce a sound of similar strength", (Ichiyanagi, 1967). These vague descriptions provide a particular function when the performers play the piece together. The independently notated instruments are unified by the requirements stated in the accompanying performance notes. Each instrument is processed with the ring modulator, whose parameters change in relation to the actions performed by the 'marked performer(s)' and their position in the score. This produces a chain reaction of unfolding aural events through a mixture of improvisation and pre-defined gestures, resulting in indeterminate outcomes in both the instrumental activity and processing characteristics. Ichiyanagi had created a score that could be used as a tool for producing a unique piece of music in every performance, outlined by a pre-organized sonic framework that is built up from the devices and instruments chosen for the piece.

Tudor mentioned in his interview with Teddy Hultberg, that he had dedicated *Untitled* to Ichiyanagi after working together on *Activities for Orchestra* in 1962. "Toshi's score was one of such vagueness, that it made me think, How can I do this with electronics?" (Hultberg, 1988). Using a set of instructions to produce a range of unpredictable results in this way gave Tudor the idea of recreating a similar situation with electronics. Ichiyanagi's approach to notation resonated with one of Tudor's favourite Busoni quotes, that (traditional) "notation is an evil spirit separating music from musicians" (Kuivila, 2001, p.2). The scores for *Appearance,* and many other early Japanese experimental compositions are not only a vital prerequisite for the production of indeterminate music operations, but they helped form an aesthetic unique to Japanese culture. Ichiyanagi's aesthetic approach to composition (particularly throughout the 1960s) appears to reject any traditional musical interrelations, "producing results that can be identified with anarchy and revolution" (Schiffer, 1974).

Reappearance I/II

For this study two pieces of music have been produced that explore aspects of Toshi Ichiyanagi's approach to composition. A scoring system has been designed specifically for the realization of each piece, exploring the use of graphic notation as the primary performance instruction. A combination of pre determined outlines and improvisation techniques are combined to provide a distinctive performance outcome.

Reappearance I

(https://soundcloud.com/user-128065381/reappearance-i)

This piece uses the Mackie 1202 as a no input feedback instrument. Three feedback paths are individually processed with distortion and delay, using an Electro Harmonix Deluxe Big Muff followed by a Boss DD3, Boss Super Overdrive and a Dime Distortion, signals can be summed together and directed through additional feedback loops within the mixer. The distortion pedals act like a compressor, reducing any peaks in feedback volume, as well as adding harmonic content, which produces a spectrally rich output signal.

Like many of Ichiyanagi's scores, the performance instructions are extremely vague and require a large amount of interpretation by the performer (figure 29). The numbers referring to the duration are left suggestible and do not have any implications over the aesthetic context of the piece. Although the instructions appear rather non-descriptive, this correlates to the instrument itself. The very nature of no input mixing subjects any performer with moments of anticipation through the process of discovering a sound world that resolves the perhaps undesired sonic results in its search. A performance that revolves around feedback is usually expected to encounter moments where precise control of sonic output is absent, a balance of intension and free improvisation become the primary performance feature. The following video demonstrates the instrument in practice: https://www.youtube.com/watch?v=JDUN-h38KBw

Reappearance II

(https://soundcloud.com/user-128065381/reappearance-ii)

The piece takes an alternative musical approach to this type of score, providing a different compositional outcome. The score (figure 31) is similar to *Reappearance I*, using the same symbol set with a slightly different arrangement. A second layer consisting of coloured shapes has been applied to represent harmony, texture, and musical tones. As there are no performance instructions accompanying this version of the score, this could be interpreted in any way. The system used is similar to that of *Weatherings*, where the concept of 'output processing' has been utilized to provide a predefined sonic outline for the input material.

Here the Machinedrum UW MRKII has been introduced (figure 30), using two sequenced sine wave patterns. One shifts between two notes in the lower frequencies and is fed through an external mono output, whilst the second sine is situated in a higher frequency range, using the internal LFOs to modulate the amplitude and panning parameters before being fed to the internal reverb and master output. Amplitude modulation replaces the ring modulators used in Ichiyanagi's *Appearance*, as they were not accessible on this device. A noise generator from the Machinedrum is also sent to the master output with some high and low pass filter modulation. By separating the sine wave outputs, the lower frequencies can be sent to auxiliary processors independently to the noise and higher sine wave signals, enabling flexible processing options. These signals enter two inputs on the Mackie 1202. The first auxiliary uses the Electro-Harmonix Big Muff deluxe. The second uses a reverb from the RFX 1000 with a long decay time. The Tascam 414 is used to introduce additional audio material from a series of recordings printed to an extended cassette loop of around 30 seconds. These consist of acoustic guitar, which has been processed with Robert Henke's Granulator, two recordings of Ableton's Operator, which have also been subjected to granulation, and a custom patch from the MicroKorg Vocoder. The second auxiliary send of the Tascam 414 has been routed to the Boss DD3 followed by a Electro-Harmonix Oceans 11 tremolo effect, which is fed to an input on the Mackie mixer, allowing processed tape signals to be mixed independently to the tape machine’s master signal. The parameters used as performance tools were mainly volume level faders on both the Mackie and Tascam machine, along with their auxiliary send values. Performance actions are influenced by the fixed input material and sequenced patterns. Musical phrases overlap at shifting points in time due to the difference between the Machinedrum sequencer and the tape loop length. The only indeterminate aspects of the piece are produced by the two shifting sequences, an idea which was based on the evolving interaction of instruments notated in the score for *Appearance*. Figure 32 shows the routing for all components used in the piece.

The Machinedrum routing diagram (figure 32.1) shows the three wave generators and each modulated parameter. Sine wave frequencies are controlled by the midi-sequencer, whereas amplitude modulation, filtering and pan use midi information generated by the LFOs. Any signal directed through the Machinedrum master outputs is sent through the internal FX module. By using the 'alt track output' a signal can bypass the master FX for external processing. A demonstration of this system can be seen in the following video.
https://www.youtube.com/watch?v=c7WCsvgPDWo

David Tudor - *Rainforest I*

(https://www.youtube.com/watch?v=wQYeqfcUvhw)

Possibly Tudor's most widely recognized composition, *Rainforest I* presented itself with a unique identity distinguishable from many of his other works. It would be the first in a series that explored the resonant quality of objects when subjected to different frequencies and sound material, a technique which developed parallel to Tudor's career in electronics. In 1968, Tudor was commissioned by the Merce Cunningham Dance Company to write a piece for a dance titled *Rainforest* (Driscoll, & Rogalsky, 2004). As he had previously been working on the construction of a new electronic system, Tudor decided to implement these ideas within this new piece, naming it after the title of the dance. It would appear coincidental that Tudor's motive for producing a rainforest-type soundscape had any relation to the aesthetic theme of Cunningham's choreographic piece (only the title suggests an intentional link to a virtual natural soundscape, as Tudor had composed the piece prior to the request) In 1968, "Tudor built the first series of Rainforest oscillators by patching the output of a commercial amplifier back to its input and inserting various processors in the feedback path" (Nakai, 2021, p.349).

We see another technique reappear from the 9 Evenings concert in 1966. The four objects used onstage as loudspeakers for the *Bandoneon!* performance could be seen as a primitive version of *Rainforest.* Using objects as a type of instrument was not an entirely new discovery. This had been explored in a number of compositions involving Tudor dating back to 1961, such as Cage's *Cartridge Music* (1960). The idea of transducing audio signals in physical materials extended the potential for amplification techniques, which became the primary feature of *Rainforest* (Nakai, 2021, p.104.). The first version of *Rainforest* used a series of objects that were small enough to carry to different concerts, Tudor states in John Fullemann's 1985 interview that, "The objects were so small that they didn't have any sounding presence in the space, so I then amplified the outputs with the use of contact microphones" (Fullemann, 1984). In this scenario, the objects became a type of modulation device themselves, due to their resonant qualities and response to different input materials.

To be able to transmit sound through each object successfully, speaker cones were attached causing the material to resonate. Tudor built these speakers with the help from a schematic found in the *Popular Mechanics Magazine* (figure 33) (Ashworth, 1966. p.168). By using a coneless speaker, sound vibrations could be output directly to a material surface, forcing the object to resonate functioning like a loudspeaker. (Driscoll, & Rogalsky, 2004. p.26). The audio materials transduced to each object were made up from a combination of four processed oscillators that mimicked bird and animal type sounds - a suitable addition that would emphasize the image provoked by the titled of the piece (Nakai, 2021). *Rainforest I* was a joint performance between Tudor and Japanese electronic music composer Takehisa Kosugi, a well-known member of Group Ongaku and NHK Studios of Japan. Kosugi had previously collaborated with Tudor in the performance of Cage's *Cartridge Music,* in 1960 (Adams, 2001). It is unclear what roles each played, but both the input material and output signals of objects were manipulated in real-time through the performance. The following versions of *Rainforest* would implement larger scaled objects, chosen specifically for their resonant characteristics.

Roomforest I

(https://soundcloud.com/user-128065381/roomforest-11)

Roomforest I is an experiment based on research into Tudor's *Rainforest*. Causing objects to resonate in a similar way to the original *Rainforest* was not an available option in this particular study. Therefore, recreating a natural soundscape with an electronic system would be the primary focus for this piece. Rather than sounds being transduced through objects and amplifying them, sounds have been passed through a sampler in real-time, where parameters are modulated in such a way that distorts and reassembles the audio material as it passes through. This was achieved by using the sampler function in the Machinedrum UW, which also has the ability to use internal LFO patterns to modulate a number of parameters.

Sound materials are played back from two cassette tapes, one with four tracks and the other with two. The Tascam 414 uses a tape loop with a recording dedicated to each of the four tracks. These sounds were selected to mimic the characteristics of a natural soundscape, all of which were prepared on the computer in order to achieve a particular type of sonic quality. Track one holds a stem that imitates the spatial aspects of a natural landscape. The idea for this process came from listening to a passing mid-summer thunderstorm. As each burst of thunder rolled around the surrounding valley, the reflections produced a series of echoes that could be heard from different points of the landscape in relation to the listening position. This artificial recreation was achieved by recording the sound of a plastic bottle being crumpled, which was lowered in pitch by four octaves. This is then sent to three return channels in Ableton, each consisting of a reverb and delay. The return channels are used to imitate the acoustic qualities of different locations in the landscape. For example, the first return channel uses a reverb followed by a utility, reducing the stereo signals to a single mono source which helps accentuate the pan position, in this instance around 45 degrees to the left. From the first return channel the signal is sent straight to a second return channel, which uses similar spatial processing only with a longer delay time and a central panning position. This is then routed to the final return channel where the pan is situated around 45 degrees to the right. This process was recorded to a single file, which was duplicated and pitched down slightly; when the two files are played back simultaneously phasing is heard through the speed (pitch and time) difference of each recording. This emulates the natural phasing sometimes heard in thunderstorms, in respect to the physical qualities of the landscape (e.g. a storm heard at sea would have vastly different reflections and acoustic qualities from a storm heard in a mountain range).

Admittedly, *Roomforest I*, does not replicate the acoustic resonant features of the original *Rainforest I* experiment. I decided to approach this limitation of equipment with a creative solution inspired by Tudor's configuration and reorganisation of components in order to produce a completely new musical system. The idea was to turn the five-second-tape loop of feedback into repeating phrases with various timing and pitch characteristics.

The sound recorded to the second tape channel was made up from a stereo recording of tin foil being rustled, this was granulized with Cecelia in such a way that the grains (or sample frames) are short enough to emulate the sonic characteristics of rainfall. A location recording captured at a shopping mall was printed to the third tape channel and also uses some granular processing. Transients were smeared out to provide another spatial quality. These channels are summed together in the Tascam's master output, which is directed to an input on the Mackie 1202. The second tape machine is used to play a cassette loop of around 5 seconds; two tracks hold recordings of a no-input mixing performance, which tries to emulate the sound of birds. These are output to two separate input channels on the Mackie 1202, where signals are routed straight to an input on the Machinedrum by using the alternate output, which is activated by the channel mute switches. By separating these two input channels to the mixer, levels of feedback material can be adjusted accordingly before being directed to the audio buffer of the Machinedrum, which outputs the sampled material back to another buffer through the external output on the rear of the machine (indicated green in the diagram). This is processed by a second sampler using the same modulation techniques, which is then sent to an input channel on the mixer (figure 34, 35).

A noise generator from the Machinedrum uses a series of filters and equalization parameters, which are modulated by a number of internal lfos. An additional sine wave with a short decay is used to produce sub frequencies with a slow repeating pulse. All input materials are processed through the Mackie 1202 auxiliary sends with a reverb from the Electro-Harmonix Oceans 11, and an additional reverb from the Zoom RFX 1000. Figure 32 shows the routing arrangement for the system.

Circuit Diagram

The following diagram demonstrates how signals can be passed through the Machinedrum for real-time sampling (figure 36). The green cables show the signal path from the tape machine to the sampler. As indicated, the sampled audio material is output into the second Machinedrum input before being output again to the mixer. This allows both the input and output signals of the Machinedrum to be mixed before and after the sampler processing stage. The 'Machinedrum UW Routing' diagram shows the internal configuration (figure 36.1). The Machinedrum is capable of producing generative sequences from the step sequencer as well as the internal noise wave LFOs. By routing the midi output straight back the midi input, an internal LFO can be used to trigger MIDI note numbers, which are assigned to different functions within the machine. This method is used to produce triggers that operate with varying degrees of indeterminacy, as combined LFO outputs carry a wider range of information than the typical internal unidirectional sequencer.

Variations of sonic material are produced by the conditions of the Machinedrum sampler settings. By feeding the repeating bird-like sounds from the cassette tape-loop into a buffer, LFOs can be used to manipulate the playback features of the sampler such as pitch, sample start position and sample loop length, in order to produce an evolving life-like characteristic. This technique will be explored further in the next stage of the project, where different aspects of real-time sampling will be used in a musical feedback system to produce different outcomes of a composition.

Diagrams

Tudor's diagrams have been vital in carrying out these experiments. These documents could be categorised as composition scores in their own right. However, these ‘scores’ do not use a traditional musical vocabulary, but rather give instructions for a system which produces a particular set of musical features. These scores can be used to reproduce some of the techniques found in Tudor's original pieces. Although each system is identified primarily by the signal routing arrangements, changing devices within the same circuit framework allows the systems to produce different expressive personalities.

Composing Technology: Realising A New Virtual Landscape & Creative Framework for Live Electronic Music Systems

David Tudor’s processes reveal a unique approach to composing electronic music, which is formed by a collaboration of his ideas and the tools available in his surroundings. The studies demonstrate his ability to reconstruct technology in order to produce a unique electronic instrument. Music systems are designed with an intention to project sonorities that reflect the internal mechanical activity of certain electronic signal interactions. By making decisions on which devices a system is constructed from, a technological outline can be used as a foundation for sonic explorations. Systems that employ autonomous operations can provide an abundance of indeterminate sonic features generated by the conditions of different signal routing configurations. Tudor’s systems could be characterized by the different sonic personalities that devices may exhibit in a performance. By observing these processes the symbiotic relationship between the biological composer and mechanical environment is unveiled. Tudor’s aesthetic approach to composition appears to be driven by his desire to reveal the independent expressive personalities, concealed within the internal circuitry of electronic technology (Tudor, 1976). Creating a network where all components make up a type of organism, which is capable of producing expressive gestures of its own accord. Designing a framework for a particular set of functions provides a unique order of musical features, accessed through the operational procedures carried out in the performance stages. To be able to express through the medium of electronics, 'composing technology' is required in order to access a view of an extensive musical landscape. This can be appreciated through observations carried out on Tudor's work.

Tudor's integrated circuits have inspired the likes of John Chowning with his studies into Frequency Modulation, a term which has been defined as "an economical means of generating time-carrying complex spectra." (Lazzarini, 2008, p.9). Even today, computational speeds and input data can be a limiting factor of signal-processing characteristics. By using modulation sources that derive from audio signals, natural processing characteristics can be achieved easily in real-time through the use of feedback. "Because 'nature' is doing most of the 'work', the technique is far simpler than additive or subtractive synthesis techniques which can produce similar spectra" (Chowning, 1973). This is also one of the reasons Tudor continued to experiment with analogue technology after the popularisation of new digital music applications. Instability was a huge part of his work. His experiments were driven by a desire to hear new sounds, which were revealed through the unpredictable nature of his systems.

These studies have allowed me to incorporate a range of unique strategies into my own composition process. By recreating Tudor's systems with the tools available to me, I have been able to discover new functions for devices which may have been designed for another purpose. The research has enabled me to gain a deeper understanding of the technological aspects of my devices along with the personalities they are able to exhibit in a live performance. By experimenting with some of Tudor's feedback techniques, I was able to find a number of unique musical functions that give a particular identity to compositions. Feedback has been used as a sound material, which can be processed to taste or be used as a modulation signal for a vast range of devices. The different paths and devices feedback signals are subjected to give the signal its musical features, providing an endless option of sonic characteristics. By using feedback, components are able to interact with one another, bringing a system to life where a personality can emerge.

Tudor's self-modulating system techniques have been particularly useful for my own compositions. The output processing used in *Weathered* has provided a flexible processing module for either input material or feedback signals. This unique processing chain has enabled flexible processing options in a live performance, without the need for any post-production treatments. Output processing allows a typical studio process to become a dominant performance technique. By understanding Tudor's use of 'mutual modulation', a greater awareness of the different processing characteristics that modulation is able to produce has also been achieved. By using the sound material signal heard in the output stage as a modulation source for its own processes, unique sonic characteristics are formed that relate to the physical properties of the sound material. This type of modulation has enabled me to produce a wide range of sonic mutations that provide original musical features. These techniques have allowed me to create a number of personalised electronic musical instruments each with a unique influence on the compositional outcomes.

The technique Tudor used in *Untitled* (1972) using filters to produce pitch changes to the feedback signal has been explored by many artists in recent years. Asher Tuil's *extensities* (2020), is a work that uses feedback generated by passing radio broadcast sounds through a resonant filter, producing a mixture of layered harmonic and inharmonic tones that drift continuously through brief, soft melodic gestures. *As Loud As Possible* (1995) by Incapacitants is another iconic work that explores feedback with much more visceral approach to the sonic output. A systems general configuration can outline a wide range of possibilities in sound characteristics. For example, Reappearance I shares the same idea of using feedback networks as *Caryatid*. The contrasting sonic output of these pieces is due to the tools used that form the circuit.

The performance is the process where system functionality, limitation and expressive qualities can be explored through the reflected sonic output.
These types of performance situations present themselves as problem solving activities, where the nature of external physical engagement is determined by the available options that reveal different expressive features of the instrument's and performer's personality. Performance actions sometimes require methods of navigation, taking the form of gestures that are influenced by the variable nodes available within a system’s structure. Questions that surround the relationship between the composer and material environment characterise the notion of embodied cognition - that thinking becomes a physical interactive process between the mind, body and external environment (Cox, 2016). Understanding how the physical environment influences our ideas and modes of interaction leads to a greater awareness of the ecological factors surrounding live electronic music systems. These subjects resonate with Andy Clark and Dave Chalmers’ notion of the ‘Extended Mind’ (Clarke, & Chalmers, 1998).

The symbiosis between the composer and the instrument is evident in these studies, through a tangible feedback loop ‘closed’ by the body, mind and technology. Live electronic music composition becomes a process for exploring philosophical ideas stimulated by our environment.

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Appendices

Figure 1: Edited schematic, original taken from *Inside Untitled*, Ron Kuivila, 2004

Figure 2: Instructions for Multi Coupler, *Popular Electronics* Magazine, 1970

Figure 3: *Caryatid* Ableton Project

Figure 4: *Caryatid* - 1st Processing chain

Figure 5: *Caryatid* feedback chain - volume and send settings

Figure 6: *Caryatid* Circuit diagram

Figure 6.1: *Caryatid* Circuit diagram Key

Figure 7: *Weatherings* diagram – retrevied from You Nakai's, *Hear After: Matters of Life & Death in David Tudor's Music*.

Figure 8: *Weatherings* effects processers, images taken from effectsdatabase.com

Figure 9: *Weathered* Matrix Mixer 1

Figure 10: 1st Processing chain

Figure 11: 2nd processing chain

Figure 11.1: 2nd processing chain

Figure 12: 3rd processing chain

Figure 13: 1st Aux processing

Figure 14: 2nd Aux processing

Figure 15: Panning master signal, 2nd matrix

Figure 15.1: Panning master signal, 2nd matrix

Figure 16: Extended Cassette Tape Loop

Figure 16.1: Extended Cassette Tape Loop

Figure 17: *Weathered* Circuit Diagram

Figure 17.1: *Weathered* Circuit Diagram

Figure 17.2: *Weathered* Circuit Diagram

Figure 17.3: *Weathered* Circuit Diagram

Figure 18: *Mesa Two Source Duo* - Circuit Diagram

Figure 19: Peavey Bandit 112 Spring Reverb Tank

Figure 20: Manipulated Cassette Tape Loop

Figure 21: Reaktor – Cybersonic Matrix

Figure 22: Behringer BRC 2000

Figure 23: Reaktor - Clock/Audio Rate Divider

Figure 24: *Mesa II*– Analogue Domain

Figure 25: *Mesa II* Circuit Diagram

Figure 26: *Mesa II* Mixer Signal Diagram

Figure 27: *Mesa II* Reaktor Signal Routing

Figure 28: *Mesa II* Key

Figure 29: *Reappearance I* Score

Figure 30: *Reappearance II* - Machinedrum UW MRKII

Figure 31: *Reappearance II* Score

Figure 32: *Reappearance II* – Circuit Diagram

Figure 32.1: *Reappearance II* – Circuit Diagram

Figure 33: *Popular Mechanics* Magazine, June 1966

Figure 34: *Roomforest I* - Machinedrum Routing

Figure 35: *Roomforest I* – Machinedrum LFO matrix

Figure 36: *Roomforest I* - Machinedrum UW Routing

Figure 36.1: *Roomforest I* - Machinedrum UW Routing