

Analysis and Reconstruction of Interactive Electroacoustic Works for Obsolete Technology: Thea Musgrave's *Narcissus*

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Abstract

*Performers interested in presenting interactive electroacoustic works face serious obstacles when the required equipment or technology becomes obsolete or unavailable. Transcription for updated technology provides at best a temporary solution. Detailed and device-independent documentation of the interactive electronic systems used in older works can guide new realizations using available equipment. As an example of such documentation, the technical requirements for Thea Musgrave's 1987 *Narcissus*, for flute (or clarinet) and digital delay, are analyzed and described. A careful examination of the composer's original equipment (a Vesta Koza DIG-411) allows a description of the required electronic effects as parameter values for standard signal processing algorithms, equivalent to the device-specific settings notated in the score. This method may serve as a model for the analysis and preservation of other works for live instruments and interactive technology.*

1 Introduction

Concert music that combines live performers with interactive electronics is often composed for specific technological resources, based on available studio equipment or as a demonstration of a newly invented system or technique. Performers interested in developing an interactive electroacoustic *repertoire* are faced with the problems of a) finding works that are playable using the resources available to them, and b) integrating the extremely diverse technology requirements of different composers' works into their own technical setups.

The specific technical resources required to play a given piece of music may be unavailable to many interested performers, and will likely become obsolete within a relatively short period of time. Composers may update their works periodically through transcription for newer systems, but this process must continue indefinitely—something few composers are willing or able to do alone. Once transcribed, a piece is temporarily functional, but the newly updated version will itself be vulnerable to technological obsolescence within a brief timeframe. Furthermore, software transcriptions of older works are rarely exact

reflections of the original, but are adaptations to the idiosyncrasies of a new system. If a transcription becomes the source for subsequent migrations to other platforms, the process of “analog degradation” is likely to continue. At some point, one must return to the primary source to get an accurate picture of what the piece originally required.

This paper proposes a model for analysis and documentation of interactive systems from which such musical works could be realized again and again by multiple interpreters using completely different technical resources. This documentation model does not describe a new implementation of a work using specific devices or systems, but instead describes the functions of the electronics used in a given piece in terms of standard synthesis and signal processing algorithms, event sequences, control structures, human-machine interactions, acoustic phenomena, and underlying musical ideas.

Thea Musgrave's *Narcissus* (1987), for flute or clarinet and digital delay, provides an excellent test case for this type of technical analysis. *Narcissus* requires a digital delay system, controlled from the stage by the performer. Though relatively simple, the electronics were originally notated in the score for the particular model of digital delay equipment used by the composer: a Vesta Koza DIG-411 (no longer made). Some elements of the delay system can be easily reconstructed with the information provided in the score. However, certain effects remain completely unexplained and are given only in terms of knob positions and markings on the DIG-411.

Flutist Wendy Rolfe, a co-commissioner of *Narcissus*, has very kindly loaned me the original DIG-411 (with which she has performed this work many times since 1987) in order to facilitate comparison of its functions to my own Max/MSP emulation. My aim is to define the digital delay system for *Narcissus* as a set of simple signal processing algorithms and related parameter values, rather than as settings specific to a device that is now obsolete.

2 Technical Analysis of *Narcissus*

The electronics for *Narcissus* can be broken down into three basic parts: a sound I/O and reinforcement system (microphone, amplifier, and loudspeakers), the digital delay

system (creating echo effects with several variable parameters), and a control interface (to change delay settings during performance). The following is an explanation of the required effects, and the technical methods for implementing them.

2.1 Sound I/O and Reinforcement

The sound reinforcement requirements for *Narcissus* are straightforward, and will generally pose no special problems in adapting to available equipment. As with almost any work for live instruments and electronics, a microphone, either contact or standard, is required to capture the sound of the solo instrument, and care must be taken to avoid feedback and ambient noise.

Two-channel audio output is required. The setup diagram included in the score specifies that the delay output should be routed to a loudspeaker placed stage right, while the amplified but otherwise unaffected (“dry”) flute/clarinet signal should be routed to a second speaker placed stage left. This relatively simple arrangement is intended to force and aural separation between the live instrument and its digital “reflection.”

2.2 The Digital Delay System

A digital delay is a standard effect found on most commercially available signal processing equipment, and will be quite familiar to anyone working in fields related to digital audio. In its basic form it creates a simple echo—the input signal is played back after a specified time interval has elapsed. This time interval can be expressed in milliseconds, a standard unit of measurement that applies to all systems regardless of manufacturer.

Six digital delay features must be controlled during performance of *Narcissus*: delay interval (time), feedback level, delay time modulation, hold, volume, and bypass. Each component of the delay system will be described in terms of basic signal processing techniques and the required adjustable parameters, with translations of DIG-411 settings to actual parameter values.

Delay Time. Musgrave indicates three distinct delay times to be applied at various points. The DIG-411 delay time was set using two separate knobs. The first determined the base delay time (labeled “range”), with available settings of 2, 8, 32, 128, and 512 milliseconds. The second selected a multiplier of the base delay time, with values ranging continuously from 0.5 to 2 (labeled “time”). *Narcissus* calls for a base delay time set to 512 milliseconds throughout. Multiplier values of 0.5, 1.0, and 2.0 are used, resulting in 3 separate delay times: 256, 512, and 1024 milliseconds.

Feedback. Delay feedback creates a repeating echo by routing a portion of the delay output back to its own input. Normally, the signal being fed back is at a lower volume than the output, and the repeating echoes fade away

gradually, with a duration that depends on the amount of feedback.

Delay feedback is notated in *Narcissus* using specific DIG-411 settings; values are indicated from 0 to 6 (on a scale from 0 to 10). The most logical assumption is that the settings from 0 to 10 would correspond to feedback gain from 0 to 100% of the original signal, with each number on the dial representing a 10% increment. Therefore, the maximum setting in the score, feedback at 6, would be interpreted as 60%. However, the DIG-411 behaves quite differently. Settings above 6 actually produce some very undesirable effects: rather than diminishing and fading away, the repeated echoes become louder and begin to distort, eventually overloading the system. Apparently, settings above 6 create feedback levels effectively greater than 100%, so that even the quietest sounds introduced into the system quickly build into an overwhelming noise. It would seem that by limiting the delay settings in *Narcissus* to 6 and below, Musgrave was simply working within the idiomatic boundaries of the equipment on hand, rather than choosing settings according to any arbitrary rules.

The practical question remains: using an alternate system, what levels of delay feedback would most closely match the DIG-411 settings indicated in the score? To answer this question, I measured the output of the DIG-411 using a test application created with Max/MSP software. With delay time set to 512 milliseconds (“512 x 1”), a synthesized test signal was sent to the DIG-411 input (DIG-411 input was calibrated for a test signal at 0 dB on the front panel “headroom” indicator), and the delay output for each of the three feedback settings found in the score (2, 4, and 6) was recorded into an AIFF sound file for analysis. A feedback setting of 6 yielded approximately 18 seconds of diminishing repetitions (or 36 repeats). With feedback at 4, repetitions lasted for 5 seconds (10 repeats). Feedback at 2 created 2.5 seconds of echo (5 repeats).

The same signal was then put through a software-based delay with variable feedback (also in Max/MSP), in order to simulate the results of the DIG-411 test. The DIG-411 feedback setting of 2 corresponded to a software delay feedback setting of approximately 25%. DIG-411 feedback of 4 was roughly equivalent to 50%, and the DIG-411 setting of 6 corresponded most closely to 75% feedback in the software simulation.

Admittedly, more sophisticated tests may be possible, but the values given here I believe are sufficient to serve as a guide for faithful realizations of the delay system. It should be noted that on the DIG-411 itself, feedback is not limited to discrete settings. The feedback control knob is a potentiometer that allows for settings anywhere along the range between the minimum (0) and maximum (10) values. Considering the fact that the performer is required to quickly change these settings manually while handling a flute or clarinet at the same time, it is likely that some variation would occur in performance from the notated

values. In actual practice with this machine, feedback settings of 2, 4, and 6 would be merely target values.

Furthermore, differences in microphones (and their placement), individual playing style, and concert hall acoustics will produce slightly different results in actual practice. My analysis of the DIG-411 feedback settings, as 25, 50, and 75 percent of the delay output signal, should be used only as an approximate guide for recreation of the digital delay.

Modulation. The modulation effect is not clearly defined in the score or in any other published article to date concerning this work. Flutist Patricia Spencer, another co-commissioner of the work, describes the modulation effect as a pitch bending effect “up and down in a slow glissando.” (Spencer 1994)

Pitch fluctuation of this sort can be achieved by continuously varying (modulating) the delay time by a small amount, similar to a typical “flange” effect. As the delay time shifts, audio samples in the delay buffer are played back at a shifting rate of speed. As playback speed increases, the pitch rises. As playback speed decreases, the pitch falls. It should be noted that this pitch shifting effect only occurs while the delay time is still changing. Once the delay time is set, the pitch stabilizes. The degree of pitch shifting is directly related to the amount of offset from the original delay time and the speed of modulation. Larger offsets at faster speeds create more radical pitch shifting effects.

The score indicates that “[m]odulation speed remains at 0 throughout, modulation depth ranges from 0 – 10 (0 – 3 [sic] used).” (Musgrave, 1987) According to the front panel of the DIG-411, modulation speed is actually scaled from .1 Hz to 10 Hz, with a continuous range of settings available in between. Therefore the modulation speed setting of zero indicated in the score should be implemented as 0.1 Hz when using other equipment. The score indicates depth values of 0, 1, and 2 on a scale of 0-10. An analysis of the of the DIG-411 output, with an input signal of a sine tone at 440 Hz, shows that a modulation setting of 0 causes no pitch deviation, a setting of 1 causes pitch to fluctuate between 438 and 442 Hz, and a modulation depth setting of 2 produces a pitch variation from 432 to 448 Hz. Using a modulated delay constructed in Max/MSP software, I was able to produce the same pitch variations as the DIG-411 and observe the amount of delay time modulation required (as a millisecond deviation from the base delay time). In other words, to produce the ± 2 Hz pitch variation recorded from a modulation setting of 1, the delay time should be varied by approximately 7 milliseconds in either direction (delay time continuously fluctuates between 1017 and 1031 milliseconds) at a rate of 0.1 Hz. For a modulation setting of 2 (pitch fluctuation between 432 and 448 Hz), a delay time modulation of 21 milliseconds is required, i.e. delay time cycles gradually between 1003 and 1045 milliseconds.

The Vesta Koza modulation was best simulated when the LFO waveform was sinusoidal.

One caveat: on the Vesta Koza DIG-411, the knob control for modulation depth, like the one for feedback, allows for continuous adjustment between values, rather than discrete settings. Using the original instrument the exact values for pitch variation would have been slightly different from one performance to the next. Therefore, some slight variation might be acceptable to accommodate the limitations of the particular equipment used for a given performance realization.

Hold. The hold function allows the performer to capture a short duration of sound in the delay line that loops continually. While the hold feature is engaged, no new sounds are added to the delay, so the hold loop becomes a background to whatever the performer then plays.

The DIG-411 had a particularly smooth hold feature, with no audible clicks or other artifacts creeping in to the sound when engaged or released. Musgrave mentions this requirement as an absolute necessity for any performance implementation of the delay system. (Musgrave, 1987)

A hold feature can be implemented (if it is not already built in to the delay system used for a given performance) simply by cutting the input to the system while raising the feedback level to 100%. Audio captured in the delay buffer will continue to loop indefinitely while the live flute/clarinet signal bypasses the delay system. When the hold is disengaged, feedback returns to its original position and the input is turned back on. To avoid clicks or other undesirable noise, input to the system can be ramped in an out for smooth transitions.

Volume. Several places in the score call for the delay signal to gradually fade in or out. The original setup called for a simple analog volume pedal between the delay output and the loudspeaker. However it is accomplished, final output volume from the delay system should be under direct control of the performer, allowing for dynamic changes in the delay between full volume and silence.

Bypass. The bypass function is used in *Narcissus* to turn the entire delay system on or off by controlling its input. This feature is used at the opening of the piece so that the unaccompanied introductory section is unaffected by the digital delay. Once the bypass is disengaged, the delay system is active. As with the hold function, input should be ramped in and out to avoid pops or clicks when it is used.

Summary. The six digital delay effects required for *Narcissus* are easily translated into standard signal processing algorithms, and the DIG-411 settings given in the score can be given as parameter values for use in alternate realizations of the digital delay system. Table 1 summarizes the required effects and their variable parameters as notated in the score, and as actual values to be used as a guide for reconstruction with alternate equipment:

Effect	Notated	Actual Values
Delay time	512 x 0.5	256 msec
	512 x 1	512 msec
	512 x 2	1024 msec
Feedback	0	No feedback
	2	25%
	4	50%
	6	75%
Modulation (sine wave @ 0.1 Hz)	0	No modulation
	1	Delay time \pm 7 msec
	2	Delay time \pm 21 msec
Hold	On	Feedback = 100%, Input Off
Bypass	On	Input Off
Volume	< >	0 (off) to 1 (full vol)

Table 1 - Parameter Values for DIG-411 Settings

2.3 Control Interface

Musgrave's directions in the score for changing delay settings are so specific to the DIG-411 that any new realization of the work will require some departure from the original notation. Using the DIG-411, the performer was required to manipulate by hand the front panel knobs for feedback, modulation depth, and time. Bypass, hold, and volume were controlled by two foot-switches and a volume pedal connected to input jacks on the back panel.

Alternate delay systems (whether hardware- or software-based) may not feature the same type of physically accessible controls for these variable parameters. Aware of this fact at the time *Narcissus* was published, Musgrave mentions the possibility of using a third footswitch to advance through a sequence of pre-programmed delay settings to change the time, feedback, and modulation values automatically. Such an arrangement allows the performer to change delay system parameters while remaining focused on the music. The points in the score that require changes to these three parameters are as follows:

Score Event	Time	F/B	Mod
1. measure 1	256	0	0
2. measure 78		2	
3. measure 89	512	4	
4. measure 172		6	
5. measure 247	256	4	
6. measure 316		6	
7. measure 370			1
8. measure 387			2
9. measure 398	1024		
10. measure 426			1
11. measure 428			0

Table 2 – Narcissus Score Events

Many strategies currently exist for cycling through a series of effects changes, either by footswitch control or by

other means. More than likely, new strategies will emerge in the near future for controlling parameter changes within an interactive computer music system, to which this list of control events should be easily adaptable.

3 Summary

The digital delay system required for *Narcissus* could be easily reconstructed using a wide range of equipment or software-based audio processing environments. I have based my analysis of the digital delay system and its use in the score on a close examination of the original Vesta Koza DIG-411 system used by Musgrave in composing this piece. By translating DIG-411 settings into specific parameter values for standard signal processing algorithms, I hope to provide a reliable guide for anyone attempting a recreation of the digital delay system for *Narcissus* using alternate equipment or technology. Ideally, this analysis will enable performance realizations that are as close as possible to the intentions of the composer. Furthermore, this analysis provides a model for the analysis, documentation, and realization of more complex interactive electroacoustic works.

4 Acknowledgments

Thanks to Thea Musgrave, F. Gerrard Errante, McGregor Boyle, and Jerry Kirkbride for their guidance and assistance. Special thanks are due to Wendy Rolfe for so kindly providing the Vesta Koza DIG-411 for analysis.

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