SPECTRAL DELAYS WITH FREQUENCY DOMAIN PROCESSING

Dr. David Kim-Boyle

University of Maryland, Baltimore County, Dept. of Music, 1000 Hilltop Circle,
Baltimore, Maryland, 21250 U.S.A.
kimboyle@umbc.edu

ABSTRACT

In this paper the author presents preliminary research undertaken on spectral delays using frequency domain processing. A Max/MSP patch is presented in which it is possible to delay individual bins of a Fourier transform and several musically interesting applications of the patch, including the ability to create distinct spatial images and spectral trajectories are outlined.

1. INTRODUCTION

Delaying individual FFT bins in a short-time Fourier transform, can create interesting musical effects that are unobtainable with more traditional types of delay techniques. By delaying select bins by a small time value on one channel of a stereo signal, for example, distinct spatial images for spectral bands can be realized which can take on even more musically interesting characteristics when the delay values for the bins are dynamically assigned or are determined through signal analysis.

While several commercially available software plug-ins allow one to realize spectral delays[1], the open-ended architecture of Cycling '74's Max/MSP allows an implementation with greater levels of control and the ability to explore some unique musical applications, such as that briefly outlined above, which commercially available plug-ins do not facilitate [1].

2. FFT IMPLEMENTATION

The delay architecture employed in the Max/MSP patch is based on a model in which FFT frames are resynthesized from delayed FFT bins. The size of the delays, measured in integer multiples of the FFT length, are determined by indexing user-defined buffers which are updated at the signal level.

Figure 1 outlines the pfft~ subpatch which is used to transform the input signal. Windowing functions are automatically determined by the pfft~ object.

An FFT is performed on a signal with a Hanning window. Real and imaginary components are converted to magnitude and phase values before being written to two buffers via a pair of gate~ objects which open upon initiation of the delay process. A modulo on the index to these buffers and to the resynthesis abstractions is used to help conserve Max/MSP memory. An additional delay~ object is also used on the index to the resynthesis abstractions to provide delay headroom should the delay for a particular bin require indexing samples that have not yet been written.

The spectral delay process that constitutes the resynthesis part of the patch is contained within two abstractions, one for both the left and right channel. Due to limitations of the pfft~ object, each of these abstractions must be located at the same root level as the pfft~ sub-patch. Figure 2 shows the patch contained within each of these abstractions.

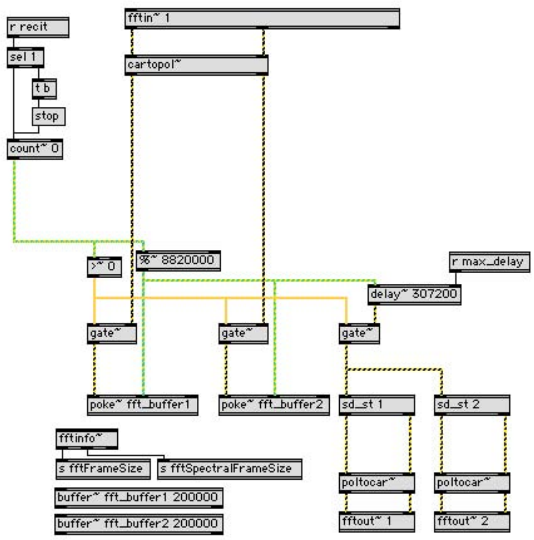

Figure 1: *The pfft~ subpatch.*

A signal is used to index a buffer which contains delays for each FFT bin. As mentioned, these delay values are integer multiples of the FFT length. The delay value is then subtracted from the current index to determine the sample number to read from the magnitude and phase buffers. A delay value of 3, for example, for bin #7 will mean that the magnitude and phase components of the resynthesized bin #7 will be read from bin #7 of the third previous FFT frame. While this is a crude way to realize these delays, it is computationally inexpensive and simple to implement.

As the delay values are integer multiples of the FFT length, the minimum delay time is defined by the FFT size. With a 2048-point FFT at a sampling rate of 44100Hz the minimum delay time is 46.44ms, a 1024-point FFT – 23.22ms, a 512-point FFT – 11.61 ms. While this makes it difficult to simulate interaural time differences between channels where the timing differences may be in

[1] See Native Instruments' "Spektral Delay" for example

the order of only a few milliseconds, it does nevertheless allow distinct spatial images to be realized through the precedence effect. This application will be expanded upon later.

Scaling functions, read from another user-defined buffer are also used to provide amplitude control over the frequency response of each abstraction. Like the delay buffers, these buffers can also be updated at the signal level. In addition, they can also be written to with values obtained from a separate FFT analysis of the input signal. This technique enables a degree of performance control over delay values and amplitude scaling which is particularly useful in interactive computer music applications.

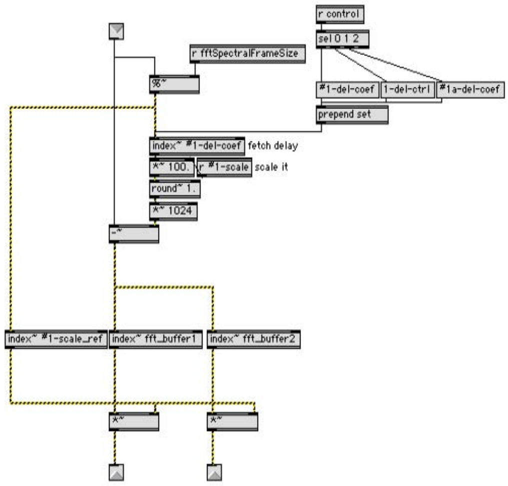

Figure 2: *Spectral delay abstraction.*

3. CONTROL

Several waveform~ objects are used in the patch as basic controllers to determine FFT bin delays and values for amplitude scaling. While the waveform~ object is a somewhat unwieldy way to attribute the large amount of data required by the FFT, especially in the perceptually significant initial 25% or so of the bins, one of its more attractive features is that it provides an instantaneous method of writing to buffers, unlike other objects such as the multislider which requires additional levels of control.

In an attempt to facilitate greater control over the waveform~ object, several macro functions have been added. These include the ability to instantaneously copy data from one buffer to another, the ability to increment or decrement by a small amount the entire contents of the buffer and the ability to write a value to a specific range of bins.

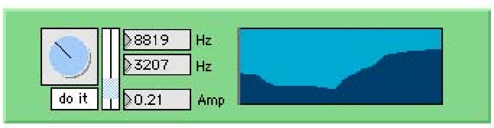

Figure 3: *Using the waveform~ object to determine amplitude scaling.*

The buffers indexed in the spectral delay abstractions can also be determined through signal analysis. The following Section of this paper will describe this application.

4. MUSICAL APPLICATIONS

The spectral delay patch allows several unique applications and musically interesting effects to be achieved. These include the following.

4.1. Signal analysis control

Through performing an FFT analysis of a control signal, which does not have to be the same signal as that processed, it is possible to establish correlations between the harmonic components of the signal and the corresponding delay times for the FFT bins. For example, strong harmonic components may produce long delay times for those corresponding bins while weak harmonic components may produce shorter delays. This implementation is presented in Figure 4

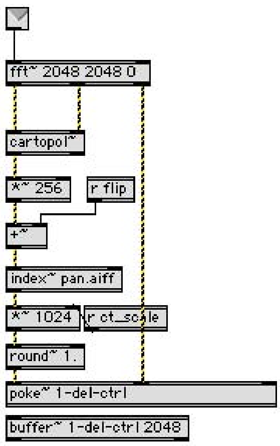

Figure 4: *Signal control of delay times.*

Through a simple inverse function, it is also possible to map short delay times to weak harmonic components and longer delays to stronger components.

Other interesting results can also be obtained through gradually morphing from one set of delay values to another – for example from random, noise-like values to user-defined values.

4.2. Stereo spatial effects

By varying the delay times of one channel with respect to the other it is possible to create unusual spatial effects across certain spectral bands. For example, referring to Figure 5, if the delays for FFT bins 1-20 on the right channel are increased over time a gradual panning to the left for frequencies below around 860Hz, for a 1024-point FFT, will occur. Frequencies above 860Hz will remain spatially stable.

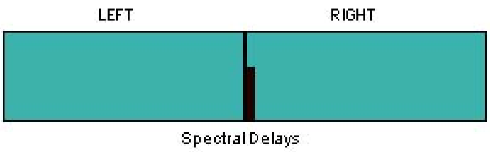

Figure 5: *Spectral panning effects.*

Unlike other types of spectral panning algorithms [2] that are based on the multiplication of a spectral band's amplitude with a coefficient, the spatial images created through spectral delays are created by the precedence effect. As noted by Wallach, Newman and Rosenzweig in their seminal study of the effect [3] the ability to localize sound through the precedence effect is affected by the nature of the sound itself. Sharp, transient sounds cannot be spatialized with the spectral delay technique quite as successfully as sounds of a more continuous, complex nature.

4.3. Multichannel spatial effects

Working on the same principles as those involved in creating stereo effects, the addition of two or more spectral delay abstractions can allow spectral panning effects to take place in more than two channels.

By cascading delays between channels spectral bands can be made to move in circular motions around the listener, see Figure 6.

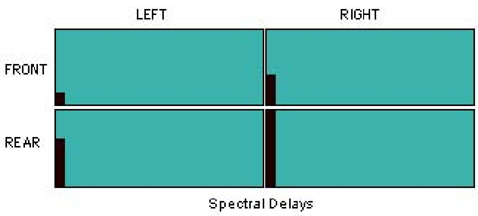

Figure 6: *Circular spatial movement.*

4.4. Spectral reverberation

By chaining delay abstractions together, a primitive type of spectral reverb can be created. With each abstraction simulating the effects of early reflections, it is possible to attribute different reverberation characteristics across the frequency spectrum. Striking effects can be created when these "reflections" are then sent to a series of all-pass filters which simulate a reverberant tail.

5. FUTURE WORK

The author is continuing to explore more refined methods of signal control and line message like control of delay times. Various methods of including spectral feedback within the patch are also being explored. Of particular interest as well is an exploration of whether it is possible to integrate head related transfer functions in order to simulate spectral movement that gives the spatial illusion of height.

6. ACKNOWLEDGEMENTS

The author would like to extend his thanks to Cort Lippe for his many helpful suggestions during research on this project

7. REFERENCES

[1] D. Zicarelli, "An Extensible Real-Time Signal Processing Environment for Max," *Proc. of Int. Computer Music Conf.*, Ann Arbor, MI, 1998, pp. 463–466.

[2] R. H. Torchia and C. Lippe, "Techniques for Multi-Channel Real-Time Spatial Distribution Using Frequency-Domain Processing," *Proc. of Int. Computer Music Conf (ICMC'03),* Singapore, 2003, pp. 41–44.

[3] H. Wallach, E. Newman and M. Rosenzweig, "The Precedence Effect in Sound Localization," *The American Journal of Psychology*, vol. 62, no. 3, pp. 315–336, 1949.