Feedback: the interaction in Physical Models

We already became acquainted with the two distinct global system elements of the acoustical musical instruments: excitator(s) or driver(s) and resonator(s). No acoustic musical instrument without these two systems.

However, what is at least as important is the interaction between these two parts. Especially when your reference is the traditional 'analog synth world' you usually don't think about it. Simply because interaction is usually not there. An oscillator is connected to a filter, from the filter to an amplifier.

You can tweak the filter settings for years to come, but nothing really happens to the element before, the oscillator. In short, there is no feedback, no interaction. Feed forward only!

Interaction plays a crucial role especially in wind and string instruments. Because of its importance this article: "Feedback: the interaction in Physical Models".

Arp 2600
In a previous life, the seventies of the last century, when I did a demo tour for the Arp importer along various studios in the Netherlands, I first discovered that interaction. Together with the 2600 came also a book to help you on your way: the Arp 2600 Patch Book.

In particular, example 66, 'Inharmonic Sequencing', was and still is an ear and eye opener. Initially I did not pay any attention to this patch, because I interpreted inharmonic as non-harmonic: random pitches. Finally I patched #66. That was already a few years later. I then had access to two Arp 2600s from the Tilburg music school where I was employed as a electronic music teacher. The sounding result gave me an Aha experience.

This patch produced melodies in a minor scale. Apart from the minor mood, the intervals, which were pure, the impact on my listening experience, the transitions from one tone to another, was even so important. After some tweaking, the same patch also turned out to be able to generate riffs in the harmonic series, the natural overtone series.

Those transitions between successive tones seemed to be similar to what happened when you were blowing over on a brass wind instrument or flute. I recognized that instantly. I once started playing flugelhorn in the village band and later I also started with all kinds of flutes. After some searching in literature, this Arp patch seemed to be a variant of what is known in electronics as a phase locked loop (PLL) cicuit. The original multiplier as heart in this PLL circuit was repaced by a sample and hold module (S&H) in the Arp patch.

PLL

The original PLL circuit originates from radio technology in the thirties of the last century. For a good radio reception, you must tune your receiver to the correct transmission frequency. At that time all analogous stuff of course. You also know it from the real old analog synths: after careful tuning, the oscillators are still detuned after a while.

The same thing with that analogue receiving oscillator in the radio. Then you got an annoying type of distortion known as fading. A smart circuit was then realized to lock the receiving oscillator at the transmission frequency.

Anyway, in the case of the Arp patch, it goes as follows: a reference oscillator (the transmitting frequency), in the role of resonator, clocks a sample and hold and take care of the sampling commands. But what is sampled? That is a so-called sawtooth slave oscillator, which represents the excitator or driver.

With each input pulse of the reference, the clock, a sample is taken of the amplitude value of the sawtooth output of the slave oscillator, and then sent to the output of the S&H module and held until the next clock pulse arrives. The sampled values now appear sequentially in the 'rhythm' of the reference frequency at the output of the S&H module. Thereafter they were inverted (which is simply multiplied by -1) and, returned to the FM Lin input of the slave oscillator.

With a correct adjustment of the amount of feedback, a self-regulating system is created which adjusts itself from a chaotic situation to a stable state, in which the slave oscillator can produce only whole multiples or whole divisors of the reference frequency: the harmonic series and the subharmonic series respectively.

In the case of harmonic locking, the system adjusts to a *constant feedback value*; the sampling moments then always fall in the same place in the sawtooth of the slave oscillator, the two frequencies are synchronized to each other. When synchronizing with subharmonics, we see a *staircase signal* at the output of the slave oscillator and at the S&H output. The number of steps in the output stage indicating the frequency division integer.

A musical instrument considered as a modulated carrier

The puzzle pieces suddenly came together. I realized that the transitional phenomena when going from one harmonic to the next represented the so-called 'internal fine structure modulation' as the overblowing in wind instruments. The beautiful enlightening story about the consideration of a musical instrument as a carrier modulator can be found in the book Elektronische muziek.

In this, Tempelaars distinguishes three principally distinct modulations:

1. *the global modulation*, those are the notes that are written on paper, or

that you have written down yourself. Obviously, these are gross abstractions of what you really play;

2. *external fine structure modulation*, that which you really play with pitch bends, vibrato, timing dynamics, etc., in short, everything you can refine yourself in your game, summarized as expression;

3. *internal fine structure modulation* from the instrument, from the system itself. These are all characteristic features of the instrument that you can not, or only influence to a very limited extent.

These characteristics arise to a large extent through the interaction between excitator and resonator. You can hear this interaction, this feedback, in the `PLL-Instrument.pch2` download patch

PLL Instrument.pch2
This patch contains eight different subpatches that you find in the 'Variation' menu. They are all based on the same PLL model.

The yellow modules form the actual phase locked loop.

The green module is a (high) pass filter that simulates the flare of a wind instrument

The blue module represents a virtual player. In this case LfoA, the RndStep or the (smooth) Rnd output is used to 'improvise' the slave oscillator harmonics or subharmonics.

When using the RndStep output, this only represents the global modulation, ie the notes. With smooth Rnd, the output signal gradually changes from one value to another and therefore accommodates external fine-structure modulation in addition to the global modulation. The output of this LfoA is also fed back to its own 'Rate' input. This creates a modality in which pitch is linked to tone duration. High tones sound shorter than low ones.

Because the two random outputs of the Lfo do not just randomly generate a 'dice event', more modality appears, an additional feature. The two random outputs produce a so-called 'drunk' random. A kind of drunken movement. The big line is a dice case. Imagine that between two random values is interpolated according to a zigzagging movement. That is now the drunken man who goes from A to B; he'll get there, but swallowing and zigzagging. All in all, this results in a global (and possibly external fine-structure modulation) output signal that appears quite natural and logical; you could have played it yourself.

The other phenomena that you hear, such as trills and the wavering between one and the other (sub)harmonic arises from the system itself, the internal fine structure. Yes, indeed due to the feedback loop from the S&H output to the FM input of the slave oscillator.

As the last link in the patch we see the gray modules. That is simply a stereo output with a stereo delay module, which serves as a productional addition on the one hand and acts as a sort of echo and canon machine on the other hand, thus simulating polyphony. Take the time to listen to the eight different variations and listen especially to what happens between the tones. Another time we will extend the PLL model to a more reality-based patch that simulates wind and string instruments.

Ernst Bonis

This article was originally published in Dutch as ‘Feedback, de interactie in Physical Models’ in Interface 92 October 2005.

Literature

Elektronische muziek
F.C. Weiland en
C.A.G.M. Tempelaars
Bohn, Scheltema & Holkema
Utrecht/Antwerpen 1982