Sondius Physical Modeling Work at CCRMA 1993-1997

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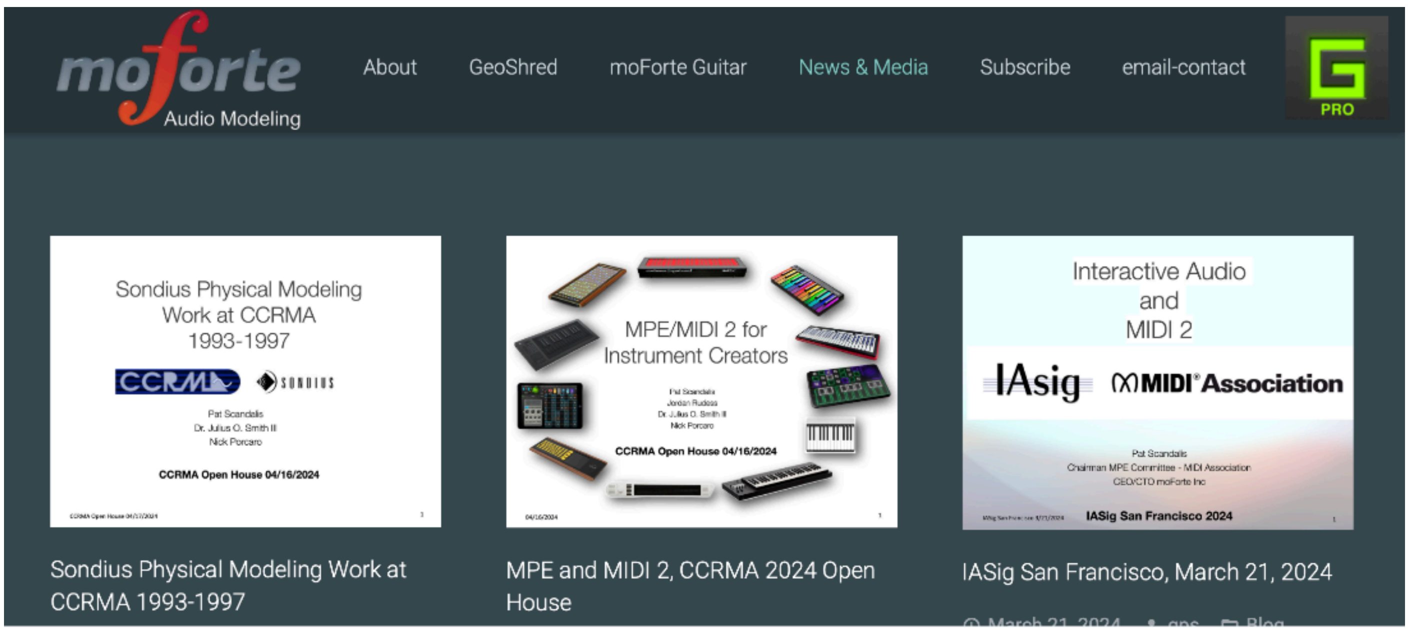


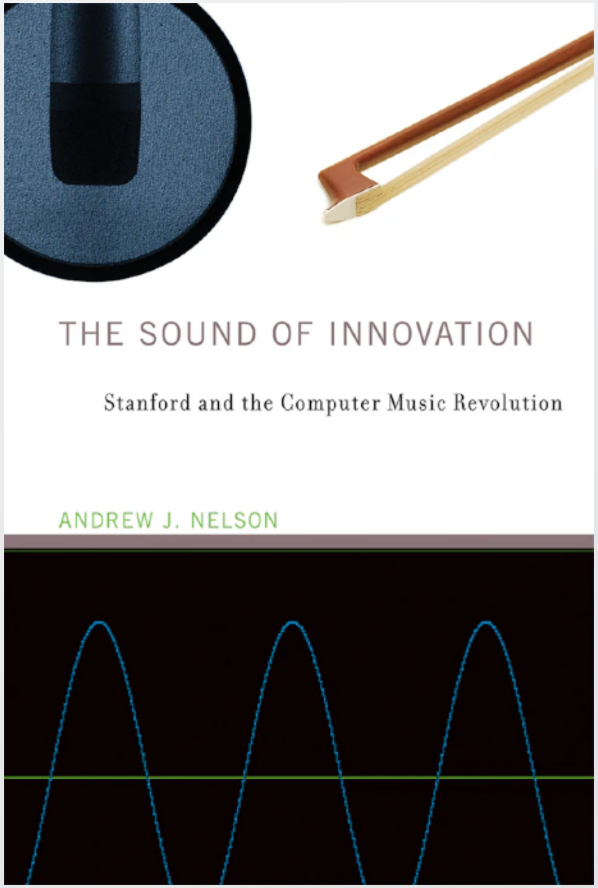
This Thing on the CCRMA Timeline, Down on the First Floor

1997 Stanford and Yamaha partner to establish the Sondius-XG trademark

I'm going to talk about this

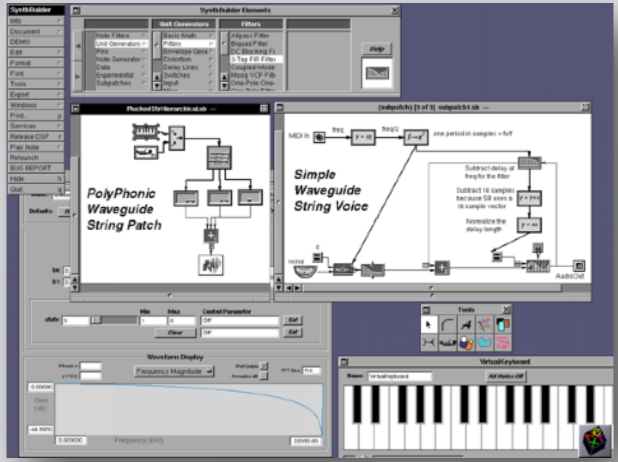
CCRMA History Source

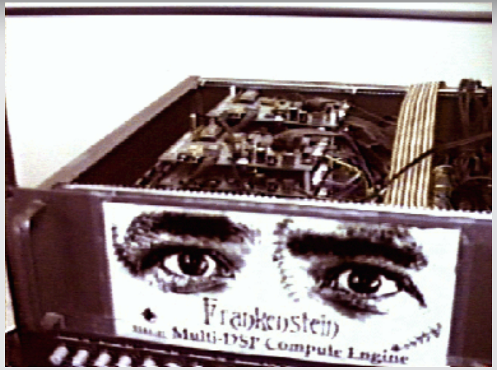
- Andrew Nelson's "The Sound of Innovation" is an excellent overview of the history of CCRMA.
- The period of time leading up to and including the Sondius Project is covered in Chapter 6 "From Exposition to Development" and Chapter 7 "Plucking the Golden Gate Bridge".
- This presentation includes many audio and image artifacts from that period of time.
- The focus is mostly on the technology developed at CCRMA with very little about the Office of Technology Licensing's (OTL) licensing efforts.



Stanford Sondius Project (1993-1997)

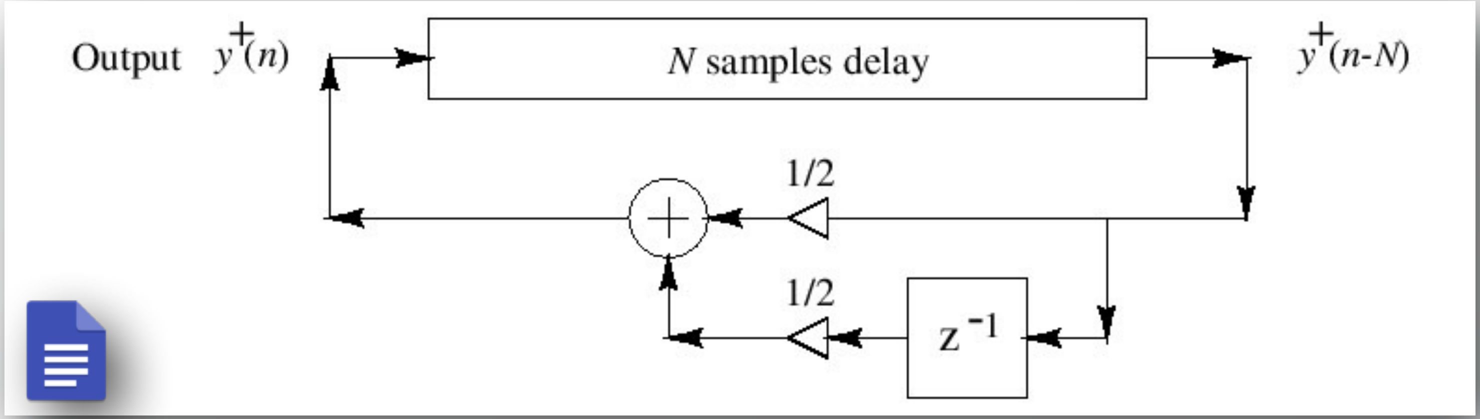
- Stanford OTL/CCRMA created the Sondius project to assist with commercializing physical modeling technologies.
- The result was a modeling tool known as SynthBuilder (Porcaro, et al.), an 8 blade DSP farm (aka Frankenstein) (Putnam , et al.) a set of models covering about two thirds of the General MIDI set and a portable C implementation for licensees (SynthServer/SynthScript)
- Many modeling techniques were used including EKS, Waveguide, Commuted Synthesis, Coupled Mode Synthesis, Virtual Analog.





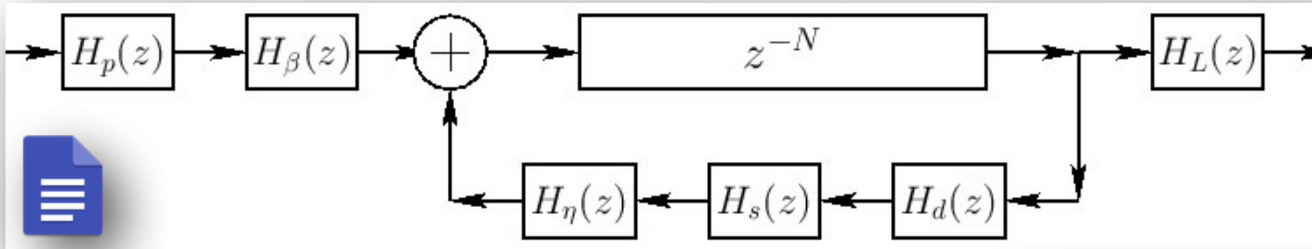
CCRMA/Sondius Physical Modeling Pre-History

Karplus-Strong (KS) Algorithm (1983)



- Discovered (1978) as "self-modifying wavetable synthesis"
- Wavetable is preferably initialized with random numbers
- Licensed to Mattel
- The first musical use of the algorithm was in the work "*May All Your Children Be Acrobats*" written in 1981 by David A. Jaffe.

EKS Algorithm (Jaffe-Smith 1983)



$$H_p(z) = \frac{1-p}{1-p\,z^{-1}} = \text{pick-direction lowpass filter}$$

$$H_\beta(z) = 1 - z^{-\lfloor \beta N + 1/2 \rfloor} = \text{pick-position comb filter, } \beta \in (0,1)$$

$$H_d(z) = \text{string-damping filter (one/two poles/zeros typical)}$$

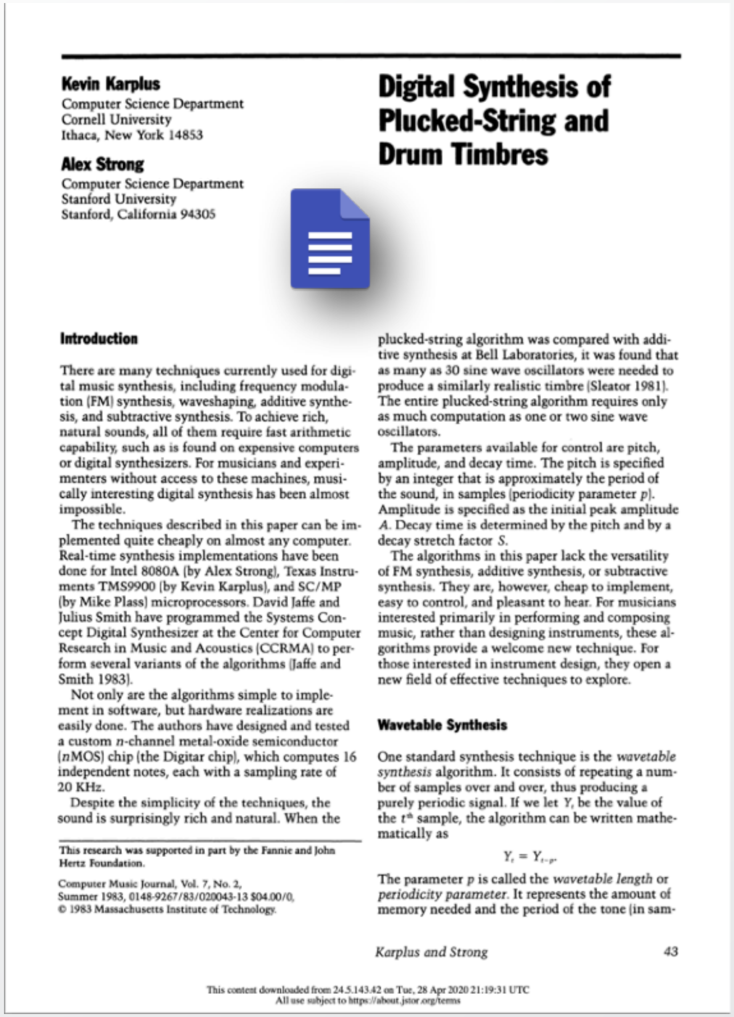
$$H_s(z) = \text{string-stiffness allpass filter (several poles and zeros)}$$

$$H_\eta(z) = -\frac{\eta(N) - z^{-1}}{1 - \eta(N)\,z^{-1}} = \text{first-order string-tuning allpass filter}$$

$$H_L(z) = \frac{1-R_L}{1-R_L\,z^{-1}} = \text{dynamic-level lowpass filter}$$

- Musical Example “Silicon Valley Breakdown” (Jaffe 1992)
- Musical Example BWV-1041 (used to intro the NeXT machine 1988)

The KS and EKS Papers Were Published Simultaneously in the Computer Music Journal (CMJ) (1983)



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Digital Synthesis of Plucked-String and Drum Timbres

Introduction

There are many techniques currently used for digital music synthesis, including frequency modulation (FM) synthesis, waveshaping, additive synthesis, and subtractive synthesis. To achieve rich, natural sounds, all of them require fast arithmetic capability, such as is found on expensive computers or digital synthesizers. For musicians and experimenters without access to these machines, musically interesting digital synthesis has been almost impossible.

The techniques described in this paper can be implemented quite cheaply on almost any computer. Real-time synthesis implementations have been done for Intel 8080A (by Alex Strong), Texas Instruments TMS9900 (by Kevin Karplus), and SC/MP (by Mike Plass) microprocessors. David Jaffe and Julius Smith have programmed the Systems Concept Digital Synthesizer at the Center for Computer Research in Music and Acoustics (CCRMA) to perform several variants of the algorithms (Jaffe and Smith 1983).

Not only are the algorithms simple to implement in software, but hardware realizations are easily done. The authors have designed and tested a custom *n*-channel metal-oxide semiconductor (*n*MOS) chip (the Digitar chip), which computes 16 independent notes, each with a sampling rate of 20 KHz.

Despite the simplicity of the techniques, the sound is surprisingly rich and natural. When the plucked-string algorithm was compared with additive synthesis at Bell Laboratories, it was found that as many as 30 sine wave oscillators were needed to produce a similarly realistic timbre (Sleator 1981). The entire plucked-string algorithm requires only as much computation as one or two sine wave oscillators.

The parameters available for control are pitch, amplitude, and decay time. The pitch is specified by an integer that is approximately the period of the sound, in samples (periodicity parameter *p*). Amplitude is specified as the initial peak amplitude *A*. Decay time is determined by the pitch and by a decay stretch factor *S*.

The algorithms in this paper lack the versatility of FM synthesis, additive synthesis, or subtractive synthesis. They are, however, cheap to implement, easy to control, and pleasant to hear. For musicians interested primarily in performing and composing music, rather than designing instruments, these algorithms provide a welcome new technique. For those interested in instrument design, they open a new field of effective techniques to explore.

Wavetable Synthesis

One standard synthesis technique is the *wavetable synthesis* algorithm. It consists of repeating a number of samples over and over, thus producing a purely periodic signal. If we let Y_t be the value of the t^{th} sample, the algorithm can be written mathematically as

$$Y_t = Y_{t-p}.$$

The parameter p is called the *wavetable length* or *periodicity parameter*. It represents the amount of memory needed and the period of the tone (in sam-

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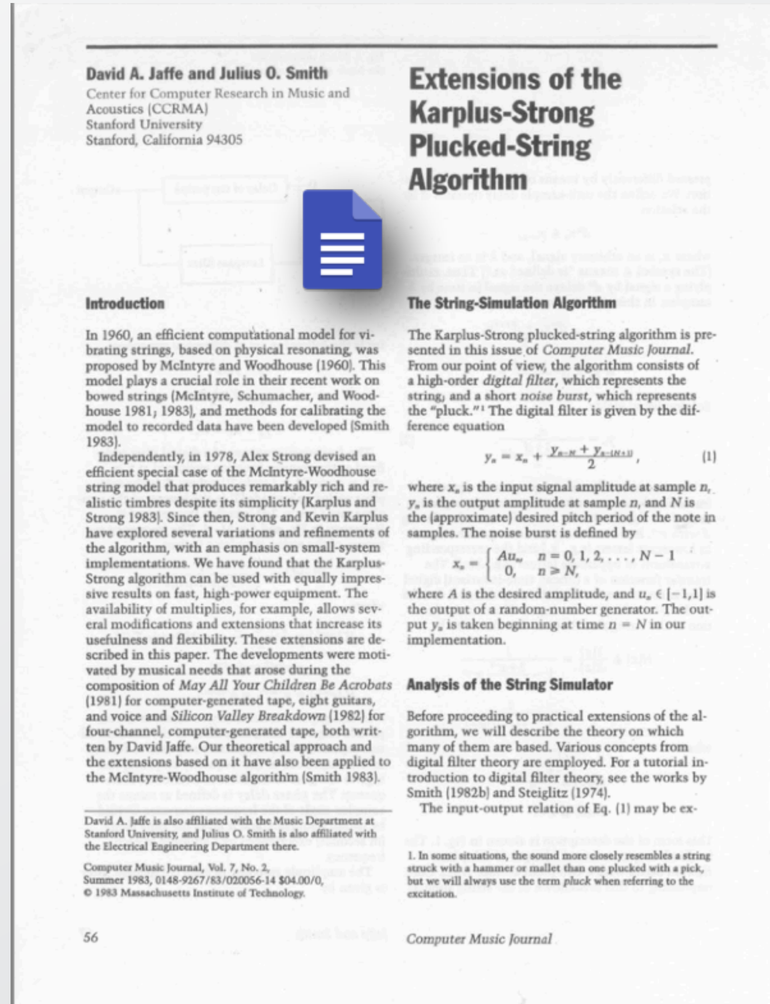
Computer Music Journal, Vol. 7, No. 2,
Summer 1983, 0148-9267/83/020043-13 $04.00/0,



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Extensions of the Karplus-Strong Plucked-String Algorithm

Introduction

In 1960, an efficient computational model for vibrating strings, based on physical resonating, was proposed by McIntyre and Woodhouse (1960). This model plays a crucial role in their recent work on bowed strings (McIntyre, Schumacher, and Woodhouse 1981; 1983), and methods for calibrating the model to recorded data have been developed (Smith 1983).

Independently, in 1978, Alex Strong devised an efficient special case of the McIntyre-Woodhouse string model that produces remarkably rich and realistic timbres despite its simplicity (Karplus and Strong 1983). Since then, Strong and Kevin Karplus have explored several variations and refinements of the algorithm, with an emphasis on small-system implementations. We have found that the Karplus-Strong algorithm can be used with equally impressive results on fast, high-power equipment. The availability of multiplies, for example, allows several modifications and extensions that increase its usefulness and flexibility. These extensions are described in this paper. The developments were motivated by musical needs that arose during the composition of *May All Your Children Be Acrobats* (1981) for computer-generated tape, eight guitars, and voice and *Silicon Valley Breakdown* (1982) for four-channel, computer-generated tape, both written by David Jaffe. Our theoretical approach and the extensions based on it have also been applied to the McIntyre-Woodhouse algorithm (Smith 1983).

The String-Simulation Algorithm

The Karplus-Strong plucked-string algorithm is presented in this issue of *Computer Music Journal*. From our point of view, the algorithm consists of a high-order *digital filter*, which represents the string; and a short *noise burst*, which represents the "pluck."[1] The digital filter is given by the difference equation

$$y_n = x_n + \frac{y_{n-N} + y_{n-(N+1)}}{2}, \qquad (1)$$

where x_n is the input signal amplitude at sample n, y_n is the output amplitude at sample n, and N is the (approximate) desired pitch period of the note in samples. The noise burst is defined by

$$x_n = \begin{cases} Au_n, & n = 0, 1, 2, \ldots, N-1 \\ 0, & n \geq N, \end{cases}$$

where A is the desired amplitude, and $u_n \in [-1,1]$ is the output of a random-number generator. The output y_n is taken beginning at time $n = N$ in our implementation.

Analysis of the String Simulator

Before proceeding to practical extensions of the algorithm, we will describe the theory on which many of them are based. Various concepts from digital filter theory are employed. For a tutorial introduction to digital filter theory, see the works by Smith (1982b) and Steiglitz (1974).

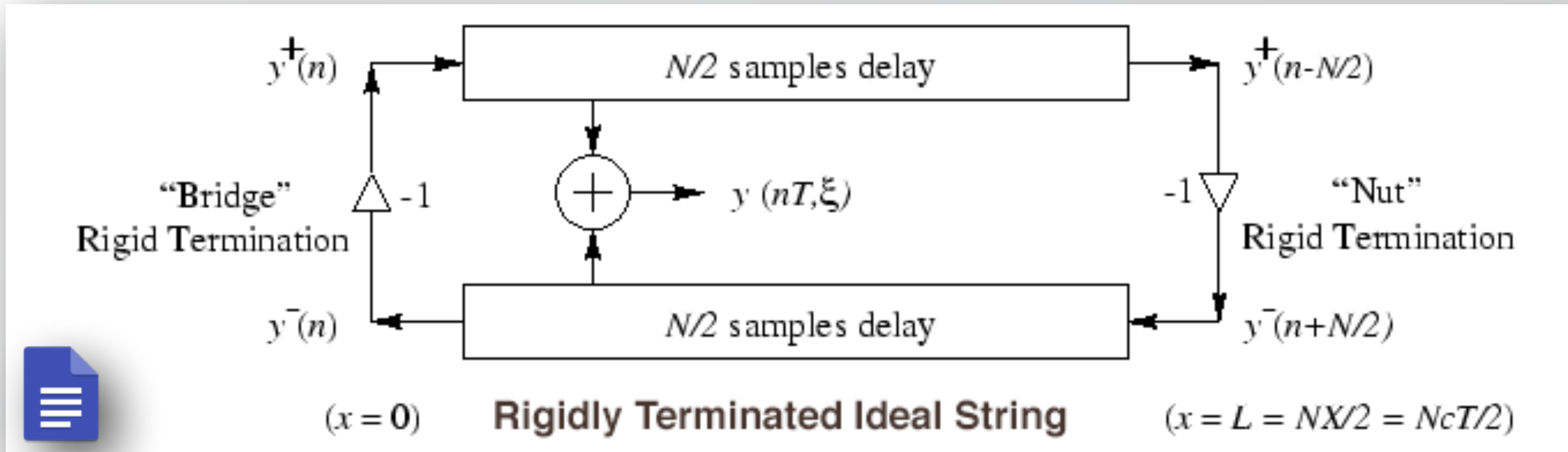
The input-output relation of Eq. (1) may be ex-

David A. Jaffe is also affiliated with the Music Department at Stanford University, and Julius O. Smith is also affiliated with the Electrical Engineering Department there.

Computer Music Journal, Vol. 7, No. 2,
Summer 1983, 0148-9267/83/020056-14 $04.00/0,

1. In some situations, the sound more closely resembles a string struck with a hammer or mallet than one plucked with a pick, but we will always use the term *pluck* when referring to the excitation.

Digital Waveguide Models (Smith 1985)

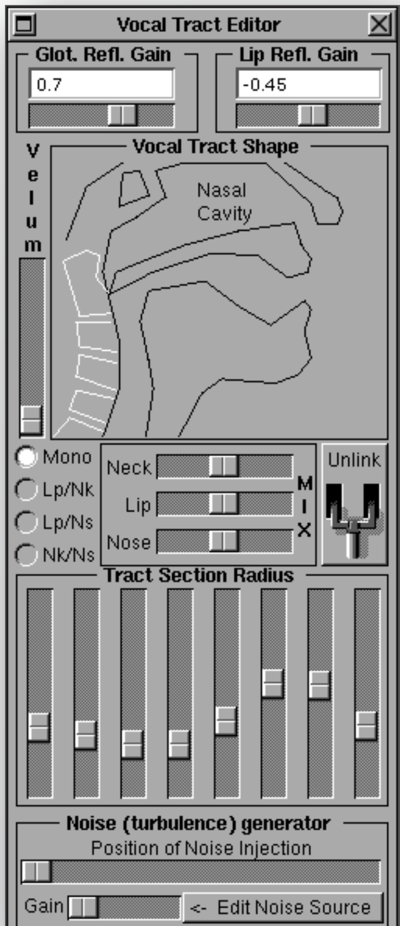


- Equivalent to d'Alembert's Solution to the Partial Differential Equation for a string (1747)
- Used for the Yamaha VL Family (1994)
- Shakuhachi, Tenor Sax

The NeXT MusicKit (1988)

- The NeXT MusicKit unified MIDI (Control) and Music V (Unit Generators) Paradigms. (Jaffe, Smith, et al.)
- The launch of the NeXT Machine in 1988 included a performance of a 6 string physical model along with Dan Kolbialka playing Violin.
- In 1989 Mike Minnick created SynthEdit using the MusicKit and the NeXT Draw Program
- In 1992 CCRMA took over supporting the NeXT MusicKit.
- in 1993 Eric Jordan and David Jaffe created GraSP using the MusicKit and the NeXT Draw Program

Sheila Vocal Track Modeling (Cook 1990)



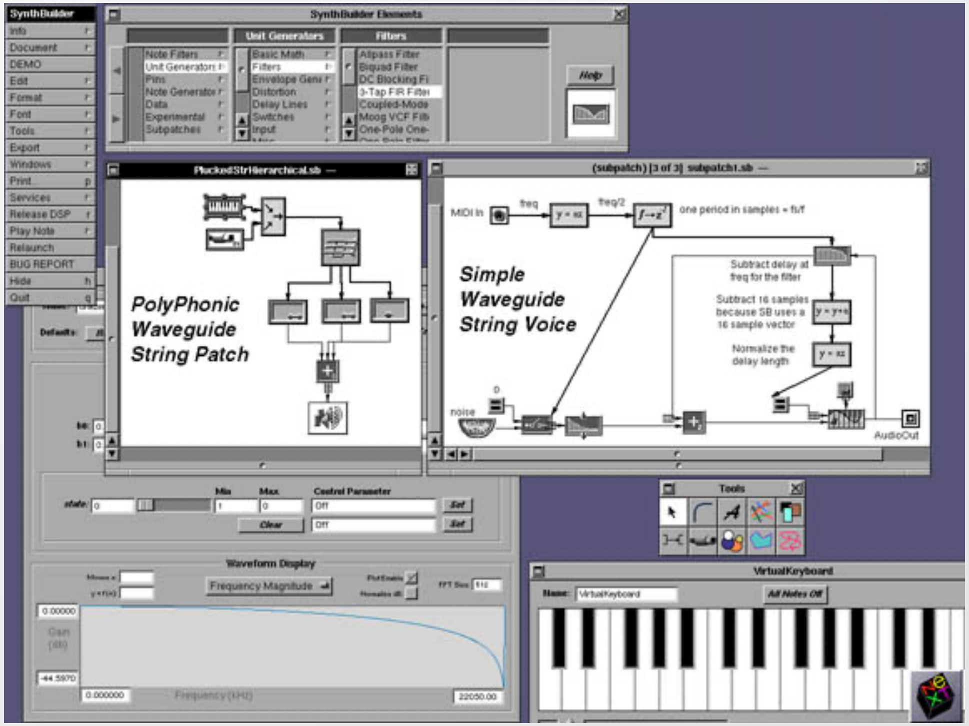
Perry Cook's SPASM **"Singing Physical Articulatory Synthesis Model"**

In 1994 Physical Modeling Was Poised to be "The Next Big Thing".

- By 1994, FM was the standard for PC Game Music. In part due to it's small memory footprint.
- PM was seen by OTL and Yamaha as the successor to FM (John Chowning's pioneering FM patent was expiring). This drove the creation of the Sondius Project.
- However, the cost of memory starting plummeting in 1996. Sampling (aka Wavetable) became common. The memory footprint advantage was lost.
- Some expressivity could be achieved by extensively interpolated samples.
- Voicing PM is difficult (like FM), voicing samples is more direct.
- Controllers that could express multiple dimensions were not common.

SynthBuilder (1993-1997)

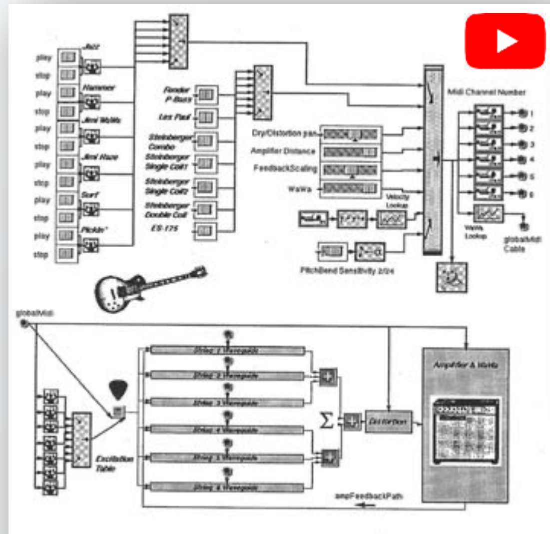
- SynthBuilder was a rapid-prototyping tool on the NeXT machine for the development of music synthesis and effects patches. Initially for the 56k DSP and later for SynthServer/ SynthScript.
- Leveraged the NeXT Music Kit and the source code for the NeXT Draw Program.
- It played a major role in the development of physical models including Coupled Mode Synthesis (Van Duyne), Virtual Analog (Stilson, Smith).
- SynthBuilder was written by Nick Porcaro with significant contributions from David Jaffe and Pat Scandalis, Julius Smith, Tim Stinson and Scott Van Dyne.



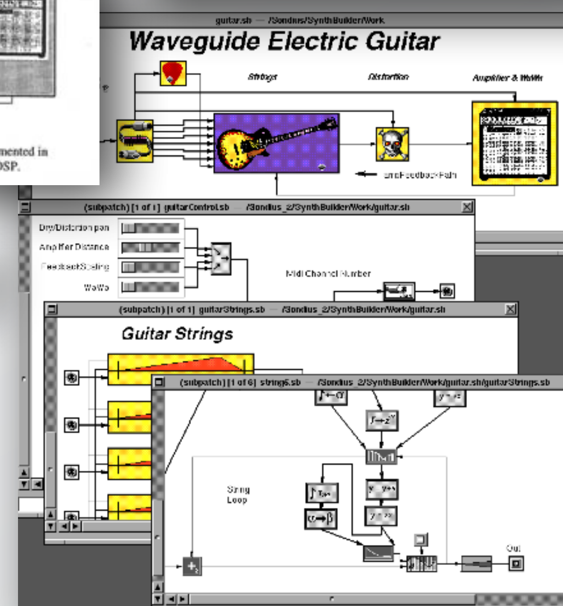
1997 SynthBuilder won the Grand Prize in the Bourges International Music Software Competition

Guitar Model (1996)

- Distortion, feedback and effects.
- Initial period excitations to capture the sound of different guitars.
- Controlled with Yamaha G10 guitar controller similar to today's MPE.



A six string electric guitar model with distortion, feedback and wawa, implemented in SynthBuilder. This model runs on on a single 72Mhz Motorola 56002 DSP.



Coupled Mode Synthesis (CMS) (Van Duyne) (1996)

- Modeling of percussion sounds
- Modal technique with coupling
- Tibetan Bell Model
- Wind Chime Model
- Tubular Bells Model
- Percussion Ensemble
- Taiko Ensemble

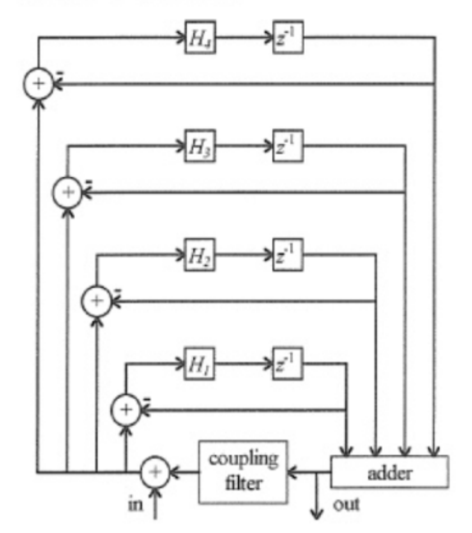
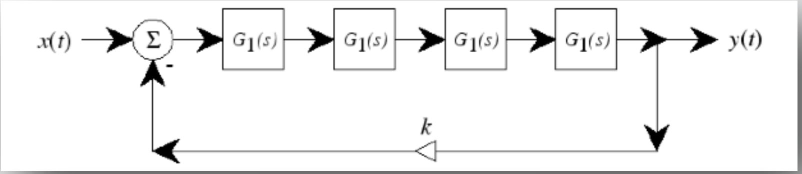
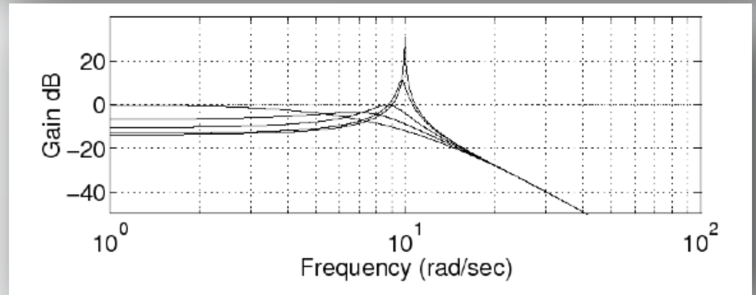


Figure 2: The Coupled Mode Filter Structure

Virtual Analog (Stilson-Smith) (1996)

- Alias-Free Digital Synthesis of Classic Analog Waveforms
- Digital implementation of the Moog VCF. Four identical one-poles in series with a feedback loop.
- Sounds great!





Full Ensembles all Physical Modeling (1997)

SONDIUS

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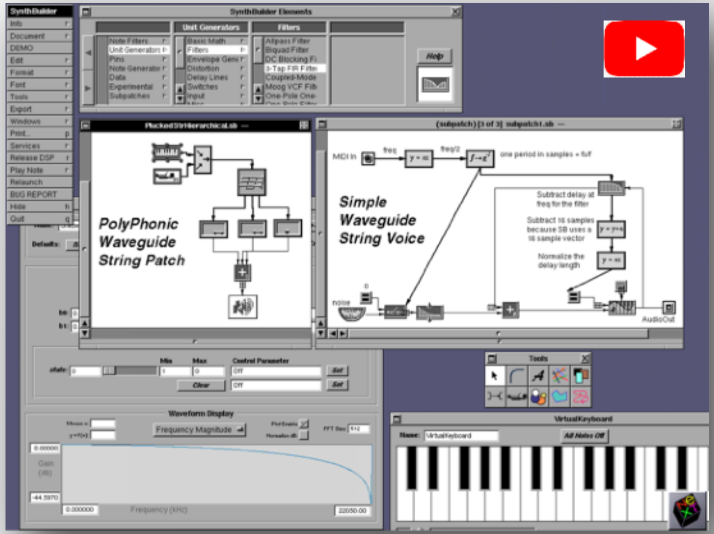
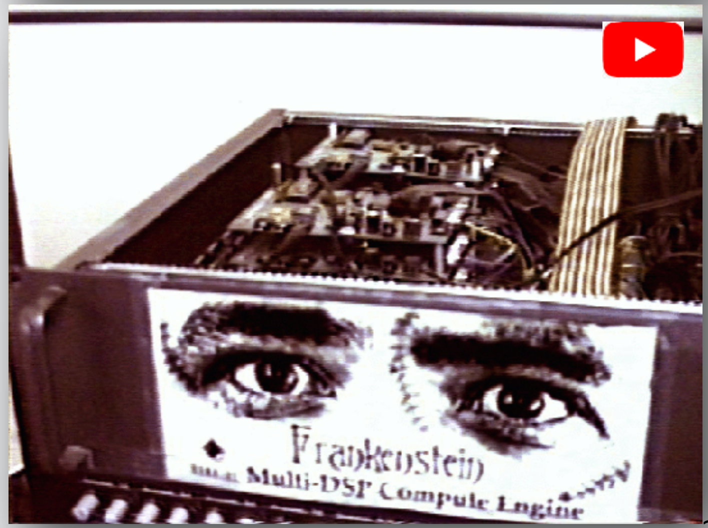
- Many modeling techniques were used including EKS, Waveguide, Commuted Synthesis, Coupled Mode Synthesis, Virtual Analog.





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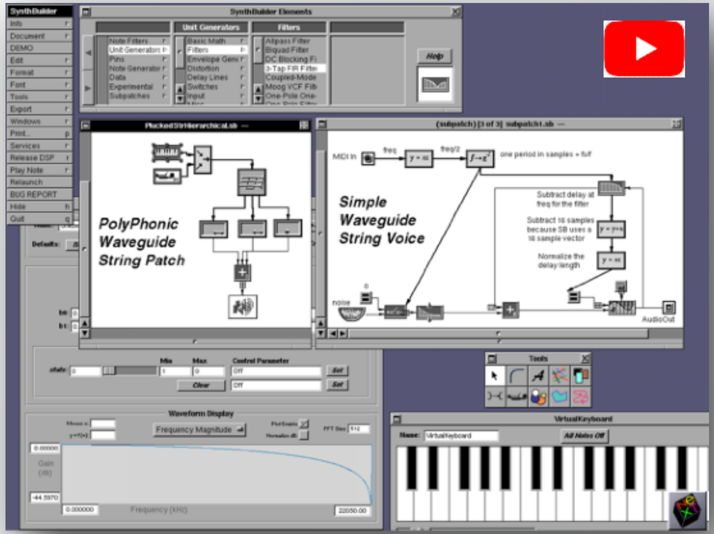
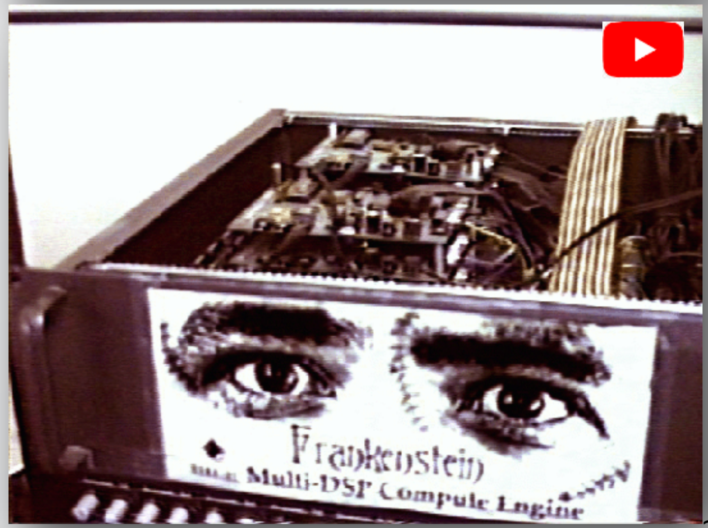
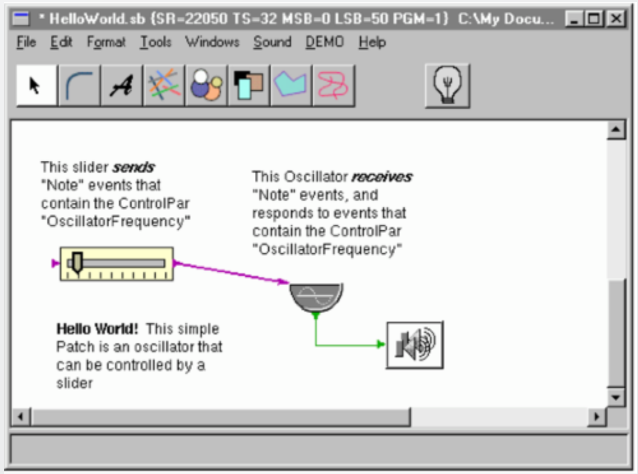




SynthServer/SynthScript 1996/1997

- SynthServer was a portable reference server, implemented in C with object oriented Programming techniques, that was used to realize SynthScript Patches in either non-real Time, or in Real time on various Platforms.
- SynthScript is an interchange format that will allow the exchange of Software based synthesis "programs" (Patches) and Scores between various platforms.
- SynthServer/SynthScript were created so that Sondius Licensees could have actual code to work with.




```
oscgUG MyOscillator
        (out=oscgUGOut, control=sliderNFOut,
             [ amp=0.5,
              freq=440.0:OscillatorFrequency
             ]
 );
```

Papers

"SynthBuilder: A Graphical Rapid-Prototyping Tool for the Development of Music Synthesis and Effects Patches on Multiple Platforms" (pdf, 1.5 mb) , Nick Porcaro, David Jaffe, Pat Scandalis, Julius Smith, Tim Stilson, and Scott Van Duyne, Computer Music Journal, Volume 22, Number 2, pp. 35 - 43, MIT Press, 1998.

"A Lossless, Click-Free, Pitchbend-able Delay Line Loop Interpolation Scheme" (pdf, 671 kb), Scott A. Van Duyne, David A. Jaffe, Gregory Pat Scandalis, Timothy S. Stilson, 1997 International Computer Music Conference, Greece, 1997.

"SynthBuilder and Frankenstein" (pdf 305 kb), N. Porcaro, W. Putnam, P. Scandalis, T Stilson, D. Jaffe, and J. O. Smith, S. Van Duyne, ICAD 1996.

"Work in Progress, SynthScript and SynthServer" (pdf 8 kb), P. Scandalis, David Jaffe, CCRMA Affiliates Presentation 1996

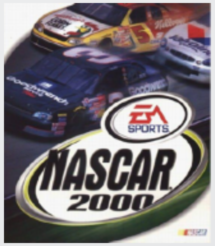
"SynthBuilder: A Rapid-Prototyping Tool for Sound Synthesis and Audio" (pdf 14kb), Nick Porcaro, Pat Scandalis, Julius Smith, 1996 Presented at Berkeley EE seminar.

"Using SynthBuilder for the Creation of Physical Models" (pdf 283 kb), N. Porcaro, P. Scandalis, D. Jaffe, and J. O. Smith, 1996 International Computer Music Conference, Hong Kong. 1996.

"SynthBuilder Demonstration, A Graphical Real-Time Synthesis, Processing and Performance System" (pdf 415 kb) Nick Porcaro, Pat Scandalis, Julius Smith, David Jaffe and Tim Stilson, 1995 International Computer Music Conference, Banff. 1995.

Sondius Epilog

- Yamaha and OTL combined all patents into a portfolio called Sondius-XG (1997)
- The Sondius Team spun out as Staccato Systems (1997)
- Staccato Systems created a synthesis engine called SynthCore which offered physical models for games (Nascar 2000) and General MIDI for game music.
- SynthCore was designed to run at Windows Ring 0 and essentially looked like a hardware device, displacing expensive sound cards for MIDI game music.
- Analog Devices acquired Staccato Systems in 2000 and used SynthCore/General MIDI/Ring 0 combined with a $2 AC97 codec to kill the sound card market.



Thanks!

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- Scott Levine
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- Nick Porcaro
- Bill Putnam
- Pat Scandalis
- Dr. Julius O. Smith II
- Tim Stilson
- Scott Van Duyne
- Jonathan Norton
- Yamaha

And CCRMA

Questions?