# Current State of Physically Modeled Musical Instruments on Handheld Mobile Devices.

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# Ubiquitous Handheld Mobile Computing Devices

- Handheld mobile computing devices are now ubiquitous.
- These devices are powerful, connected and equipped with a variety of sensors.
- Their pervasiveness has created an **opportunity** to revisit parametrically controlled, physically modeled, virtual musical instruments using handheld mobile devices.

# Overview

- We will provide a brief history of physically modeled musical instruments as well as some commercial products that have used this technology.
- Along the way we will talk a bit about the technology behind modeling.
- We will demonstrate what is currently possible on handheld mobile devices using the moForte Guitar.

# First a Quick Demo!


[Demo (youTube)]

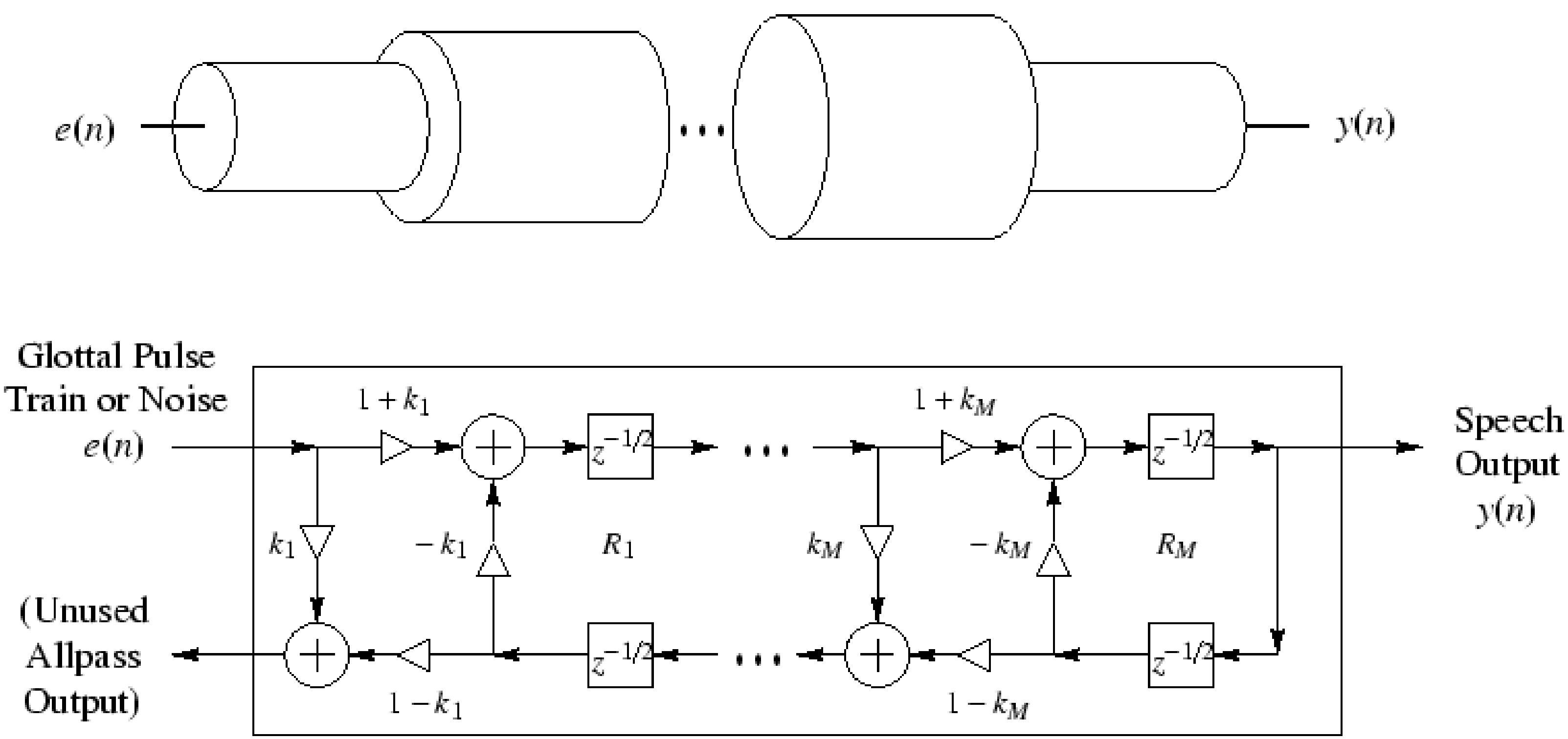
# Brief (though not complete) History of Physical Modeling Synthesis

As well as a few commercial products using the technology

# Physical Modeling Synthesis

- Methods in which a sound is generated using a mathematical model of the physical source of sound.
- Any gestures that are used to interact with a real physical system can be mapped to parameters yielded an interactive an expressive performance experience.
- Physical modeling is a collection of different techniques.

# Kelly-Lochbaum Vocal Tract Model (1961)



Kelly-Lochbaum Vocal Tract Model (Piecewise Cylindrical)



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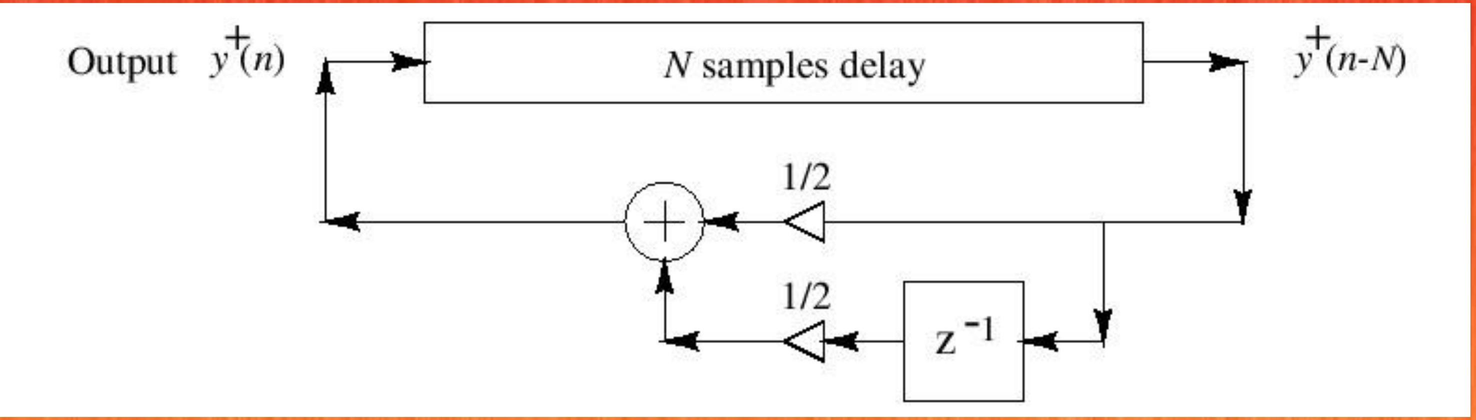
# Daisy Bell (1961)

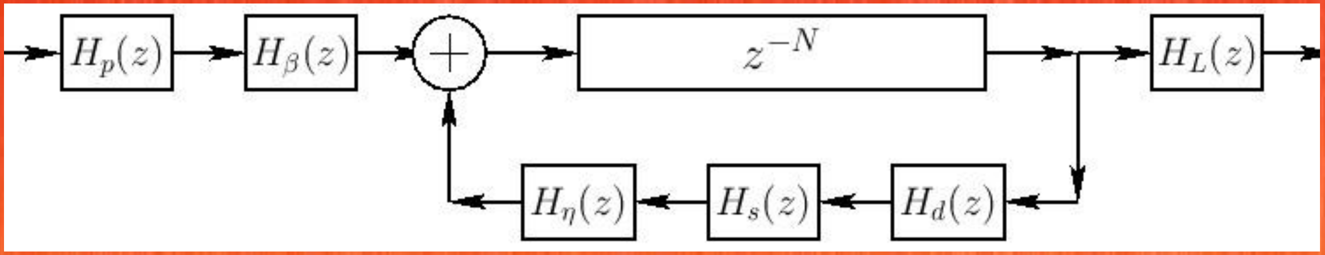
- Daisy Bell (MP3)
- Vocal part by Kelly and Lochbaum (1961)
- Musical accompaniment by Max Mathews
- Computed on an IBM 704
- Based on Russian speech-vowel data from Gunnar Fant's book
- Probably the first digital physical-modeling synthesis sound example by any method
- Inspired Arthur C. Clarke to adapt it for "2001: A Space Odyssey" the Hal 9000's "first song"

# 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. (MP3)

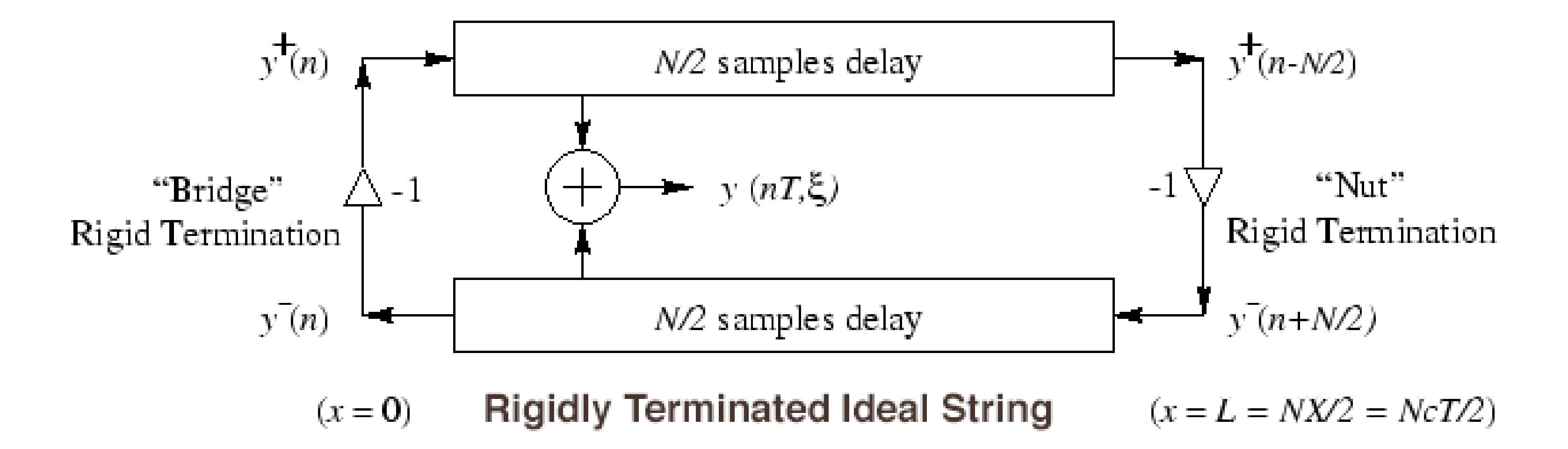
# EKS Algorithm (Jaffe-Smith 1983)




$$
\begin{aligned}
H_p(z) &= \frac{1-p}{1-p\,z^{-1}} = \text{pick-direction lowpass filter} \\
H_\beta(z) &= 1 - z^{-\lfloor \beta N + 1/2 \rfloor} = \text{pick-position comb filter, } \beta \in (0,1) \\
H_d(z) &= \text{string-damping filter (one/two poles/zeros typical)} \\
H_s(z) &= \text{string-stiffness allpass filter (several poles and zeros)} \\
H_\eta(z) &= -\frac{\eta(N) - z^{-1}}{1 - \eta(N)\,z^{-1}} = \text{first-order string-tuning allpass filter} \\
H_L(z) &= \frac{1-R_L}{1-R_L\,z^{-1}} = \text{dynamic-level lowpass filter}
\end{aligned}
$$

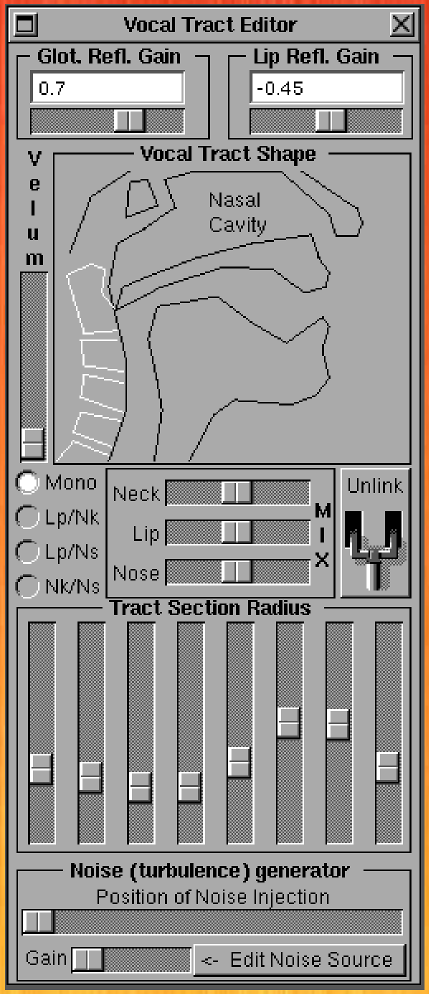
- Musical Example “Silicon Valley Breakdown” (Jaffe 1992) (MP3)
- Musical Example BWV-1041 (used to intro the NeXT machine 1988) (MP3)

# Digital Waveguide Models (Smith 1985)




- Useful for efficient models of
  - Strings
  - Bores
  - plane waves
  - conical waves

# Sheila Vocal Track Modeling (Cook 1990)



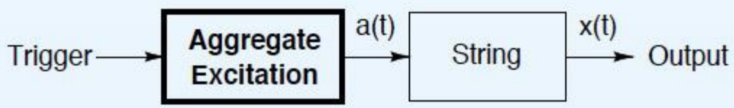

Perry Cook's SPASM **"Singing Physical Articulatory Synthesis Model"**

- Diphones: (MP3)
- Nasals: (MP3)
- Scales: (MP3)
- "Sheila": (MP3)

# Commuted Synthesis (Smith) (1994)


Schematic diagram of a stringed musical instrument.


Equivalent diagram in the linear, time-invariant case.




Use of an aggregate excitation given by the convolution of original excitation with the resonator impulse response.

# Commuted Synthesis Examples

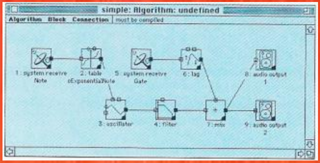
- Electric guitar, different pickups and bodies (Sondius) (MP3)
- Mandolin (STK) (MP3)
- Classical Guitar (Mikael Laurson, Cumhur Erkut, and Vesa Välimäki) (MP3)
- Bass (Sondius) (MP3)
- Upright Bass (Sondius) (MP3)
- Cello (Sondius) (MP3)
- Piano (Sondius) (MP3)
- Harpsichord (Sondius) (MP3)

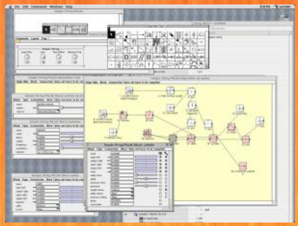
# Yamaha VL Line (1994)

- Yamaha Licensed "Digital Waveguide Synthesis" for use in its products including the VL line (VL-1, VL-1m, VL-70m, EX-5, EX-7, chip sets, sound cards, soft-synth drivers)
- Shakuhachi: (MP3)
- Oboe and Bassoon: (MP3)
- Tenor Saxophone: (MP3)

# Korg SynthKit Line (1994)

- SynthKit (1994)
- Prophecy (1995)
- Trinity (1995)
- OASYS PCI (1999)
- OASYS  (2005)
- Kronos (2011)



# “The Next Big Thing” (1994)


The Next Big Thing 2/94

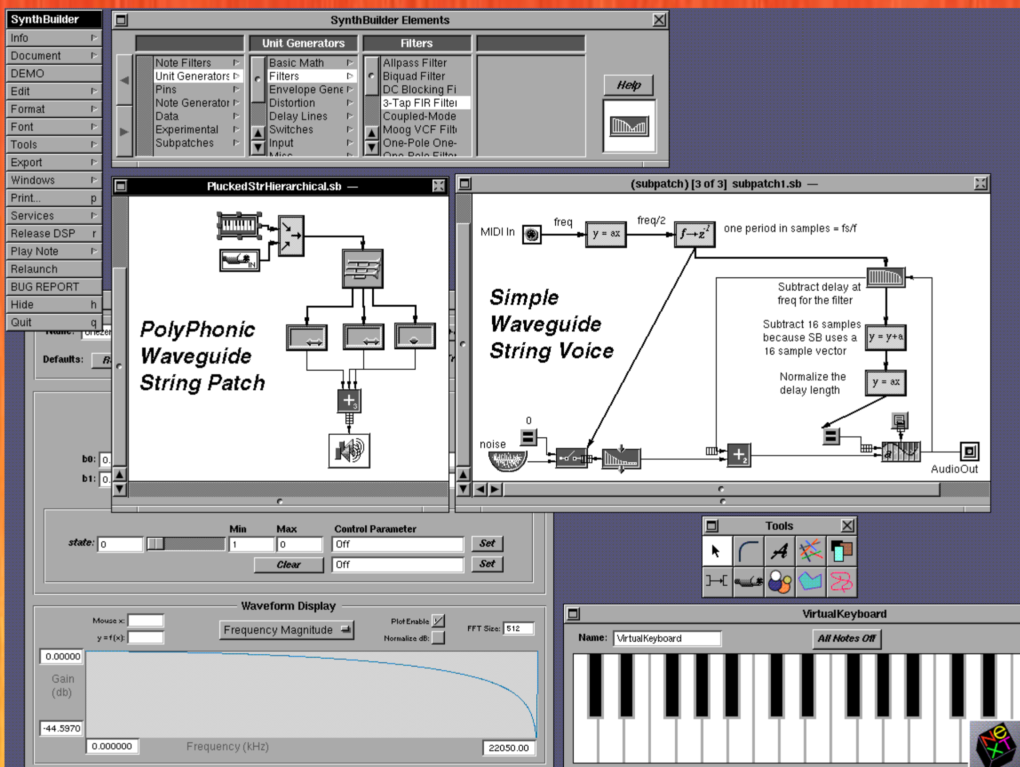

The History of PM 9/94

# Stanford Sondius Project (1994-1997)

SONDIUS

- Stanford OTL/CCRMA created the Sondius project to assist with commercializing physical modeling technologies.
- The result was a modeling tool known as SynthBuilder, and a set of models covering about two thirds of the General MIDI set.
- Many modeling techniques were used including EKS, Waveguide, Commuted Synthesis, Coupled Mode Synthesis, Virtual Analog.

# SynthBuilder (Porcaro, et al) (1995)

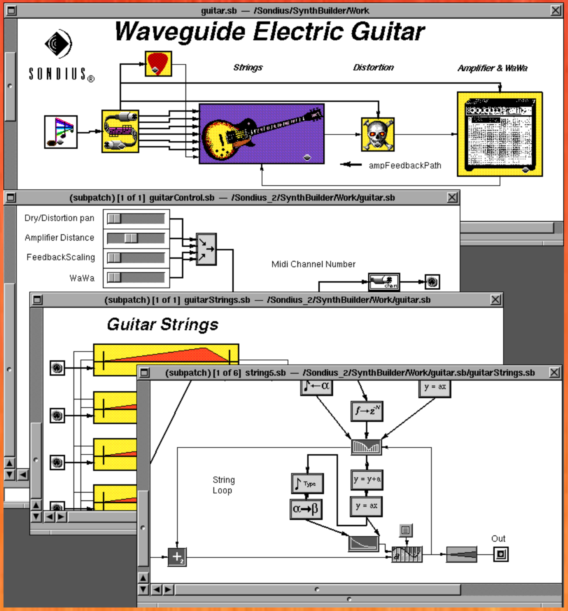


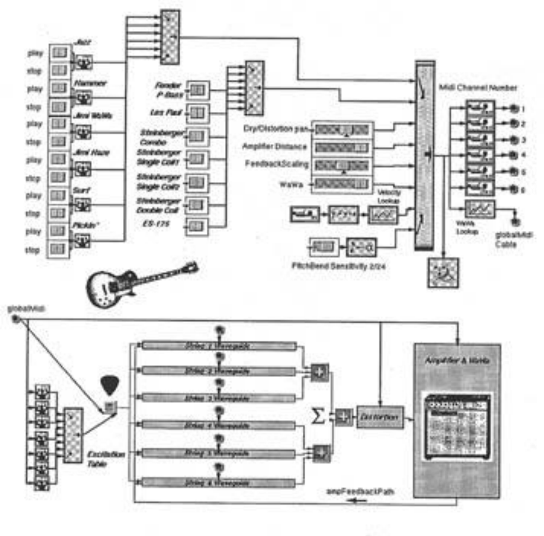

- SynthBuilder was a user-extensible, object-oriented, NEXTSTEP Music Kit application for interactive real-time design and performance of synthesizer patches, especially physical models.
- Patches were represented by networks consisting of digital signal processing elements called unit generators and MIDI event elements called note filters and note generators.

# The Frankenstein Box (1996)

- The Frankenstein box was an 8 DSP 56k compute farm build by Bill Putnam and Tim Stilson
- There was also a single card version know as the “Cocktail Frank”
- Used for running models developed with SynthBuilder
- The distortion guitar ran on 6 DSPs with an additional 2 DSPs used for outboard effects.


# The Sondius Electric Guitar (1996)



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.

- Pick model for different guitars/pickups (commuted synthesis, Scandalis)
- Feedback and distortion with amp distance (Sullivan)
- Wah-wah based on cry baby measurements (Putnam, Stilson)
- Reverb and flanger (Dattorro)
- Hybrid allpass delay line for pitchBend (Van Duyne, Jaffe, Scandalis)
- Performed using a 6-channel MIDI guitar controller.
- With no effects, 6 strings ran at 22k on a 72 Mhz Motorola 56002 DSP.
- Waveguide Guitar Distortion, Amplifier Feedback (MP3)

# Sondius Sound Examples (1996)

- Waveguide Flute Model (MP3)
- Waveguide Guitar Model, Different Pickups (MP3)
- Waveguide Guitar Distortion, Amplifier Feedback (MP3)
- Waveguide Guitar Model, Wah-wah (MP3)
- Waveguide Guitar Model, Jazz Guitar (ES-175) (MP3)
- Harpsichord Model (MP3)
- Tibetan Bell Model (MP3)
- Wind Chime Model (MP3)
- Tubular Bells Model (MP3)
- Percussion Ensemble (MP3)
- Bass (MP3)
- Upright Bass (MP3)
- Cello (MP3)
- Piano (MP3)
- Harpsichord (MP3)
- Virtual Analog (MP3)

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

- Modeling of percussion sounds
- Modal technique with coupling
- Tibetan Bell Model (MP3)
- Wind Chime Model (MP3)
- Tubular Bells Model (MP3)
- Percussion Ensemble (MP3)

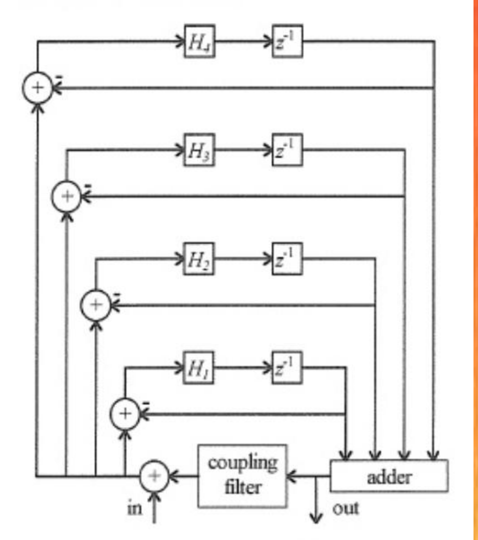



Figure 2: The Coupled Mode Filter Structure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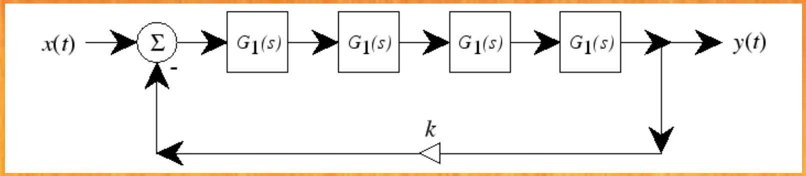
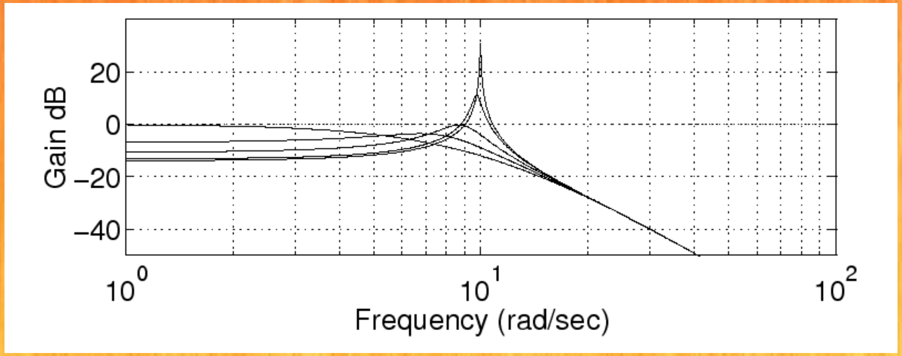
# Virtual Analog (Stilson-Smith) (1996)

- 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! (MP3) (youTube)

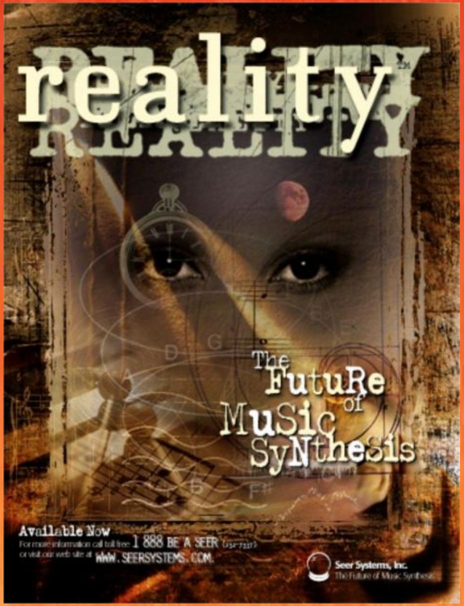


# Synthesis Tool Kit (STK) (1997)

- Synthesis Tool Kit (STK) by Perry Cook, Gary Scavone, et al.  distributed by CCRMA
- The **Synthesis Toolkit** (**STK**) is an open source API for real time audio synthesis with an emphasis on classes to facilitate the development of physical modeling synthesizers.
- Pluck example (MP3)
- STK Clarinet (MP3)

# Seer Systems "Reality" (1997)

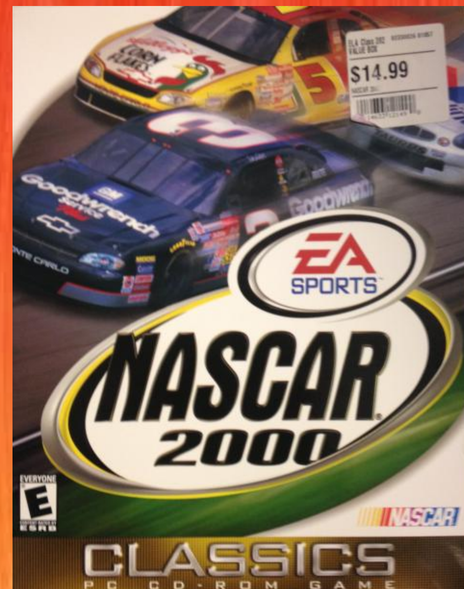



- Stanley Jungleib, Dave Smith (MIDI, Sequential Circuits)
- Ring-0 SW MIDI synth. Native Signal Processing.
- Offered a number of Sondius Models.

# Staccato SynthCore (1999)

- Staccato Systems spun out of Sondius in 1997 to commercialize Physical Modeling technologies.
- SynthCore was a ring-0 synthesis driver that supported both DLS (Down Loadable Sounds) and Staccato's proprietary Down Loadable Algorithms (DLAs). It was distributed in two forms.
- Packaged as a ring-0 "MIDI driver", SynthCore could replace the wavetable chip on a sound card, as a software based XG-lite/DLS audio solution (SynthCore-OEM) (SigmaTel, ADI)
- Packaged as a DLL/COM service, SynthCore could be integrated into game titles so that games could make use of interactive audio algorithms (race car, car crashes, light sabers) (SynthCore-SDK) (Electronic Arts, Lucas Arts…)

# SynthCore Game Models (2000)



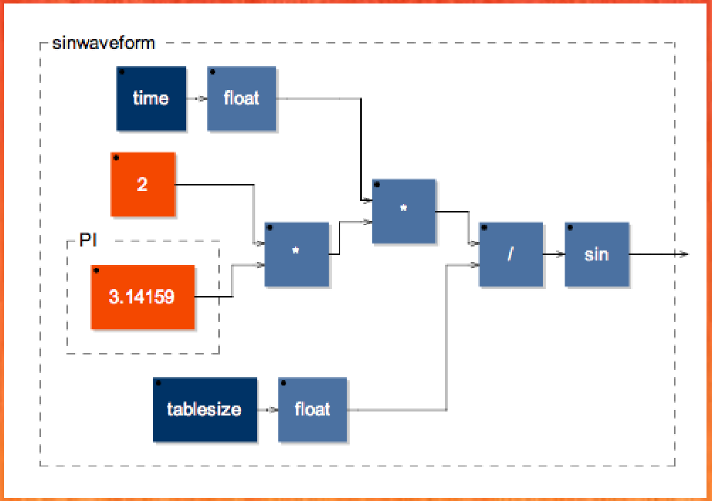

- Jet (Stilson) (MP3)
- Race Car (Cascone, et al) (MP3)

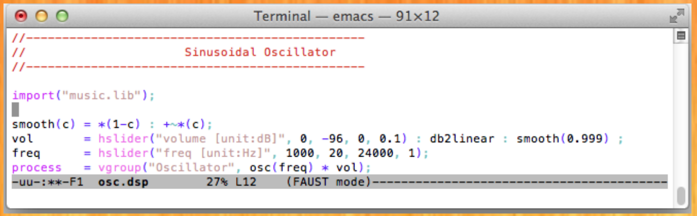
# SynthCore Wavetable Chip Replacement

- About half of the General MIDI set was implemented with physical models though few existing MIDI scores could make use of the expression parameters.
- Staccato was purchased by Analog Devices in 2000. ADI combined Staccato's ring-0 software based XG-lite/DLS MIDI synth with a low cost AC97 codec and transformed the PC audio market from sound cards to built-in audio.

# Faust-STK (2011)

- FAUST [Functional Audio Stream] is a synchronous functional programming language specifically designed for real-time signal processing and synthesis.
- The FAUST compiler translates dsp specifications into equivalent C++ programs, taking care of generating efficient code.
- The FAUST-STK is a set of virtual musical instruments written in the FAUST programming language and based on waveguide algorithms and on modal synthesis. Most of them were inspired by instruments implemented in the Synthesis ToolKit (STK) and the program SynthBuilder.



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# Smule Magic Fiddle (2010)

**Smule | Magic Fiddle for iPad [St. Lawrence String Quartet] (youTube)**

# moForte Guitar (2013)


[Demo (youTube)]




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# MoForte Guitar Features

- Modeled distortion and feedback
- Strumming and PowerChord modes
- Selection of Guitars
- Modeled guitar articulations including: harmonics, pinch harmonics, slides, apagado, glissando, string scraping, damping and auto-strum.
- 5000+ chords and custom chords
- Fully programmable effects chain including: distortion,
- compression, wah, auto wah, 4-band parametric EQ,
- phaser, flanger, reverb, amplifier with presets.
- Authoring tools for song chart creation.
- Share creations with friends on popular social networks.
- In-app purchases available for charts, instruments, effects and feature upgrades

# Compute for string models over the years

- NeXT Machine (1992)
  - Motorola DSP56001 20MHz 128k dram, 22k sample rate
    - 6 plucks
    - or 2-4 Guitar Strings
- Frankenstein, Cocktail Frank (1996)
  - Motorola DSP56301 72MHz 128k dram, 22k sample rate
    - 6 guitar strings, feedback and distortion,
    - Reverb, wah-wah, flange running on a additional DSPs
- Staccato (1999)
  - 500MHz Pentium, native signal processing, 22k sample rate
  - 6 strings, feedback and distortion used around 80% cpu
- iPhone 4S (2013)
  - 800 MHz A5, 44k sample rate
  - 6 strings, feedback and distortion use around 37% cpu
- iPad 2 (2013)
  - 800 MHz A5, 44k sample rate
  - 6 strings, feedback and distortion use around 37% cpu

# Properties of Handheld Mobile Devices

- Ubiquitous
- Small
- Powerful
- Multi-touch screens
- Sensors: acceleration, compass, gyroscope, camera, gestures
- Connected to networks
- Socially connected
- Integrated payment systems

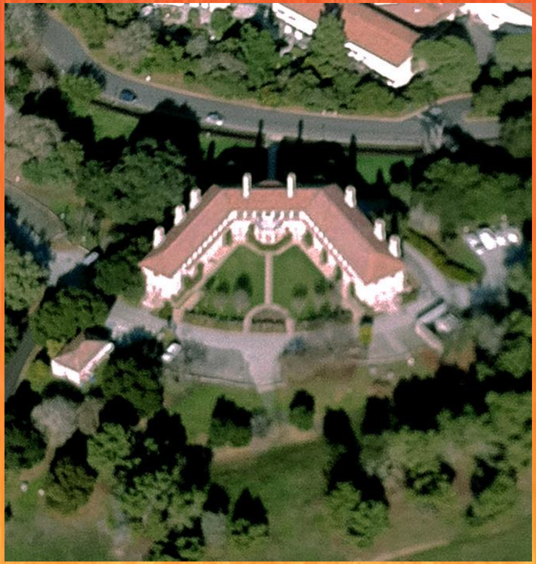
# So, What is the Future for Physically Modeled Musical Instruments on Handheld Mobile Devices?


All this cool stuff

Goes here…Whole lotta fun apps, makin' sharing music!

# Thanks!

- Mary Albertson
- Chris Chafe
- John Chowning
- Perry Cook
- Jon Dattorro
- David Jaffe
- Joe Koepnick
- Fernando Lopez-Lezcano
- OTL
- Nick Porcaro
- Bill Putnam
- Julius Smith
- Tim Stilson
- Scott Van Duyne
- Yamaha



and CCRMA