# Physical Modeling of Musical Instruments on Handheld Mobile Devices.

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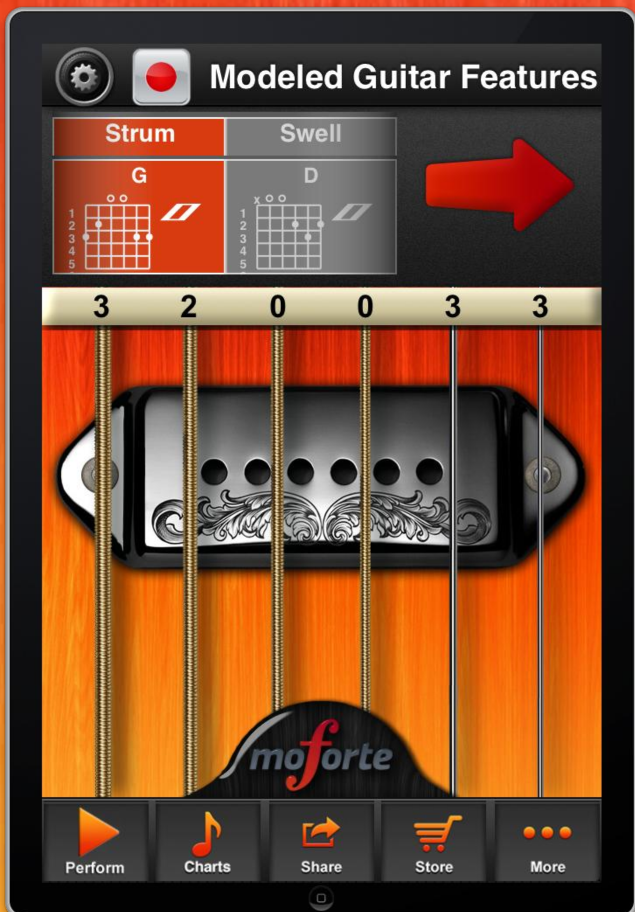
Computational Methods in Musical Acoustics II
Session 5pMU5
2:15, Friday December 6, 2013

# Overview

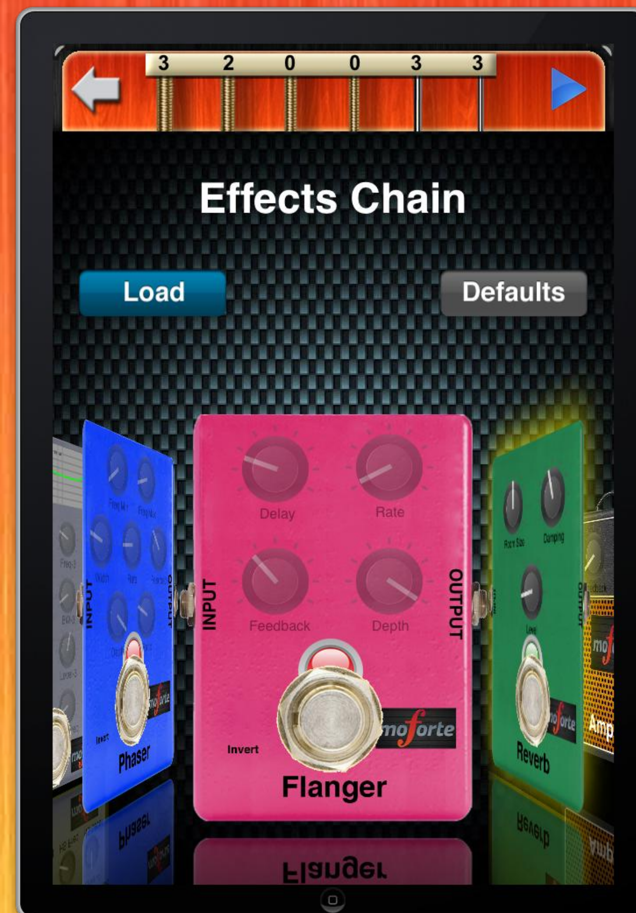
- We will provide a brief history of physically modeled musical instruments as well as some commercial products that have used this technology.
- We will demonstrate what is currently possible on handheld mobile devices using the moForte Guitar.

# First a Quick Demo!




[Demo (youTube)]

**DEMO: Modeled Guitar Features, Purple Haze**



# Why Musical Physical Models on handheld mobile 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.

# 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

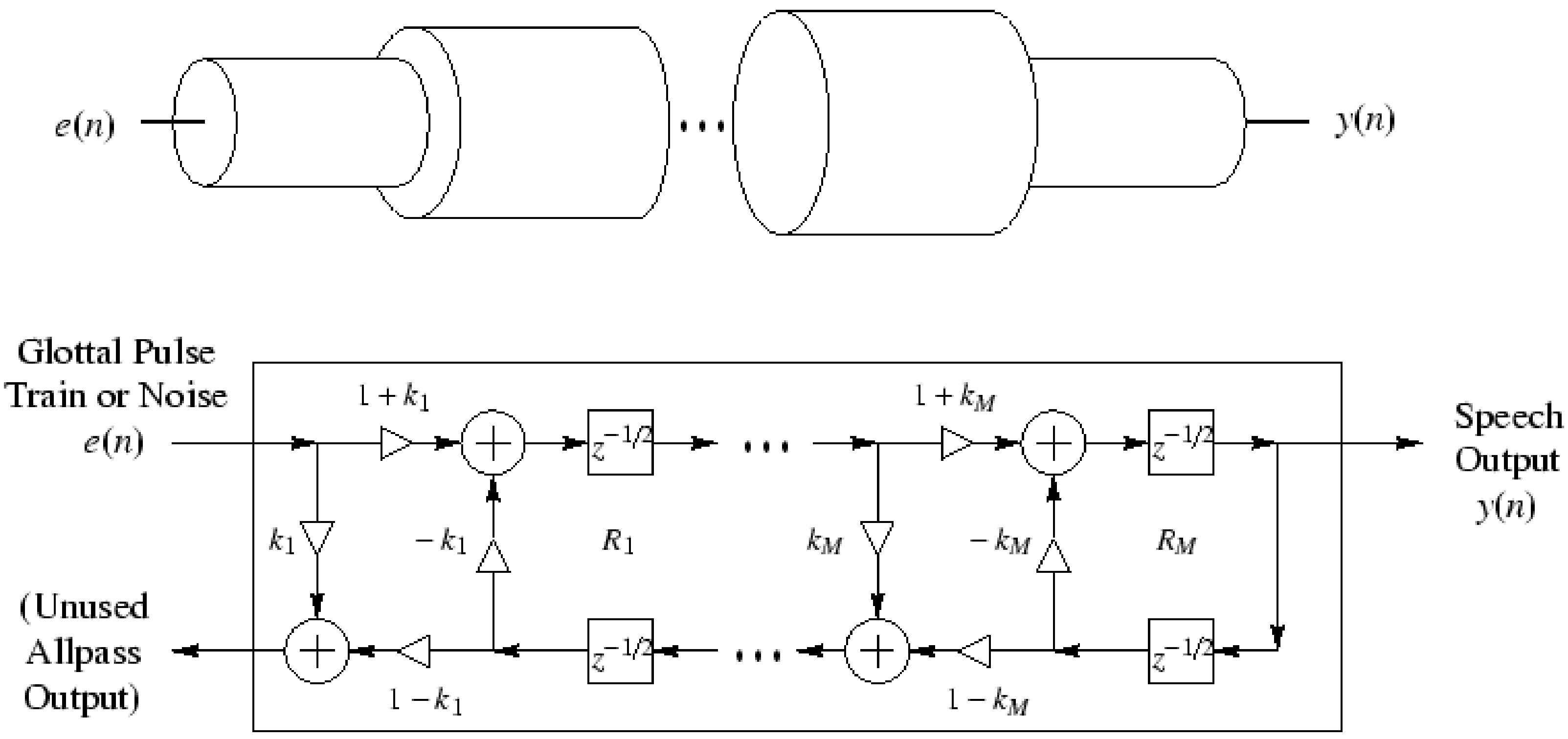
# Brief (though not complete) History of Physical Modeling Synthesis

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)

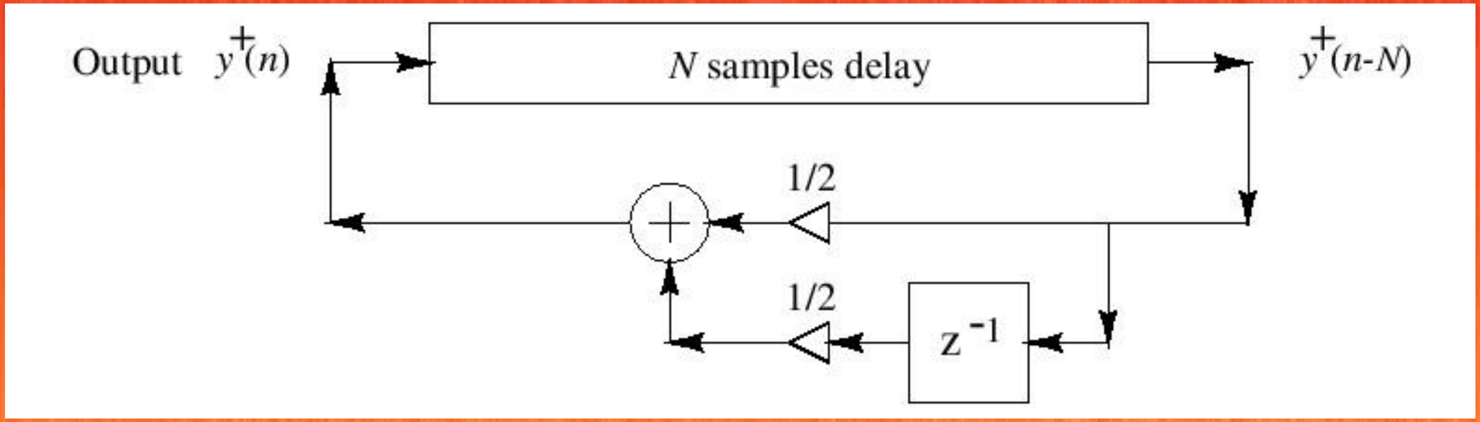



Kelly-Lochbaum Vocal Tract Model (Piecewise Cylindrical)

# Daisy Bell (1961)

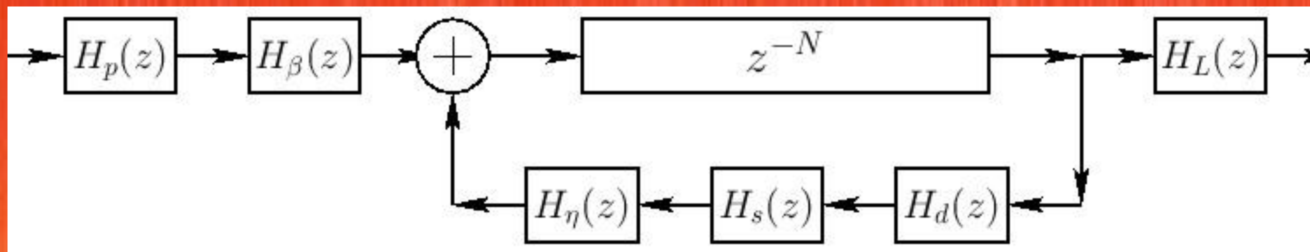
- Daisy Bell (MP3)
- Vocal part by Kelly and Lochbaum (1961)
- Musical accompaniment by Max Mathews
- Computed on an IBM 704
- Based on Russian speech-vowel data from Gunnar Fant's book
- Probably the first digital physical-modeling synthesis sound example by any method
- Inspired Arthur C. Clarke to 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)]

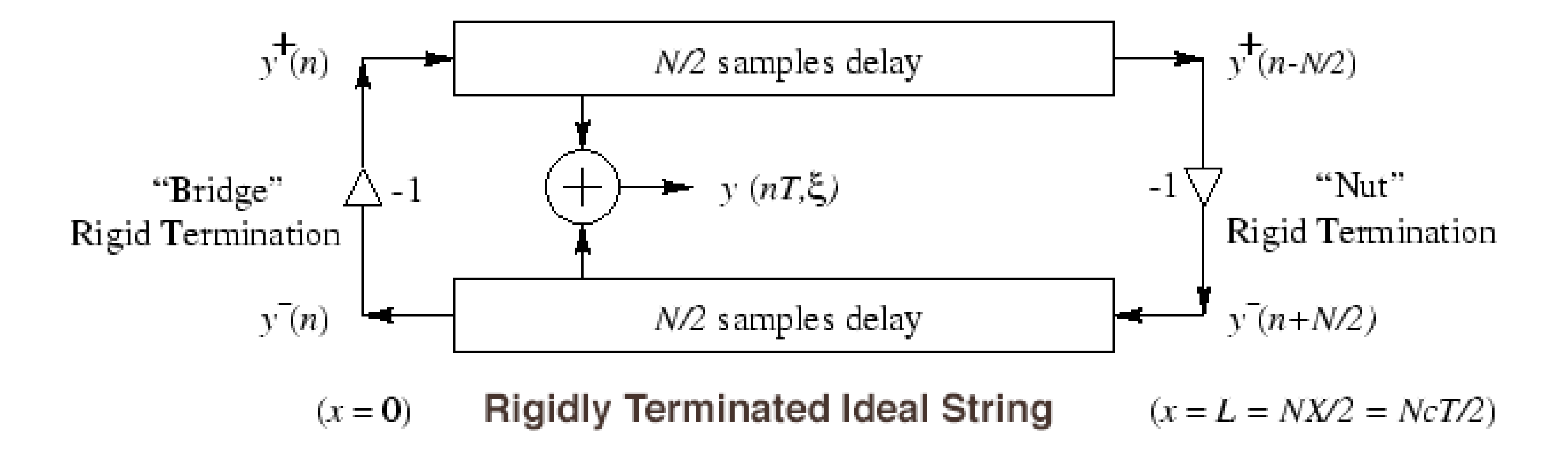
# EKS Algorithm (Jaffe-Smith 1983)




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

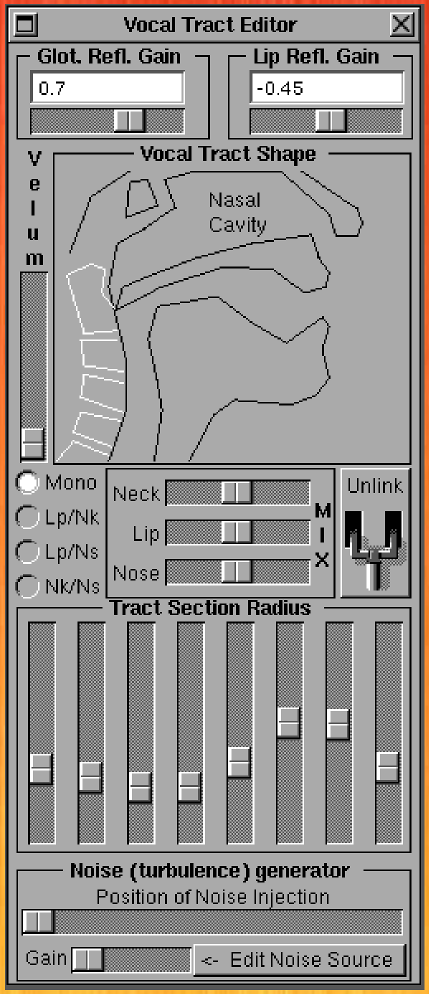
- Musical Example “Silicon Valley Breakdown” (Jaffe 1992) (MP3)
- Musical Example BWV-1041 (used to intro the NeXT machine 1988) (MP3)

# Digital Waveguide Models (Smith 1985)




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

# Sheila Vocal Track Modeling (Cook 1990)



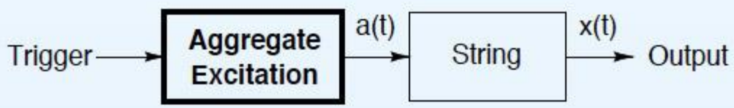

Perry Cook's SPASM **"Singing Physical Articulatory Synthesis Model"**

- 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

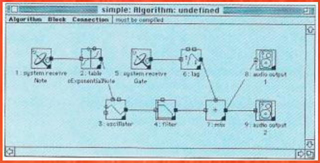
- Electric guitar, different pickups and bodies (Sondius) (MP3)
- Mandolin (STK) (MP3)
- Classical Guitar (Mikael Laurson, Cumhur Erkut, and Vesa Välimäki) (MP3)
- Bass (Sondius) (MP3)
- Upright Bass (Sondius) (MP3)
- Cello (Sondius) (MP3)
- Piano (Sondius) (MP3)
- Harpsichord (Sondius) (MP3)

# 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)

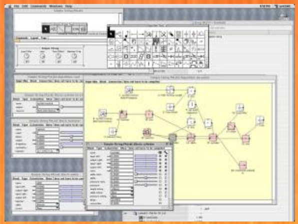
- SynthKit (1994)



- Prophecy (1995)

- Trinity (1995)

- OASYS PCI (1999)



- OASYS  (2005)

- Kronos (2011)

# “The Next Big Thing” (1994)

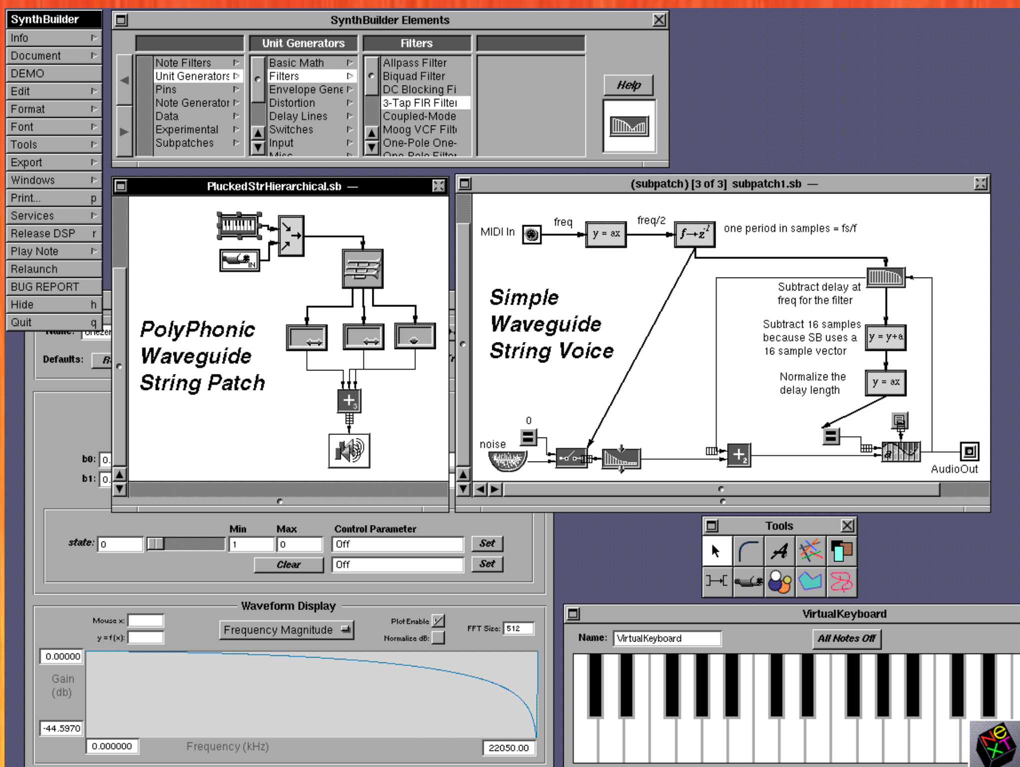

The Next Big Thing 2/94


The History of PM 9/94

# Stanford Sondius Project (1994-1997)

- 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)

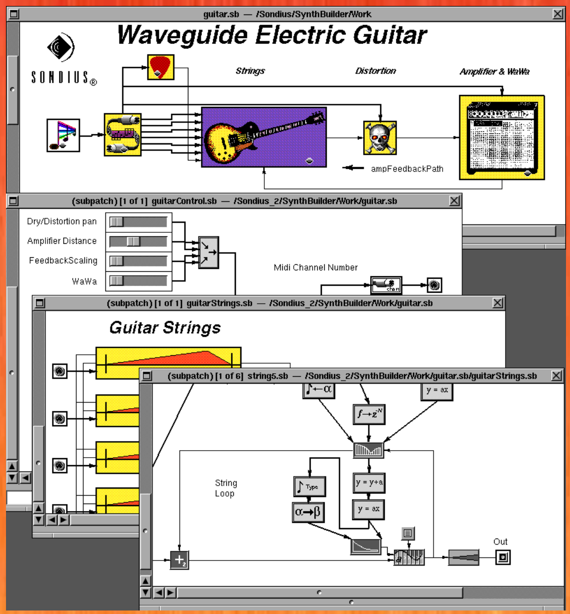


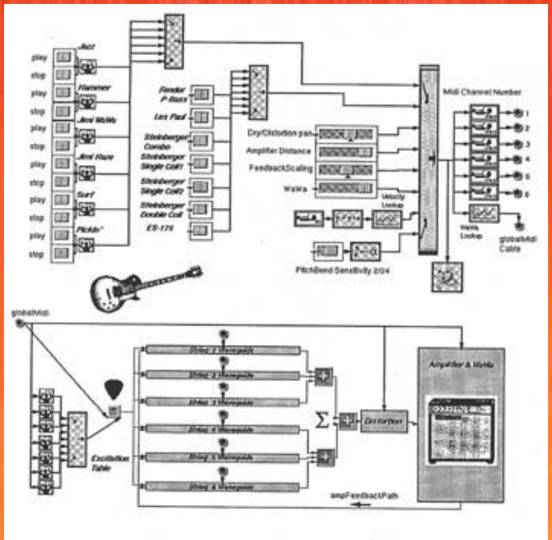

- SynthBuilder was a user-extensible, object-oriented, NEXTSTEP Music Kit application for interactive real-time design and performance of synthesizer patches, especially physical models.
- Patches were represented by networks consisting of digital signal processing elements called unit generators and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

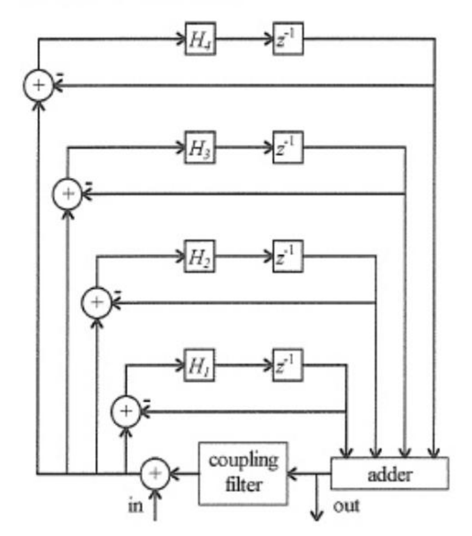
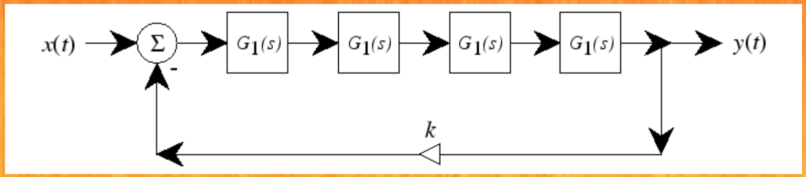
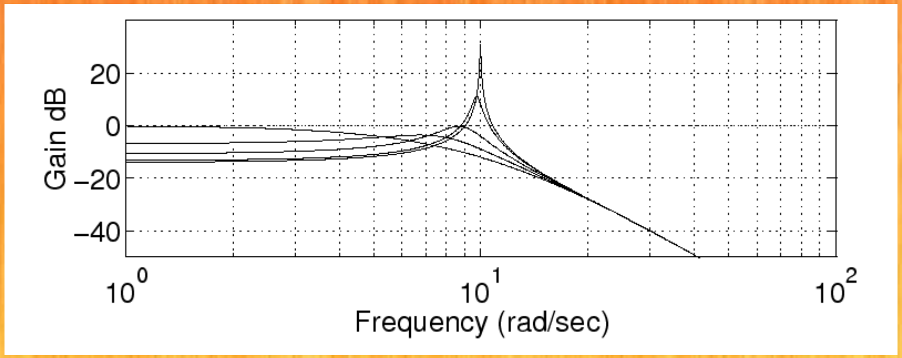


Figure 2: The Coupled Mode Filter Structure

# 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)

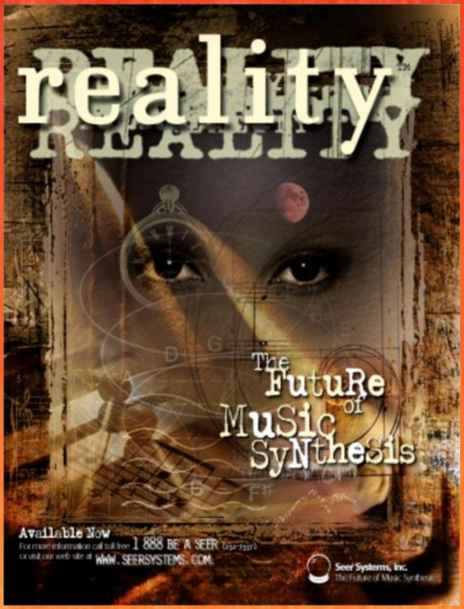


# Synthesis Tool Kit (STK) (1997)

- 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)

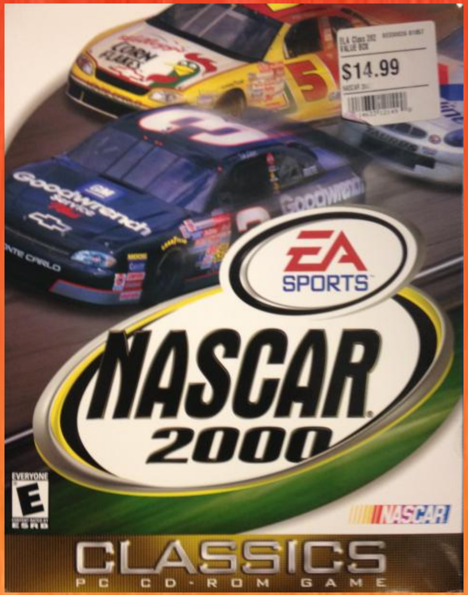



- Stanley Jungleib, Dave Smith (MIDI, Sequential Circuits)
- Ring-0 SW MIDI synth. Native Signal Processing.
- Offered a number of Sondius Models.

# 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)



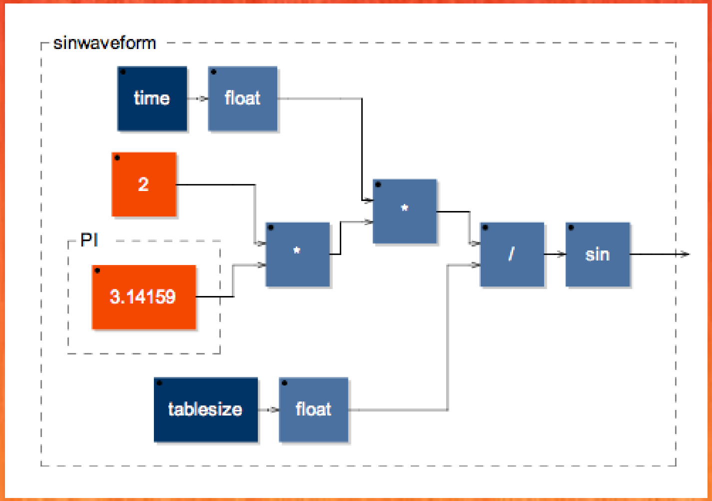

- Jet (Stilson) (MP3)
- Race Car (Cascone, et al) (MP3)

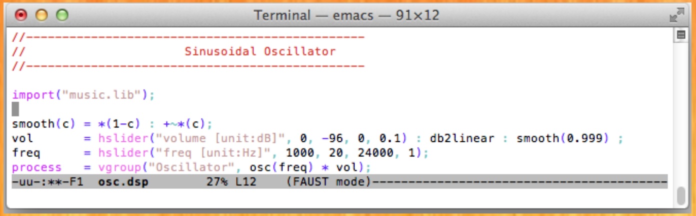
# SynthCore Wavetable Chip Replacement

- 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.



# Smule Magic Fiddle (2010)

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

# Compute for string models over the years

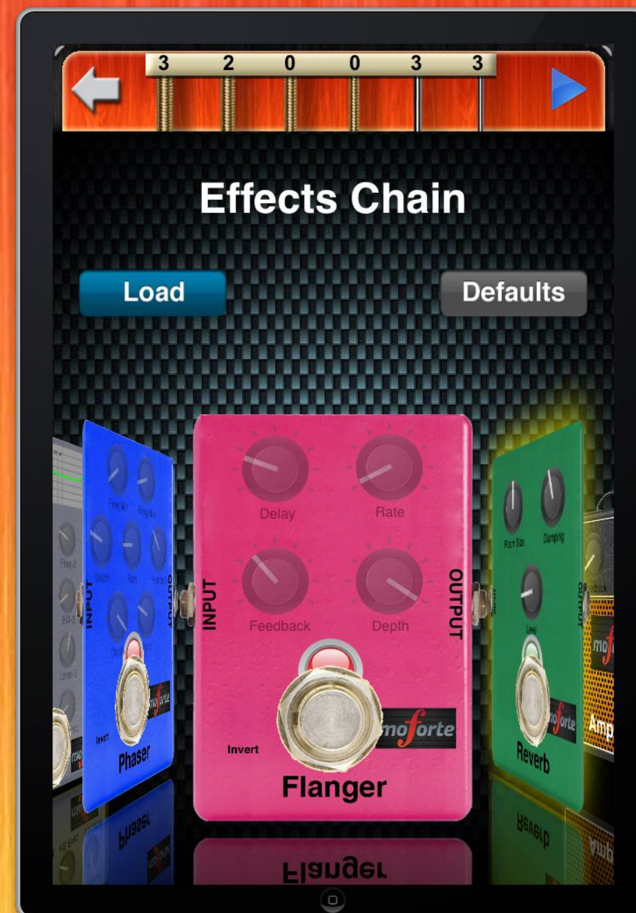
- NeXT Machine (1992)
  - Motorola DSP56001 20MHz 128k dram, 22k sample rate
    - 6 plucks
    - or 2-4 Guitar Strings
- Frankenstein, Cocktail Frank (1996)
  - Motorola DSP56301 72MHz 128k dram, 22k sample rate
    - 6 guitar strings, feedback and distortion,
    - Reverb, wah-wah, flange running on 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

# moForte Guitar 2013

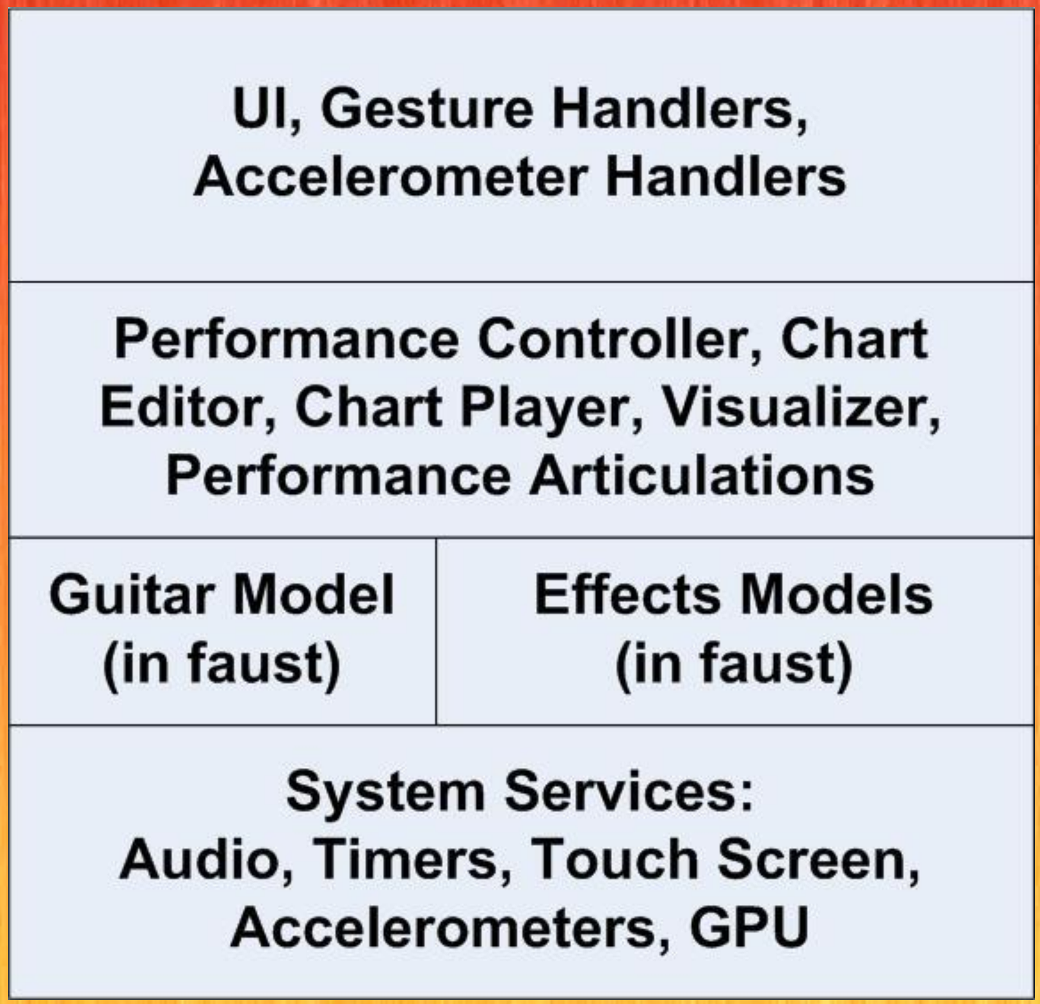

[Demo (youTube)]



# 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.
- 10,000+ 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 tool for song chart creation.
- Share creations with friends on popular social networks.
- In-app purchases available for charts, instruments, effects and feature upgrades

# The moForte Guitar Stack



# The DSP Guitar Model

- Numerous extensions on EKS and Waveguide
- Can be calibrated to sound like various guitars. Realized in Faust
- Charts can access and control ~50 controllers.
- A selection of controllers:
  - Instrument (select a calibrated instrument)
  - velocity
  - pitchBend, pitchBendT60 (bending and bend smoothing rate)
  - t60 (overall decay time)
  - brightness (overall spectral shape)
  - velocity
  - harmonic (configure the model to generate harmonics)
  - pinchHarmonic (pinch harmonics)
  - pickPosition  (play position on the string)
  - Apagado (palm muting)

**DEMO: Different Guitars, Rock and Roll - Strum**

# The Effects Chain

- Chart Player, Guitar, Distortion, Compressor, Wah, Auto Wah, 4 band Parametric EQ, Phaser, Flanger, Reverb, Amplifier.
- Realized in Faust.

**DEMO: Strumming Chart**

# The Performance Model

- Strumming and PowerChording Gestures.
- Slides
- Strum Separation Time
- Variances
- Strum Kernels
- Chart Player

# Disrupting the Uncanny Valley

- We want the playing experience to be fun.
- Aiming toward "Suspension of Disbelief".
- Use modeling to get close to the real physical sound generation experience.
- Sometimes "go over the top". Its expressive and fun!
- Use statistical variances to disrupt repetitive performance.

# Controls With Statistical Variance

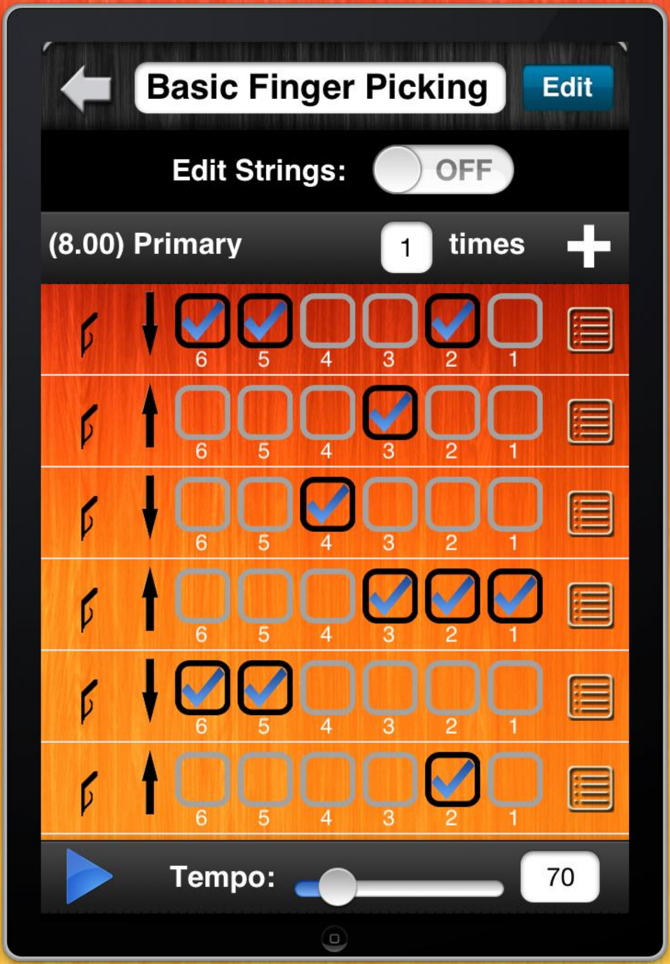
- velocity
- pickPosition
- brightness
- t60
- keyNum
- strumSeparationTime
- strumVariation (in auto strum mode)

**DEMO: Strum Variations**

# Strum Kernels

**DEMOS: Finger Picking, Stairway to Heaven, Rasguedo**

- Small strumming sequences that model how guitar players strum.
- **Separates the harmonic context and the musical presentation.** Thus the same chord sequence can be performed with different strum kernels.
- A strum is an rhythmic event that is part of a strum kernel. Each strum can model, direction, strings, velocity, pickPosition, t60, brightness, strum separation time.
- Many types of expressive performance possible, strumming, strum clamps, finger picking, comping.

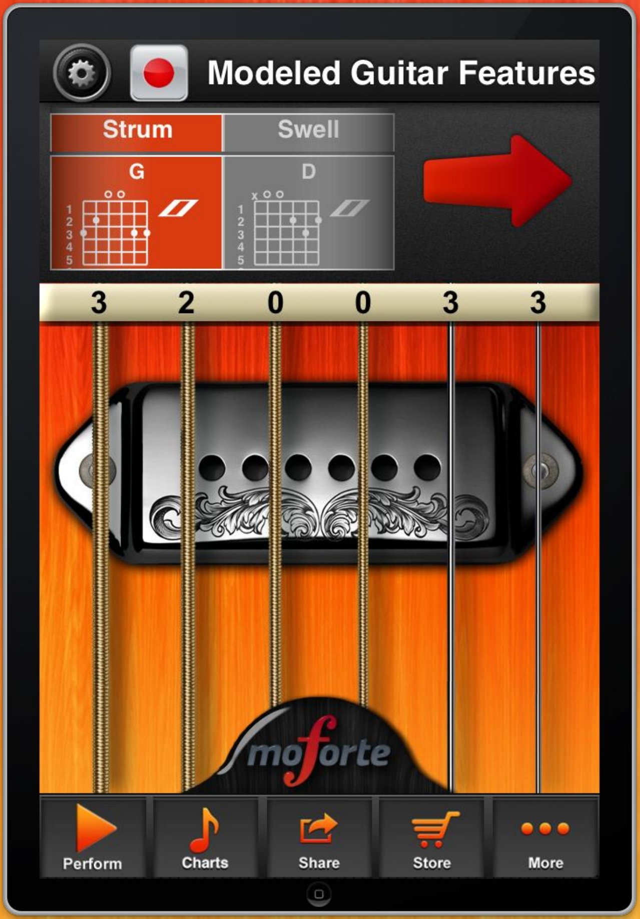


# What's Next: Modeling More Articulations

| Currently implement Articulations |
|---|
| Apagado |
| Arpeggio strum |
| Bend |
| Bend by distressing the neck |
| Burn or destroy guitar |
| Feedback harmonics |
| Finger picking |
| Glissando |
| Hard dive with the whammy bar |
| Harmonic |
| Muted strum |
| Pinch harmonic |
| Play harmonics with tip of finger and thumb |
| Polyphonic bend |
| Polyphonic slide, Polyphonic slide + open strings |
| Scrape |
| Slide |
| Staccato |
| Steinberger trans- trem |
| Strum |
| Surf apagado |
| Surf quick slide up the neck |
| Tap time |
| Vibrato |
| Walk bass |
| Whammy bend |
| Whammy spring restore |

| Future Articulations |
|---|
| Bottleneck (portamento Slide) |
| Bowing |
| Bridge/neck short strings |
| ebowing |
| Finger Style (Eddie Van Halen) |
| Hammer, polyphonic hammer |
| Individual String Pitch Bend |
| Legato |
| Pluck, sharp or soft pick |
| Pop |
| Prepared string (masking tape) |
| Pull, polyphonic pull |
| Rasqueado |
| Reverb spring Bang. |
| Scrape+ (ala Black Dog) |
| Slap |
| Strum and body tap |
| Strum and string tap |
| Touching Ungrounded Cable |
| Trill |
| Trill up the neck into echo |
| Vibrato onset delay |
| Volume pedal swell |
| Volume pedal swell into delay device |

# moForte Guitar 2013




- R1.1 Currently undergoing Apple App approval process.
- Expected to be in the App store this month.

**DEMO:**
**Blue Swirl**

# Thanks!

- Mary Albertson
- Chris Chafe
- John Chowning
- Perry Cook
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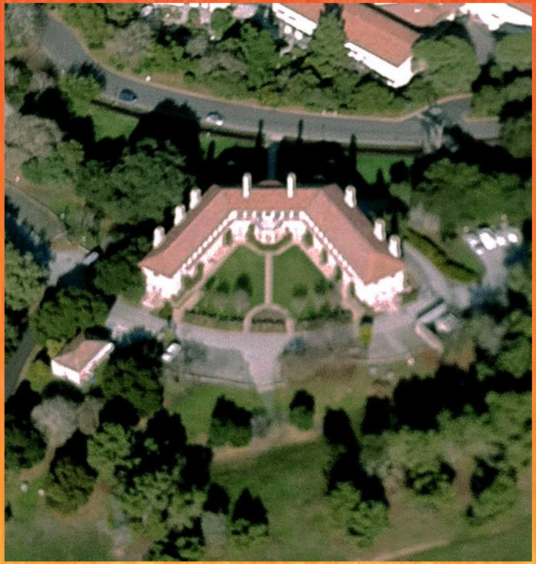
- Fernando Lopez-Lezcano
- OTL
- Nick Porcaro
- Bill Putnam
- Gregory Pat Scandalis
- Julius Smith
- Tim Stilson
- Scott Van Duyne
- Yamaha



and CCRMA