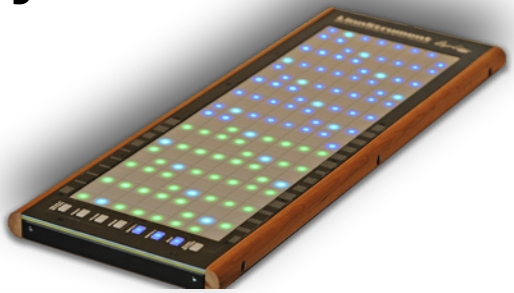
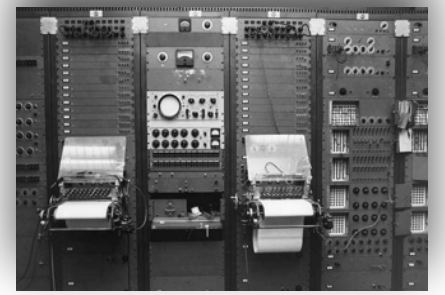
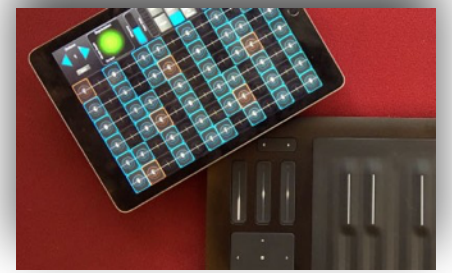
# A Brief History of Musical Synthesis

Pat Scandalis





**CCRMA Open House 3/3/2017**

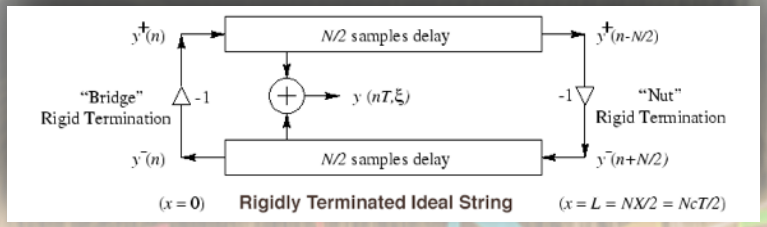
# The Seminar Presentation

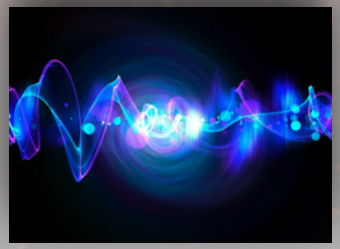
http://www.moforte.com/ccrma-open-house-presentation-2017/

Or look in the blog section of moforte.com

# Overview

- Synthesis in the Age of Radio. Tubes!
- Synthesis Techniques
- Modern Synth Instruments
- The Future



# What is your First Impression of a Synthesizer?

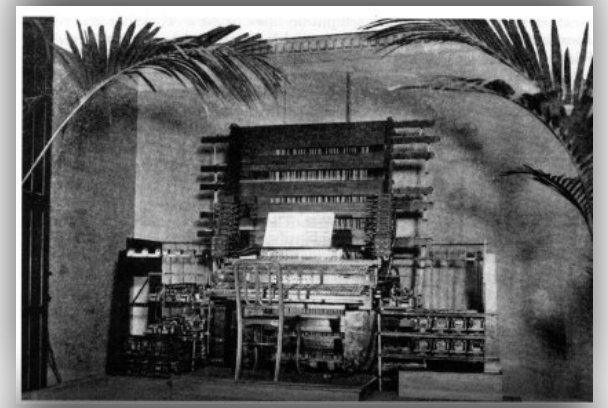
- People have always searched for new expressive ways to perform music and sound, ways to explore new timbres.
- I believe that many people who are interested in synthesized sound, experience music with Synesthesia
- My first impression was “Switched On Bach” - Wendy Carlos 1968

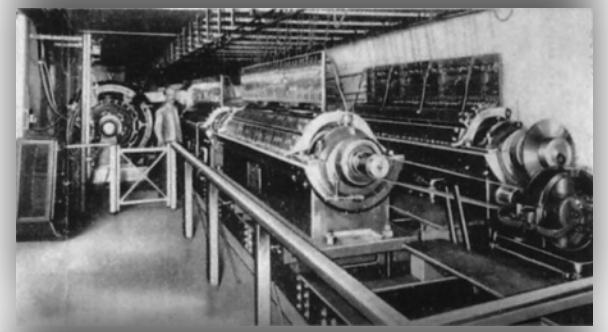
Jessica Seeley

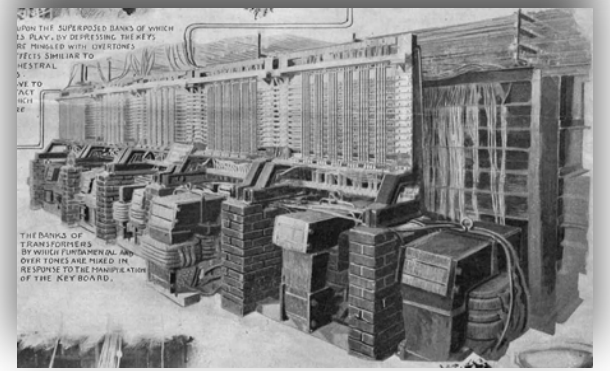
# Trick Question: What was the first subscription music service?


# The Telharmonium Mark II Thaddeus Cahill (1897 - 1912)

- Tone Wheel additive synthesis like a Hammond Organ
- … Except that it weighted 200 tons.
- Looks like a steam punk data center
- Telharmonium tones where sine waves. “Clear and pure”.
- Subscription model.  Broadcast to businesses and telephones.
- Funded like a modern venture ($200k = $5M), pitching, patents, road show …
- Cross talk with phone lines was a problem
- No recordings.  Last parts scrapped in 1962

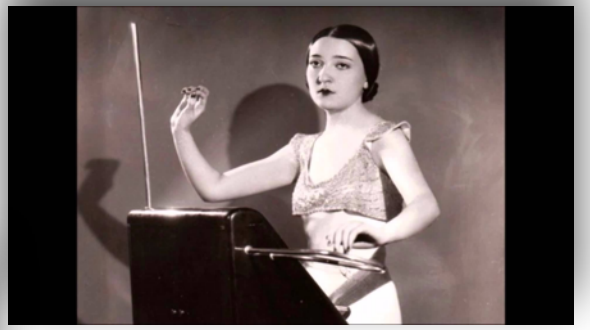






# Early Electronic/Electro Mechanical Instruments from the Age of Radio

- Telharmonium (1897)
- Player Pianos (1900)
- Theremin (1920)
- Ondes Martenot (1928)
- Trautonium (1929)
- Hammond Organ (1935)
- The Ondioline (1941)
- Novachord (1939)
- The Voder

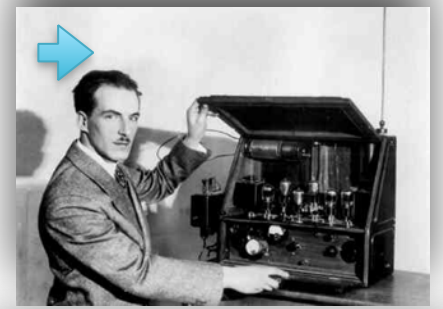


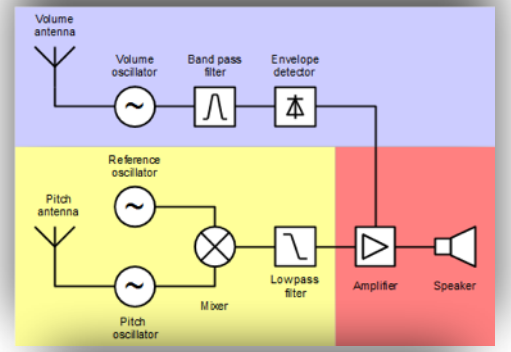
# Player Pianos (1900 - Present)

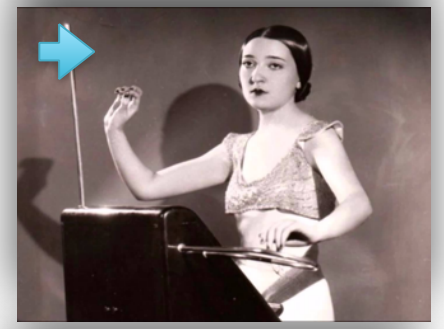
- Some designs as early as 1876
- Pianola and reproducing pianos.
- Peaked in 1924,
- Audio recordings are still made from reproducing rolls (Stravinsky, “Rite of Spring”)
- QRS Documentary “Punching a Hole … Playing a Roll”.
- Modern realizations include the Disklavier, QRS PNOmation ..

# Theremin (1920)

- As a young physicist Theremin did Soviet sponsored research on proximity sensors.
- Came to the US and patented the Theremin in 1928.  Licensed to RCA
- Audio is generated via heterodyning (@500k). The frequency antenna is used to set the f of a pitch oscillator that “beats” against a reference oscillator.
- Clara Rockmore became an acclaimed classical player.  Lydia Kavina as well.
- Robert Moog built Theremins in college.
- Used for [“The Day the Earth Stood Still”](#).
- The Theremin remains a popular and relevant instrument.

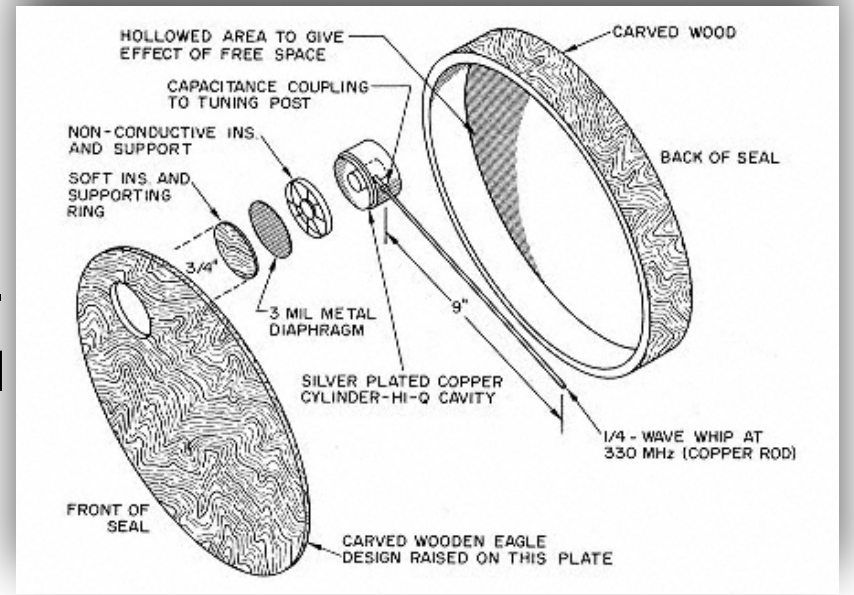




# Theremin KGB Footnote (1945-1952)

- Documentary “Theremin and Electronic Odyssey”
- Kidnapped by KGB and returned to the Soviet Union in 1938.
- Created “The Thing”, an ingenious passive listening bug in the US ambassador’s office for 7 years.
- Disguised as the Great Seal of the United States, gifted to the ambassador by the Young Pioneers.
- Theremin returned to the US in 1991 and visited Stanford/CCRMA.

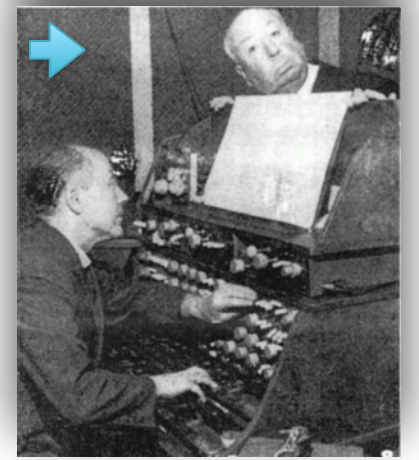


# Ondes Martenot (1928)

- Similar principle as the Theremin
- Traditional keyboard, sliding pitch ring (like the Roli Rise), and force sensitive dynamics bar (touche d'intensité).
- Switches select various waveforms, sine, triangle, square, pulse train, and pink noise!
- Different types of speakers are used as resonators.
- Used in classical repertoire and film scores.
- Was manufactured as late as 1988.

# Trautonium (1929)

- No keyboard.  Resistive wires that contact a conductive plate.  The user can be slide back and forth on the wire.  In some ways similar to the continuum.
- Relaxation Oscillators (tube) that produce triangle and square waves.
- Envelopes, noise, formant filters. Its a subtractive synth!
- Used in Hitchcock's "The Birds"
- Development continued until 2002



# Hammond Organ (1935)

- Mechanical tone wheel additive synthesis.
- Like the Telharmonium, except instead of 200 tons it only weights 400 lbs ;-)
- Based on synchronous clock motor
- Manuals, drawbars, presets, vibrato, chorus, harmonic percussion with legato, Leslie Speakers, bass pedals. Its a Beast!
- While playing, you could turn off the motor and it would sound like the end of the world!

# The Voder (1937-39) - Homer Dudley

- Analog Electronic Speech Synthesis
- Analog model of the vocal tract
- Develop from research on voice compression at Bell Labs.
- Featured at the 1939 Worlds fair
- YouTube

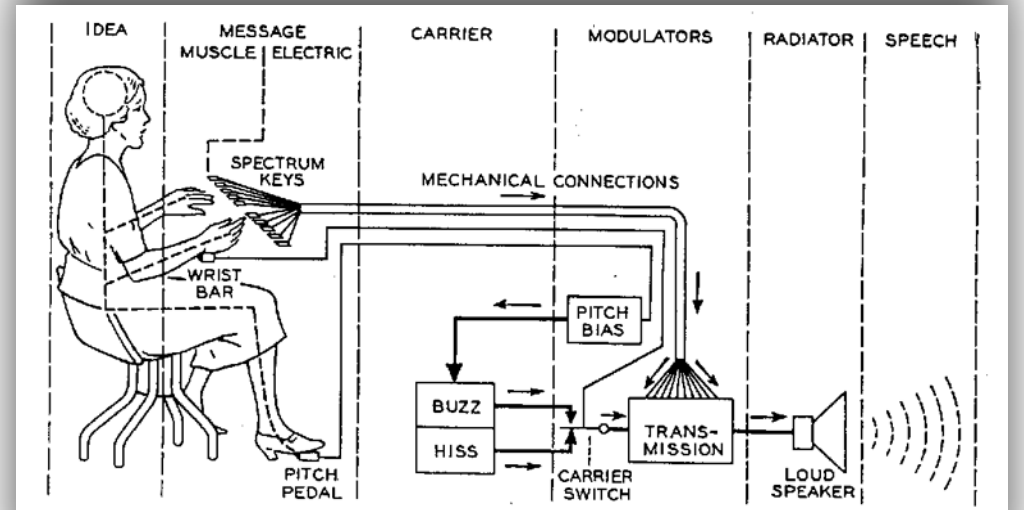
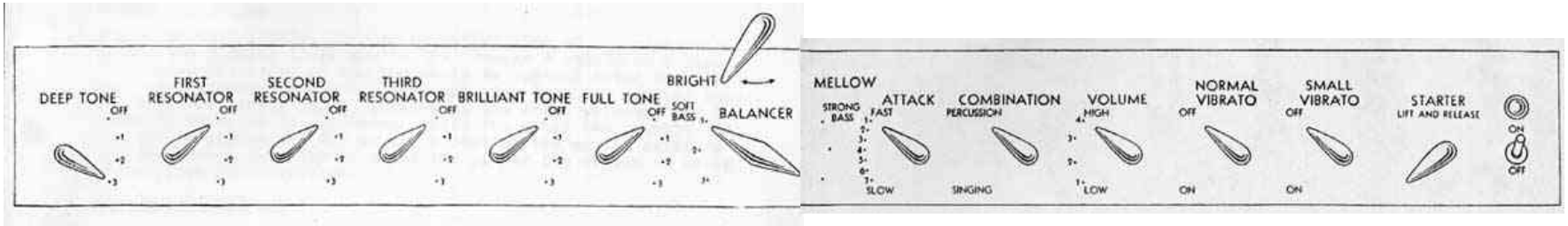


Fig. 8—Schematic circuit of the voder.

# Novachord (1939)

- First polyphonic subtractive synth!
- ADSR with 7 preset envelopes
- Resonant filters
- 163 tubes, 1000 caps
- The Polymoog uses a similar polyphonic design
- #1 went to FDR
- Only 1069 ever made only 200 extant.  Few still operate.

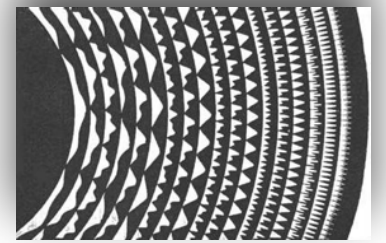


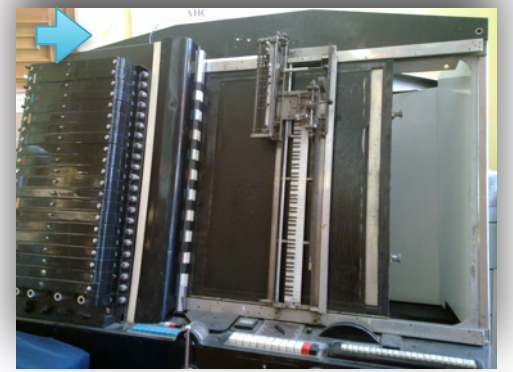
# The Ondioline (1941)

- Forerunner of today's synths.
- Still uses tubes, but not the Theremin circuit.  Its a multivibrator oscillator with rich harmonics + a complex filter bank.  Subtractive synthesis!
- The Keyboard was mounted on springs so that it could be wiggled for vibrato.
- Used extensively on Motown recordings in place of union string players.
- 900 build, only about 12 still exist.


# Optical Synthesis (1937-1957)

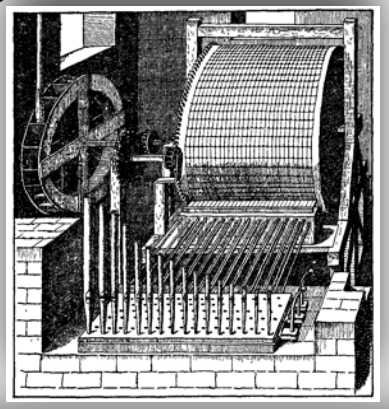
- Waveforms on optical media performed using photoelectric circuits.
- Phototone Organ - Edwin Welte (1937)
- ANS Synthesizer - Yevgeny Murzin (1937-1957). Named for Alexander Nikolayevich Scriabin. Used in the soundtrack for Solaris.
- Oramics - Daphne Oram BBC Radio Workshop (1957)

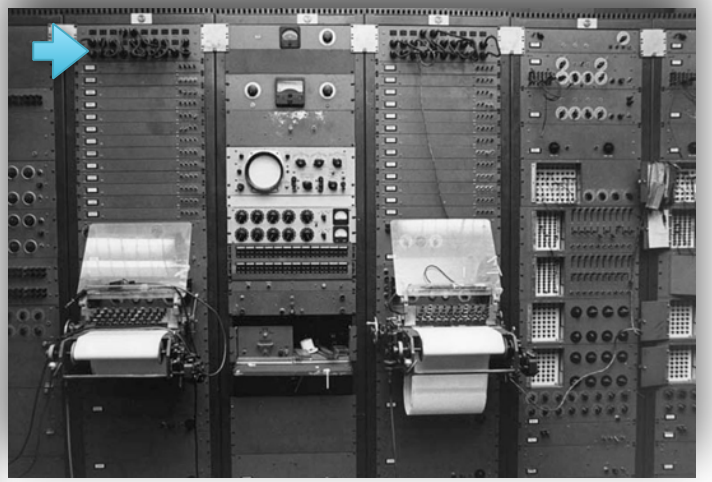


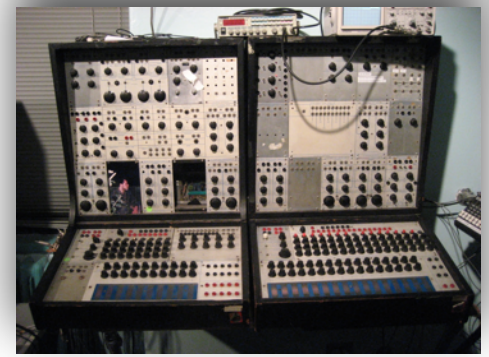


# Early Sequencing

- Pin Barrels (1400ss)
- Music Boxes (1800s)
- Player Pianos (1900s)
- The RCA Mark II (Victor) did sequencing with a piano roll like interface (1957). Mix down was engraved to a lacquer record.
- Buchla 100 (1964)







# Synthesis Techniques

- Additive
- Subtractive
- Sampling
- Physical Modeling
- KS
- WaveGuide
- Modal
- Analog Modeling
- Formant Synthesis
- FM and Phase Distortion
- Granular Synthesis
- WaveTable
- Spectral Morphing
- Linear Arithmetic
- Vector Synthesis
- Circuit Bending
- Vocoding

# Voltage Control (1940s)

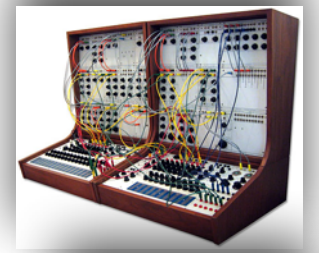
- Invented by Hugh Le Caine for the Electronic Sackbut.
- Supported control of volume, pitch and timbre with voltage control
- Buchla and Moog adopted. Standard for control through the 60s and 70s.

# Additive (1897)

- Adding Sine waves
- Telharmonium (1897)
- Hammond Organs (1937)
- Fairlight CMI (1976)
- Bell Labs Digital Synthesizer, Alice (1977)
- Synclavier II (1979)
- As evolved to additive analysis/resynthesis (SMS)

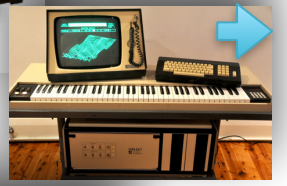
# Subtractive (1939)

- Harmonically rich waveforms + filters
  - Filters typically Low Pass, Band Pass, Notch Pass, High Pass
  - Envelopes to control filters
- Hammond Novachord (1939)
- Moog (Moog Documentary) (1964)
- Buchla 100 series (1960s)
- Arp Odyssey (1972)
- Korg MS-20 and others (1978)



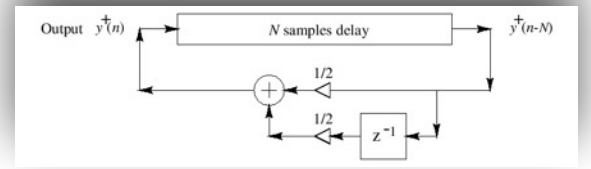
# Sampling (1949)

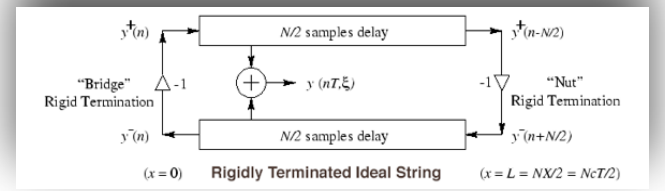
- Sampled Recordings
- Chamberlin (1949)
- Mellotron (Documentary) (1963)
- EMS Musys system (1969)
- Mattel Opticon (1970)
- Fairlight CMI (1979)
- Emulator (1981)

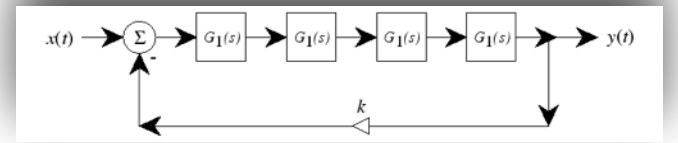


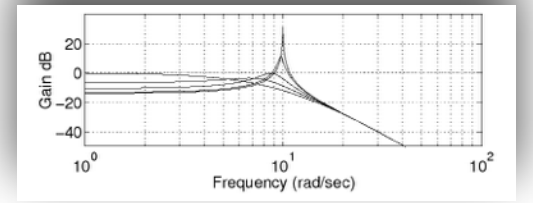
# Physical Modeling (1983)

- Karplus-Strong (KS)
- Extended Karplus-Strong (EKS)
- Digital Waveguide
- Commuted Synthesis
- Coupled Mode Synthesis (CMS)
- Virtual Analog (VA)

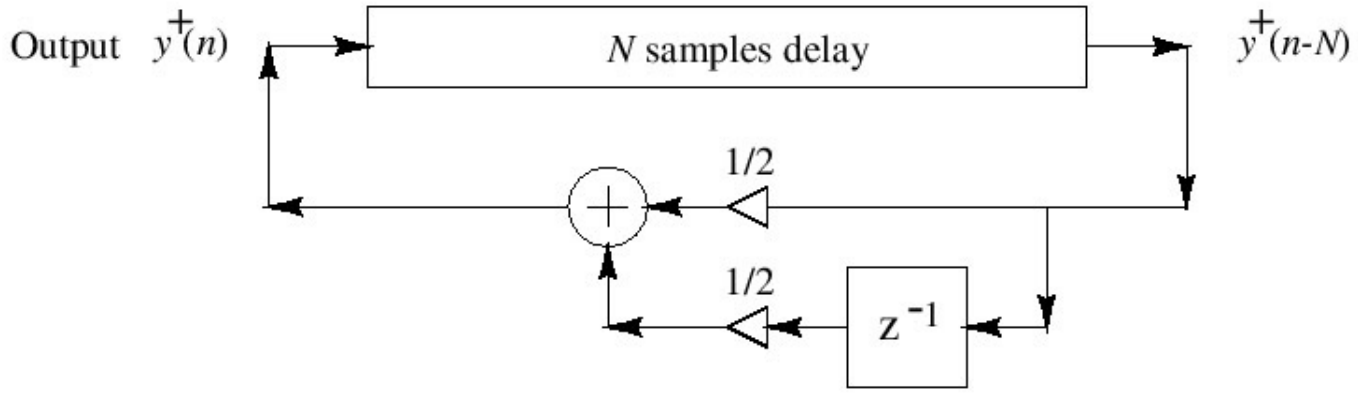


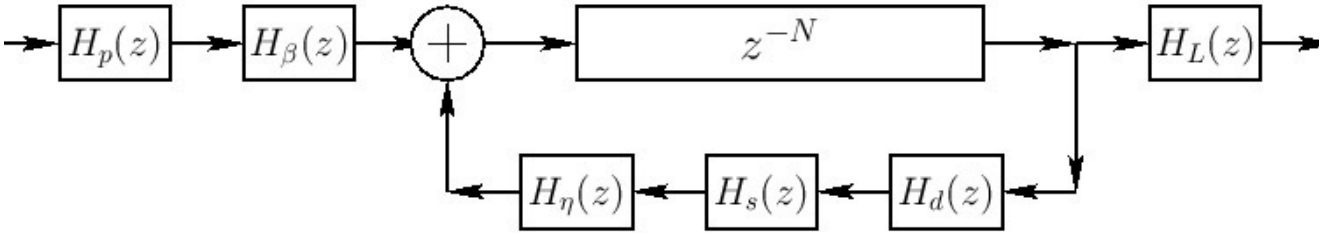



# Karplus-Strong (KS) Algorithm (1983)




- 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)




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

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

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

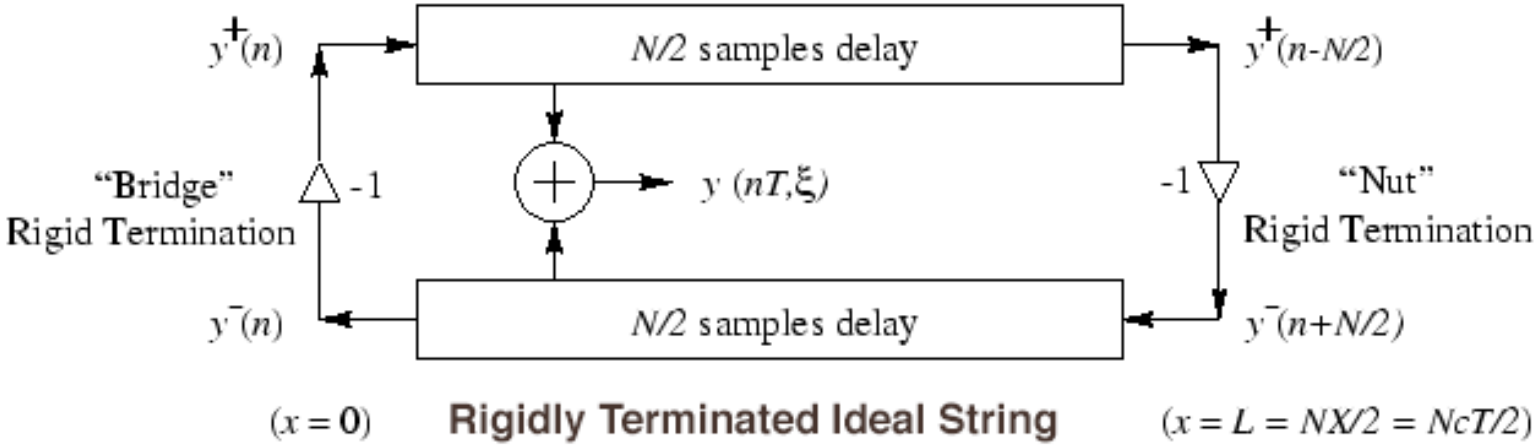
$$H_s(z) = \text{string-stiffness allpass filter (several poles and zeros)}$$

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

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

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

# Digital Waveguide Models (Smith 1985)

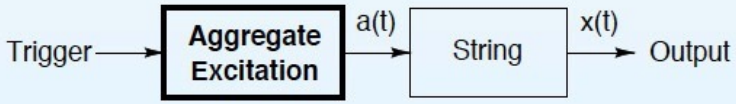



- Equivalent to d'Alembert's Solution to the Partial Differential Equation for a string (1747)
- Useful for efficient models of
  - Strings
  - Bores
  - plane waves
  - conical waves

# 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)

# 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)

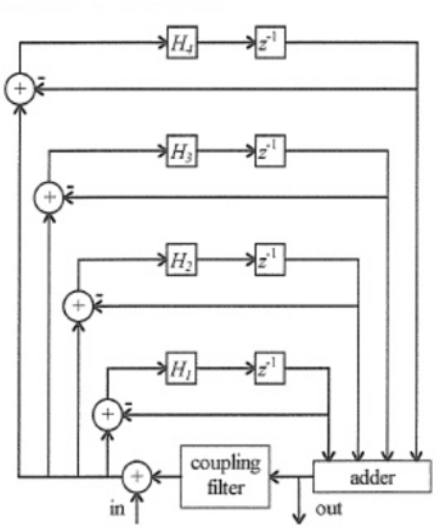
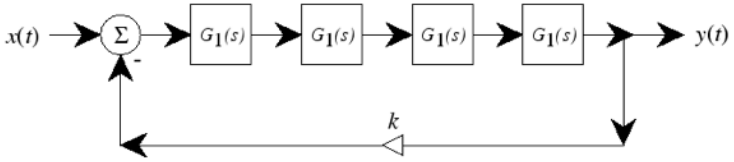
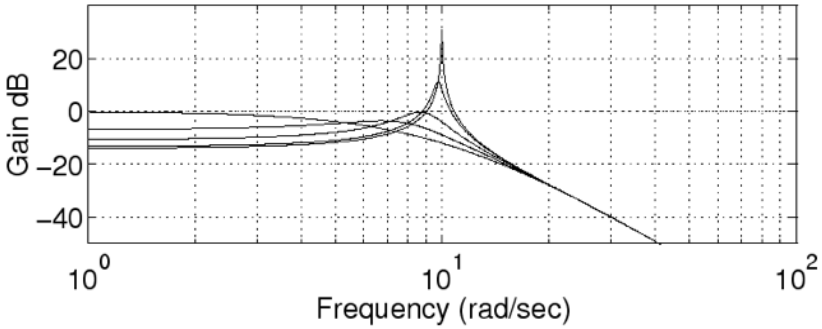


Figure 2: The Coupled Mode Filter Structure

# 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)



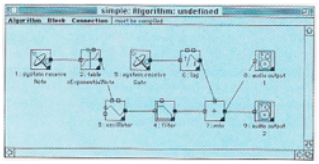



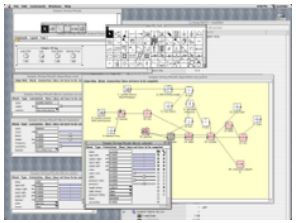
# Yamaha VL Line (1994)

- 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)





# 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.

# Aureal ASP 301 Chip (1995-1997)


- Targeted for Sound Cards
- Hardware implementation of Digital Waveguide
- A version of the electric guitar ran on this chip

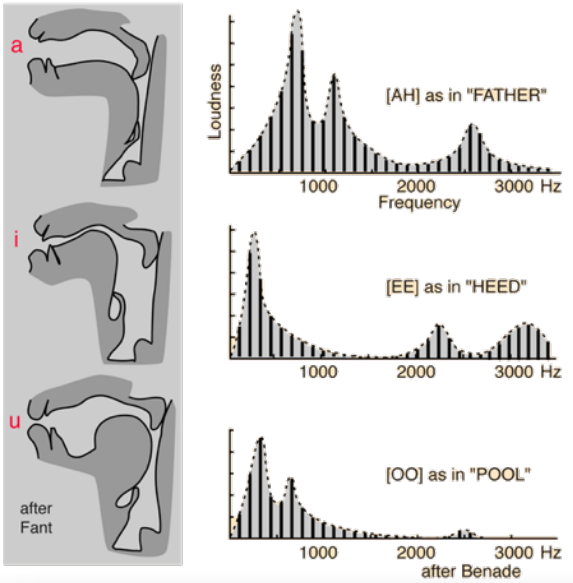
# GeoShred (2015)

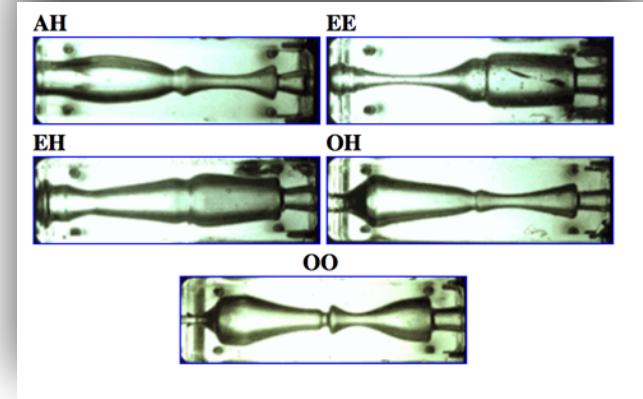
- Physically modeled guitar
- Highly expressive playing surface
- Intelligent pitch rounding
- Modeled feedback
- Modeled effects
- Arpeggiator
- Finger vibrato  slide
- Extensive editing capabilities
- Customizable control surface
- Alternate tuning and interval support


Video Gallery

# Formant Synthesis (1937)

- Harmonic resonances that are the consequence of a complex resonant geometry, like a vocal tract.
- Its been know for a long time that the vocal tract can be modeled with a bellows, a reed, a number of different size resonators and special elements for the tongue, the mouth. [See Exploratorium Vocal Vowels.]



# The Voder (1937-39) - Homer Dudley

- Analog Electronic Speech Synthesis
- Analog model of the vocal tract
- Develop from research on voice compression at Bell Labs.
- Featured at the 1939 Worlds fair
- YouTube

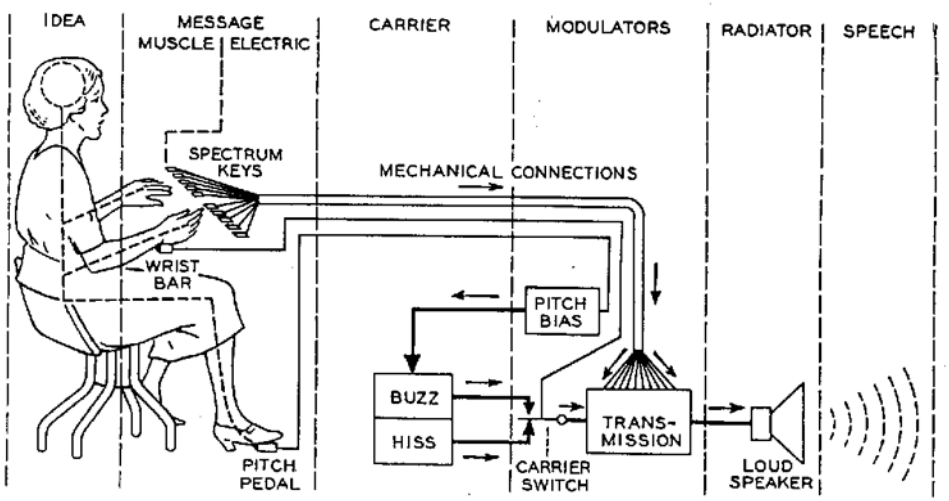
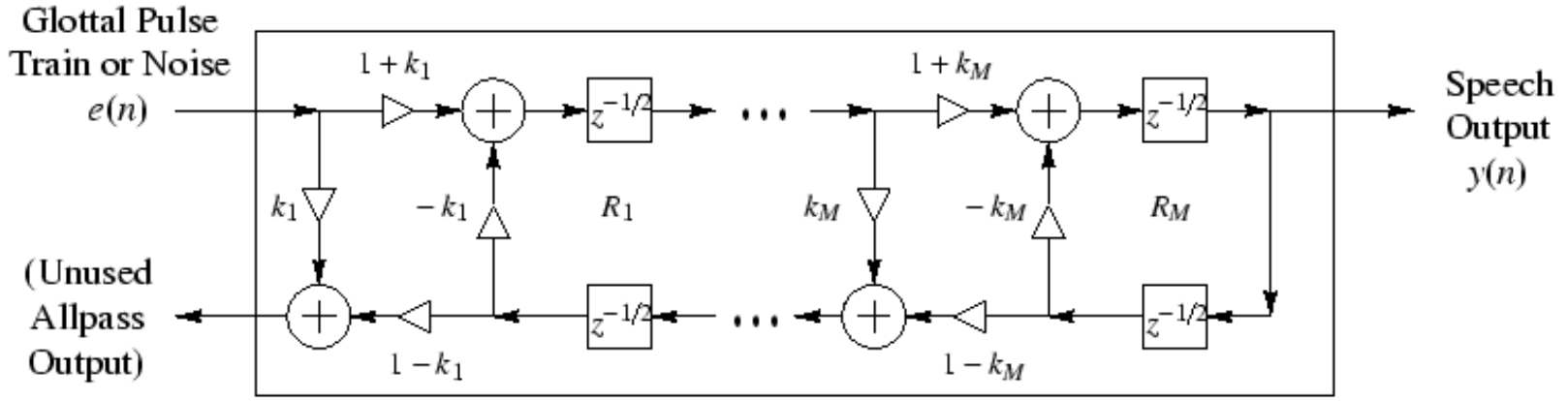


Fig. 8—Schematic circuit of the voder.

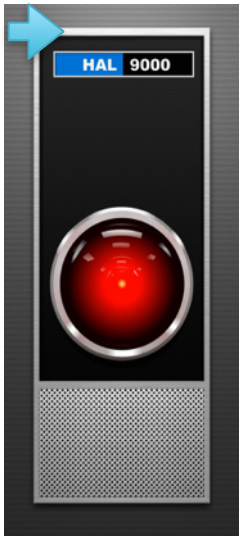
# Kelly-Lochbaum Vocal Tract Model (1961)


Kelly-Lochbaum Vocal Tract Model (Piecewise Cylindrical)

# Daisy Bell (1961)

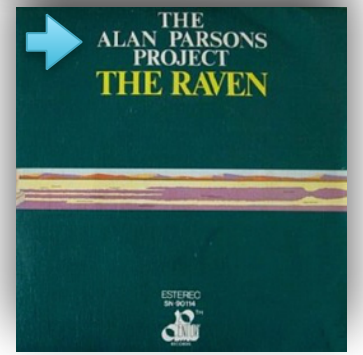
- Daisy Bell (MP3)
- Vocal part by Kelly and Lochbaum (1961)
- Musical accompaniment by Max Mathews
- Computed on an IBM 704
- Based on Russian speech-vowel data from Gunnar Fant's book
- Probably the first digital physical-modeling synthesis sound example by any method
- Inspired Arthur C. Clarke to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



# Vocoding (1937)

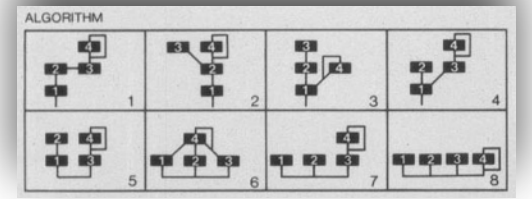
- Analysis and resynthesis
- The Voder (1937-1939)
- SIGSALY Speech Encryption (1941-1943)
- Moog Vocoder (1968)
- Moog/Wendy Carlos Vocoder - "Clockwork Orange" (1970)
- Kraftwerk "Autobaun" (1974)
- Alan Parsons Project - "The Raven" (1976)

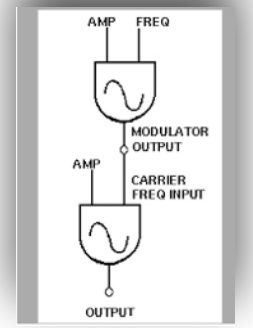




# FM and Phase Distortion (1960s/1973)

- Buchla had Analog FM (mid 60s)
- Digital FM Developed by John Chowning, Stanford (1973)
- Licensed to Yamaha and New England Digital.
- Yamaha GS-1
- Yamaha DX-7
- Digital FM is actually phase modulation. Phase distortion Synth and Phase Modulation are equivalent mathematically.




# Granular Synthesis (1959)

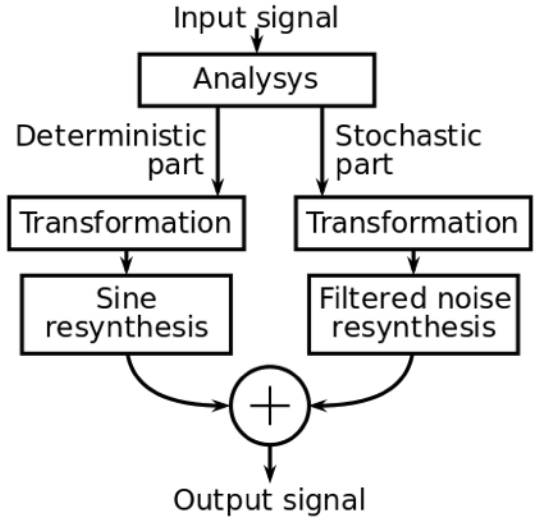
- Iannis Xenakis (1959)
- Initially done with tape. "Analogique A-B for string orchestra and tape" (1959).
- Small sample grains
- Graintable is a fusion of Granular and Wavetable

# WaveTable (1980s)

- Lookup table of periodic waveforms.
- Often known waveforms (ie brass) are combined with filters and envelopes.
- Creative Labs marketed its sample based sound cards as “Wavetable” though they were really PCM samples.
- PPG Wave (1981) made extensive use of wavetable.

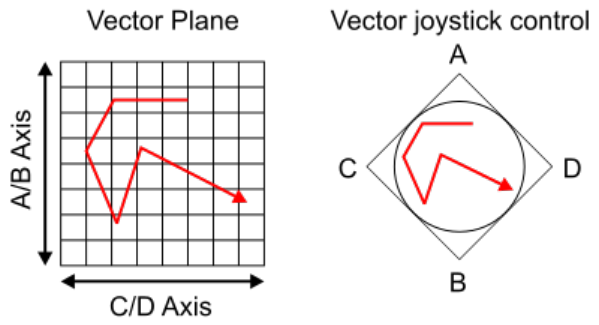
# Spectral Modeling Synthesis (1980s)

- Similar to Vocoding. Analysis and resynthesis.
- Xavier Serra (1989) developed SMS.
- Camel Audio's Alchemy (2009)
- Native Instruments Absynth (2009)




# Vector Synthesis (1986)

- Sequential Circuits Prophet VS
- Later used by Yamaha in the SY22/TG33 and in some Korg products including the Wavestation.
- Dynamic crossfading between up to 4 sound sources




# Linear Arithmetic (1987)

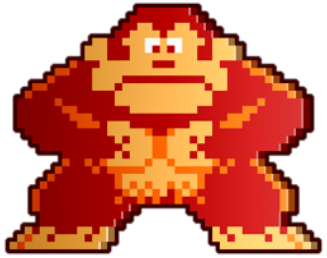
- Sampled attack (digital) + subtractive (analog)
- Roland D-50
- The sound of the 80s!

# Polyphonic Synthesis

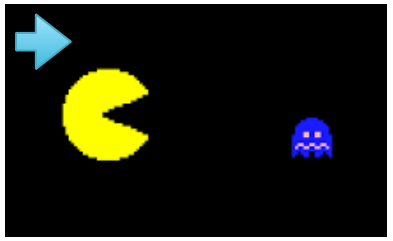
- Octave Dividing (OD) vs Voice Allocation (VA)
- Hammond Novachord (1939)
- Yamaha GX-1 (only 100 made) KE used on Fanfare (1973)
- Oberheim 4 Voice - VA (1975)
- Polymoog - OD (1975)
- Prophet 5 - VA (1978)

# Computer Music

- Music-N (1957 - 1982)
  - Max Matthews
  - First code for generating digital audio waveforms
  - Mathew's concepts, lookup tables, scheduler, are the norm for most hardware and software synthesis and audio DSP systems today
  - Many decedents: Max/MSP, Pure Data, AudioMulch, SuperCollider, JSyn, Common Lisp Music, ChucK
- Cound (1985)
  - Barry Vercoe
  - Branched from Music 11, but written in C



# Game Music



- PSG (Programmable Sound Generators) Chips (1977)
- OPL(n) (1990)—FM Sound Chips.
  - The OPL2 chosen for the MPC spec.
  - Became the standard for sound cards
  - FM based Video game Music
- Wavetable
  - 4th generation SoundBlaster (1994)
  - MIDI/PCM based music for games.
- General MIDI (1991) - Standard voices for MIDI music
- SoundFonts, DLS (1990) - Downloadable sounds.

# Ad Hoc Electronics


- Forbidden Planet - Bebe and Louis Barron (1956)
- BBC Radiophonic Workshop
  - Daphne Oram - Ormics (1957)
  - Delia Derbyshire - Dr. Who Theme by Ron Granier (1963)
- PAIA - DIY Synth and circuit kits
- Modern Circuit Bending


# MIDI (1983)

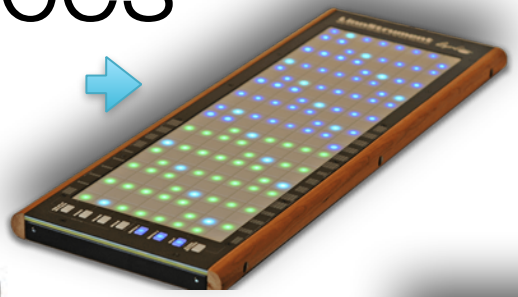

Big topic :-)

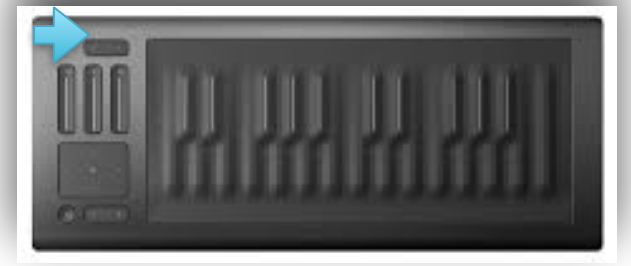
# OSC (1994,1997)

- Open Sound Control
- Evolved from ZIPI
- developed at CNMAT by Adrian Freed and Matt Wright
- Higher resolution (32 bit floating point), richer parameter space
- Open Ended URL like syntax to address control elements
- Minimal semantics.  There is no standard namespace in OSC for interfacing e.g. a synth;
- Some work in progress to define SYN a standard name space for controllers.
- Dozens of SW/HW products support OSC.

# Modern Devices

- Haken Continuum
- Linnstrument
- Kaossilator
- Eigen Harp
- Alpha Sphere
- Roli Seaboard
- Tablets
- DJ Pads

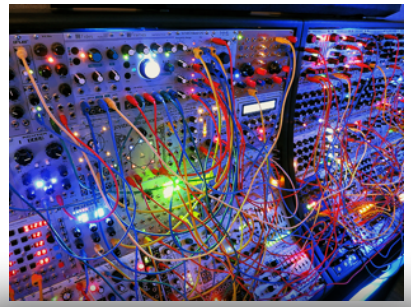





# Future Of Electronic Musical Instruments

# Future Of Electronic Musical Instruments

- EuroRack Retro Futurism
- Virtual Instruments
- Physical Modeling
- DJ driven interfaces
- Unique Controllers MIDI/OSC
- As yet to be explored new techniques




# About Pat…

- 33 years in the Silicon Valley as an Engineer
- Built my first monophonic electronic instrument in 1970 from a Radio Shack kit.
- Gigged with an Arp Avatar guitar synth (1978)
- Computer Modeling of strings and membranes (1981)
- Researcher in Physical Modeling at Stanford/CCRMA (1994)
- CTO of moForte