INTRODUCTION TO COMPUTER MUSIC

PHYSICAL MODELS

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Introduction

- Many kinds of synthesis:
  - Mathematical functions (FM, Additive)
  - Sampling
  - Source/Filter models
- None model complexities of physical systems
- When aspects of physical systems defy analysis, we can resort to simulation
- Even simulation is selective, incomplete
- Key is to model the interesting aspects while keeping the simulation computation tractable

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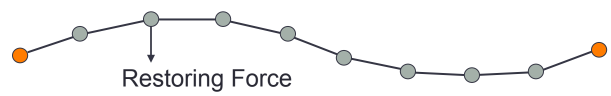
Mass-Spring Model of a String

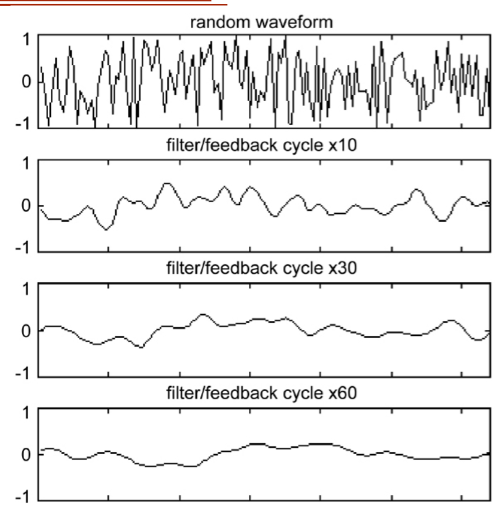


- Expensive to compute
  - But computers are fast
  - Discrete time simulation is mostly multiplies and adds
- Number of modes (partials) corresponds to number of masses.
- Can add stiffness and other interesting properties

A Variation – Karplus-Strong Plucked String Algorithm

- Fill table with noise or initial conditions
- Perform table-lookup oscillator on noise
- Phase-increment = 1
- Average adjacent samples as they are read
  - Averaging adjacent samples is a low-pass filter
  - Averaging causes global exponential decay
- Very efficient simulation of string behavior

Karplus-Strong (2)



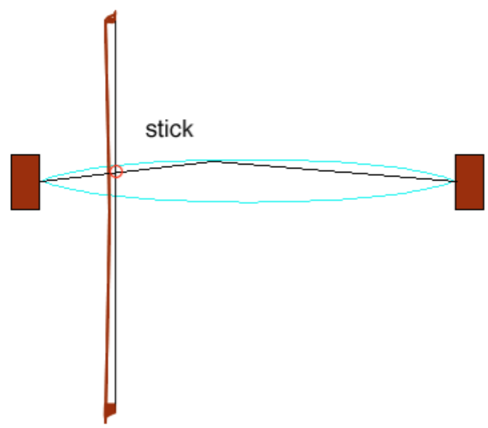
http://music.columbia.edu/cmc/musicandcomputers/chapter4/04_09.php

Improving Karplus-Strong

- Problem: integer table lengths
- Solution: all-pass filter with fractional delay
- Problem: changing string length
- Solution: interpolate all-pass filter
- Problem: controlling decay, loss
- Solution: use different filter (than averaging)

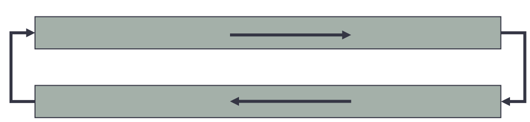
Mechanical Oscillator

- http://www.phys.unsw.edu.au/jw/Bows.html



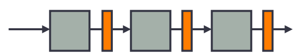
Waveguide Model

- Introduced by Julius Smith
- Wave propagation modeled by delay
- Left-going and right-going waves are separate
- Physical variable (amplitude or flow) is *sum* of corresponding values in two delay lines



"Lumped" Filters

- Real systems (transmission lines, strings, air columns) exhibit continuous, distributed losses
- Length (therefore period) can be frequency-dependent
- Can model losses within waveguide:



- Or, "lump" losses at the end for efficiency:

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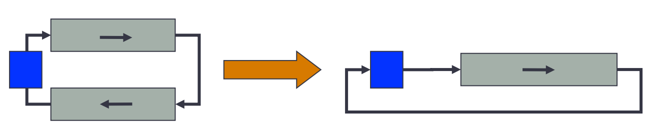
McIntyre, Woodhouse (1979), + Schumacher (1983)

- Physicists trying to understand the nature of oscillation in acoustical instruments
- Model:
  - Delay-line loop of one period
  - Low-pass filter modeling losses over one loop
  - Non-linear element to generate oscillation



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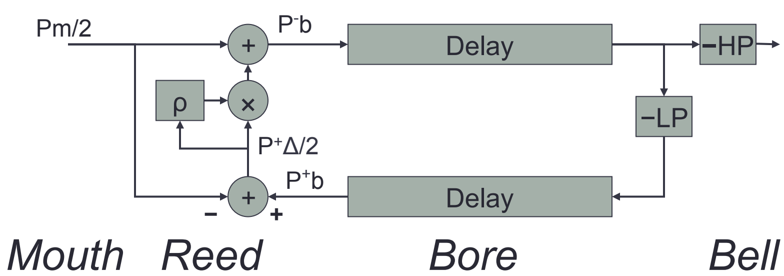
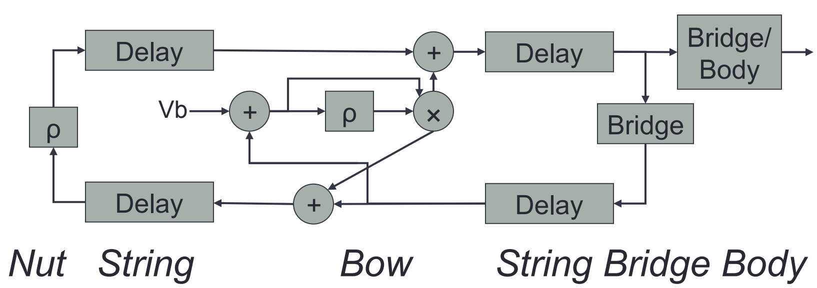
Smith: Efficient Reed-Bore and Bow-String Mechanisms (ICMC 86)



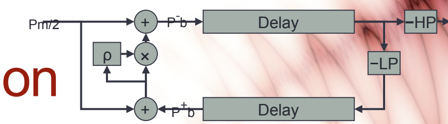
Pm/2 = mouth pressure, $\rho(P^+\Delta/2)$ = reflection coefficient (lookup table)

Bowed String Model



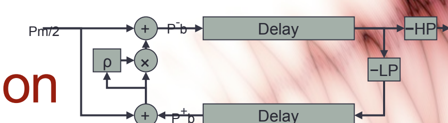
Here, delays contain velocity rather than pressure

Non-linear Oscillation



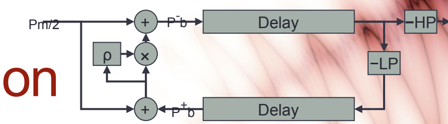
- Apply pressure – biases reed to "negative resistance"
- High pressure front to bell, reflects as negated front
- Negated front returns and reflects again (no sign inversion because mouthpiece is approximately closed, not open)
- Negative pressure zone is left behind
- Reflection from open end again brings return-to-zero wave traveling back to mouthpiece
- Positive traveling wave reaches mouthpiece and starts second period of oscillation

Non-linear Oscillation



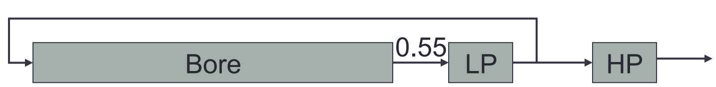
- There are losses, so we need to feed energy in
- When pressure drop reflects from mouthpiece, mouthpiece switches from high to low pressure
- Reed changes from open to closed
- Closing increases reflection coefficient and amplifies reflection (with maximum gain of 1)
- Also shuts off pressure coming from mouth – potential gain is greater than 1.

Non-linear Oscillation

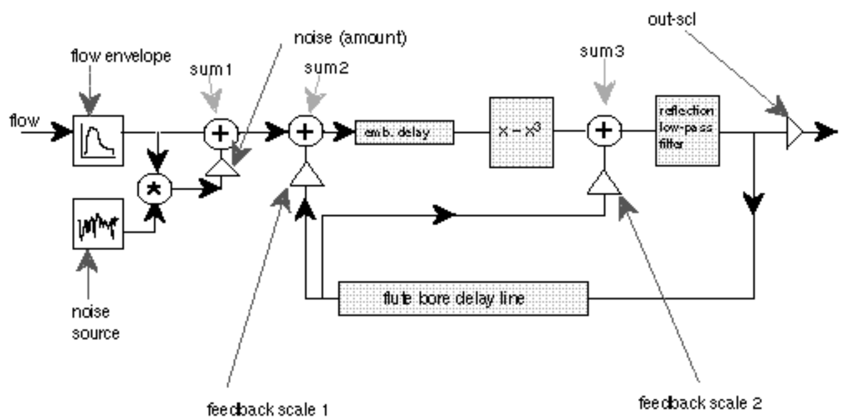


- With rising pressure at mouthpiece,
- Reflection coefficient falls with opening of reed
- Attenuates reflection coefficient, but
- Increases pressure let in from mouth
- Positive wave reflection is
  - Boosted when below a certain level
  - Attenuated when above a certain level
- Negative wave reflection is limited by shutting of reed
- Dynamic equilibrium is established

Flute Physical Model



Detailed Diagram



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Physical Models in Nyquist

(pluck *pitch* [*dur*] [*final-amp*])

Variations on STK clarinet model:

(clarinet *step breath-env*)

(clarinet-freq *step breath-env freq-env*)

(clarinet-all *step breath-env freq-env vibrato-freq vibrato-gain reed-stiffness noise*)

Variations on STK saxophony model:

(sax *step breath-env*)

(sax-freq *step breath-env freq-env*)

(sax-all *step breath-env freq-env vibrato-freq vibrato-gain reed-stiffness noise blow-pos reed-table-offset*)

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More Physical Models in Nyquist

- See manual for more.