CS599 Physically Based Modelling and Interactive Simulation for Games

Scribe Notes : Sound Simulation I (March 30, 2010)   [Deepanshu Malik]

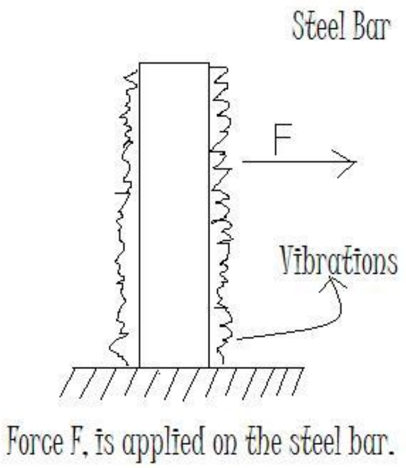
The branch of science that studies sound is known as ***Acoustics***.

There are two ways to simulate sound :

1. Data Driven (Traditional Method) : Pre-Record sound and play. Tweak around with sound clips. Adjust different parameters to get the right affect.
2. Physical Simulation : Simulate sound's physically. We are going to focus on this.

How is sound generated?

Consider a metal bar resting vertically on the ground.



When a force F is applied on the steel bar then deformations take place on the surface of the steel bar. These deformations are of high frequency and are short-lived. Deformations are not visible to human eye but these deformations generate sound. Pressure waves are propagated out when force is applied.

Some Important Facts about Sound

1. Propagation Speed of Sound (c) $\propto \frac{1}{\text{density of medium}}$
2. Speed of sound in air is 340 m/s.
3. In general, speed of an object (v) < < c
4. v > c produces Doppler Effect.
5. Sound bends at corners.

Other Relevant factors of Sound

- Human audible frequency range is 20 – 20,000 Hz.
- According to Nyquist Equation : To get a quality audio output, one should sample at twice the Sampling frequency. The standard sampling frequency is 44100 Hz to get a good quality audio. This means, $\Delta t = 1/44100$ seconds.
- WAV files (.wav) are a good way to store sound. These files store sound as amplitude over time.

Post-processing of Sound

- Need a real-time API to send and receive signals on the fly.
- A spectrogram is an image that shows how the spectral density of a signal varies with time. Spectrograms are used in the fields of music, sonar/radar, speech processing, seismology, etc. The instrument that generates a spectrogram is called a spectrograph or sonograph.
- A sliding window of variable size and overlap is used to calculate the spectrogram. It is very difficult to get rich spectrograms from physical simulation of sound.

Steps involved in Sound Simulation

By numerically pre-computing the shape and the frequencies of an object's deformation modes, audio can be synthesized interactively directly from the force data generated by a standard rigid body simulation.

Our 1st Approximation : Ignore Sound Propagation. Advanced methods are required for propagation but we are going to use :

$$P \propto \frac{1}{r},$$ where **P** is the pressure wave at a distance **r** from the object.

Method for modelling the sound generated by rigid objects makes use of a well studied technique known as Modal Analysis.

A physical system that has been discretized using a finite element, finite differencing, or other similar method can be expressed in the following general form:

$$M(\ddot{d}) + D(d,\dot{d}) + K(d) = F$$

The above equation can be linearly approximated because we are simulating very small deformations.

$$M(\ddot{d}) + D(d,\dot{d}) + Ku = F \qquad (1)$$

Where,

$U \in R^{3n}$

M is 3n x 3n Mass Matrix

D is Damping Matrix

K is stiffness Matrix

Linear Modal Analysis

$Ax = \lambda x$ is kown as an eigen-value problem.

$Kx = \lambda Mx$ is known as a generalized eigen-value problem.

Assuming both K and M are symmetric positive definite, we have $\lambda>0$

Once we know K and M, use a solver(eg: ARPACK) to get the eigen-values.

Retain a few eigen values, say 50

$$0 < \lambda 1 < \lambda 2 < \lambda 3 \ldots\ldots\ldots\ldots < \lambda 50$$

$$\lambda = \omega^2$$

$$\omega = 2\pi\nu$$

After some values, λs go out of audible range.

$$U = [\ \lambda 1\ \lambda 2\ \lambda 3 \ldots\ldots\ldots \lambda 50\ ]$$

$U(t) \approx U \,.\, q(t)$ (2) -Model Reduction (Refer to the previous class)

Substituting (2) in (1) we get :

$$U^T MU\ddot{q} + U^T DU\dot{q} + U^T Kuq = U^T F$$

Next step is to express the damping matrix as a linear combination of stiffness and mass matrix.This process is known as Raleigh Damping.

$$D = \alpha M + \beta K$$

$$\alpha, \beta > 0$$