Physics-Based Animation

17 — Sound simulation

November 3, 2015
Project proposals

Grades and brief comments on Moodle
Homework

Fluid simulation on a grid

• FLIP advection using particles
• Pressure solve using a staggered grid
• Should be easy to adapt for liquids
Presentation critique

- Critique both content/organization and delivery
- Anonymous copies provided to presenter
Finite elements
(quick recap)
Finite element method

nodes

elements
Finite element method

**Precompute:**

- Node masses \( m_i \)
- Element basis matrices \( D_m \) and inverses \( D_m^{-1} \)

**At runtime:**

- Compute element deformation, strain, stress
- Accumulate forces (and Jacobians?) on nodes
- Perform time integration as usual
Sound simulation
What is sound?
What is sound?

object vibrates
What is sound?

object vibrates

creates pressure waves in air
What is sound?

- Object vibrates
- Creates pressure waves in air
- Sampled by ears

20 – 20,000 Hz
Sound simulation

Sound synthesis

Sound propagation
Sound simulation

1. **Sound synthesis**: given an object and an excitation, how does it vibrate?

2. **Sound propagation**: given the emitted sound, how does it propagate through the scene?
Sound synthesis
Sound synthesis

Simple solution:

• Treat the object as an elastic body

• Perform mass-spring or FEM simulation
Sound synthesis

Simple solution:

• Treat the object as an elastic body

• Perform mass-spring or FEM simulation at 40,000 time steps per second
Sound synthesis

Only consider small displacements from the rest configuration. Then internal forces are approximately linear:

\[ M\ddot{q} = -Kq \]

for external forces, damping

see O’Brien et al. (2002)
Vibrational modes
Vibrational modes

(a) Mode shape associated to the first natural frequency: $f_{01}=7.326$ Hz
(b) Mode shape associated to the second natural frequency: $f_{02}=9.208$ Hz
(c) Mode shape associated to the third natural frequency: $f_{03}=12.385$ Hz
(d) Mode shape associated to the fourth natural frequency: $f_{04}=18.296$ Hz
(e) Mode shape associated to the fifth natural frequency: $f_{05}=19.810$ Hz
(f) Mode shape associated to the sixth natural frequency: $f_{06}=22.299$ Hz

Figure 11  Floor vibration modes of model number 8.
Vibrational modes

\[ M\ddot{q} = -Kq \]

- When is \( \ddot{q} = \lambda q \)?

\[ -Kq = \lambda Mq \]

- Each solution \( \psi \) vibrates independently with angular frequency \( \omega = \sqrt{-\lambda} \), period \( T = \frac{2\pi}{\omega} \)
Vibrational modes

Write $q, \dot{q}$ in terms of $\psi_1, \psi_2, \ldots$

$$q(0) = \alpha_1 \psi_1 + \alpha_2 \psi_2 + \cdots,$$
$$\dot{q}(0) = \dot{\alpha}_1 \psi_1 + \dot{\alpha}_2 \psi_2 + \cdots,$$

Then

$$q(t) = (a_1 \cos \omega_1 t + b_1 \sin \omega_1 t) \psi_1 + (a_2 \cos \omega_2 t + b_2 \sin \omega_2 t) \psi_2 + \cdots$$
Sound simulation

Sound synthesis

Sound propagation
Sound propagation

“Global illumination for sound”
Sound propagation

Geometric acoustics

Wave acoustics