Haptic Rendering
Outline

- Announcements
- Human haptic perception
- Anatomy of a visual-haptic simulation
- Virtual wall and potential field rendering
- A note on timing...
Sharing Devices...
Haptic Perception

CS277 - Experimental Haptics, Stanford University, Spring 2014
Touch Perception

haptic perceptual system

cutaneous receptors

kinaesthetic receptors

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Figure 1. Vertical section through the glabrous skin of the human hand. Schematic depiction of the two major layers of nervous tissue. The locations of the organized nerve terminals are also shown. Mr, Meissner corpuscle; Ml, Merkel cell complex; R, Ruffini ending; P, Pacinian corpuscle. From “Tactile Sensory Coding in the Glabrous Skin of the Human Hand,” by R. S. Lederman and A. B. Vallbo, 1983, Trends in Neurosciences, 5, p. 28.
Cutaneous Perception

- Inputs from different types of mechanoreceptors embedded in the skin
  - vibration and texture perception
  - pressure and skin stretch (grasped object)
Kinaesthetic Perception

- Inputs from mechanoreceptors in muscles, tendons, and joints
  - limb position and movement
  - larger contact forces and loads
Cutaneous/Tactile Feedback

- Devices can be very difficult to realize
  - requires high spatial actuator resolution
Kinaesthetic Feedback

- Key realization: tool-mediated interaction
  - system need only render tool contact forces
Kinaesthetic Devices

- Driven by two common types of control strategies
  - *Impedance-control* haptic devices simulate mechanical impedance
  - *Admittance-control* haptic devices simulate mechanical admittance
Impedance vs Admittance

- Impedance devices
  - sense position
  - commanded force

- Admittance devices
  - sense force
  - commanded position
Impedance vs Admittance

- **Impedance** haptic devices
  - are cheaper to build
  - back-drivable

- **Admittance** haptic devices
  - higher range of forces
  - requires force sensor ($$$$
  - generally less common
Devices for CS277

- We will focus on studying
  - kinaesthetic devices: tool-mediated interaction
  - impedance control: render forces (impedances)
  - 3-DOF actuated devices, 3- or 6-DOF sensed
Visual-Haptic Simulation
The Basics

How does a basic visual-haptic simulation work?

Virtual Environment (VE)  Haptic Device

Avatar
The Interface

position

force
Haptic rendering is the process of computing and generating forces in response to user interactions with virtual objects.

Haptic interface devices include actuated, sensed or not sensed.

Admittance-based devices, such as the Haptic Master, reduce impedance-type architectures are most common.

Position and send force.

System architecture for haptic rendering

- Collision-detection algorithms return a force to the haptic device in such a way that minimizes the error between ideal and applicable forces.
- Their return values are normally force and torque vectors, as pain, or even discomfort, can distract the user, when wearing or manipulating the haptic interface.
- We characterize the possible movements or forces exchanged between device and operator. A DOF can be passive or actuated, sensed or not sensed.

Haptic interface devices simulate mechanical impedance—they read user approximating the ideal interaction force to the best of the device's capabilities.

Several components compose a typical haptic rendering algorithm. We identify three main blocks, illustrated in Figure 3.

1. Simulation engine
2. Force-response algorithms
3. Control algorithms

Forces between avatars and virtual objects when a collision occurs are approximated by the force-response algorithms as closely as possible the contact forces that would normally arise during the contact between real objects. Force-response algorithms approximate the ideal interaction forces occurring between an avatar at position $X$ and objects in the virtual environment.

Simulation of the possible contact points between avatars and virtual objects.

Haptic device

Collision detection

Force response

Control algorithms

Graphics engine

Video

In this course...

We focus on the haptic rendering component.
The Virtual Environment

- representations of virtual objects
- real-time simulation of physical behaviour
- geometric modeling and computer animation (CS348a, CS205b)
Haptic Device

- We treat the device as a “black box”
- We’ll crack it open near the end of the course
- Take ME347 to learn more!
Visual Rendering

- Given a virtual environment, render its state on the screen (in real time)
- We will let CHAI3D do this for us
- CS148, CS248, CS348b
Haptic vs. Visual Rendering
Bi-Directionality

- Bi-directional information flow is the most distinguishing feature of haptic interfaces
- This has many consequences that we will visit in later classes
Getting to Know Your Falcon
The Hardware
The Software

- Download, compile the CHAI3D library
- No drivers necessary on Mac/Linux
- Three platforms supported:
  - Mac OS X → Xcode
  - MS Windows → Visual Studio
  - Linux → makefiles
  - CMake?
Run CHAI3D Demo to Test
Device Distribution

- April 7 (Mon) and April 8 (Tue)
- See Sonny in Clark Center E100 (Salisbury Robotics Lab)
- Times TBD, but will be announced on class email and on Piazza.
Potential Fields
Starting Simple

- A plane is one of the simplest virtual environments we can conceive and render
- How can we render such a “virtual wall”?

\[ F = f(x) = ? \]
Virtual Walls

- The simplest VE: a linear spring in 3D
- Can be used to study stability
- Useful building block for more complex virtual environments and interactions
Virtual Wall Algorithm

\[ F(x) = \begin{cases} 
-kx & \text{if } x > 0 \\
0 & \text{otherwise}
\end{cases} \]
Virtual Wall Stiffness

- Stiffness ($k$) affects how the wall feels

$$F = -kx$$

Graph showing the relationship between force ($F$) and displacement ($x$) for different materials. Harder materials result in a steeper slope, while softer materials have a shallower slope.
Another Shape

- What is the simplest way to render a sphere in 3D?
Potential Field Examples

- Virtual wall is the simplest one
- A sphere that attracts toward its surface
  \[ F(x, y, z) = -k(x^2 + y^2 + z^2 - r^2) \]
- A sphere
  \[ F(x, y, z) = \begin{cases} 
  -k(x^2 + y^2 + z^2 - r^2) & \text{if } x^2 + y^2 + z^2 < r^2 \\
  0 & \text{otherwise} 
\end{cases} \]
- A box...
Potential Fields

- The term *potential field* is borrowed from physics/mechanics

- Force is a vector field gradient of potential

\[ \vec{F} = \nabla U \]

- We normally just skip to defining force field
Why Potential Fields?

- They make intuitive sense (3D springs)
- They are easy to compute
- ... but with simplicity comes limitations
Summary

- Human haptic perception
  - kinaesthetic feedback and impedance devices
- Anatomy of a visual-haptic simulation
  - we’ll focus on haptic rendering
- Virtual wall and potential field rendering
- Time is of the essence!