Introduction to Haptic Rendering

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**Haptic (adj.):**
related to the sense of touch.

**Graphical Rendering:**
process of displaying synthetically generated 2D/3D visual stimuli to the user

**Haptic Rendering:**
process of displaying synthetically generated 2D/3D haptic stimuli to the user

**Haptic Interface:** device for touch interaction in real and virtual worlds
Applications

Haptic Feedback for Molecular Simulation

Haptic Feedback for Medical Simulation and Training

Source: Caltech
Applications

Haptic Feedback for Collaborative Engineering Design

Haptic Visualization

Haptic Feedback for Crew Training

Tangible Interfaces

- buttons
- dials
- slider bars
- folders
- layers
- force fields

Tangible data

Simulation of repair and maintenance tasks
Human vs Machine Haptics:
Machine Haptics:

Types of Haptic Devices

Net Force Displays

Tactile Displays

Source: Sensable Tech. Inc

Source: R. Howe, Harvard University
Types of Haptic Devices

Passive

keyboard, trackball, mice, etc.

Active

Force

Source: Sensable Tech. Inc.
Types of Haptic Devices

Grounded

Attached

combined

Source: Immersion Corp.

Source: Sarcos Corp.

Source: Virtual Tech. Inc.
Integration of Vision and Touch

Haptic Thread
- Motor Torques
- Encoder Positions
- Display Force
- State

Visual Thread
- Images
- Display Visuals
- State

Shared Database

Haptic Interface

Visual Interface

HUMAN OPERATOR
Haptic Rendering with a Force Display

- Position Orientation
- Collision Detection
- Contact Information
- Collision Response
- Object Database
  - Geometry
  - Material

virtual wall

F
Types of Haptic Interactions with 3D Objects:

- **Point-Object**
- **Line Segment-Object**
- **Object-Object**

Source: R. Avila, GE Corp.
Haptic Rendering Of 3D Geometric Primitives
(point-object interaction)

```c
void calculate_force (Vector &force)
{
    float X, Y, Z, distance;
    float R = 20.0;
    X = HIP[0]; Y = HIP[1]; Z = HIP[2];
    distance = sqrt(X*X + Y*Y + Z*Z);
    if(distance < R) //collision check
    {
        force[0] = X/distance * (R-distance);
        force[1] = Y/distance * (R-distance);
        force[2] = Z/distance * (R-distance);
    }
}
```
Haptic Rendering of 3D Objects
(point-object interaction)

\[ F = k \Delta x \]

3D Primitives
no problem!

3D Object
- optimization
- rule-based techniques
Modeling Choices for 3D Object Representation
(point-object interaction)

- polygonal
- implicit
- NURBS
- voxel

will be covered in this tutorial

see my notes for related references
Representation of a 3D Polyhedron

Database

3D Polyhedron

Polygon

Edge

Vertex

Edge

Vertex

SoSeparator

SoCoordinate3

SoIndexedFaceSet

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Open Inventor/VRML file
Key Components of the Rendering Algorithm

1) Bounding-box hierarchy

2) Contact history

3) Local coherence
Haptic Rendering of Polygonal Surfaces

see Ho et al., 1999 for details
Haptic Display of Surface Details

- Haptic smoothing of object surfaces
- Rendering of haptic textures
- Haptic rendering of surfaces with friction
Common Principle: Perturbation of force vector!

**Force Shading**
ref: Phong Shading

\[ N_s = \frac{\sum_{i}^{3} A_i \cdot N_i}{\sum_{i}^{3} A_i} \]

---

**Friction**
ref: Mechanics books

\[ \nabla h = \frac{\partial h}{\partial x} \hat{i} + \frac{\partial h}{\partial y} \hat{j} + \frac{\partial h}{\partial z} \hat{k} \]

\[ h(x,y,z) : \text{texture field} \]

---

**Texture**
ref: Bump Mapping

\[ F_{\text{perturb}} \]
Haptic Texturing

- image-based
  \[ s \rightarrow t \]
  two-stage mapping
  Bier & Sloan, 1986

- procedural
  \[ h(x,y,z) \rightarrow \text{bump mapping} \]
  Blinn, 1978;
  Max and Becker, 1994
Force-Reflecting Deformable Models:

Real-time FEM

Surgical Simulation

Animation/Ergonomics

Web-based haptics for product design and purchase

Haptic Sculpting

Free-form Deformation
Rigid Body Dynamics:

Method (c) is computationally better than (b)!
Recording and Playing-back Haptic Stimuli:

- file format
- data structure
- device independent support
- internet protocol
- data compression
...

Web-based Haptics

Gear.wrl
Virtual Prototyping with Haptic Feedback

Problems in Engineering Design:

concept ➔ CAD ➔ CAE ➔ CAM ➔ production

haptic sculpting?

➡ digital prototype

A few problems with current systems:

• automated systems cannot duplicate the knowledge and intelligence of an experienced designer.
• limits the ability of design engineers to experiment with different design configurations.
• design process is slow, sequential, and non-intuitive.
• testing the functionality/ergonomics of a product is costly and requires many iterations.
Benefits of Touch Feedback in Engineering Design:

1. Path planning
2. Assembly sequence
3. Digital Prototyping
4. Functionality & Maintenance
5. Ergonomics

areas where haptic feedback can contribute significantly to design process

However, haptic feedback can be used for

- finding the insertion/removal paths of objects
- precision mating
- planning the sequence of assembling products
- guiding/constraining the user during digital sculpting
- improving depth perception and resolving visual ambiguities
- testing the functionality of products in virtual worlds
- designing user friendly interfaces