Force feedback interfaces & applications

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*Based on material by Jukka Raisamo, Jussi Rantala and Roope Raisamo*

Outline

- Force feedback interfaces & devices
- Haptic rendering
- Force feedback applications

Force feedback interfaces

Force feedback interfaces can be viewed as having two basic functions (Tan *et al*., 1994)

1. To measure the positions and contact forces of the user's hand (and/or other body parts)
2. To display contact forces and positions to the user

# Display of texture and shape

A

B
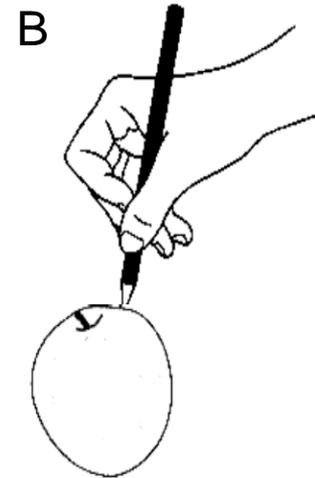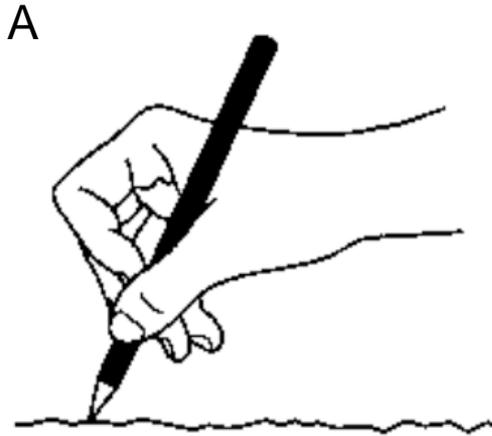
- In figure A, the sensation of a textured surface can be produced via a stylus that moves according to the virtual surface texture

- In figure B, a stylus can be used to probe the surface characteristics of a virtual object

Haptic interaction
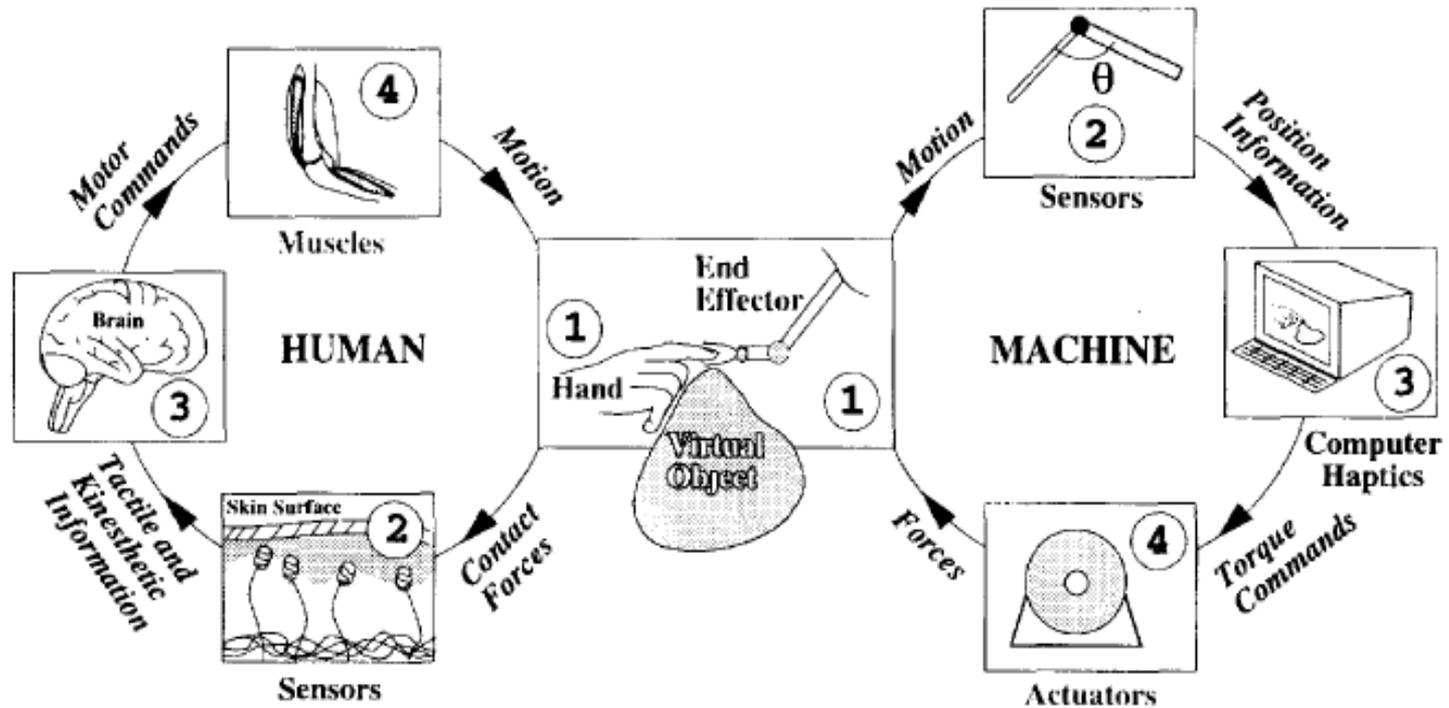
Physical modeling of virtual objects
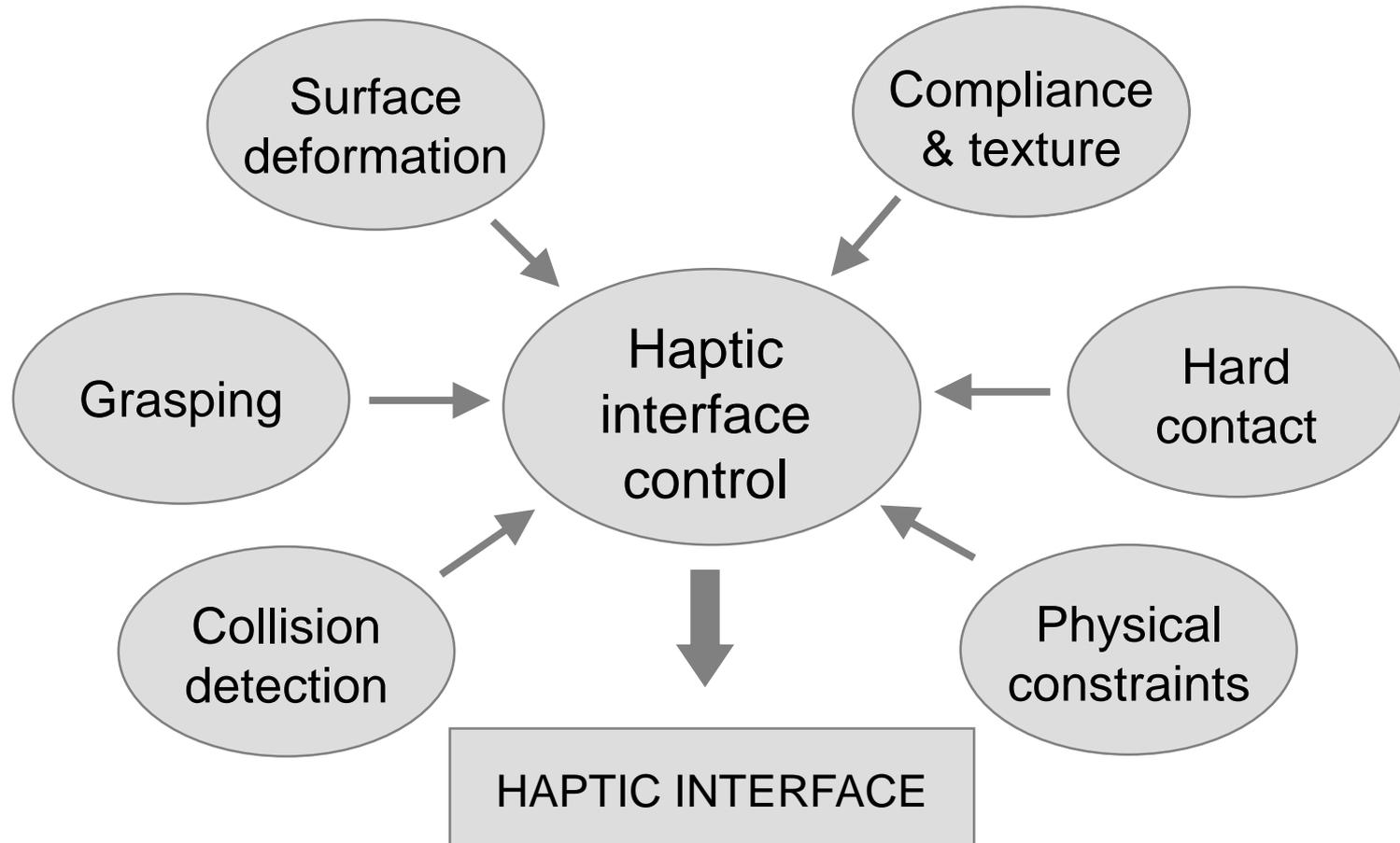
(Adopted from Burdea, 1996)

Haptic system architecture

User

Distributed computing platform

Visual, audio feedback

Haptic feedback

High-level control

Haptic interface

Interface controller

Low-level control
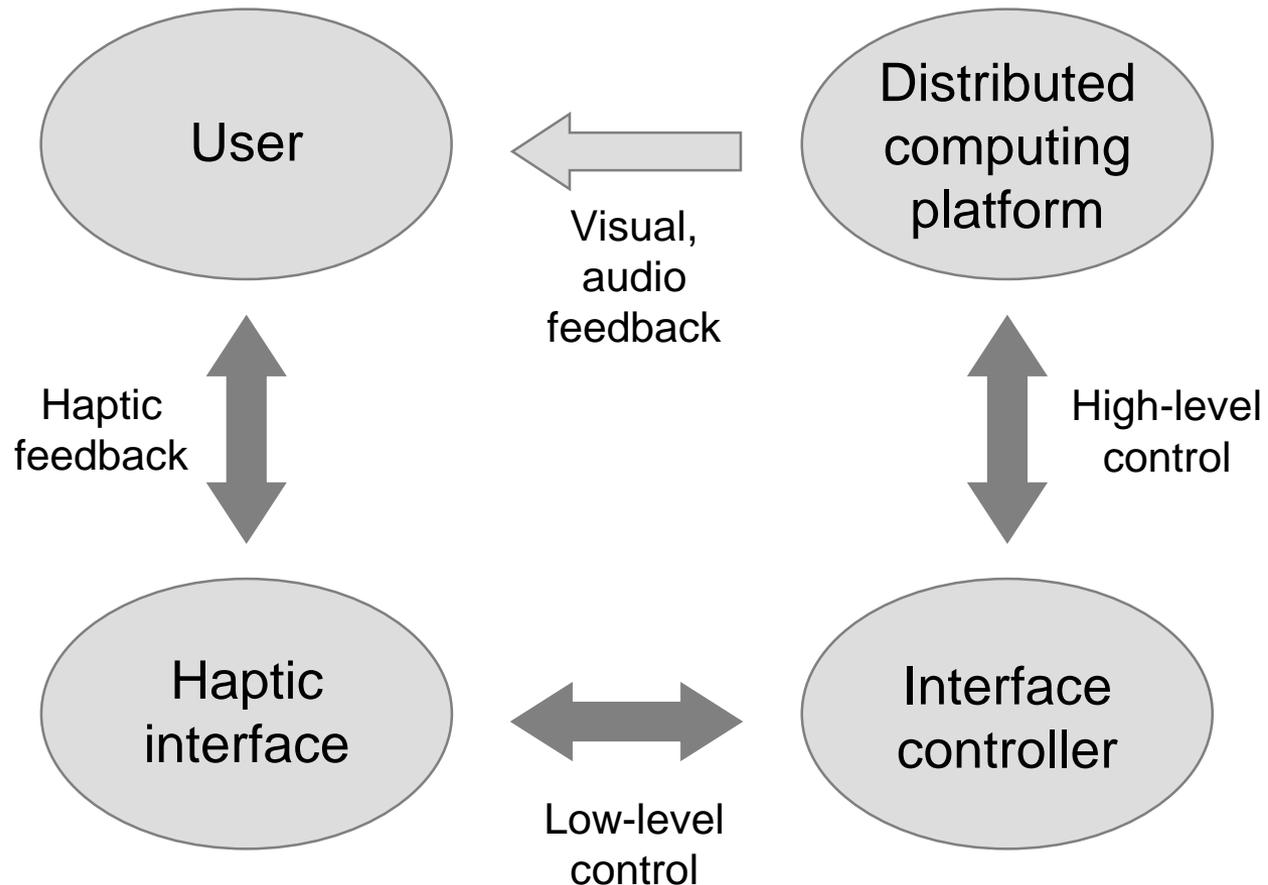
Bi-directional energy flow

One-way information flow

(Adopted from Burdea, 1996)

Force feedback devices

History of force feedback systems (1/2)

- Argonne National Laboratory 1954, first master-slave system
  - For manipulating highly radioactive materials

- Salisbury 1980, independent master and slave
  - Kinematically independent master and slave devices where the master device was optimized for the human operator

- Minsky 1990, the Sandpaper
  - Exploration of textures using a 2-DOF force feedback joystick

History of force feedback systems (2/2)

- Massie & Salisbury 1994, the PHANTOM device
- Early 1990's to 1997, 3-DOF haptics
- Late 1990's to today, 6-DOFhaptics
- Early 2000 to today, 7-DOF haptics

Force feedback devices (1/5)

1

- Examples of 1-DOF devices
  1. Steering Wheels
  2. Hard Driving (Atari)
  3. Ultimate Per4mer (SC&T2)

2

3

Force feedback devices (2/5)

- Examples of 2-DOF devices
    1. Pen-Based Force Display (Hannaford, U. Wash)
    2. MouseCAT/PenCAT (Hayward, Haptic Tech., Canada)
    3. Feel-It Mouse (Immersion)
    4. Force FX (CH Products)
    5. Sidewinder Force Feedback Pro (Microsoft)

1

5

4


2

3

Force feedback devices (3/5)

- Examples of 3-DOF devices
    1. Geomatic Touch (formerly Sensable Phantom Omni)
    2. Omega (Force Dimension)
    3. Novint Falcon
   4. Impulse engine (Immersion)

1

2

3

4

Force feedback devices (4/5)

- Examples of 6-DOF devices

  1. PHANTOM Premium
  2. Delta (Force Dimension)
  3. Freedom 6S (Hayward, MPB Technologies)

1

2

3

Force feedback devices (5/5)

1

- Examples of 7-DOF devices
    1. Omega.7 (Force Dimension)
    2. Freedom 7S (Hayward, MPB Technologies)

2
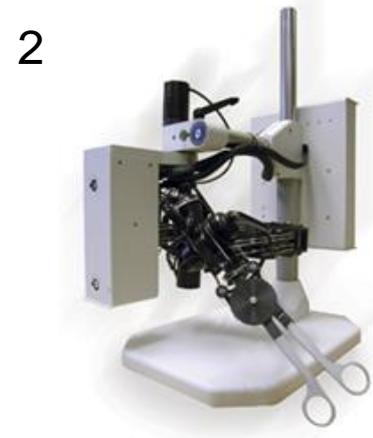
Geomagic (formerly Sensable)

http://www.geomagic.com

15

Force Dimension: Omega and Delta

http://www.forcedimension.com

Novint Technologies: Falcon

http://www.novint.com

FCS Systems: HapticMASTER

http://www.fcs-robotics.com
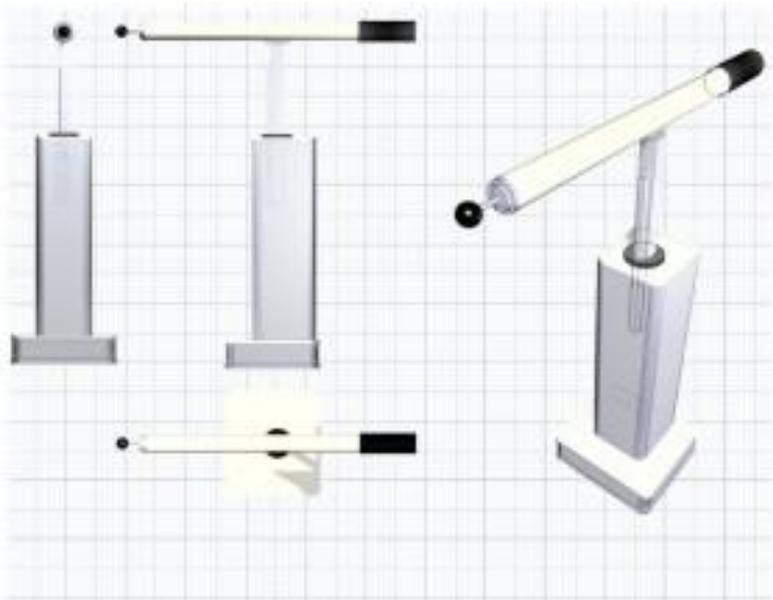
MPB Technologies: 3-7 DOF devices

http://www.mpb-technologies.ca

Haption: 3-6 DOF Virtuose devices

http://www.mpb-technologies.ca
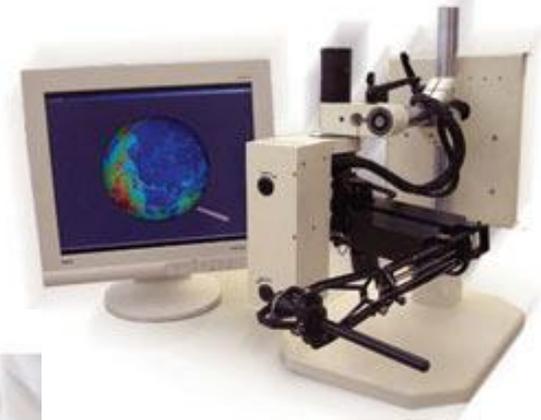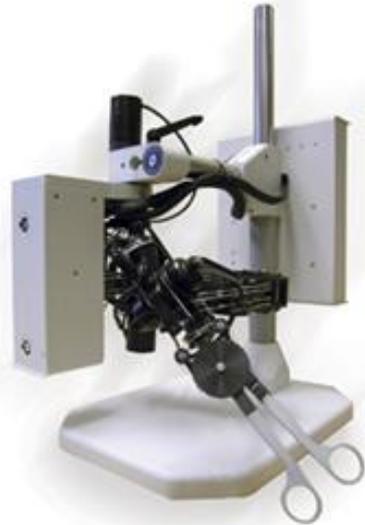
Butterfly Haptics: Maglev 200

http://butterflyhaptics.com

Immersion CyberGrasp

http://www.immersion.com

What makes a good haptic interface? (1/3)

- The interface must operate within human abilities and limitations

- Approximations of real-world haptic interactions are determined by limits of human performance

What makes a good haptic interface? (2/3)

- Free motion must feel free
  - Low back-drive inertia and friction
  - No motion constraints

- Ergonomics and comfort
  - Sizing and fatigue are also important issues, especially for exoskeletal devices
  - Pain, discomfort and fatigue will detract from the experience
  - Bad ergonomics can easily ruin otherwise excellent haptic display

What makes a good haptic interface? (3/3)

- Suitable range, resolution and bandwidth
  - User should not be able to go through rigid objects by exceeding force range
  - No unintended vibrations

- Solid objects must feel stiff
  - What is the stiffness required to convince a user that an object is rigid?
  - For example, users can consistently judge the relative stiffness of different virtual walls even though they are never as rigid as the real walls due to hardware limitations

Haptic rendering

Haptic rendering (1/2)

- *Haptic rendering* is the process of computing and generating forces in response to interactions with virtual objects, based on the position of the device

- Haptic rendering of an object can be seen as pushing the device out of the object whenever it tries to move inside it

- The human sense of touch is sensitive enough to require a processing speed of at least 1000 Hz in terms of haptic rendering

Haptic rendering (2/2)

- The further inside the object you move, the greater the force pushing you out

- This makes the surface feel solid

Collision detection & response
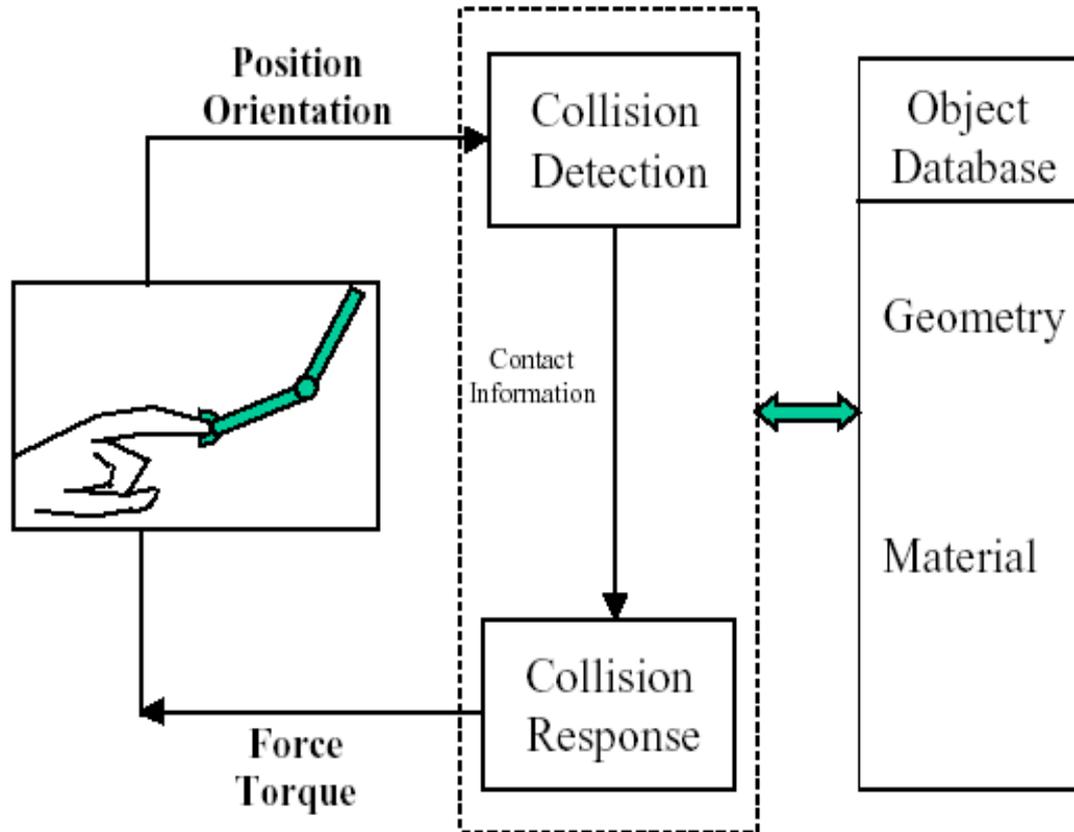
Rendering speed of 1000 Hz

- 1000 Hz is necessary so that the system does not suffer from disturbing oscillations

- Many haptic devices run their control loop at 1000 Hz

- Stable and fast processing is needed when running haptic software

Rendering of haptic and visual loops

- ## Haptic real-time loop (~1000 Hz)

    - Necessary due to the high sensitivity of human touch

    - Not necessary to look at every object in the scene 1000 times per second

- ## Visual scene-graph loop (~60 Hz)

    - Looks at every object in the scene and generates surface instances that are rendered at 1000 Hz

Rendering (1/3)
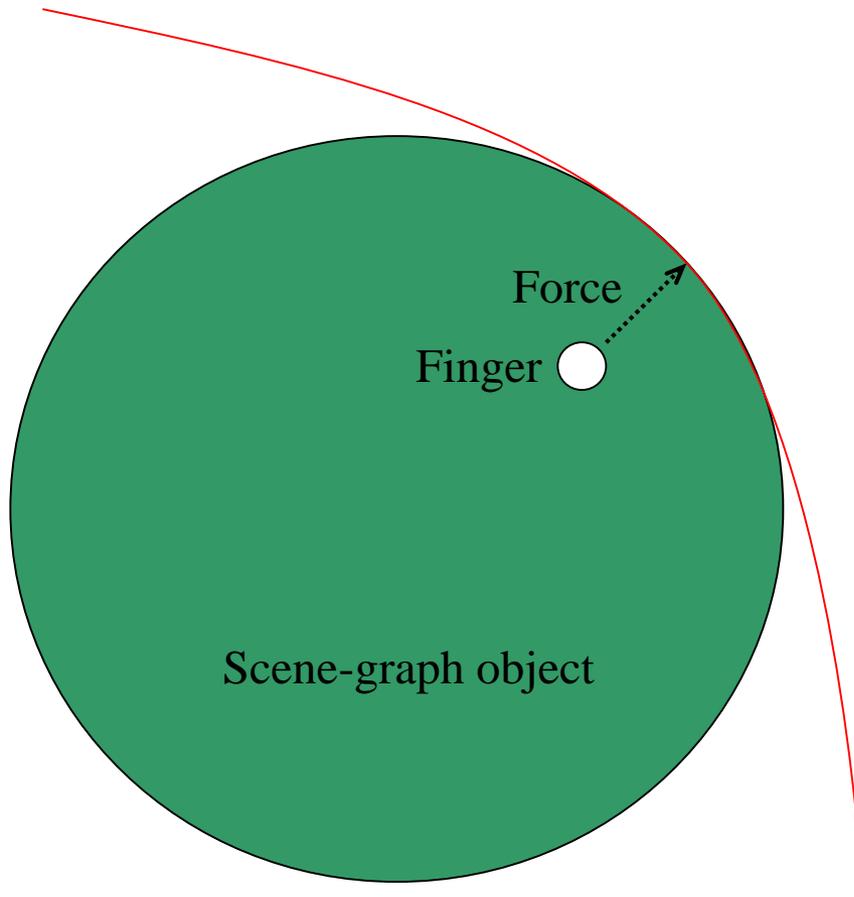
- The real-time "surface" is a parametric surface

- This means that it can be curved to closely match the real surface curvature locally

- The finger is the actual position of the haptic device

Rendering (2/3)

Haptic position

T

S
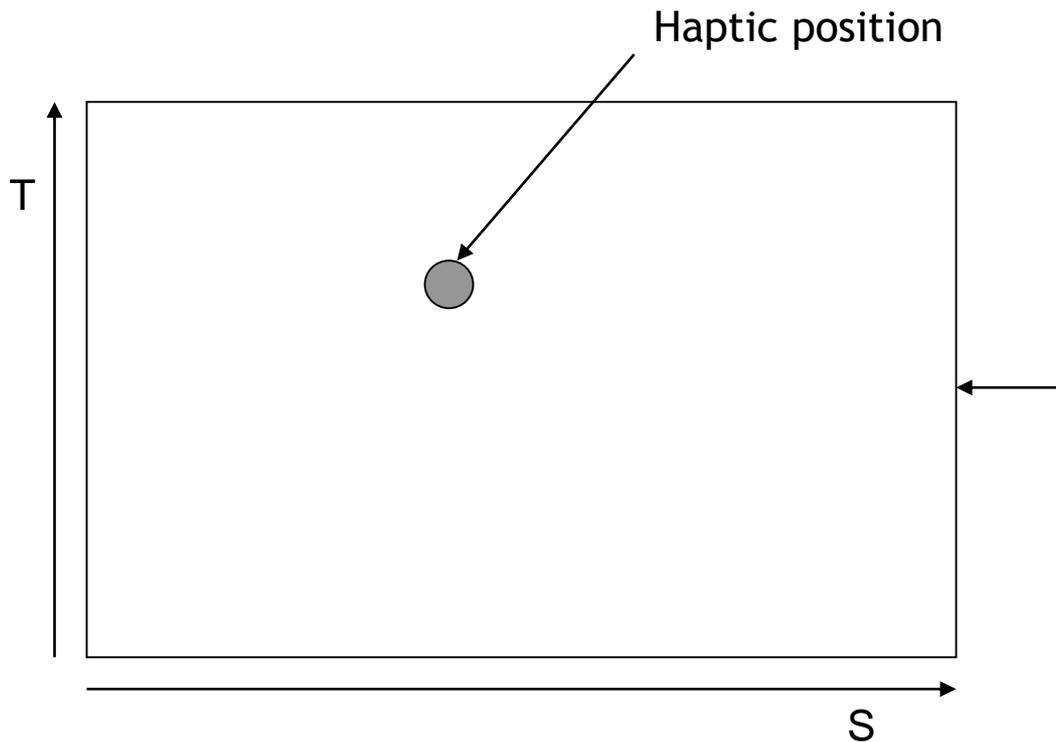
- The real-time "surface" has a 2D coordinate space

- Allows programmers to define haptic surface effects as a function of position and penetration depth

Rendering (3/3)

- 3-DOF haptic devices are rendered in programming APIs using a spherical "proxy"

- The proxy stays on the surface of objects

- Maintained in such a way that it is at the closest point on the surface of an object to the haptic device

PROXY

FINGER
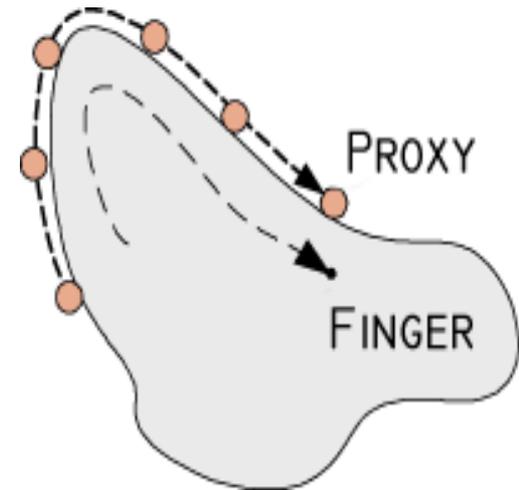
3-DOF haptics

- Output: 3D force → 3DOF haptics

- Limited to applications where point-object interaction is enough
  - Haptic visualization of data
  - Painting and sculpting, some medical applications

Object-Object

Point-Object
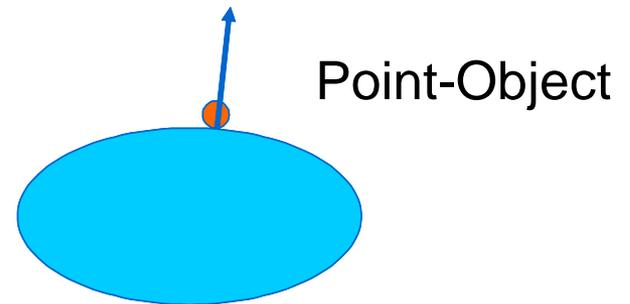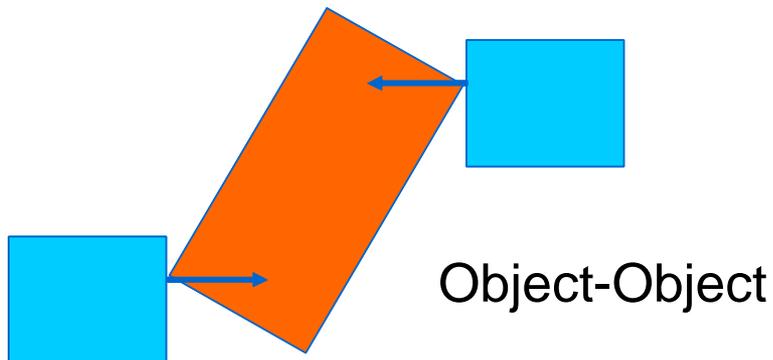
6-DOF haptics

- Output: 3D force + 3D torque

- For applications related to manipulation
  - Assembly and maintenance oriented design
  - Removal of parts from complex structures

- Typical problem: peg-in-the-hole
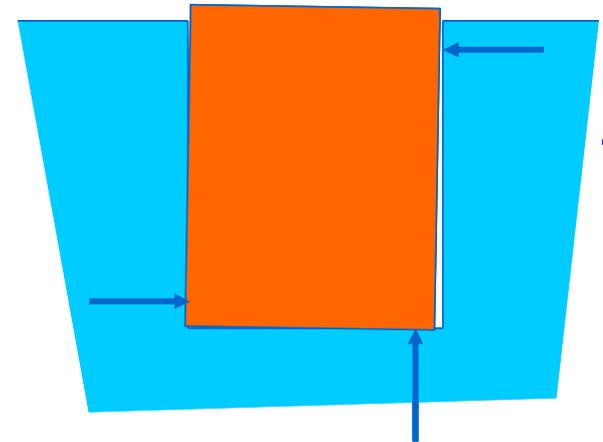
Two types of interactions

1. ## Point-based haptic interactions
   – Only end point of device, or haptic interface point (HIP), interacts with virtual object
   – When moved, collision detection algorithm checks to see if the end point is inside the virtual object
   – Depth calculated as distance between HIP and closest surface point

2. ## Ray-based haptic interactions
   – Probe of haptic device modeled as a line-segment
   – Can touch multiple objects simultaneously when the line touches them

This presentation is partly based on material by the following people:

Pierre Boulanger, Department of Computing Science, University of Alberta

Max Smolens, University of North Carolina at Chapel Hill

Ming C. Lin, University of North Carolina at Chapel Hill

Ida Olofsson, Reachin Technologies AB

Force feedback applications

Medical applications (1/3)

- Haptic modeling and visualization of, for example, different tissues

- No need to use paid volunteers or dead bodies in training
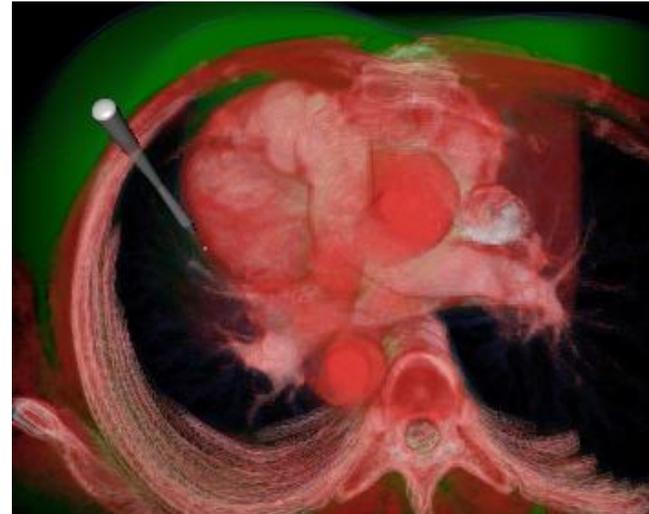
Medical applications (2/3)

- **Especially useful for training of minimally invasive procedures**
  - E.g., laparoscopic operations & needle insertation
  - Provide realistic training

- **Also applications for carrying out remote surgeries have been developed**
  - The best surgeons can perform many similar operations with less fatigue

Medical applications (3/3)

- Bimanual haptic interaction can be simulated in training (Ullrich *et al.*, 2011)

- A scenario with a hand and a needle used simultaneously
  - Separate PHAMTON Omni devices for both hands
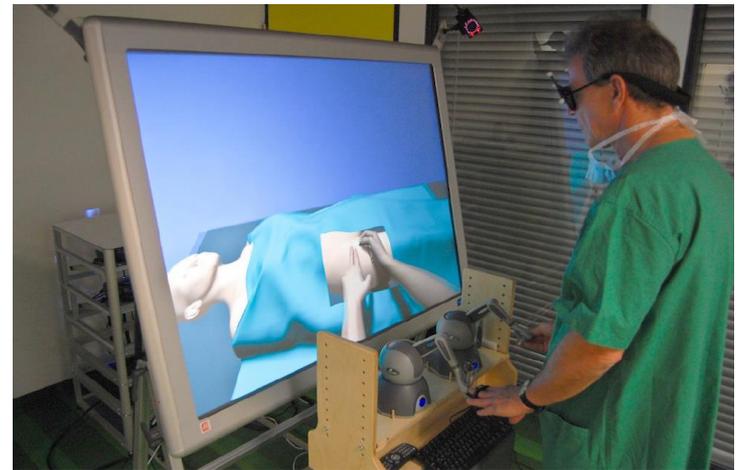
video

Rehabilitation of motor impairments

- For example, supporting weak muscles or removing tremble

- Assisting forces can be reduced gradually once muscle strength increases

(Acosta *et al.* 2011)

Three-dimensional modeling (1/3)

- The user does not just see the object but can also feel it

- Helps to better understand the shape of an object

- Virtual prototyping of new products

Three-dimensional modeling (2/3)

- For example, 3D modeling and production of custom body parts for medical purposes
  - Soft-tissue implants
  - Titanium dental inlays

- Faster than carving models out of wax or clay

Three-dimensional modeling (3/3)

- Using Phantom Omni force feedback devices for virtual sculpting of 3D objects
  - The object surface can be felt already during modelling

- Objects can be 3D printed later on to get a physical version

http://inition.co.uk

Applications for the visually impaired (1/2)

- For example, presenting virtual models of complex structures with a haptic display

- Haptic visualization of data

Applications for the visually impaired (2/2)

- Phantom devices were used in a solar system application (Tanhua-Piiroinen *et al.*, 2008)

- The application allowed visually impaired children to explore the orbits of planets
  - The surfaces (textures) of different planets could also be touched

Applications for teaching

- Haptic application for physics teaching (Tanhua-Piiroinen *et al.*, 2010)
    - Uses a Novint Falcon device

- Presents the periodic table of elements
    - The weight of each element can be felt by selecting it
    - Also, the density of each element can be observed by dropping it into a pool of water