



# Haptic Rendering

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[www.cs.ucl.ac.uk/teaching/VE](http://www.cs.ucl.ac.uk/teaching/VE)

[www.cs.ucl.ac.uk/staff/a.brogni/public/Teaching/VE\\_haptics](http://www.cs.ucl.ac.uk/staff/a.brogni/public/Teaching/VE_haptics)

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# Outline

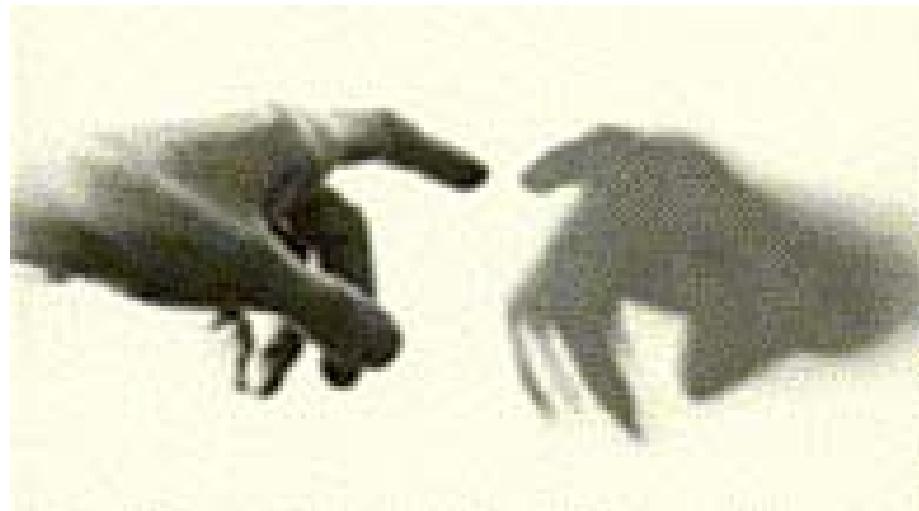
- Intro to Haptic and Haptic Rendering
- Examples of Haptic Devices
- Example of Haptic Applications
- Human Haptic
- Basic of the Haptic Control
- Haptic Rendering
- Math
- Conclusions

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# Haptic ...

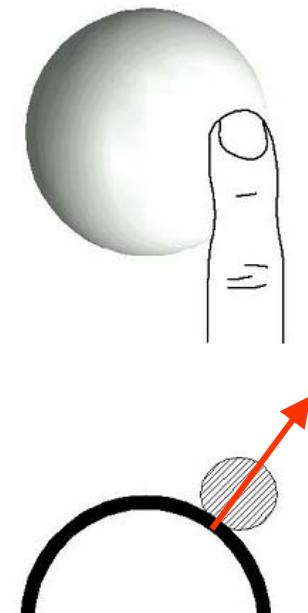
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...means “Use the sense of touch to interact with  
Virtual Environments”



# Haptic Interface ...

... is a robotic device that gives the user a FORCE FEEDBACK from the Virtual Environment



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# Haptic Rendering ...

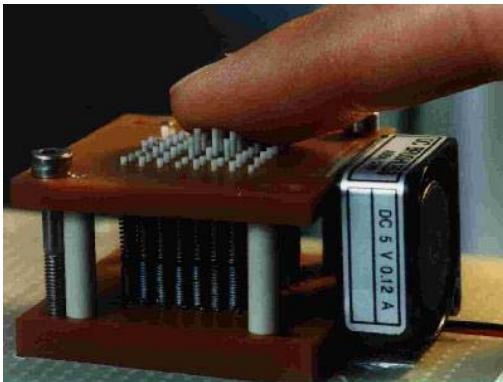
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*“... is the process of **computing and generating forces** in response to user interactions with virtual objects.”*

*(Salisbury, 1995)*

# Haptic Interfaces

## Touching and Grabbing



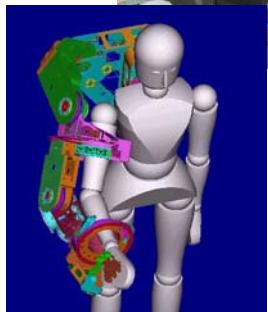
# Haptic Interfaces

## Touching and Manipulating



# Haptic Interfaces

## Complex Systems



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# What a HI is for ?

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- **Natural Interaction**

It provides a natural interaction with the environment

- **Augmented Experience**

It adds another possibility in the interfacing with the environment

- **Touch**

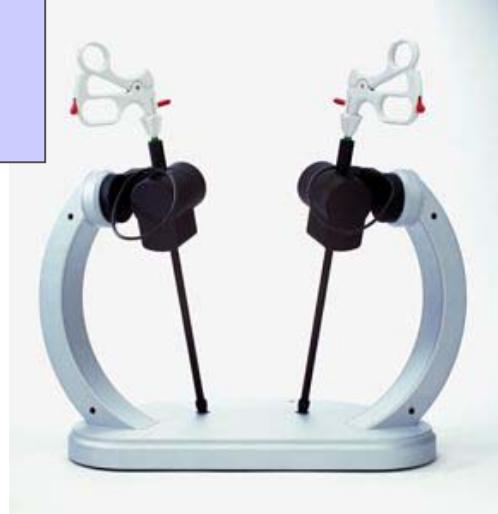
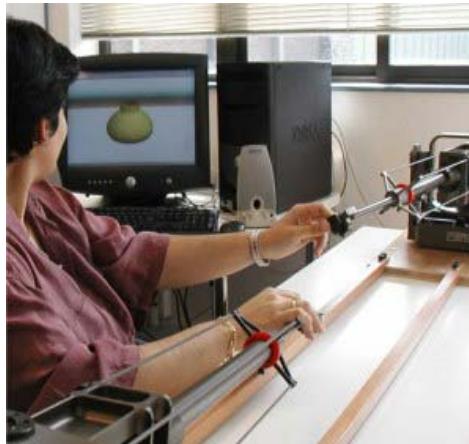
It adds another human sense at the system

# Haptic Applications

## Medicine

### Medicine

- Surgical simulators
- Minimally invasive surgery
- Telemedicine
- Disabled

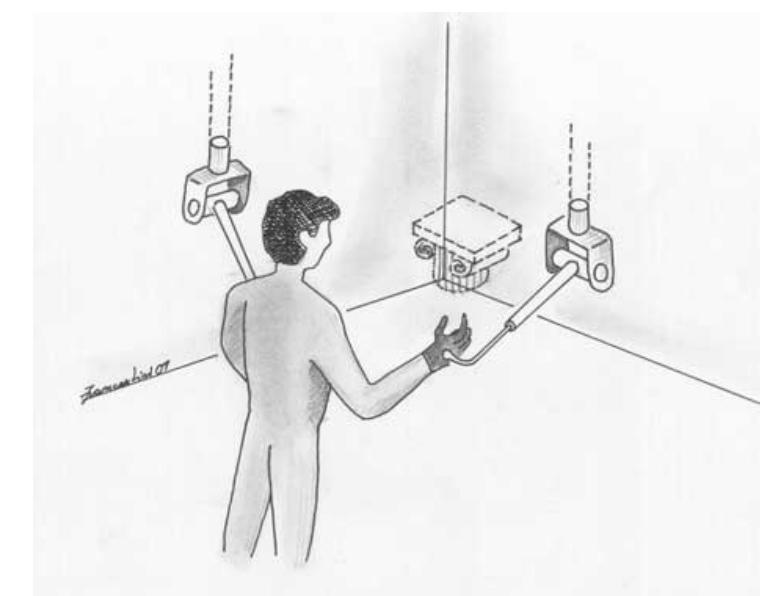


# Haptic Applications

## Arts

### Arts

- Virtual painting and sculpting
- Virtual Museums



# Haptic Applications

## Education & Entertainment

### Education & Entertainment

- Studying complex data sets
- Video Games and Simulators

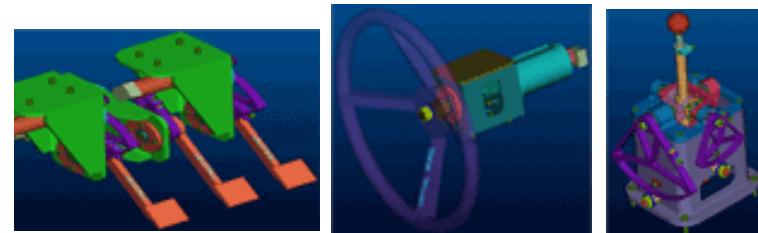


# Haptic Applications

## Industry

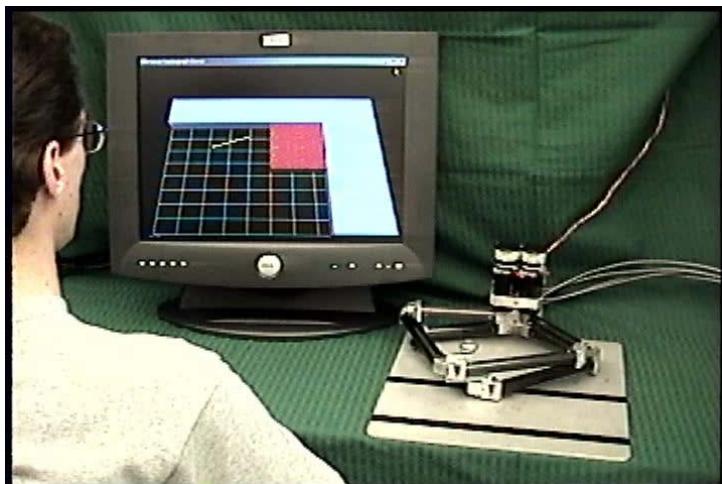
### Industry

- CAD systems
- Virtual prototyping
- Simulations



# Movies

## General



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# Movies

## Surgery

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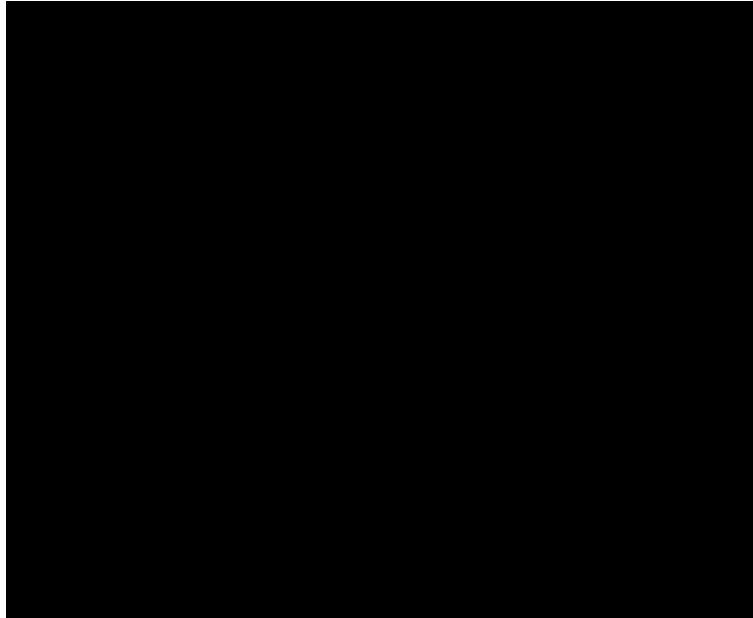


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# Movies

## Entertainment

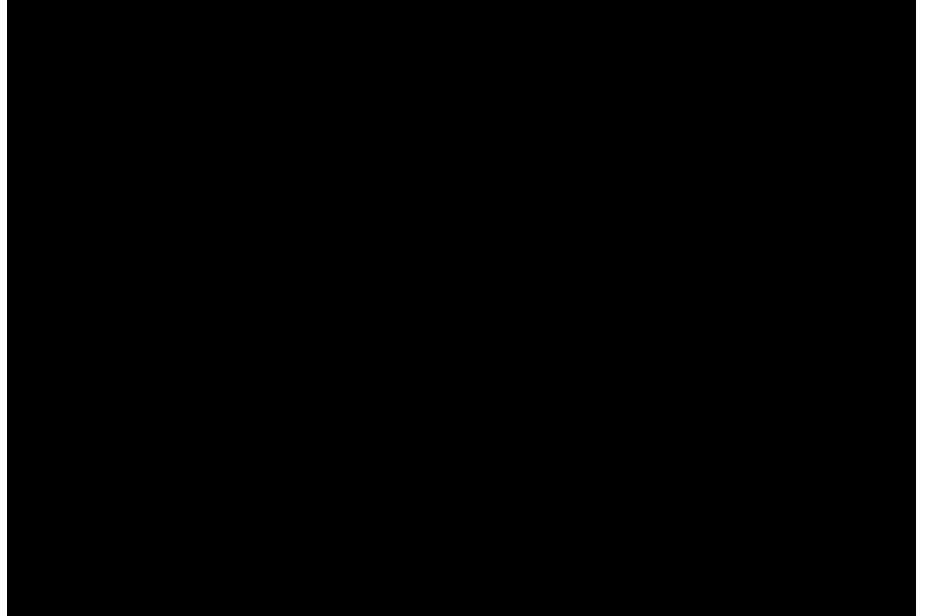
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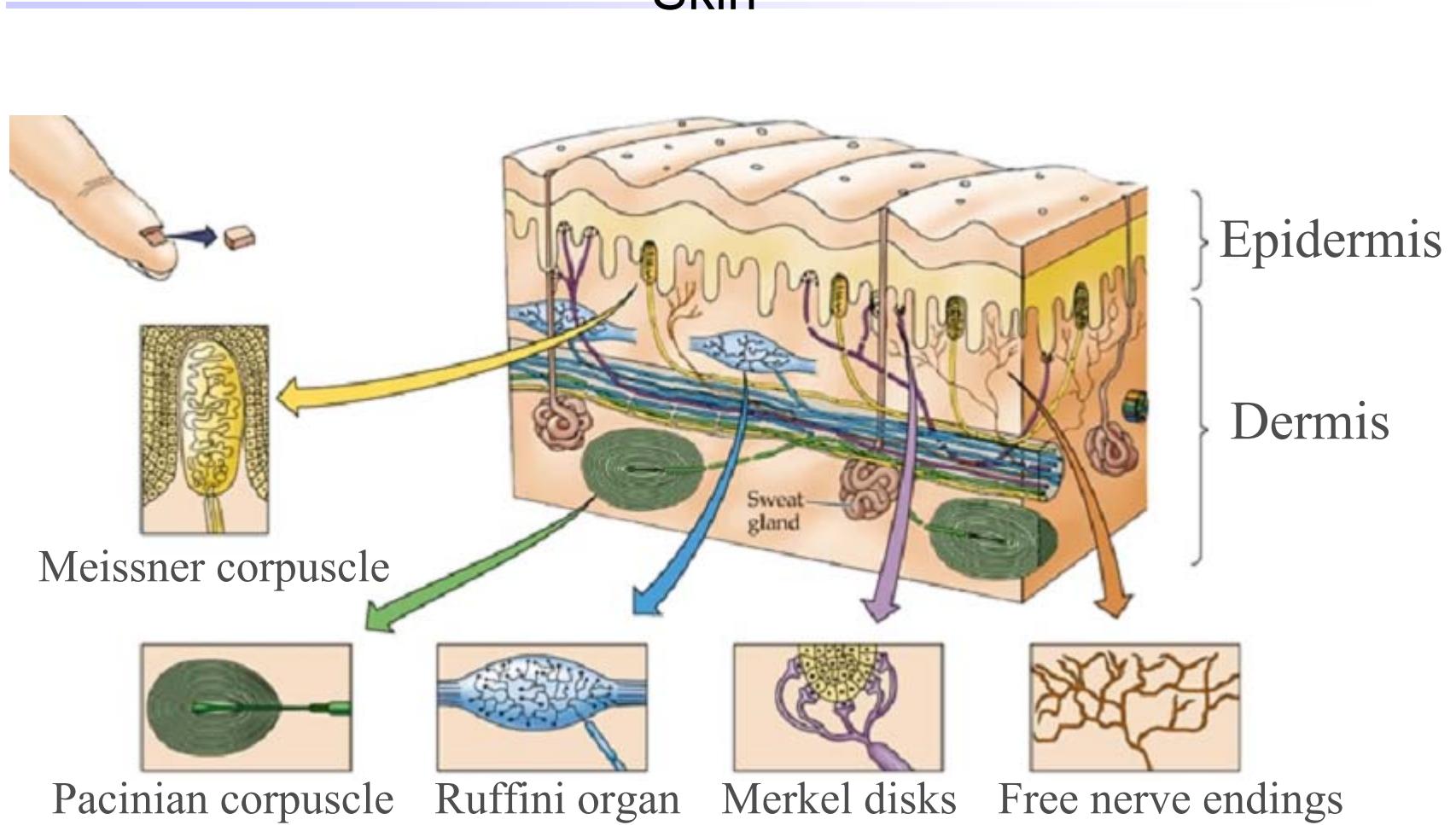
Haptic  
Battle

Painting

Sculpturing

A large black rectangular placeholder image, likely a placeholder for a painting or sculpture image.

# Human Haptic Skin

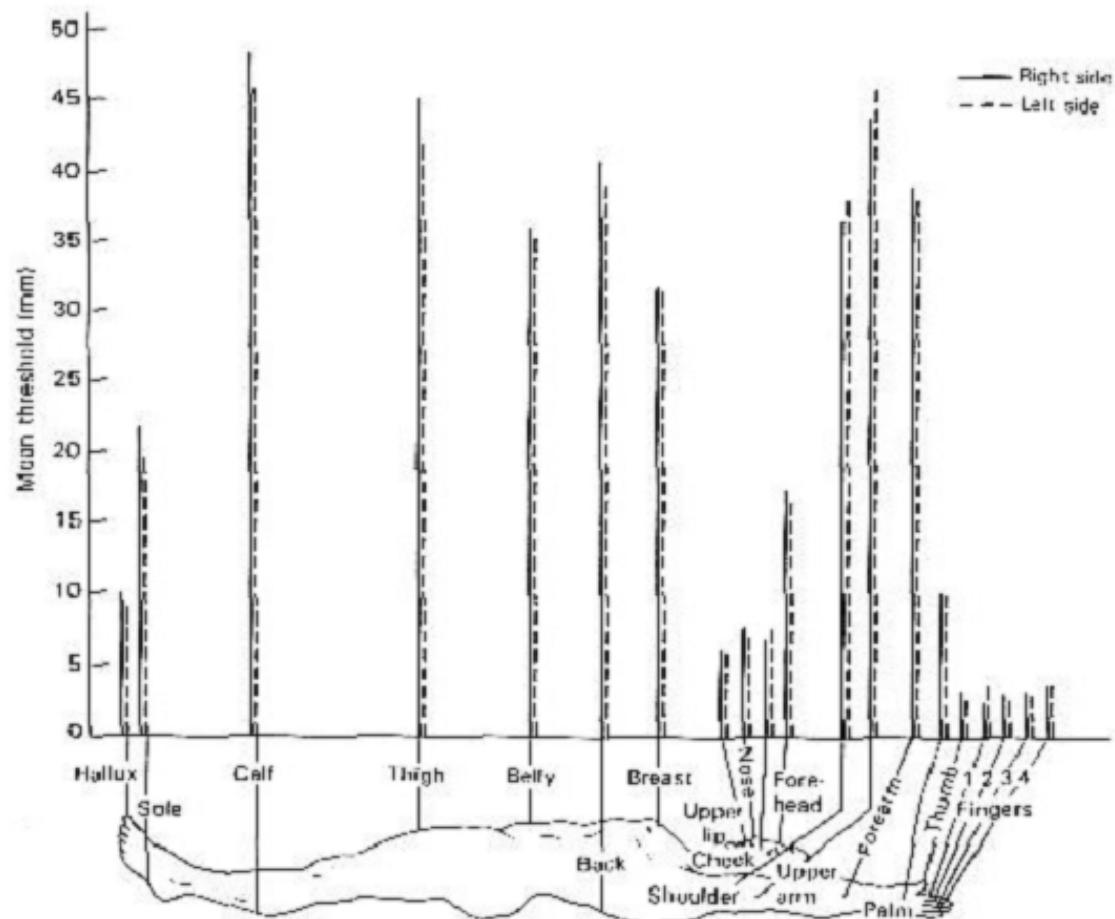


# Human Haptic Receptors

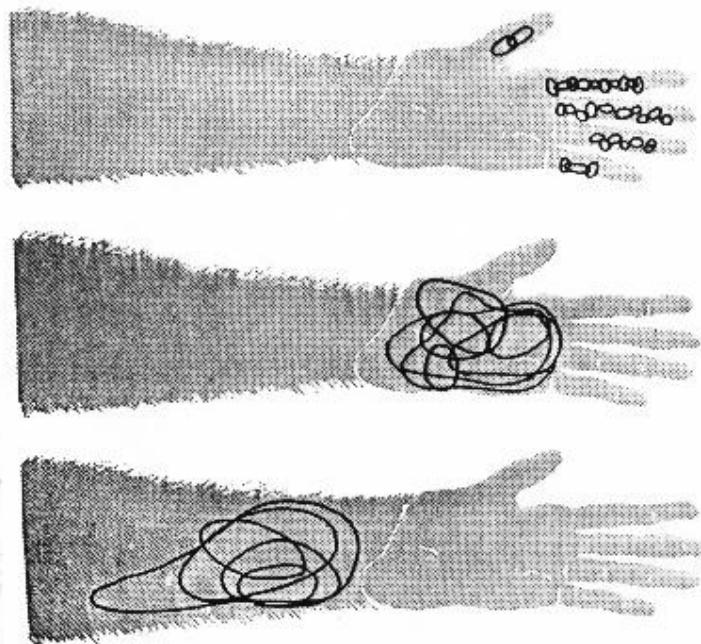
Receptors	Frequency Range	Perception	RF Size
Merkel	0.3-3 Hz	Pressure	Small
Meissner	3-40 Hz	Flutter	Small
Ruffini	15-400 Hz	Stretching	Large
Pacinian	10-500 Hz	Vibration	Large

# Human Haptic

## Spatial Resolving Capacity - Two-points threshold



# Human Haptic Homunculus



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# Human Haptic

## Complementary Channels

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### ➤ TACTILE / CUTANEOUS

- Skin contact with an object
- Slipping, fine textures, small shapes and softness
- Spatial and temporal distribution of forces

### ➤ KINESTETIC

- Perception of one's own body position and motion
- Large shapes, coarse properties of the objects
- Receptors located within the body's muscles and tendons

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# Human Haptic Resolution

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## Kinesthetic Resolution

- 2 degrees for fingers and wrist
- 1 degree for shoulder

## Force exerted by a finger

- 50 to 100 N (Newton) maximum
- 5-15 N during exploration and manipulation

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# Human Haptic

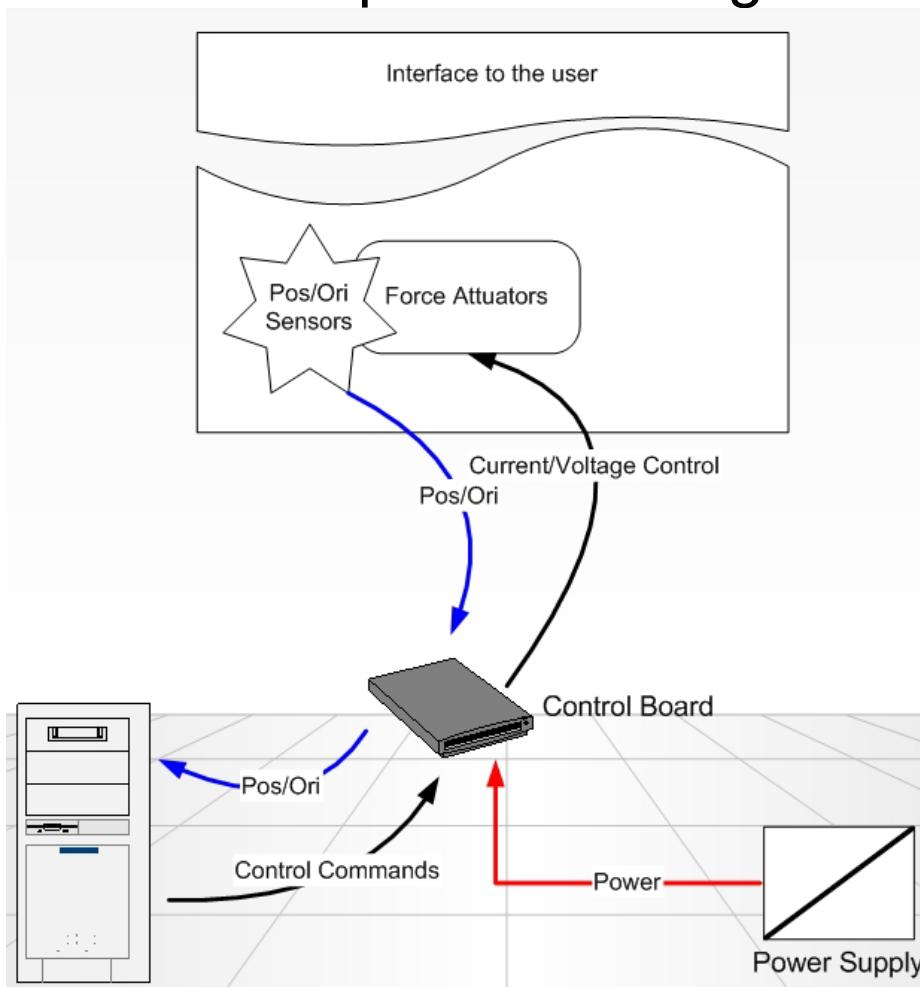
## Property of Objects

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- Geometric ( size, shape ...)
- Material    texture (roughness, stickiness ...)  
                  hardness (compliant)  
                  apparent temperature
- Weight      (total mass, inertia ...)

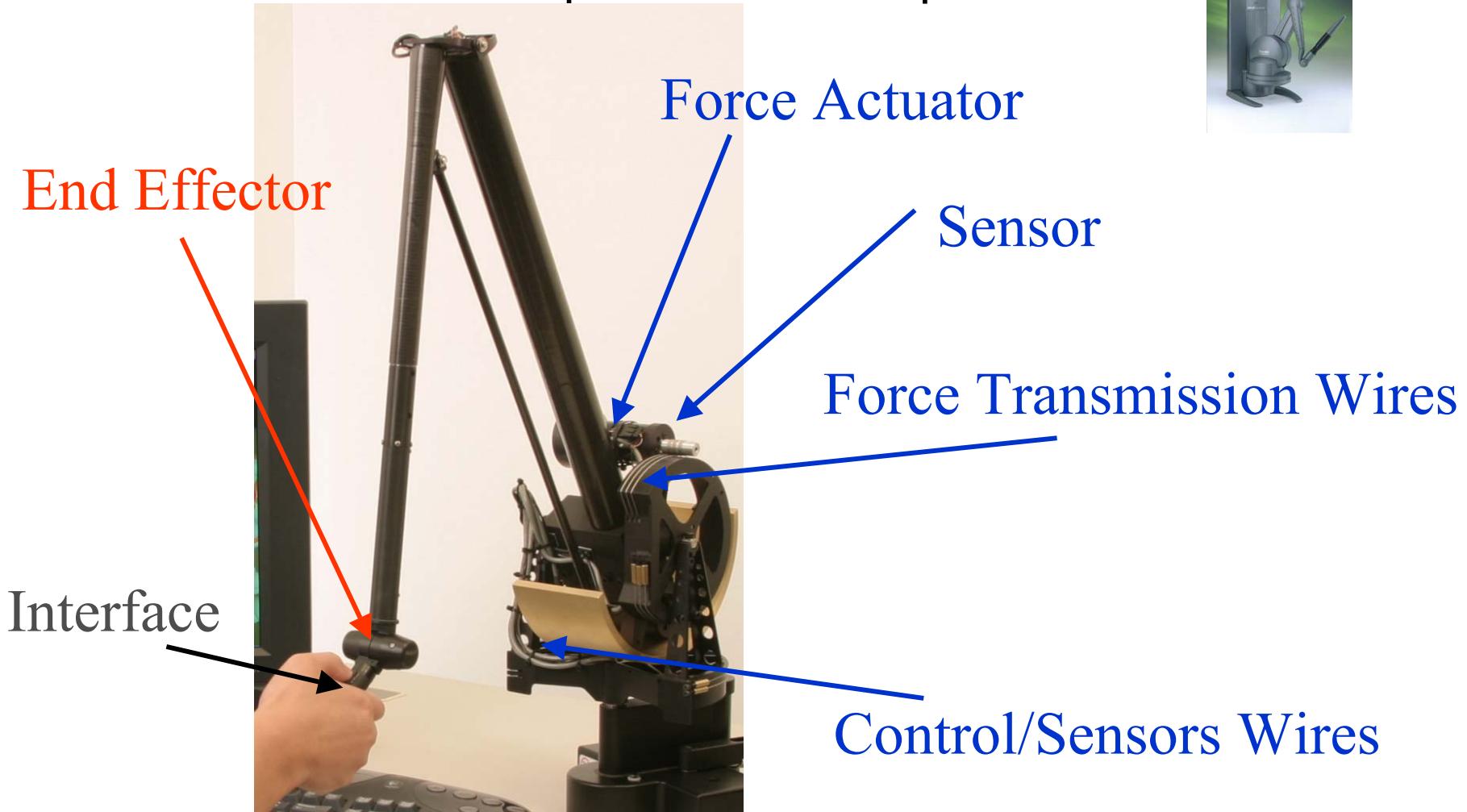
# Haptic Interfaces

## Components - diagram

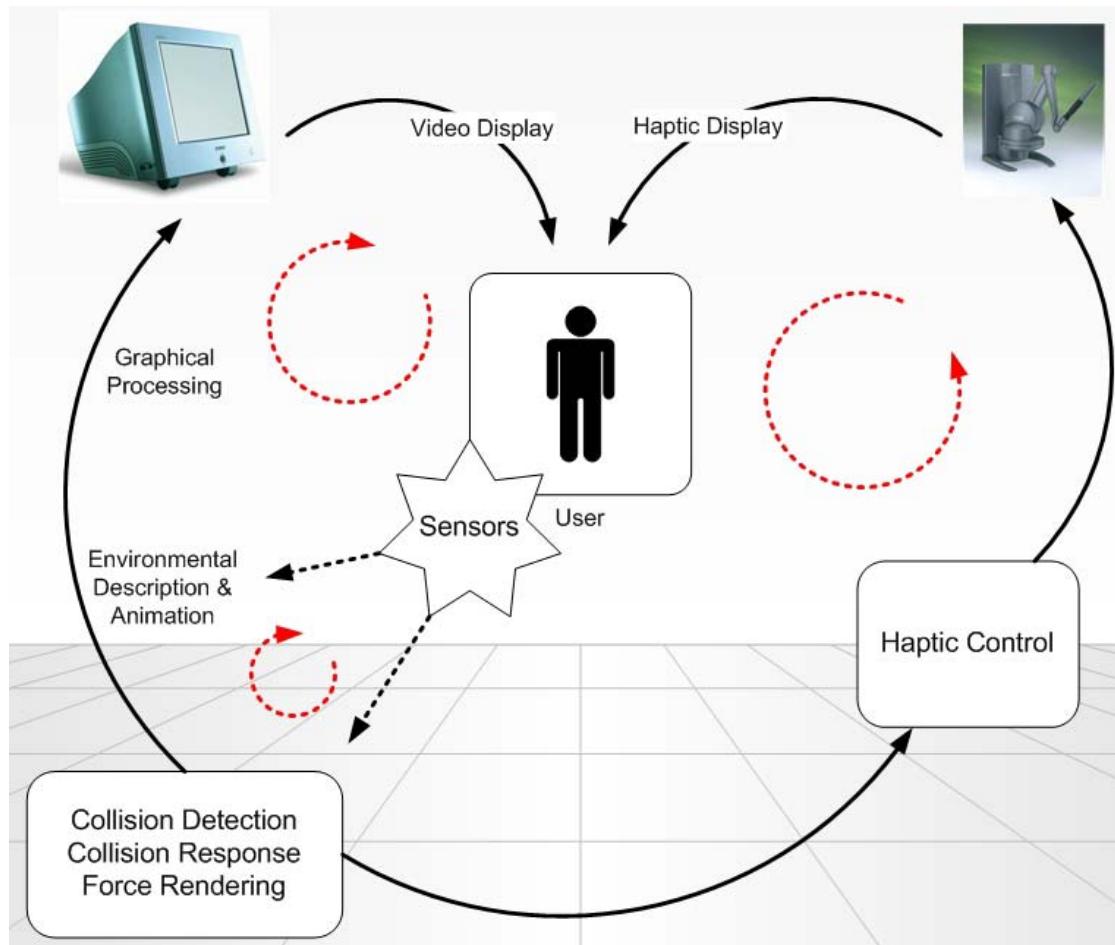


# Haptic Interfaces

Components - example



# Haptic Control Loops

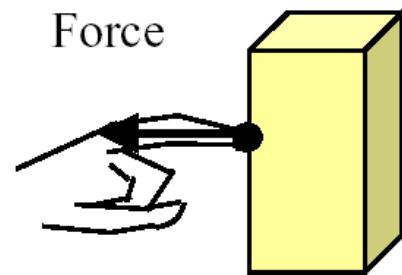


# Haptic Rendering

## Interactions

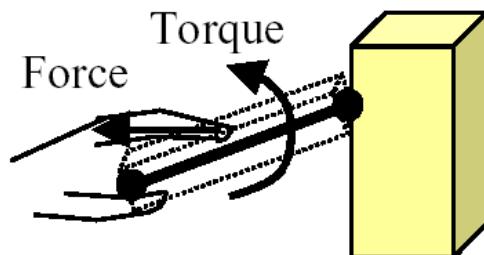
### ➤ Point Based

- Only the end-effector of the device interacts with the virtual surface
- Detection of the position of the end-effector



### ➤ Ray Based

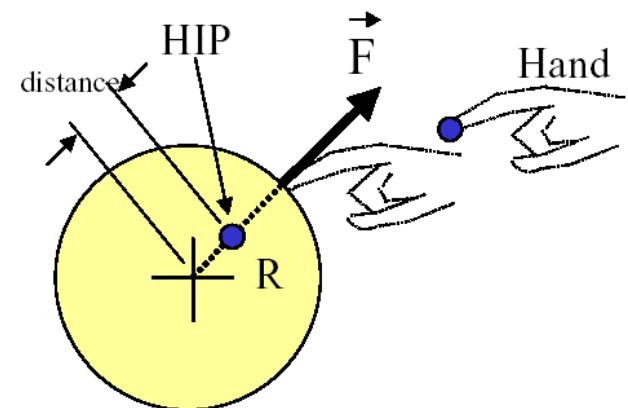
- Torque interactions
- Touch multiple objects simultaneously
- Probe as a linear segment with orientation



# Collision Detection

## General

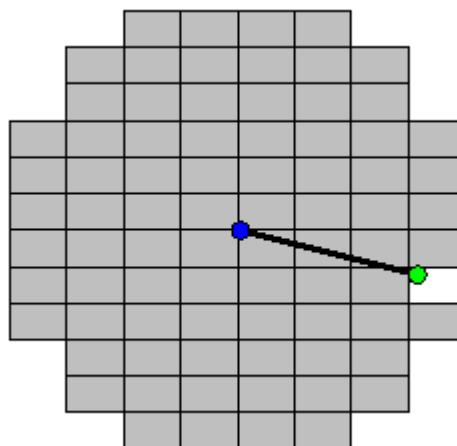
- Detection of the collision between the probe and the virtual object
- Updating rate at least 1 KHz
- Methods:
  - Spatial decomposition
  - Bounding Volume hierarchy
  - Multiresolution
  - .....



# Collision Detection

## Penalty Methods

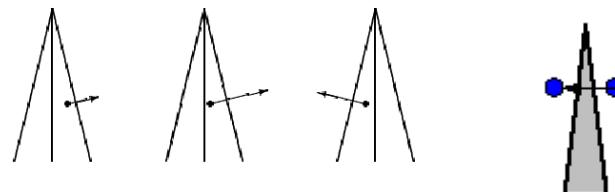
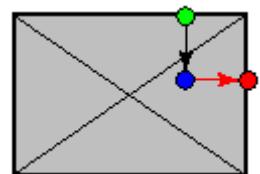
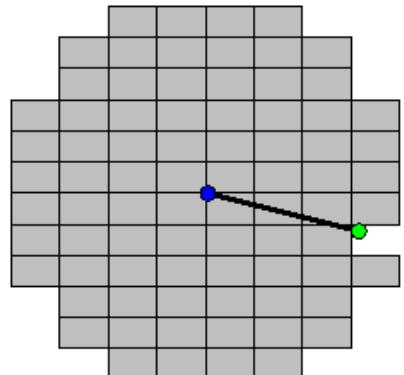
- Determine the feedback force using the penetration depth
  - Work well for simple objects
  - Subdivide the internal volume and associate each sub-volume with a surface



# Collision Detection

## Penalty Methods - problems

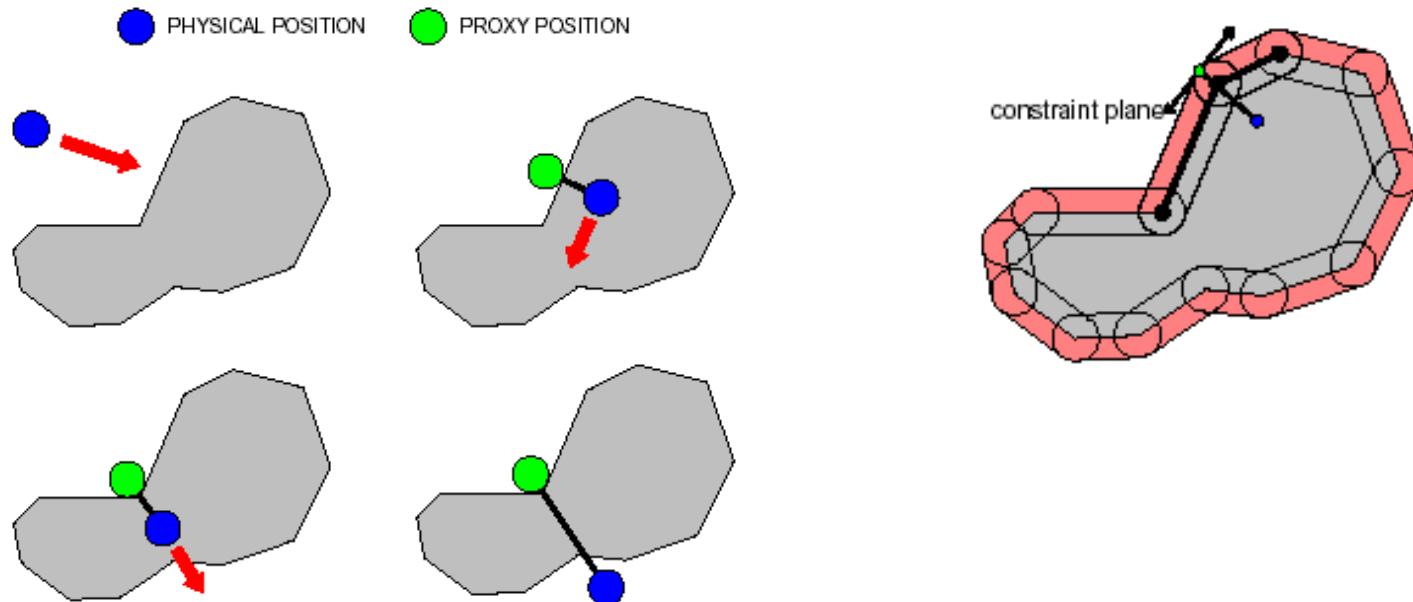
- Lack of locality: difficulty to determine which exterior surface should be associated with a given internal volume
- Force discontinuity: a probe can be attracted by another surface
- Pop-thru: thin objects may have insufficient internal volume to generate constrain and let the probe go through



# Collision Detection

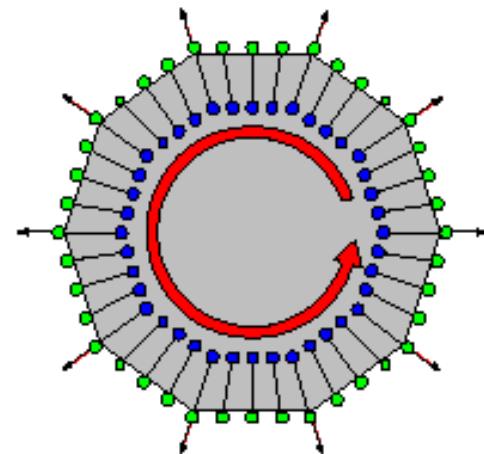
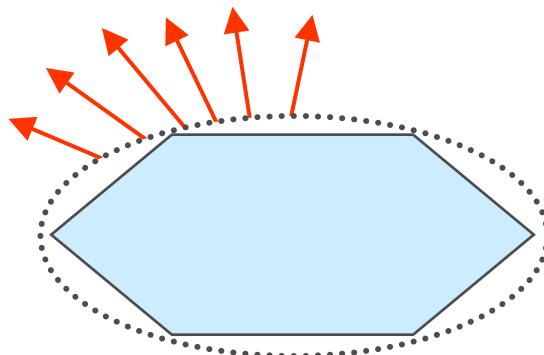
## Constrain Methods

Constrain Methods – they constrain the virtual proxy to remain on the virtual surface



# Force Shading

- ✓ Analogous to the Phong shading for graphics
- ✓ Try to represent the surface smooth and continuous



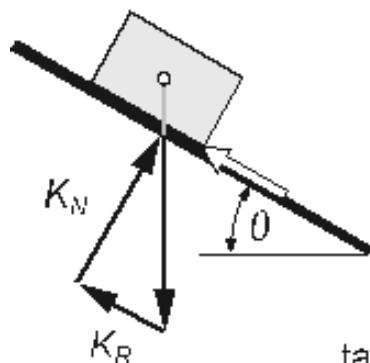
# Surface Friction

what

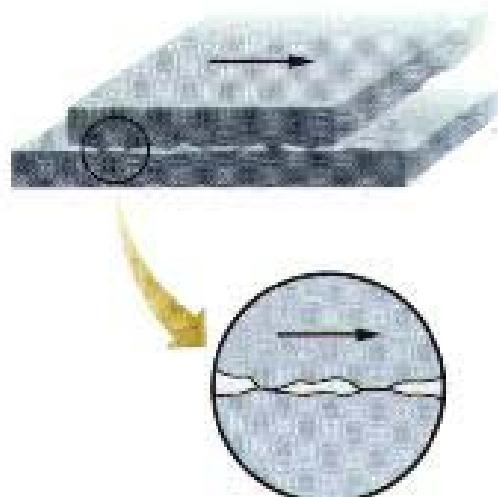


# Surface Friction

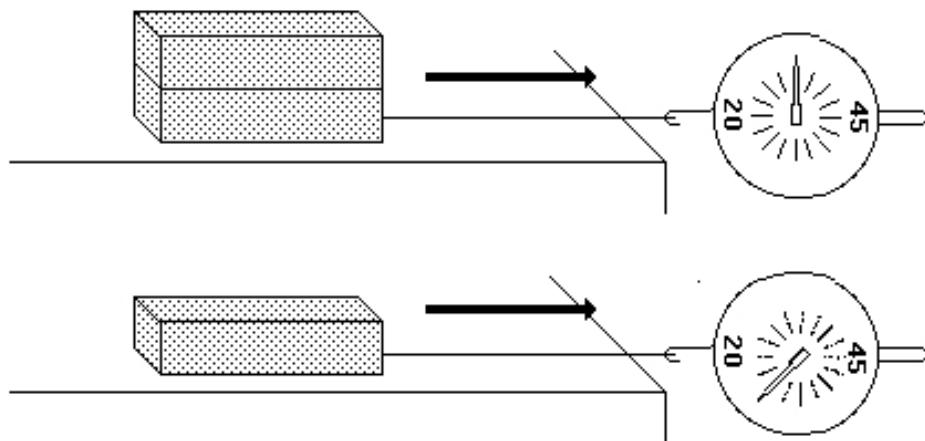
how



$$\tan \theta = \frac{K_R}{K_N} = \mu$$



- Double the mass by stacking identical blocks



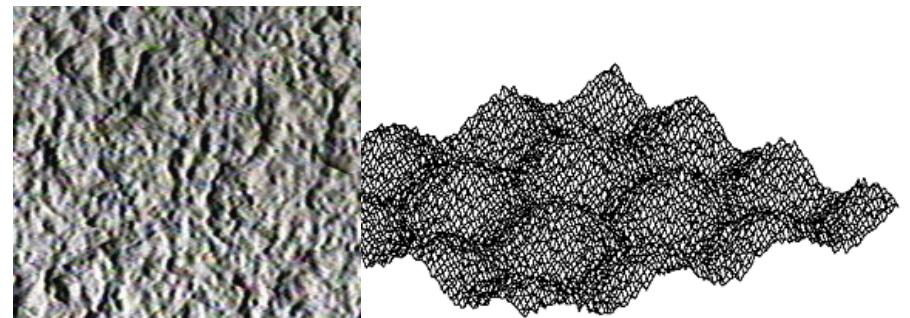
# Surface Friction

when/why

- It happens when the user touch the virtual surface with the probe and move it along the surface
- It's a lateral force opposite the motion
- It's a function of the *FRICTION COEFFICIENT* and the normal force in the contact point
- There are *STATIC* and *DYNAMIC FRICTIONS* (Coulomb)

# Haptic Textures

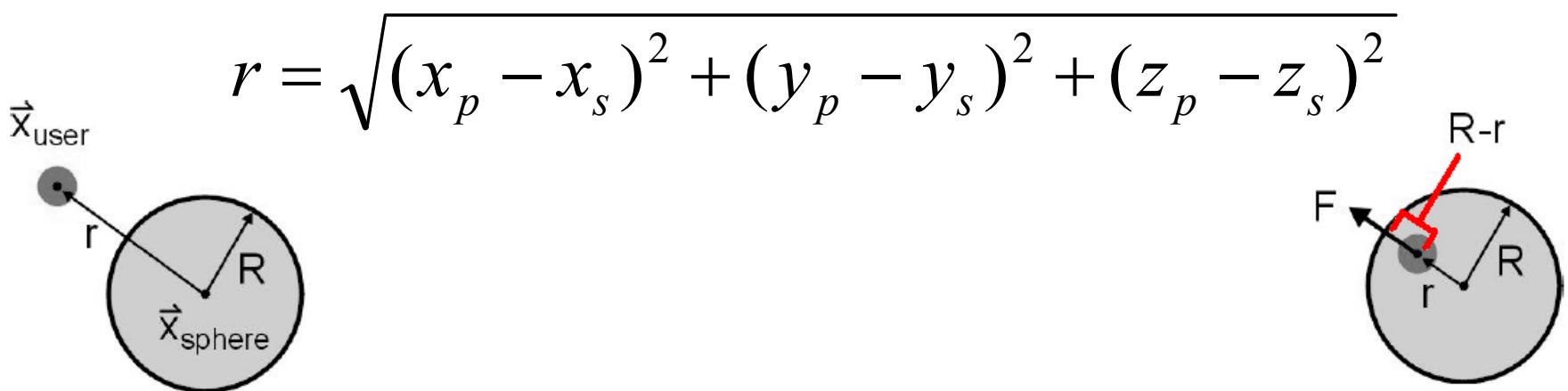
- Flat surface
- Modification of the force feedback based on the position
- Direction and magnitude of the force from different methods:
  - ✓ 2D image data (grey scale / colour scale)
  - ✓ Mathematical functions
  - ✓ Haptic recording
  - ✓ .....



# A little bit of Math ...

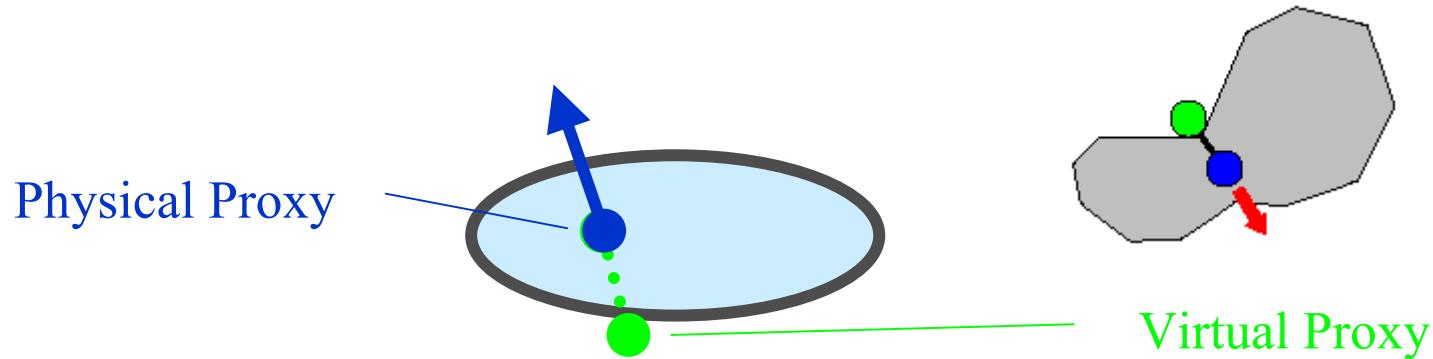
## Simple Force

$$Force = \begin{cases} 0 & \text{for } r < R \text{ (no contact)} \\ k(r - R)\hat{r} + B\hat{v} & \text{for contact/inside (plus surface viscosity)} \end{cases}$$



# A little bit of Math ...

## Constrain Method – Force Model



- Minimize the absolute distance between the virtual (**P**) and the physical proxy (**X**)

$$\|\hat{X} - \hat{P}\|$$

# A little bit of Math ...

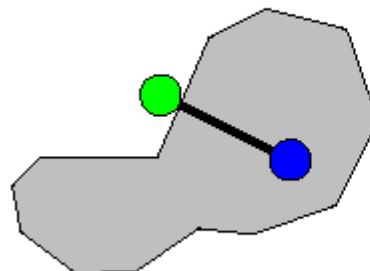
## Friction

$$f_t - \mu_d f_n = m\ddot{x} + b\dot{x}$$

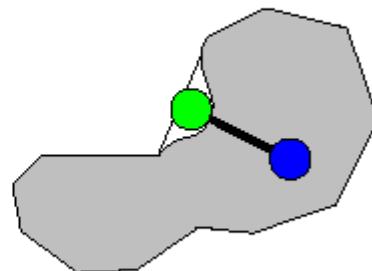
This sets the limit of the proxy's movement

$f_t$  tangential component of the force  
 $f_n$  normal component of the force  
 $m$  mass of the object (approaching to zero)  
 $b$  viscous term  
 $\mu_d$  coeff. Of the Coulomb friction

● PHYSICAL POSITION    ● PROXY POSITION



STIFF



SOFT

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# Summary

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- Haptic adds another sense to the Virtual Reality
- Human Feeling has too many variables
- Hardware is various
- Software control has a lot of math
- Haptic is complex !!!