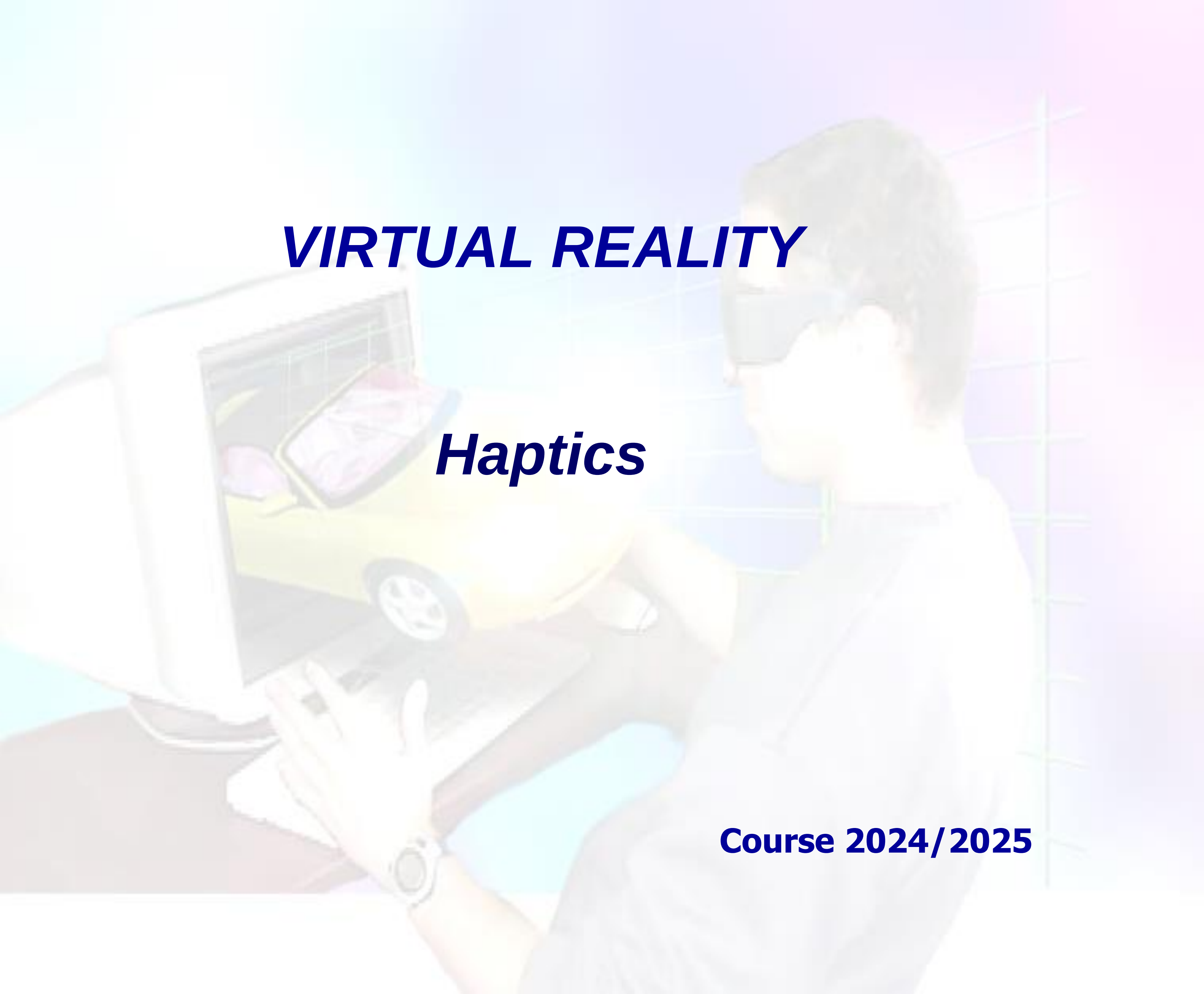


VIRTUAL REALITY

Haptics

Course 2024/2025

Overview

1. Definitions
2. The sense of touch
3. Haptic perception
4. Tactile simulation
5. Haptic devices
6. Haptic rendering
7. Applications

Definitions

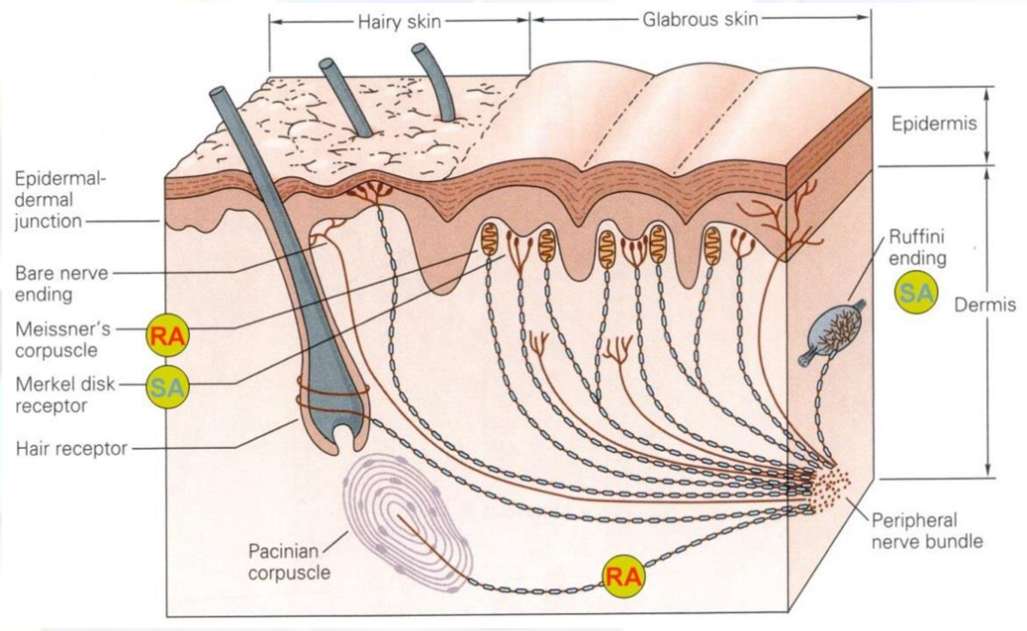
- ***Tactile***
  - Pertaining to sensory information derived from cutaneous inputs (i.e., via skin receptors)
- ***Kinesthetic***
  - Pertaining to sensory information from proprioceptors concerning limb movement and orientation of body parts
- ***Haptic***
  - Pertaining to sensory information derived from both tactile and kinesthetic receptors, typically involves active touch

Definitions

- ***Haptic interface***
  - A user interface permitting human to have haptic interaction with real or virtual environments
- ***Haptic device***
  - An interaction device actively producing haptic feedback

The sense of touch

- ***Touch:*** feeling caused when the skin receives a mechanical, heating, chemical or electrical stimulus
  - Thermoreceptors: they respond to the heating changes
  - Mecanoreceptors: they respond to a mechanical action (force, vibration, sliding)
  - Nocioreceptors: they transmit pain/ache



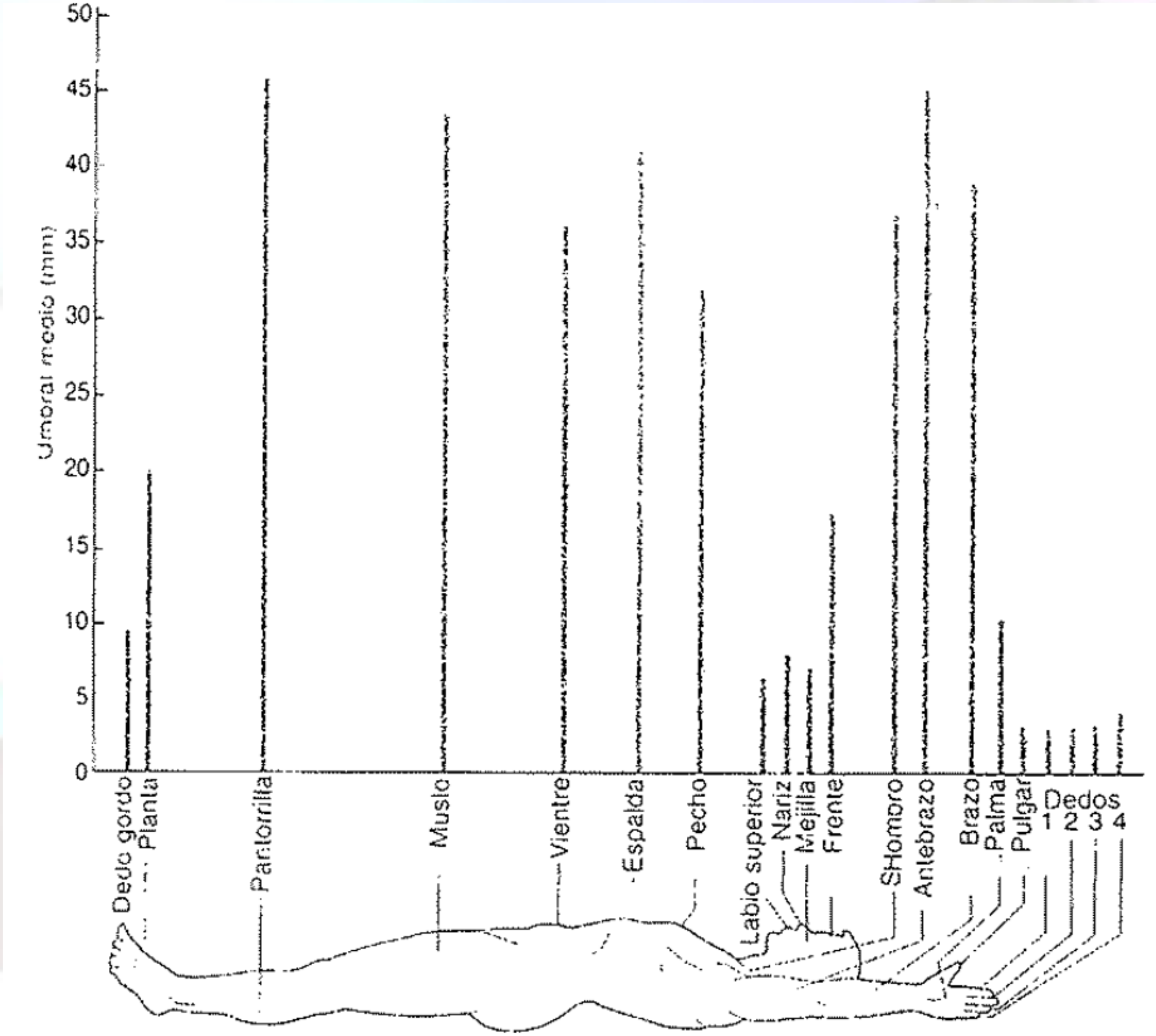
The sense of touch (II)

- *Sensorial accomodation:* it quantifies the variation on time of the electrical discharge number generated by a certain receiver in response to a stimulus.
  – slow accomodation
  – fast accomodation (glasses, gloves)

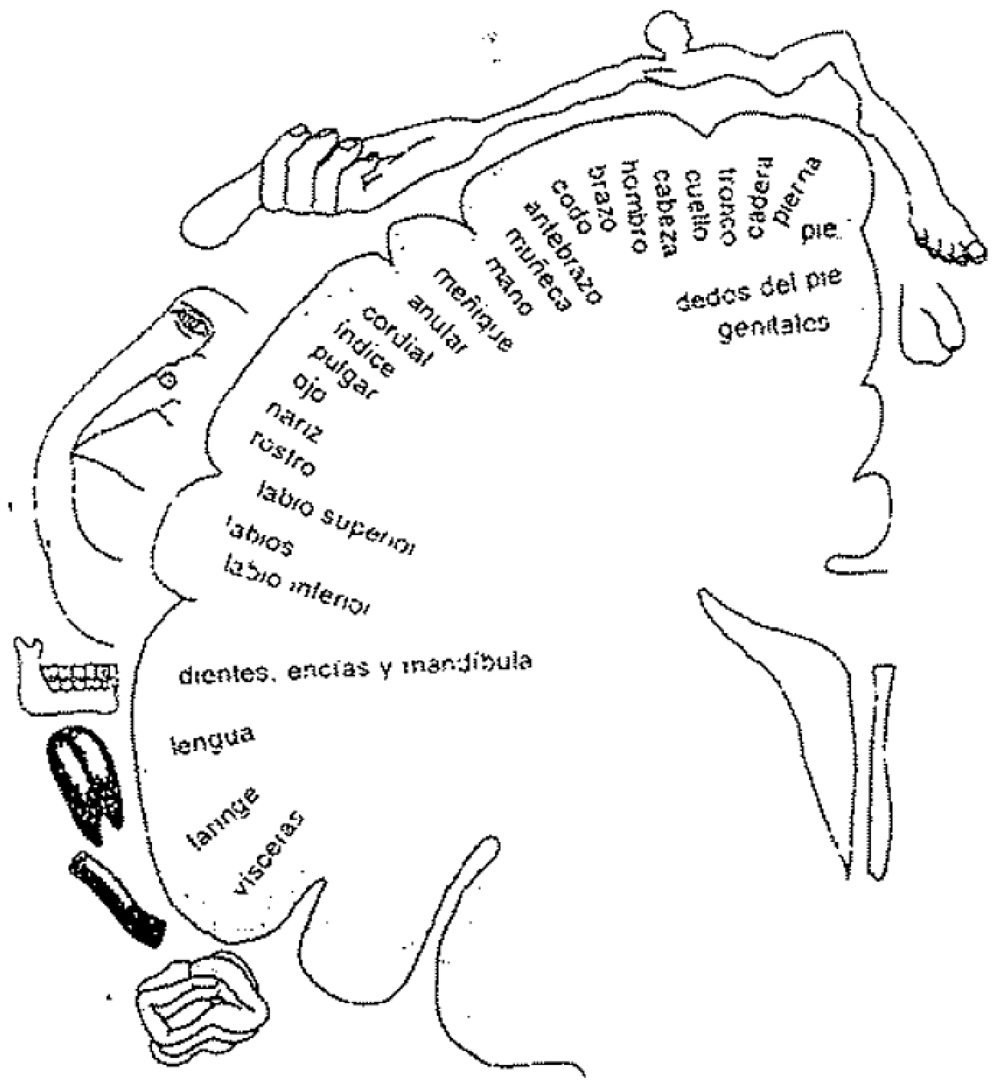
The sense of touch (III)

- *Spatial resolution:* The reception field is defined as the area where a stimulus can excite the receiver (between 1-2 mm^2 and 45 mm^2)
  - it depends of the body part (lower leg and leg around 45 mm^2, while hand fingers between 1 and 2 mm^2)
  - directly related with how big is the area of the brain that interpret the stimulus (higher spatial resolution, bigger area in the brain)

The sense of touch (IV)



The sense of touch (V)



The little man inside the brain

The sense of touch (VI)

- *Time resolution:* minimum time needed to be able to distinguish between two consecutive successes
  - aproximately around 5ms, much shorter than the one of the view, 25ms (“hand is much faster than eye”)
  - But in order to recognize the order the stimuli have been produced it requires 20 ms aprox.
  - Welch & Warren (1986): response to a touching stimulus = 0.11 s, but to recognize braille code response = 0.87-1.56 s

The sense of touch (VII)

- *Propioception:* sense in charge of inform of the position the body parts have
- *Cinestesia*: feeling that gives information of their movement
  - the resolution is mesured in grades and indicates the difference of angle which is non perceived as a change of position in a body join (the hip has the biggest precision, while the foot fingers the smallest)

The sense of touch (VIII)

- *Passive touch*:
  - feeling when an object touch the skin (only stimulates the cutaneous receivers, non owned movement).
- *Active touch:*
  - feeling produced when we touch in an active form an object (push buttons, slide over surfaces, …)
    - active better to identify objects by touching

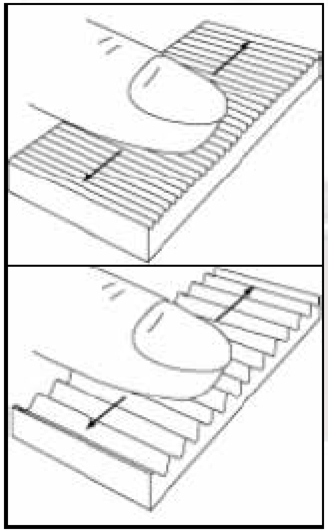
The sense of touch (IX)

- ***Touch is not an absolute sense***
  - Several factors affect the touch sensitivity:
    - Age
    - Sex
    - Individual differences
    - Attention, fatigue, mood, stress
    - Diseases, disabilities
    - Training

$\Rightarrow$ *Scalability is an important factor in tactile interfaces!*

Haptic perception

- ***Haptic perception*** integrates somatosensory information in recognizing objects
  - Touch mediates material properties (e.g., texture, hardness & temperature)
  - Proprioception provides spatial and motor information (e.g., object geometry & hand position)



- The perceived frequency of the grating depends on
  1) The physical frequency of stimulation, and
  2) Information about how fast the finger is being moved across a surface

Haptic perception (II)

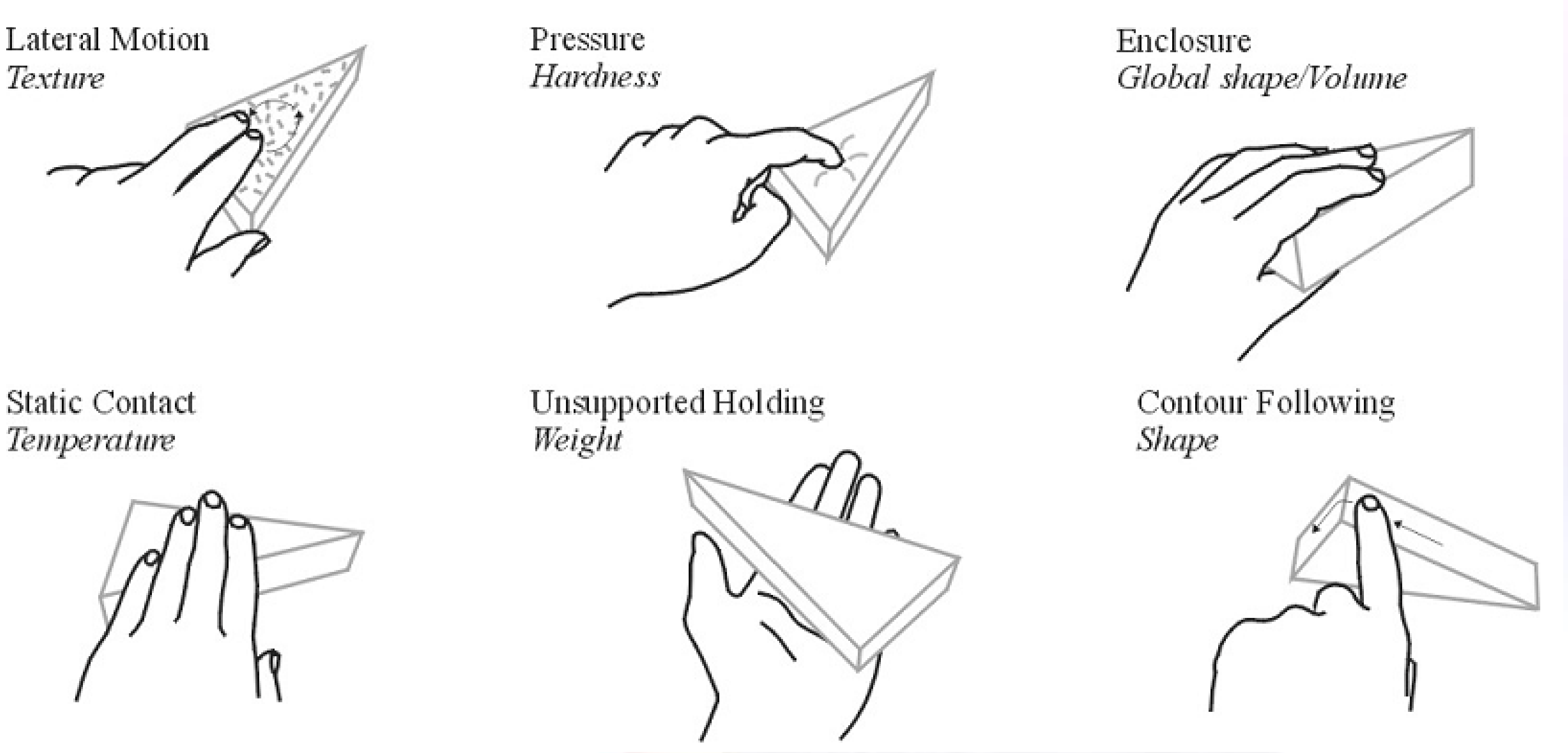
- Vision vs. touch simplified:
  - Vision more capable of providing geometric information & general picture
  - Touch more effective in providing material information & fine surface details
- Different strategies for touching
  - Active touch (focus on the object properties)
  - Passive touch (focus on the sensation experienced)

Haptic perception (III)

- “The great cookie-cutter experiment” by Gibson (1962)
  - Experimenter pushes a cookie cutter onto participant’s palm
    - $\Rightarrow$ 49% correct identification
  - Participant actively feels cookie cutter with the palm
    - $\Rightarrow$ 95% correct identification
- Demonstrated that active exploration is essential in our ability to perceive objects in the physical world

Haptic perception (IV)

- Exploratory procedures defined by Lederman & Klatzky(1987)
  - These stereotypical ways of touching enhance the relevant perceptual information



Tactile simulation

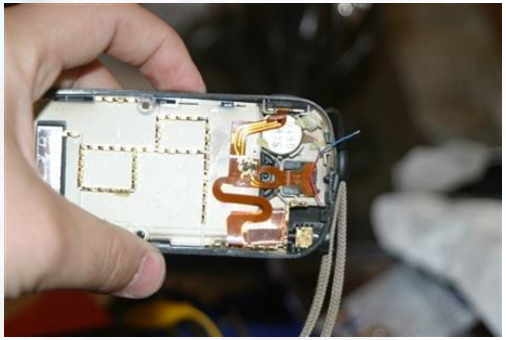
- The tactile sense can be stimulated using a variety of different methods
- These methods include:
  - Skin deformation
  - Vibration
  - Electric stimulation
  - Skin stretch
  - Friction (micro skin-stretch)
  - Temperature

Tactile simulation (II)

- There are several different technologies used in tactile interfaces
  - Vibrating motors
  - Linear motors
  - Solenoids
  - Piezoelectric actuators
  - Pneumatic systems
  - ... whatever causes an effect can be used
- Possible actuator configurations
  - Single element
  - Multiple elements (an array/matrix)

Tactile simulation (III)

- ***Vibrating motors***:
  - How they work:
    - Applies motion either directly to the skin or through mediating structure
    - Provide relatively small-amplitude vibration (linear or rotary)
    - Used singly or in arrays
  - Most common types
    - DC-motors with an eccentric rotating mass
    - Voice coils

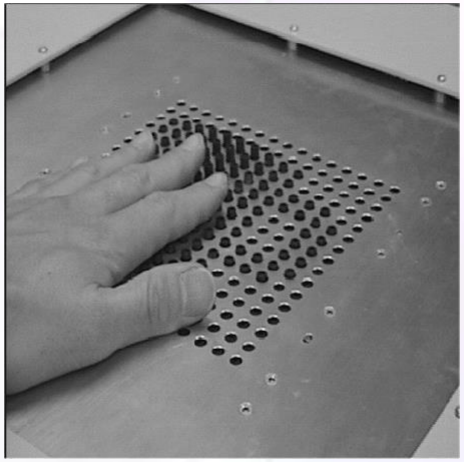


Tactile simulation (IV)

- ***Vibrating motors***:
  - Advantages:
    - Simple, existing technology
    - Relatively inexpensive
    - Easily powered and controlled
    - Quite small power consumption
  - Disadvantages:
    - Not very expressive feedback
    - Vibration can sometimes be irritating
    - Can be hard to miniaturize efficiently

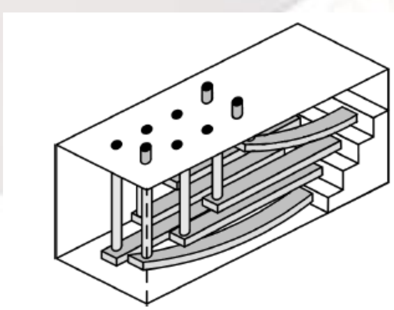
Tactile simulation (V)

- ***Linear motors:***
  - How they work:
    - Pins in an array are actuated independently
    - The actuated pins contact the surface of the skin
  - Advantages:
    - Simple, readily available
    - Continuously positionable, fast movement
    - Versatile: static pressure, vibration, shapes
  - Disadvantages:
    - Very difficult to pack tightly
    - Relatively expensive (several motors per device)



Tactile simulation (VI)

- ***Piezoelectric actuators:***
  - How they work:
    - Single or multilayer ceramic elements
    - An element expands/bends when voltage is applied
    - Multiple layers can be used to amplify the effect
  - Properties:
    - Very large forces but small motions
    - One element typically around 0.2-1.0 mm thick
    - Resolution for frequencies ~0.01 Hz



Tactile simulation (VII)

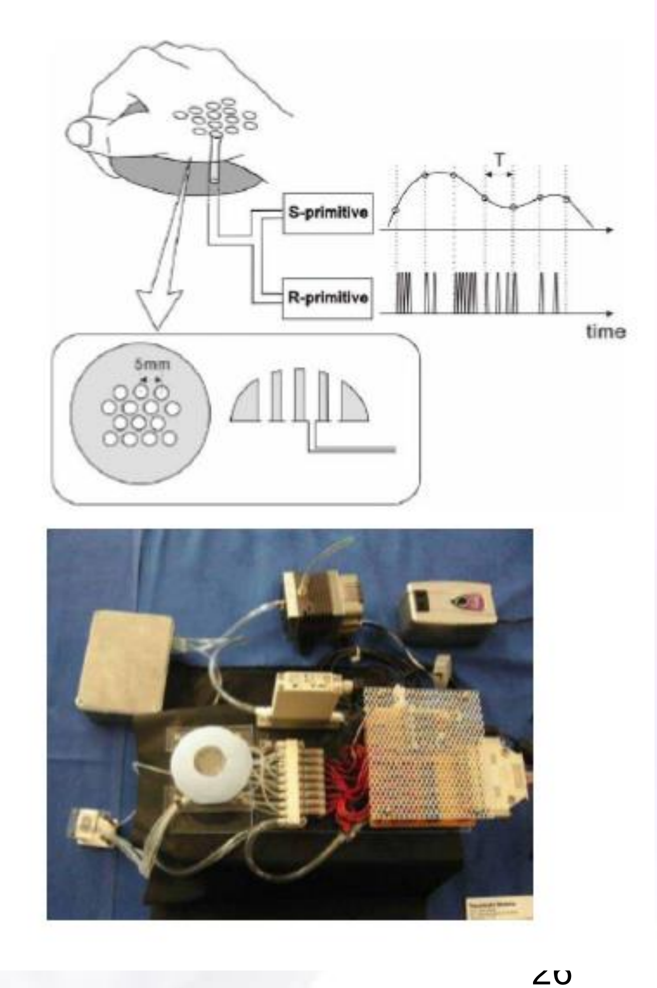
- ***Piezoelectric actuators:***
  - Advantages:
    - Usually small in size
    - Potentially inexpensive in large volumes
    - High frequency and static modes
    - Very fast response time
    - Low power consumption
  - Disadvantages:
    - Dynamics: small displacements require accurate amplification
    - High driving voltage

Tactile simulation (VIII)

- ***Pneumatic systems:***
  - Three possible output modes based on skin indentation (and vibration)
    - Suction
    - Air-pressure
    - Vortices
  - How it works:
    - Technologies: fillable air-pockets, air jets, suction holes
    - Vibratory rates: typically 20-300 Hz
    - Static pressure with sealed pockets

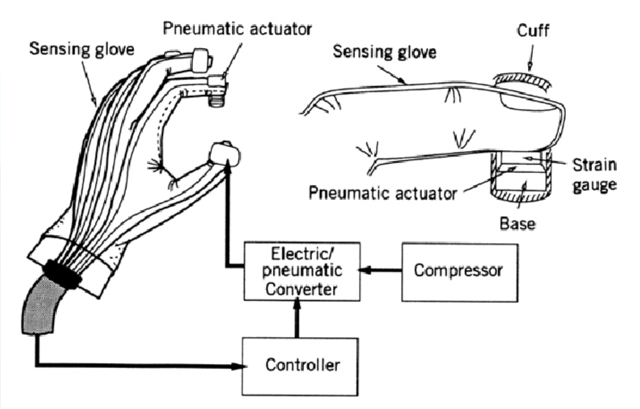
Tactile simulation (IX)

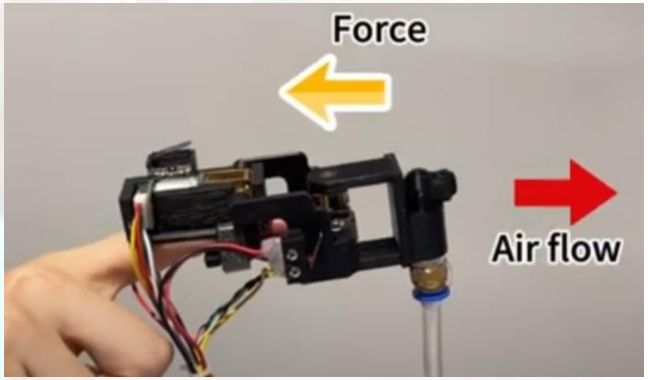
- ***Pneumatic systems: suction***
  - Draws air from a suction hole creating an illusion that the skin is pushed
    - Very low spatial resolution (only appropriate for the palm)
  - Two basic patterns of stimulation (large holes and small holes)
    - Need for regulation of air pressure (= lots of equipment)



Tactile simulation (X)

- ***Pneumatic systems: air-pressure***
  - DataGlove
    - Bandwidth of 5 Hz, amplitude & frequency modulated
  - Teletact II
    - 29+1 air pockets (40 tubes to control the air-pressure)
    - Object slippage (fingers) + force feedback (palm)



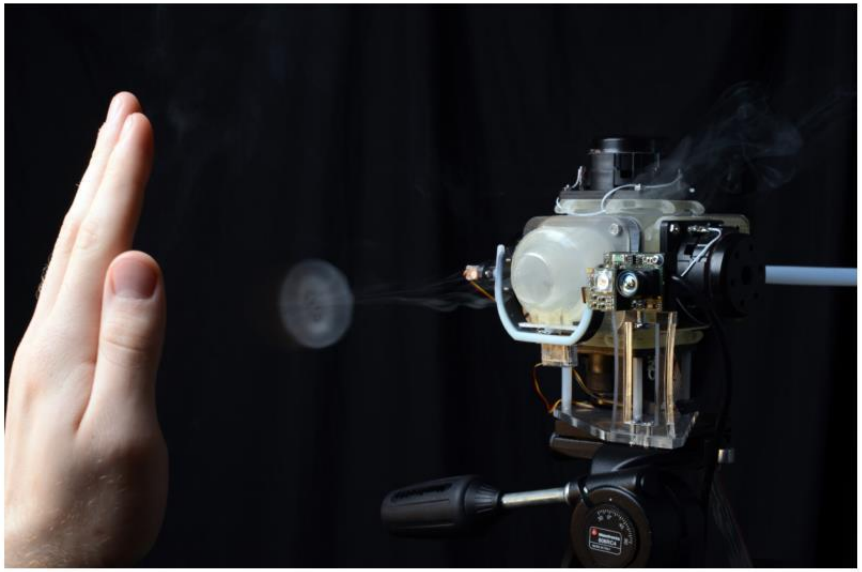


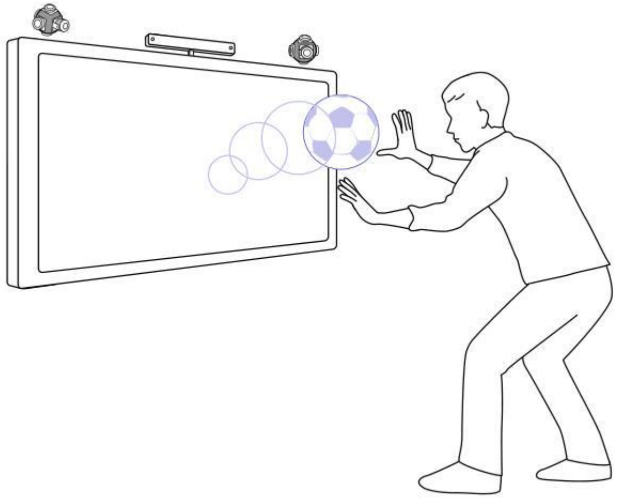
ACM SIGCHI-2024 - AirPush

Tactile simulation (XI)

- ***Pneumatic systems: vortices***
  - Emits a ring of air called a vortex that can be felt in mid-air
    - Controlling a flexible nozzle allows for directed sensations
    - Operating distance of roughly one meter

AIREAL (Sodhi et al. 2013)





Tactile simulation (XII)

- ***Pneumatic systems:***
  - Advantages:
    - Pressure can be more appropriate for some applications than pins or vibrating motors
    - Can mimic skin-slip (with multiple inflated pockets)
    - Vortices can enable mid-air interaction
  - Disadvantages:
    - Not really portable, can be very noisy
    - Difficult to display sharp edges or discontinuities

Tactile simulation (XIII)

Requirements:

- The most used contact element is the hand
- We need the force range a user can produce and feel (values between 16N and 102N, different for man/woman)
- We have to distinguish between the maximum force for a short time or a continued force

Tactile simulation (XIV)

- *Sensitive bandwidth*: frequence to what the touching stimuli is noticed, propioceptives and cinestetics
- *Active bandwidth*: velocity with which one can respond to the stimuli
  - the sensitive is much higher than the active
  - for the human finger, the active is between 1 and 16 Hz while the sensitive is between 30 Hz and 10 kHz

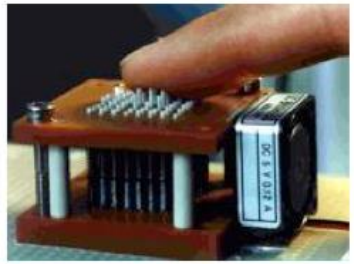
$\Rightarrow$ having a frequency of **1000 Hz** we can simulate all the touching efects

Haptic devices

- *Different classifications:*
  - *Sense-oriented:*
    - *Tactile*
    - *Kinesthetic*
    - *Hybrid*
  - *DOFs achieved*

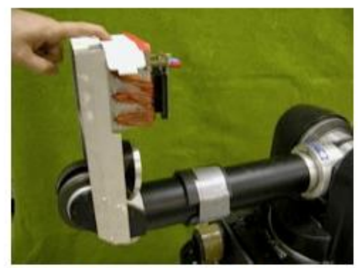
Haptic devices (sense oriented)

Haptic Interfaces



Tactile Devices

Stimulate skin to create contact sensations



Hybrid Devices

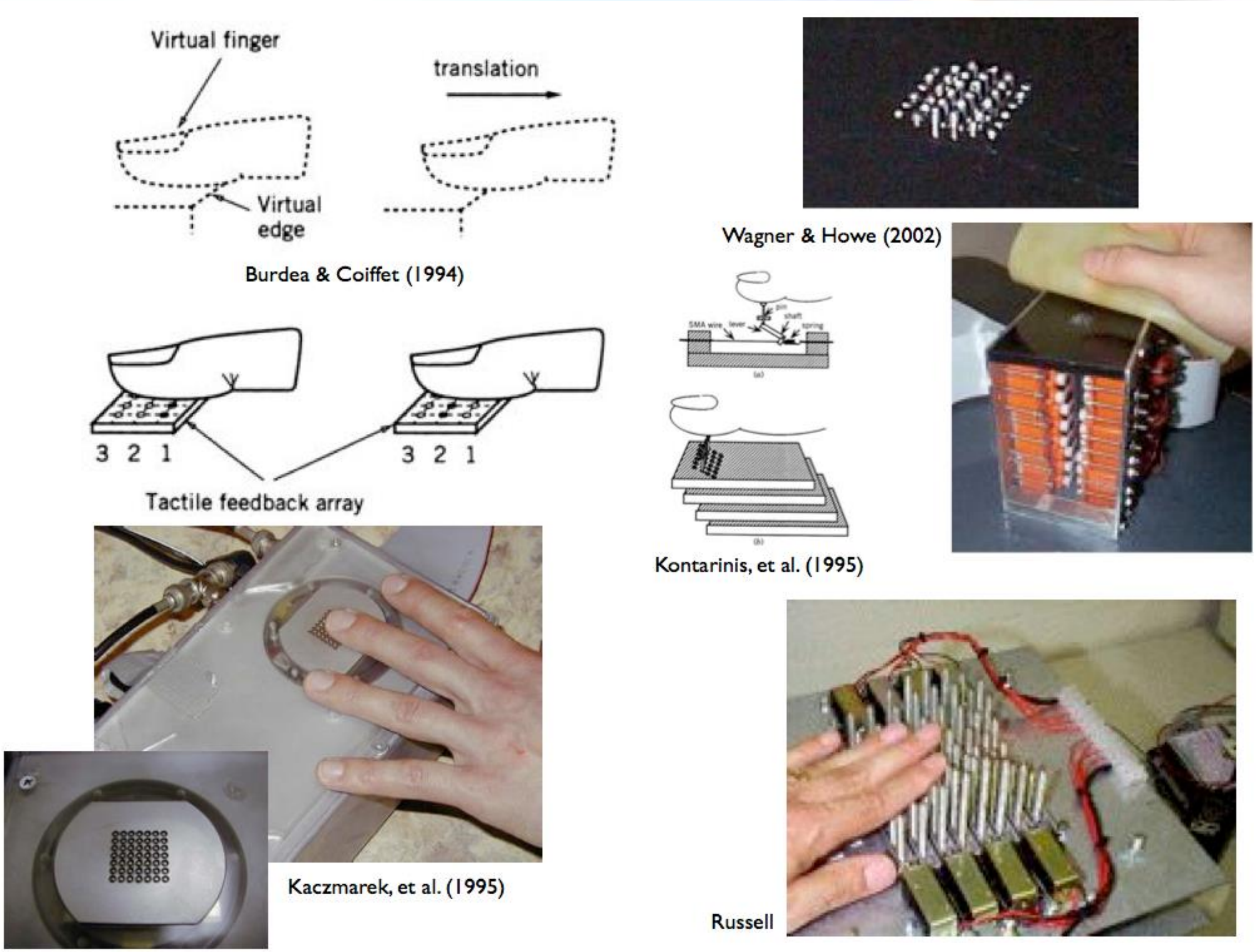
Attempt to combine tactile and kinesthetic feedback

Kinesthetic Devices

Apply forces to guide or inhibit body movement

Haptic devices (sense oriented) (II)

- Tactile devices:



Burdea & Coiffet (1994)

Wagner & Howe (2002)

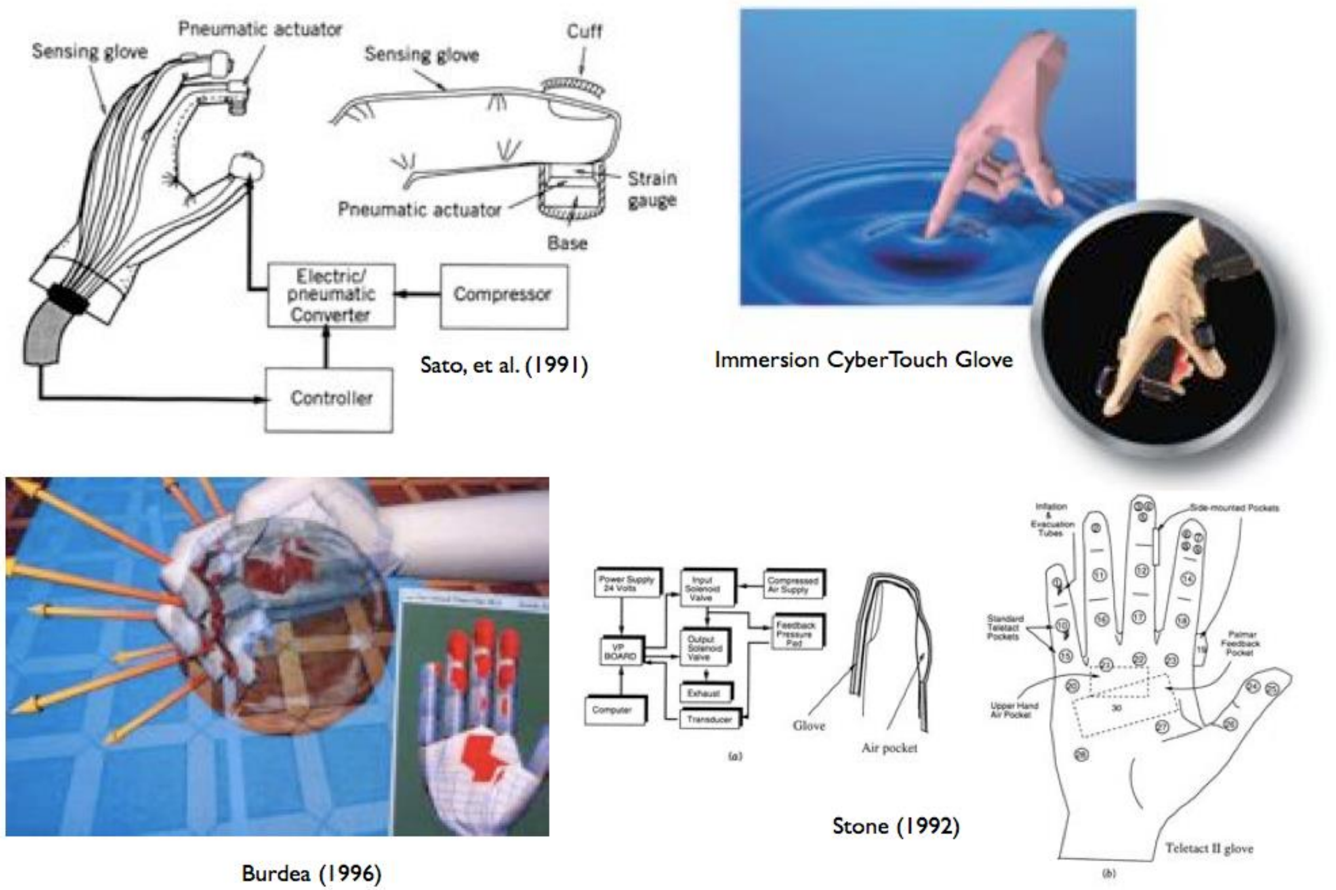
Kontarinis, et al. (1995)

Kaczmarek, et al. (1995)

Russell

Haptic devices (sense oriented) (III)

- Tactile devices:



Haptic devices (sense oriented) (IV)

- Tactile devices: challenges
  - stimulation density needs to be high
  - high complexity and weight diminishes portability,
  - practicality, generality
  - passive touch does not feel natural
  - tactile device design is difficult!

Haptic devices (sense oriented) (V)

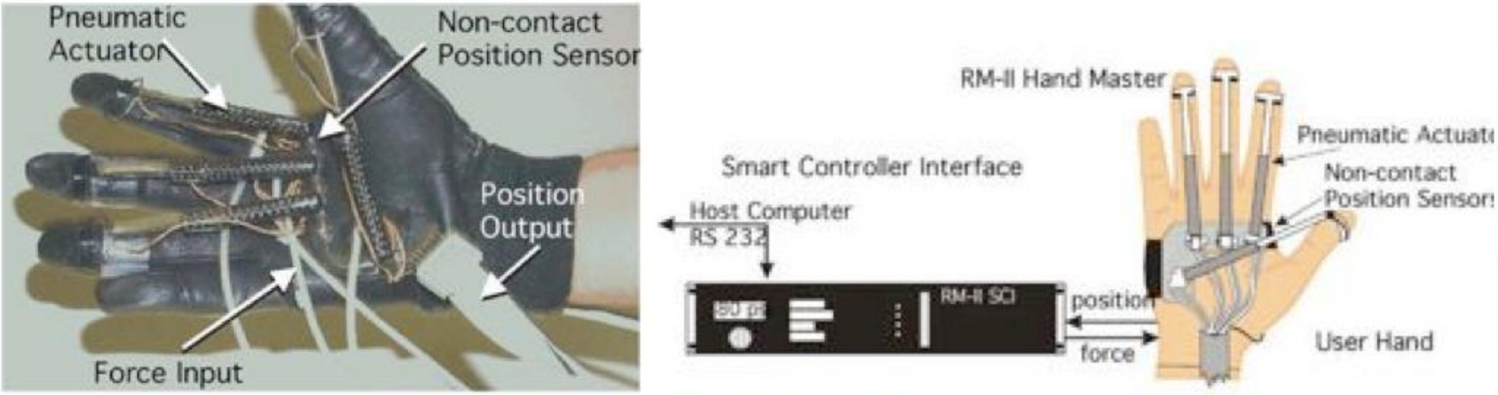
- Kinesthetic devices:

Haptic devices (sense oriented) (VI)

- Ungrounded Kinesthetic Devices

EXOS EAM Arm Exoskeleton

Immersion CyberGrasp Glove



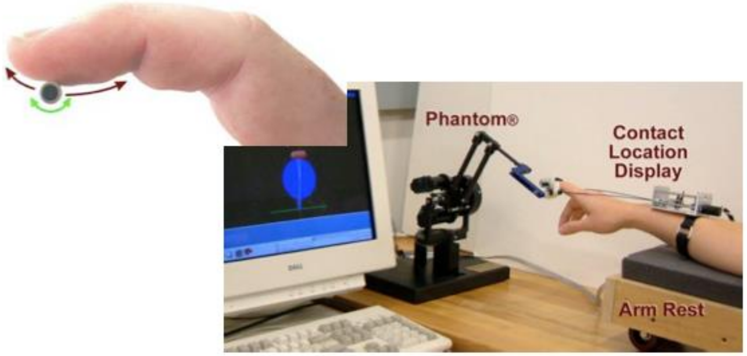
Rutgers Master II Force Feedback Glove

Haptic devices (sense oriented) (VII)

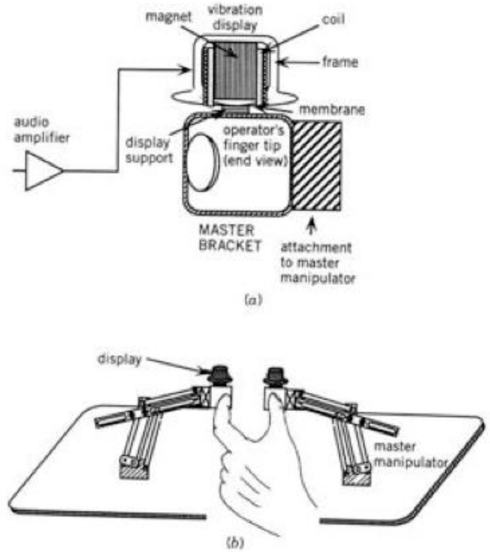
- Kinesthetic devices: challenges
  - competing goals of high stiffness and low mass
  - force feedback feels soft
  - point-based interactions are overly simple
  - devices of sufficient quality are expensive
  - limited workspace size and actuation power
  - usually constrained to sit at a desk

Haptic devices (sense oriented) (VIII)

- Hybrid devices:

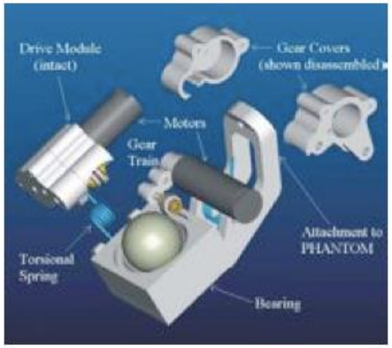


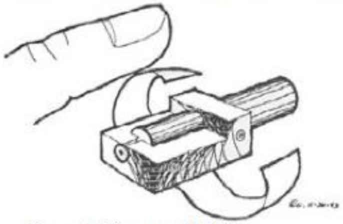
Provancher, Kuchenbecker, Niemeyer, & Cutkosky (2003-4)



Kontarinis & Howe (1995)

Webster, Murphy, & Okamura (2004)



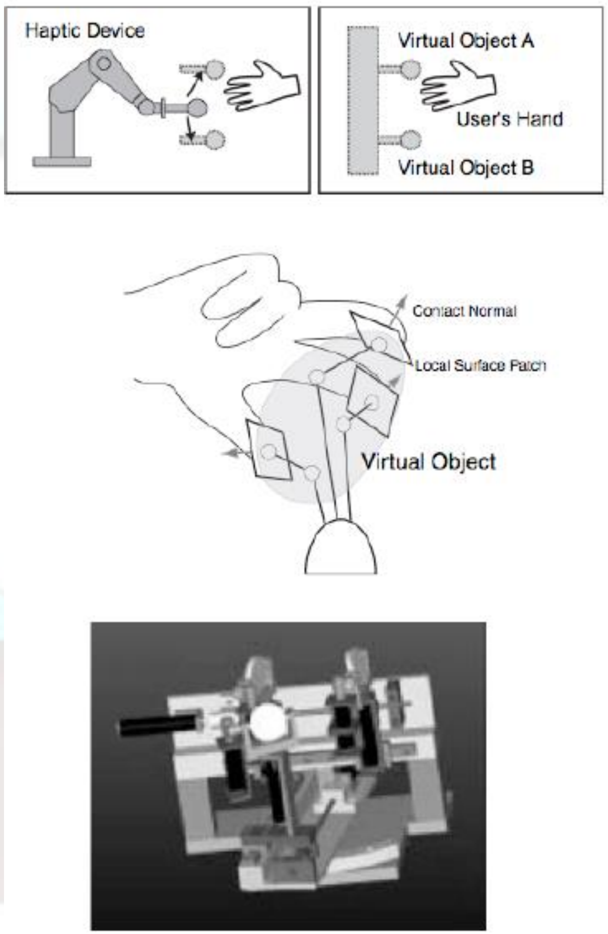


Chen & Marcus (1995)

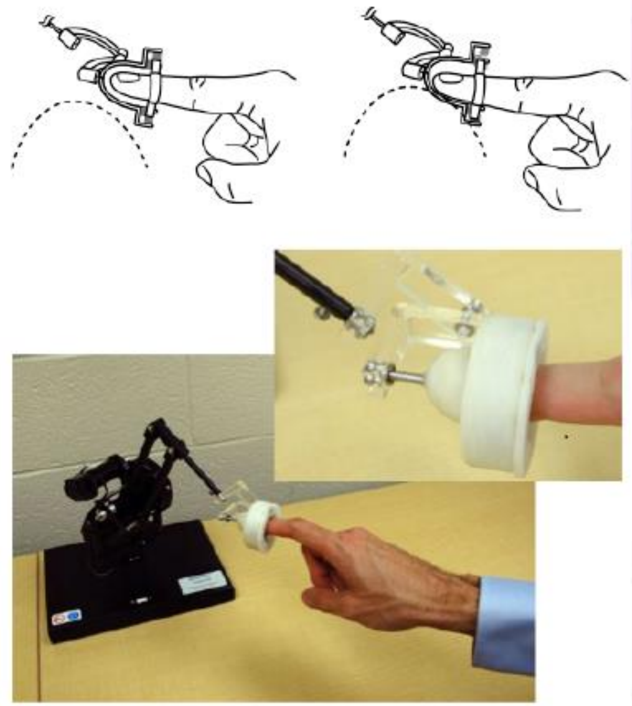
Howe (1995)

Haptic devices (sense oriented) (IX)

- Hybrid devices:



Yokokohji, et al. (2005)



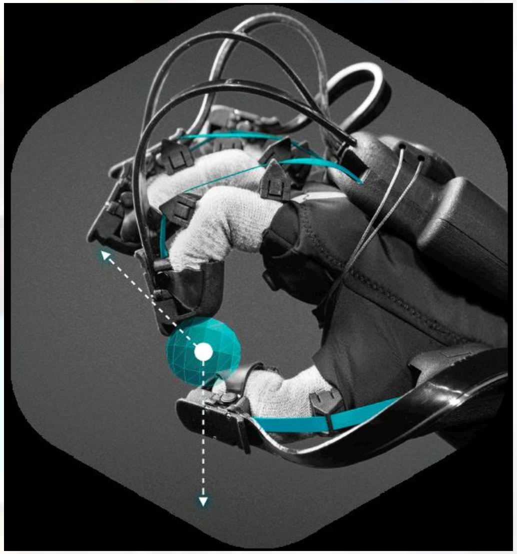
Kuchenbecker, Ferguson, Kutzer, Moses, and Okamura (2008)

Haptic devices (sense oriented) (X)

Hybrid devices (exoskeleton gloves):

VRGluv (2017)

https://www.youtube.com/watch?v=dVJhTsp5ilM



Haptx (2018)

https://youtu.be/0WQw4GmFGVg

Haptic devices (sense oriented) (XI)

- Hybrid devices: challenges
  - all of the above!
  - weight is especially disadvantageous
  - synchronization between force and tactile
  - tradeoff between complexity and functionality
  - need for clever innovations

Haptic devices (DOFs achieved)

Examples of 1-DOF devices

– 1.Steering Wheels
– 2.Hard Driving (Atari)
– 3.Ultimate Per4mer (SC&T2)

Haptic devices (DOFs achieved) (II)

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)





Haptic devices (DOFs achieved) (III)

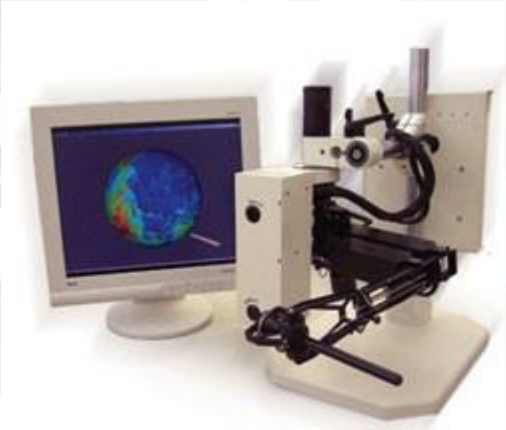
Examples of 3-DOF devices

- 1.GeomaticTouch (formerly SensablePhantom Omni)
- 2.Omega (Force Dimension)
- 3.NovintFalcon
- 4.Impulse engine (Immersion)

Haptic devices (DOFs achieved) (IV)

Examples of 6-DOF devices

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

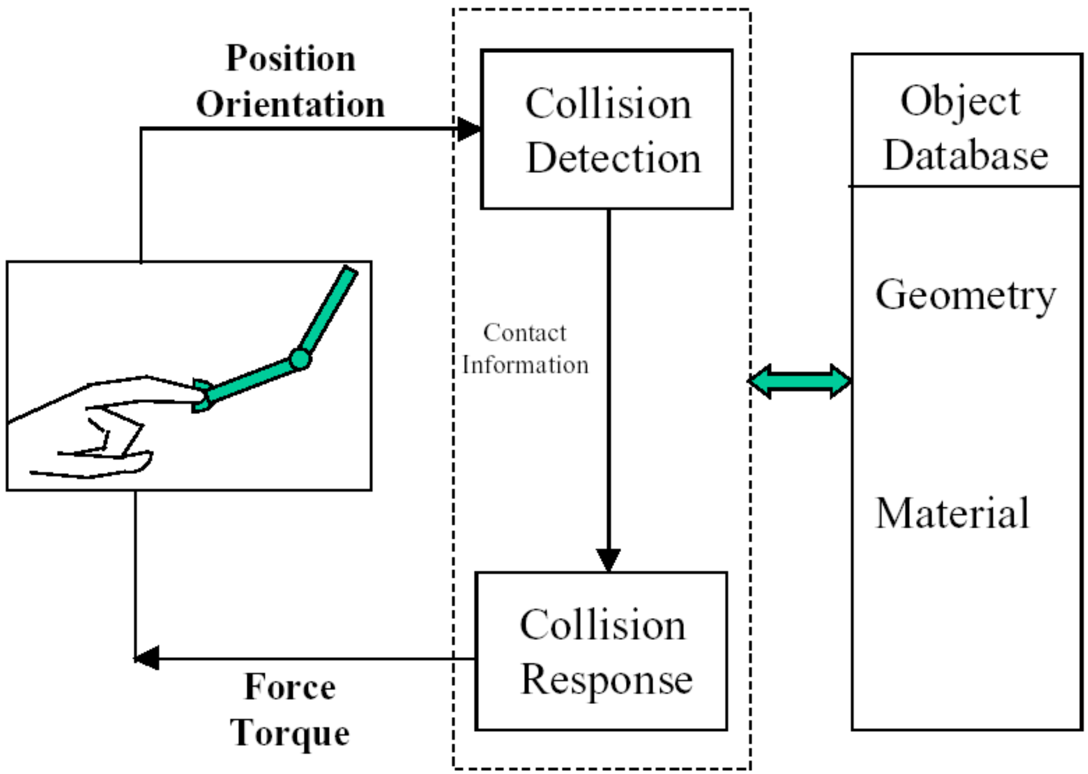


Haptic rendering

- ***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 (II)

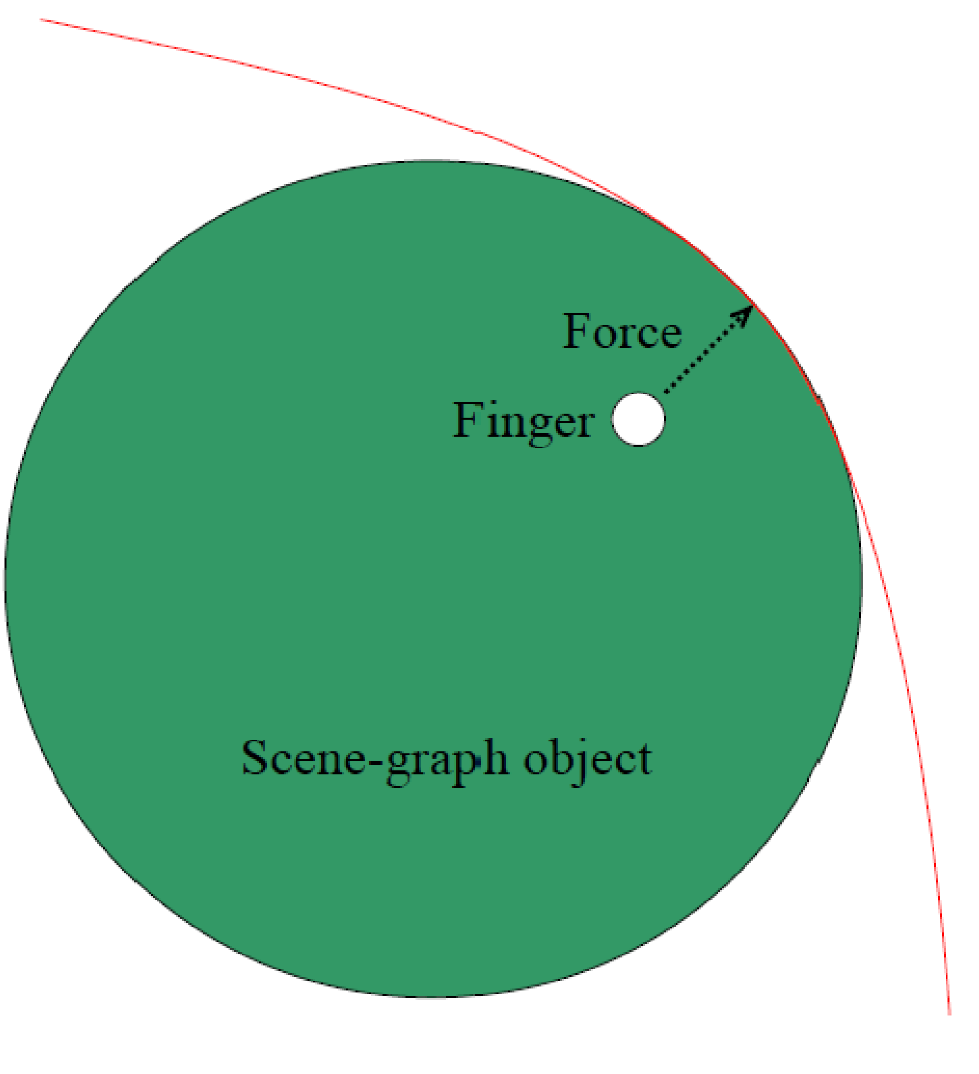
- The further inside the object you move, the greater the force pushing you out
- This makes the surface feel solid



Haptic rendering (III)

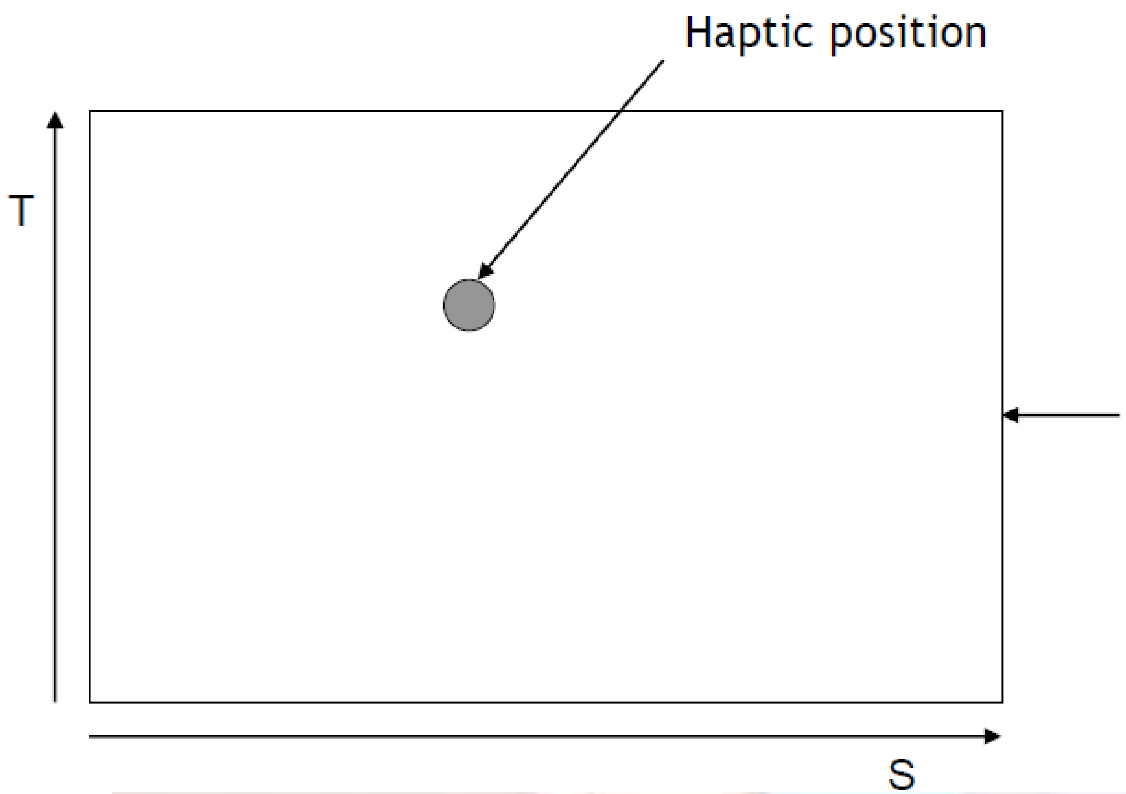
- 1000 Hz is necessary so that the system does not suffer from disturbing oscillations
- Many haptic devices run their control loop at 1000 Hz
- Stable and fast processing is needed when running haptic software
- Haptic real-time loop (~1000 Hz)
  - Necessary due to the high sensitivity of human touch
  - 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

Haptic rendering (IV)



- 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

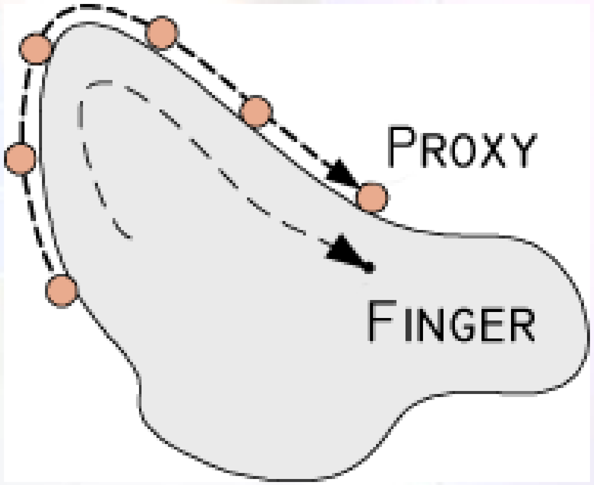
Haptic rendering (V)



- The real-time “surface” has a 2D coordinate space
- Allows programmers to define haptic surface effects as a function of position and penetration depth

Haptic rendering (VI)

- 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

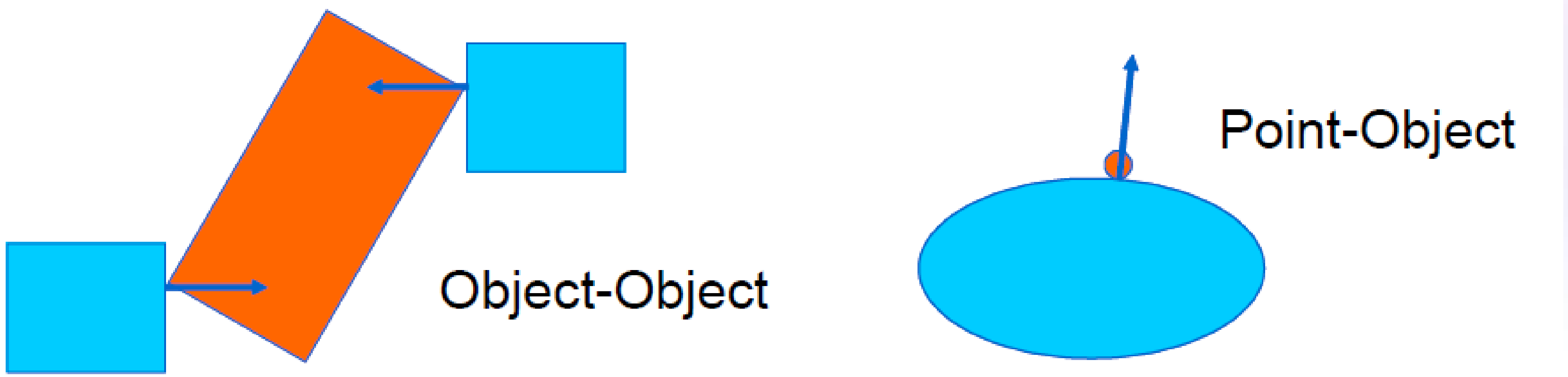


Haptic rendering (VII)

3-DOF haptics:

- Output: 3D force → 3DOF haptics

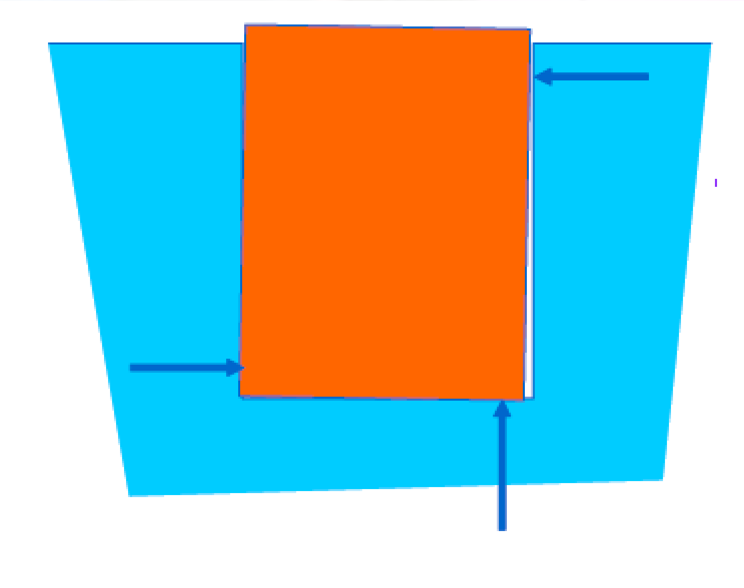
- Limited to applications where point-object interaction is enough
  - Haptic visualization of data
  - Painting and sculpting, some medical applications



Haptic rendering (VIII)

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



Haptic rendering (IX)

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

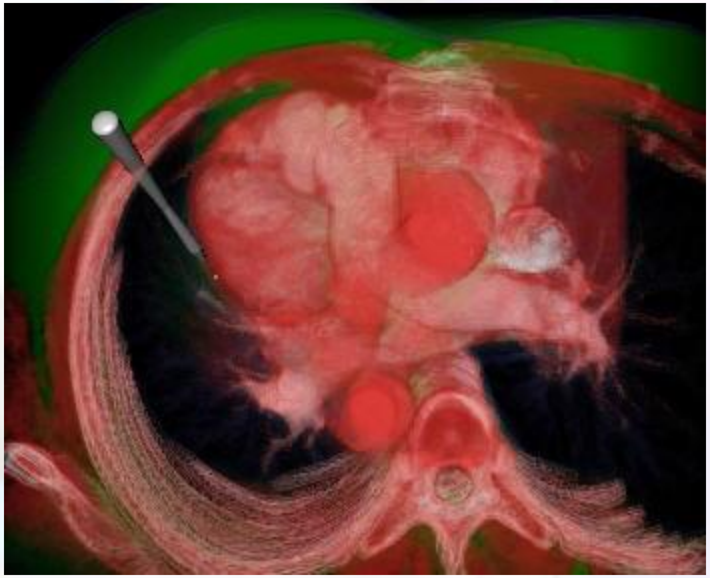
Applications

- Medicine:
  - Surgery simulation
  - Tele-medicine
  - Training
  - Patient rehabilitation pacients for neurologic problems
- Mechanical design:
  - Pieces assembling
- Entertainment:
  - Paint in 3D
  - Characters animation
- Scientífic:
  - Geophysical data analysis
  - Molecular manipulation

Applications (II)

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

- No need to use paid volunteers or dead bodies in training



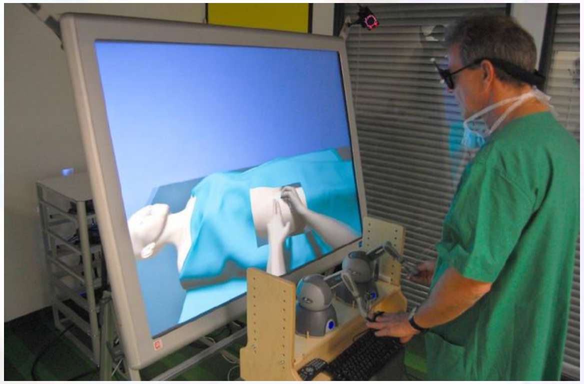
https://www.youtube.com/watch?v=h0xA8HtWgI4

Applications (III)

- 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

Applications (IV)

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



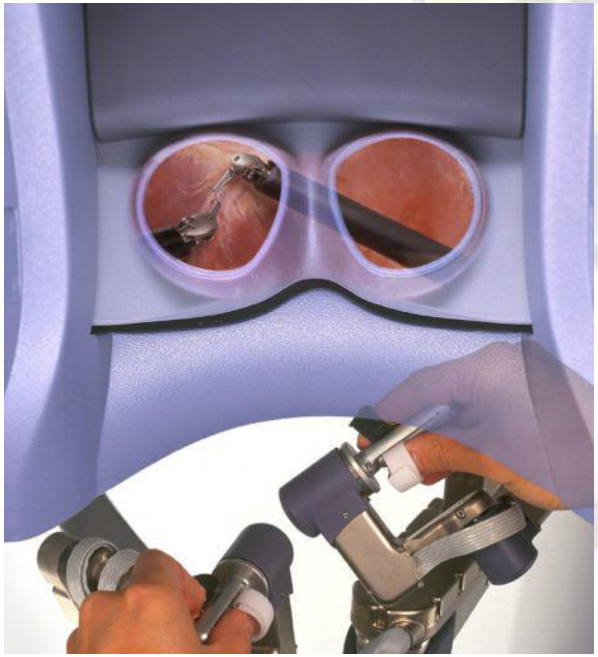
  - *Coles et al., 2011*
    https://www.youtube.com/watch?v=aFafx7m-Xxs

Applications (V)

- For example, supporting weak muscles or removing tremble
- Assisting forces can be reduced gradually once muscle strength increases

Applications (VI)

- Surgical robotics
  (da Vinci Surgical System)

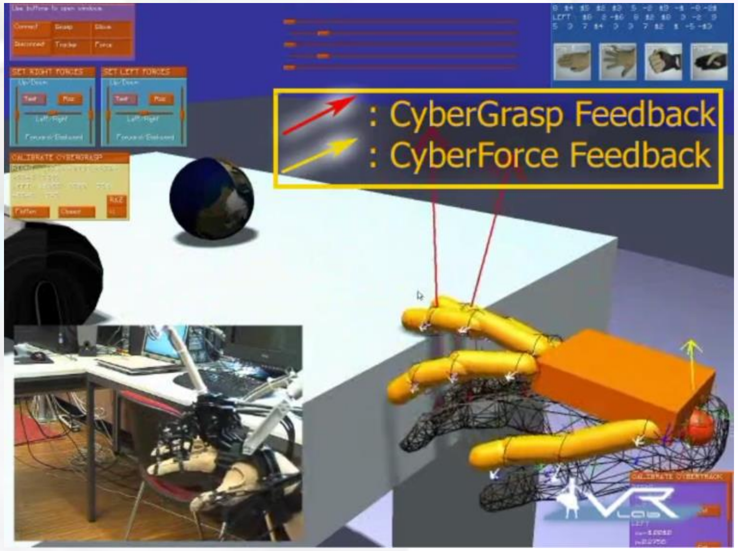


Applications (VII)

- 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 lateron to get a physical version

Presence Improvement

- *Spring-Damper Hands*:
  - Virtual hands driven by the Haptic Workstation that can collide a virtual object without penetrating into it
  - simplifies the computation of force feedback, and offers a better user experience in term of presence



https://www.youtube.com/watch?v=dYXPCiSLMI8

Other Videos

- Physics effects (2009)
  http://www.youtube.com/watch?v=ruZVjXgaptE
- Teleoperation (haptic + robot) (2008)
  http://www.youtube.com/watch?v=970mckgfOio&feature=related
- SenseGraphics 3D (2008)
  http://www.youtube.com/watch?v=nZBrH2g5NCc

VIRTUAL REALITY

Haptics

Course 2024/2025