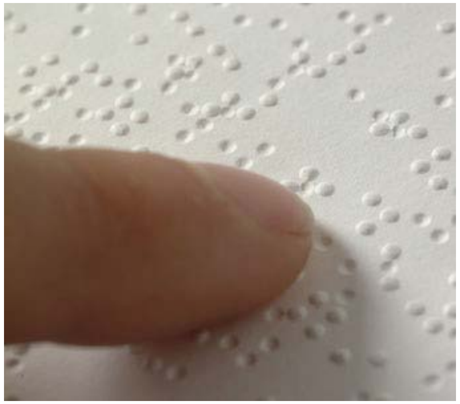
Haptic interfaces

1. Definition, scope and history
2. Haptic display characteristics
3. Haptic display types
4. Haptic design guidelines
5. Haptic interaction through virtual coupling
6. From Haptic to pseudo-haptic feedback

1. Definition, scope and history

- **Haptic** : [W]
  - From greek *haptikos*/sense of touch and *haptethai*/ to touch
  - Include both the synthesis of *touch* and *force/torque* stimuli



- **tactile sensors**: surface texture, vibration, pressure, temperature, ...
  - Highest density on hand palm and finger tips
  - Alternate tactile regions used as sensory substitution : tongue [I 2010]

- **Kinesthesic sensors**: muscles, joints, tendons, ...
  - To determine the body posture and the nature of body interaction with the environment: exerted force/torque on contact locations

1. Definition, scope and history (2)

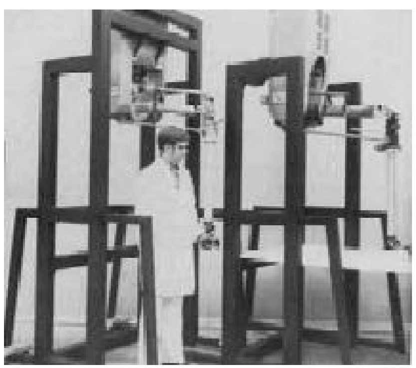
- A haptic device IS…

  … a **force** reflecting device which allows a user to touch, feel, manipulate, create, and/or alter simulated objects in a virtual environment

  ... NOT a device which tracks movement, such as head-trackers, eye-trackers, magnetic or optical motion trackers, without providing force-reflecting feedback to the user.

1. Definition, scope and history (3)

- History
  - force feedback joystick for aircraft simulators [W]
  - in the 50s, the nuclear industry needed mechanical systems for the remote manipulation of nuclear components (Argonne USA, CEA Saclay FR).



    - Teleoperators = master / slave manipulator arm
    - The gesture performed by the user on the Master arm is reproduced on the slave arm and the force/torque reaction on the slave is felt by the user on the master arm at the level of the gripper.
    - Became electromechanical in the 60-70s.
  - Early 70s: sensor substitution/neural plasticity, Bach-y-Rita [W]
  - In the 90s minimally invasive medical training : laparoscopy
  - Games controllers: from arcade (70s) to home

Some examples of real-world haptic systems

Master-Slave system : the collision of the slave system on a solid box is reflected on the master articulated arm http://www.youtube.com/watch?v=iIGy6K-vjpA

Sensory substitution on high-density sensor region (tongue) [CBS : see with tongue with brainport]

http://www.youtube.com/watch?v=RaTzQVHi-C4
https://www.youtube.com/watch?v=OKd56D2mvN0

2. Haptic display characteristics [BKLP 2005]

- Haptic presentation capability
  - Tactile / kinesthetic / or both ?
  - If kinesthetic: how many points of force does it provide ?
  - What part of the body is it designed for (finger(s), wrist, feet,...)
  - How big/cumbersome ? What is the range of motion ?

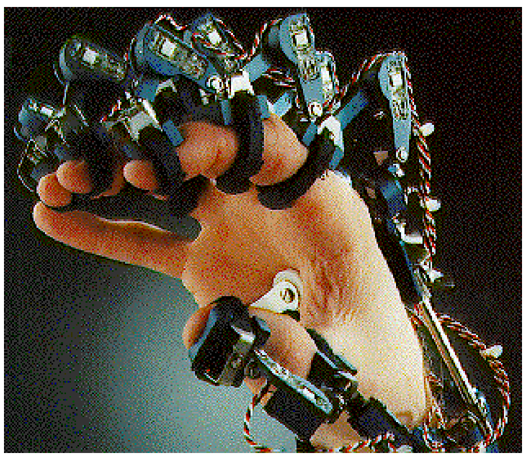
- Spatial/temporal resolution
  - Spatial resolution must be much higher for finger tips vs forearm
  - Temporal resolution: 1000 Hz update rate is necessary for stability of the rendering of stiff contact (otherwise appear soft or unstable). Two distinct threads for simulation & rendering.

- Ergonomics
  - a critical requirement : Safety
  - a serious limitation : Comfort

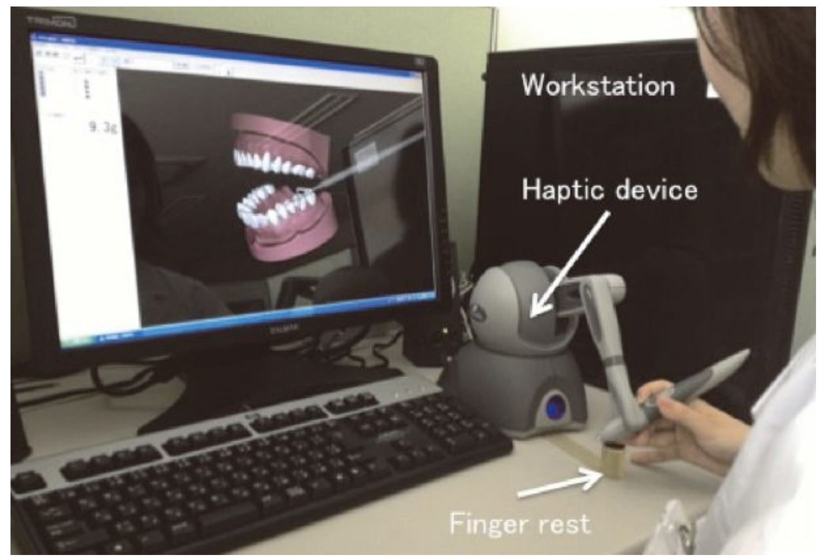
3. Haptic display types [BKLP 2005]

Body-referenced haptic device [Utah hand]

Ground-referenced haptic device [Phantom]
(on desk, floor, wall, ceiling...)



Placed on the user body: exoskeleton with motors or cables. Need calibration to user skeleton.



Dental materials journal 2013, 32(5)

Force-reflecting joystick, pen-based force feedback, stringed devices, motion platform, large articulated arm

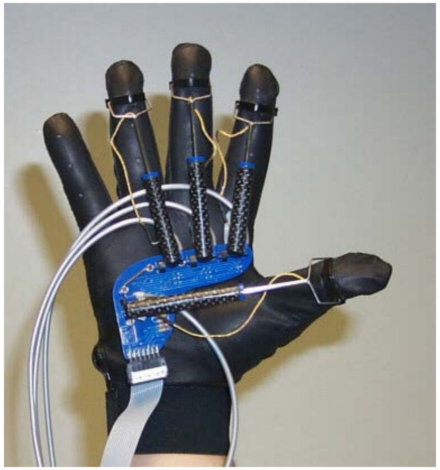
3. Haptic display types (2)

Body-referenced haptic device :

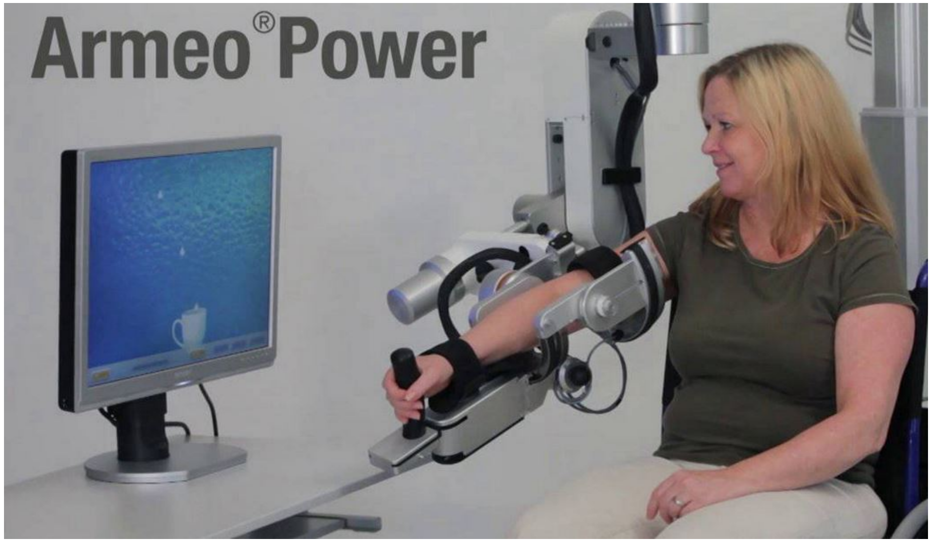
more freedom of motion

Tradeoff due to weight

Rutgers Master II



PERCRO (Pisa)



Exoskeleton from Hocoma for rehabilitation

The concept of **haptic suit** is popular is science fiction (film «Ready Player One») but limited to vibrating units or muscular electrical stimulation (**teslasuit** below)

Electrical Muscle Stimulation replicates the small electrical stimulation produced by the brain and carried by the efferent neural signals.

Used in sport and rehabilitation ->

wikipedia.org: Electrical_muscle_stimulation

3. Haptic display types (3)

Ground-referenced haptic device : "desktop" systems

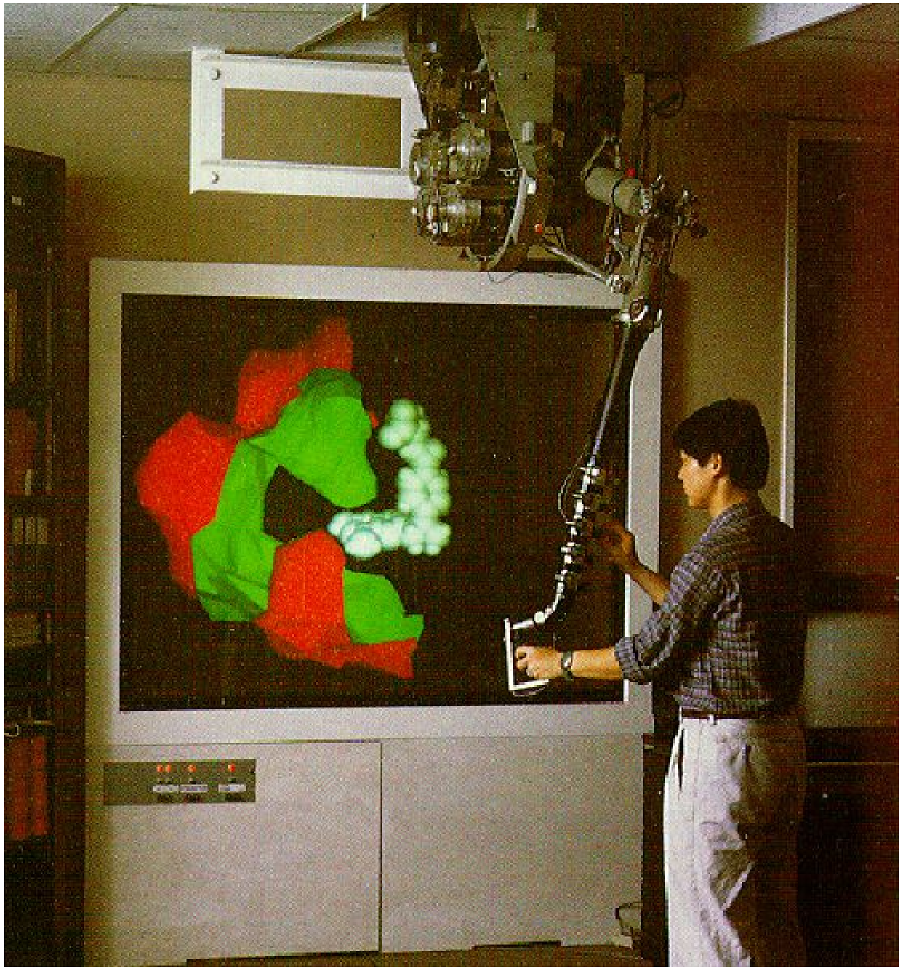
Virtuose from Haption (FR): Cable system allowing human arm scale

Da Vinci (USA): Master-Slave minimally invasive surgical system (haptic visual **substitution**)

Force Dimension (CH): high stiffness Based on Delta Robot from EPFL

+ recent miniature system *Foldaway* from EPFL-RRL

3. Haptic display types (4)



GROPE III, 6 Degree of Freedom (DoF) Force & Torque haptic display [B 1990]

Ground-referenced haptic device :

- Research project from UNC by Brooks team, started in 1967.
- Goal: help chemists to find more easily good docking position for news drugs (i.e. relative location of complex molecules at which some receptor can be exploited).
- Results: such task was achieved about twice as fast with haptic feedback compared to only stereo graphics display.
- Chemists have a new understanding of the receptor force field and the docking

3. Haptic display types (5)

Ground-referenced haptic device : using 2 phantom-like devices for bimanual training of stomach laparoscopic surgery (Rensselaer Polytech. / Reuter / 2011)

Laparoscopic surgical tools

The 2 devices providing the force feedback

The interaction must integrate a realtime deformation model of the organ to compute the correct reaction force and mesh deformation

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

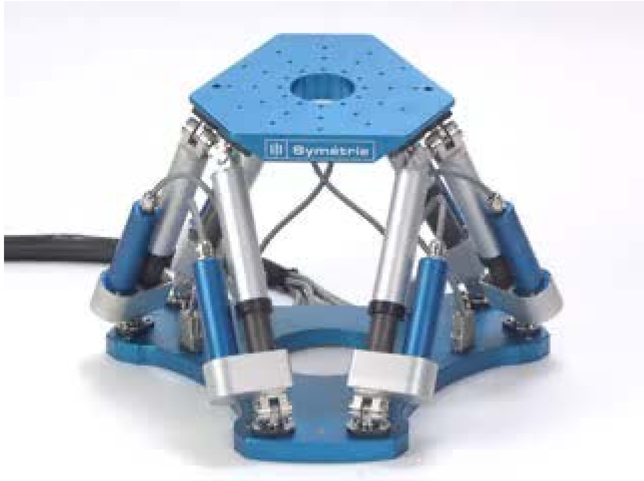
SW platform on physics-based tissu deformation:

https://www.sofa-framework.org/about/story/

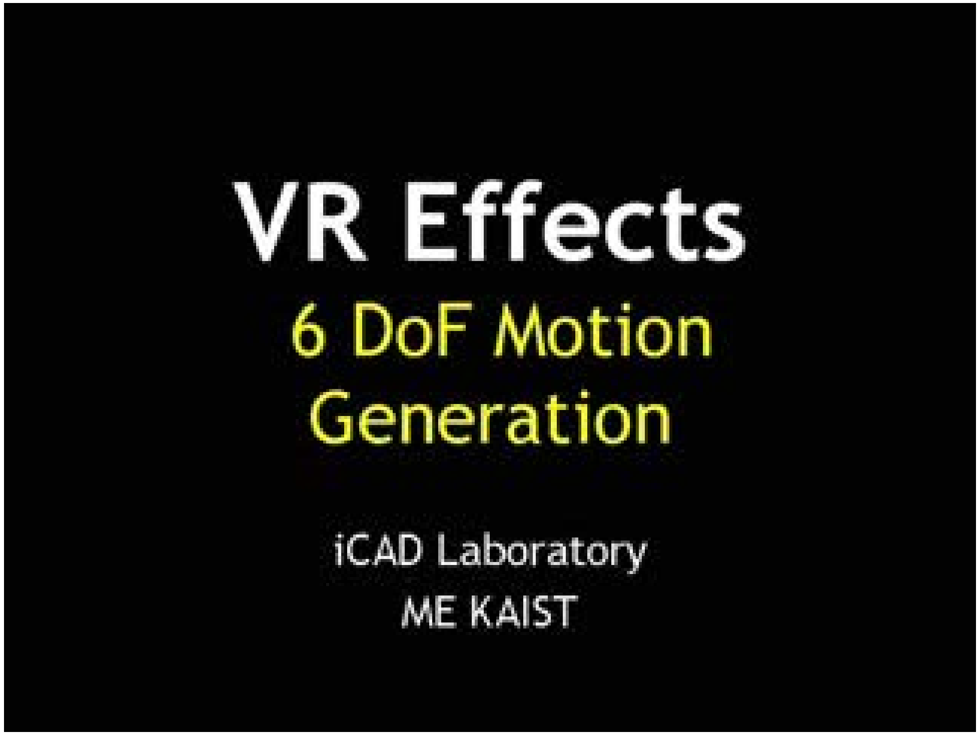
3. Haptic display types (6)

Ground-referenced haptic device exploiting a Stewart Platform are mostly used to stimulate the vestibular system sensitive to accelerations, for driving /flight simulators , arcade games and theme parks:

Stewart Platform=
6 DoFs but with
limited range



Check also:
www.bluetiger.com
www.simbolrides.com



6 DoFs driving platform: KAIST (Korea)

Ferrari F1 simulator: https://www.youtube.com/watch?v=5T_tXG-89IU

3. Haptic display types (7) Research setup

Ground-referenced haptic device : Kuka robot used in MPI Tuebingen for studing human perception, cognition and action [Prof. Buelthoff]

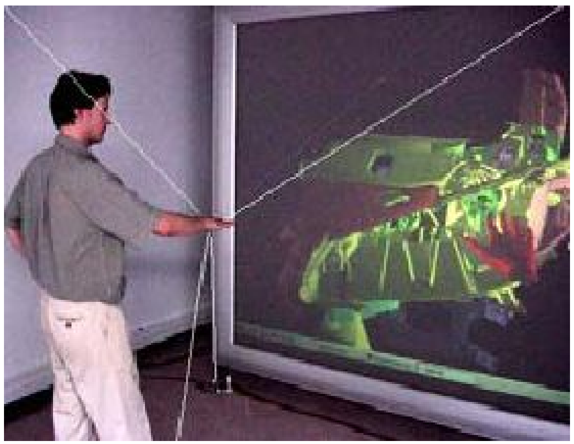
The robot is ideal for producing acceleration stimulations and displacements over a large range

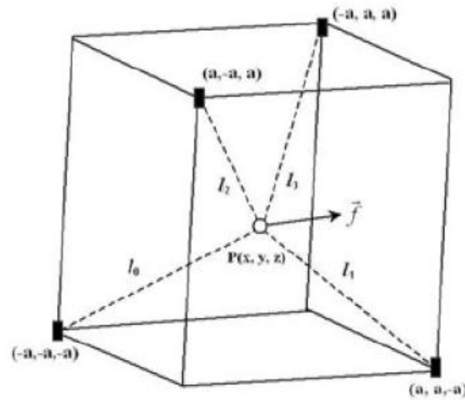
Toward RT aircraft Simulation with the MPI motion simulator, (MPI & Univ. Pisa), Niccolini, Pollini, Innocenti, & Giordano, Teufel, Buelthoff

http://www.youtube.com/watch?v=jrvnC6L9nPA&feature=related

3. Haptic display types (8)

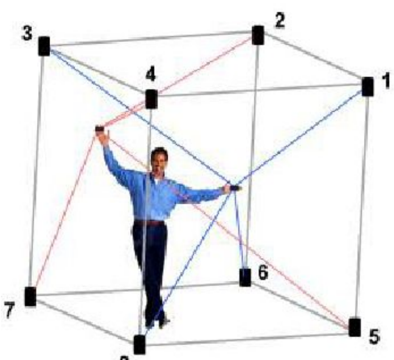
Ground-referenced haptic device : Space Interface Device for Artificial Reality (SPIDAR) is a stringed system [Sato 1989]: a good compromise for large space interaction at low cost, lightness, and high safety



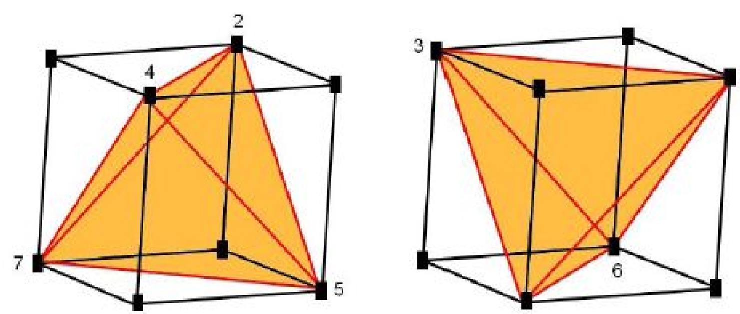


$$
\begin{cases}
x = \dfrac{(l_0{}^2 - l_1{}^2 - l_2{}^2 + l_3{}^2)}{8a} \\
y = \dfrac{(l_0{}^2 - l_1{}^2 + l_2{}^2 - l_3{}^2)}{8a} \\
z = \dfrac{(l_0{}^2 + l_1{}^2 - l_2{}^2 - l_3{}^2)}{8a}
\end{cases}
$$

LISA Anger & IBISC Evry [N 2009]

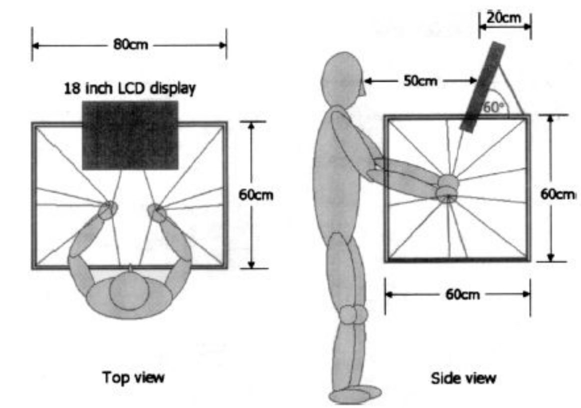


right & left haptic range →

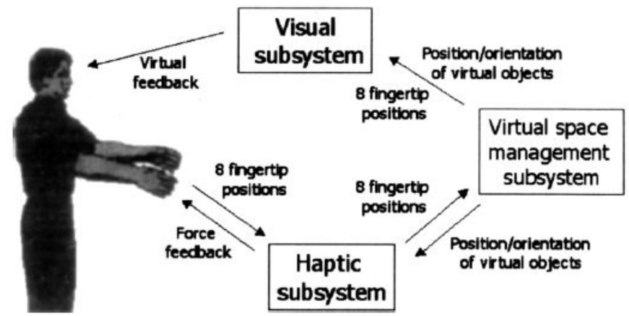


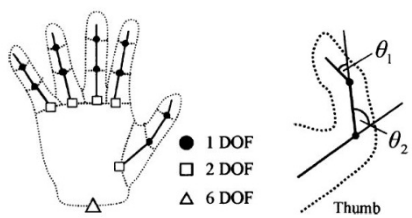
3. Haptic display types (9)

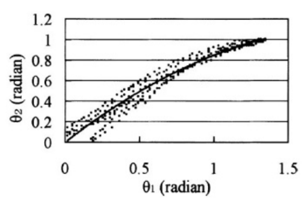
A bimanual SPIDAR system from Tokyo Institute of Technology, Yokohama [W 2004]



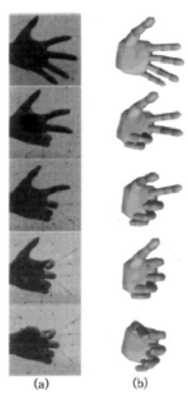
The user interacts by looking at a screen that displays virtual hands estimated from the location of the 8 finger caps

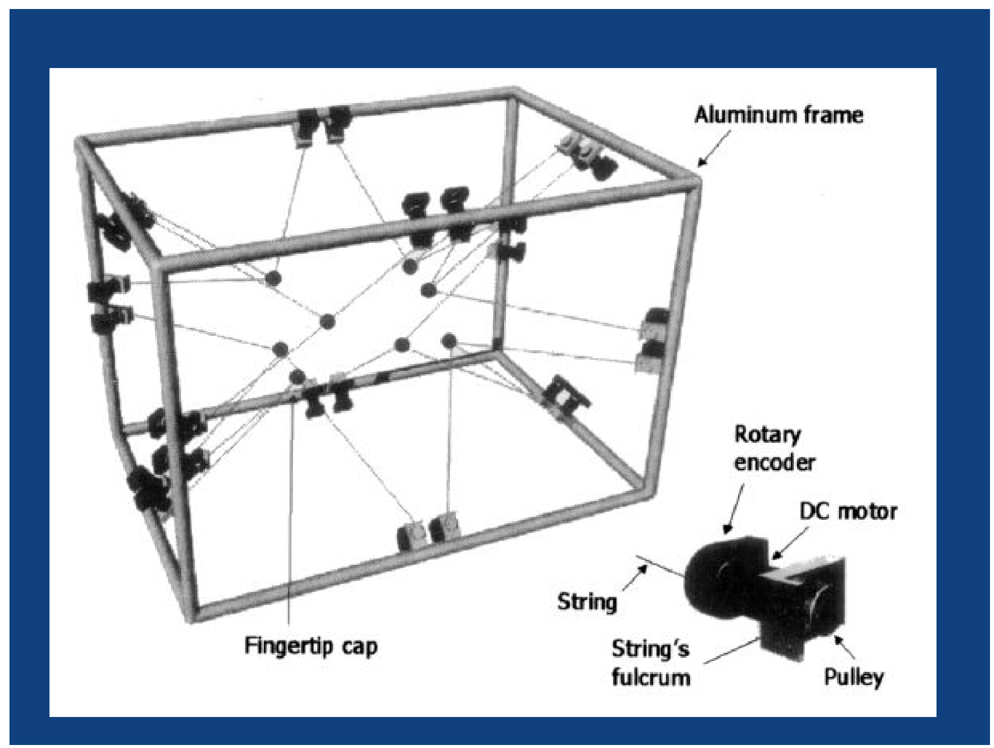






An anatomic model of a 17 DoF hand with finger joint coupling is used to infer the virtual hand with an Inverse Kinematics algorithm





http://www.youtube.com/watch?v=m-DS1U_INpQ

3. Haptic display types [BKLP 2005] (10)

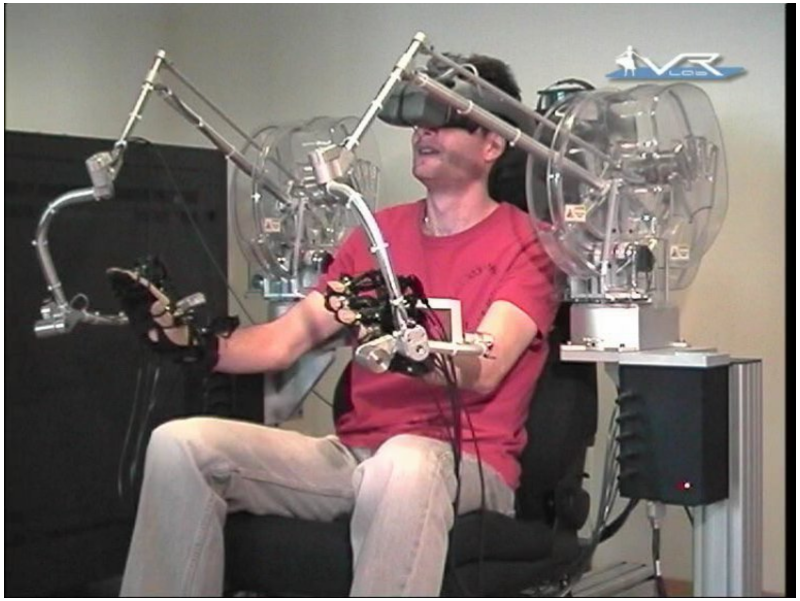
Finger pulling device

Tactile device

CyberGrasp TM: from Immersion
Each finger can be pulled from the back side of the hand to force it to open. It cannot force the hand to close

CyberTouch TM: integrate small **vibrotactile** units on each finger of an Immersion CyberGlove.
Each unit can be programmed to generate pulse or sutained vibrations

Combination: Haptic Workstation
= 2 CyberForce & Cybergrap



CyberForce® is a force feedback armature that not only conveys 3D forces to the wrist and arm but also provides 6 DoF (degre of Freedom) wrist tracking :

3 Dof in translation

+ 3Dof in orientation

Max : 60N

4. Haptic design guidelines[BKLP 2005]

Ground-referenced	+ can produce high level of force if needed
	+ don’t have to wear them
	+ accurate trackers
	- limited movement when using them ...
	- ... or high cost (e.g. Kuka from MPI)
	+ some compromise exist, e.g. SPIDAR
Body-referenced	+ more freedom of motion
	+ more control for direct manipulation
	- user has to bear the weight of device
	- can be tedious to put on and calibrate
Tactile /electrical	+ smaller than force display
	- difficult to get sensation correct
	- limited to small skin area
Hybrid	+ combines force and tactile feedback
	- more complex devices

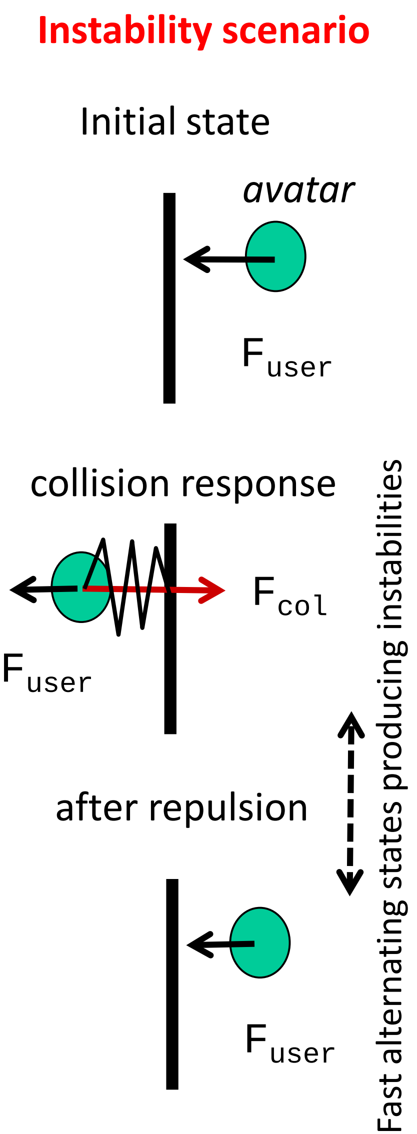
5. Haptic interaction through virtual coupling

- Requested haptic control update rate: min 300 Hz up to 1 KHz – 2 KHz

  - Otherwise instabilities or the haptic sensation is too soft.

  - But 1 KHz /1ms is not sufficient for updating & displaying the whole state of the VR interaction
    - Difficult to prevent a visible interpenetration

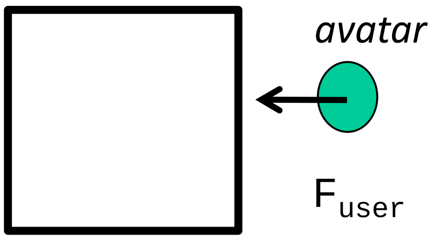
  - Solution: coordinate two systems [M 1996]:
    - haptic rendering updated at 1 KHz
    - simulation and graphical update at 20 Hz - 60 Hz
    - coordination through ***Virtual Coupling [LO 2006]*** with the concept of **proxy**, named **god object** in [Z 1995])



5. Haptic interaction through virtual coupling (2)

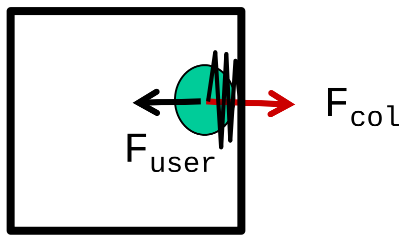
- Improving the **avatar** with the **proxy** [Z 1995, TVR Vol3, LO 2006]
  - <u>Goal:</u> encapsulate the *history* of the interaction to prevent arbitrary discontinuity in the computation of the collision response (rigid objects)

Initial state

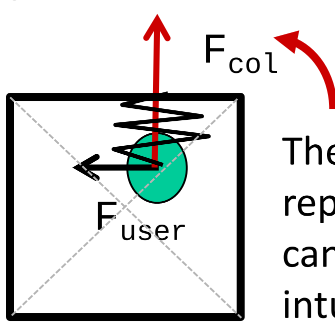


The **avatar** and the **proxy** coincide when there is no collision

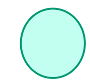
collision response without proxy: the avatar may sink into the object…

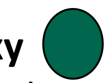


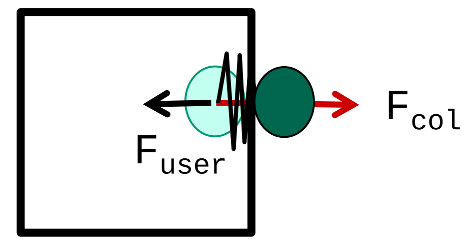
…and if the user pushes a bit deeper one gets closer to a different surface

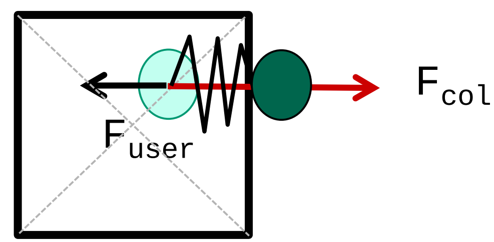


The change of repulsion force can be large/not intuitive

Tracked user location 

collision response with **proxy** 
(only the **avatar-proxy** is displayed)



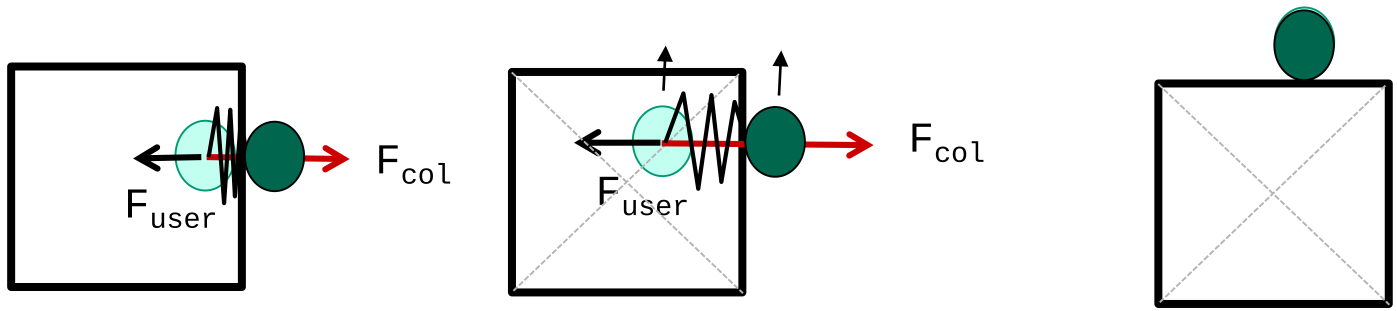


The proxy preserves the coherence of the interaction

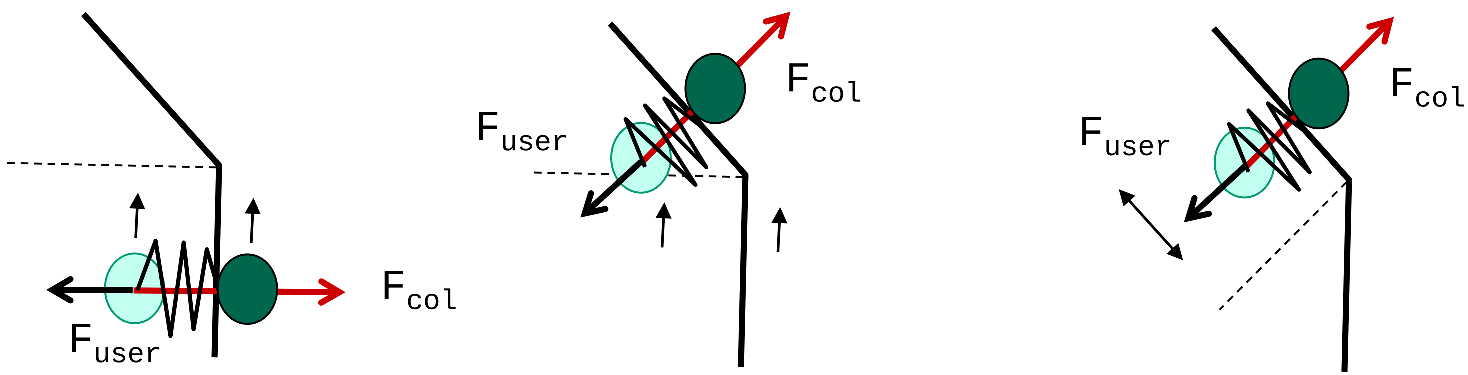
5. Haptic interaction through virtual coupling (3)

- Tracking the **proxy** across polygons[H2000]

Tracked user location collision response with **proxy** (only the **avatar-proxy** is displayed)



The proxy preserves the coherence of the interaction ; however some discontinuity is still possible



condition for polygon switching

the last polygon normal defines the boundary for polygon switching

- Typical complexity for N polygons [H2000]:
  - <u>First intersection:</u> log(N) provided the meshes are organized with hierarchical bounding boxes or similar approach (cf UNC GAMMA project)
  - <u>Tracking the intersection</u> is in O(1) because only neighbour polygons are explored

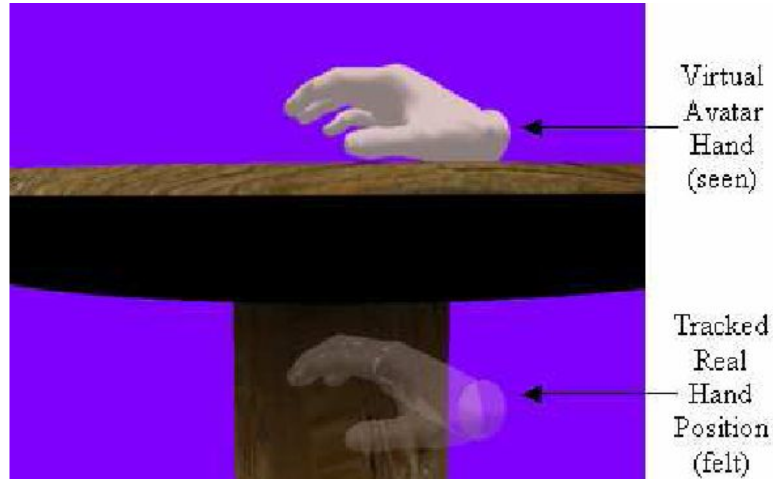
implementation of the avatar-proxy concept

with Haptic Workstation = 2 CyberForce & Cybergrap

The proxy concept is extended to the full articulated hand [Ott et al 2008] (.avi)

5. Haptic interaction through virtual coupling (3)

The sink-in problem [B2006]



The avatar-proxy solution [B 2006]

- But the **proxy** induces a visual-proprioceptive discrepancy [B 2006]
  - Translation: what the user sees does not match exactly with the postural state elaborated by the body scheme.
    - Example: in case of a hand avatar: it is not displayed exactly where it should be in space. The user hand is **no more co-located** with its visual representation.

Question: is such visual-proprioceptive discrepancy more disturbing than seeing the correct location of the virtual hand sinking in a virtual obstacle ?

5. Haptic interaction through virtual coupling (4)

- **E. Burns** et al study, at UNC [B 2006] showed that users are less sensitive to small posture missmatch than to visual sink-in, i.e. *vision* dominates *proprioception*.
- Additional study in [B 2007] regarding the *retraction* phase, when the user moves backward to prevent a collision. Compared 3 methods:
  - ***rubber-band*** : the proxy does not move until the avatar reaches it
    - *Velocity discrepancy*
  - ***Incremental motion***: the proxy start moving backward with exactly the same quantity as the user
    - *Position discrepancy*
  - ***Hybrid technique MACBETH*** : the proxy makes a ***scaled*** movement allowing to progressively reach back the tracked user hand. The faster or slower scaling factors depend on the body-related direction.

Velocity discrepancy threshold

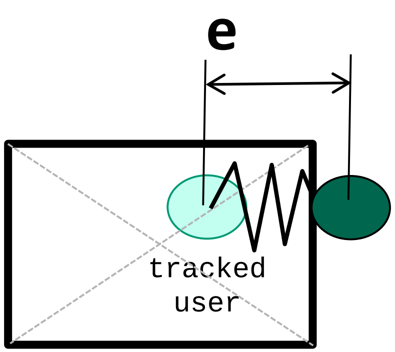
Real-Hand Motion Direction	Faster scale factor	Slower scale factor
Left	+0.44	-0.08
Right	+0.40	-0.06
Up	+0.51	-0.16
Down	+0.38	-0.27
Toward	+0.63	-0.46
Away	+0.69	0.00

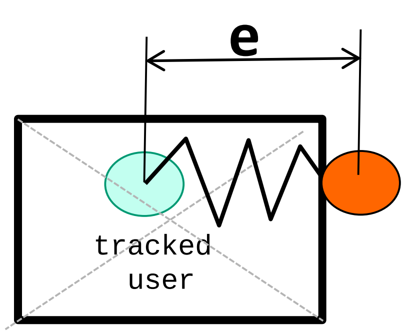
5. From Haptic to pseudo-haptic feedback

- The **avatar-proxy** management and display is possible even without haptic device.

- <u>Pseudo-haptic</u>: Instead of synthesing a force it is possible to render the error between the **tracked user** and the **avatar-proxy** through an alternate modality (visual, audio, ...)

The error **e** can be used to modulate the graphical display of the avatar-proxy (color, texture, special particle effects, etc…) and/or to produce a modulated sound





On-going research

- **Interaction with deformable tissues** (e.g. Basdogan team)
  - **Training minimally invasive surgery**

[Software Development Kits]

- **Sensable** GHOST SDK / now OpenHaptics Toolkit
- **Force Dimension** Haptic SDK / **CHAI3D** open source lib
- **Haption** IPSI library for Catia TM
- **Immersion** MOTIV TM SDK for tactile effects on Android mobile phones
- **ReachIn** & HAPTX Software products
- **SOFA** framework.org for physics-based tissue deformation
- Physically-based Simulation: **Nvidia** PhysX(in Unity3D), **Bullet.org**

[References]

[TRV 2006] Traité de Réalité Virtuelle, Ed. P. Fuch, Vol 2, chap 6-8, Vol 3, chap 5-6

[BKLP 2005] 3D User Interfaces, D. Bowmann, E. Kruijff, J. LaViola, I. Poupyrev, Addison Wesley, 2005

[LO 2006] Haptic Rendering, Eds M. Lin And M. Otadui, A. K. Peters

[B 1990] Frederick P. Brooks, Jr., Ming Ouh-Young, James J. Batter, and P. Jerome Kilpatrick. 1990. Project GROPEHaptic displays for scientific visualization. SIGGRAPH Comput. Graph. 24, 4 (September 1990), 177-185. http://doi.acm.org/10.1145/97880.97899

[B 2006] E. Burns PhD, UNC 2006 + E. Burns et al., "The Hand Is More Easily Fooled Than the Eye: Users Are More Sensitive to Visual Interpenetration than to Visual-ProprioceptiveDiscrepancy," Presence vol. 15, 2006, pp. 1–15

[B 2007] Eric Burns, Sharif Razzaque, Mary C. Whitton and Frederick P. Brooks1, MACBETH: Management of Avatar Conflict by Employment of a Technique Hybrid, The International Journal of Virtual Reality, 2007, 6(2):11-20

[H2000] Ho, Basdogan, Srinivasan, Ray-based haptic rendering, Int. Journal of Robotic research, 19(7), july 2000, pp 668-683

[N 2009] M. NAUD, D. CHAMARET, L. HAMON, S. ULLAH, E. RICHARD, P. RICHARD, Human-Scale Haptic Interaction using the SPIDAR, Joint Virtual Reality Conference (JVRC09) – Lyon

[W 2004] Walairacht, S., Yamada, K., Hasegawa, S., Koike, Y. and Sato, M. (2004), Two-handed multiple-finger virtual object manipulation environment with haptic cues. Electronics and Communications in Japan (Part II: Electronics), 87: 65–73. doi: 10.1002/ecjb.20117

[M 1996] William R. Mark, Scott C. Randolph, Mark Finch, James M. Van Verth, and Russell M. Taylor, II. 1996. Adding force feedback to graphics systems: issues and solutions. In Proceedings of the 23rd annual conference on Computer graphics and interactive techniques (SIGGRAPH '96).

[web References]

http://en.wikipedia.org/wiki/Haptic_technology

http://gamma.cs.unc.edu/research/collision/

Sensor substitution / Brainport: http://en.wikipedia.org/wiki/Paul_Bach-y-Rita

[I 2010] Blind soldier 'sees' with tongue device

http://www.independent.co.uk/news/science/blind-soldier-sees-with-tongue-device-1921830.html

http://www.youtube.com/watch?v=RaTzQVHi-C4

CBS: Blind Learn To See With Tongue

http://www.youtube.com/watch?v=OKd56D2mvN0

Hand Masters reference page:

http://lims.mech.northwestern.edu/projects/finger_exo/

http://www.youtube.com/watch?v=32f2UxKjydI

MPI Tuebingen: lab of Human Perception, Cognition and action

http://www.kyb.tuebingen.mpg.de/research/dep/bu.html

http://www.youtube.com/watch?v=jrvnC6L9nPA&feature=related

SPIDAR

http://www.youtube.com/watch?v=m-DS1U_INpQ

[web References 2]

Master_Slave system:

http://www.youtube.com/watch?v=iIGy6K-vjpA

Da Vinci demo and press article about issues with this type of interaction in surgery

http://www.youtube.com/watch?v=VJ_3GJNz4fg

http://www.informationweek.com/healthcare/clinical-information-systems/robotic-surgery-da-vinci-versus-the-ideal/d/d-id/1112732

Rensselaer Polytechnic bimanual surgery training

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

Hocoma haptic rehabilitation

http://player.vimeo.com/video/26048381?title=0&byline=0&portrait=0&color=ff9933