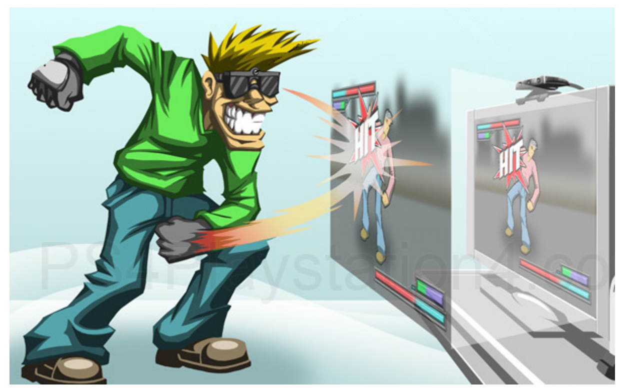
Bremen

Virtual Reality & Physically-Based Simulation
Haptics



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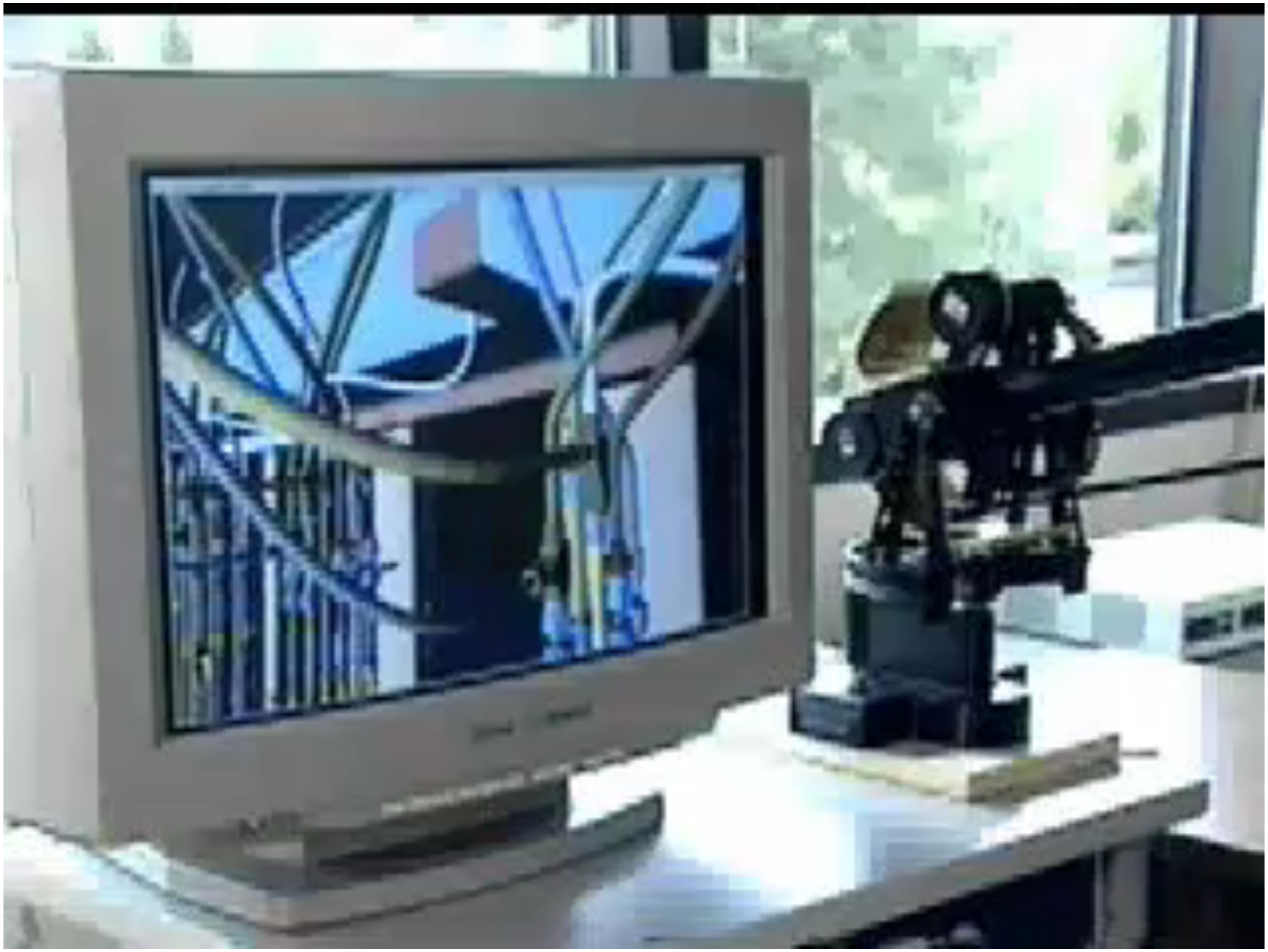
In the Following, We'll Consider a Class of Non-Visual Displays

- Haptics = sense of touch and force (griech. *haptesthai* = berühren)
- Special case: force feedback
- What is to be rendered:
  - Forces on the user's hand / arm (= haptic "image" of objects)
  - Haptic surface texture (roughness, grain, friction, elasticity, ...)
  - Shape of objects by way of touching/feeling (think pin board)
- Applications:
  - Training of minimally invasive surgery (surgeons mostly work by feeling, instead of seeing)
  - Games? (probably would increase presence)
  - Industry: virtual assembly simulation (e.g., to improve worker's performance / comfortwhen assembling parts), styling (look & feel of a new surface)
  - Ideally, one would like to answer question like "how does the new design of the razor feel when grasped?"

Example Application: Minimally Invasive Surgery

Another Application: Assembly Simulation



Some Info on Human Haptics

- Tactile information:
  - Obtained by sensors in the human skin
  - Can sense details of a shape, texture, friction, ...
  - Human factors of the tip of a finger:
    - Precision = 0.15 mm with position of a point
    - Spatial acuity = 1 mm (= discrimination of 2 points)
    - Detection thresholds: 0.06 micrometers for ridges; 2 micrometers for single points
    - Temporal resolution: 1 kHz (compare that to the eye!)
- Kinaesthetic (proprioceptive) information:
  - Obtained by sensors in the human muscles
  - Can sense large-scale shapes, spring stiffnesses, ...
  - Human factors:
    - Acuity: 2 and 1 degrees for finger and shoulder, resp.
    - 0.5-2.5 mm (finger)

A Collection of Force Feedback Devices

CyberForce

(movie)

Phantom

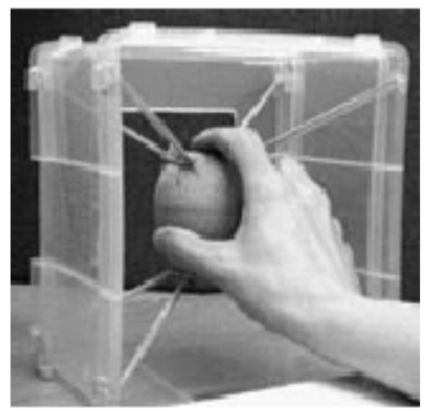
Sarcos (movie)

CyberForce

"Maglev" (magnetic levitation device)

Tsukuba

(movies)



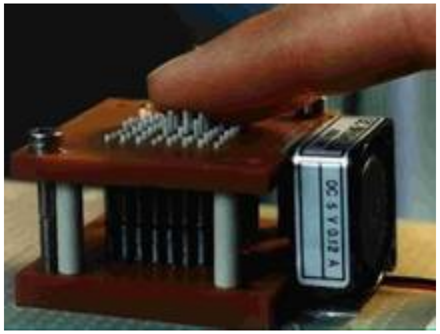
Spidar

Devices with Force Feedback via Wires (Spidar Variants)

Two-Handed Multi-Fingers Haptic Interface Device: SPIDAR-8

INCA 6D von Haption

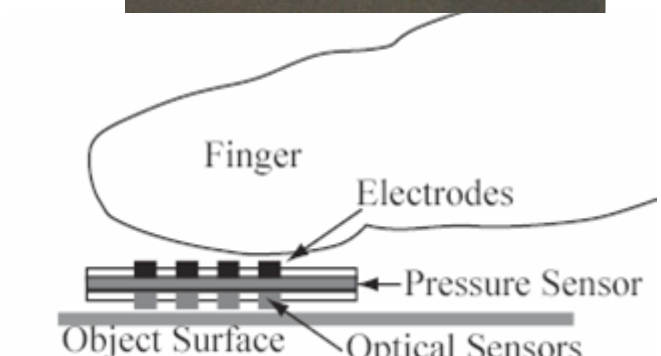
Tactile Displays



CyberTouch

AURA INTERACTOR

Feelex



SmartTouch (movie)

Motion Platforms (not really Force-Feedback)

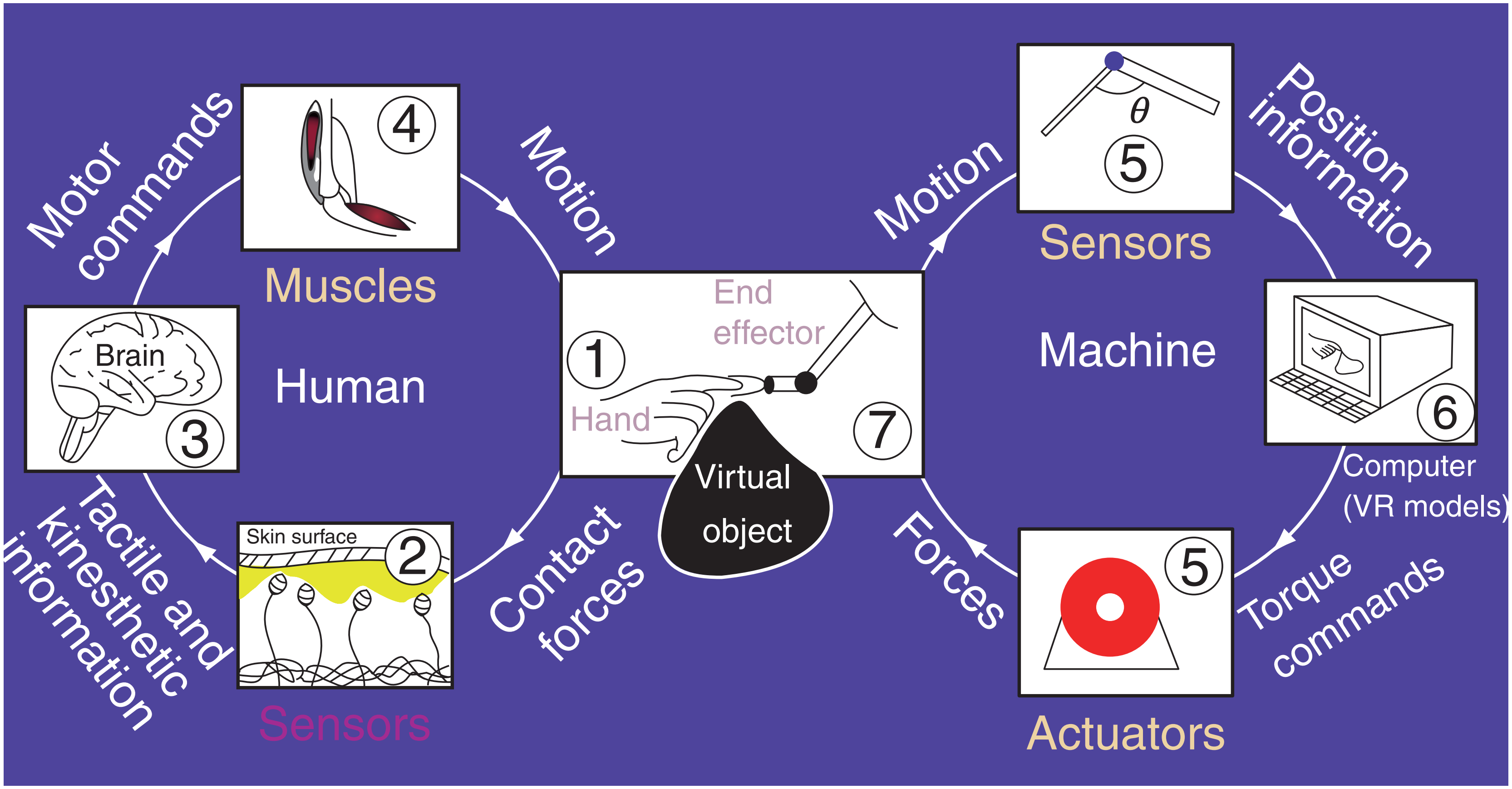
Flogiston

The Number of Degrees-of-Freedom with Force-Feedback Devices

- Number of DoF's a device can display: typ. ≤ 6 with *Force-Feedback*
- Number of inner DoF's = sum of DoF's of all joints

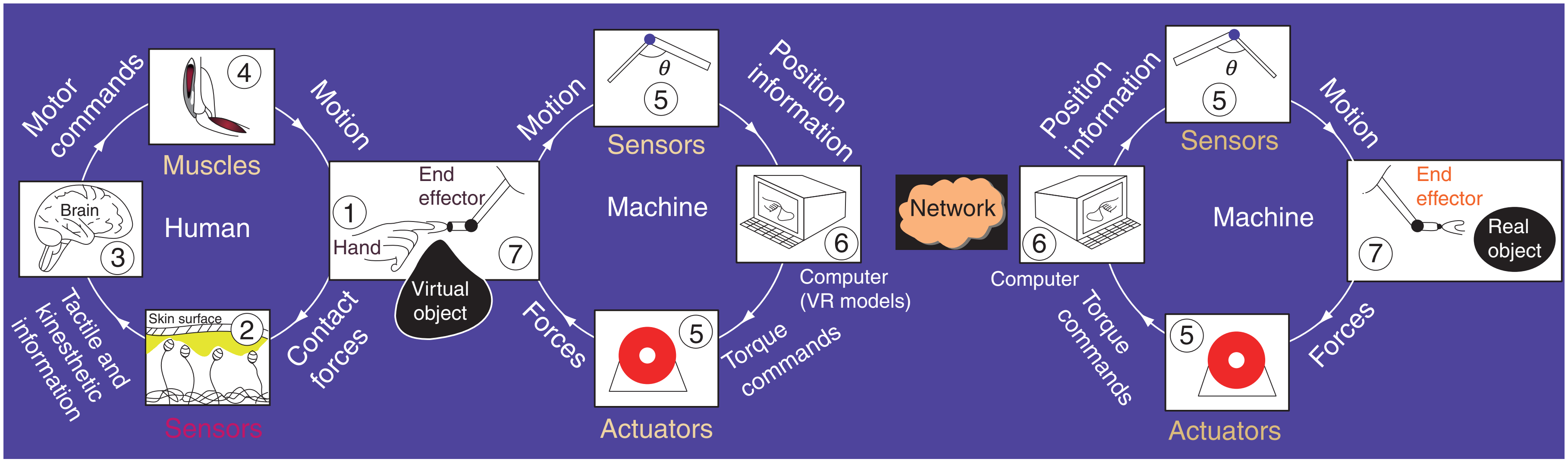
Cybernet

The Special Problem of Force-Feedback Rendering



M A Srinivasan & R Zimmer: *Machine Haptics*.
New Encyclopedia of Neuroscience, Ed: Larry R. Squire, Vol. 5, pp. 589-595, Oxford: Academic Press, 2009

... and that of Telepresence



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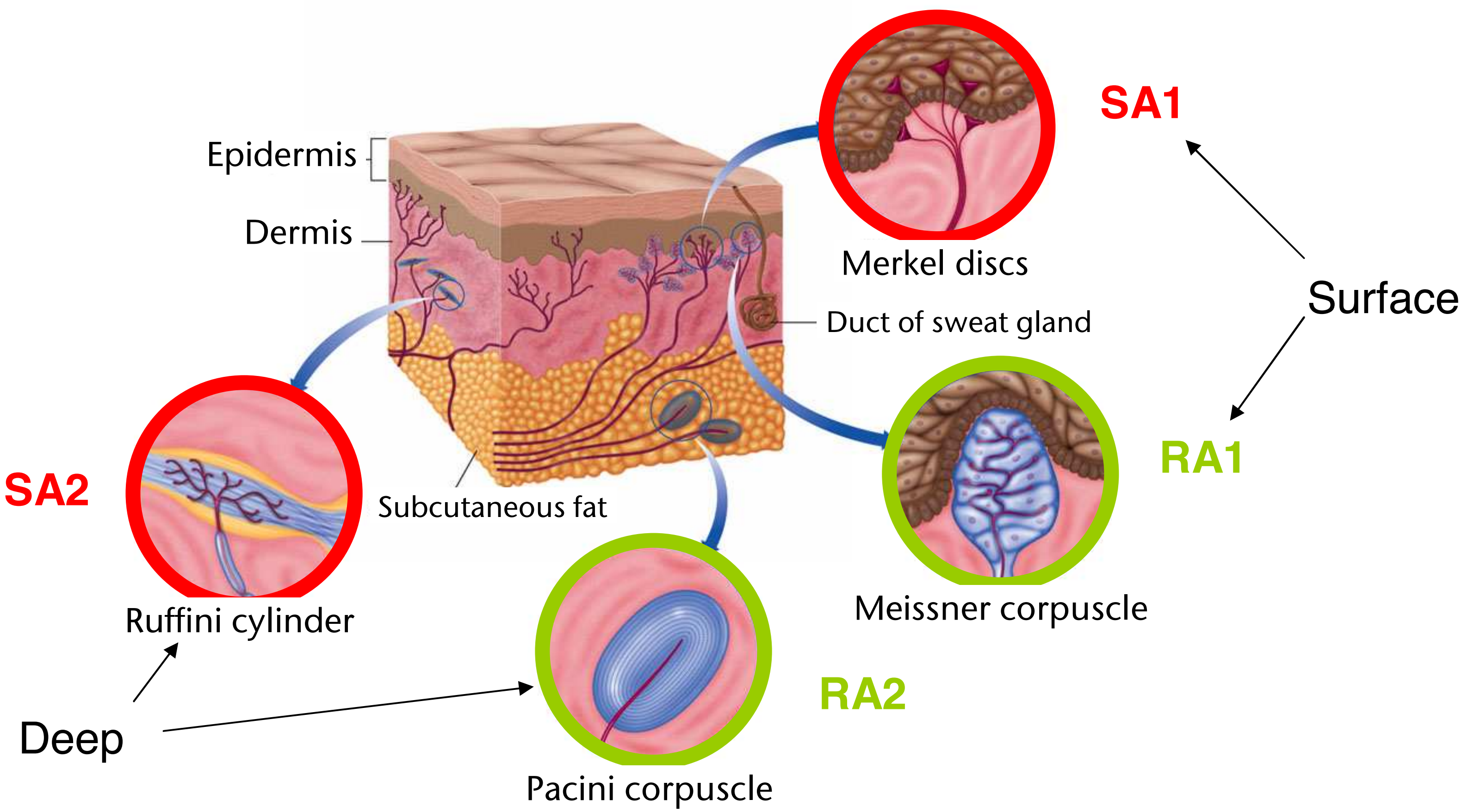
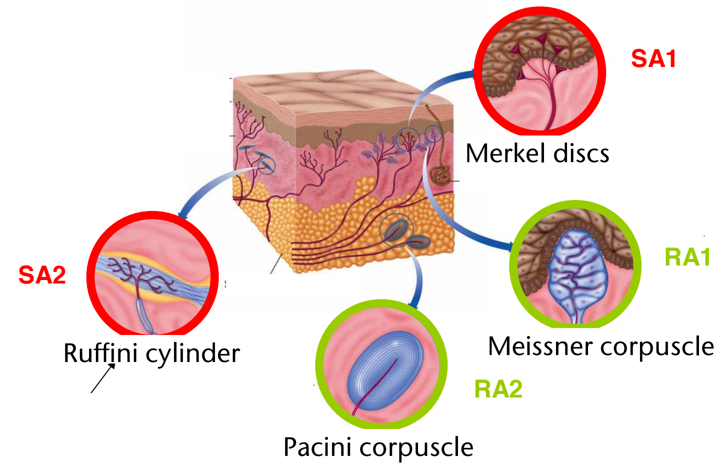
The Human Tactile Sensors

- There are 4 different kinds of sensors in our skin:



- Their characteristics:
  - Ruffini & Merkel: slowly adapting (SA), fire as long as the stimulus persists
  - Meissner & Pacini: rapidly adapting (RA), fire only at onset and offset of stimulus



Adapting Rate

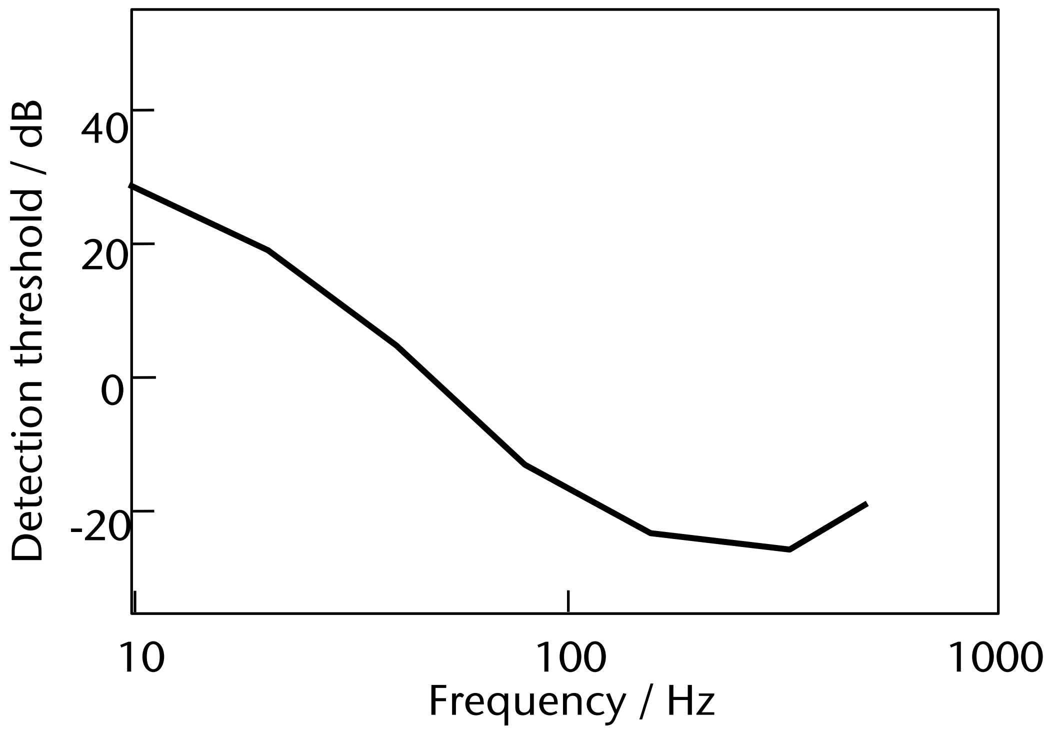
Response to vibration frequency		slow	fast	Location in Skin
	low	Merkel	Meissner	surface
	high	Ruffini	Pacini	deep

Human Factors with Respect to Haptics

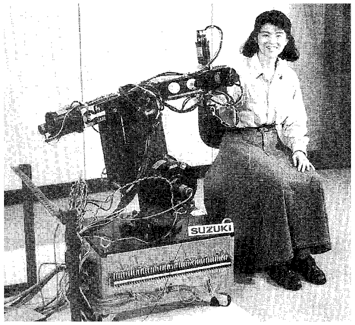
- Time until a reflex occurs:
  - Reflex through muscle: 30 millisec
  - Reflex through spinal cord: 70 millisec
  - Voluntary action: ?
- The frequency of human forces generation:
  - 1-2 Hz for irregular force signals
  - 2-5 Hz when generating periodic force signals
  - 5 Hz for trained trajectories
  - 10 Hz with involuntary reflexes
- Forces:
  - Max. 50-100 N
  - Typ. 5-15 N (manipulation and exploration)

- Sensation of stiffness/rigidity: in order to render hard surfaces, you need >1 N/mm (better yet 14 N/mm)

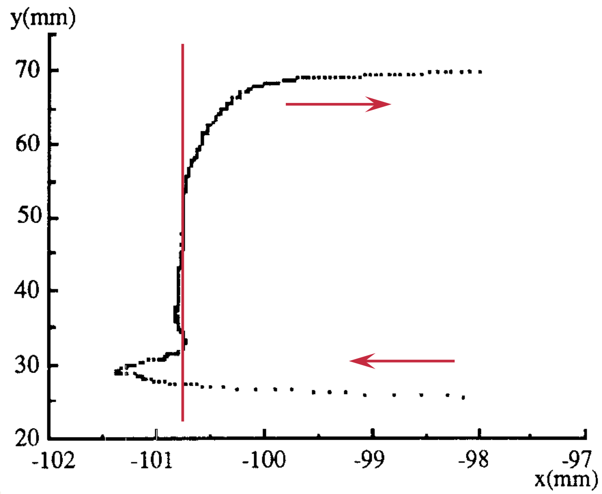
- Detection threshold for vibrations:

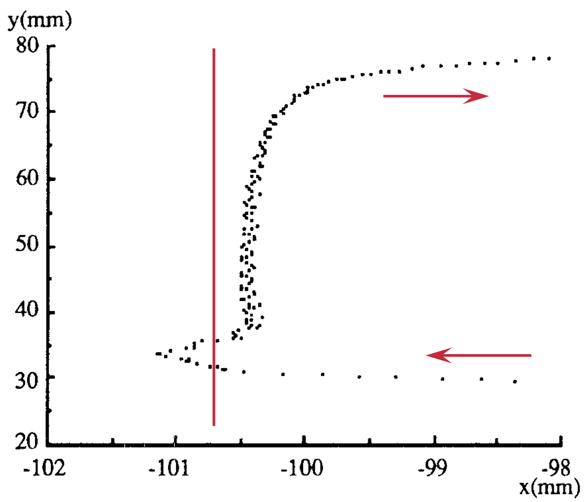


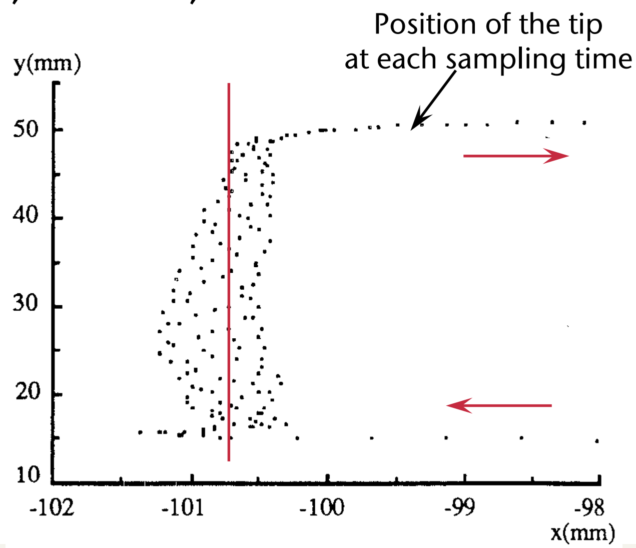
Rule of Thumb: 1000 Hz Update Needed for Haptic Rendering



- An Experiment as "proof":
  - That haptic device with a pen-like handle and 3 DOFs
  - The haptic obstacle = a flat polygon
  - Task: move the tip of the pen along the surface of the polygon (*tracing task*)
  - Impedance-based rendering (later)
  - Stiffness = 10000 N/m, coefficient of friction = 1000 N/(m/sec)
  - Haptic sampling/rendering frequencies: 500 Hz, 250 Hz, 167 Hz

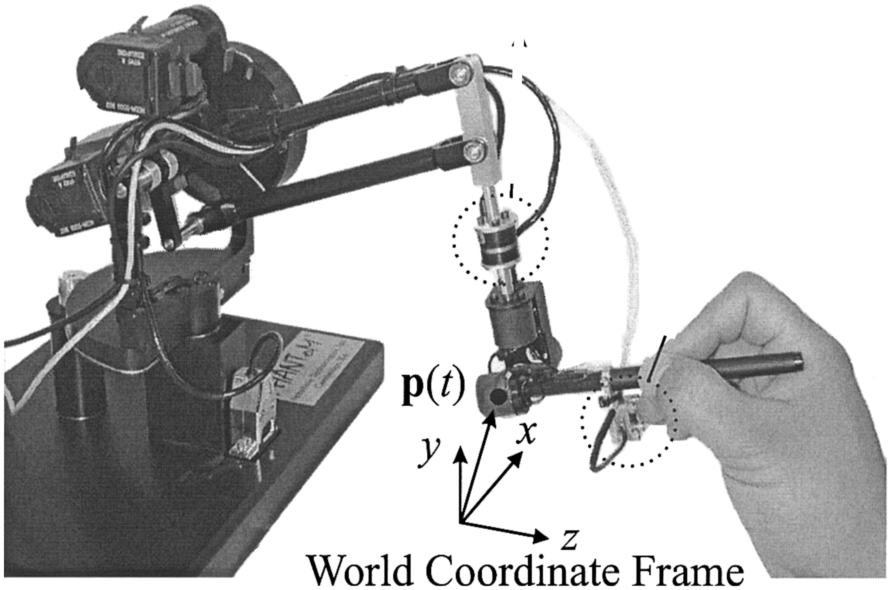






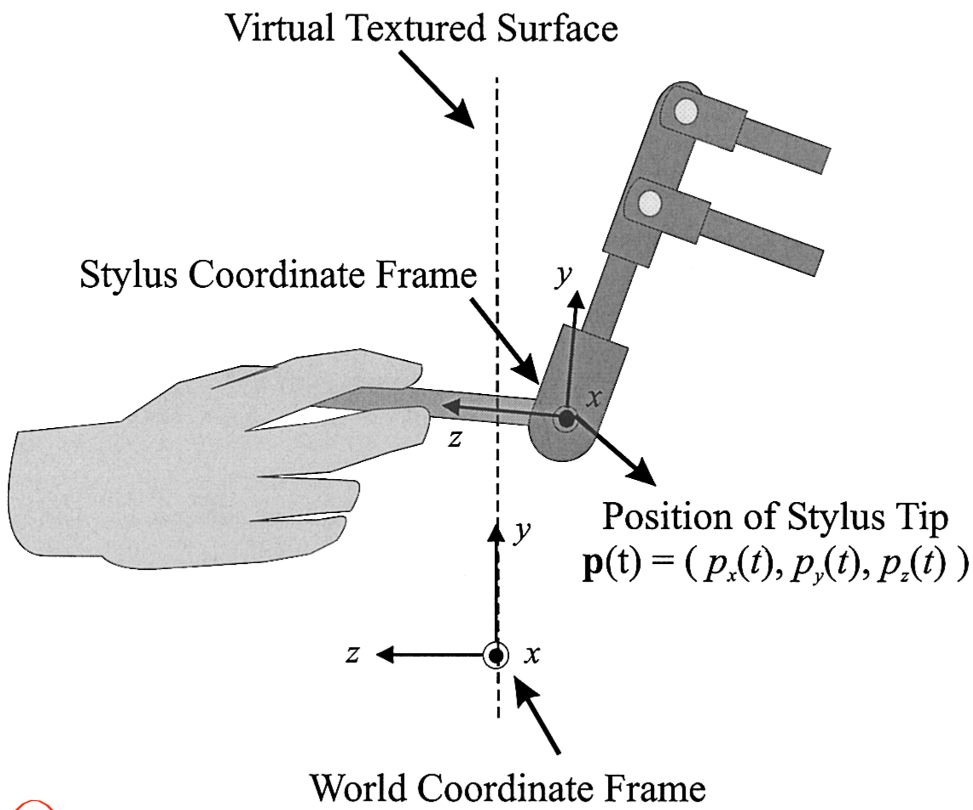
Haptic Textures

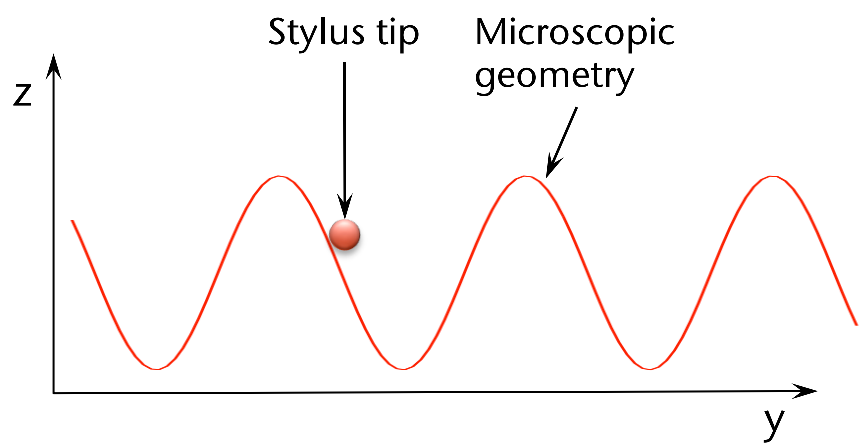
- Texture = fine structure of the surface of objects (= micro-geometry); independent of the shape of an object (= macro-geometry)
- Haptic textures can be sensed in two ways by touching:
  - Spatially
  - Temporally (when moving your finger across the surface)
- Sensing haptic textures via force-feedback device: as you slide the tip of the stylus along the surface, texture is "transcoded" into a temporal signal, which is then output on the device



A Frequent Problem: "Buzzing"

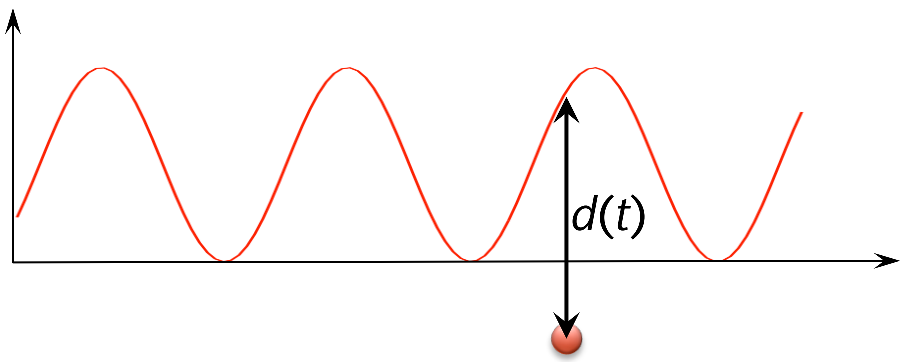
- Consider this experiment: a simple Phantom-like device and a sinus-wave haptic texture



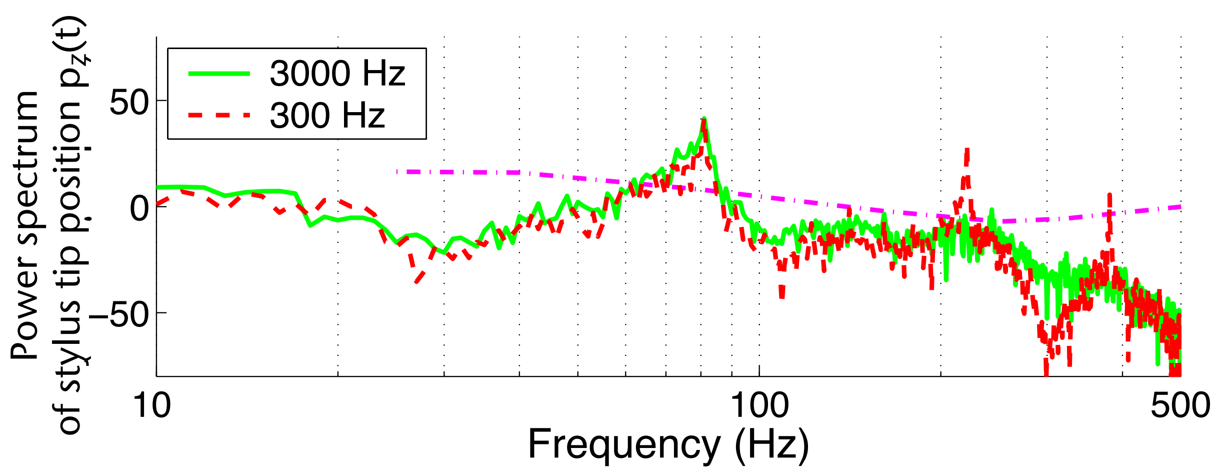


- The force that is rendered (= output on the actuators):

$$F(t) = k_s d(t)$$

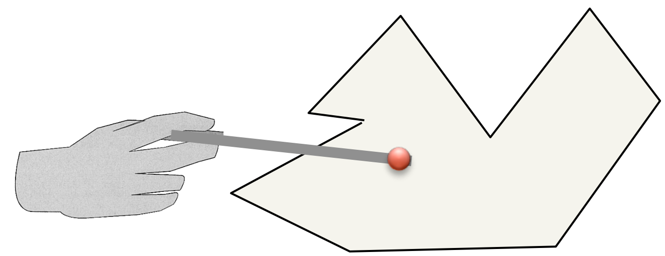


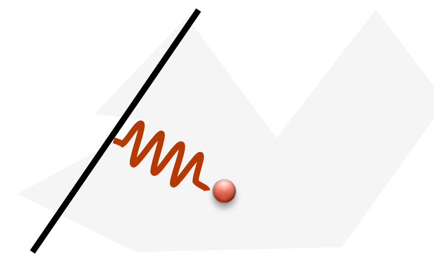
- Result with different rendering frequencies:

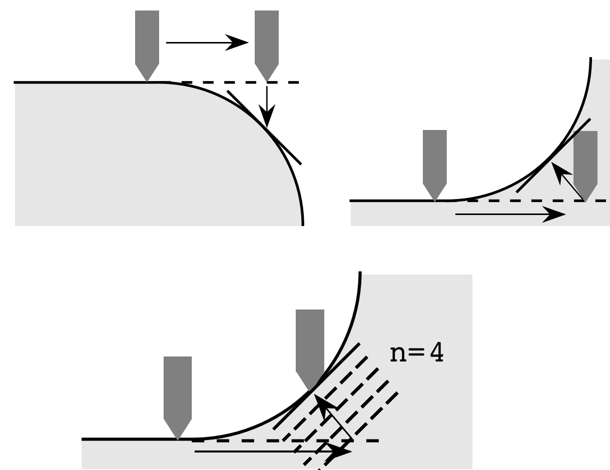


Intermediate Representations

- Problem:
  - Update rate should be 1000 Hz!
  - Collision detection between tip of stylus und virtual environment takes (often) longer than1 msec
  - The VR system needs even more time for other tasks (e.g., rendering, etc.)
- Solution:
  - Use"intermediate representation" for the current obstacle (typically planes or spheres)
  - Put haptic rendering in a separate thread
  - Occasionally, send an update of the intermediate representation from the main loop to the haptic thread







Software Archtecture

- A haptic device consists of:
  - Sensor measures force (admittance-based) or position (impedance-based)
  - Actuator moves to a specific position (admittance-based) or produces a force/ acceleration (impedance-based)

- Archtiecture: