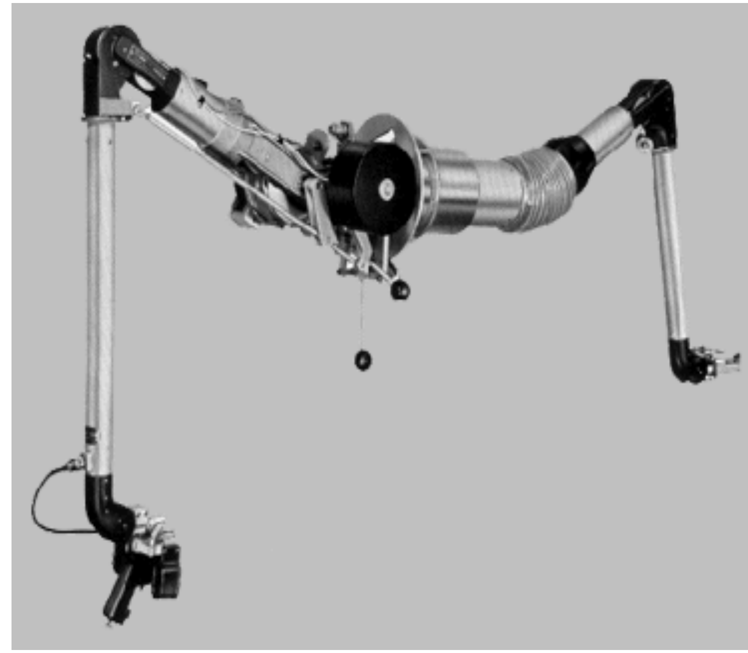
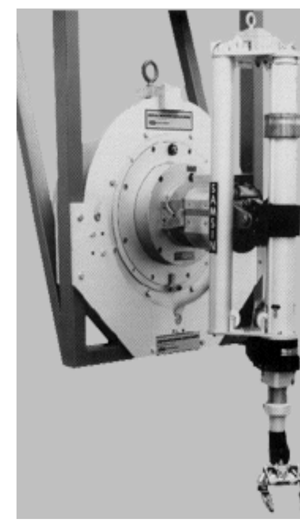
CS 277 - Experimental Haptics

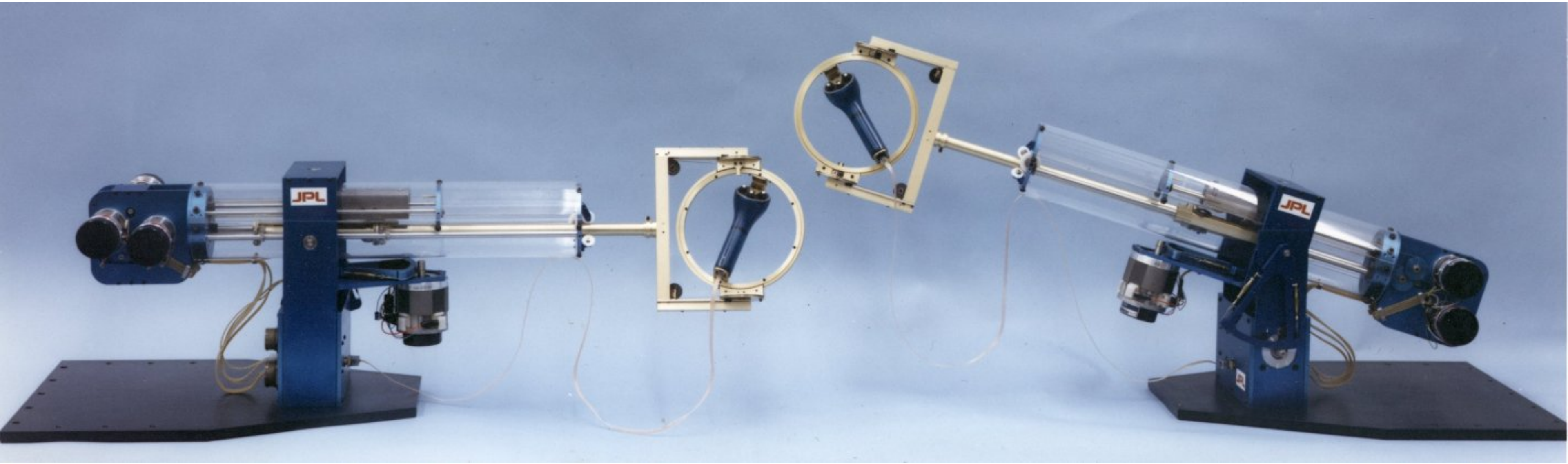
Lecture 17
“Haptic Interface Design - Theory”



CENTRAL RESEARCH LABORATORIES

A DOVER DIVERSIFIED COMPANY




JPL
JPL

Desirable Characteristics in a Haptic Interface

- Thomas Massie

Freedom and Constraint:

"free space feels free"

"constraints feel rigid"

"solid objects persist”

How well can we do this?

Extra Credit: What does this mean at different scales?

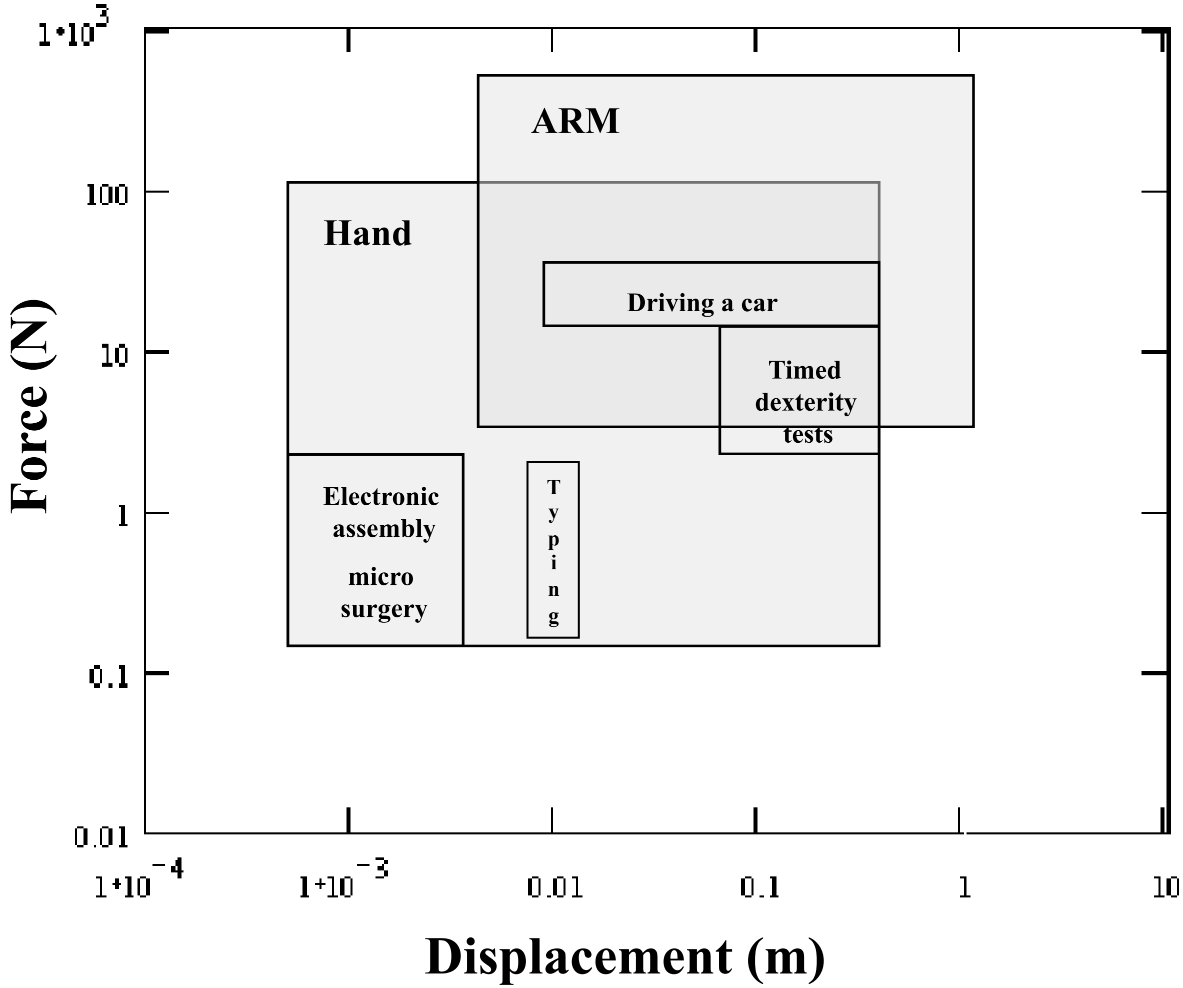
Dynamic Range: Motor Abilities

Dynamic Range: Fmax/Fmin

Human:	10^4:1 to 10^5:1
Good Motor (Maxon):	80:1
Motor (Mabuchi):	10:1
Falcon	10:1

http://www.maxonmotor.com/RE-max.asp

Dynamic Range: Human Abilities



Constraint Imposed by Contact Between Bodies

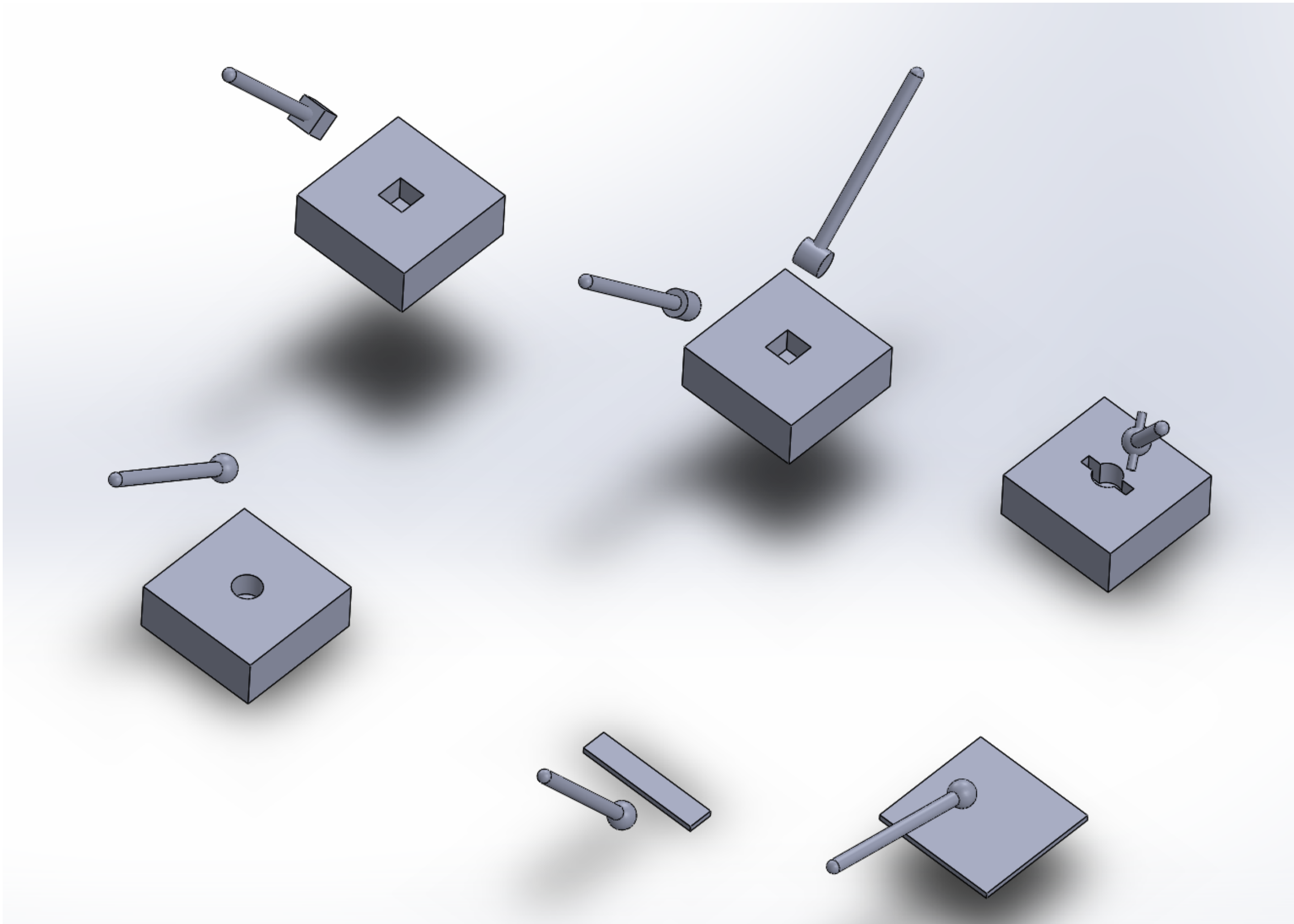
- **Point contact – 1 DOC, 5 DOF**
- **Point contact with friction – 3 DOC, 3 DOC**
- **Line contact – 2 DOC, 4 DOF**
- **Line contact with friction – 5 DOC, 1 DOF**
- **Soft finger – 4 DOC, 2 DOF**

•**Note: DOC = "Degree of Constraint**

DOF = "Degree of Freedom

DOC + DOF = 6 …. why?

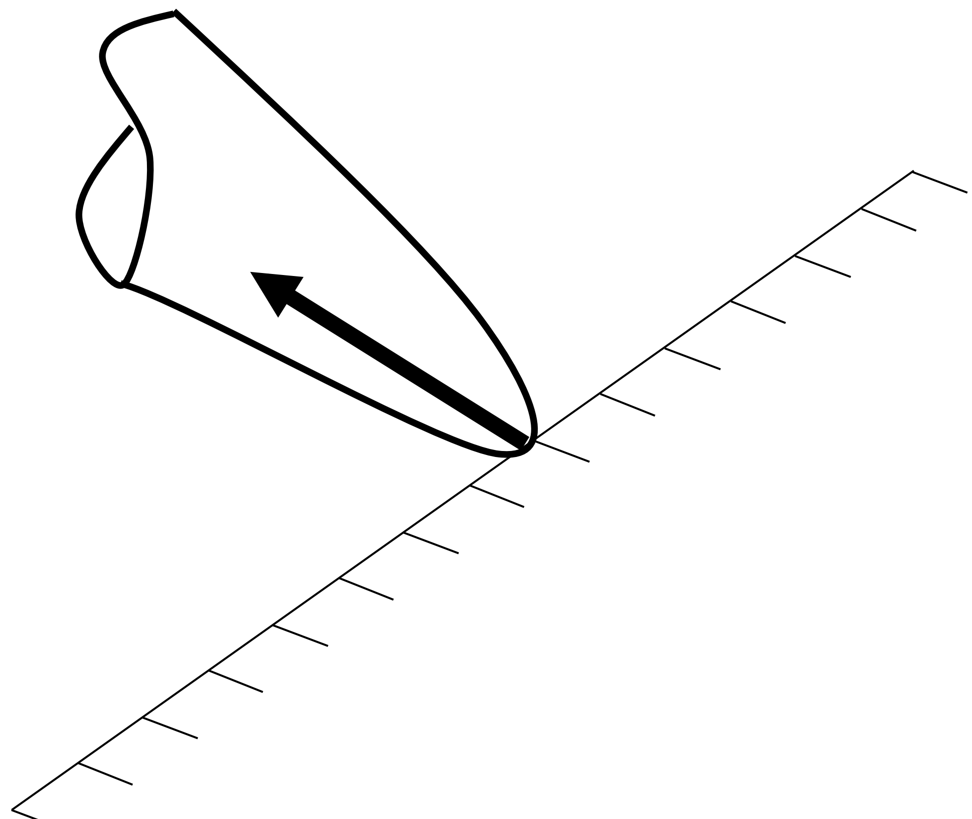
Degrees of constraint -> Task Difficulty



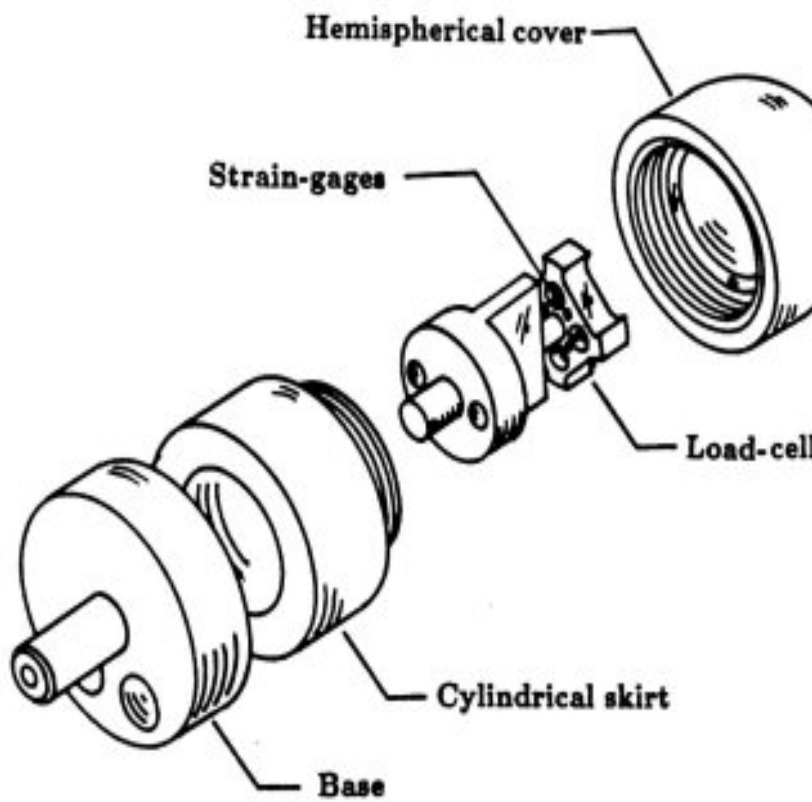
after Verplank ..

Information from Contact Force Measurements

Measurements of contact forces during exploration provide information about objects being touched from spatial and temporal variations in force.



Robot Haptics with a Force Sensing Fingertip

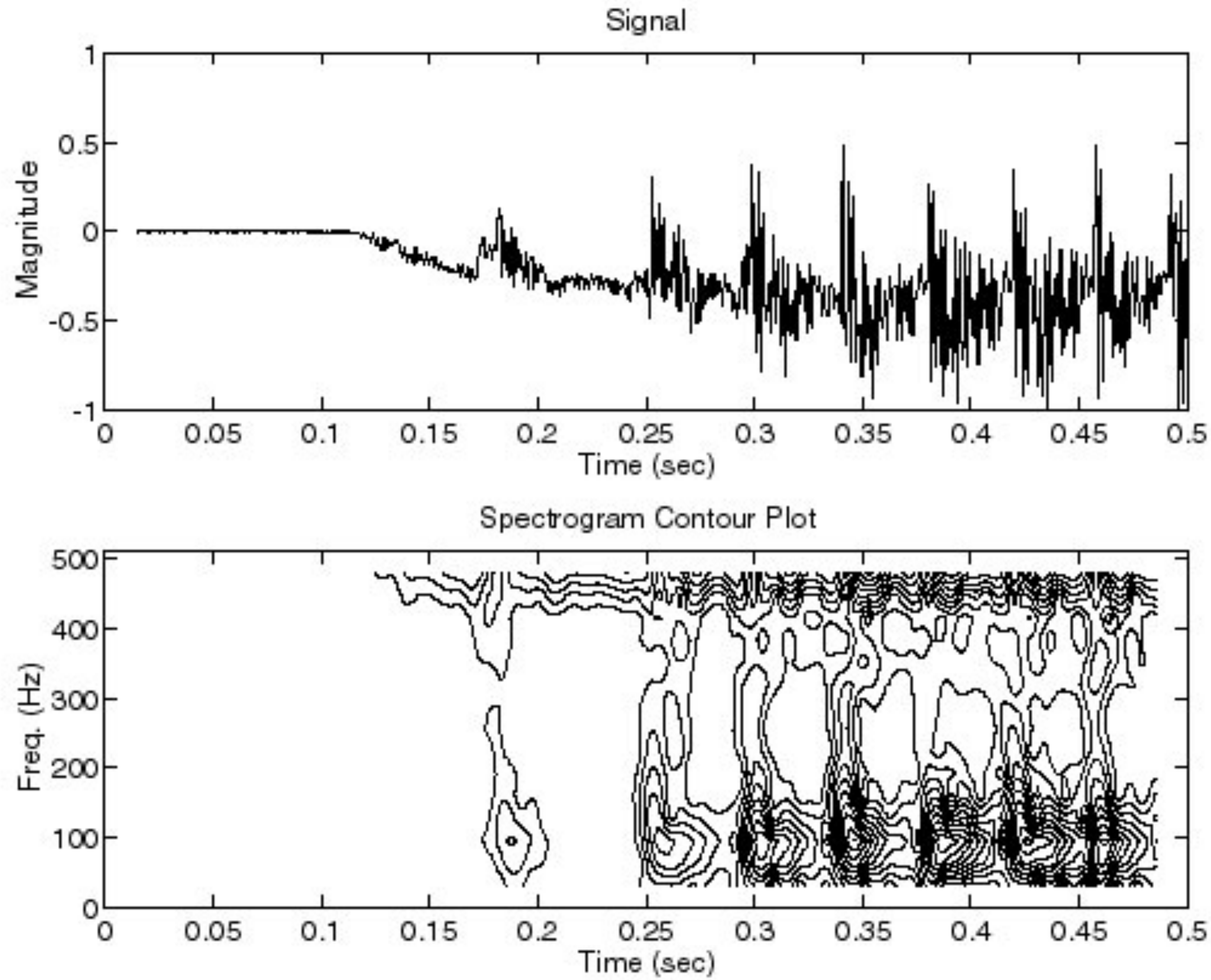


Determining Shape by Palpation

Palpating a sphere and estimating local tangent plane at each contact to provide object image.

Information from Active Exploration

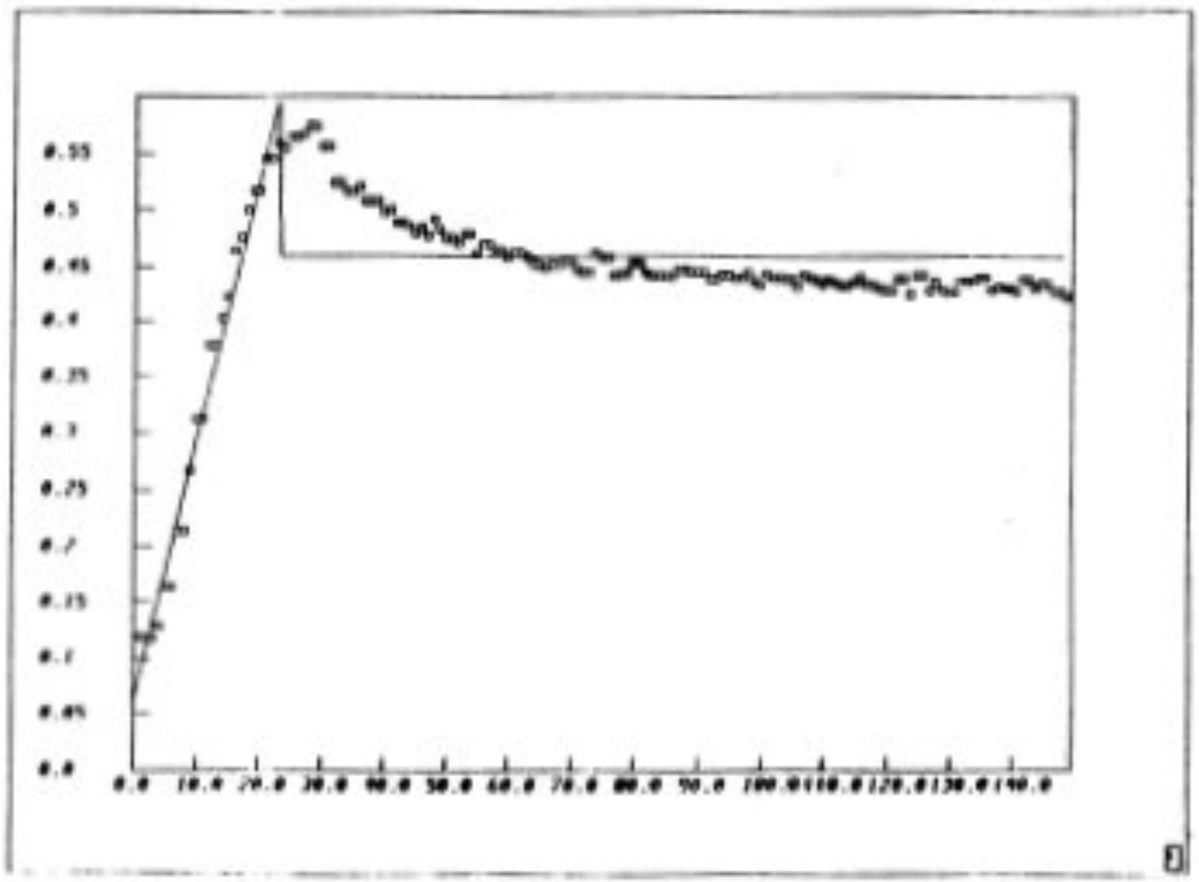
Stroking a textured surface



Friction/Texture Sensing

Finding friction coefficient and texture by stroking object

μ

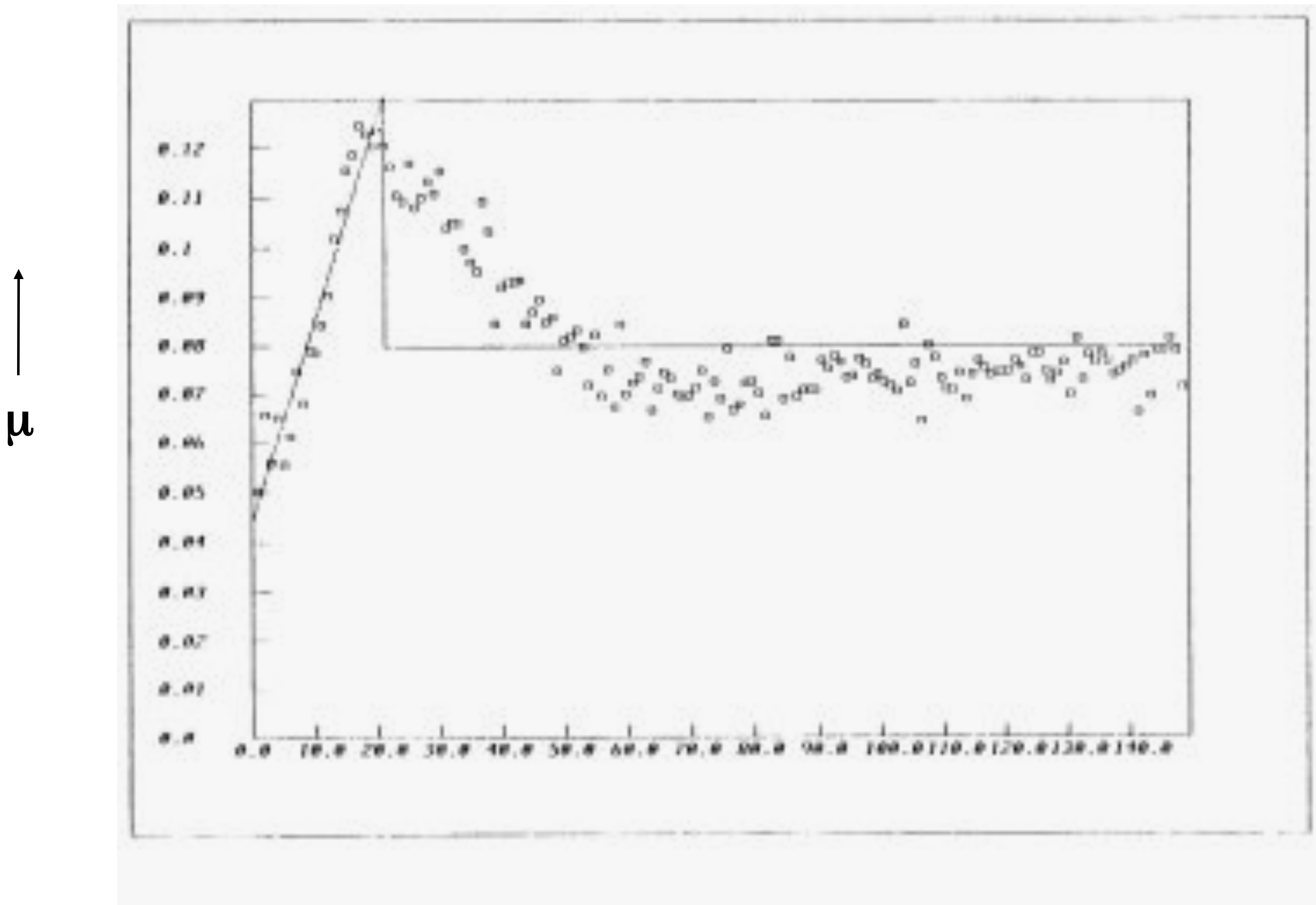


Friction Measurement: Aluminum on Rubber

time

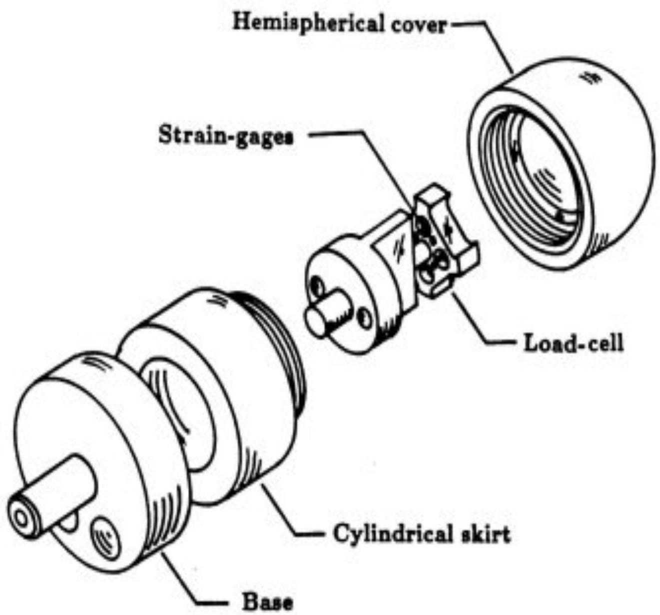
Friction/Texture Sensing

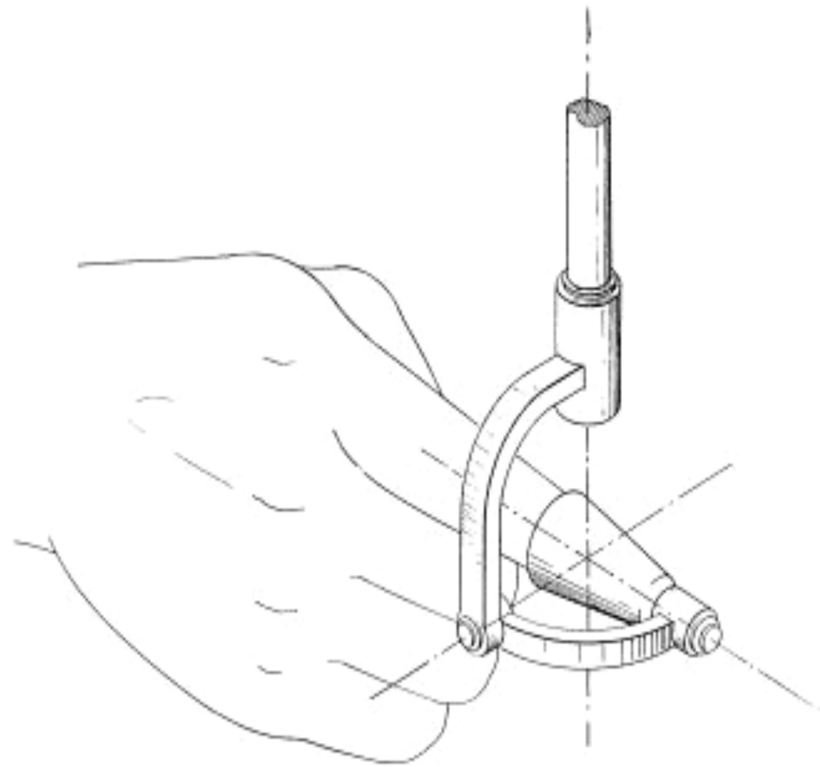
Finding friction coefficient and texture by stroking object



Friction Measurement: Aluminum on Plastic

From Robot Haptics to Computer Haptics





A good Haptic Interface maximizes "Transparency"

How?

- minimize *information distortion*

- minimize *cognitive loading*

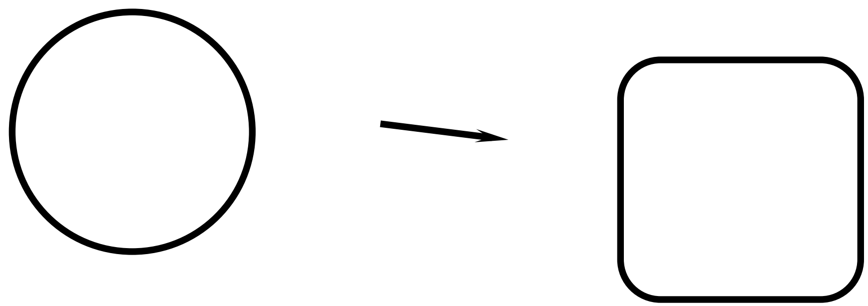
- maximize *responsiveness*

Mechanical characteristics of good haptic interfaces

- Low and well behaved friction (viscous, static, dynamic)
- Isotropic or minimal friction; symmetric friction volume
- Minimal hysteresis
- Isotropic or minimal reflected inertia

Friction Issues - distortion of force applied to mechanism with friction in joints

- Circles become squares when you operate with an interface with friction



Desired motion   Actual motion

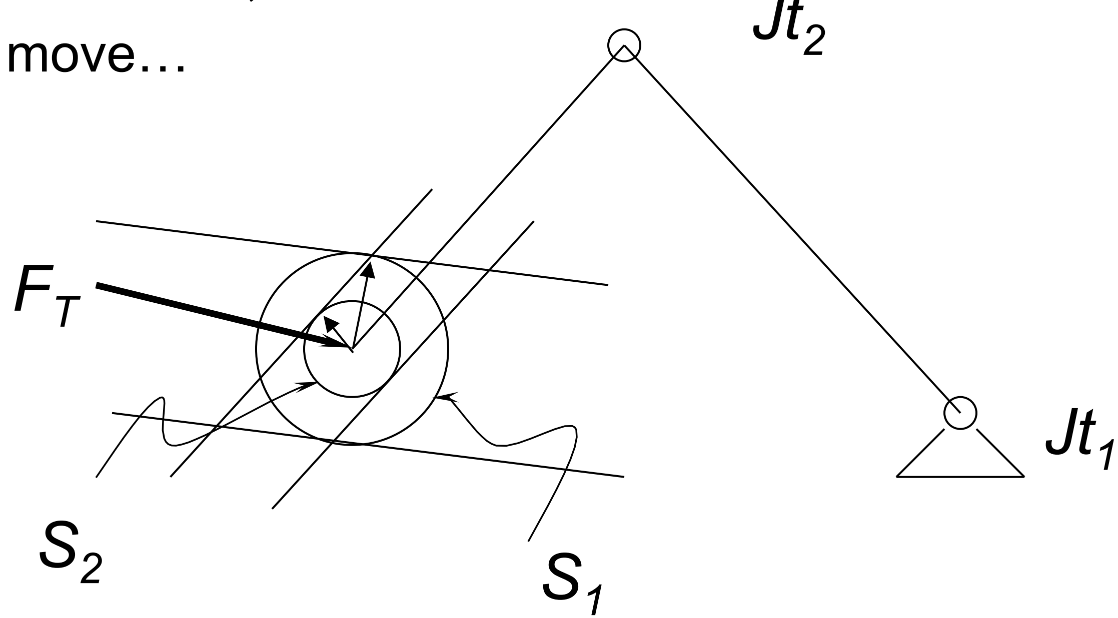
Friction Issues - distortion of force applied to mechanism with friction in joints

F_T is force applied to tip of haptic interface

If $|F_T|$ < radius of S_1 Jt_1 will not move

If $|F_T|$ < radius of S_2 Jt_2 will not move

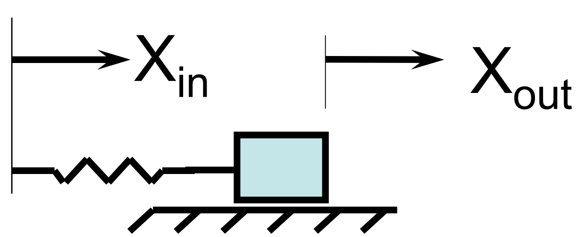
If $|F_T|$ is between these two radii, the interface may or may not move…

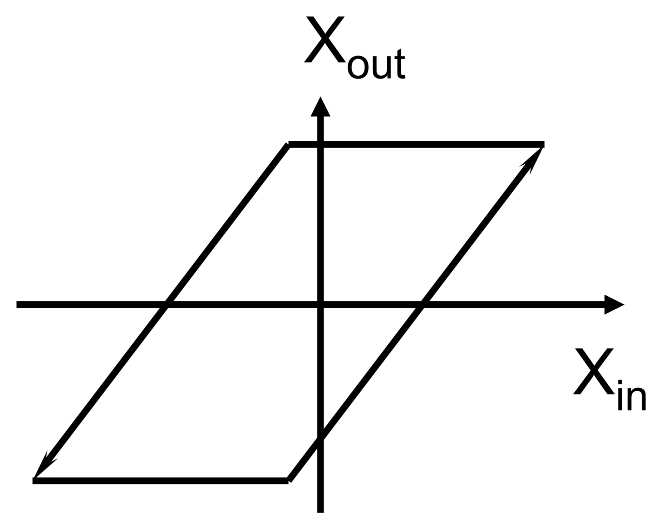


Hysteresis Issues
– distortion of force or motion due to “gaps” in transmission

Sources of Hysteresis

- backlash in gears or mechanism - position
- overcoming friction – force
- pushing on spring with friction





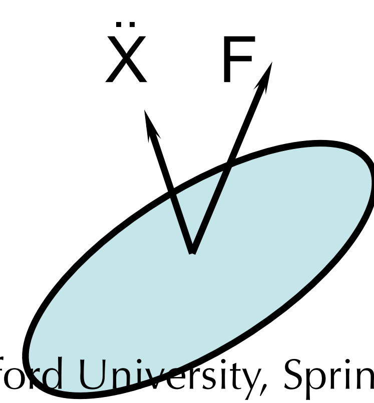
Maximizing Interface Transparency

– Inertia Issues

- Translational and Rotational Inertia
  - make small and/or isotropic

- Reflected inertia
  - reflected inertia – mass felt at tip includes apparent mass of actuators = $N^2 \cdot J_{actuator}$

- Non-Isotropic Inertia *distorts accelerations*



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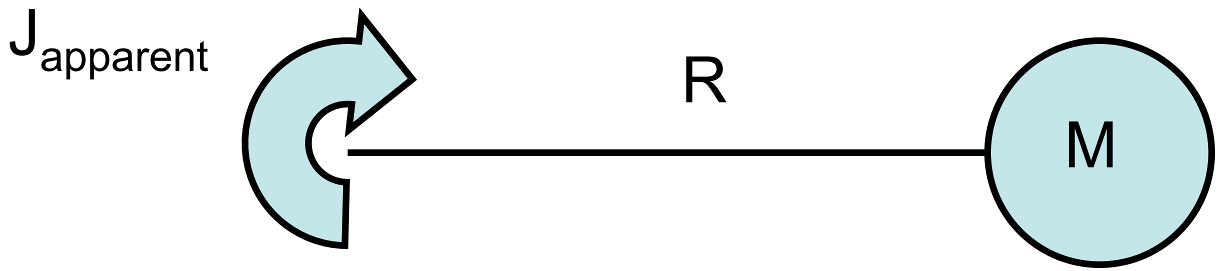
Maximizing Interface Transparency

Reflected rotational inertia at grip – ball on a stick example:

$J_{apparent} = M \cdot R^2$



Therefore, minimize R !

Building a Haptic Interface

Should it be an impedance – force source
or an admittance - a position or velocity source?

Impedance

Position in -
Force out

Admittance

Force in -
Position out

Vocabulary: Stiffness vs Compliance:

Stiffness: $K = F/x$

Compliance: $C = x/F$

$C = 1/K$ they are reciprocals

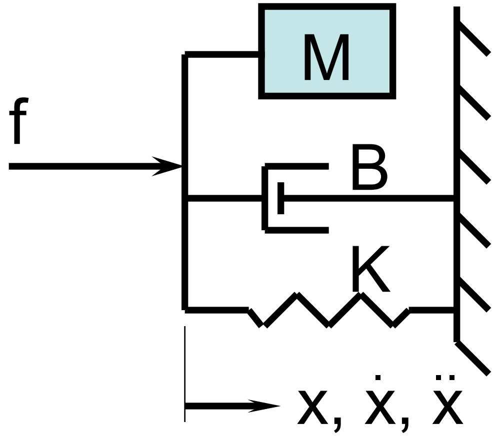
Velocity – force dependence:

Damping: $B = f/x$

Inverse damping: $1/B = xd/f$
(sometimes inexactly called admittance)

Note: Call it damping *not* dampening!

Physical Model for Impedance and Admittance



Issues:

Linearity vs nonlinear, polynomial, piecewise,

Monotonicity vs multiple valued functions

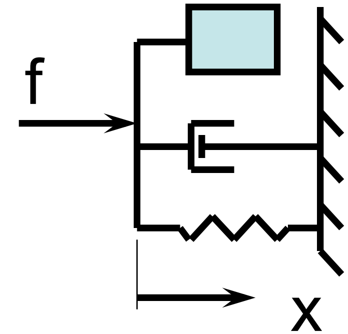
Constant coefficients vs time-varying

Causality

– what combinations are physically impossible (e.g. infinite power)

Haptic Interfaces: An Impedance Device

Impedance



Sense: interface position, velocity, acceleration

Command: force to apply to user via haptic interface

Examples:

$f = K \cdot x$; spring

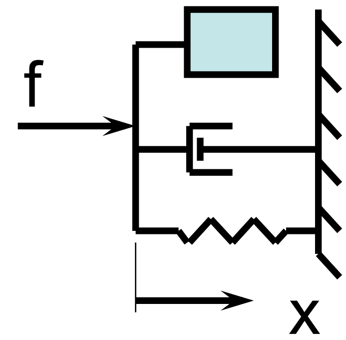
$f = B \cdot \dot{x}$; pure damper

$f = M \cdot \ddot{x} + B \cdot \dot{x} + K \cdot x$; 2nd order impedance

$f = F(x,t,\ldots)$; complex impedance

Haptic Interfaces: An Admittance Device

Admittance



Sense: force user applies to haptic interface

Command: position (and/or derivatives) of interface

Examples:

$x = 1/K \cdot F$; pure compliance

$\dot{x} = 1/B \cdot F$; pure damper

$\ddot{x} = f/M - B/M \cdot \dot{x} - K/M \cdot x$; general admittance

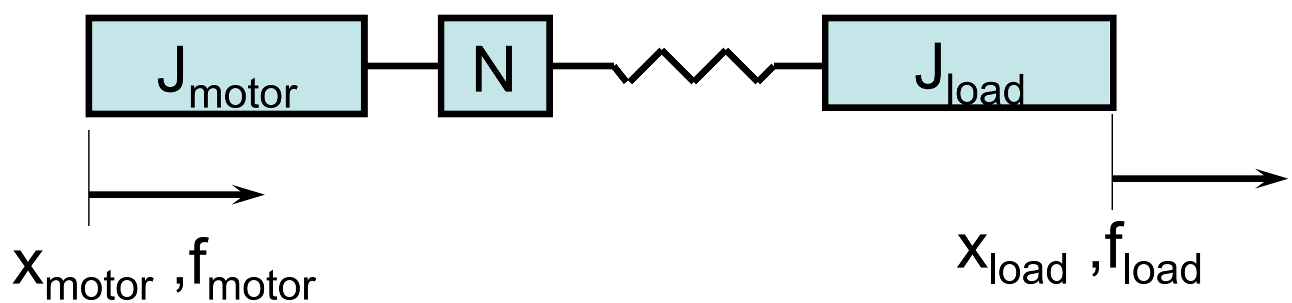
Note: Admittance = Impedance^{-1}

Good Performance

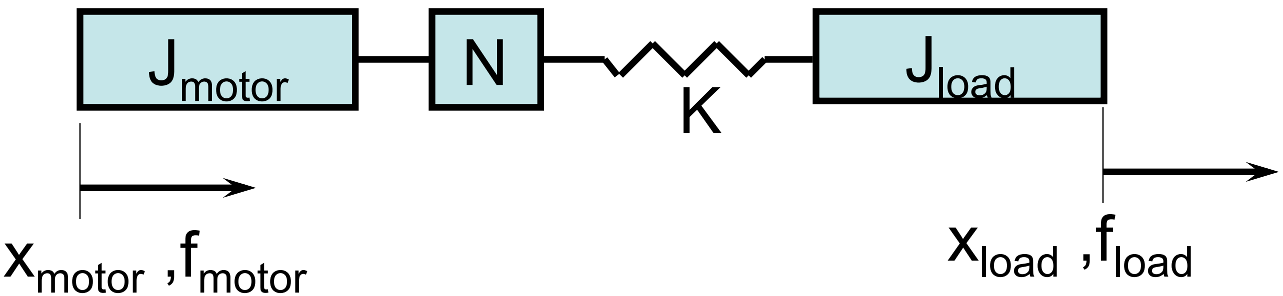
Output Bandwidth "3dB point" of transfer function:

Force Bandwidth: f_{load}/f_{cmd}

Position Bandwidth: x_{load}/x_{cmd}



Good Performance – haptic device as a transducer



Maximize minimum resonant frequency (N=1)

fixed load condition: $w_1 = sqrt(J_{motor}/K_{transmission})$

fixed motor condition: $w_2 = sqrt(J_{load}/K_{transmission})$

How to choose N?

Maximum power transfer -> Max acceleration of load -> maximizes bandwidth?

Impedance match motor and load: $J_{load} = N^2 * J_{motor}$

Good Performance

Position and Force quality: we want large dynamic range:

we want large $force_{max}/force_{min}$
we want large $position_{max}/position_{min}$

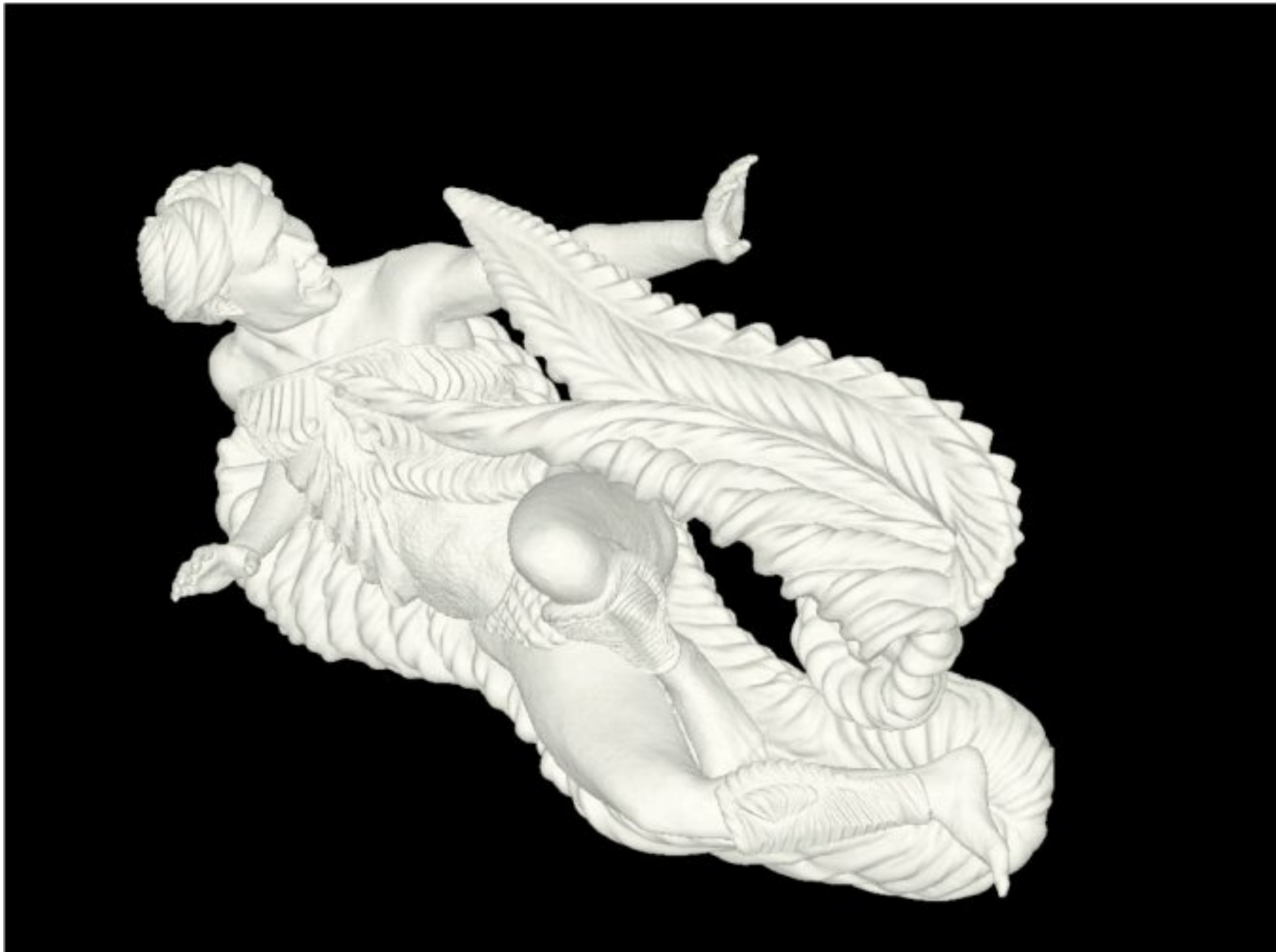
Are these scale independent measures of performance?

What do you think should be next?

- 6-Degree-of-Freedom
- Grip Force Feedback
- Multi-Finger, Multi-Arm
- Tactile Display
- Large Workspace
- Minimalist Systems

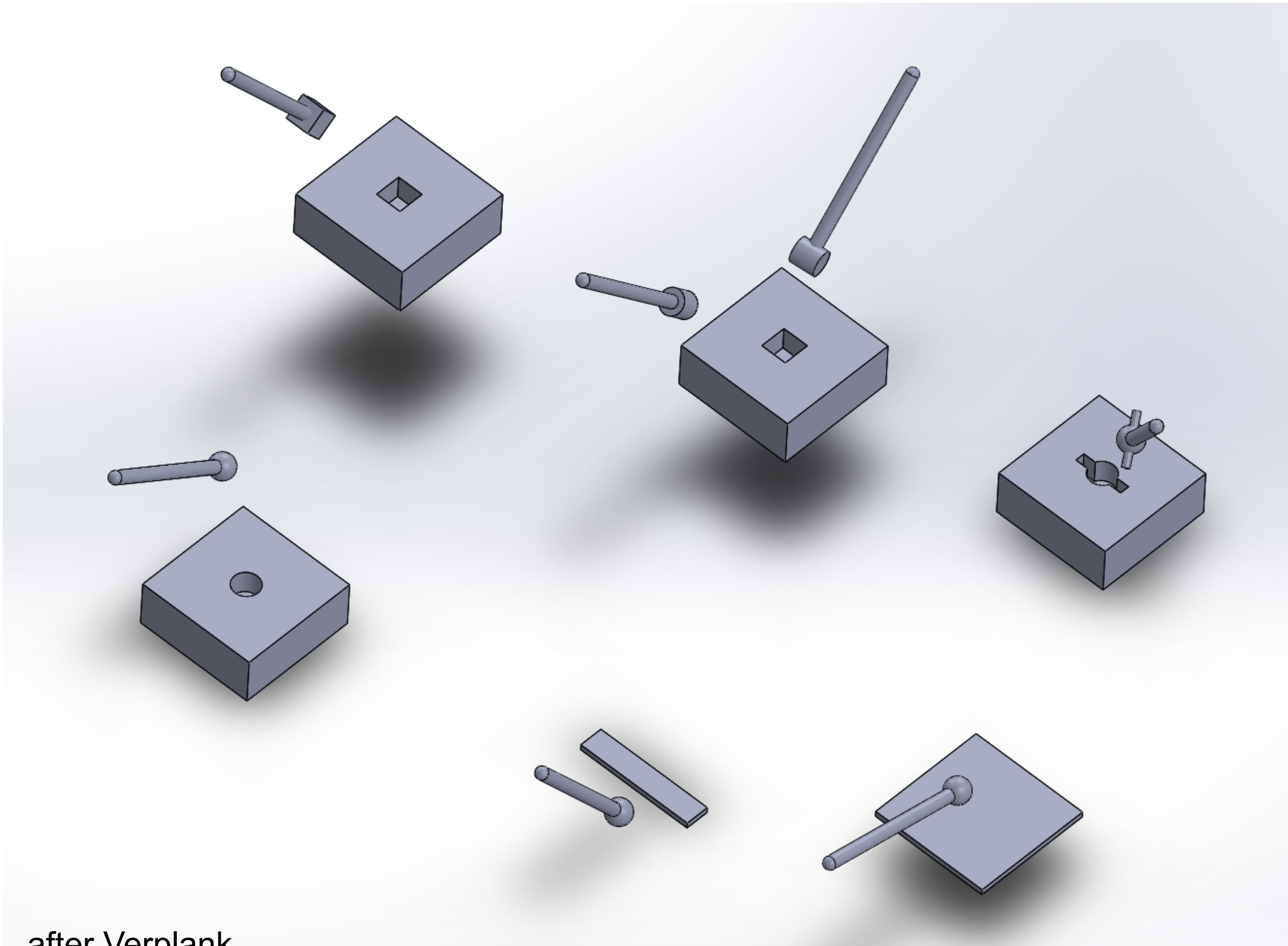
What about Human Robot Haptics?

- Contact Interactions
  - Touching and Being Touched
  - Taking and Giving
  - Leading and Being Led
- Gestural Communications
  - Non-contact gestures
  - Contact Gestures



End ☺

Degrees of constraint -> Task Difficulty



Cognitive Loading

Cognitive load:

The level of effort associated with thinking and reasoning (including perception, memory, language, etc.), thus potentially interfering with other thought processes. A user interface strives to minimize the cognitive load associated with operating the interface itself so that all of a person's cognitive resources are available for their task.

- from http://www.usabilityfirst.com