CS 277 - Experimental Haptics

Lecture 07
“Haptic Interface Design - Theory”

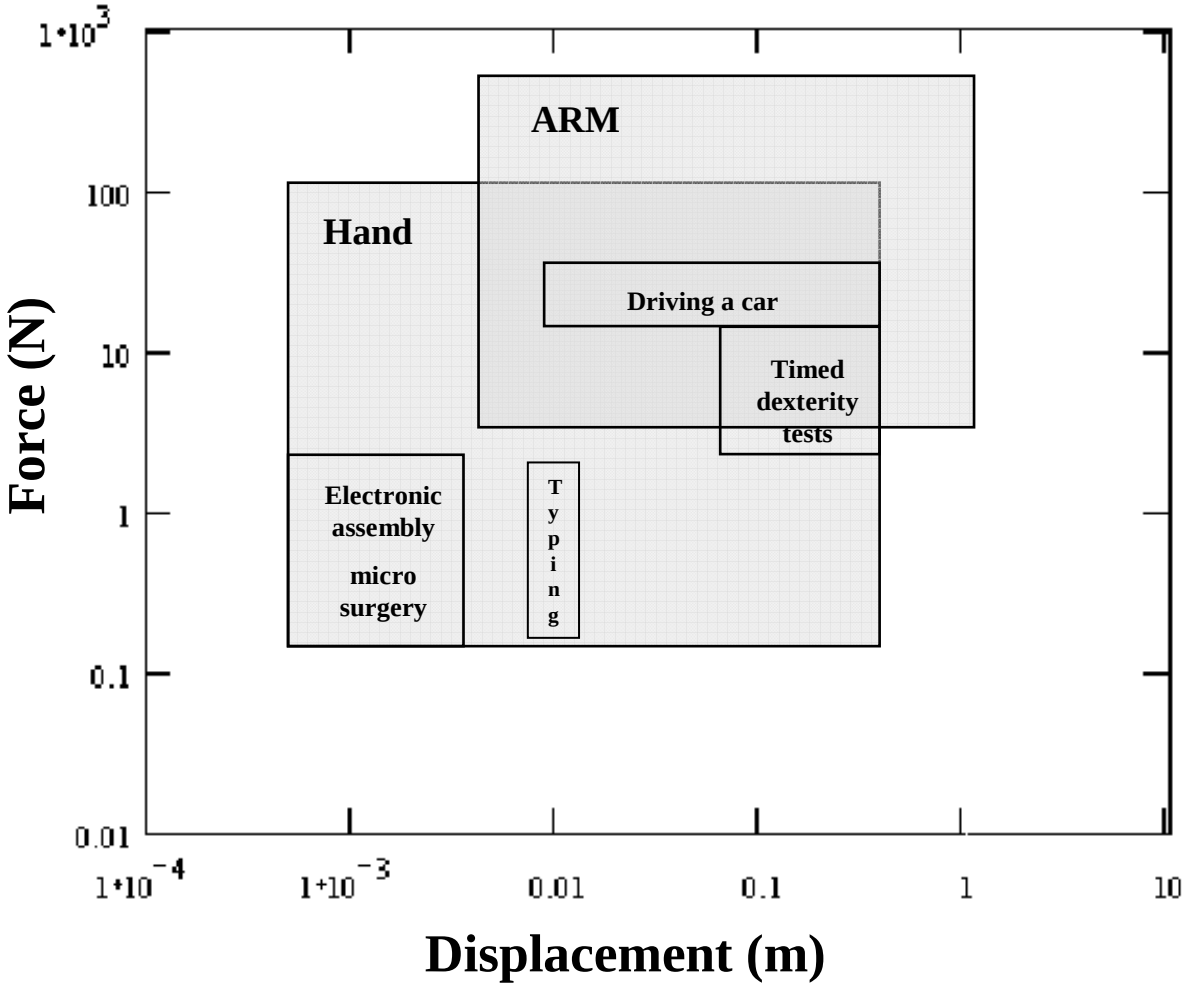
Dynamic Range: Motor Abilities

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



Courtesy of Lynette Jones, MIT

Common Problem “My Falcon Vibrates – it must be broken”

- Common Problems
    - Stiffness too high – sinusoidal instability
    - Lightly Touching Surface – non-linear limit cycle

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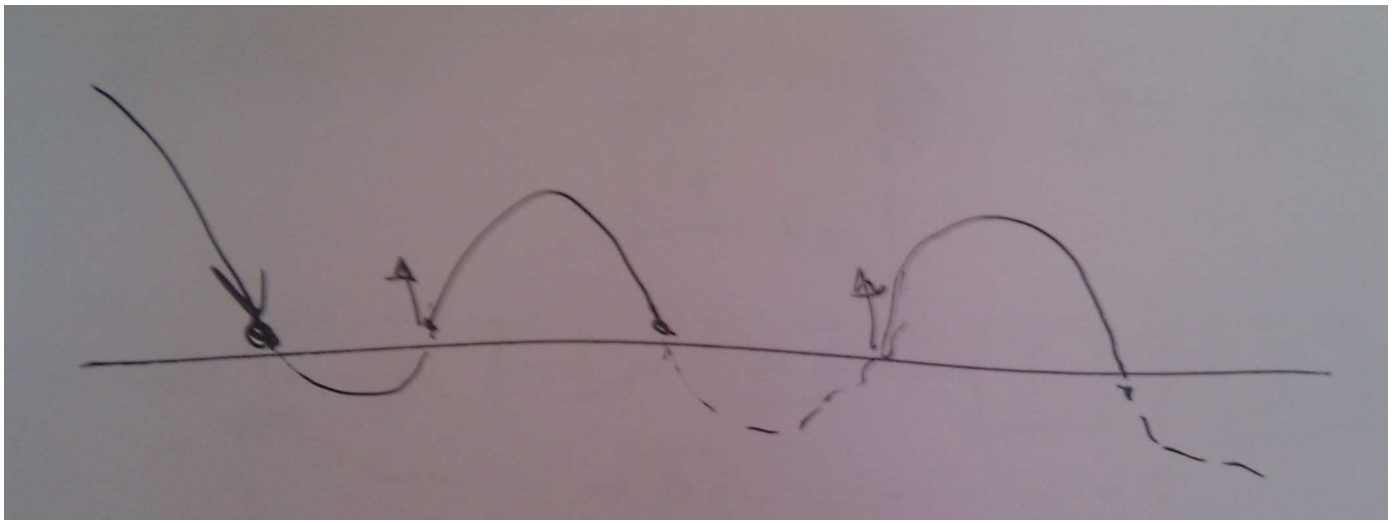
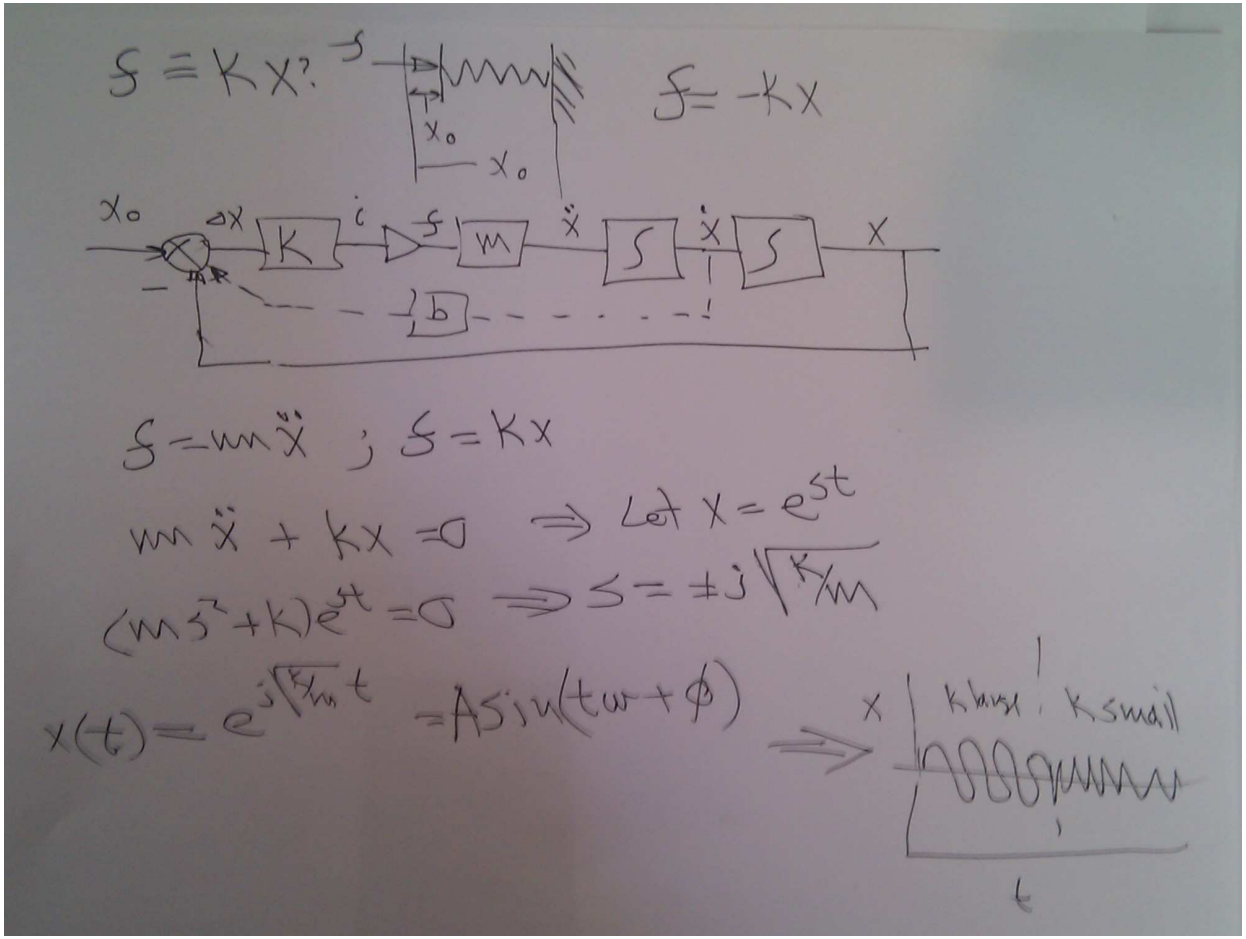


Common Problem “My Falcon Vibrates – it must be broken”

- Stiffness too high – sinusoidal instability



Desirable Characteristics in a Haptic Interface

- Thomas Massie

Freedom and Constraint:

"free space feels free"

"constraints feel rigid"

"solid objects persist”

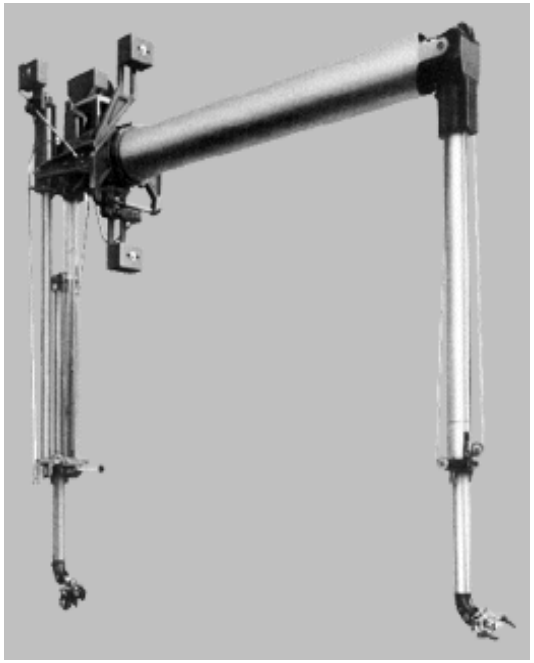
Extra Credit: What does this mean at different scales?

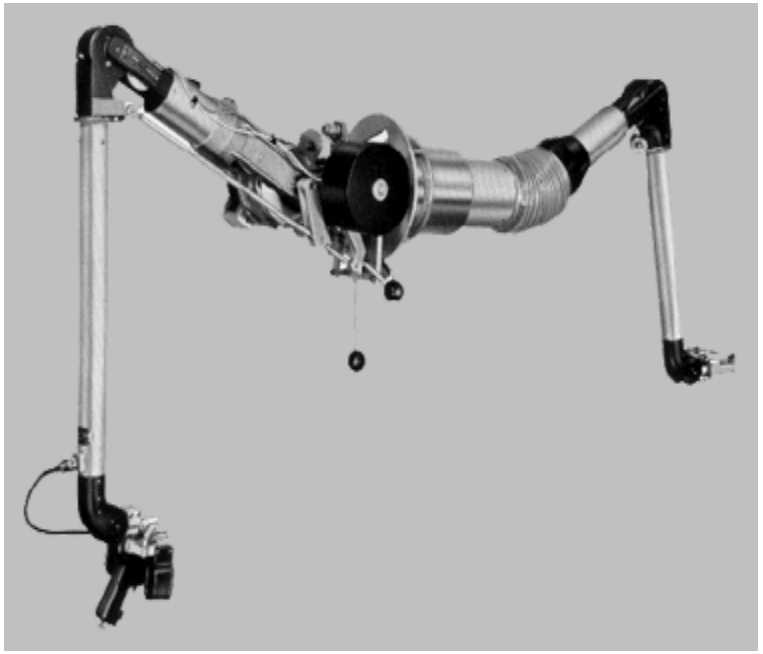
Cognitive Loading

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.

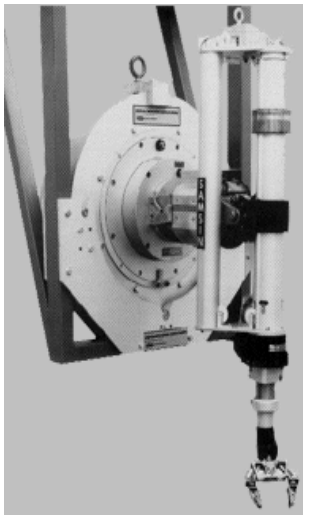
- from http://www.usabilityfirst.com





CENTRAL RESEARCH LABORATORIES

A DOVER DIVERSIFIED COMPANY




JPL
JPL

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**

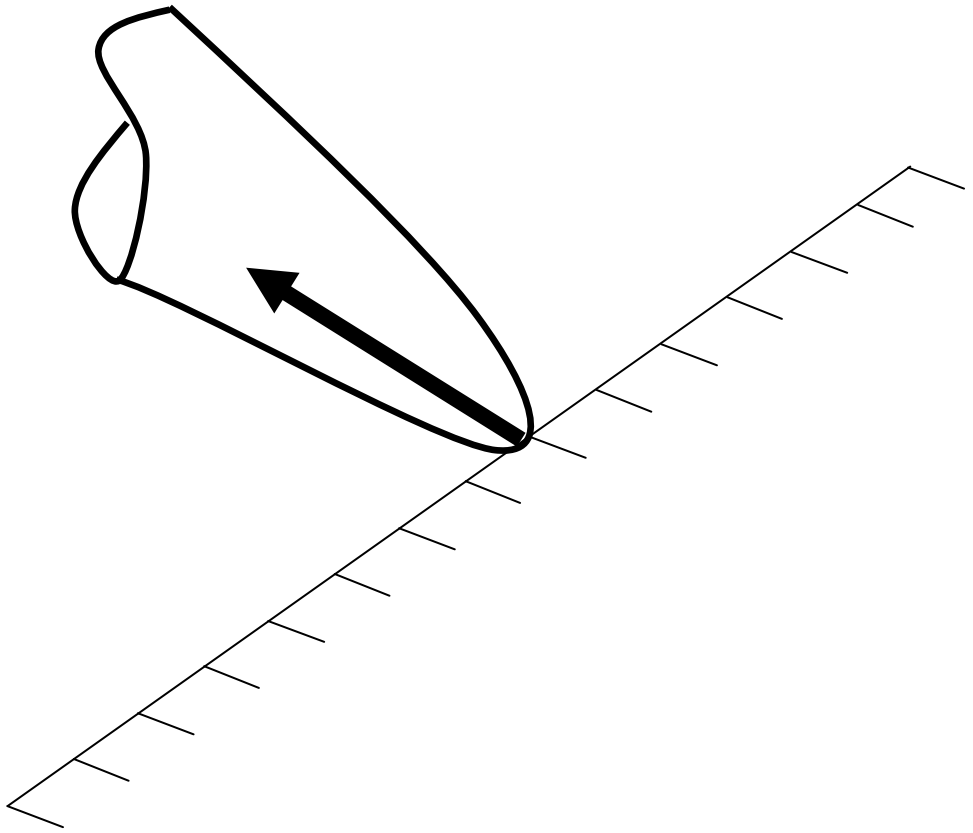
- **Note: DOC = “Degree of Constraint**

  DOF = “Degree of Freedom

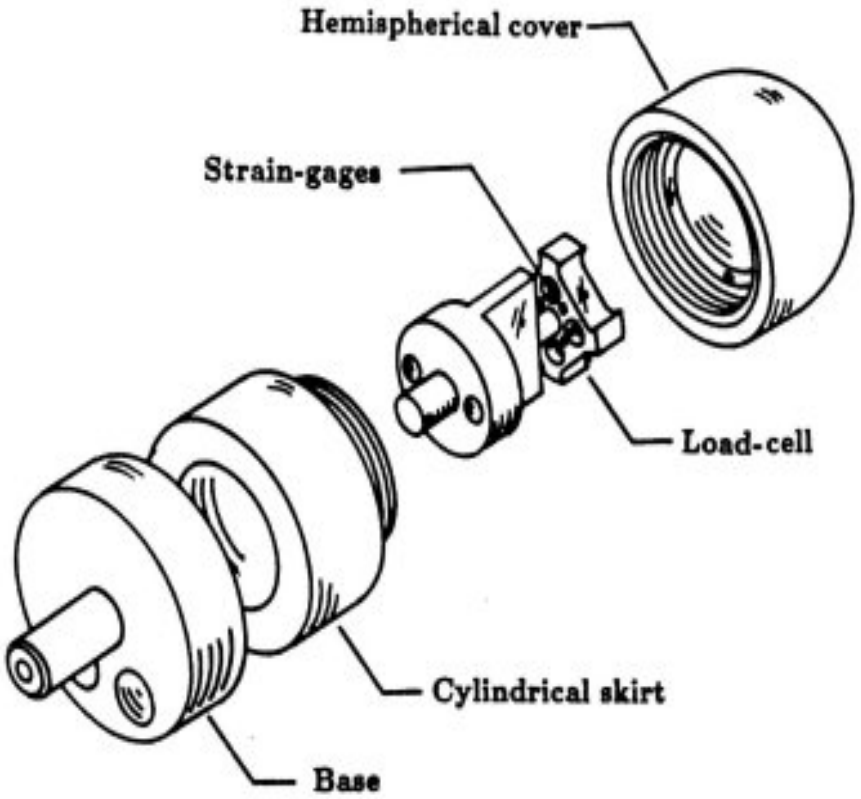
  DOC + DOF = 6 …. why?

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

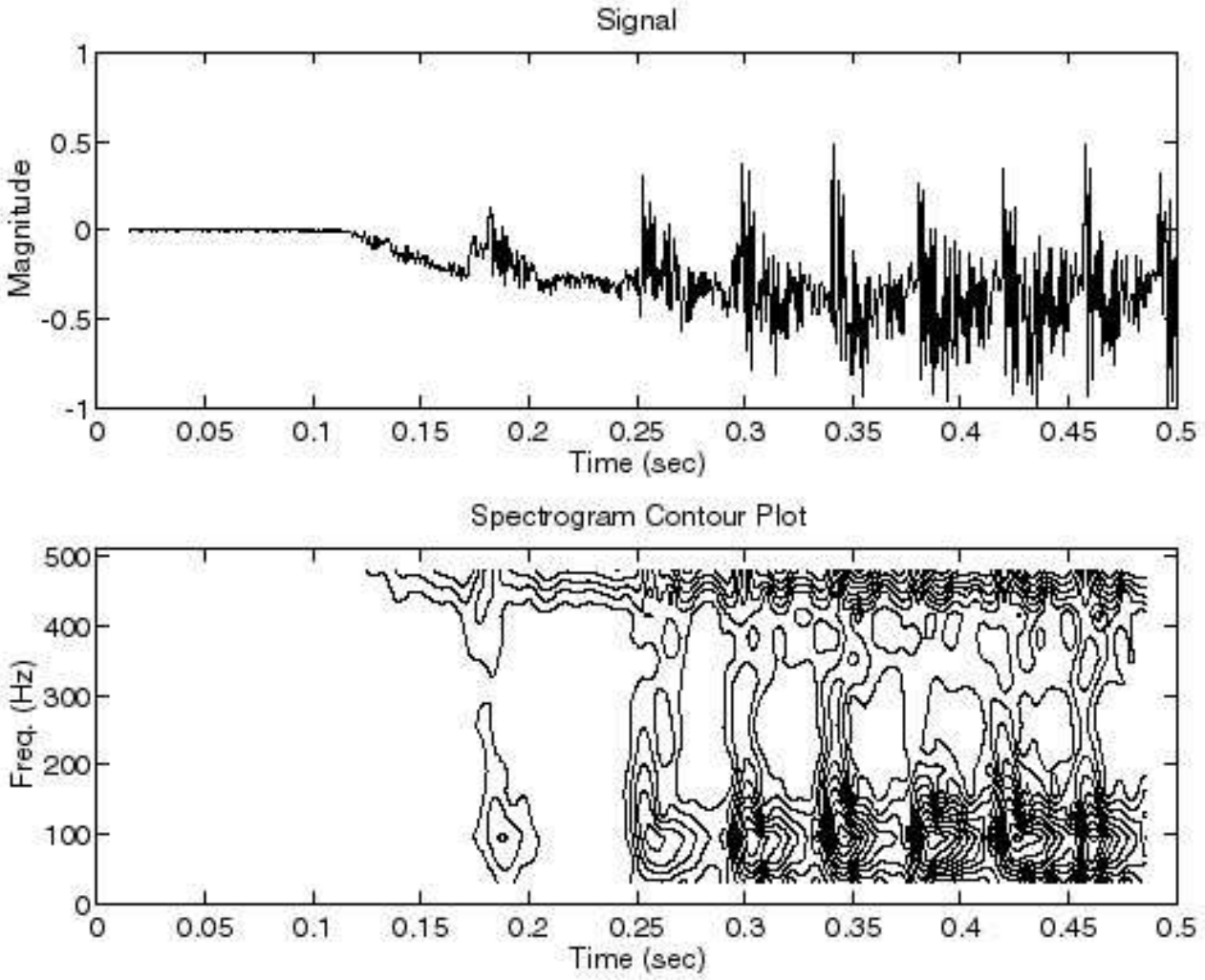


Determining Shape by Palpation

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

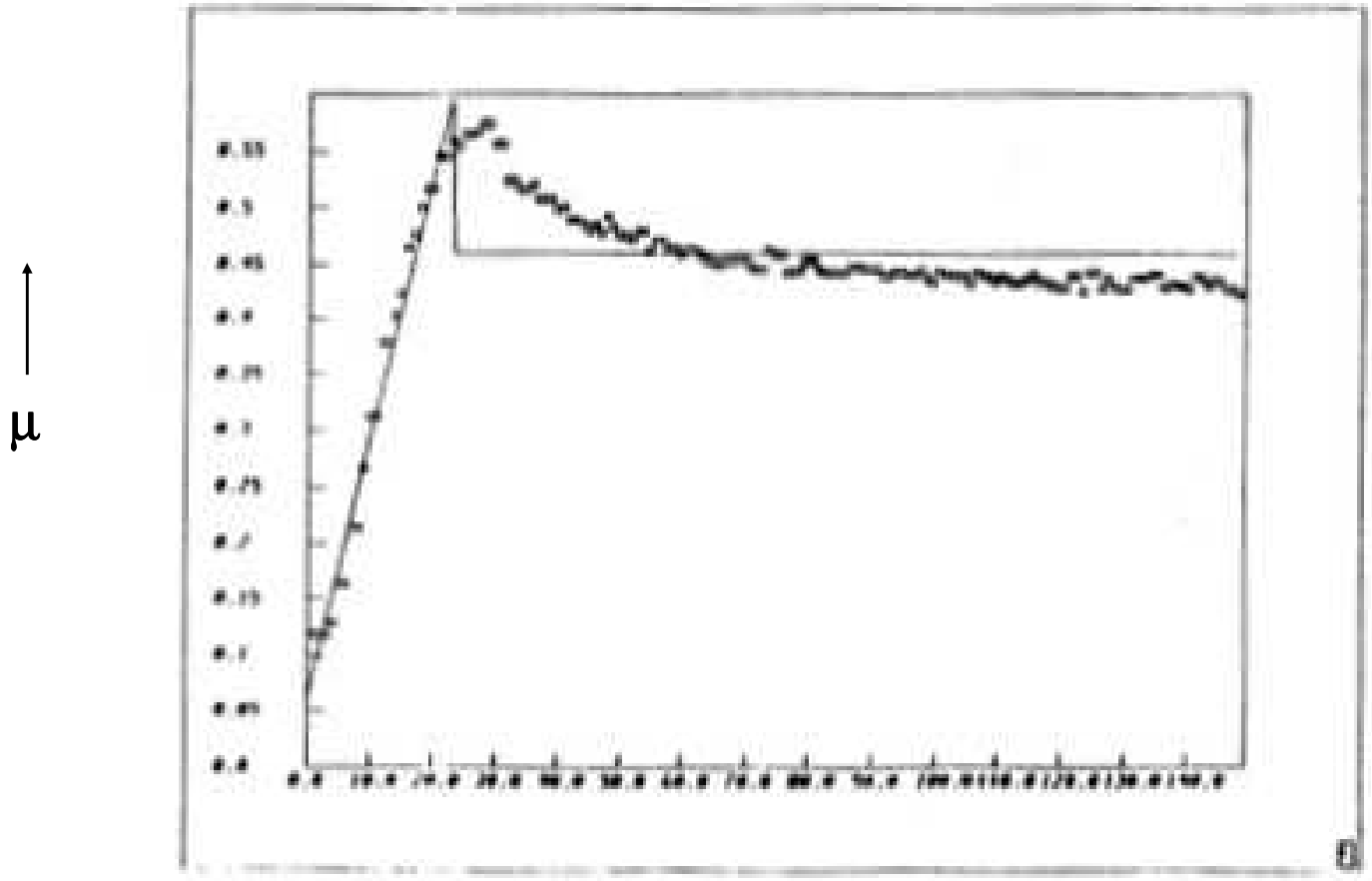
Information from Active Exploration

Stroking a textured surface



Friction/Texture Sensing

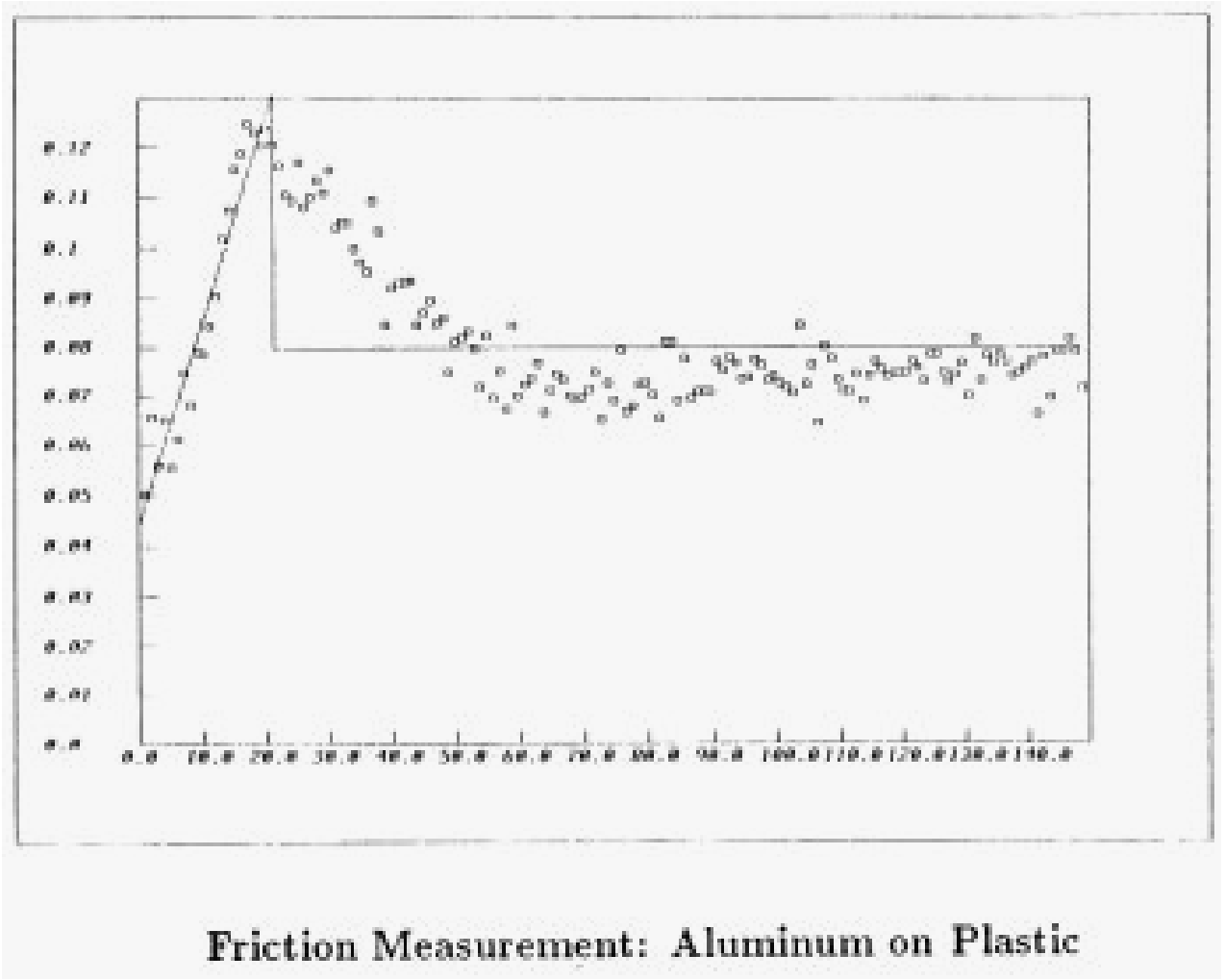
Finding friction coefficient and texture by stroking object



Friction Measurement: Aluminum on Rubber

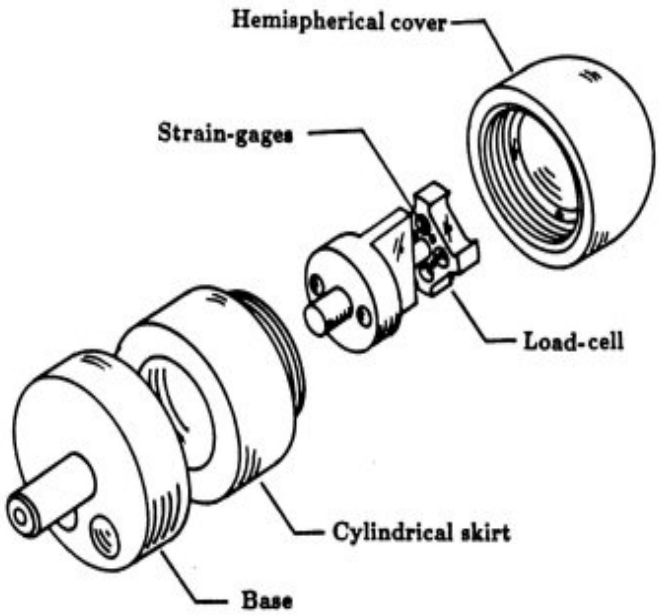
Friction/Texture Sensing

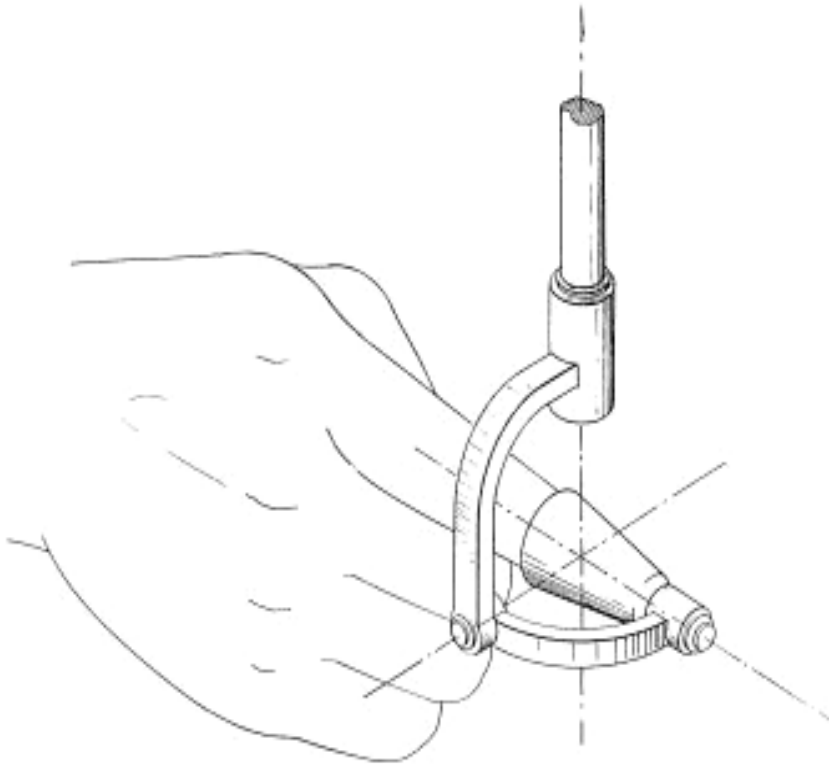
Finding friction coefficient and texture by stroking object



Friction Measurement: Aluminum on Plastic

From Robot Haptics to Computer Haptics





Performance

- Depends on Operating point
- Small Signal vs Large Signal
- Non-linear effects are important:
  - Friction, Backlash, Saturation

Basic device characteristics

- degrees of freedom (*number of joints*)
- active and/or passive (*force reflecting or not*)
- grounding location (*grounded versus exo-skeletal*)
- sensing quality (*resolution, maximum and dynamic range*)
- actuator quality (*resolution, maximum and dynamic range*)
- transmission characteristics
- bandwidth

Maximizing Interface Transparency

– building devices to minimize *information distortion* and reduce *cognitive loading*

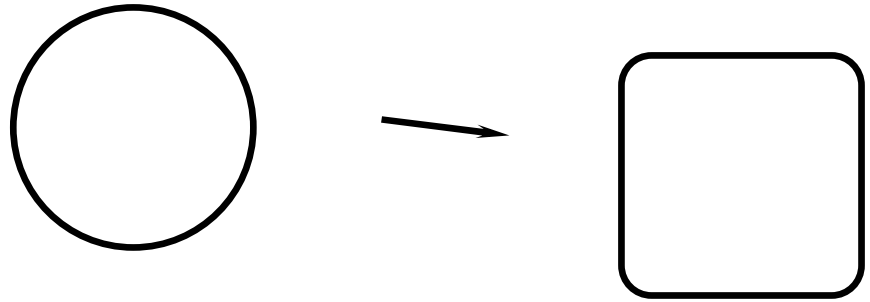
Maximizing backdriveability - when you push on an interface it should move easily. *A motor can be an actuator and a sensor if built right ….*

Good Qualities:

- low and well-behaved friction
  Viscous, Coulomb, stiction, Striebeck,
- isotropic or minimal friction - symmetric friction volume
- minimal hysteresis
- isotropic (or minimal) reflected inertia
  - spherical inertia ellipsoid $M^* = J^{-T} \cdot I_m \cdot J^{-1}$

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

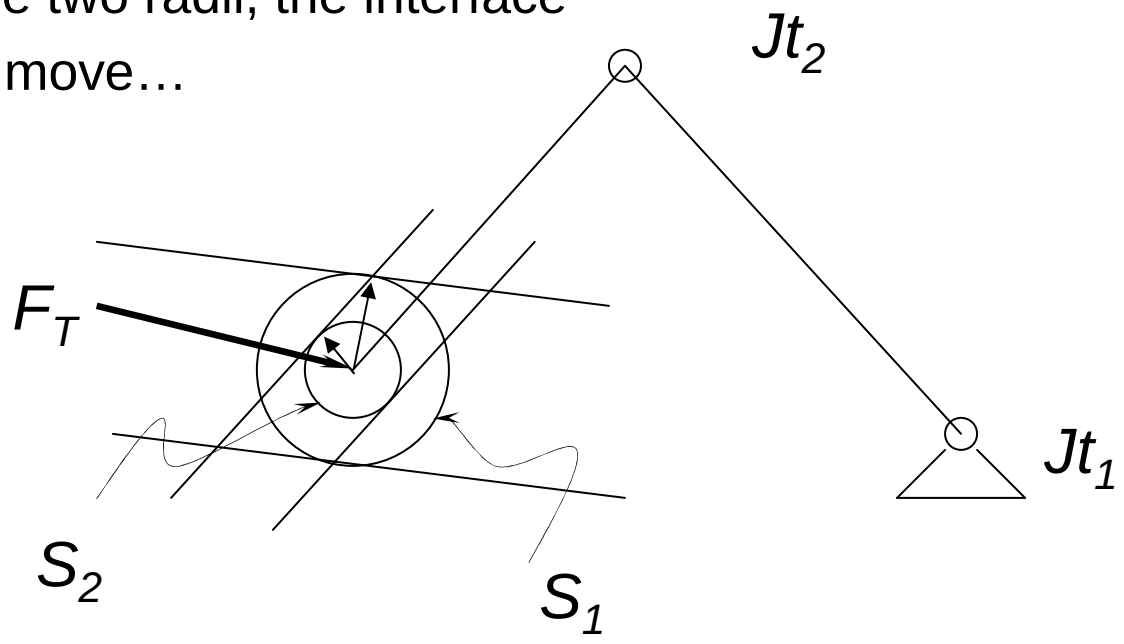
Friction Issues - distortion of force applied to mechanism with friction in joints

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…

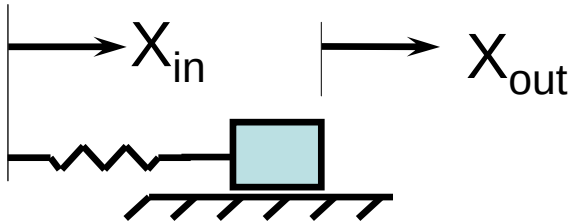


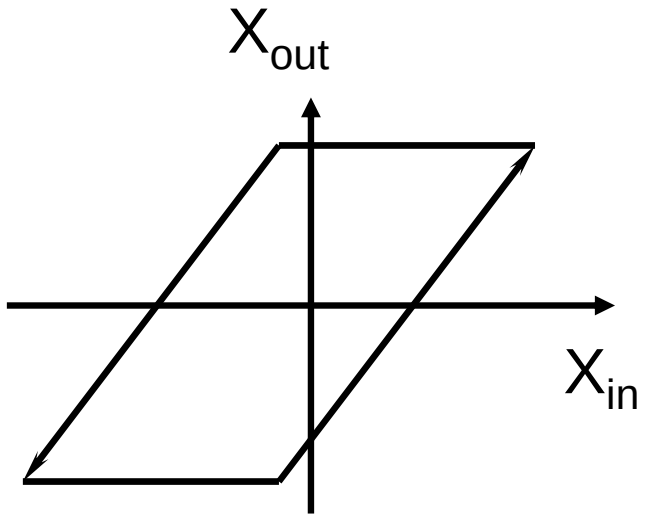
Hysteresis Issues

– 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

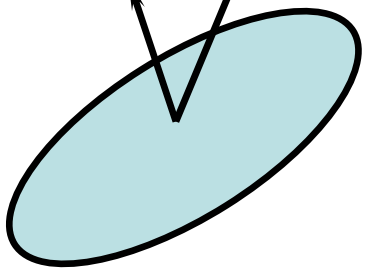
- Translational and Rotational Inertia
  - make small and/or isotropic

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

- Non-Isotropic Inertia *distorts accelerations*

$\ddot{X}$ F

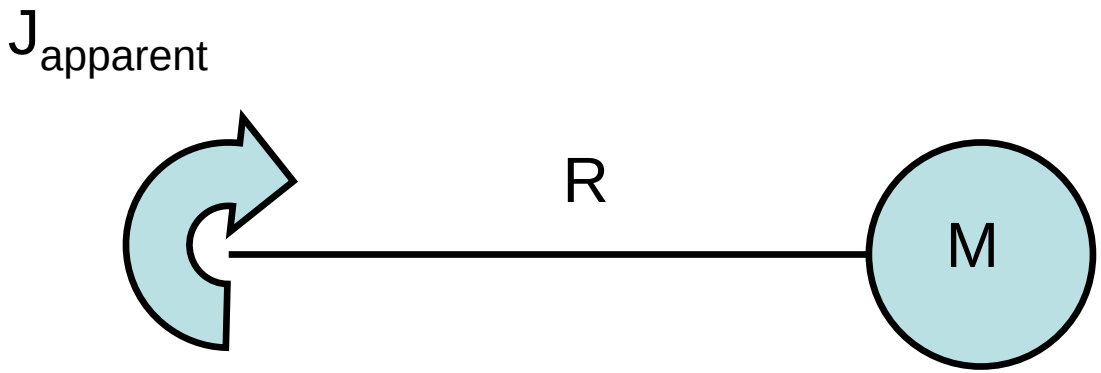
..



Maximizing Interface Transparency

Reflected inertia – ball on a stick example:

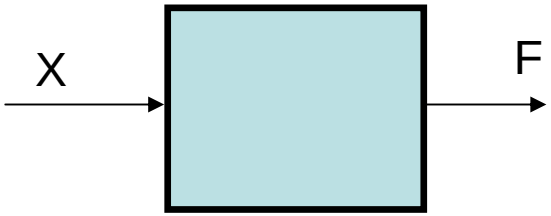
$J_{apparent} = M \cdot R^2$



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

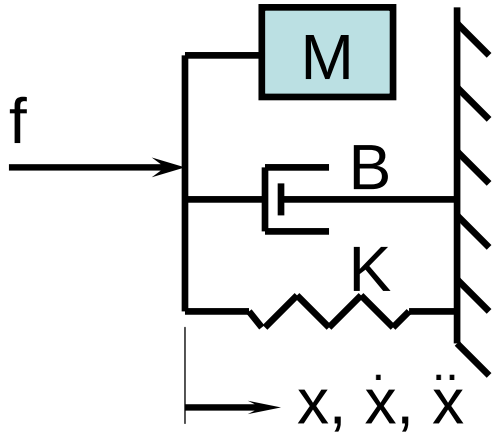
Velocity – force dependence:

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

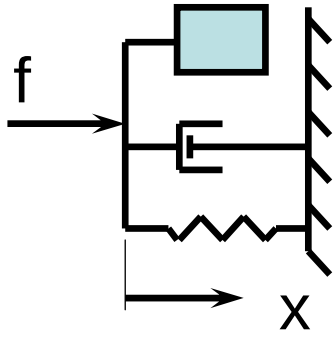
Constant coefficients vs time-varying

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

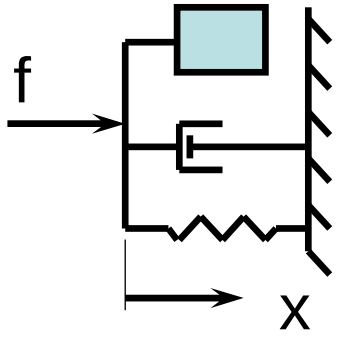
$f = B \cdot \dot{x}$; pure damper

$f = M \cdot \ddot{x} + B \cdot \dot{x} + K \cdot x$; 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

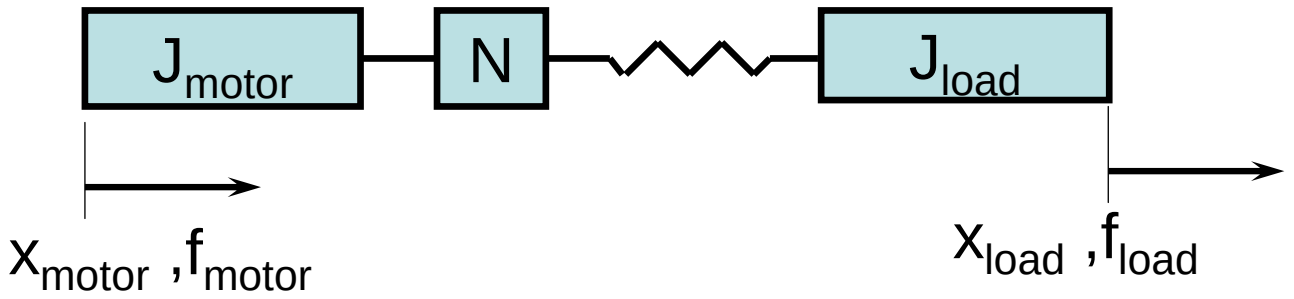
Note: Admittance = Impedance^{-1}

Good Performance

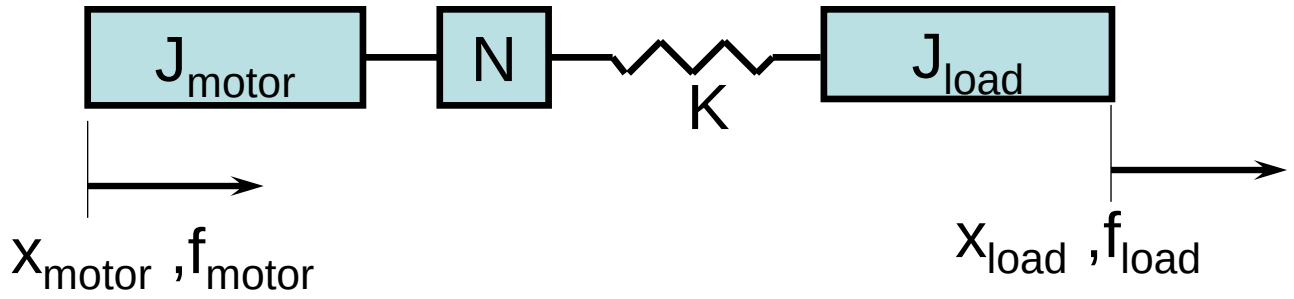
Output Bandwidth “3dB point” of transfer function:

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

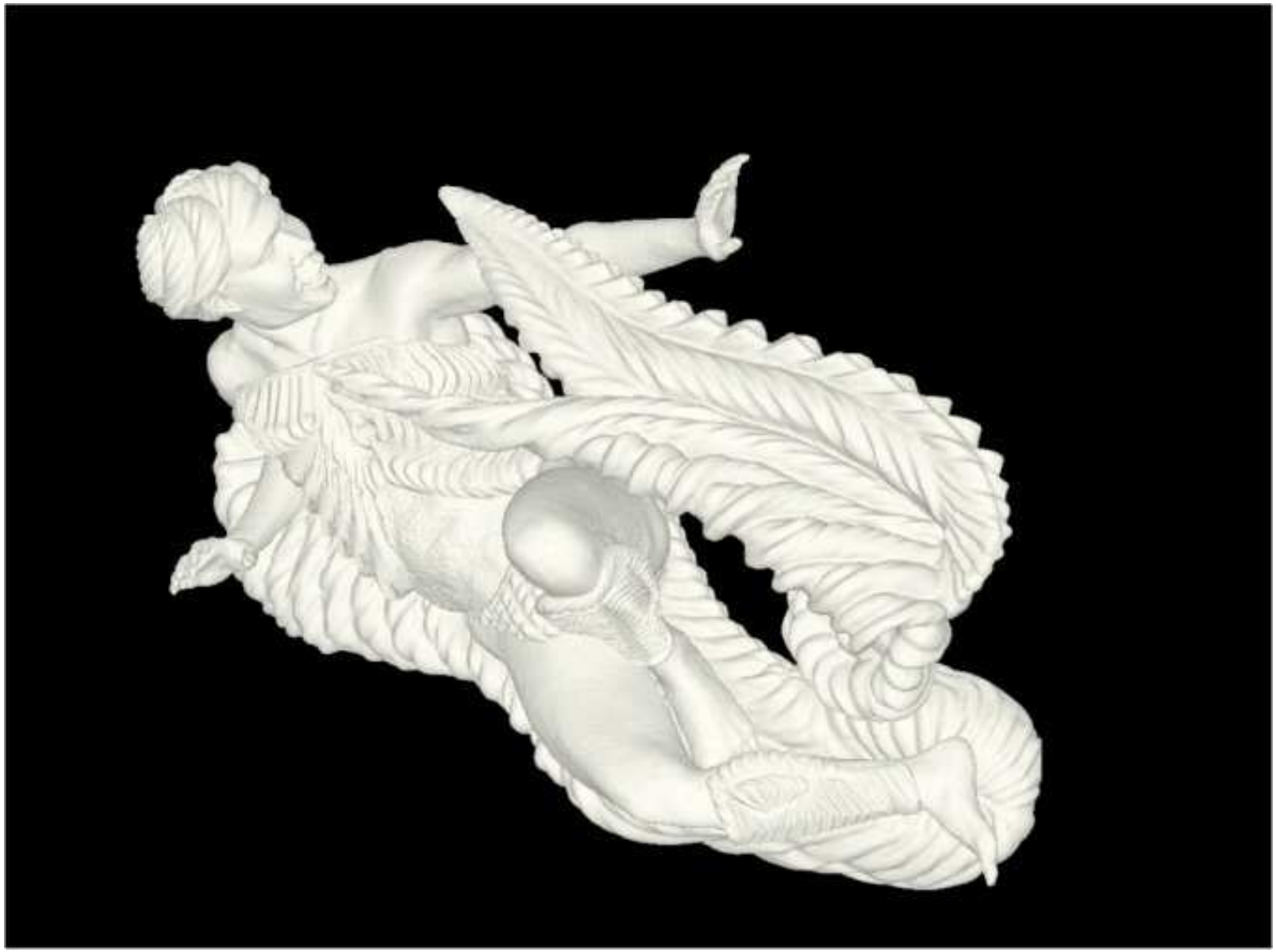
Position and Force quality: we want large dynamic range:

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

Are these scale independent measures of performance?

What is Next?

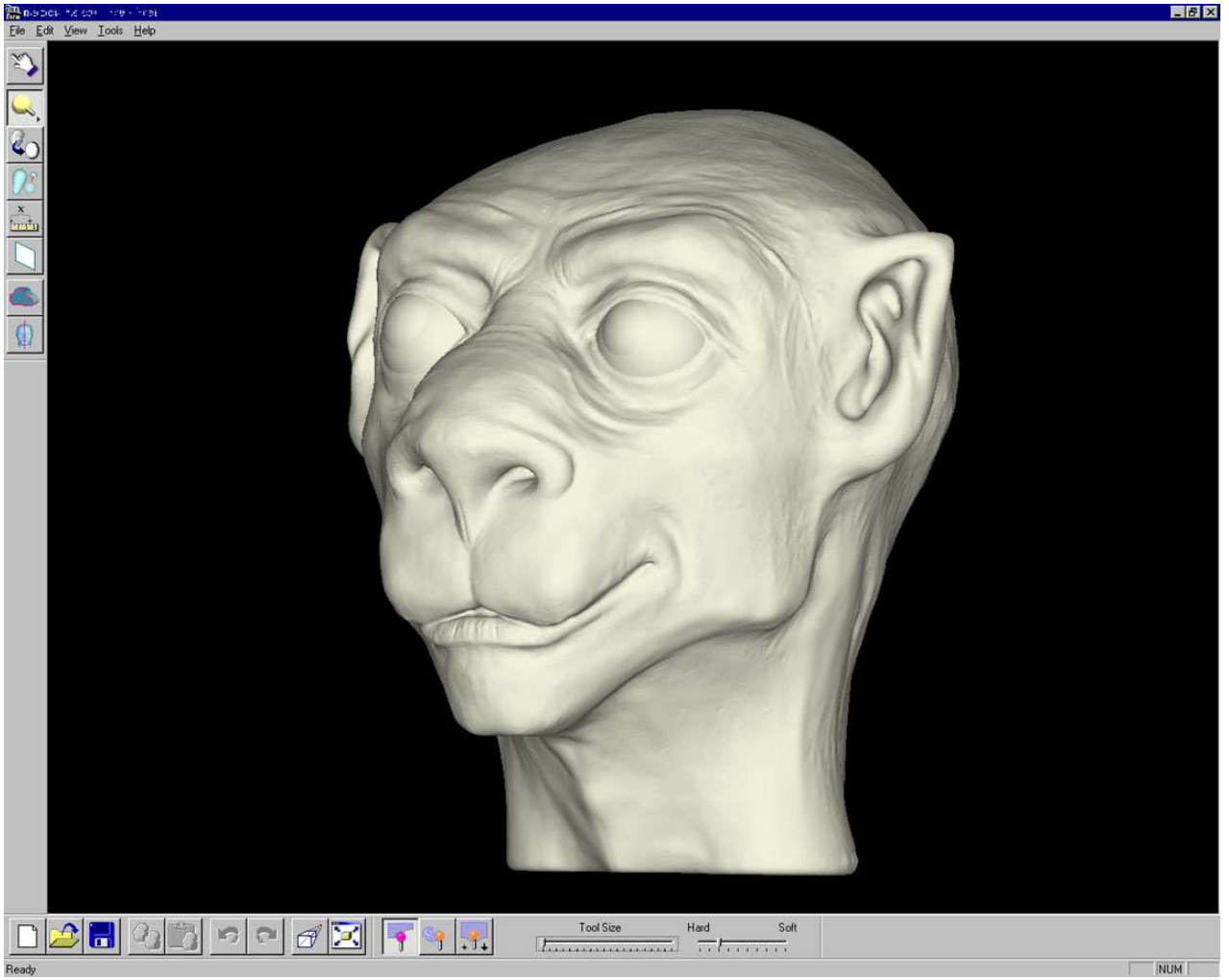
- Grip Force Feedback
- Multi-Finger, Multi-Arm
- Tactile Display
- Large Workspace
- Minimalist Systems



Personal Robots

http://www.willowgarage.com

Palpable Virtual Objects



End ☺

Haptic Nomenclature

Human haptics –

Machine haptics –

Computer haptics –

Haptic Nomenclature

Human haptics - human touch perception and manipulation

- every-day manipulation
- tools, controls
- music, art, etc.

Machine haptics - robot arms and hands

- autonomous robots
- remote manipulator systems
- surgical robots, etc.

Computer haptics – virtual touch and manipulation

- training
- design
- entertainment, etc.

Nomenclature:

human haptics:

human touch perception and manipulation

machine haptics:

concerned with robot arms and hands

computer haptics:

concerned with computer mediated haptics

Desirable Characteristics in a Haptic Interface

- Thomas Massie

Freedom and Constraint:

"free space feels free"

"constraints feel rigid"

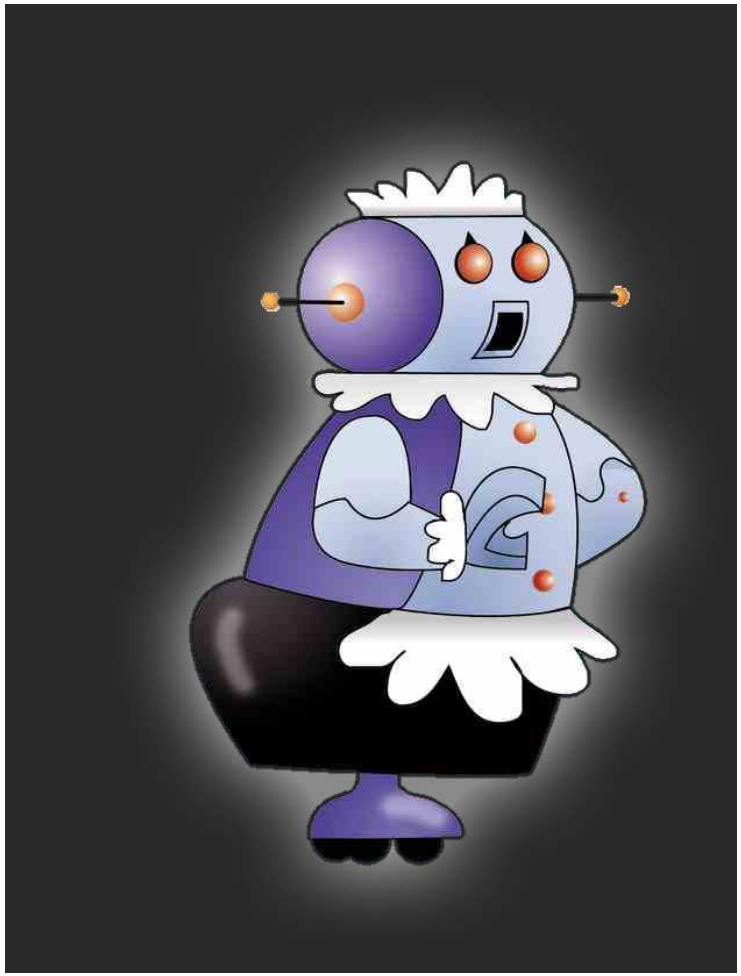
"solid objects persist”

Extra Credit: What does this mean at different scales?

What is Next?

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

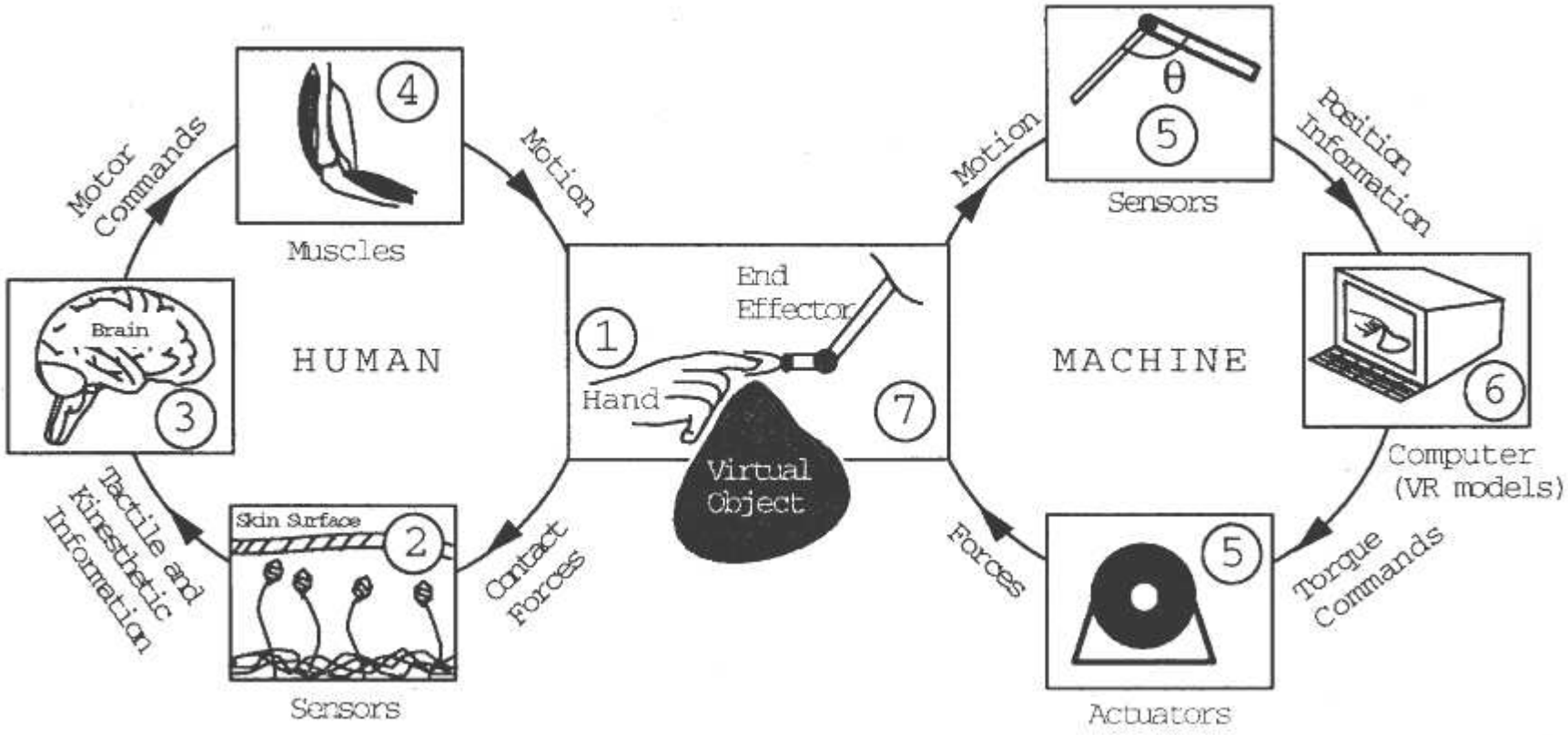
Personal Robots



http://personalrobotics.stanford.edu/videos/index.php

Haptic interaction with virtual objects

Information and power flows:



Courtesy Mandayam Srinivasan, MIT