ME 327: Design and Control of Haptic Systems
Spring 2020

Lecture 7:
Kinesthetic haptic devices: design and kinematics

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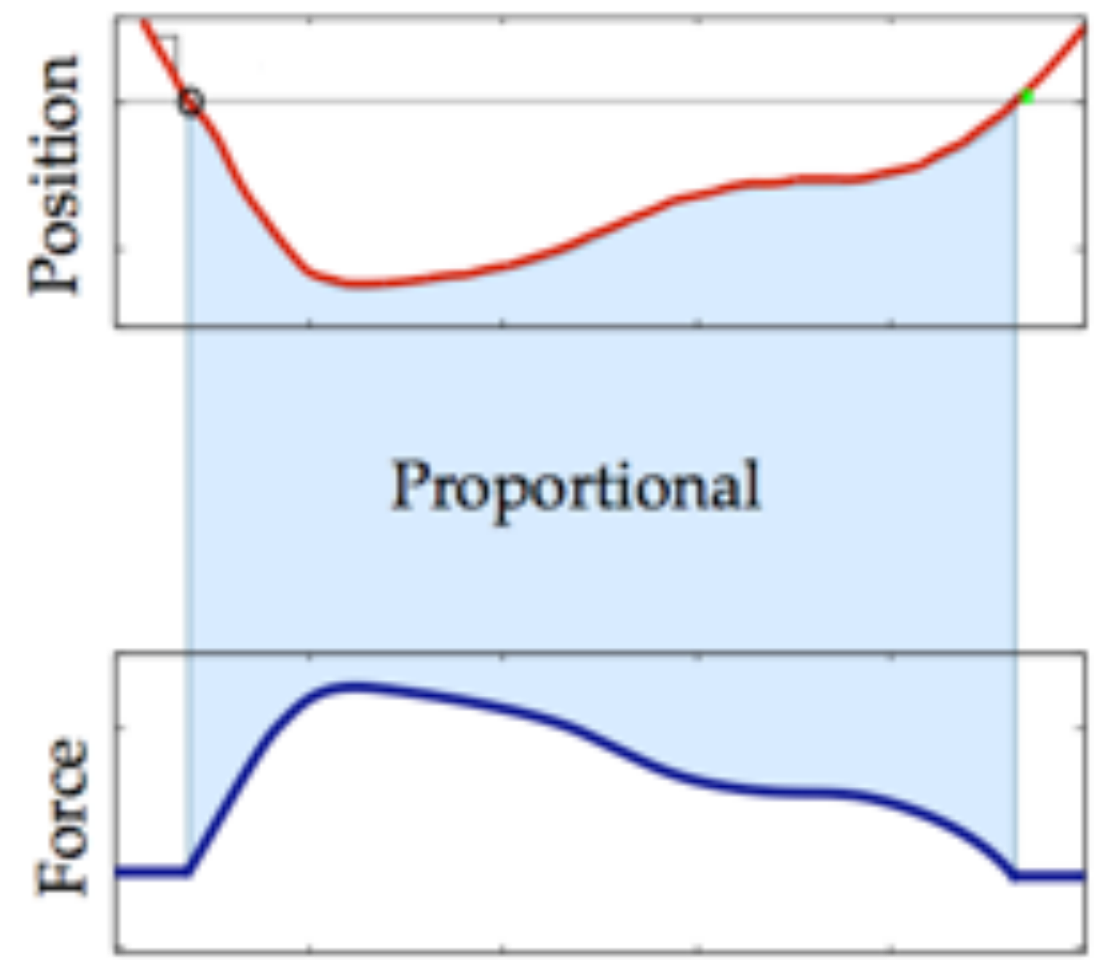
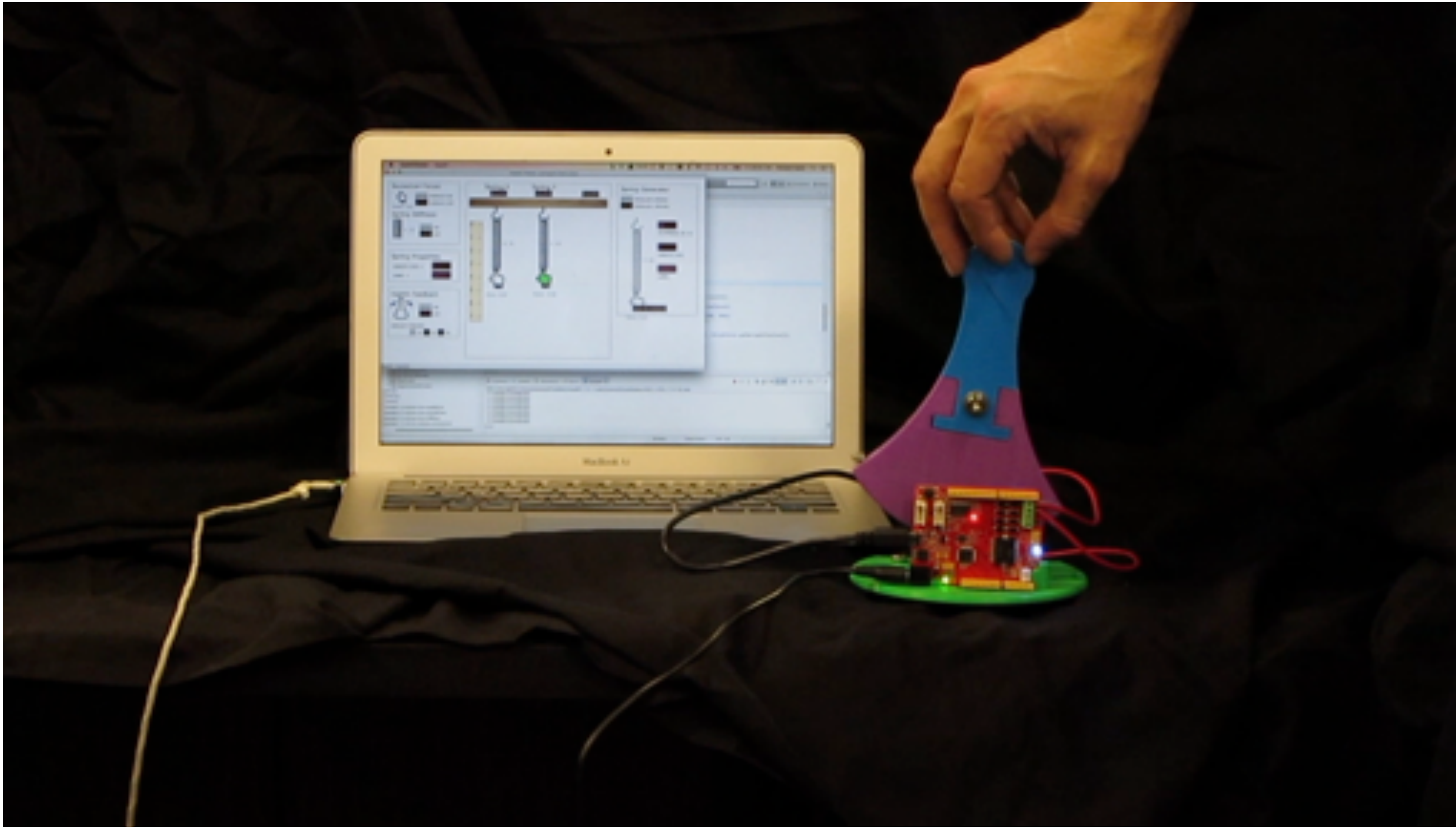
general design goals

- free space feels free
- virtual objects feel like real objects
  - large forces (need strong actuators)
  - forces change quickly (high bandwidth)
- sufficiently large workspace

haptic rendering goal

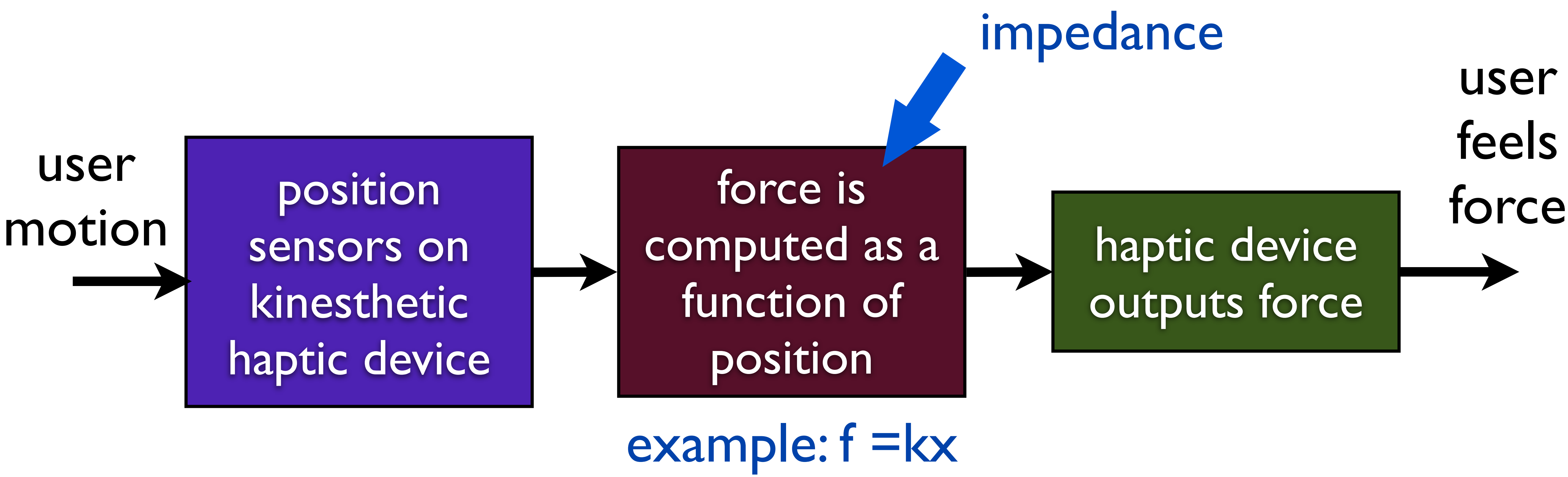


K. Kuchenbecker



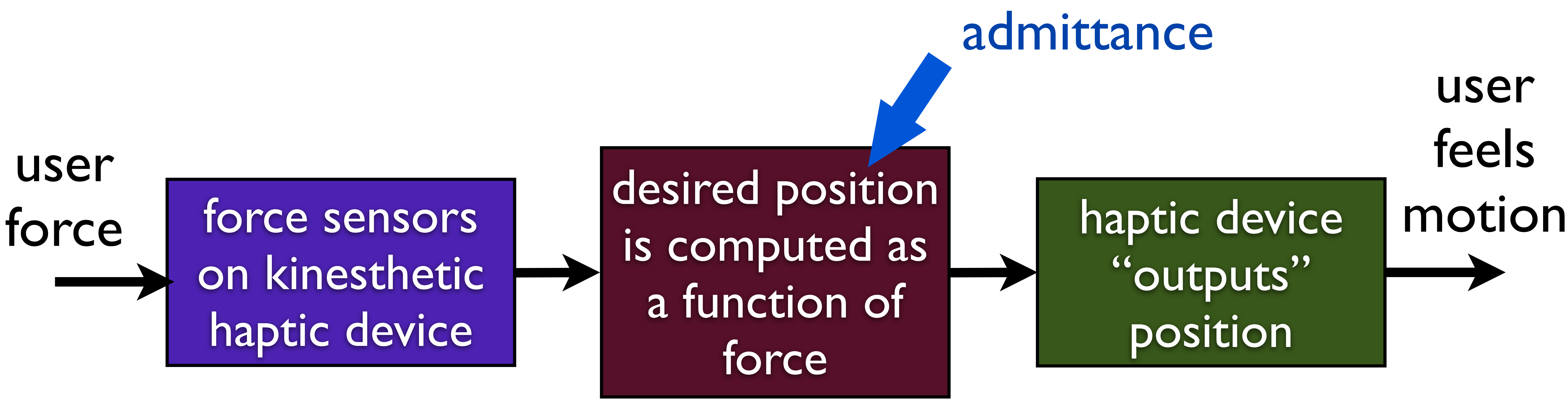
Melisa Orta Martinez

impedance-type kinesthetic devices



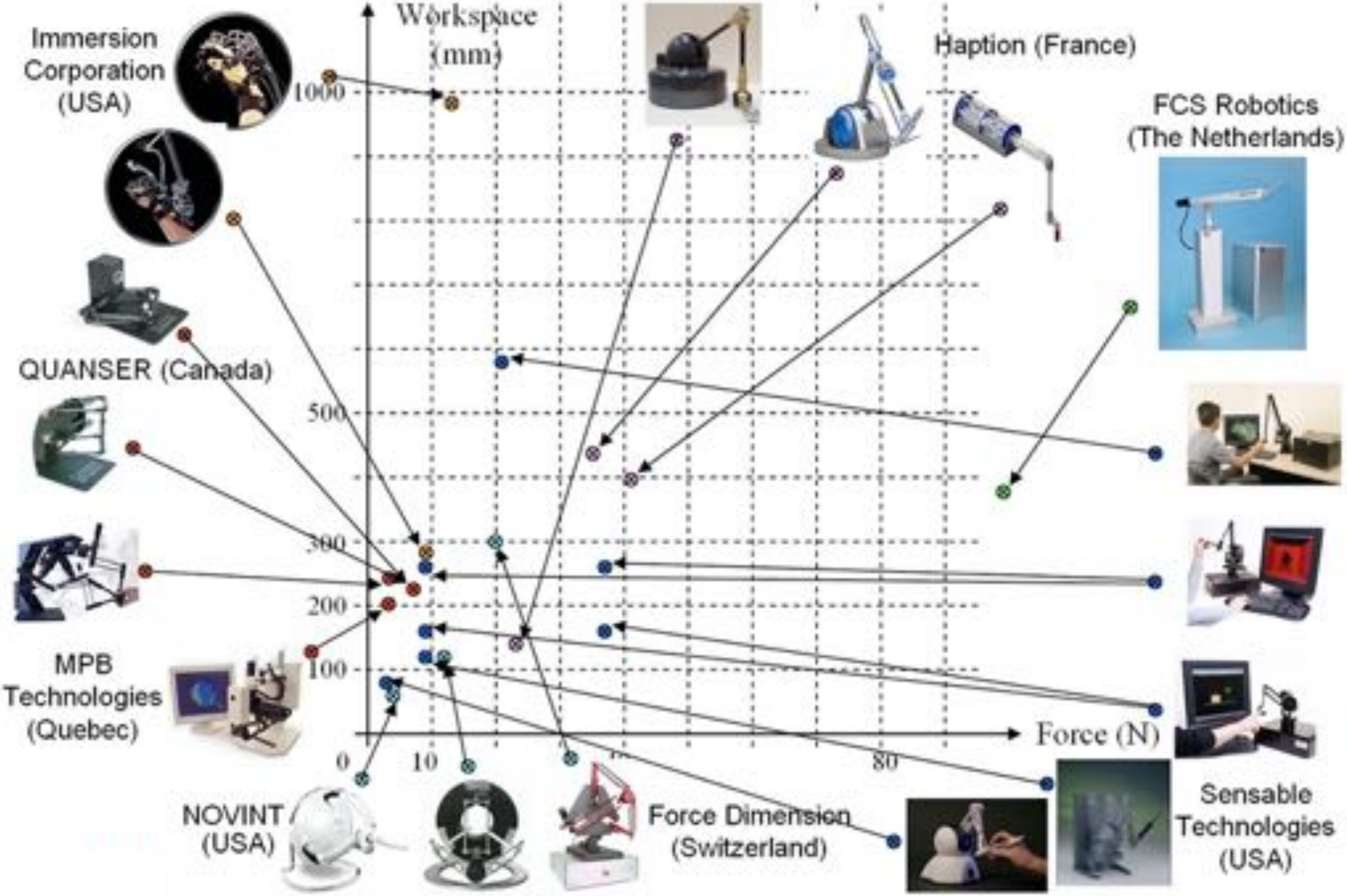
most force feedback devices are of the "impedance" type

admittance-type kinesthetic devices

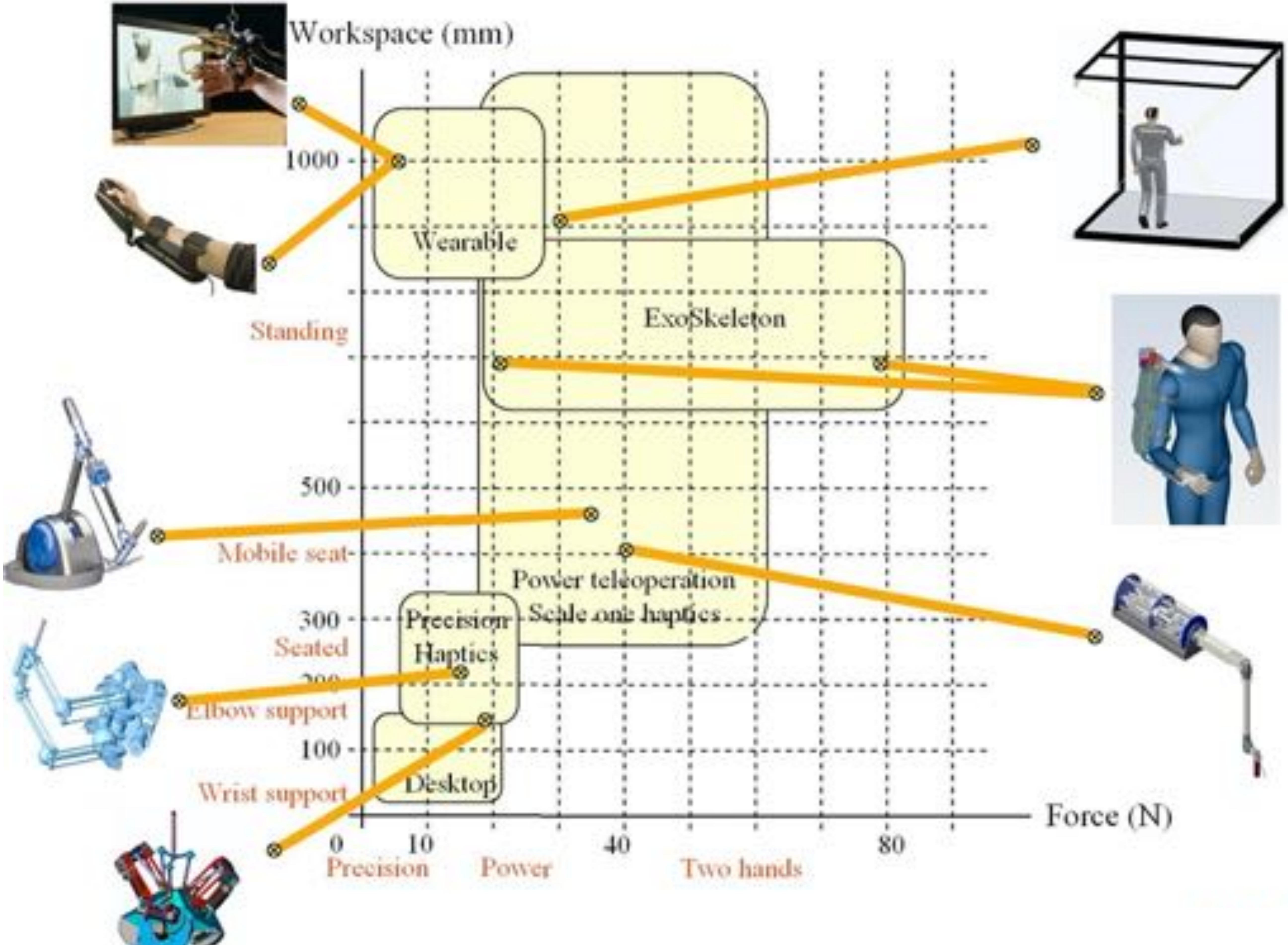


example: $x_{des} = c\ f$

"admittance"-type devices are not as common



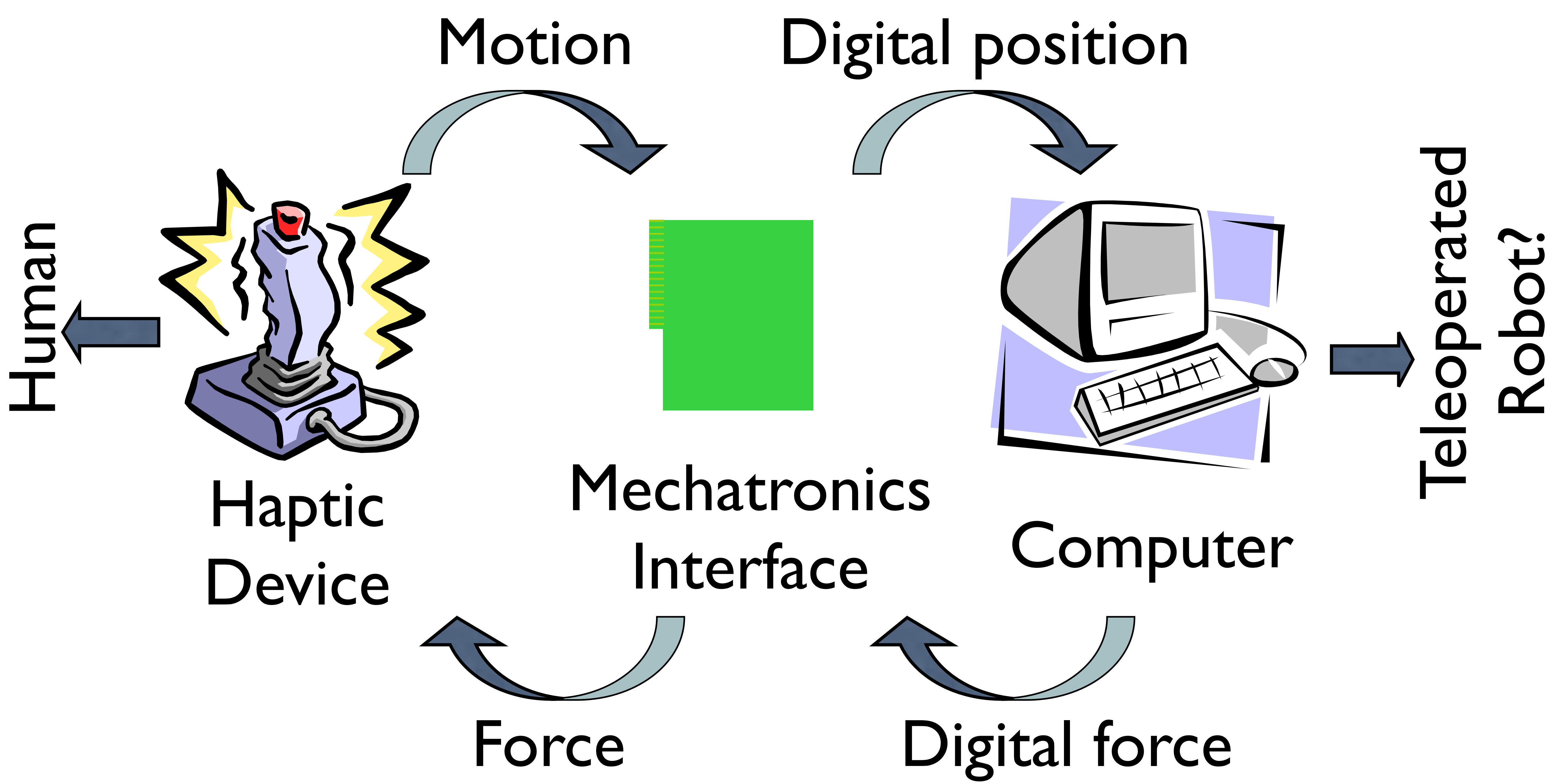
Florian Gosselin, CEA



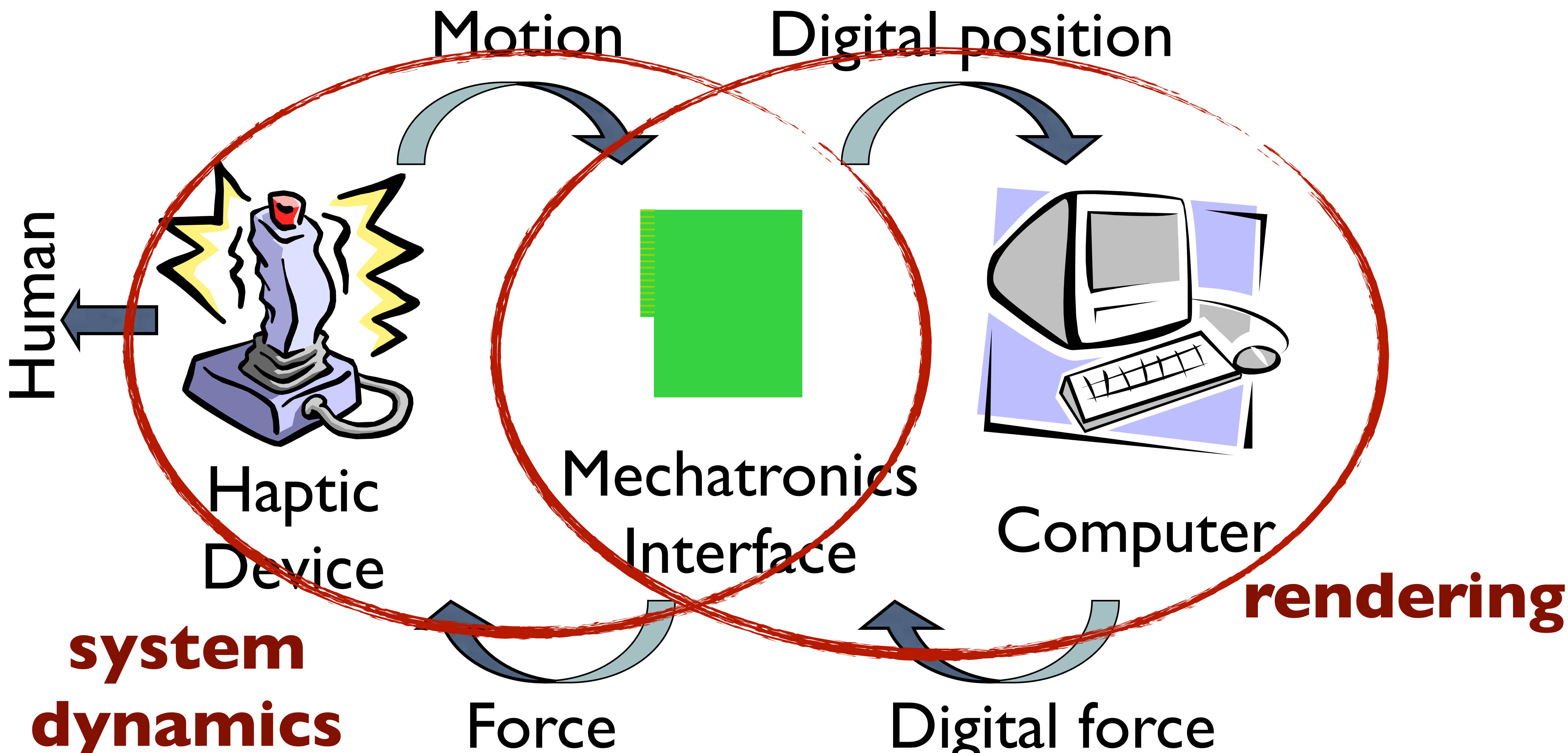
Florian Gosselin, CEA

mechatronics basics for impedance-type devices

a kinesthetic haptic system



a kinesthetic haptic system



motion signals

handle (m) → drum or motor (rad) → position sensor → computer or board → fwd kin. → virtual handle (m)

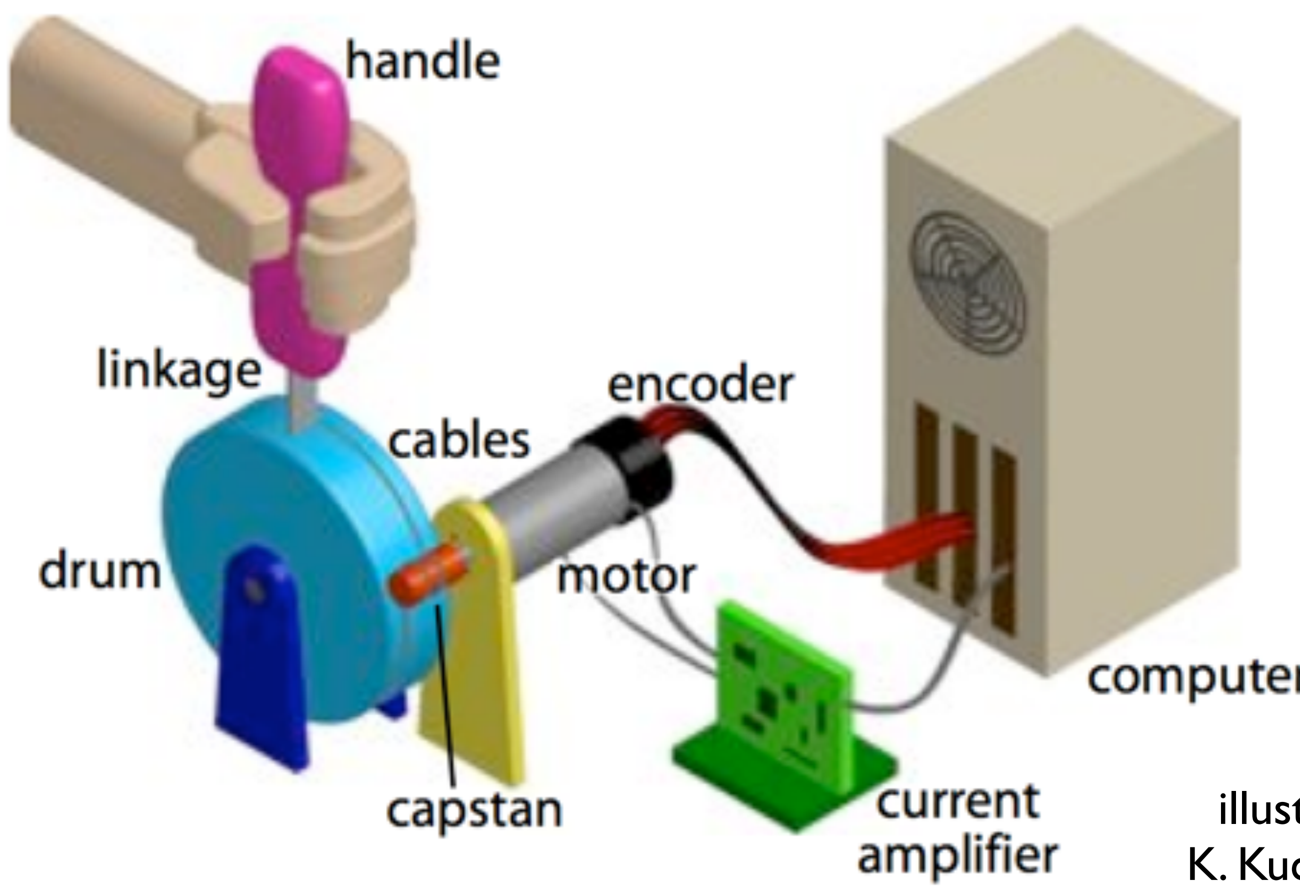


illustration by K. Kuchenbecker

force generation signals

virtual world (N) → counts → D/A or PWM → volts → amplifier → current or voltage → motor → torque → handle (N)

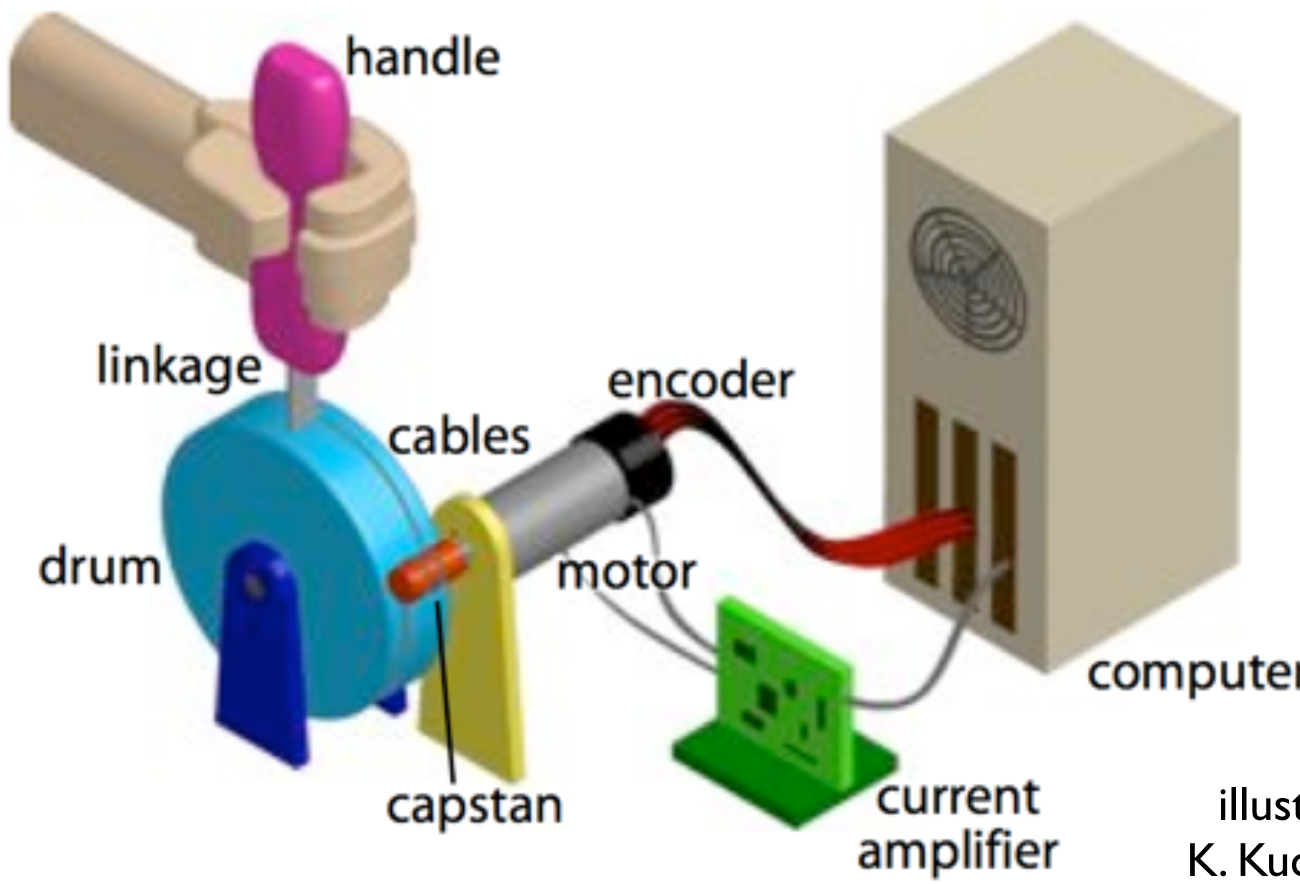
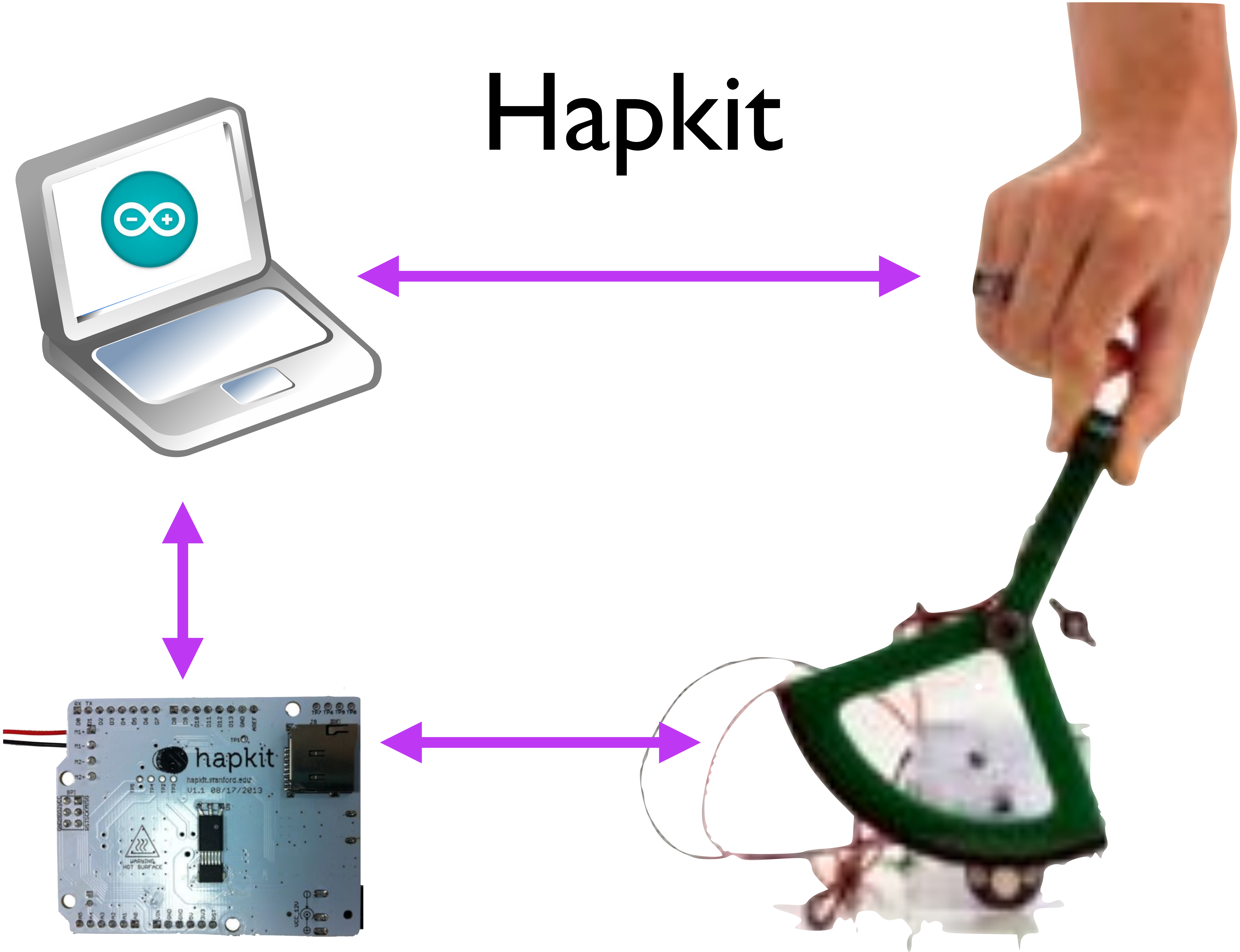


illustration by K. Kuchenbecker

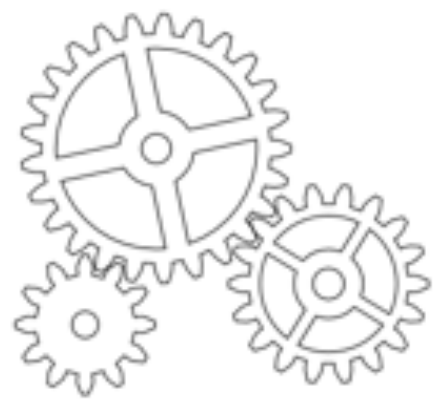
Hapkit

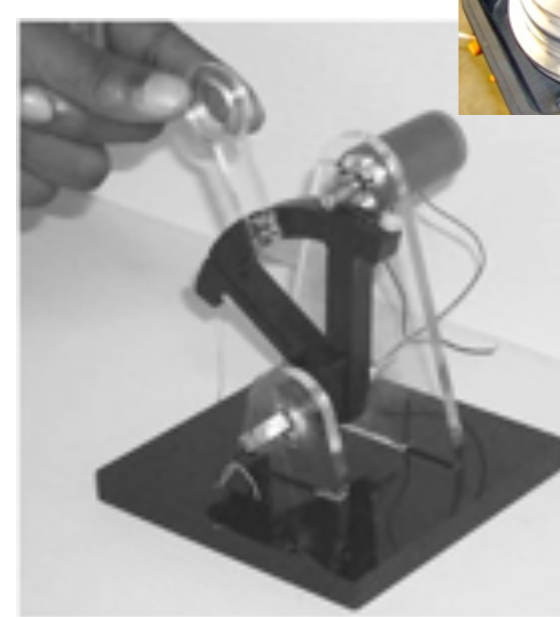


kinematics / design

transmission

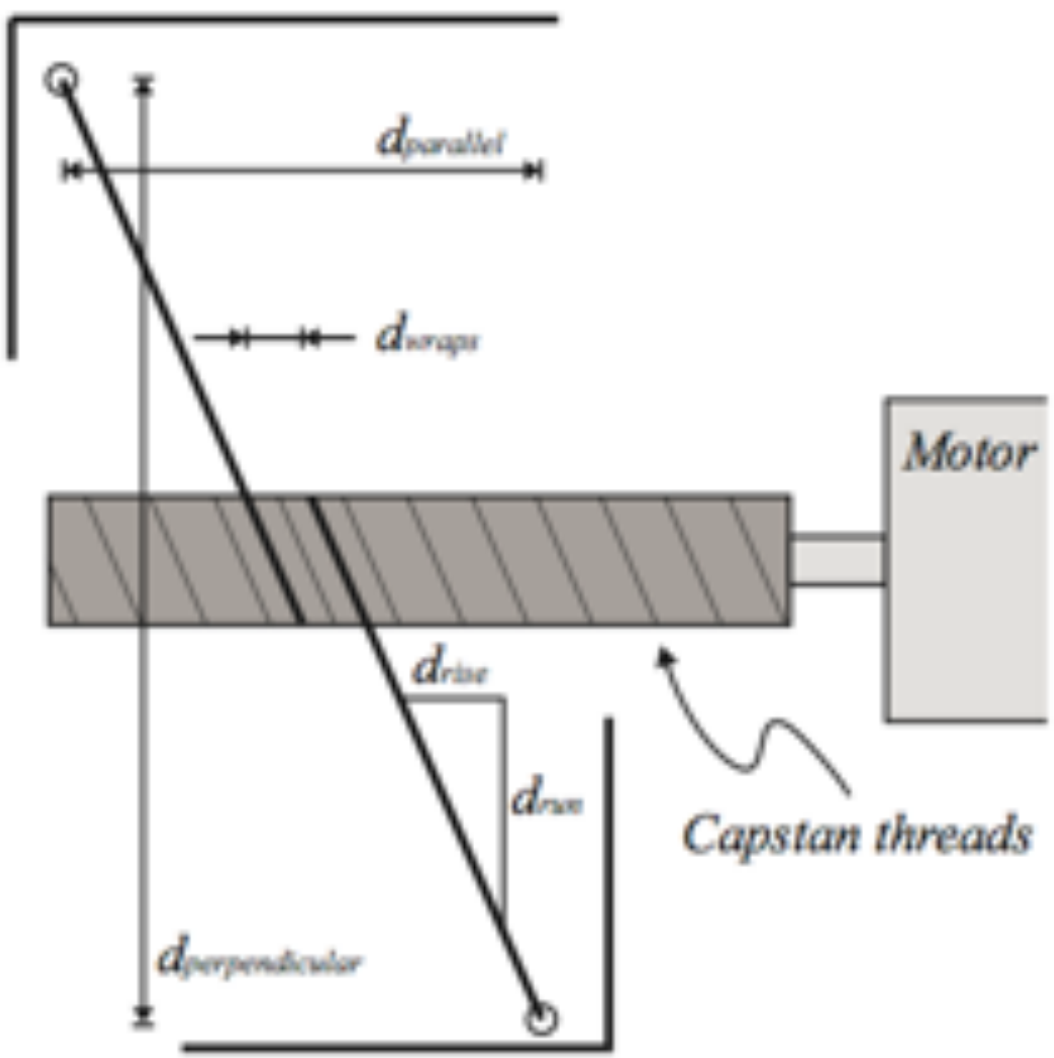
- Transfers/amplifies force/torque from motor
- You don't want to feel the effects of the transmission!
- Types:
  - gears
  - belts/pulleys
  - capstan drive
  - friction drive
  - none (direct drive)

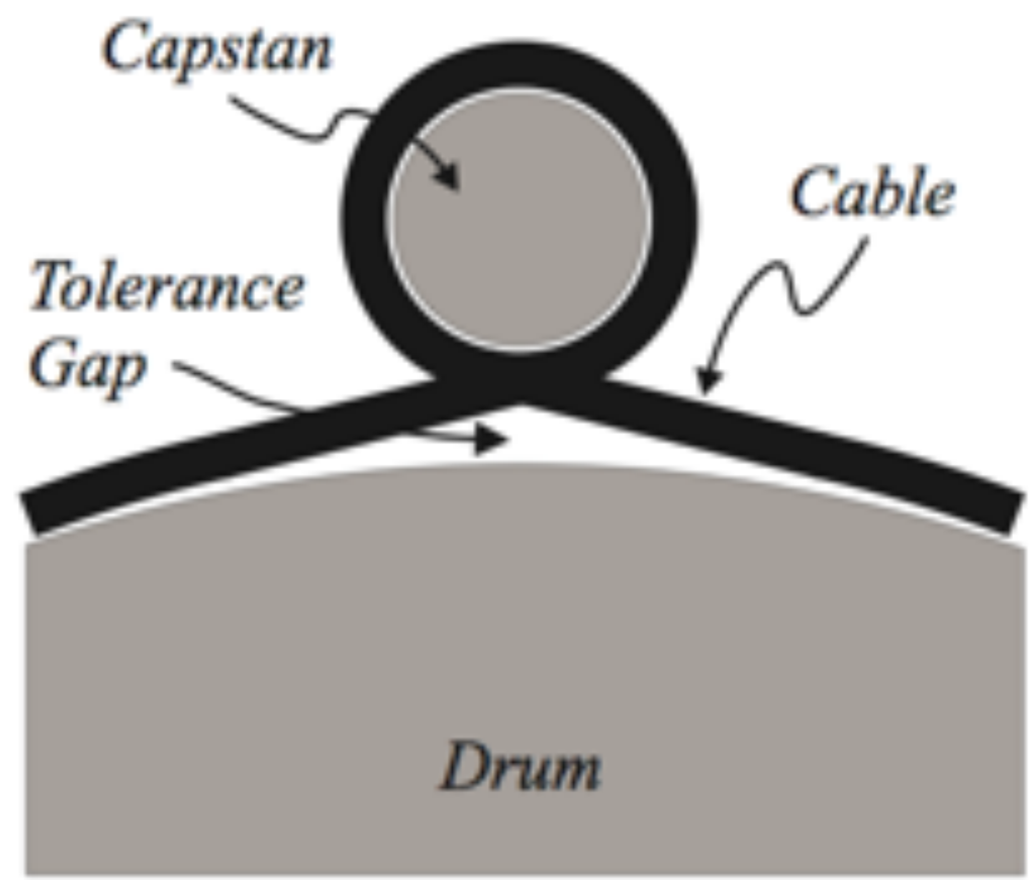




capstan drive

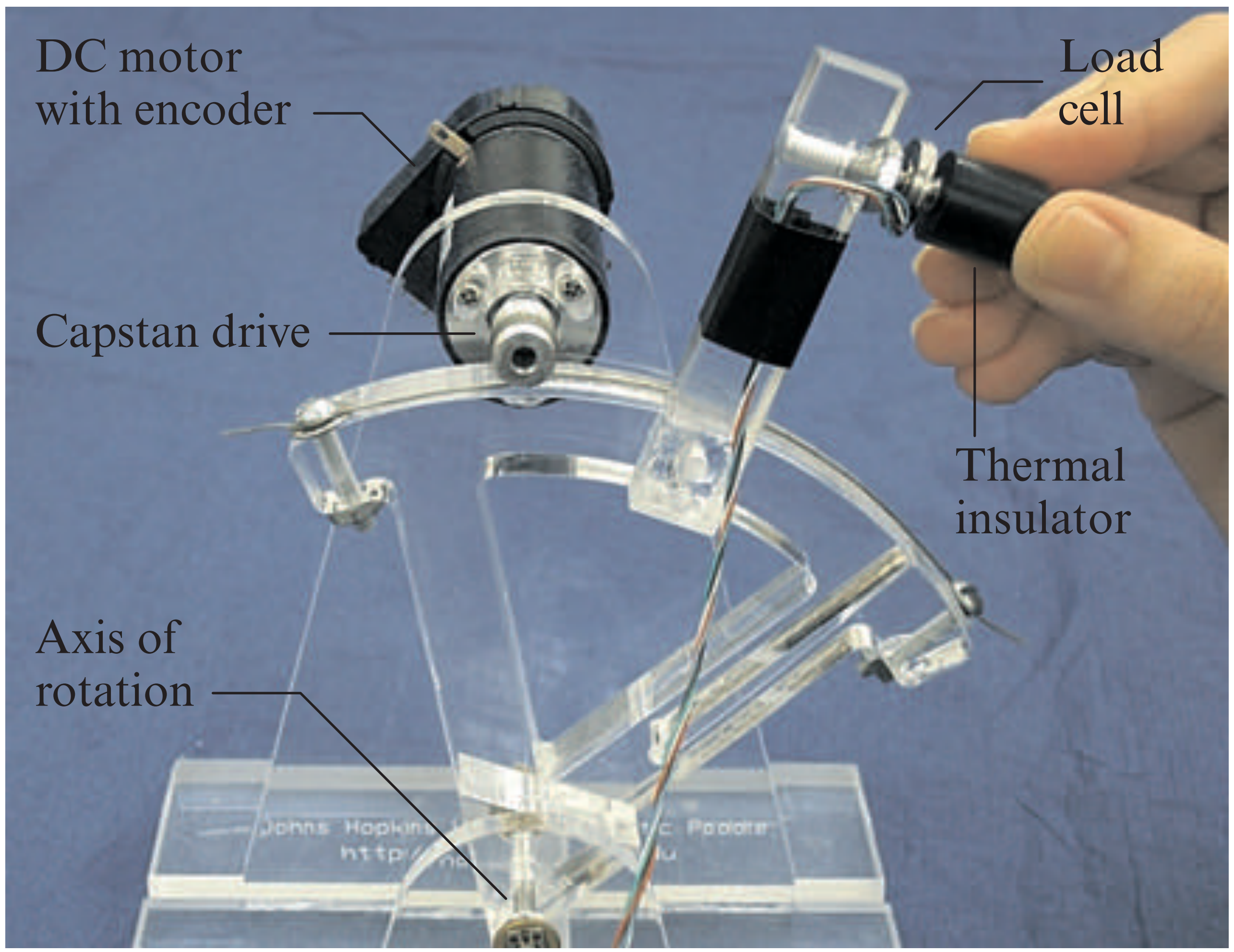
high transmitted force, low transmitted friction





Katherine Kuchenbecker

capstan drive



a version of the haptic paddle

Phantom Premium, SensAble Technologies

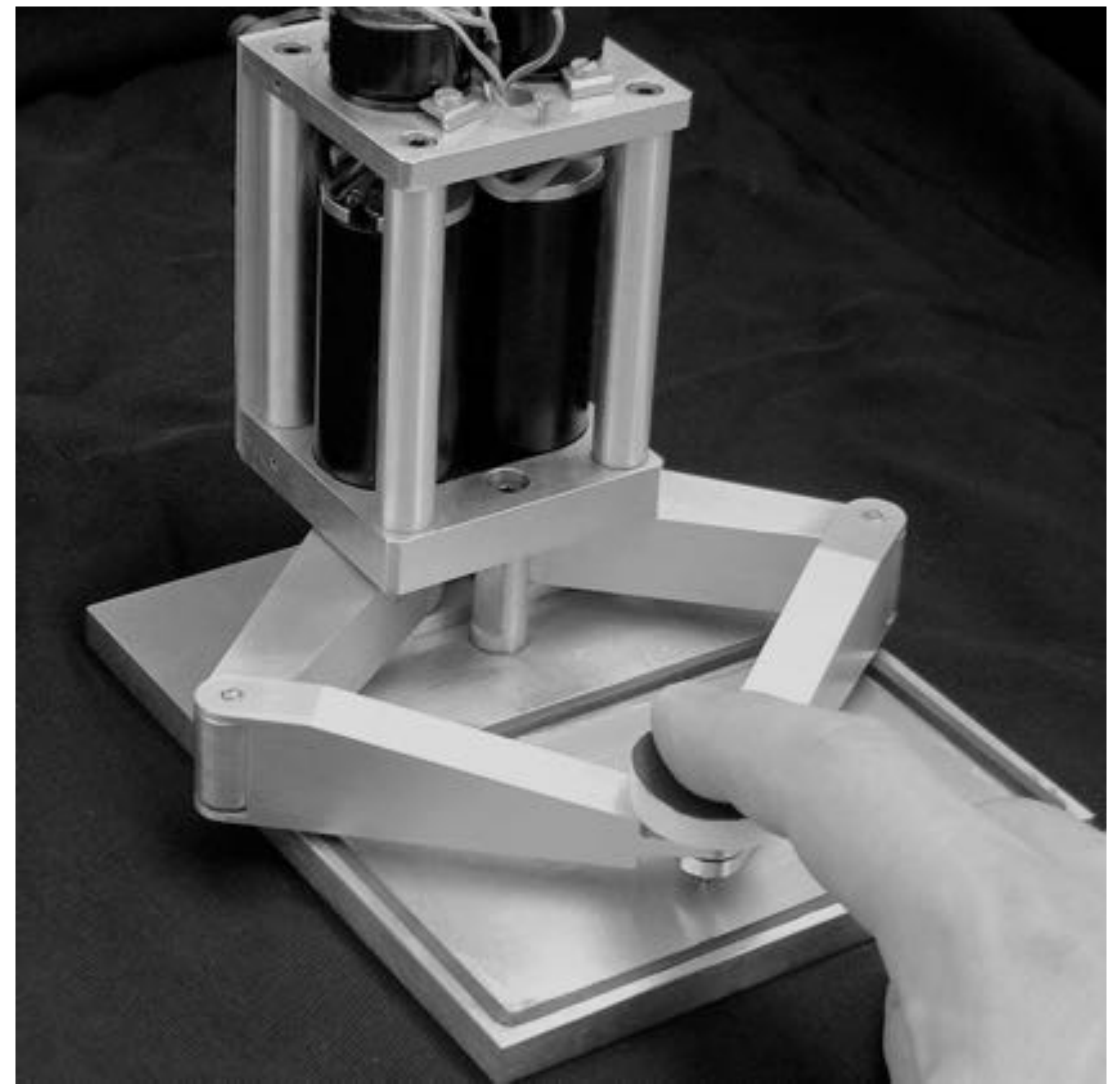
grooved pulley

- increases friction and reduces slip
- prevents the cable from falling off
- can be difficult to assemble

Cara Gonzalez Welker

direct drive

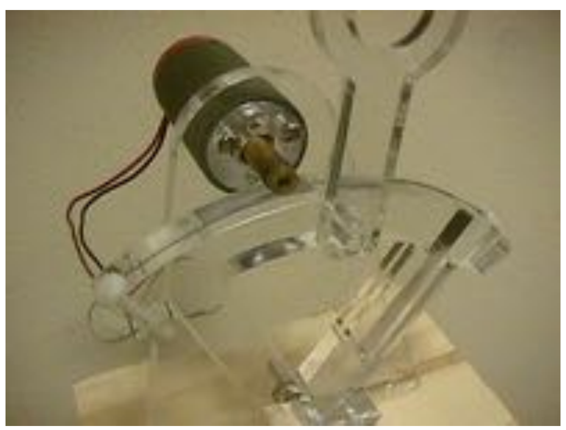
motors attached directly to link(s)

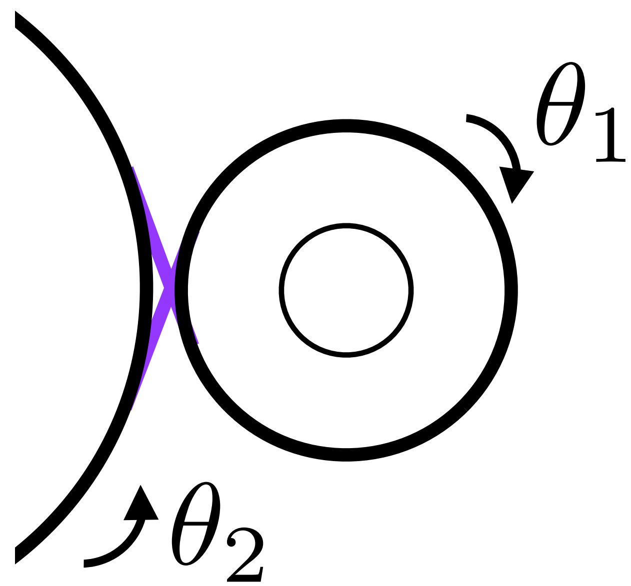


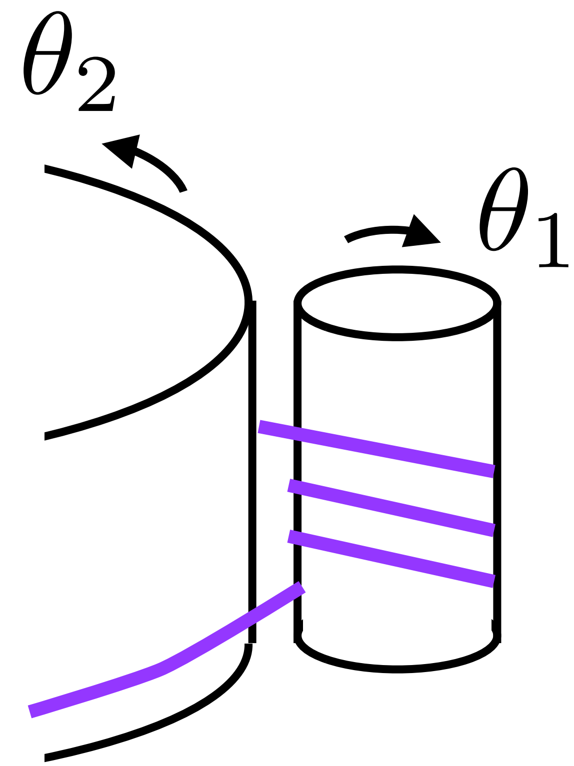
Hayward (McGill)

transmission

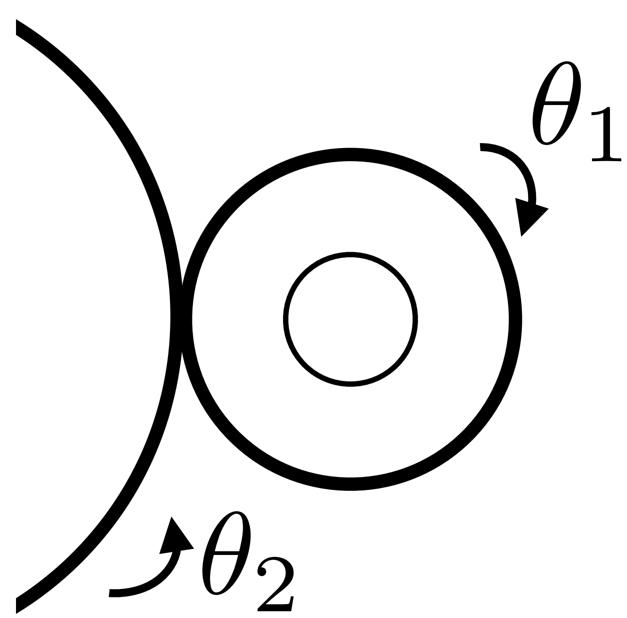
Capstan drive

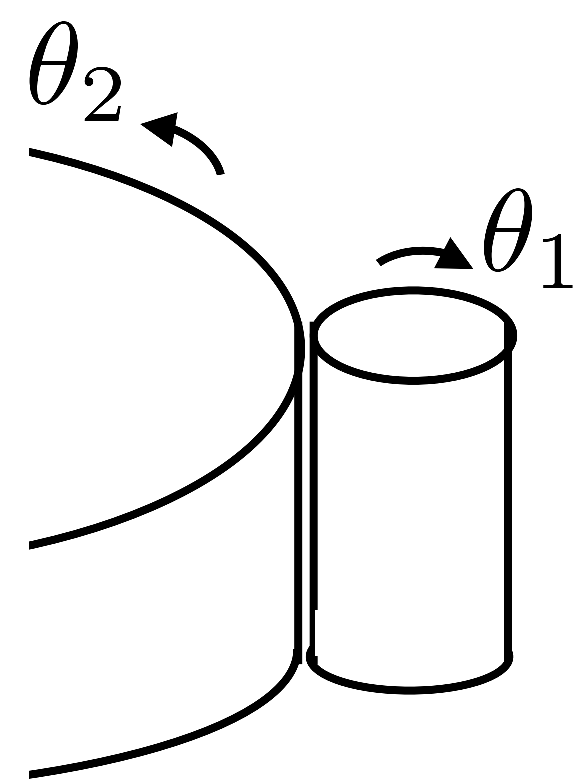






Friction drive



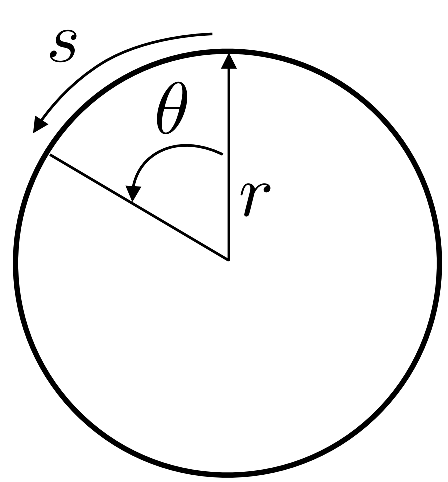


Kinematic Relationships

In this class, a key kinematic relationship is:

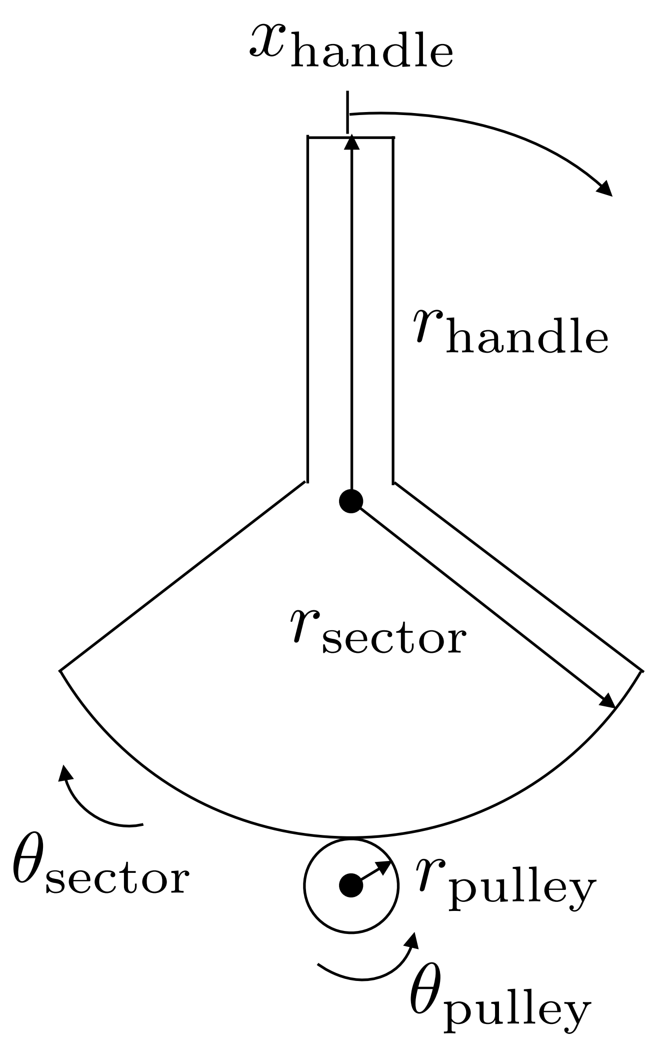
$$s = r\theta$$

arc length — radius — angle (in radians!)



π radians = 180 degrees

Hapkit Kinematics: Motions



$$r_{pulley}\theta_{pulley} = r_{sector}\theta_{sector}$$

$$x_{handle} = r_{handle}\theta_{sector}$$

$$x_{handle} = \frac{r_{handle} r_{pulley}}{r_{sector}}\theta_{pulley}$$

Force-torque Relationships

Torque, or moment, is the tendency of a force to rotate an object.

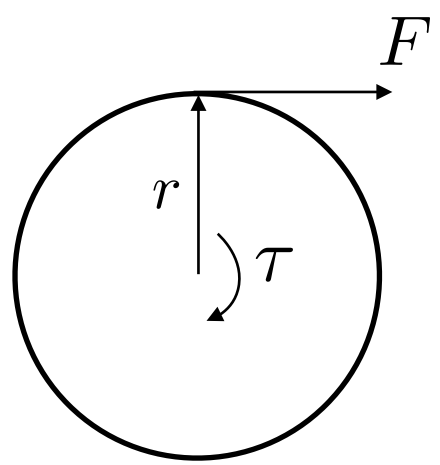
If a force is perpendicular to r (the vector connecting the point about which the torque acts to the point at which the force is applied), this is the scalar relationship between force and torque:

$$\tau = Fr$$

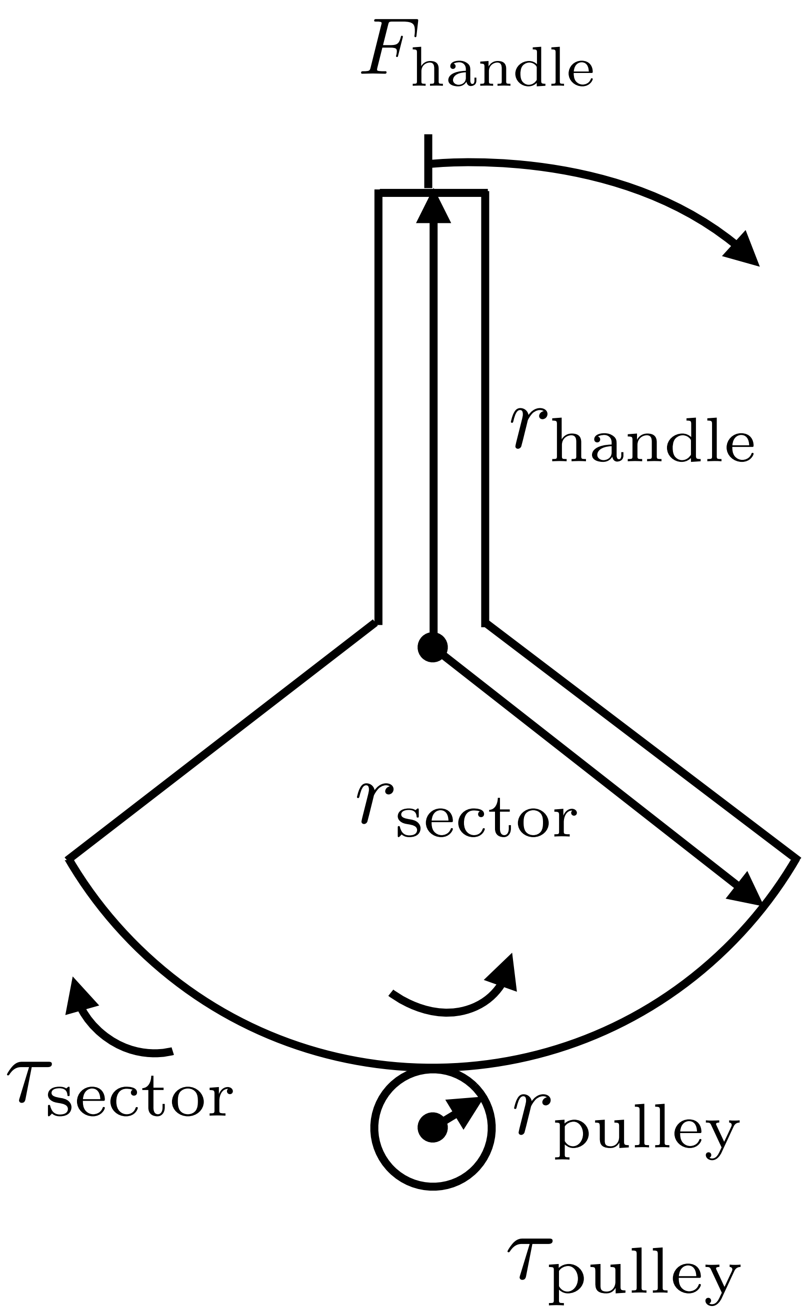
torque (in N-m)

force (in N)

radius (in m)



Hapkit force/torque relationships



relationship between force and torque: $\tau = Fr$

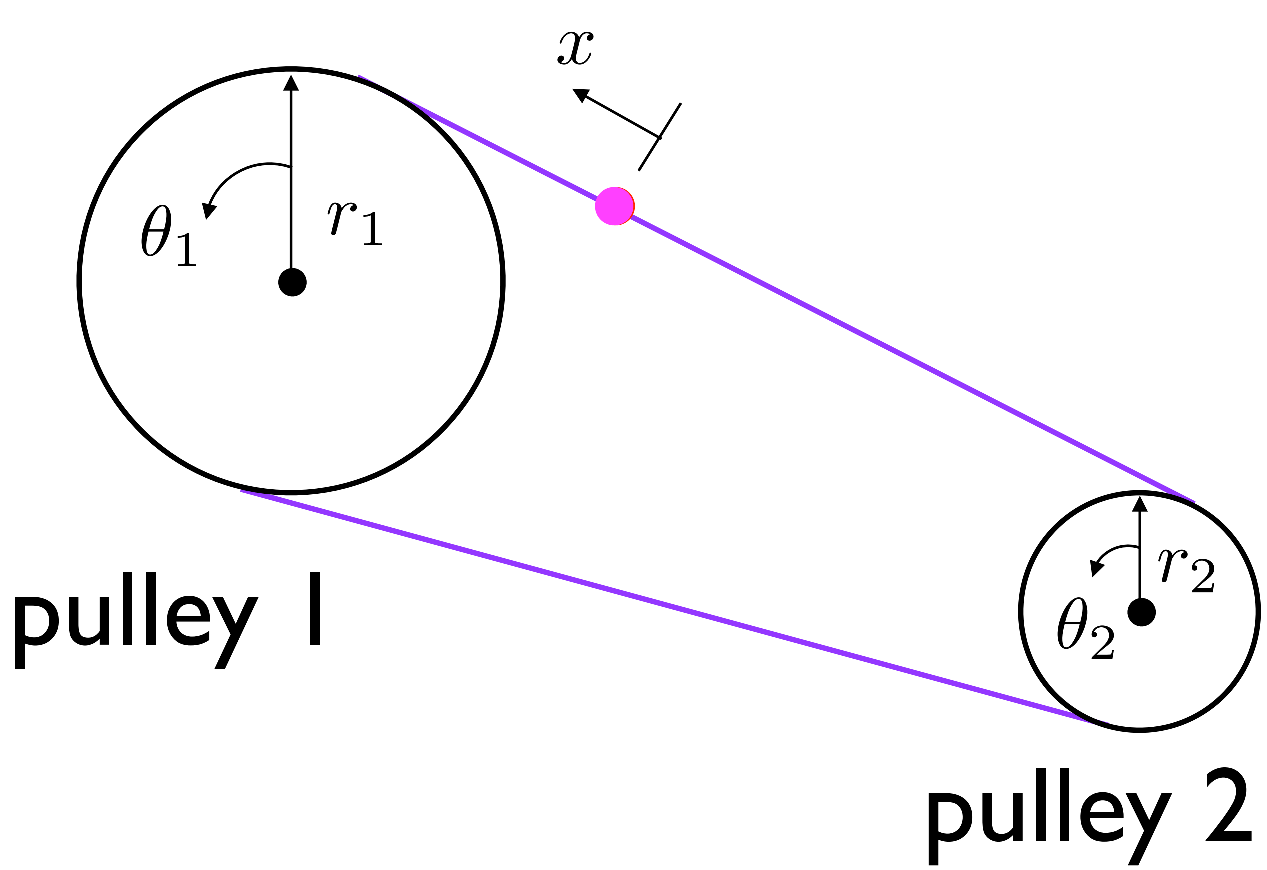
$$\frac{\tau_{\text{pulley}}}{r_{\text{pulley}}} = \frac{\tau_{\text{sector}}}{r_{\text{sector}}}$$

$$F_{\text{handle}} = \frac{\tau_{\text{sector}}}{r_{\text{handle}}}$$

$$F_{\text{handle}} = \frac{r_{\text{sector}}}{r_{\text{handle}} r_{\text{pulley}}} \tau_{\text{pulley}}$$

Kinematic Relationships

Belt-on-pulleys example



$$s_1 = r_1\theta_1$$

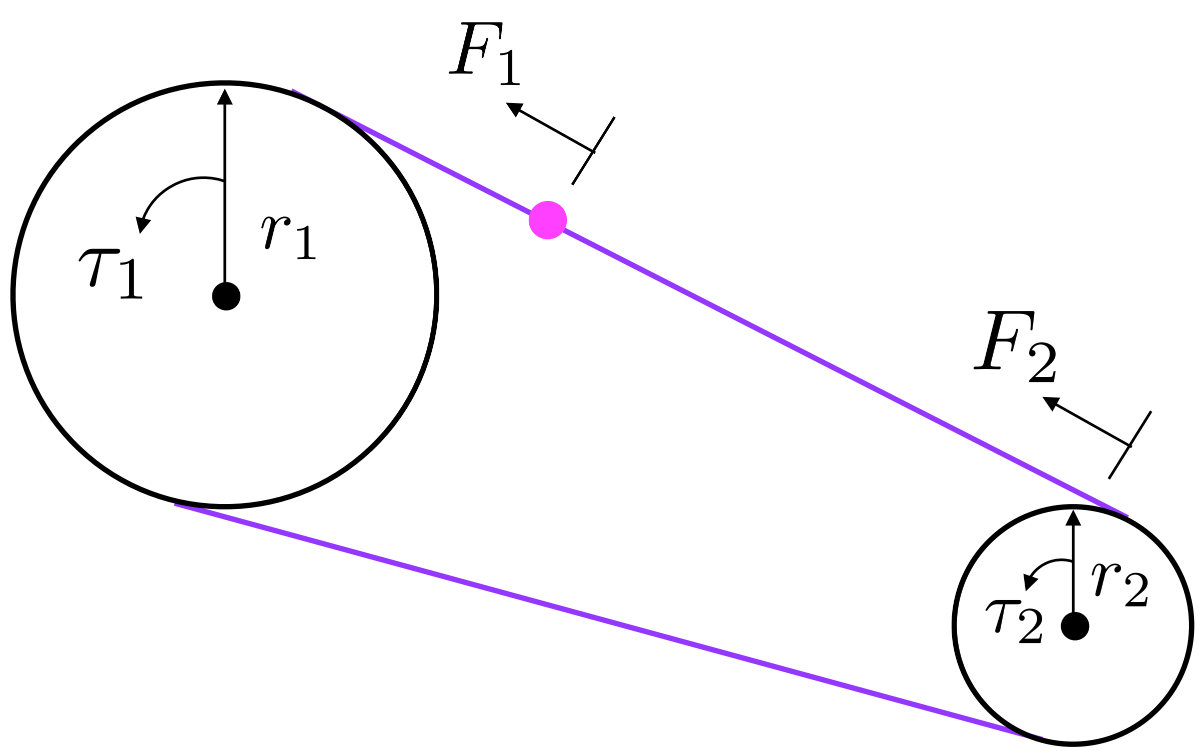
$$s_2 = r_2\theta_2$$

$$x = s_1 = s_2$$

$$\theta_2 = \frac{r_1}{r_2}\theta_1$$

Force-Torque Relationships

Belt-on-pulleys example



$$\tau_1 = F_1 r_1$$

$$F_1 = \frac{\tau_1}{r_1}$$

$$F_1 = F_2$$

$$\tau_2 = F_2 r_2$$

$$\tau_2 = \frac{r_2}{r_1}\tau_1$$

rendering a wall

(in one degree of freedom)

classic algorithm for rendering with an impedance-type device

1. **read the position of the user from the haptic display**

2. **see if there is a collision with objects in the virtual environment**

3. **if there is, calculate forces**

4. **send corresponding torque commands to motors, *and change the virtual environment state***

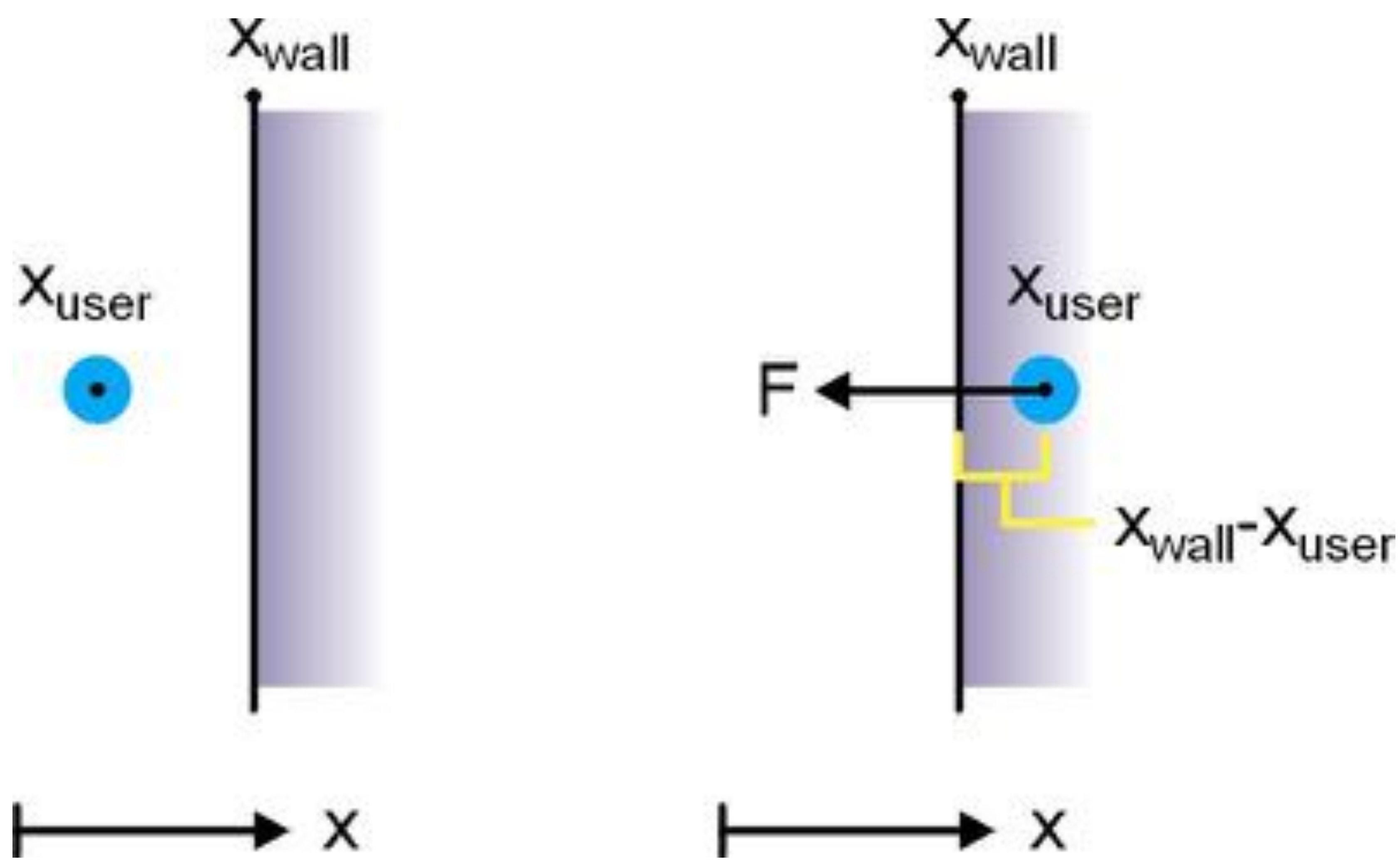
static rigid body interaction

- the virtual environment pretends that the user is holding onto a *fictional* rigid body though the haptic device handle
- this rigid body interacts with other "rigid" bodies in the virtual environment.
- *with impedance control, nothing is perfectly rigid: $F = kx$*

rendering a simple wall

$$\text{If } x_{user} > x_{wall}, F = k(x_{wall} - x_{user})$$

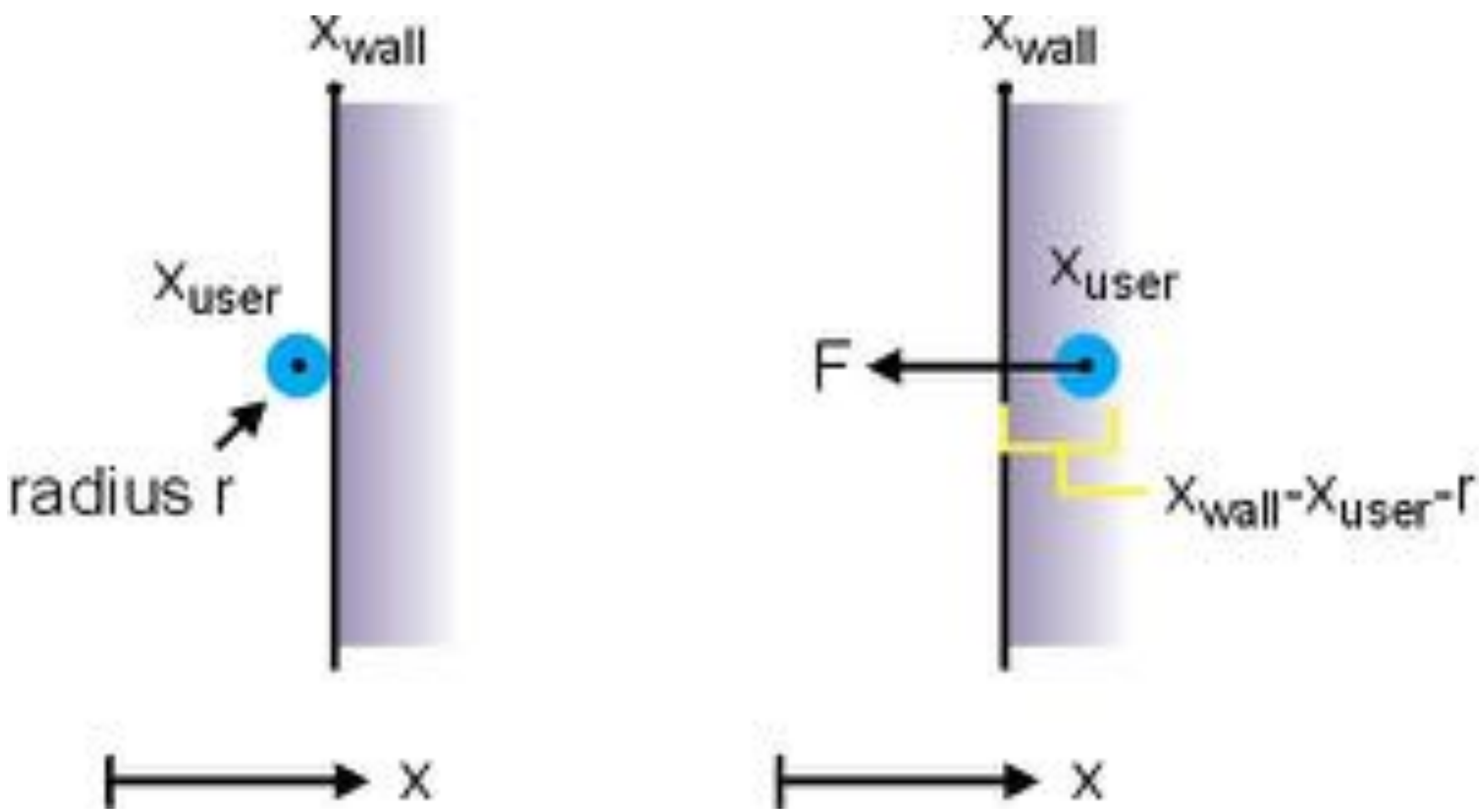
$$\text{stiffness } k > 0$$



when the tool is not a point

$$\text{If } (x_{user} + r) > x_{wall}, F = k(x_{wall} - x_{user} - r)$$

$$\text{stiffness } k > 0$$



kinesthetic device challenges

- competing goals of high stiffness and low mass
- force feedback feels soft (“Nerf World”)
- point-based interactions are overly simple
- devices of sufficient quality are expensive
- limited workspace size, degrees of freedom, and actuation power
- usually constrained to sit at a desk
- no programmable tactile feedback

