Pointing Devices and Transfer Functions

Learning Goals

- Understand …
  - controller resistance (isometric, isotonic, elastic)
  - rate control and position control
  - how a transfer function works
- Know
  - about the Buxton collection of interaction devices
  - what fundamental shortcomings a single pointing device brings
  - how to design a transfer function

Physical Properties used by Input devices

Example: Mouse with 3 Buttons and scroll wheel

	Linear			Rotary			
	X	Y	Z	rX	rY	rZ	
P			3				R
dP							dR
F							T
dF							dT
	1 10 100 inf	1 10 100 inf	1 10 100 inf	1 10 100 inf	1 10 100 inf	1 10 100 inf	

Card, S. K., Mackinlay, J. D. and Robertson, G. G. (1991). A Morphological Analysis of the Design Space of Input Devices. ACM Transactions on Information Systems 9(2 April): 99-122
https://dl.acm.org/doi/pdf/10.1145/123078.128726

Input Devices as a six-tuple

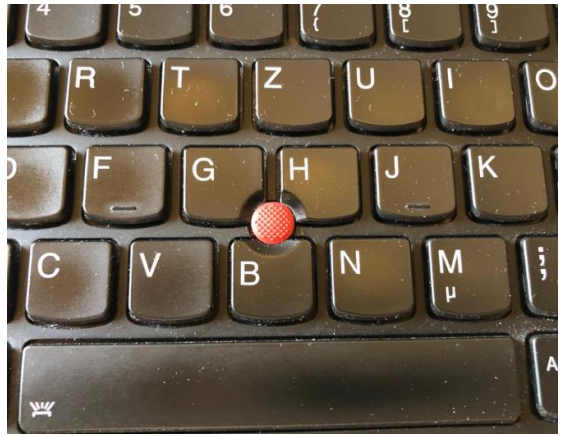
A formal view

(M, In, S, R, Out, W)

- **M** is a manipulation operator,
- **In** is the input domain,
- **S** is the current state of the device,
- **R** is a resolution function mapping from the input domain set to the output domain set,
- **Out** is the output domain set, and
- **W** is a general-purpose set of device properties that describe additional aspects of how a device works

M:
In:
S:
R:
Out:
W:

Application:



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M: $dP_{x,y}$
In: ([0,20];[0,20])
S: p=(0;0)
R: f(p)
Out: ([0,1920];[0,1080])
W: NIL

Application:
cursor position on screen

M: $P_{x,y}$
In: ([0,300];[0,200])
S: p=(0;0)
R: g(p)
Out: ([0,1920];[0,1080])
W: NIL

Application:
cursor position on screen

M: $F_{x,y}$
In: ([0,100];[0,100])
S: p=(0;0)
R: h(p)
Out: ([0,1920];[0,1080])
W: NIL

Application:
cursor position on screen

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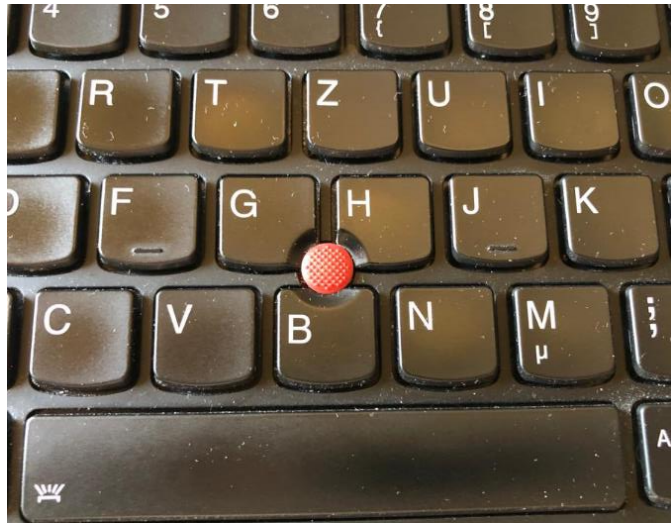
Transfer functions

How your mouse moves

- Mouse is moved across a surface in X and Y
- The mouse reports the movement as changes to x and y (dx and dy)
- The resolution of the updates relate to the resolution of the sensor in the mouse (DPI)
- How often the changes are reported relates to the polling rate (e.g. 100Hz means you get an update every 10 ms, 500Hz gives an update every 2 ms)
- We assume your cursor is at a certain position on the screen (Sx, Sy)
- Your transfer function updates the screen position of the cursor based on the received values:

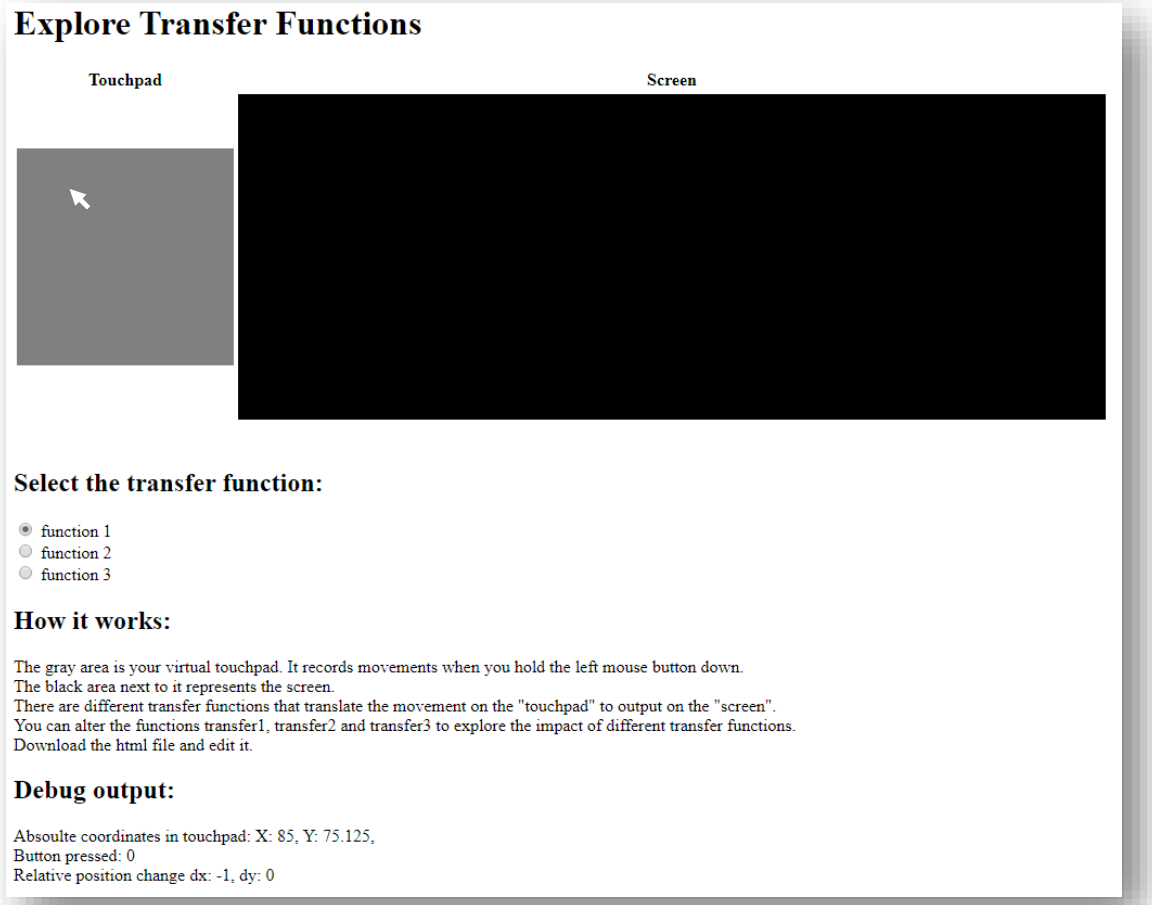
$$(Sx,Sy) = f(Sx, Sy, dx, dy)$$



Exercise: Transfer functions

How your mouse moves

- You get:
  - Relative movement **`dx`**, **`dy`**
  - Absolute position in the “touchpad” **`x`**, **`y`**
- You should calculate the position on the “screen” **`screenX`**, **`screenY`**



https://hci-lecture.org/HCI/topics/iotech/transferfunc01.html

Pointing Devices with 2DOF

- Pointing devices such as
  - Mouse
  - Trackpad
  - Track ball
  - Touch screen
  - Eye gaze
  - …
- Beyond the desktop
  - Interactive surfaces
  - Pointing gestures
  - Gaze and attention
  - …

Degrees of Freedom (DOF)

How many dimensions can you manipulate (at once)

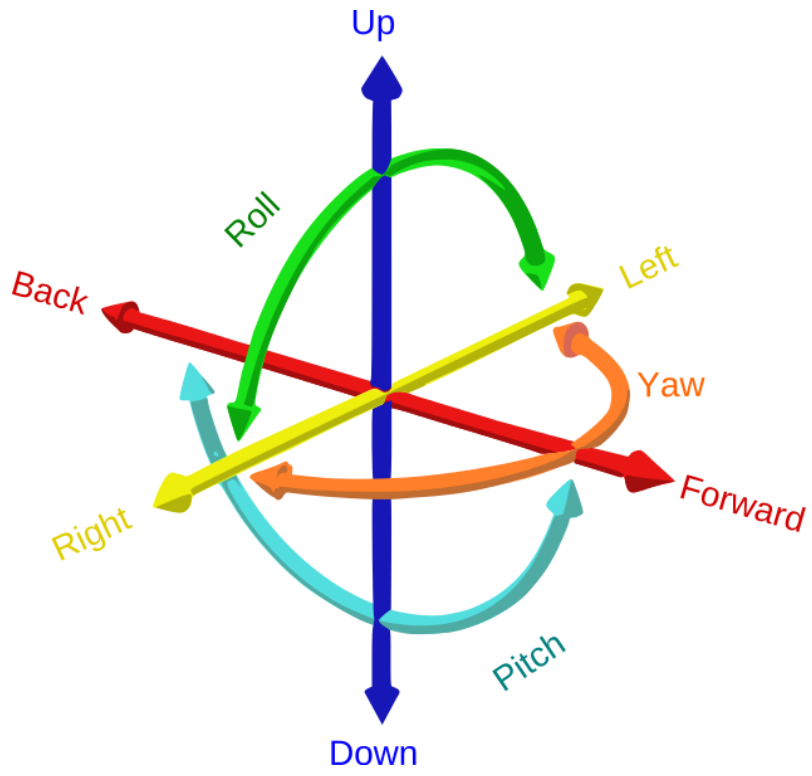
- 1 DOF
  - Slider or Knob to control the volue
- 2 DOF
  - Mouse - you can move it in X and Y
  - Touchpad – you move on it in X and Y
- 3 DOF
  - Mobile phone to rotate an object on the screen
  - Hypothetical device: a mouse that also registers rotation
- 6 DOF
  - Input devices that can control translation (x, y, z) as well as rotation (pitch, yaw, roll) in 3D space

Katzakis, N., & Hori, M. (2010, March). Mobile devices as multi-DOF controllers. In *2010 IEEE Symposium on 3D User Interfaces (3DUI)* (pp. 139-140). IEEE.

6 Degrees of Freedom (6DOF)

Possible movements of a rigid body in 3d space

- Change of position (x, y, z)
  translation in 3 perpendicular axes:
  - forward/backward (surge)
  - up/down (heave)
  - left/right (sway)
- Changes in orientation
  rotation about 3 perpendicular axes
  - yaw (normal axis)
  - pitch (transverse axis)
  - roll (longitudinal axis).

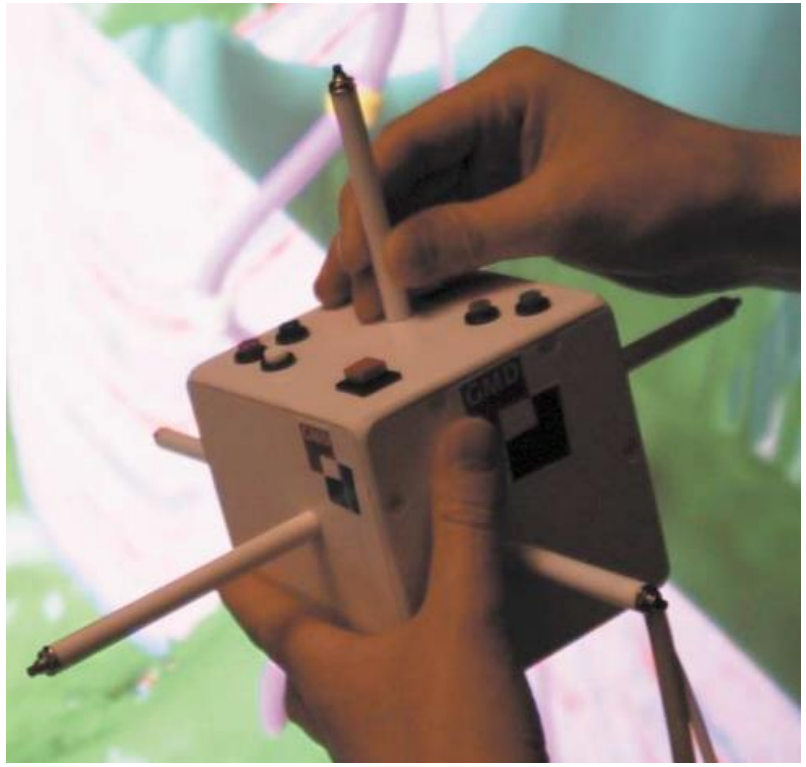


Drawing by GregorDS

A Clutch for Input Devices?

How to NOT input?

- 2DOF
  - The mouse it a the end of the table
  - You want to go further down with your cursor
    → you lift the mouse up = it will not track anymore and you can reposition the device
- 6DOF
  - You want to screw in a virtual screw
    → Clutch button – if you press it, it does NOT track and you can reposition the device



"*The **single button serves as a clutch**, allowing users to freeze the model in its current position. Releasing the clutch attaches the model to the Cubic Mouse's current location and **reorients it to the device's orientation**. The clutch also lets users **move the model further than arm's reach** by extending the arm, releasing the model, moving the arm back, reattaching the model, extending the arm again, and so forth.*"

Frohlich, B., Plate, J., Wind, J., Wesche, G., & Gobel, M. (2000). Cubic-mouse-based interaction in virtual environments. *IEEE computer graphics and applications*, *20*(4), 12-15.

Classification of Pointing devices

- **Degrees of Freedom** (DOF) / Dimensions
  - 2 DOF, 6 DOF
  - 1D / 2D / 3D
- **Direct vs. indirect**
  integration with the visual representation
  - Touch screen is direct
  - Mouse, trackpad, trackpoint are indirect
- **Discreet vs. continuous**
  resolution of the sensing
  - Touch screen is discreet
  - Mouse is continuous
- **Absolute vs. Relative**
  movement/position used as input
  - Touch screen is absolute
  - Mouse is relative

Examples of Pointing devices

Buxton Collection

BUXTON COLLECTION

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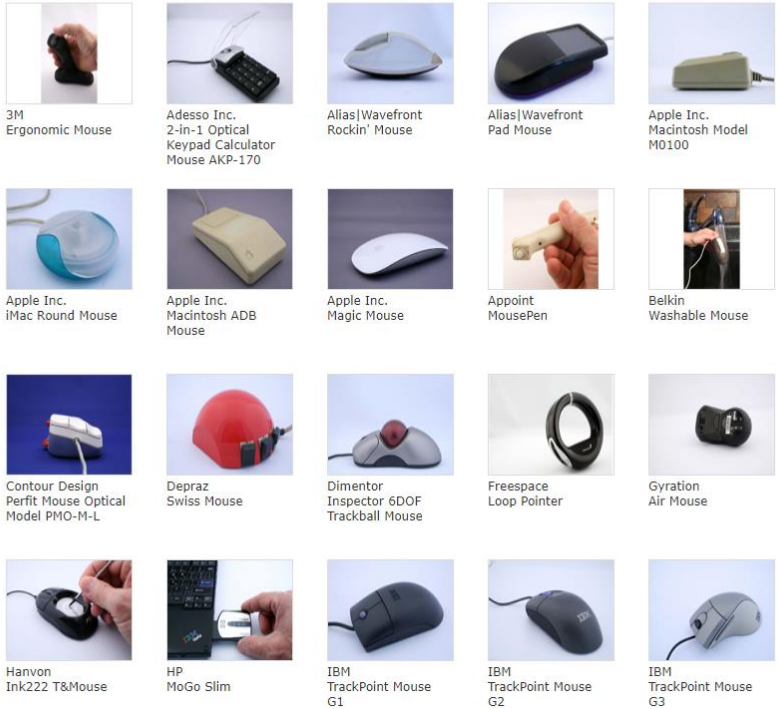
Mouse



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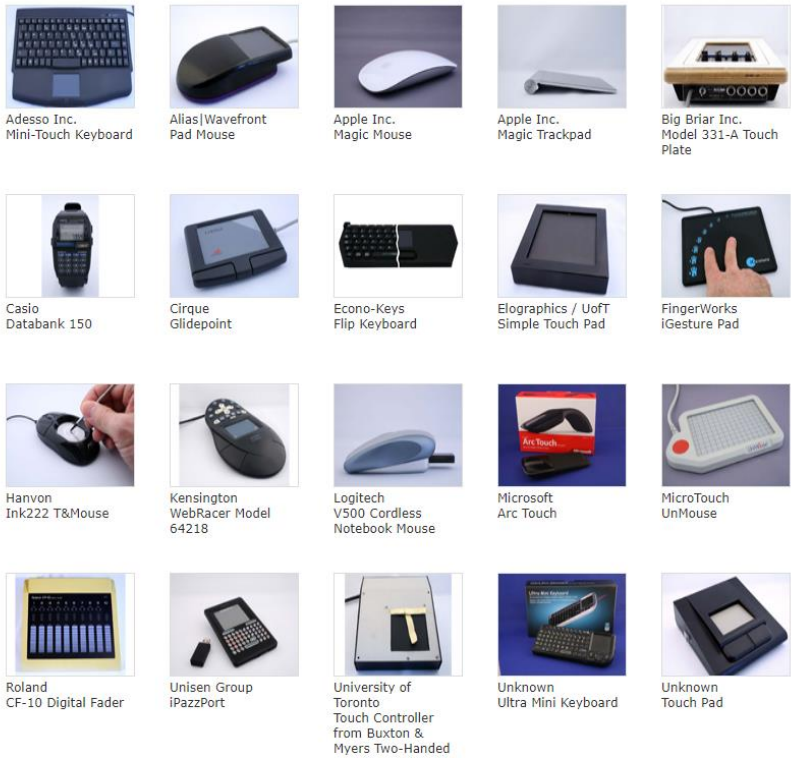
Touch Pad



https://www.microsoft.com/buxtoncollection/

Controller resistance (2DOF, 6DOF)

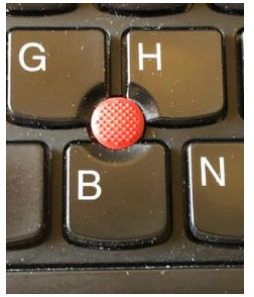
- **Isometric** (infinite resistance)
  - Device/handle is not moved
  - pressure devices / force devices
  - Infinite resistance
  - device that senses force but does not perceptibly move
  - force is mapped to rate control of the cursor (typical) or to absolute position
- **Isotonic** (free moving)
  - device/handle is moved
  - displacement devices, free moving devices or unloaded devices
  - zero or constant resistance (resistance stays the same)
  - displacement of device is mapped to displacement of the cursor

Controller resistance (2DOF, 6DOF)

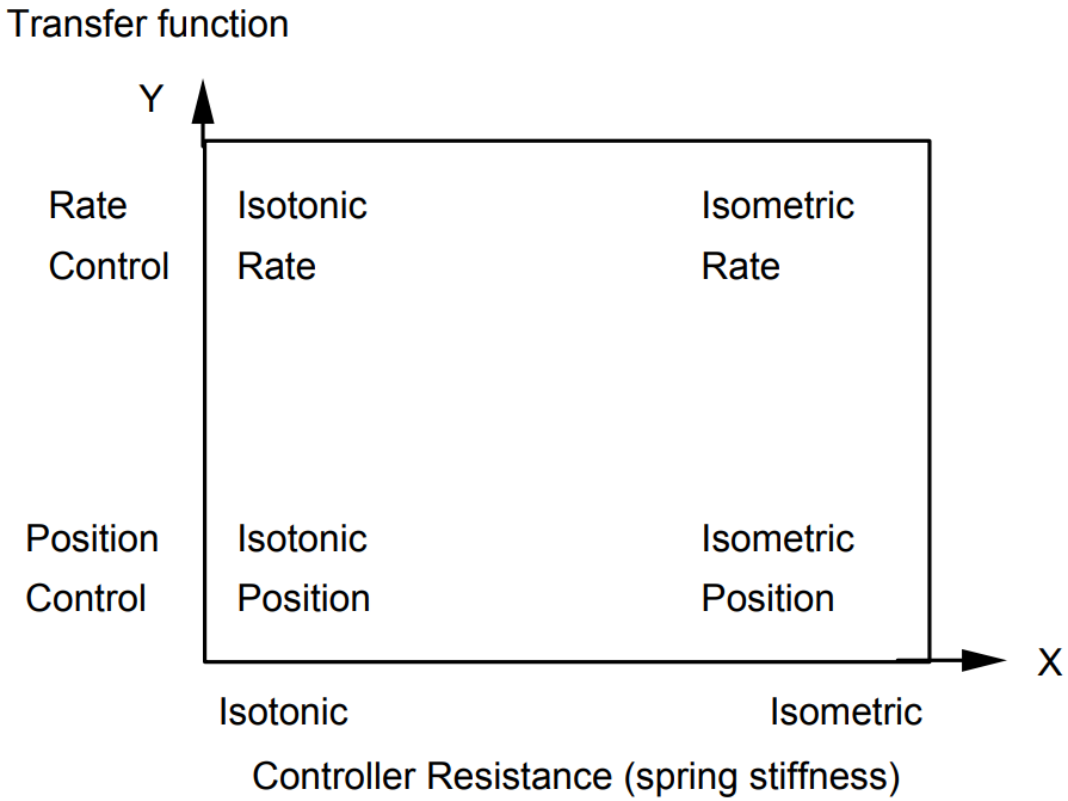
- **Elastic:**
  - Device/handle is moved
  - Device's resistive force increases with displacement (also called spring-loaded)
  - Device can sense displacement or force
  - Force/displacement is mapped to rate control of the cursor (typical) or to absolute position
- **Viscous**
  - resistance increases with velocity of movement
- **Inertial**
  - resistance increases with acceleration

Transfer function (2DOF, 6DOF)

- **Position control**
  - device displacement is mapped/scaled to position (typically for free moving/isotonic devices, also for elastic devices)
  - absolute force is mapped/scaled to position (for isometric or elastic devices)
- **Rate control**
  - force or displacement is mapped onto cursor velocity
  - Integration of input over time → first order control



Performance depends on transfer function and resistance

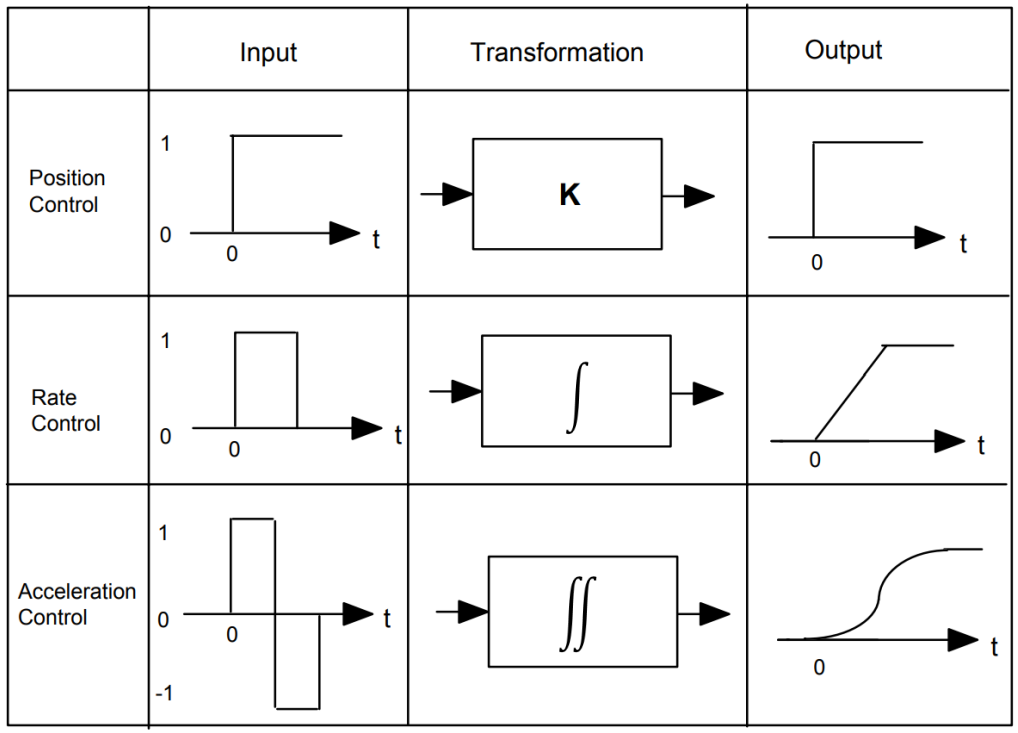


Zhai, Shumin. *Human performance in six degree of freedom input control*. PhD Thesis. University of Toronto, 1996. p12
https://www.talisman.org/~erlkonig/misc/shumin-zhai%5Ehuman-perf-w-6dof-control.pdf

Position versus Rate Control

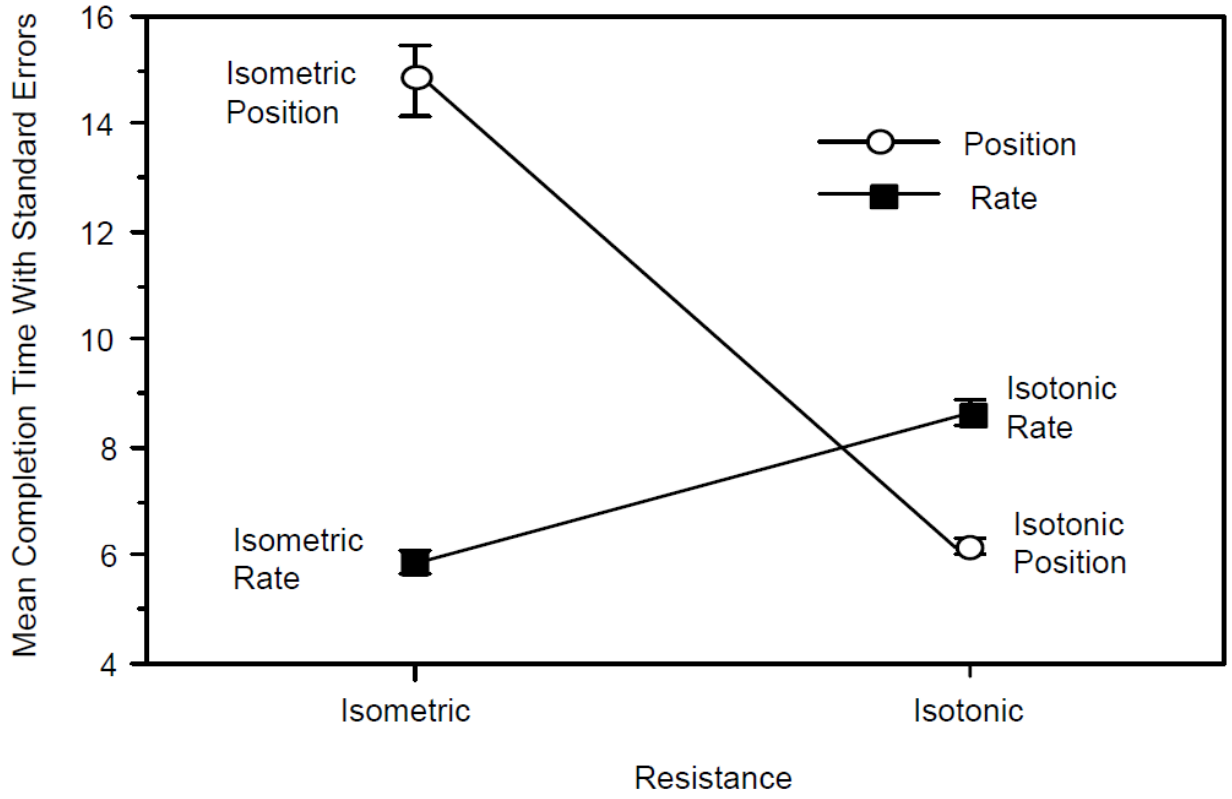
Transfer function (2DOF, 6DOF)

- **Position control**
  - device displacement or absolute force is mapped to position
- **Rate control**
  - force or displacement is mapped onto cursor velocity



Zhai, Shumin. *Human performance in six degree of freedom input control*. PhD Thesis. University of Toronto, 1996. p18
https://www.talisman.org/~erlkonig/misc/shumin-zhai%5Ehuman-perf-w-6dof-control.pdf

Performance depends on transfer function and resistance



Zhai, Shumin, Paul Milgram, and David Drascic. "An evaluation of four 6 degree-of-freedom input techniques." In *INTERACT'93 and CHI'93 Conference Companion on Human Factors in Computing Systems*, pp. 123-125. 1993.

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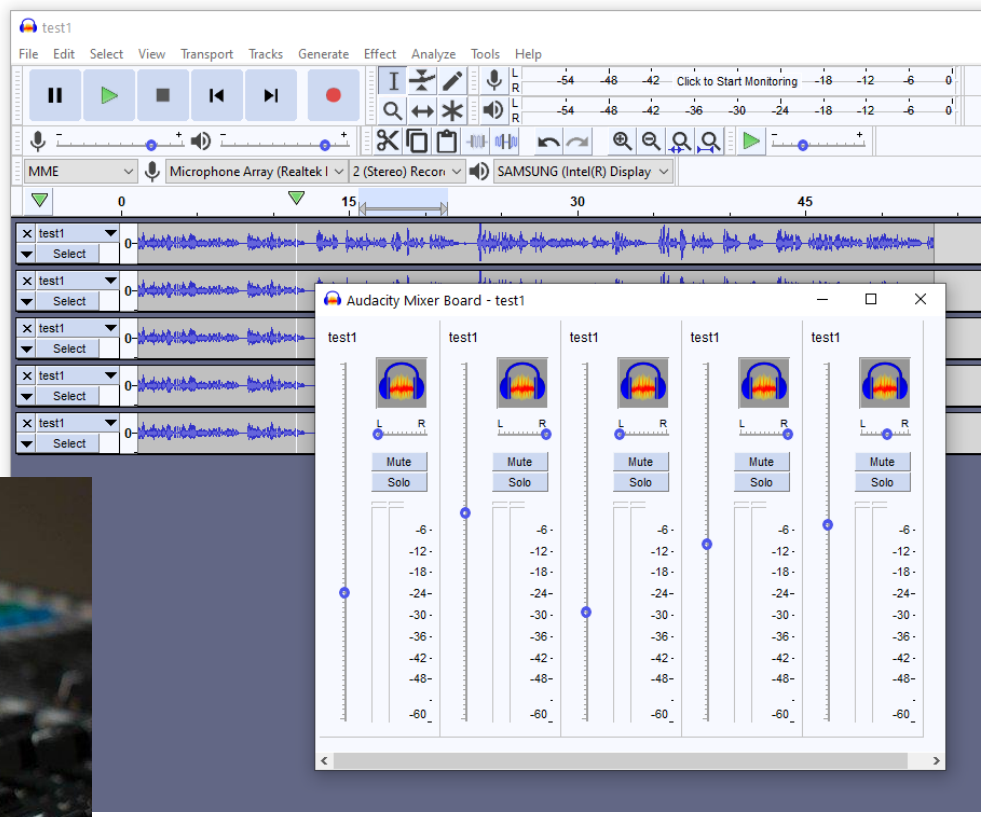
Fundamental Problems with Pointing Devices

What is the drawback of interaction using a single Pointing device?



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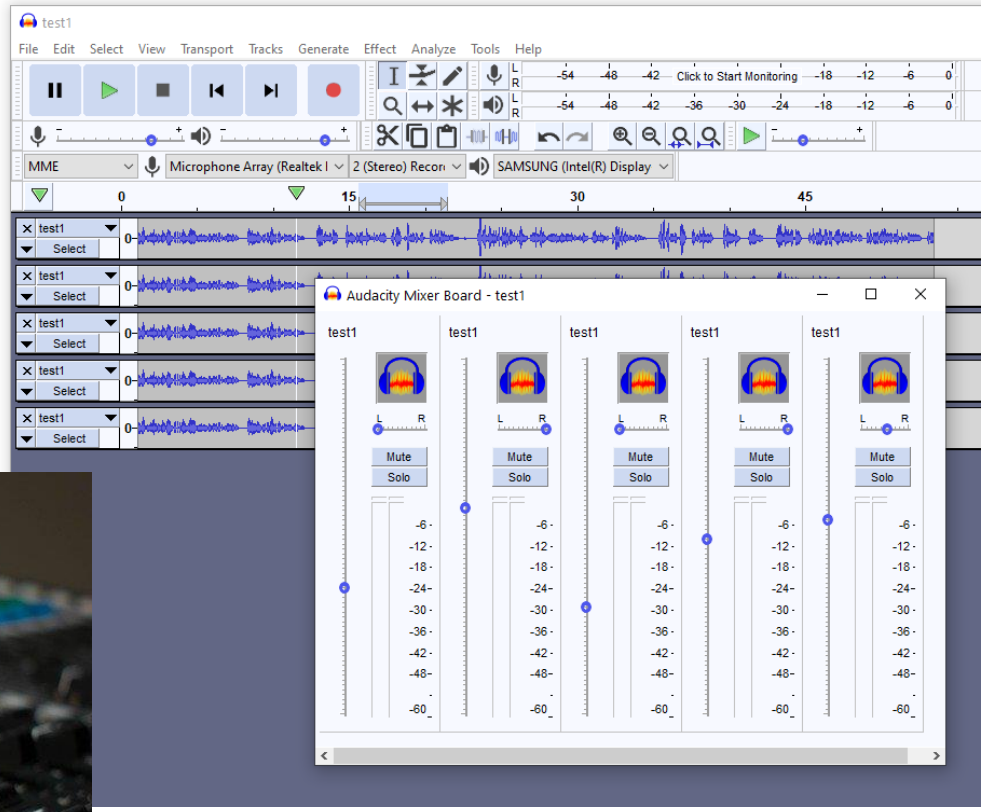

- With a single pointing device most often time multiplexing is implied!
- One operation at the time (e.g. slider can be only be moved sequentially with the mouse)

Did you understand this block?

Can you answer these questions?

- What does the Buxton collection include?
- What is a transfer function?
- Assume you a have screen where you need very precise at the left and only very coarse pointing at the right of the screen. How could you design a transfer function to support this?
- Explain the concept of controller resistance and give examples.
- When is it better to use rate control? When is position control more effective?
- What are the problems of having a single pointing device?
- Why do input device often need a clutch?

Reference

- Zhai, Shumin. Human performance in six degree of freedom input control. PhD Thesis. University of Toronto, 1996. p35 https://www.talisman.org/~erlkonig/misc/shumin-zhai%5Ehuman-perf-w-6dof-control.pdf
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- Buxton, B. https://www.microsoft.com/buxtoncollection/

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