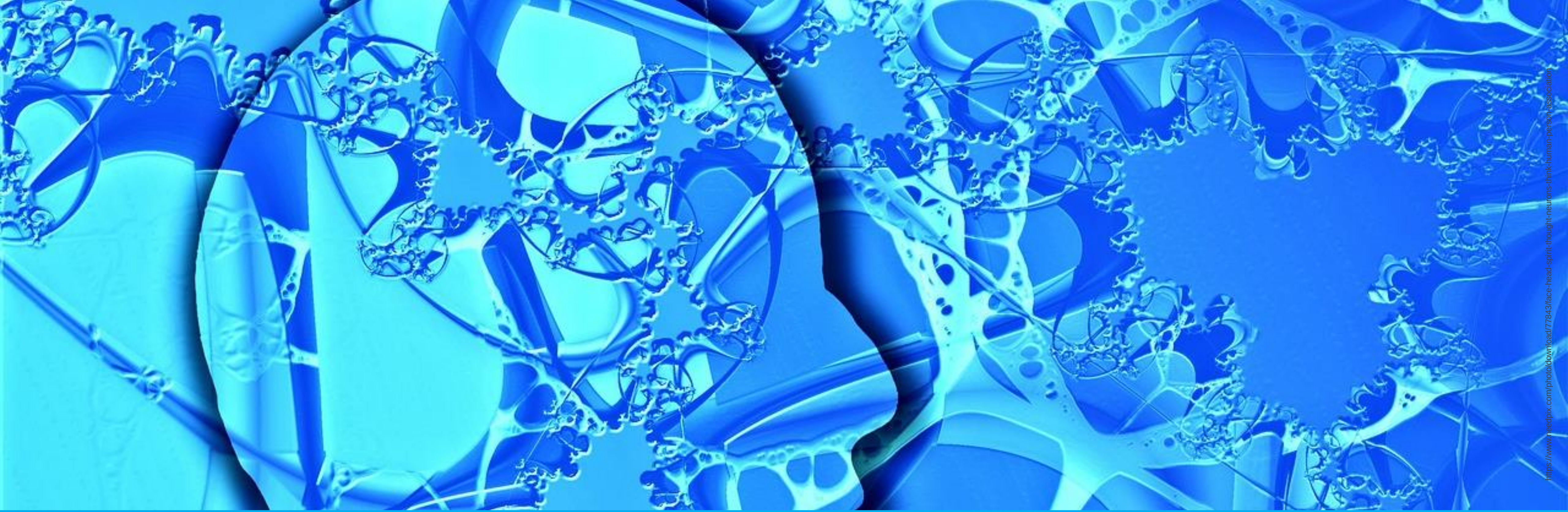


What is the Ultimate User Interface?

Albrecht Schmidt

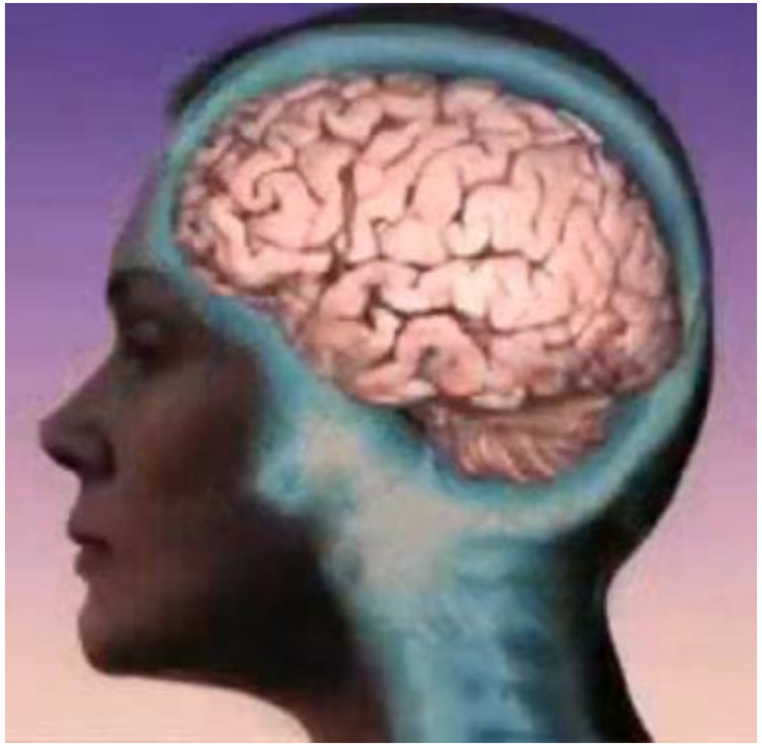
Learning Goals

- Understand …
  - The challenge of building user interfaces
  - How the user interface impacts what people can do
  - The concept of bandwidth between human an system
  - The basic input and output operations supported by UIs

The Ultimate User Interface?

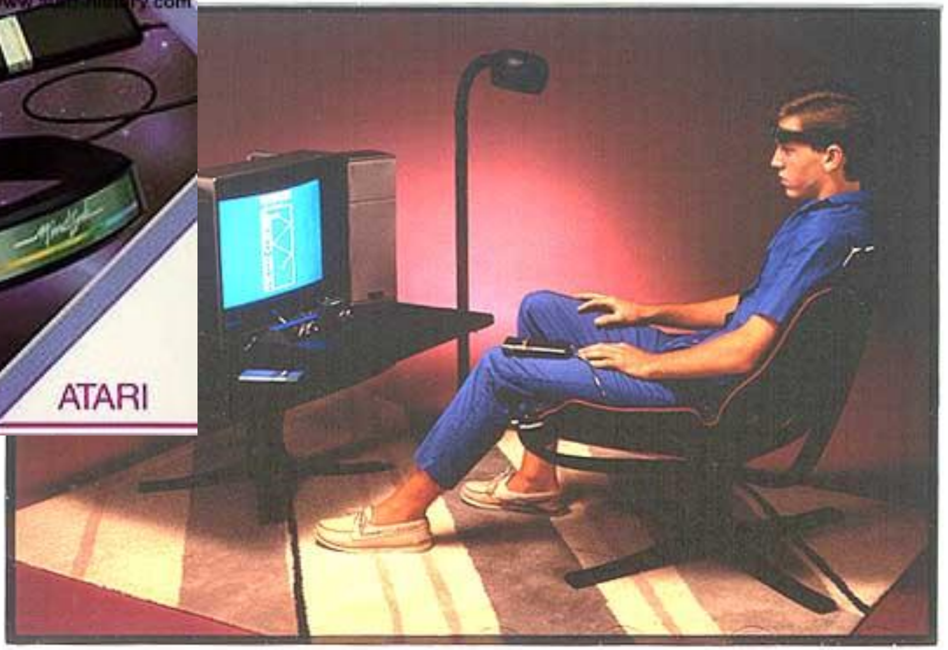
Do what I think!

- Turn my ideas and thoughts into reality.



Atari Mindlink (intended for release in 1984, never released)

… and many more, e.g. recently NEURALINK

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MED-TECH : HEALTH

Direct Brain-to-Game Interface Worries Scientists

By Emmet Cole 09.05.07

Your brain might be your next videogame controller.

That might sound pretty awesome, but the prospect of brain-controlled virtual joysticks has some scientists worried that games might end up controlling our brains.

Several makers of brain-computer interfaces, or BCIs -- devices that facilitate operating a computer by thought alone -- claim the technology is poised to jump from the medical sector into the consumer gaming world in 2008.

Companies including Emotiv Systems and NeuroSky say they've released BCI-based software-development kits. Gaming companies may release BCI games next year, but many scientists worry that users brains' might be subject to negative effects.

For example, the devices sometimes force users to slow down their brain waves. Afterward, users have reported trouble focusing their attention.

"Imagine that somebody uses a game with slow

NeuroSky's headset technology is being used in tandem with a software development kit to create BCI-based games. The first titles are expected to hit store shelves in 2008.

http://www.wired.com/medtech/health/news/2007/09/bci_games

http://www.atarimuseum.com/videogames/consoles/2600/mindlink.html

What is the Challenge in Making a UI?

… to support the user to turn ideas into reality!

- You want to tell your friends when and where to meet for dinner.
  - How can you communicate it to them remotely?
- You know there a document that describes how to repair your bike.
  - How can you find this document and get access to it?
- You have an idea for a story.
  - How to get from your idea to a book others can read?
  - How to make a movie that others see it?
- You imagine some musical tune.
  - How to capture it an make it into music others can listen to?
- You plan your new dream house.
  - How to create a 3D model that you can discuss with your friends?

What is the Challenge in Making a UI?

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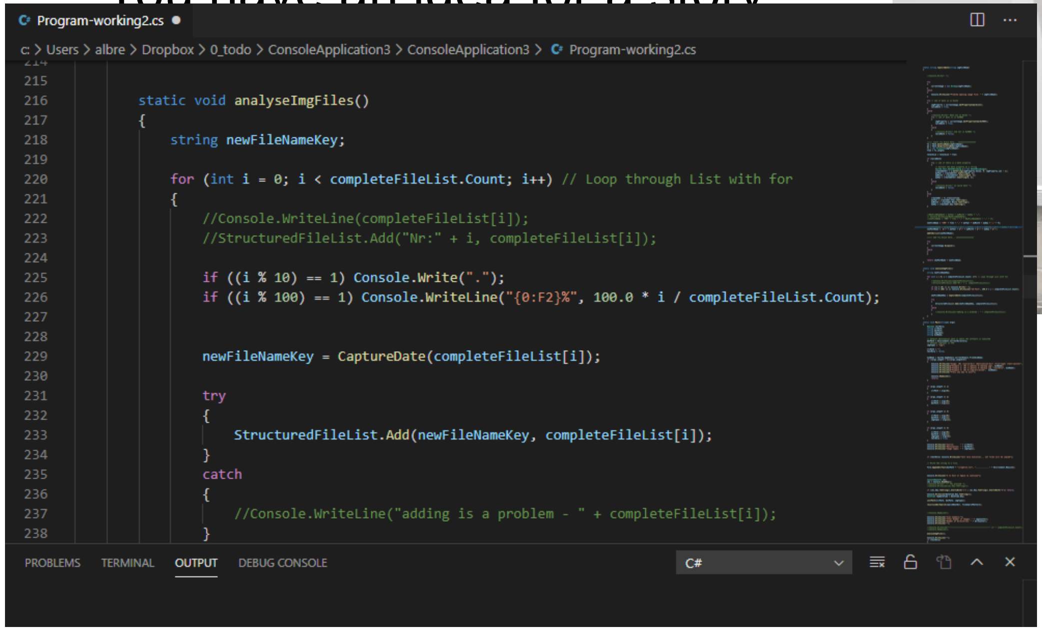


discuss with your friends?

What can UIs do?

Imagine

Everything a **professional**

- Typesetter
- Photographer
- Publisher
- Filmmaker
- …
- Programmer

can do today, could be done **by anyone**.

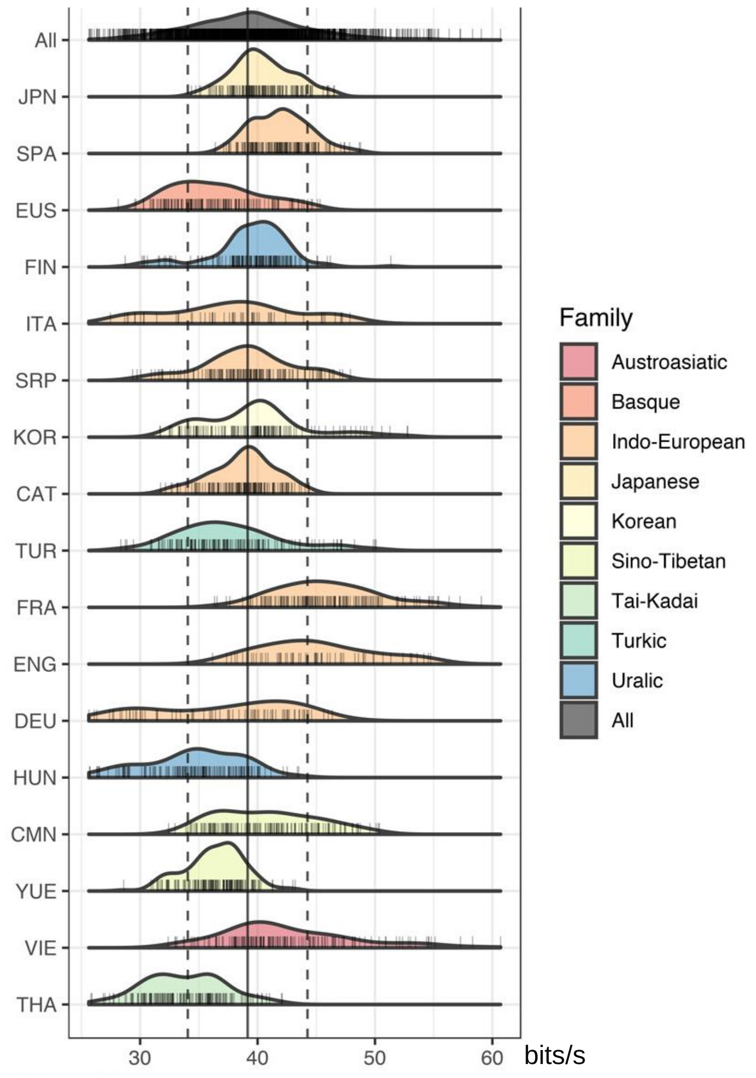
What is the User Interface?

The solution space

- What technologies are available to create UIs?
  - Hardware
  - Software
  - Systems
- How can users and interactive systems communicate?
  - Input (user to computer)
  - Output (computer to user)
- What is the time scale of interaction?
  - Immediate “real-time” interaction
  - Batch (offline) interaction

Thinking about Bandwidth of a UI

- Communication bandwidth in bits/second
- Human output bandwidth?
  - Speech: ~ 39 bits/second
  - Writing: ~ 200 characters/minute ~ 3 characters/second < 24 bits/s
  - Pointing
  - Thinking?
- Human input bandwidth?
  - Seeing < 6Mbit/s (conscious visual perception may be as low as 100bits/s)
  - Listening / hearing
  - Feeling / smell / taste
- Bandwidth is hart to tell!
  - 4K TV has 8,000,000 pixels x 3 bit x 100 Hz ~ 20 Gbit/s
  - Low bandwidth for information intake (e.g. reading about 5 words/second)
  - But we see/hear if things are wrong (e.g. music, movie, …)
- Your brain is a limiting factor!



Coupé, C., Oh, Y. M., Dediu, D., & Pellegrino, F. (2019). Different languages, similar encoding efficiency: Comparable information rates across the human communicative niche. *Science Advances*, *5*(9), eaaw2594.

Mini-Exercise: 1D Pointing

Setting: Museum exhibition

- Visualization of rainforest vegetation
- User group: kids age 4-8
- Interaction to look at vegetation at the selected height
- Given: image of 1,000 pixel wide and 12,000 pixel high (12,000 pixel represent 24 meters)
- Task: create an interface
  - Lets users select at what height the want to look
  - That is engaging
  - That does not require computer knowledge

Example: Computer Rope Interface

Winslow Burleson and Ted Selker. 2003. Canopy climb: a rope interface. In *ACM SIGGRAPH 2003 Sketches \& Applications* (SIGGRAPH '03). ACM, New York, NY, USA, 1-1. DOI=10.1145/965400.965549 http://doi.acm.org/10.1145/965400.965549

Design and Implementation options for UI

The design space?

- For **standard applications** on standard devices (desktop, mobile)
  - Based on a **software implantation** (typically using frameworks)
  - Understanding the differences in systems
  - Recommending a hardware setup
  - Best experience for potential users
  - Defining a **minimal set of requirements** (e.g. screen resolution, input device)

- For specific **custom made** products and applications
  - **Software and hardware**
  - Understanding options that are available
  - Innovative embedded user interfaces (devices, machines, cars, …)
  - Creating a different and **unique experience** (e.g. for exhibition, trade fare, museum, …)

Basic Input Operations

The design space?

Text Input

- Continuous
  - Keyboard Handwriting
  - Spoken
- Block
  - Scan/digital camera and OCR

Direct Mapped Controls

- Hard wired buttons/controls
  - On/off switch, Volume slider
  - Physical controls that can be mapped
  - Function key on keyboard
- Industrial applications

Pointing & Selection

- Degree of Freedom (1, 2, 3, 6, DOF)
- Isotonic vs. Isometric
- Transfer function
- Precision
- Feedback

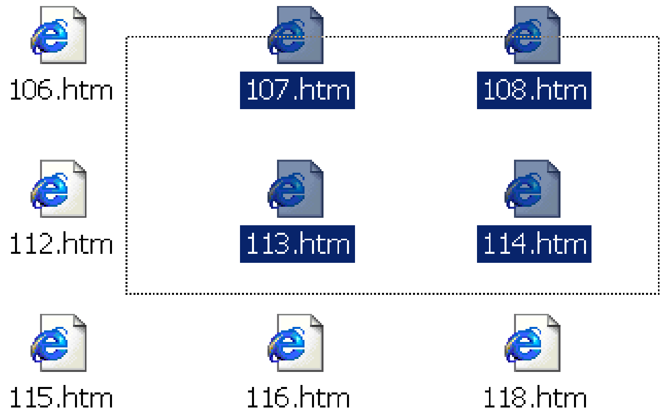
Media Capture

- Media type
  - Audio
  - Images
  - Video
- Quality/Resolution

Complex Input Operations

The design space?

- Examples of tasks
  - Filling a form = pointing, selection, and text input
  - Annotation in photos = image capture, pointing, and text input
  - Moving a group of files = pointing and selection
- Examples of operations
  - Selection of objects
  - Grouping of objects
  - Moving of objects
  - Navigation in space



Basic Output Operations

The design space?

Visual Output

- Show static
  - Text
  - Images
  - Graphics
- Animates
  - Text
  - Graphics
  - Video
- Technologies
  - Paper
  - Objects
  - Displays

Audio Output

- Earcons
- Auditory icons
- Synthetic sounds
- Spoken text (natural / synthetic)
- Music
- Technologies
  - Speakers
  - 1D/2D/3D

Tactile

- Shapes
- Forces
- Technologies
  - Objects
  - Active force feedback

Further senses

- Smell
- Taste
- Temperature
- …

Did you understand this block?

Can you answer these questions?

- How does the user interface change people's capabilities?
- Name areas where it is still hard to translate an idea into a digital artifact.
- Why is it hard to assess the bandwidth of the communication between the human and the system?
- What are basic input operations commonly used?
- What typical audio output do we consider in UIs?

Reference

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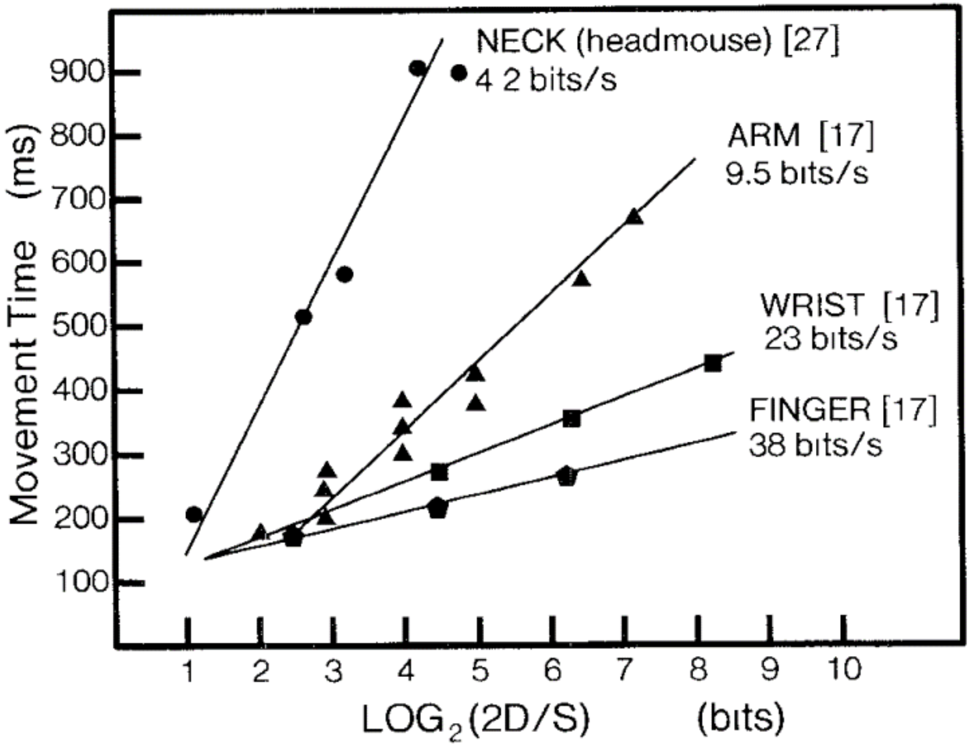
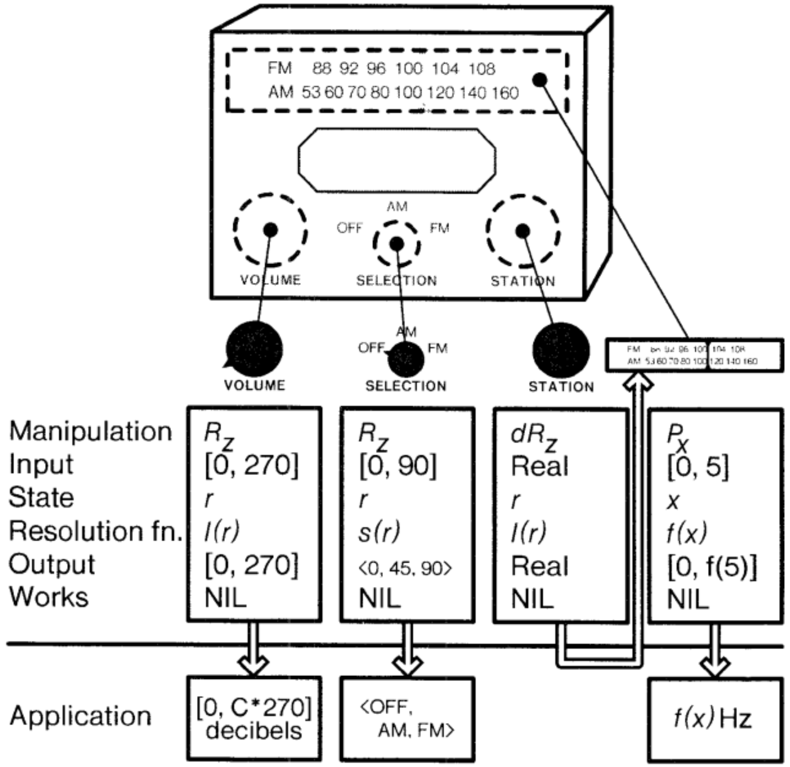
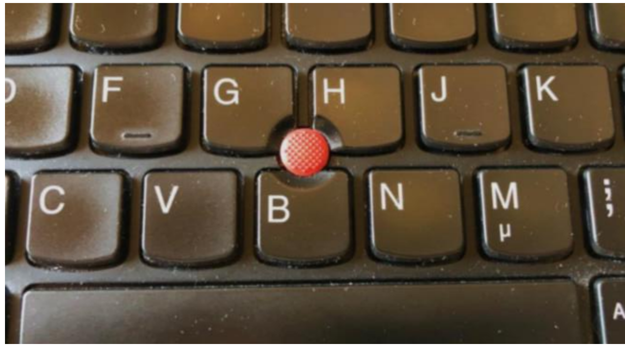
- http://www.atarimuseum.com/videogames/consoles/2600/mindlink.html

For more content see: https://hci-lecture.de







Design Space and Taxonomy

for Input Devices

Albrecht Schmidt

Learning Goals

- Understand …
  - The basic concept of an input device
  - The properties of input devices
  - How input devices can be classified
  - How human capabilities link to input devices
- Know
  - Examples for taxonomies for input device
  - A formal way of describing input devices

What is an Input Devices

Bill Buxton

"…basically, an input device is a **transducer from** the **physical properties** of the world **into the logical parameters** of an application."

http://www.billbuxton.com/input04.Taxonomies.pdf

Taxonomy

“a system for naming and organizing things, especially plants and animals, into groups that share similar qualities”[1]

Having a taxonomy for input devices helps to reflect on their properties and helps to answer questions such as:

- What criteria are relevant when looking at input devices?
- How can we organize input devices?
- How to compare input devices?
- Can one input device be replaced by another input device?
- Which input devices is more expressive?

[1] https://dictionary.cambridge.org/dictionary/english/taxonomy

Taxonomy for Input Devices

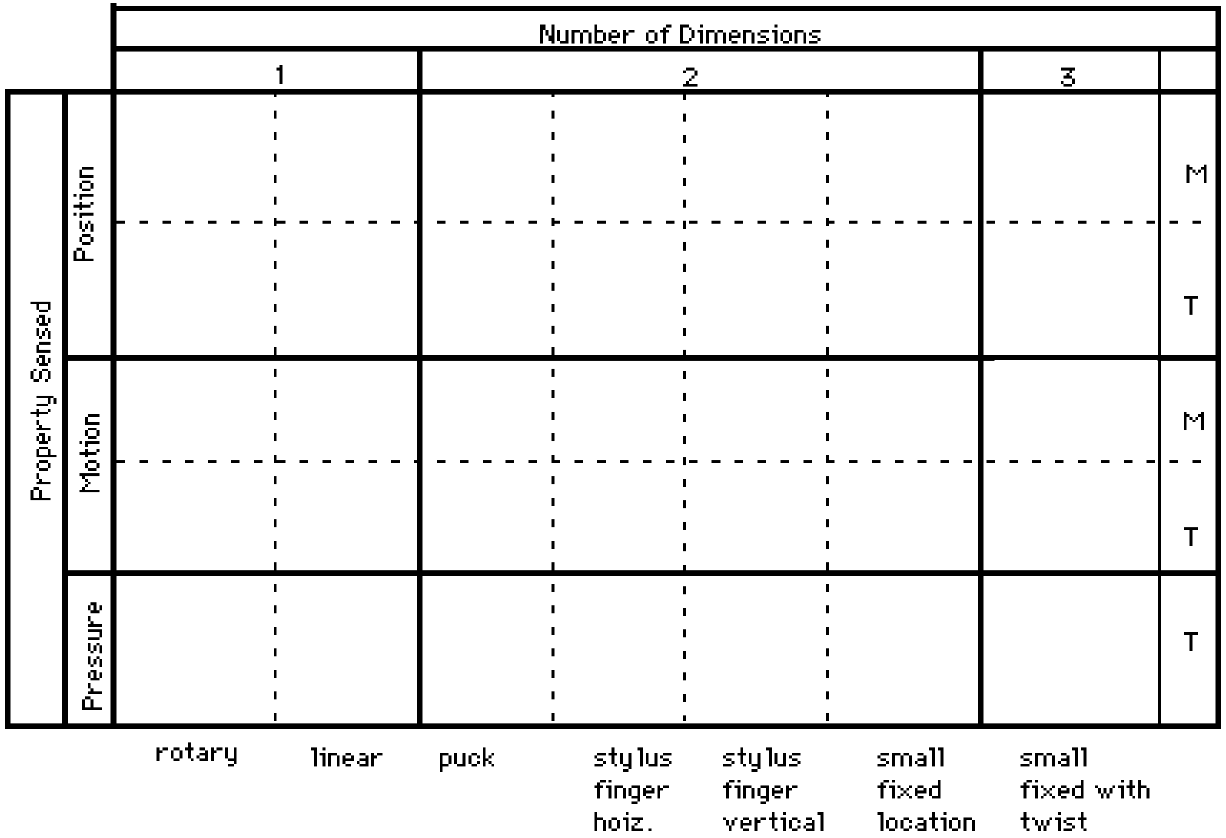
Bill Buxton

- **Criteria** to assess input devices
  - **continuous vs discrete**?
  - **agent of control** (hand, foot, voice, eyes ...)?
- **Dimensions in the Taxonomy**
  - **what is being sensed** (position, motion or pressure), and
  - the **number of dimensions** being sensed (1, 2 or 3)
  - **motor skills** to operate (similar motor skills are in sub-columns)
  - **touch vs. mechanical intermediary** (directly touched vs devices that require a mechanical intermediary between the hand and the sensing mechanism (sub-rows))

http://www.billbuxton.com/input04.Taxonomies.pdf

Taxonomy for Input Devices

Bill Buxton



Buxton, W. (1983). Lexical and Pragmatic Considerations of Input Structures. Computer Graphics, 17 (1), 31-37.
http://www.billbuxton.com/lexical.html
http://www.billbuxton.com/input04.Taxonomies.pdf

Taxonomy for Input Devices

Bill Buxton

Property Sensed		Number of Dimensions: 1		2				3	
Position		Rotary Pot	Sliding Pot	Tablet & Puck	Tablet & Stylus	Light Pen	Isotonic Joystick	3D Joystick	M
Position					Touch Tablet	Touch Screen			T
Motion		Continuous Rotary Pot	Treadmill	Mouse			Sprung Joystick Trackball	3D Trackball	M
Motion			Ferinstat				X/Y Pad		T
Pressure		Torque Sensor					Isometric Joystick		T
		rotary	linear	puck	stylus finger hoiz.	stylus finger vertical	small fixed location	small fixed with twist	

Buxton, W. (1983). Lexical and Pragmatic Considerations of Input Structures. Computer Graphics, 17 (1), 31-37.
http://www.billbuxton.com/lexical.html
http://www.billbuxton.com/input04.Taxonomies.pdf

Physical Properties used by Input devices

Card, 91

	Linear	Rotary
Position		
Absolute	P (Position)	R (Rotation)
Relative	dP	dR
Force		
Absolute	F (Force)	T (Torque)
Relative	dF	dT

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

Physical Properties used by Input devices

Card, 91

	Linear			Rotary			
	X	Y	Z	rX	rY	rZ	
P							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
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Physical Properties used by Input devices

Example 1: Touch Screen

	Linear			Rotary			
	X	Y	Z	rX	rY	rZ	
P							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	

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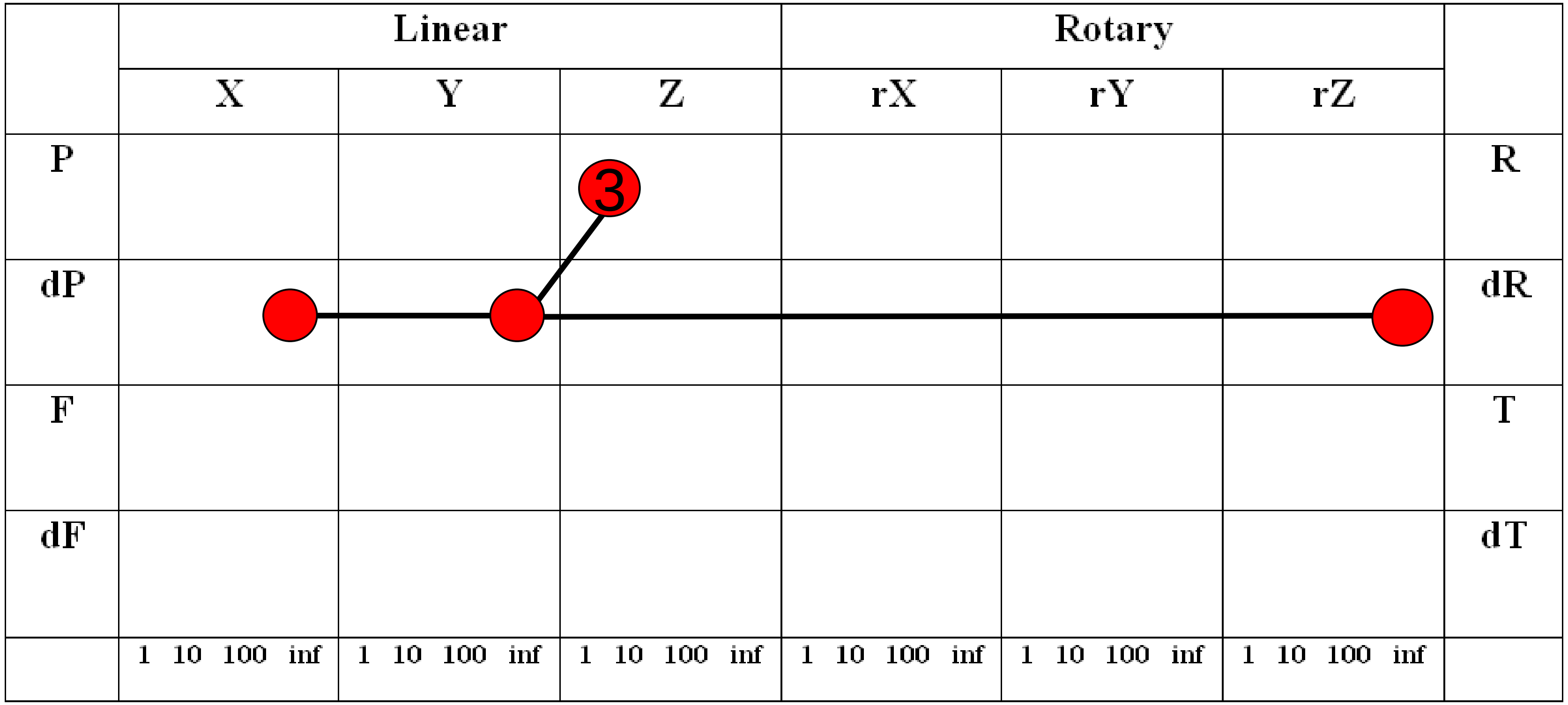
Physical Properties used by Input devices

Example 2: Mouse with 3 Buttons and scroll wheel



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Physical Properties used by Input devices

Mini Exercise: mouse (2 buttons), keyboard with trackpad, joystick

	Linear			Rotary			
	X	Y	Z	rX	rY	rZ	
P							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	

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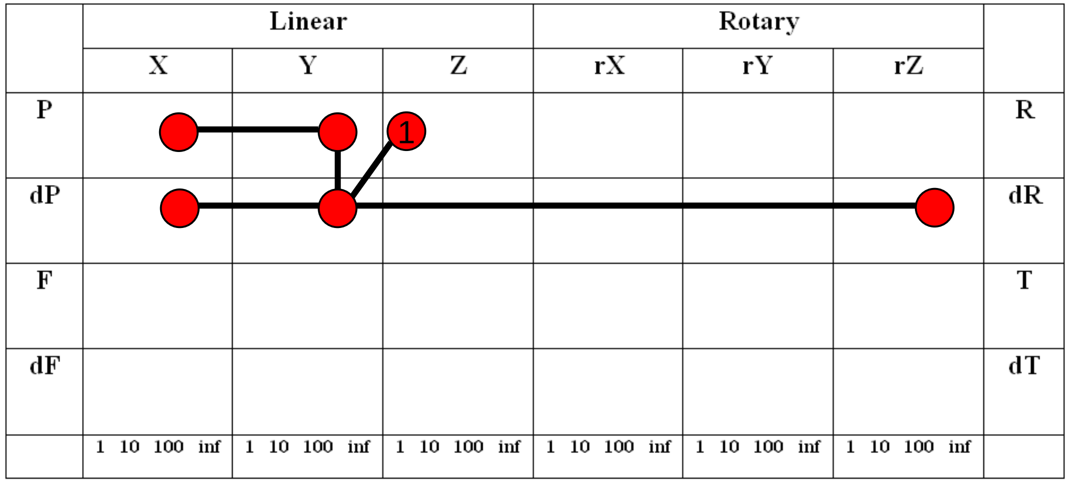
https://dl.acm.org/doi/pdf/10.1145/123078.128726

Physical Properties used by Input devices

Mini Exercise: Invent a device, that…

…allows simultaneous input of the size of rectangle, the orientation and its position on the screen

- What parameters do we need?
- How could such a device look like?



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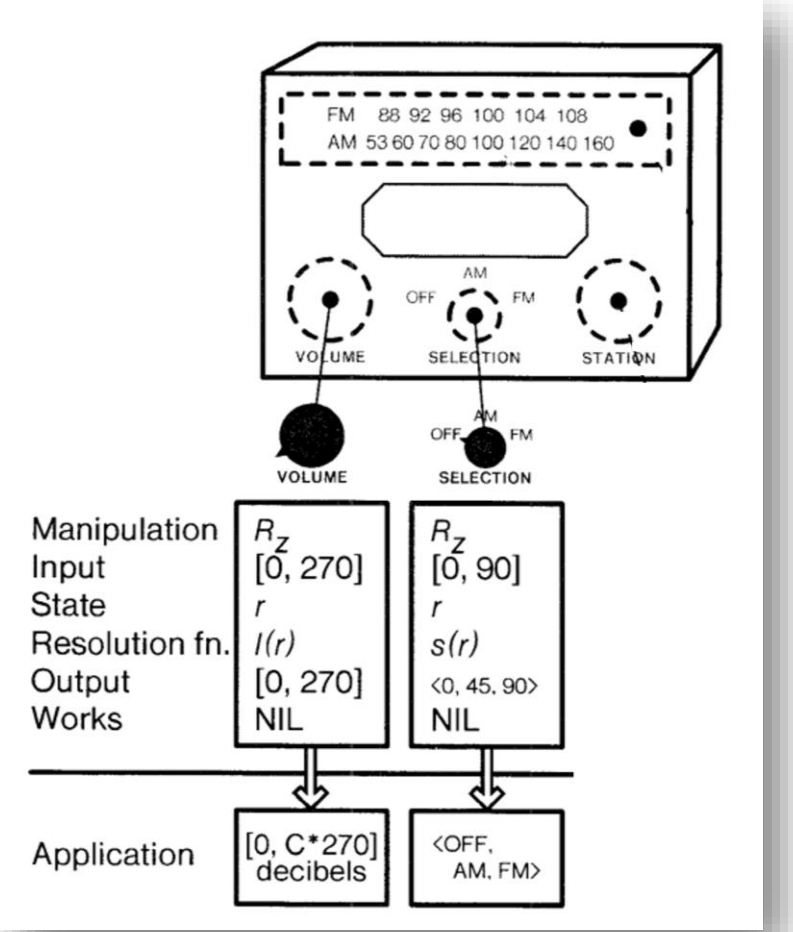
Input Devices as a six-tuple

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



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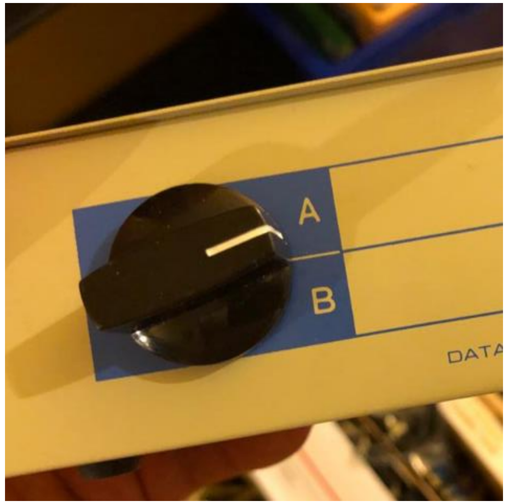
M: R_z (rotation)
In:
S:
R:
Out:
W:

Application:



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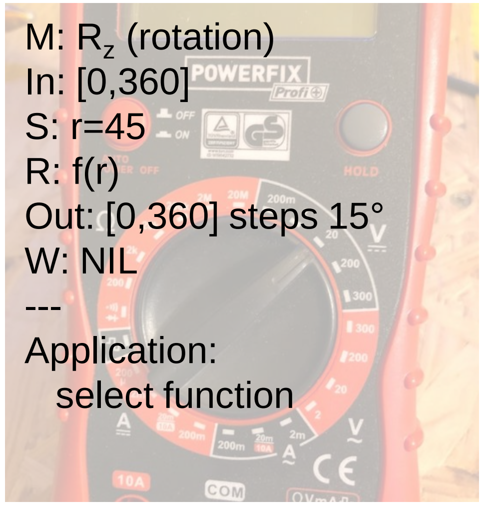
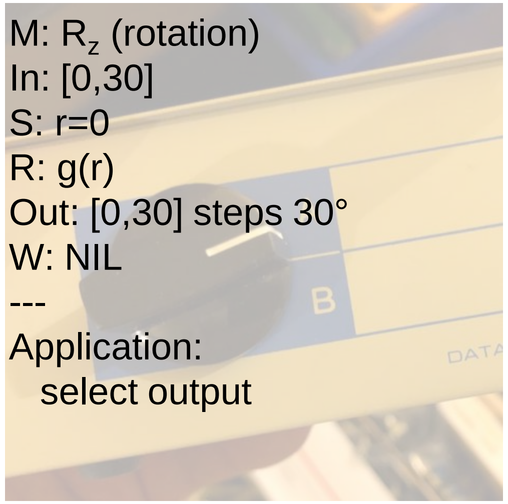


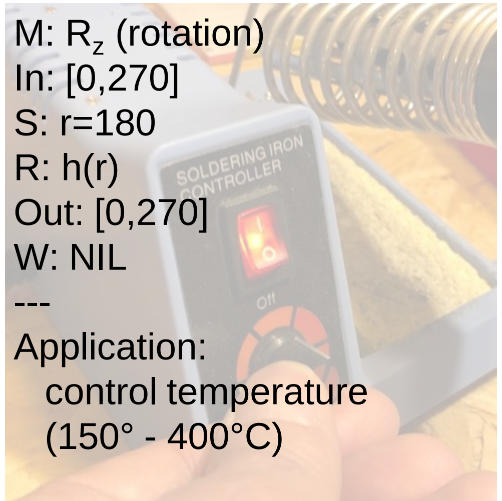
M: R_z (rotation)
In: [0,360]
S: r=45
R: f(r)
Out: [0,360] steps 15°
W: NIL

Application:
select function



M: R_z (rotation)
In: [0,30]
S: r=0
R: g(r)
Out: [0,30] steps 30°
W: NIL

Application:
select output



M: R_z (rotation)
In: [0,270]
S: r=180
R: h(r)
Out: [0,270]
W: NIL

Application:
control temperature
(150° - 400°C)

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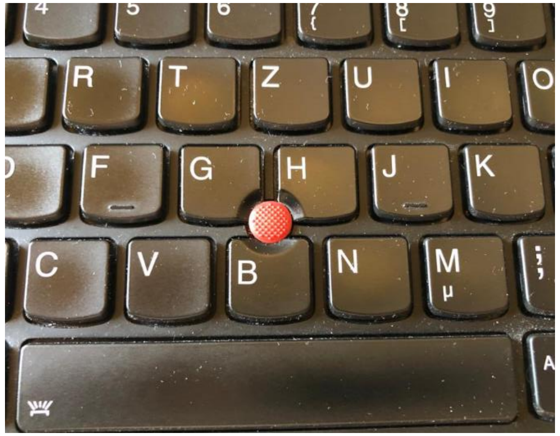
M:
In:
S:
R:
Out:
W:

Application:



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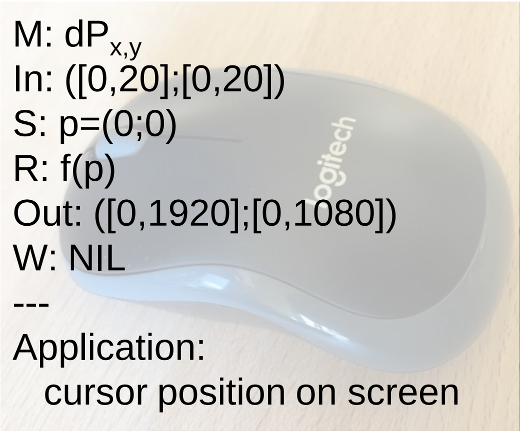

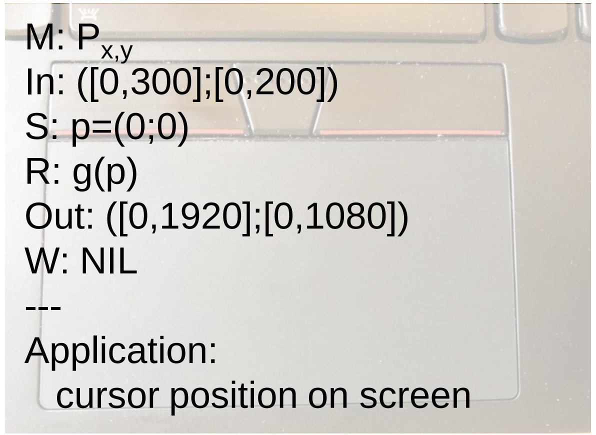

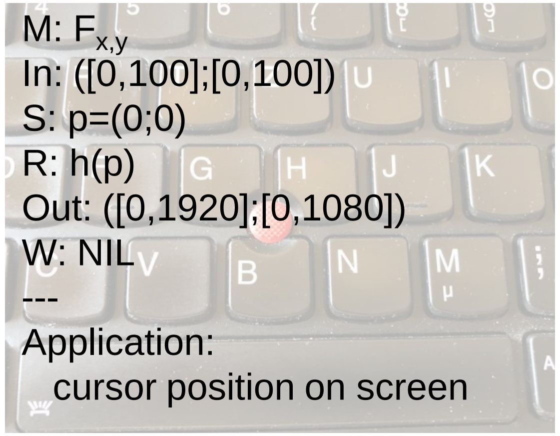

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Which manipulation operator is useful?

Some controllers fit better than others

- Example: mapping a rotary controller to linear movement

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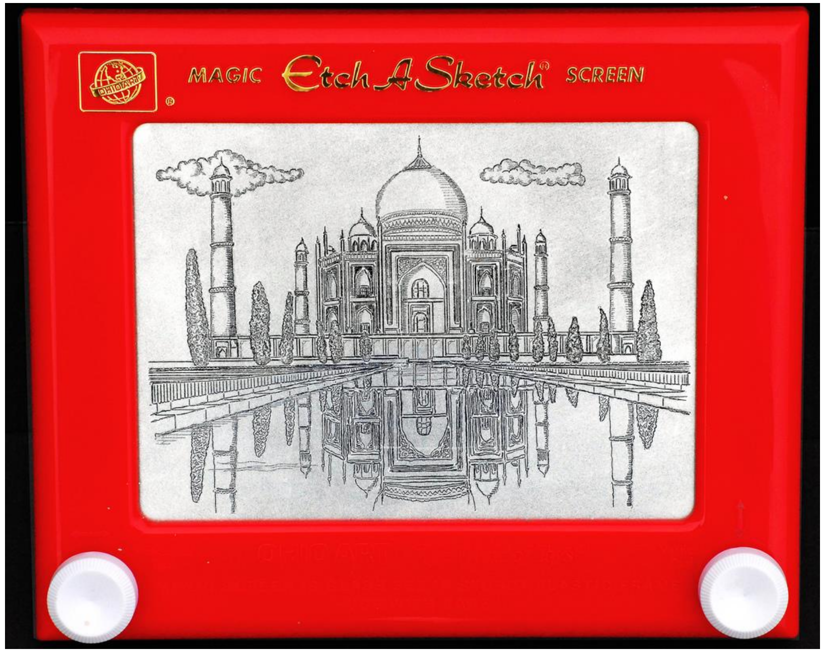

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Effectiveness of Input Devices

Criteria to assess the effectiveness

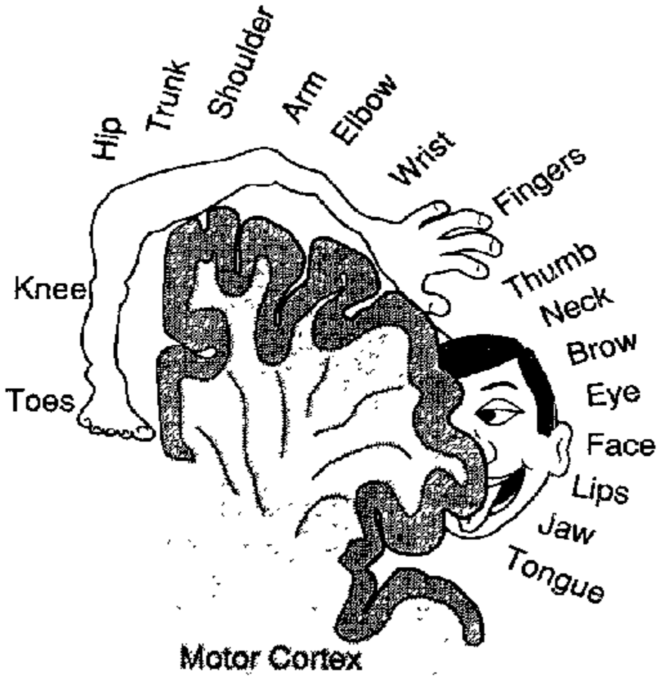
- Pointing speed (device bandwidth)
- Pointing precision
- Errors
- Time to learn
- Time to grasp the device
- User preference
- Desk footprint
- Cost

Card, S. K., Mackinlay, J. D., & Robertson, G. G. (1990, March). The design space of input devices. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 117-124). https://www.cc.gatech.edu/classes/AY2009/cs4470_fall/readings/input-design-space.pdf

Design Space for Input Devices

Card,91

- Footprint
  - Size of the devices on the desk
- Bandwidth
  - **Human** – The bandwidth of the human muscle group to which the transducer is attached
  - **Application** – the precision requirements of the task to be done with the device
  - **Device** – the effective bandwidth of the input device



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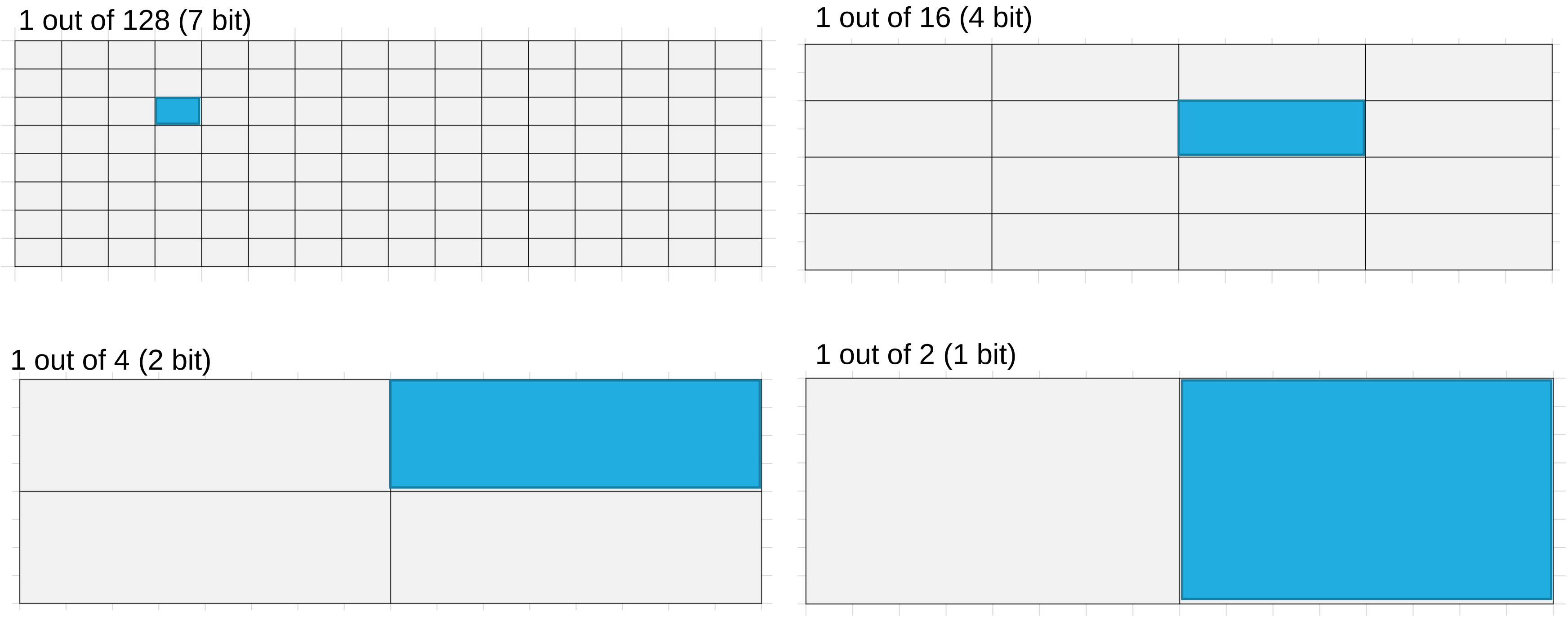
https://dl.acm.org/doi/pdf/10.1145/123078.128726

Bandwidth/Throughput simplified

In bits/s [For more see models and Fitts‘ law]

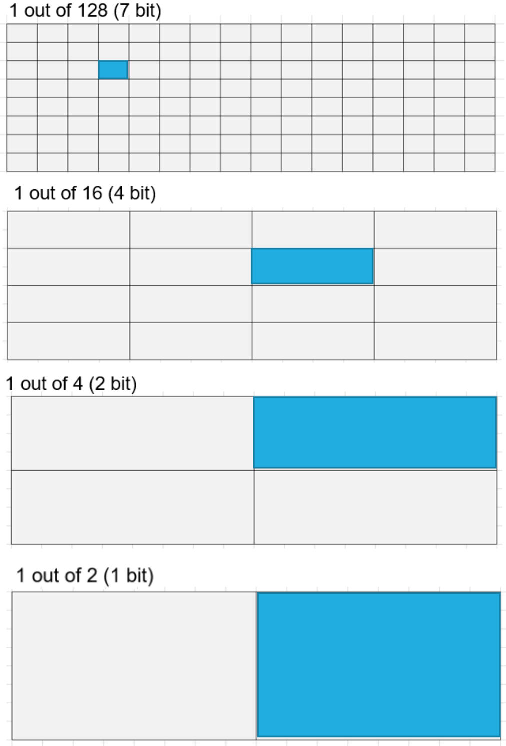
- How difficult is it to click the highlighted field?
- How fast can you do it?



Bandwidth/Throughput simplified

In bits/s [For more see models and Fitts‘ law]

- Throughput is a composite measure
- Takes into account speed and accuracy



$$Throughput = \frac{ID}{MT}$$

$$ID = \log_2\left(\frac{D}{W}+1\right)$$

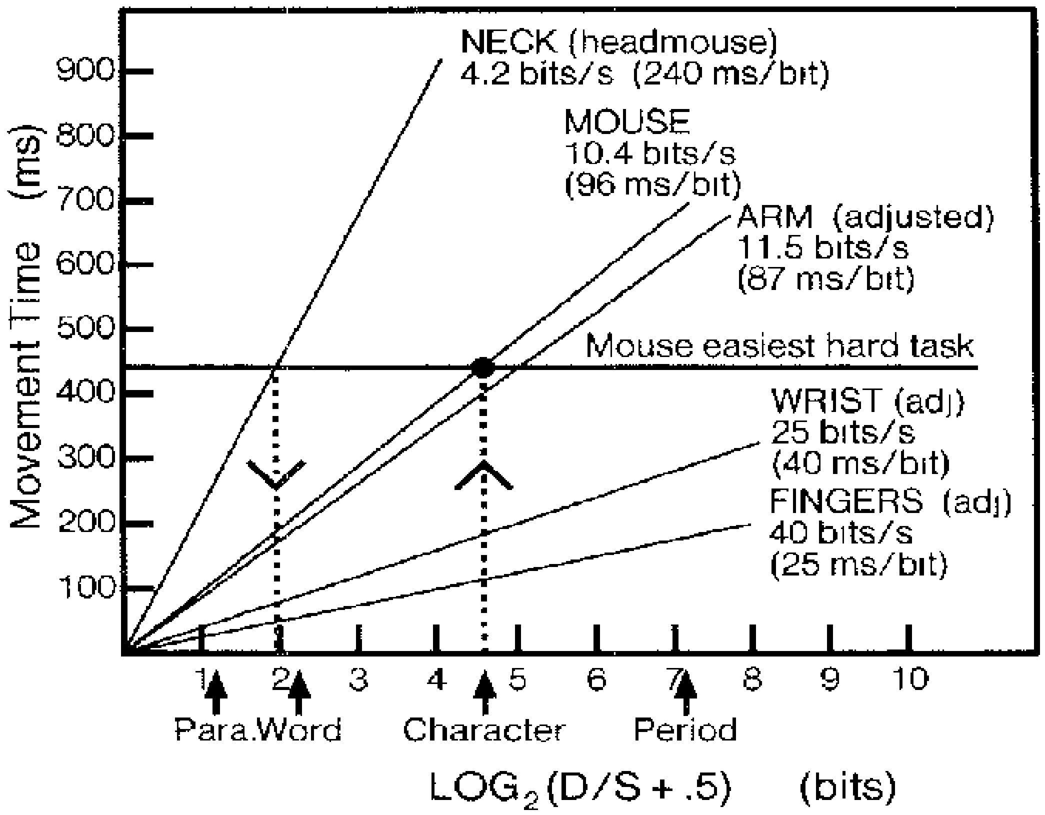
- ID is index of difficulty
- MT is movement time
- D is the distance from the current position to the target
- W represents the size (width) of the target

MacKenzie, I. S., Kauppinen, T., & Silfverberg, M. (2001, March). Accuracy measures for evaluating computer pointing devices. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 9-16).

Movement time for Different Devices / Muscle Groups

Card,91

- Mouse easiest hard task: click on a character (mouse: 10.4 bits/s)
- It is easier to point with your finger (~25 bits/s)
- It is harder to point with your neck (~4.2 bits/s)



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https://dl.acm.org/doi/pdf/10.1145/123078.128726

Did you understand this block?

Can you answer these questions?

- How does Bill Buxton define an input device?
- According to which physical properties do Card et al. classify input devices?
- Draw a trackpoint into the classification of Card et al. How does it differ from a trackpad?
- How can you write the Edge A Sketch user interface in the tuple notification (M, In, S, R, Out, W)?
- Based on which criteria can you assess the effectiveness of an input device?

Reference

- 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
- Buxton, W. (1983). Lexical and Pragmatic Considerations of Input Structures. Computer Graphics, 17 (1), 31-37.
  http://www.billbuxton.com/lexical.html
  http://www.billbuxton.com/input04.Taxonomies.pdf
- Card, S. K., Mackinlay, J. D., & Robertson, G. G. (1990, March). The design space of input devices. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 117-124). https://www.cc.gatech.edu/classes/AY2009/cs4470_fall/readings/input-design-space.pdf
- MacKenzie, I. S., Kauppinen, T., & Silfverberg, M. (2001, March). Accuracy measures for evaluating computer pointing devices. In Proceedings of the SIGCHI conference on Human factors in computing systems (pp. 9-16).

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For more content see: https://hci-lecture.de

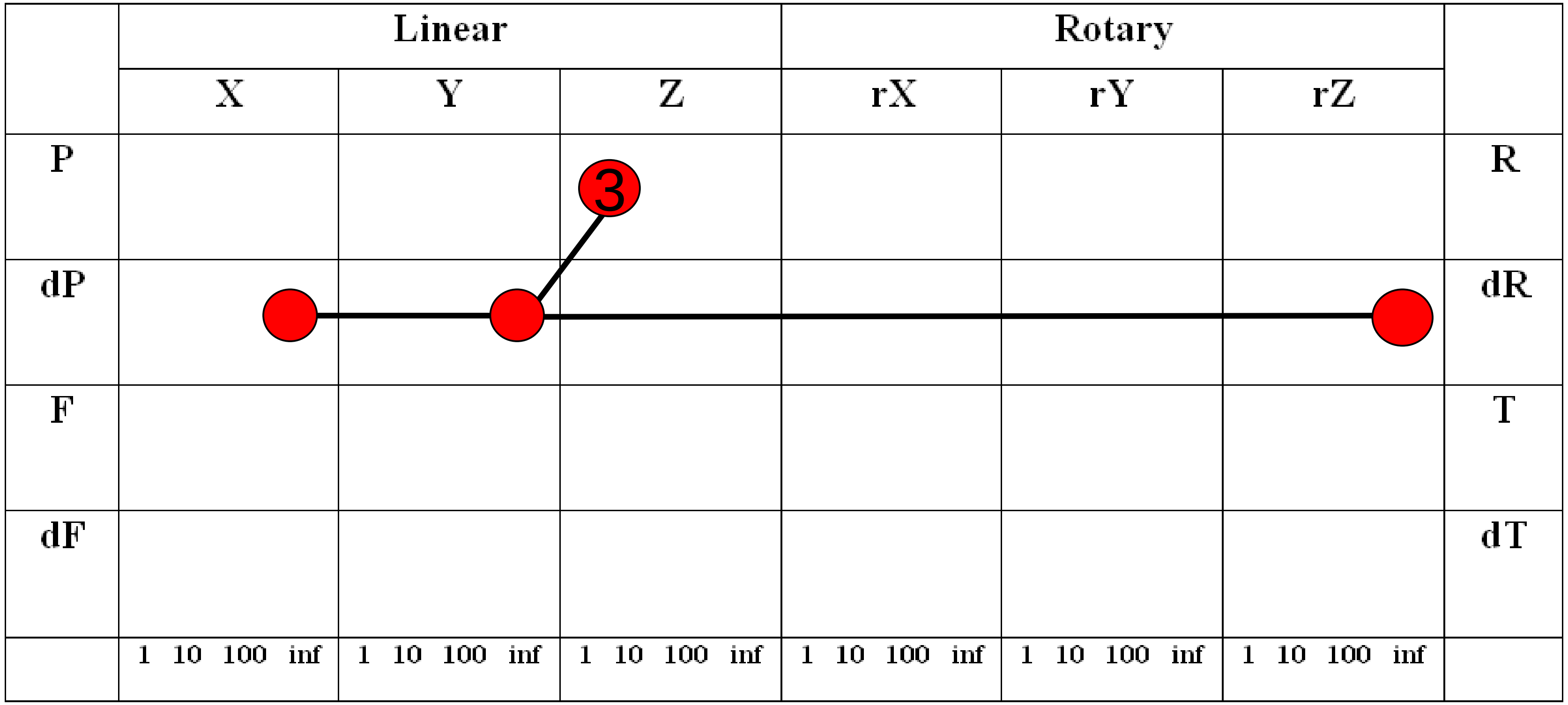
Pointing Devices and Transfer Functions

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



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Input Devices as a six-tuple

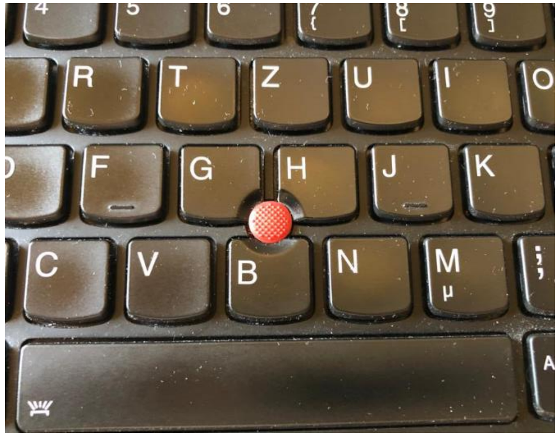
A formal view

(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

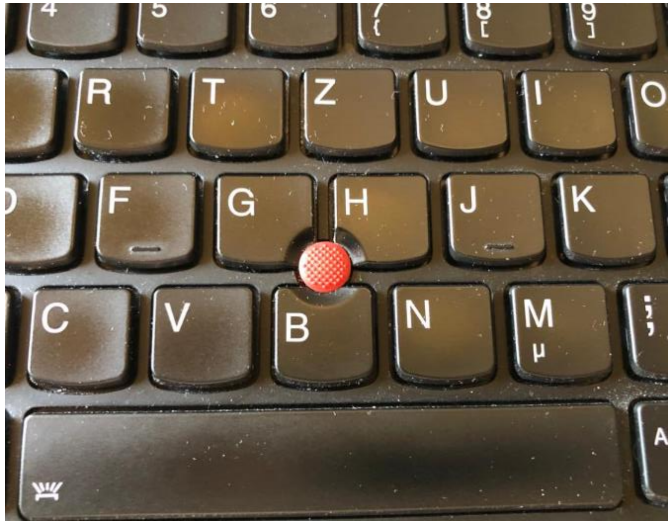
Card, S. K., Mackinlay, J. D. and Robertson, G. G. (1991). A Morphological Analysis of the Design Space of Input Devices. ACM Transactions on Information Systems 9(2 April): 99-122 https://dl.acm.org/doi/pdf/10.1145/123078.128726

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:

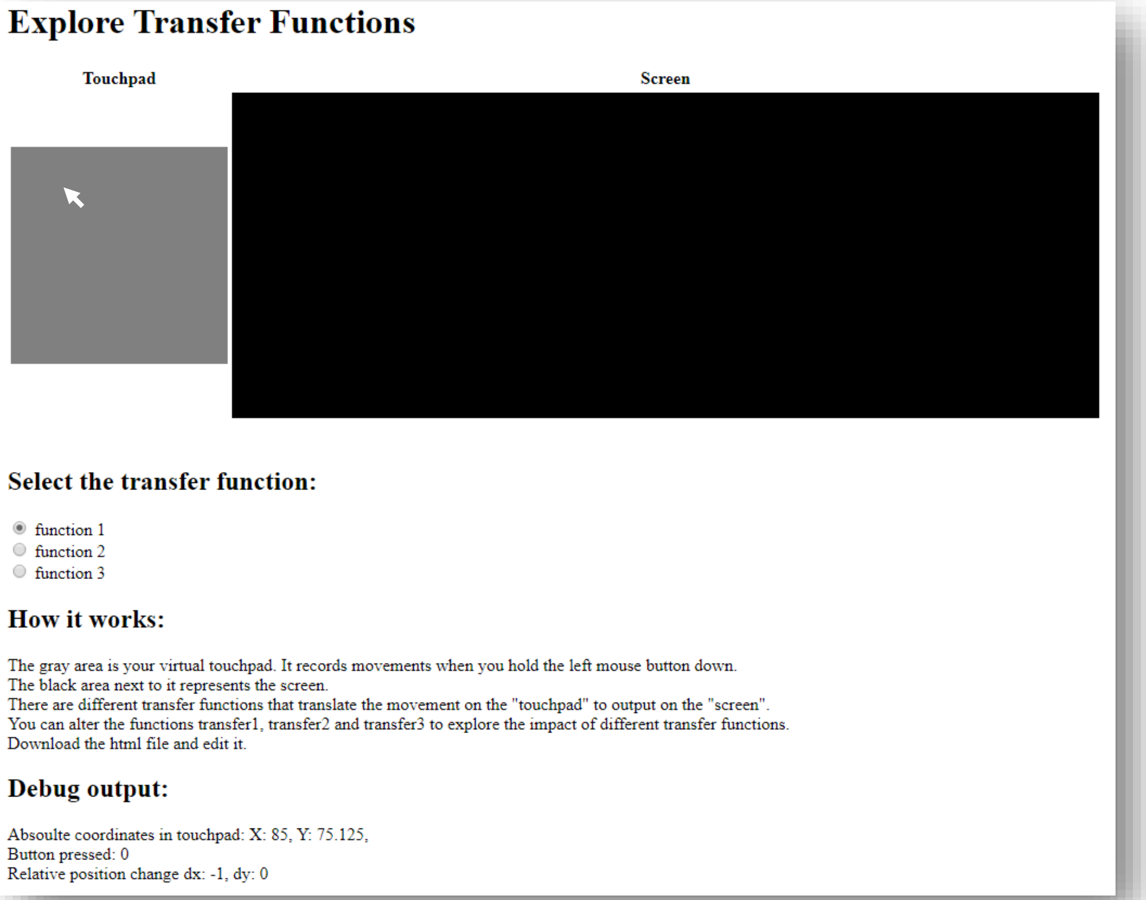
$$(Sx,Sy) = f(Sx, Sy, dx, dy)$$



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)

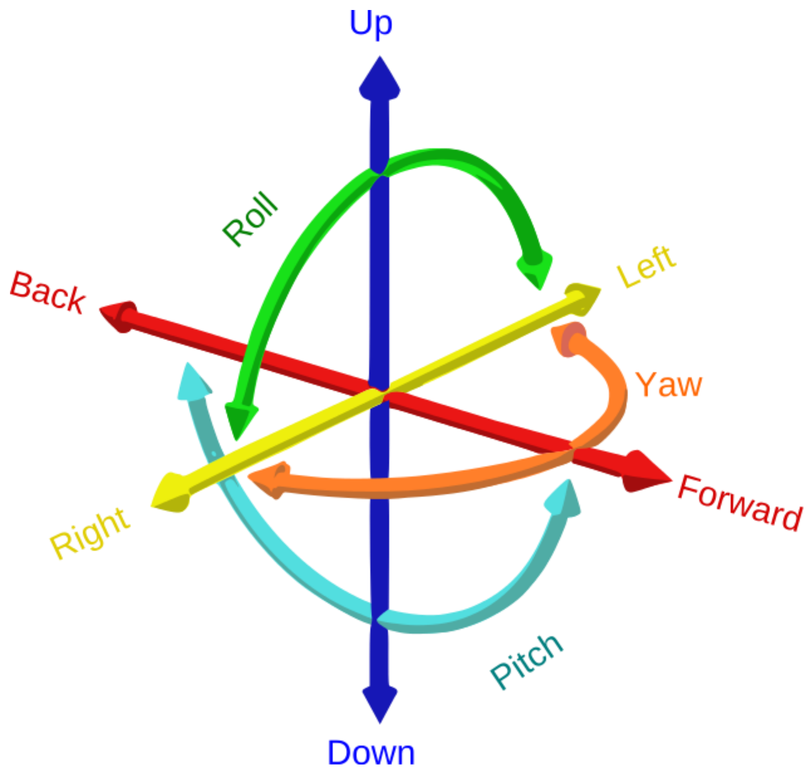
- 1 DOF
  - Slider or Knob to control the volue
- 2 DOF
  - Mouse - you can move it in X and Y
  - Touchpad – you move on it in X and Y
- 3 DOF
  - Mobile phone to rotate an object on the screen
  - Hypothetical device: a mouse that also registers rotation
- 6 DOF
  - Input devices that can control translation (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

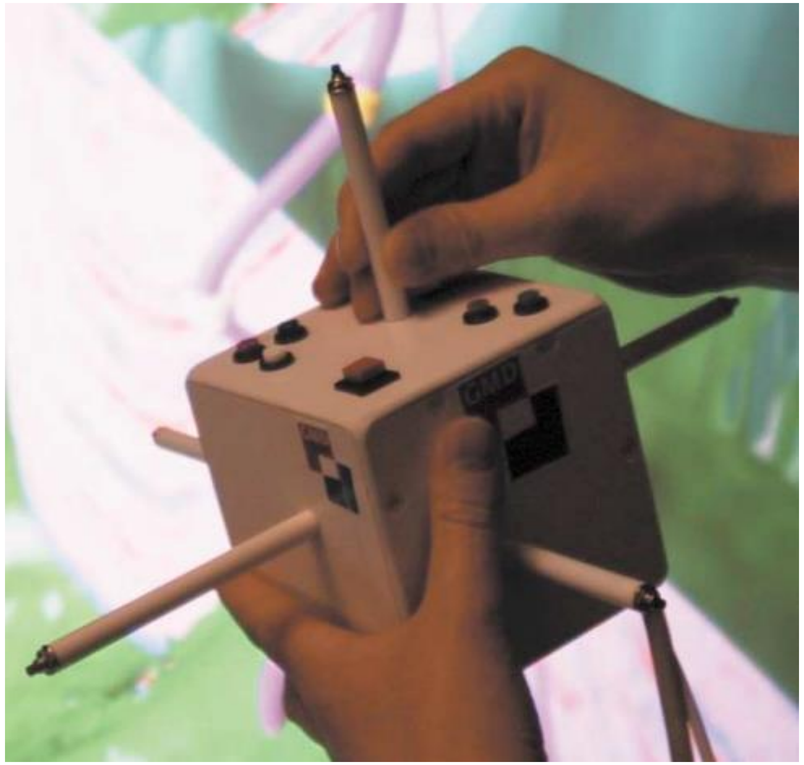
A Clutch for Input Devices?

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.*”

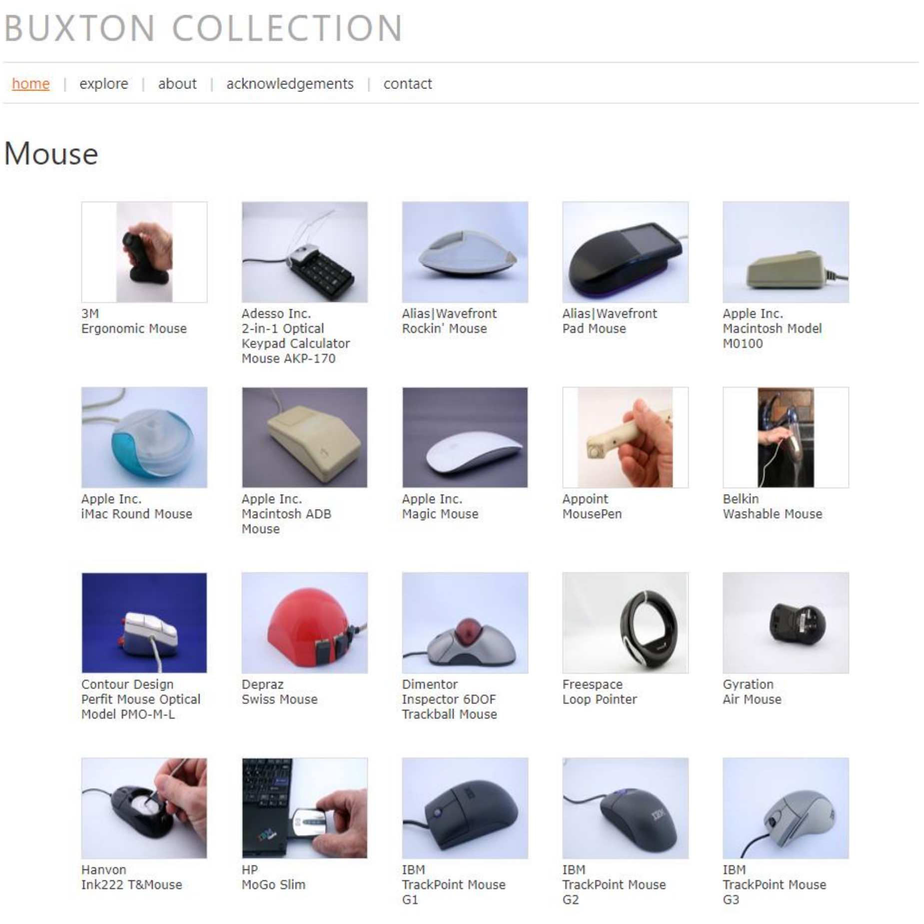
Frohlich, B., Plate, J., Wind, J., Wesche, G., & Gobel, M. (2000). Cubic-mouse-based interaction in virtual environments. *IEEE computer graphics and applications*, *20*(4), 12-15.

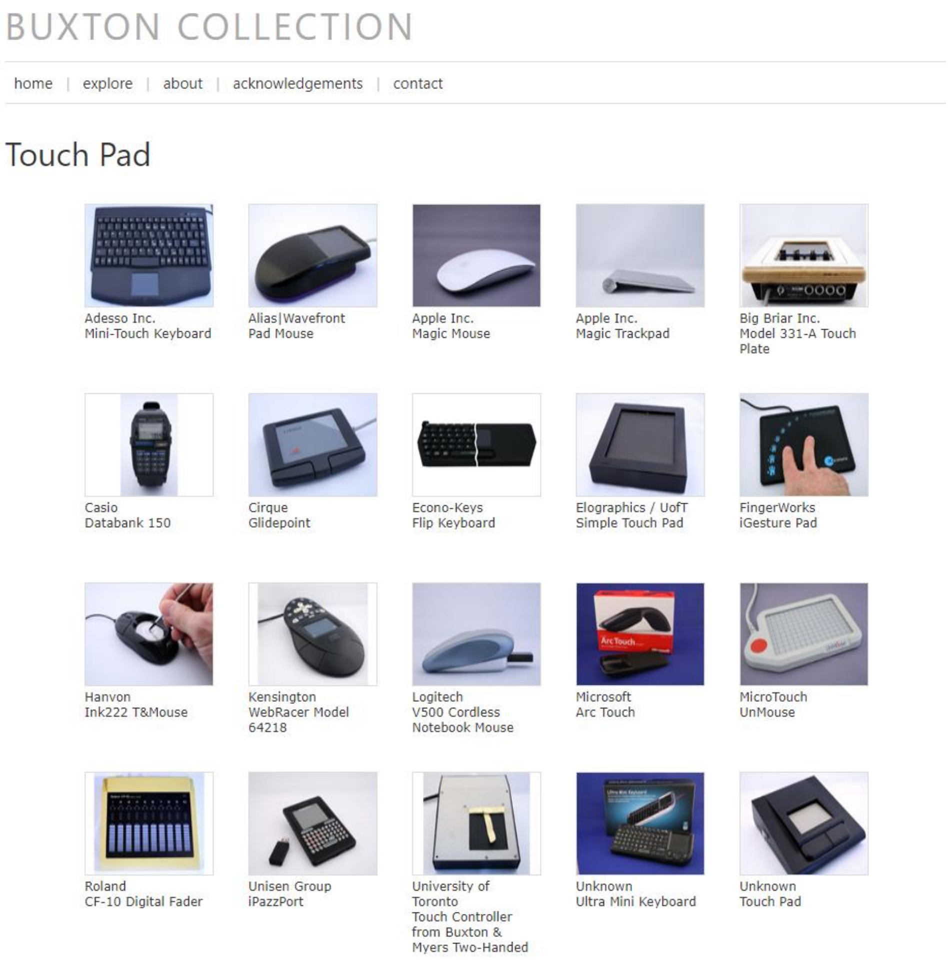
Classification of Pointing devices

- **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





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)

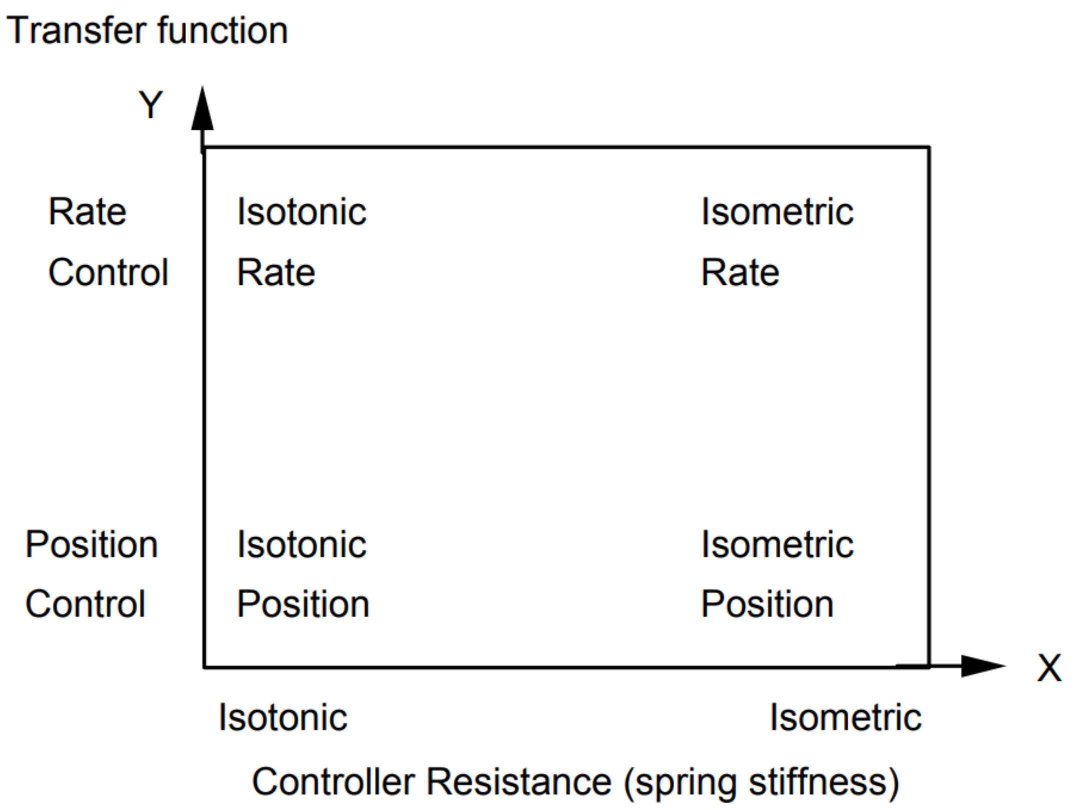
- **Elastic:**
  - Device/handle is moved
  - Device’s resistive force increases with displacement (also called spring-loaded)
  - Device can sense displacement or force
  - Force/displacement is mapped to rate control of the cursor (typical) or to absolute position
- **Viscous**
  - resistance increases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

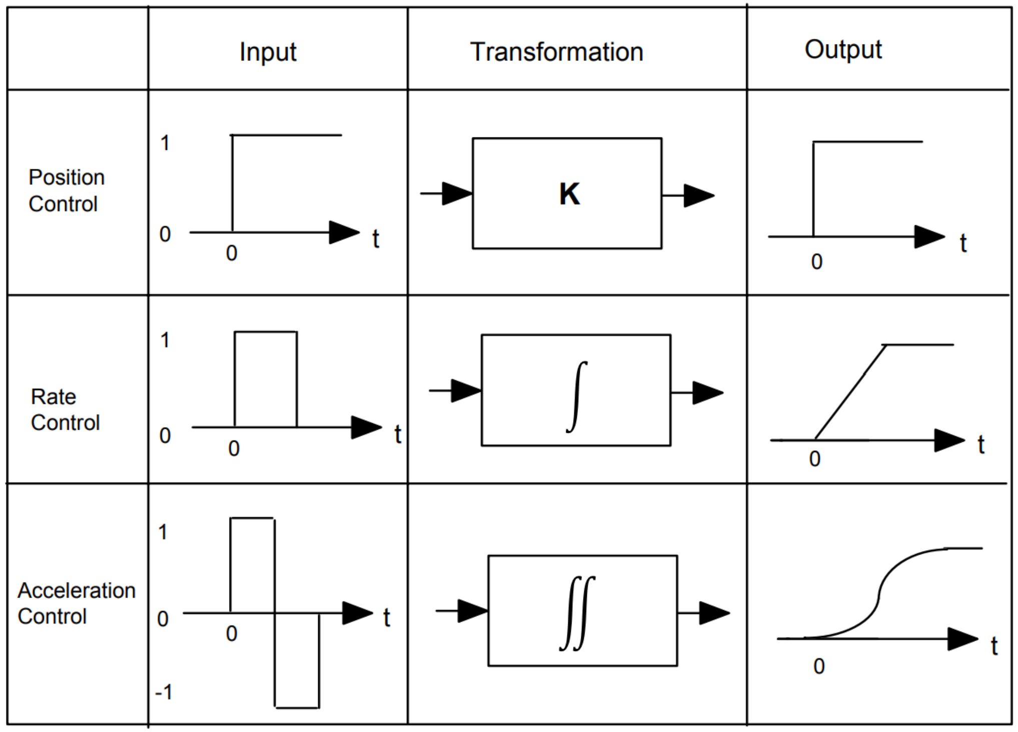


Zhai, Shumin. *Human performance in six degree of freedom input control*. PhD Thesis. University of Toronto, 1996. p12
https://www.talisman.org/~erlkonig/misc/shumin-zhai%5Ehuman-perf-w-6dof-control.pdf

Position versus Rate Control

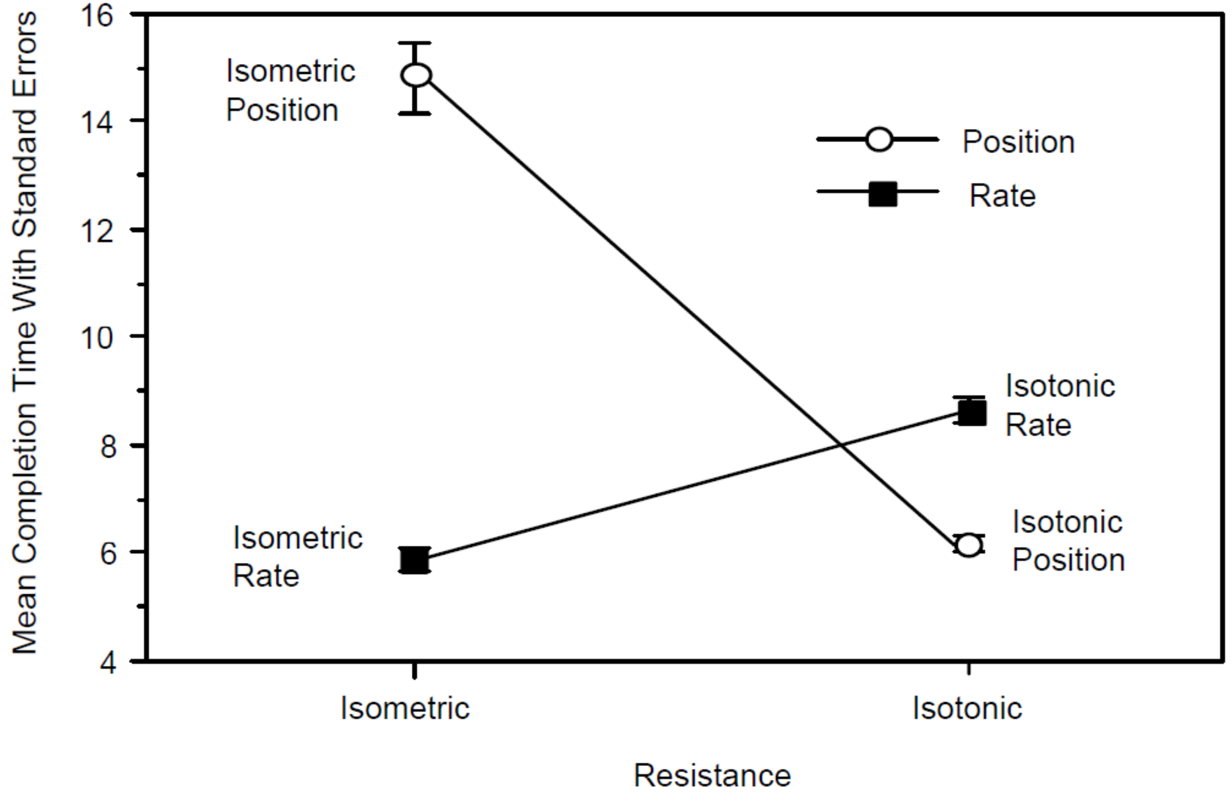
Transfer function (2DOF, 6DOF)

- **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



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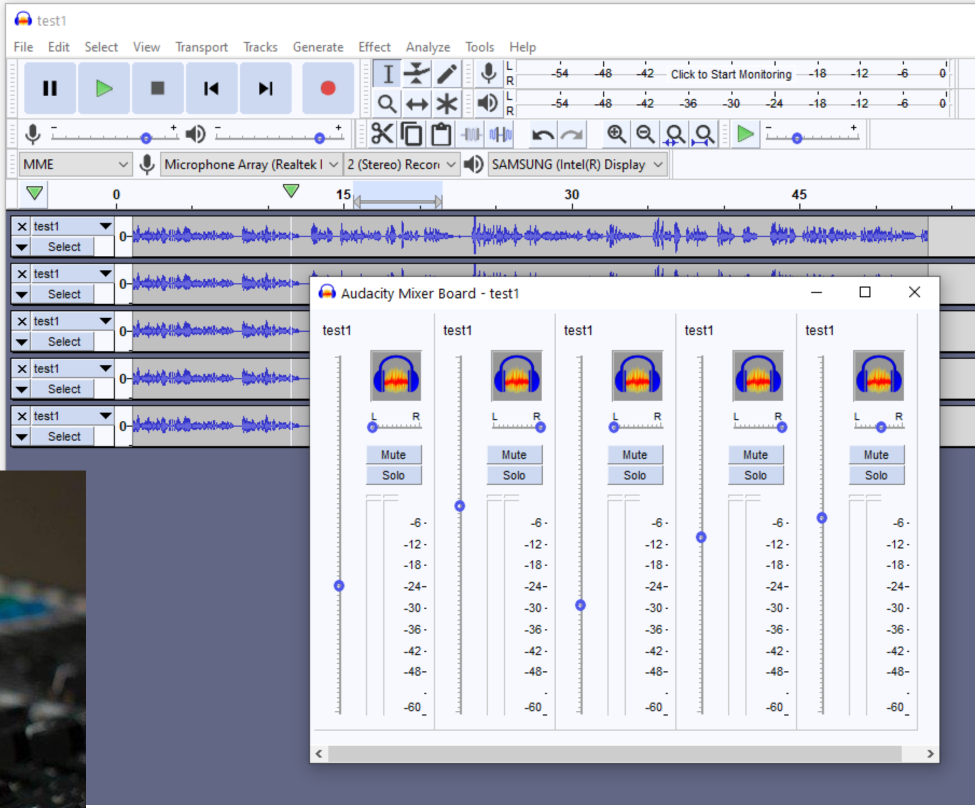
Fundamental Problems with Pointing Devices

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



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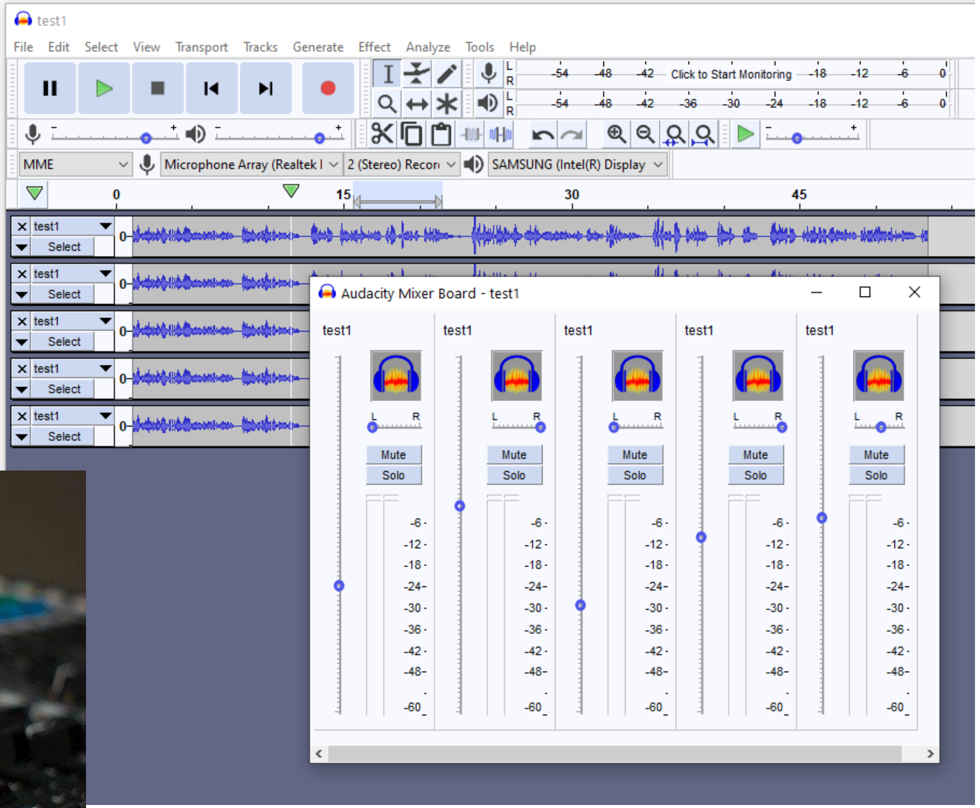

- With a single pointing device most often time multiplexing is implied!
- One operation at the time (e.g. slider can be only be moved sequentially with the mouse)

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
- 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.
- 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
- Buxton, B. https://www.microsoft.com/buxtoncollection/

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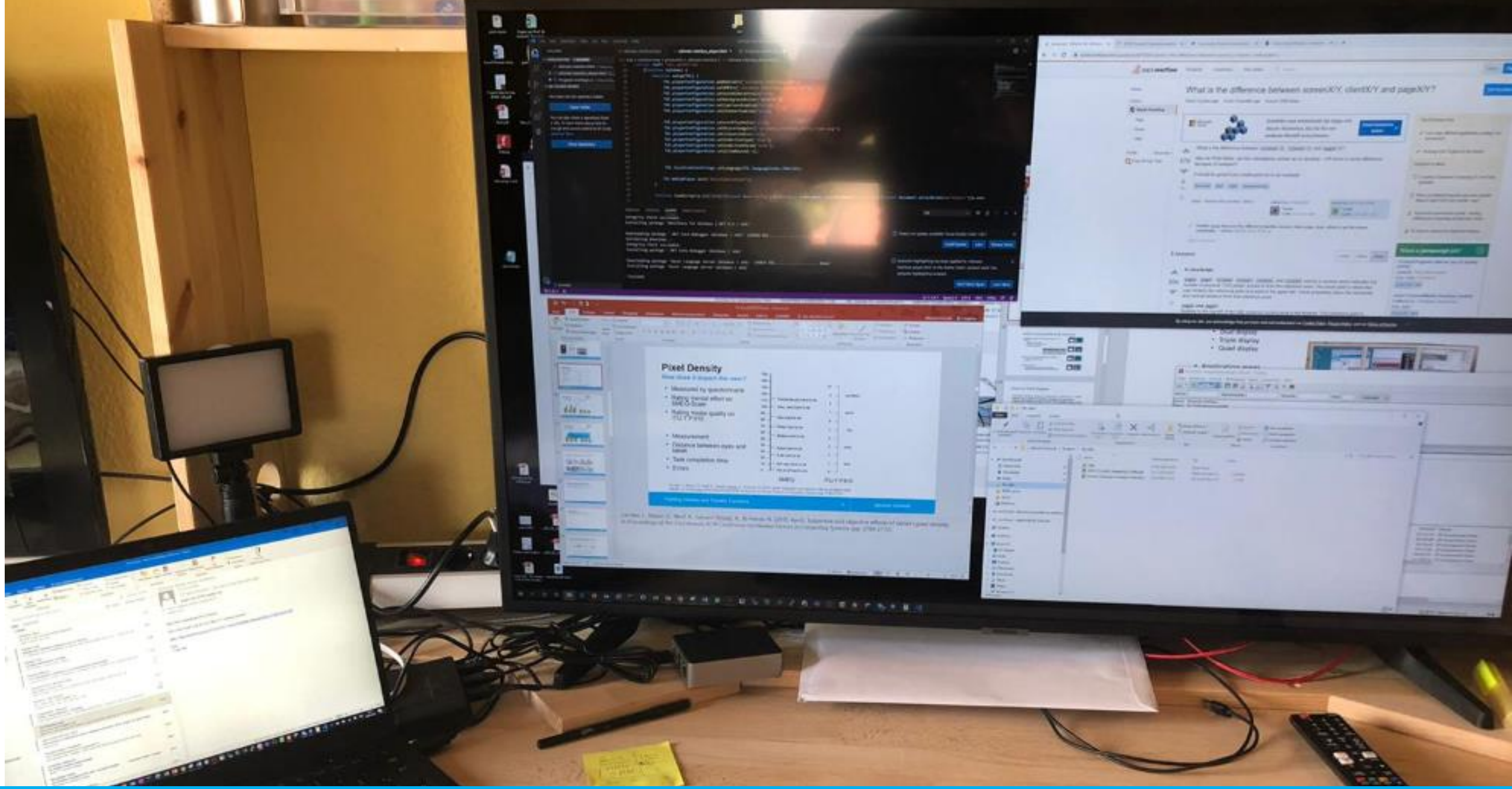

Visual Output

Learning Goals

- Understand …
  - Technical parameters for visual displays
  - The impact of display resolution on the user experience
  - The benefits and issues of large screen setups
- Know
  - How 3D content can be presented
  - About different technologies that can be used to create a real 3D output

Visual Display: Screens

Technical Parameter

- Display technology (e.g. LCD, LED, OLED)
- Size (physical size, often the diagonal in inch, e.g. 65”)
- Aspect ratio (width:height, e.g. 4:3, 16:9, or 21:9)
- Resolution (number of pixel, width x height, e.g. 1920x1080)
- Pixel density (how close are pixels together, size of pixels, pixels per inch, dots per inch, e.g. 320ppi)
- Color depth (how many colors, per color, e.g. 8-bit / 10-bit)
- Color gamut (which colors)
- Mechanisms for color calibration
- Refresh rate (related to images per second, 100Hz, 200Hz)

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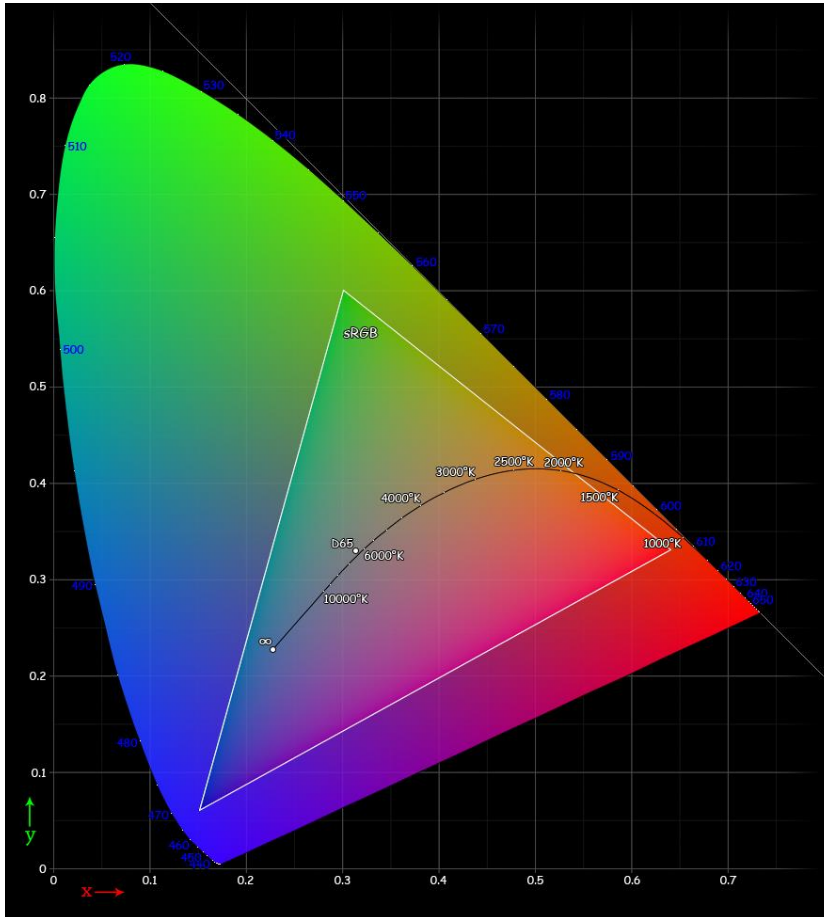
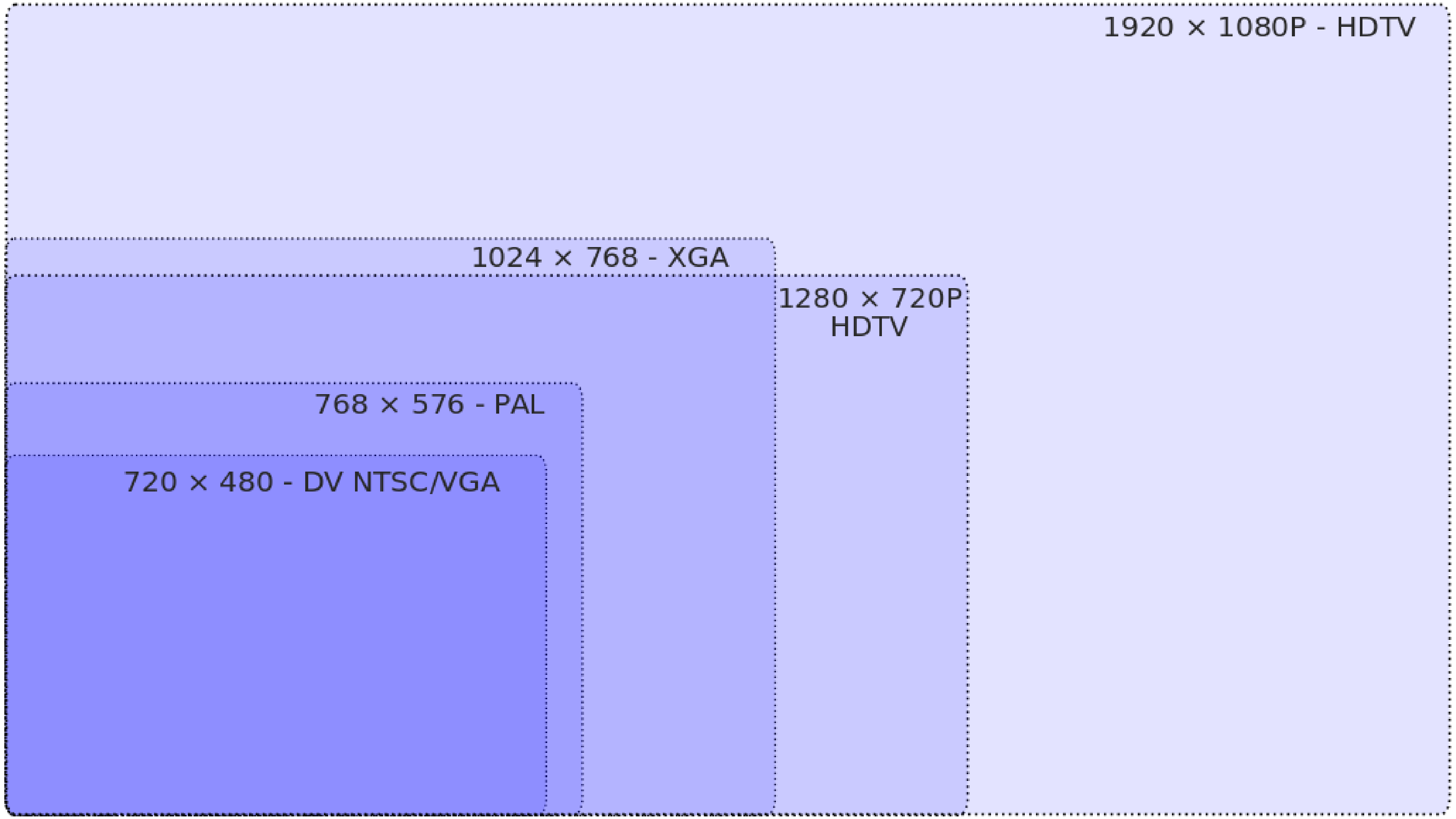


Visual Display: Screens

Aspect ration and resolution examples



“Retina Display”

A resolution that your eyes cannot see the pixels

iPad2 iPad3

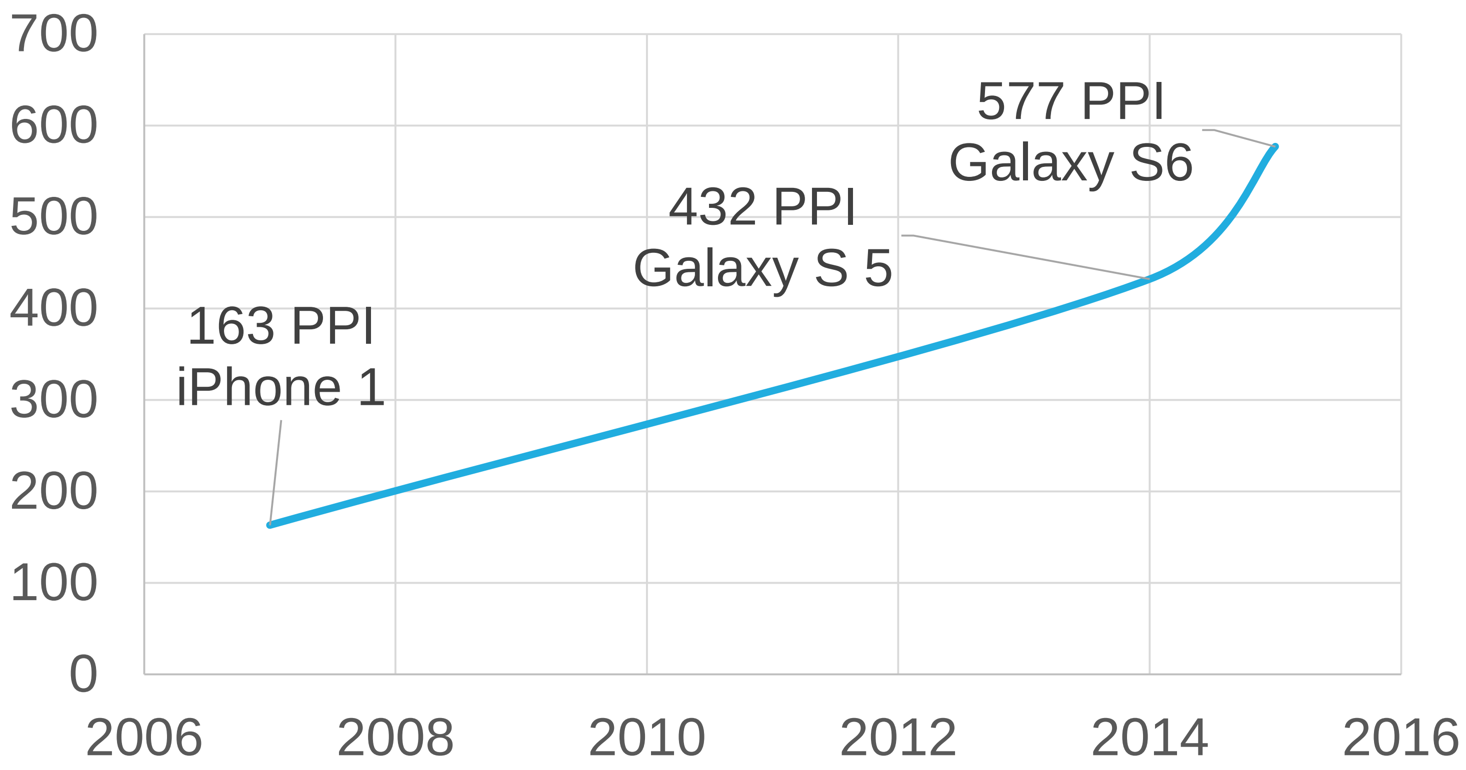
- Example iPad 2 vs. iPad 3
  - 1024 × 768 pixel (132 ppi) vs. 2048 × 1536 pixel (264 ppi)

- Angular resolution of the eye is about 1 arcminute ~ 0.02°
- Assume the following viewing angle:
  - 60° ~ requires 3.000 pixel
  - 120° ~ requires 6.000 pixel

… hence 8K will be enough (with a reasonable viewing distance).

Pixel Density

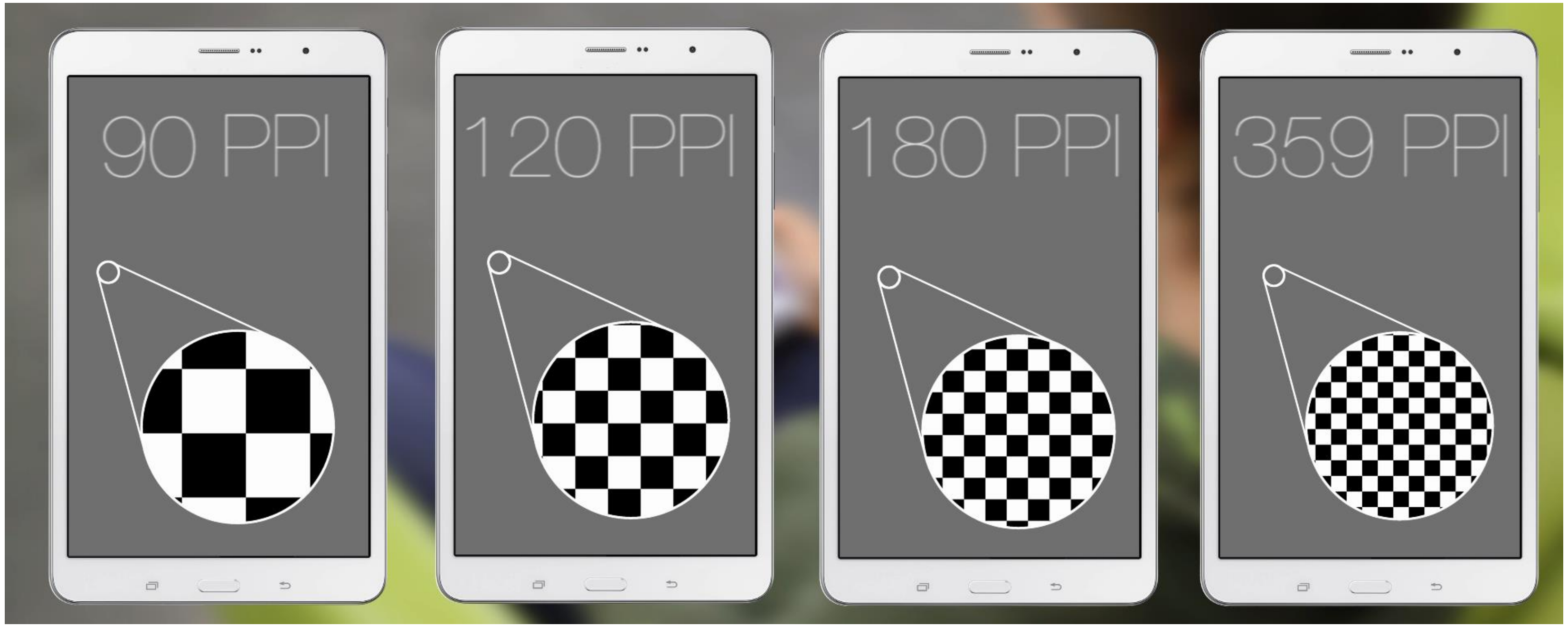
- Traditionally 72dpi (Apple) and 96dpi (Windows)
- Rapid change in the last years



Pixel Density

How does it impact the user?

- Three Tasks: image search, word counting, video analysis
- 16 participants, four Screen Resolutions



Lischke, L., Mayer, S., Wolf, K., Sahami Shirazi, A., & Henze, N. (2015, April). Subjective and objective effects of tablet's pixel density. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 2769-2772).

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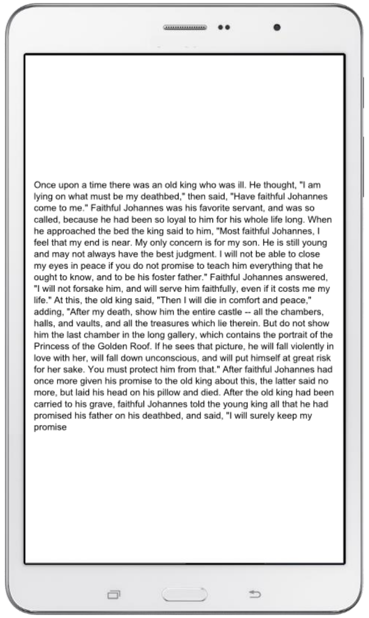

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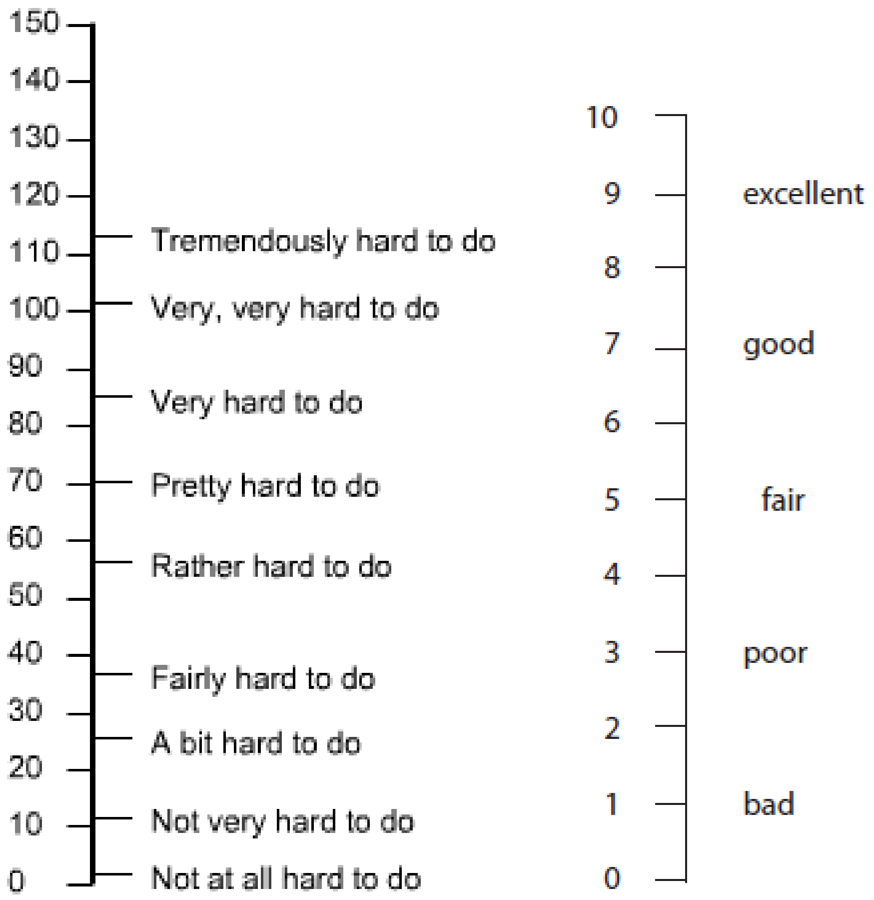
Pixel Density

How does it impact the user?

- Measured by questionnaire
- Rating mental effort on SMEQ-Scale
- Rating media quality on ITU-T P.910

- Measurement
- Distance between eyes and tablet
- Task completion time
- Errors

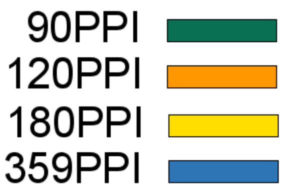


SMEQ ITU-T P.910

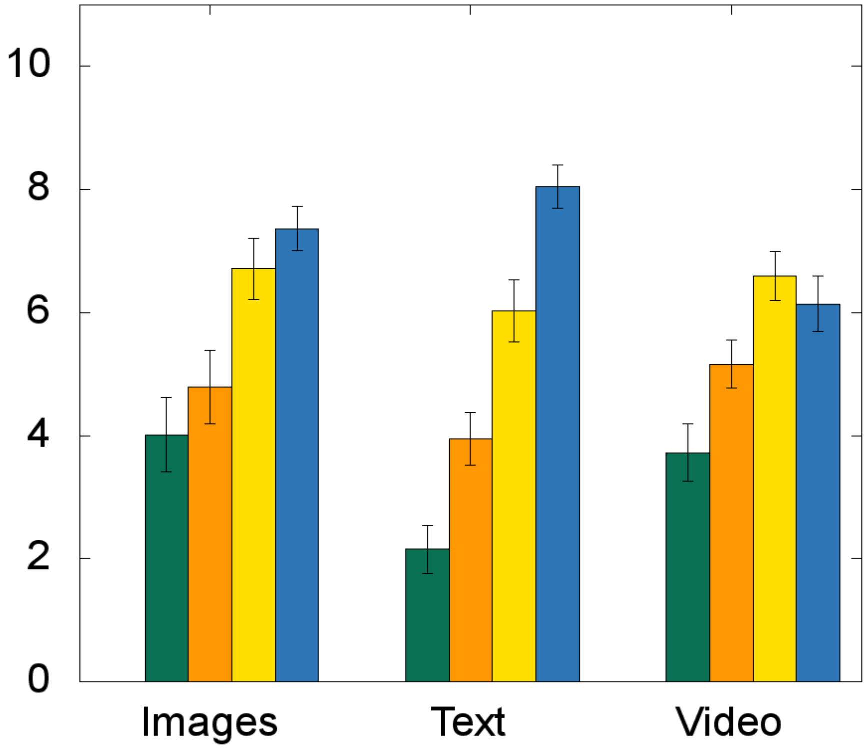
Lischke, L., Mayer, S., Wolf, K., Sahami Shirazi, A., & Henze, N. (2015, April). Subjective and objective effects of tablet's pixel density. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 2769-2772).

Pixel Density

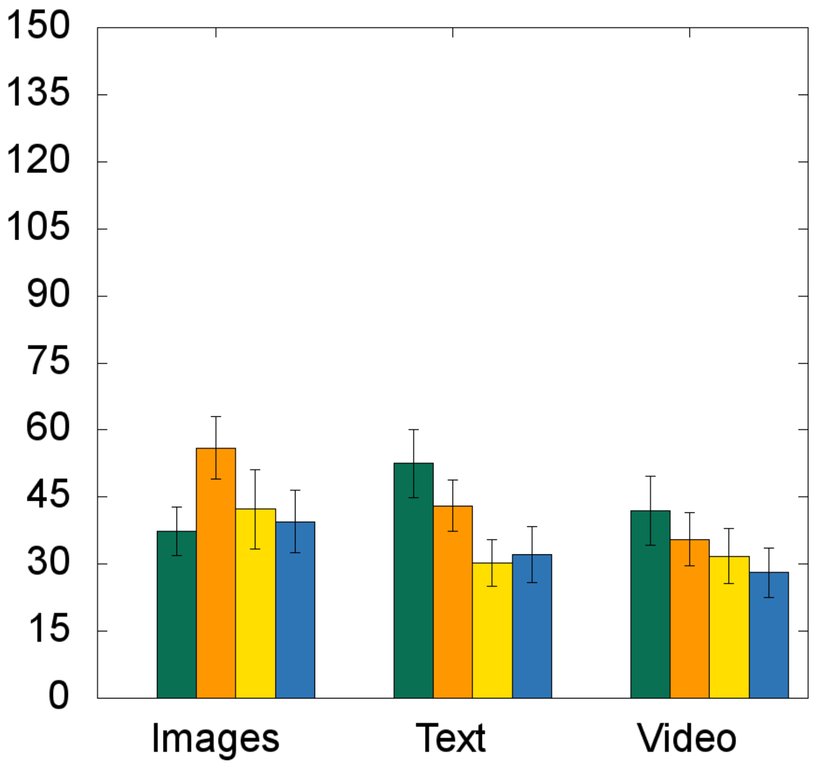
How does it impact the user? Perceived Quality



- Perceived Quality



- Perceived Effort



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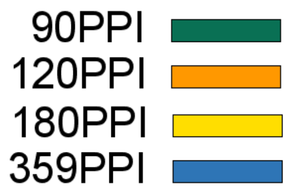
Pixel Density

How does it impact the user? Perceived Quality



- Perceived Quality
- Perceived Effort

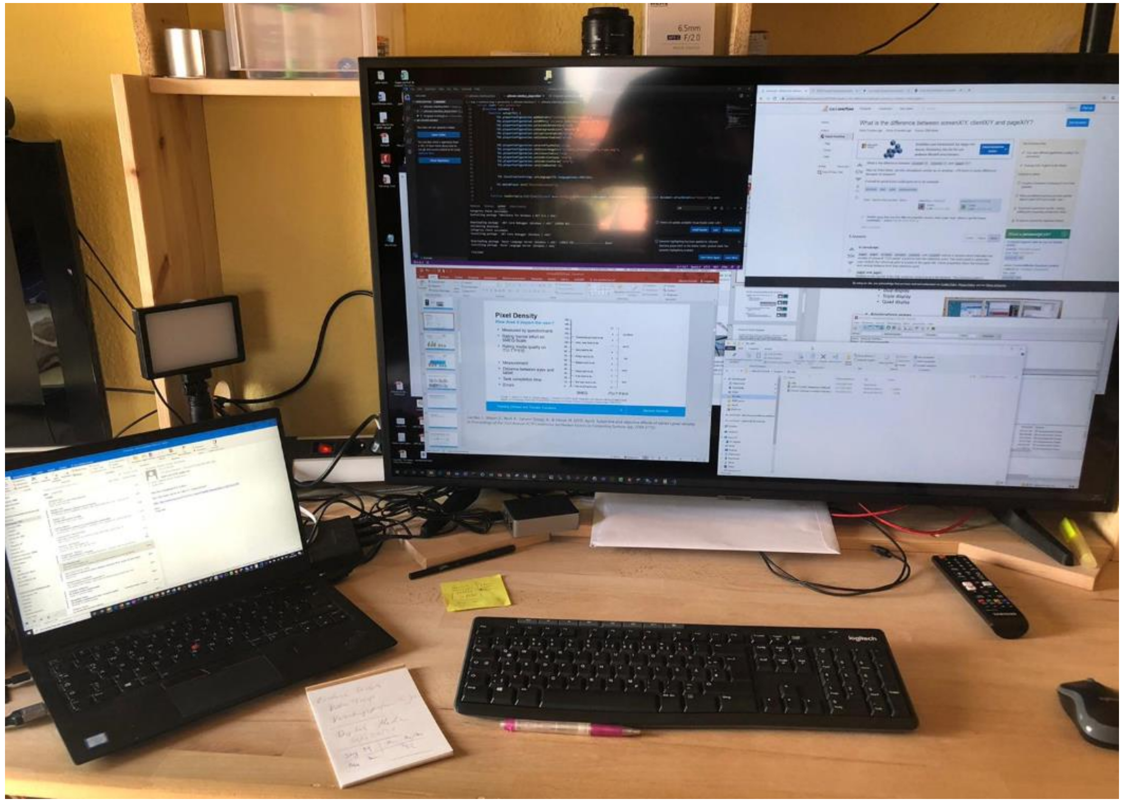
But…
No differences in distance
No differences in task completion time
No differences in error rate

Lischke, L., Mayer, S., Wolf, K., Sahami Shirazi, A., & Henze, N. (2015, April). Subjective and objective effects of tablet's pixel density. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 2769-2772).

Absolute Screen Space is Useful!

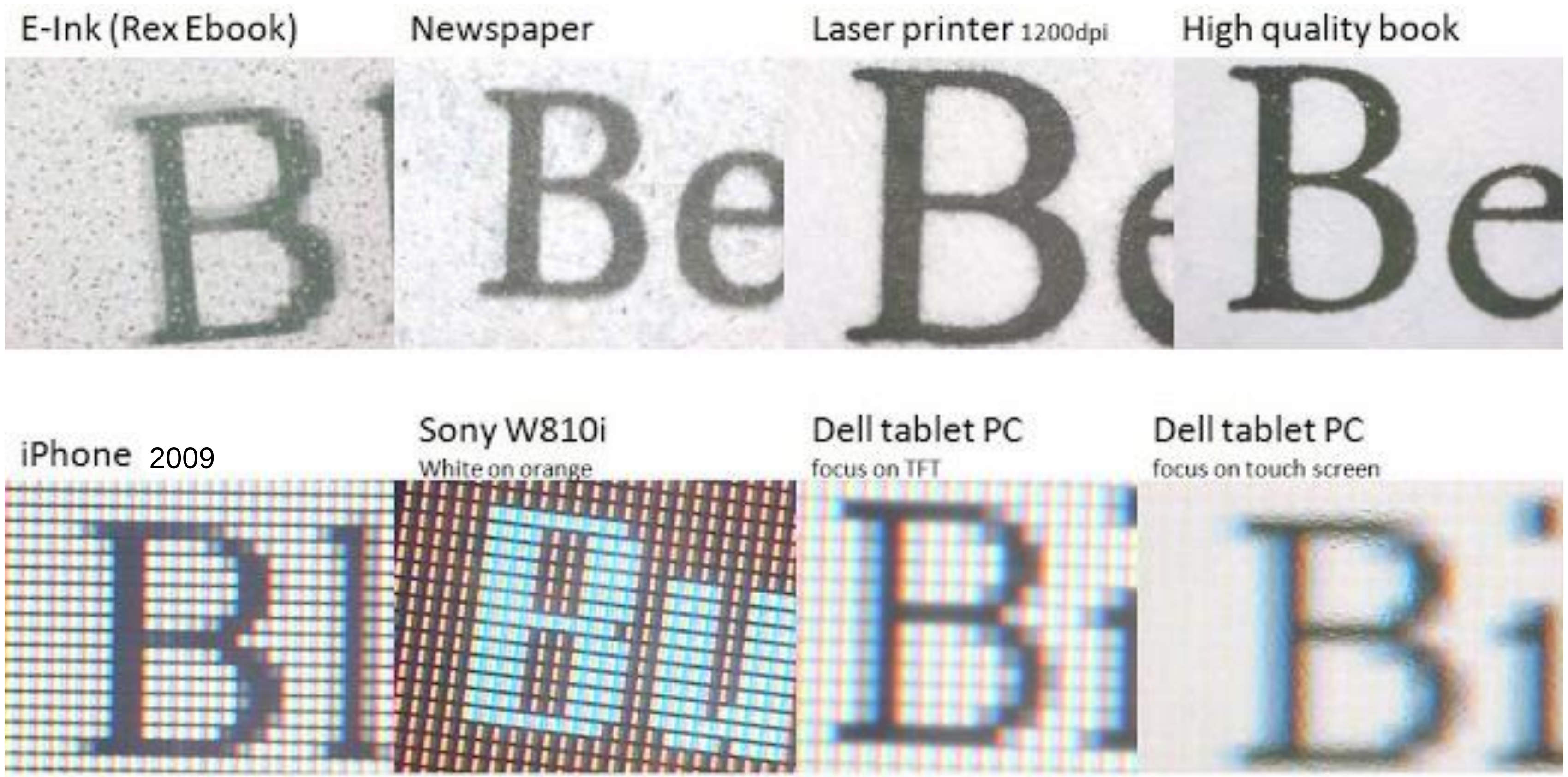
It is easier to move your gaze than to bring windows to the front, move between tabs, or scroll!

- Many tasks benefit: comparison, overview, multiple documents…
- Issues with large screens:
  - Finding the mouse cursor
  - Moving the mouse
- Practices
  - Working local in one region
  - Periphery for other documents



E-Paper vs. Paper Displays, other displays

60x magnification, 10-12 pt font



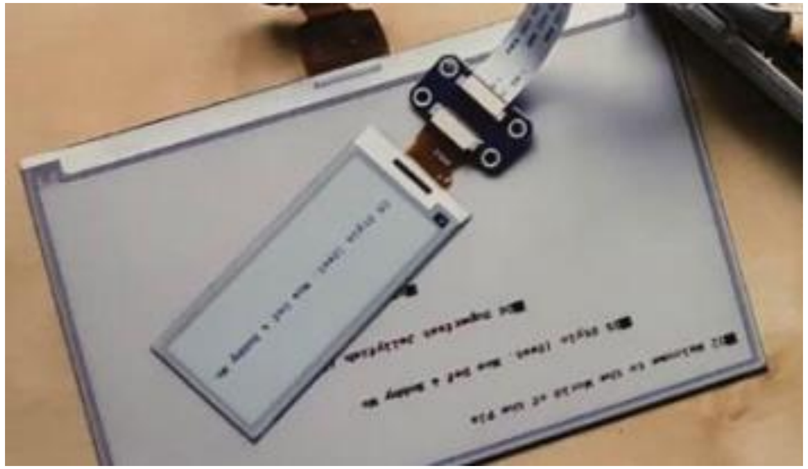
More Visual Display Technologies

Projection

- Key aspects
  - Resolution
  - Brightness (daylight, outdoors)
  - Noise
  - Projection distance
  - Lens and image correction
  - Connectivity
  - Size and weight

E-paper Displays

- Slower update rate
- Black and white or few colors
- Readable outdoors
- Require light (like paper)



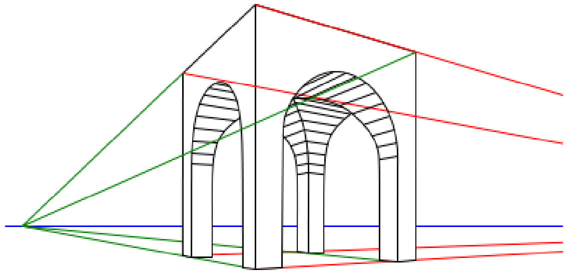
3D-Displays
Requirements

- Different images
- One image per eye

3D View on a 2D Canvas & Displays

Everything on a 2D display is 2D!

- If we see it three dimensional we imagine it…
- Expectations and experience as basis
- Displaying a projection of a 3D model
- “Options to visualize 3D graphics
  - Create a 2D image that the user translates to 3D in his head
  - Provide images (that represent a 3D model from a particular view point) for both eyes
- Monocular cues (perceived with a single eye)
  - Visual angle indicates how much of view object occupies
  - Familiar objects perceived as constant size
  - Overlapping help perception of size and depth



https://de.wikipedia.org/wiki/Perspektive

Real 3D Displays

Real 3D requires an image for each eye

- Real physical objects
- Providing a display for each eye (headset)
- Overlaying images an separating them for each eye
  - Time synchronized, e.g. shutter glasses
  - Polarization filter on projector and glasses
  - Color anaglyph systems
- Autostereoscopic displays
- Volumetric displays

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By Alessandro Nassiri (CC BY-SA) wikimedia.org

User Psoreilly on en.wikipedia (CC BY-SA)

Real 3D Displays

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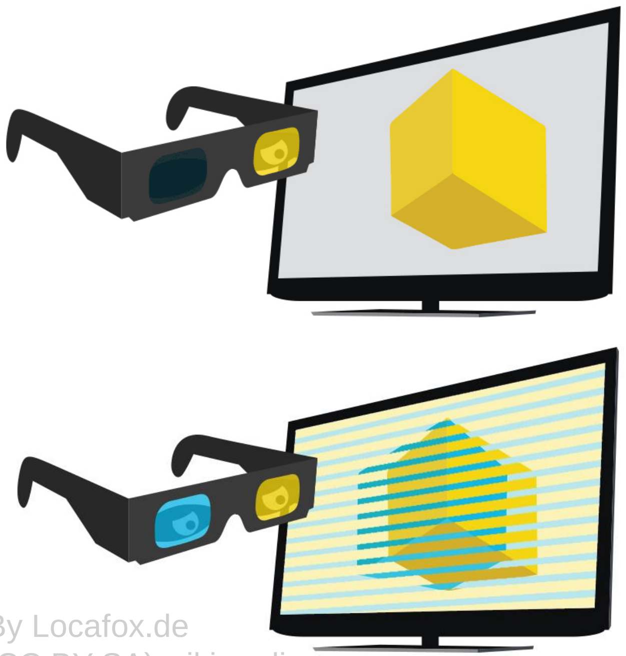

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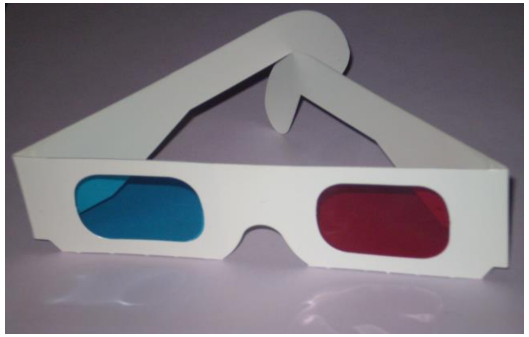

Snaily (CC BY-SA)

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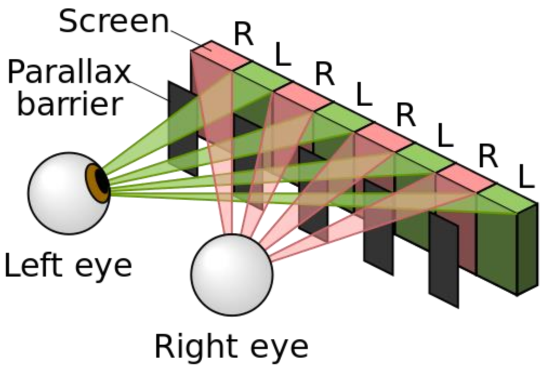

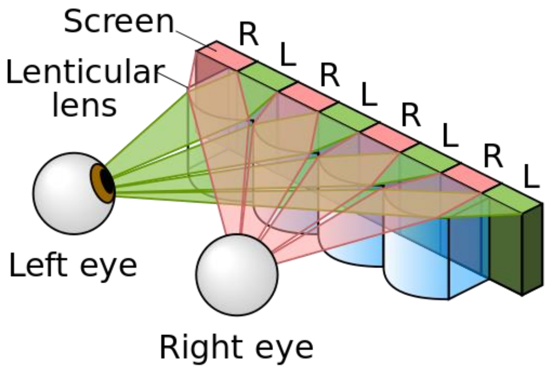

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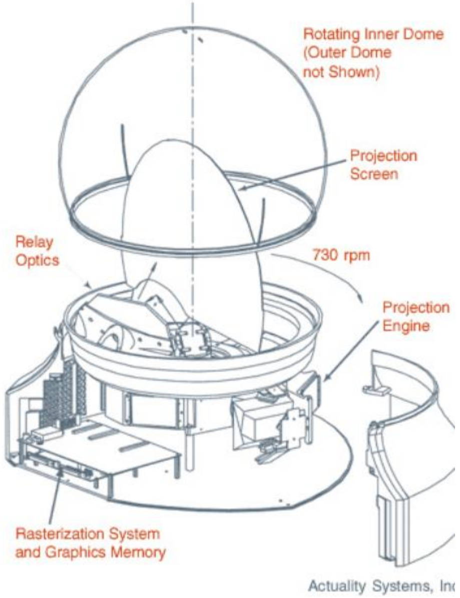
- **Volumetric displays**

Tovi Grossman, Daniel Wigdor, and Ravin Balakrishnan. 2004. Multi-finger gestural interaction with 3d volumetric displays. In Proceedings of the 17th annual ACM symposium on User interface software and technology (UIST '04). ACM, New York, NY, USA, 61-70.



Swept-screen multiplanar volumetric display

198 2-D slices

768 x 768 pixel slice resolution

100 million voxels

24 Hz volume refresh

Viewing Angle: 360º horizontal, 270º vertical

Did you understand this block?

Can you answer these questions?

- Discuss technical parameters that are relevant for visual displays?
- What is the difference between a tablet screen and an e-paper display with regard to different parameters?
- How does an autostereoscopic display work?
- How does the shutter technology work in principle?
- Why can we “see” 3D images on 2D screens?

Reference

- Lischke, L., Mayer, S., Wolf, K., Sahami Shirazi, A., & Henze, N. (2015, April). Subjective and objective effects of tablet's pixel density. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (pp. 2769-2772).
- Tovi Grossman, Daniel Wigdor, and Ravin Balakrishnan. 2004. Multi-finger gestural interaction with 3d volumetric displays. In Proceedings of the 17th annual ACM symposium on User interface software and technology (UIST '04). ACM, New York, NY, USA, 61-70.

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Audio Output

Learning Goals

- Understand …
  - Available audio output technologies
  - Different types of sounds that can be used
  - How information is communicated using audio
  - The basics of sonification
- Know
  - Advantages and disadvantages of using sound for information presentation
  - How data can be mapped to sounds
  - How to design auditory icons and Earcon

Audio Output Technologies

Technologies and Parameter

- Speakers
  - Mono, stereo
  - Multi-speaker system
- Headphones
  - Over-ear / on-ear
  - In-ear / earbuds
  - Bone conduction
- Parameters:
  - Frequency range and Frequency response
  - Volume range
  - Directionality
  - Physical setup and size
  - Connections and data transmission

Audio Output Types

What sound is it?

- Simple sounds
  - Beeps, e.g. warnings
  - Single frequency
- Designed sounds
  - Auditory icons
  - Earcons
  - Composed / Music
- Sonification
  - Turning other media into sound
- Existing sounds
  - Speech, nature, music

Audio Output

How is the sound created on a computer?

- Synthesized audio, e.g.
  - Midi
  - Text to speech
- Playback of captured audio

Auditory Icons vs. Earcons

Icons that you can hear

- **Auditory Icons**

  “informative sounds as an auditory icon” (Gaver, 1986)

  “Gaver’s auditory icons have been used in several systems […] These use **environmental sounds** that have a semantic link with the object or action they represent.” (Brewster et al.,1994)

- **Earcons**

  “We call such **structured sounds** earcons, which are defined as **nonverbal audio messages** used in the user-computer interface to provide information to the user about some computer object, operation, or interaction. Examples of computer objects are files, menus, and prompts. Editing, compiling, and executing are examples of operations. An example of an interaction between an object and an operation is editing a file.” (Blattner et al. 1989)

-Gaver, W. W. (1986). Auditory icons: Using sound in computer interfaces. *Human-computer interaction*, *2*(2), 167-177.
-Brewster, Stephen A., Peter C. Wright, and Alastair DN Edwards. "A detailed investigation into the effectiveness of earcons." SANTA FE INSTITUTE STUDIES IN THE SCIENCES OF COMPLEXITY-PROCEEDINGS VOLUME-. Vol. 18. ADDISON-WESLEY PUBLISHING CO, 1994.
-Blattner, M. M., Sumikawa, D. A., & Greenberg, R. M. (1989). Earcons and icons: Their structure and common design principles. Human–Computer Interaction, 4(1), 11-44.

Auditory Icons

Bill Gaver, 1986

- Sound vs. Vision

	TIME	SPACE
SOUND	**Sound exists in time.** • Good for display of changing events. • Available for a limited time.	**Sound exists over space.** • Need not face source. • A limited number of messages can be displayed at once.
VISION	**Visual objects exist over time.** • Good for display of static objects. • Can be sampled over time.	**Visual objects exist in space.** • Must face source. • Messages can be spatially distributed.

Gaver, W. W. (1986). Auditory icons: Using sound in computer interfaces. *Human-computer interaction*, *2*(2), 167-177.

Auditory Icons

Bill Gaver, 1986

- Example: Deleting a File

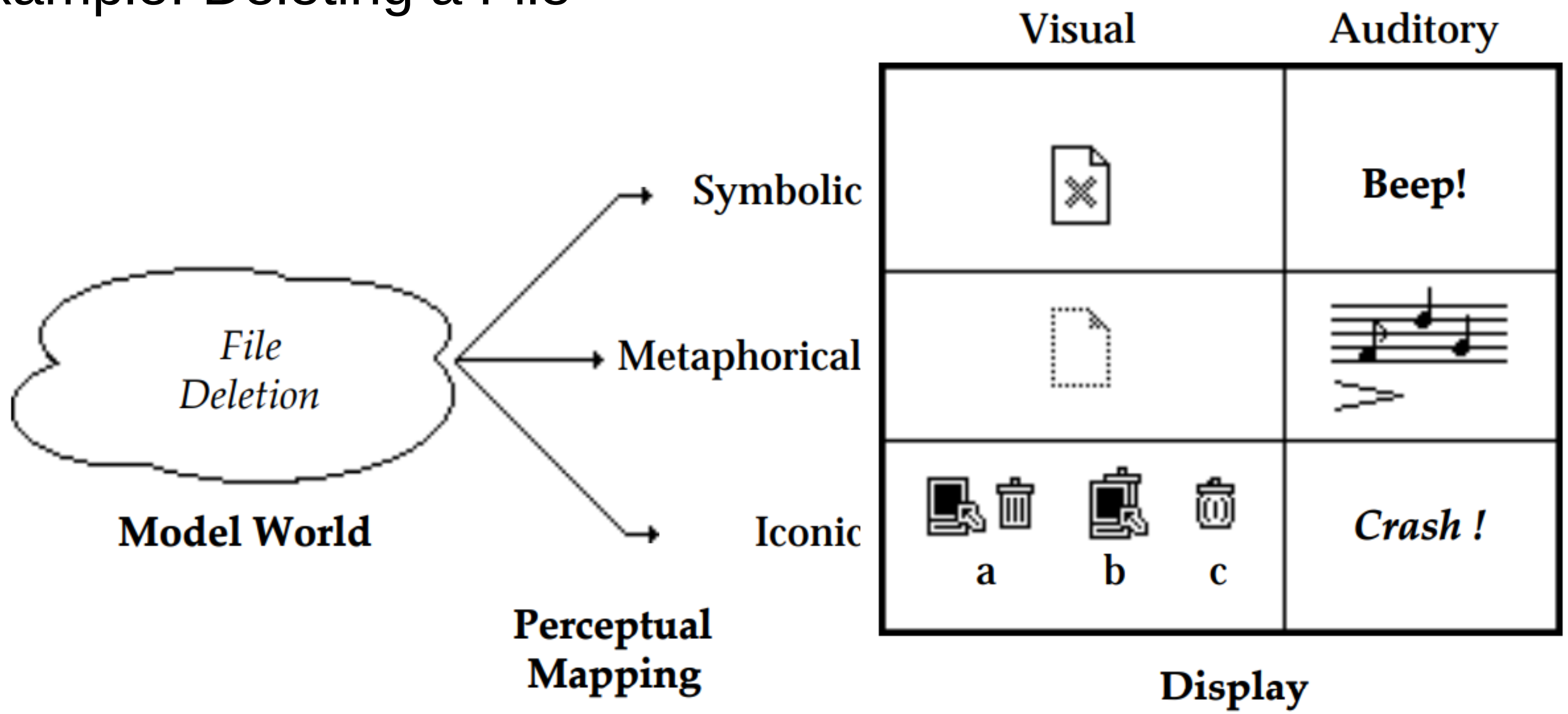


Figure 4. A conceptual file deletion may be mapped to a display in many different ways. Here six possibilities are shown, one visual and one auditory example each of symbolic, metaphorical, and iconic mappings between the event and the display.

Gaver, W. W. (1986). Auditory icons: Using sound in computer interfaces. *Human-computer interaction*, *2*(2), 167-177.

Auditory Icons

Bill Gaver, 1986

- Creating sounds that can be linked to events
- Sound helps to discriminate
  - Objects
  - Activities
  - Properties (e.g. size, number)

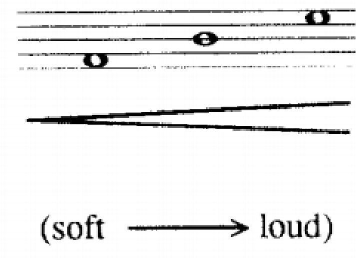
MAPPING EVENTS TO SOUND IN THE SONICFINDER

FINDER EVENTS	AUDITORY ICONS
Objects	
Selection	Hitting sound
Type (file, application, folder, disk, trash)	*Sound source (wood, metal, etc.)*
Size	*Frequency*
Opening	Whooshing sound
Size of opened object	*Frequency*
Dragging	Scraping sound
Size	*Frequency*
Where (windows or desk)	*Sound type (bandwidth)*
Possible Drop-In?	*Selection sound of disk, folder, or trashcan*
Drop-In	Noise of object landing
Amount in destination	*Frequency*
Copying	Pouring sound
Amount completed	*Frequency*
Windows	
Selection	Clink
Dragging	Scraping
Growing	Clink
Window size	*Frequency*
Scrolling	Tick sound
Underlying surface size	*Frequency*
Trashcan	
Drop-in	Crash
Empty	Crunch

Gaver, W. W. (1986). Auditory icons: Using sound in computer interfaces. *Human-computer interaction*, *2*(2), 167-177.

One Element Earcons

- “One-element earcons may be **digitized sounds, a sound created by a synthesizer, a single note, or a motive**. An element may be compared to a word, whereas a note may be compared to a letter of the alphabet.”
- “A single-motive earcon has the attributes **of rhythm, pitch, timbre, register, and dynamics**. Because single-motive earcons are relatively simple, they can represent basic, common computer entities such as certain error messages, system information, windows, and files.”
- “The user hears the click each time a character is deleted.”

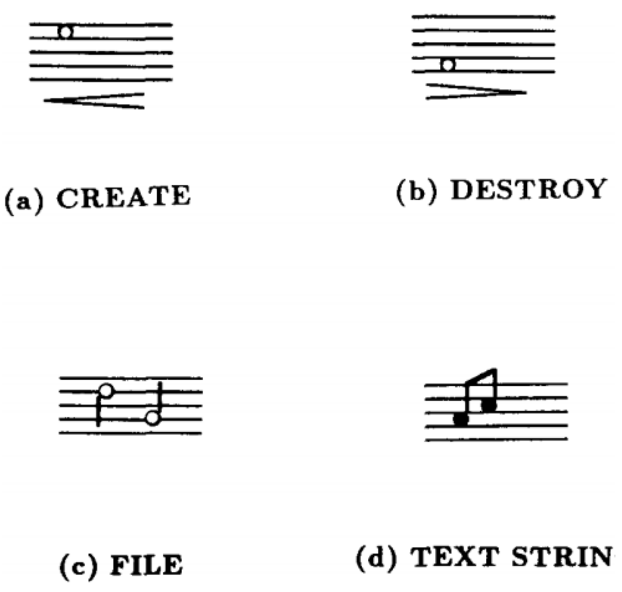


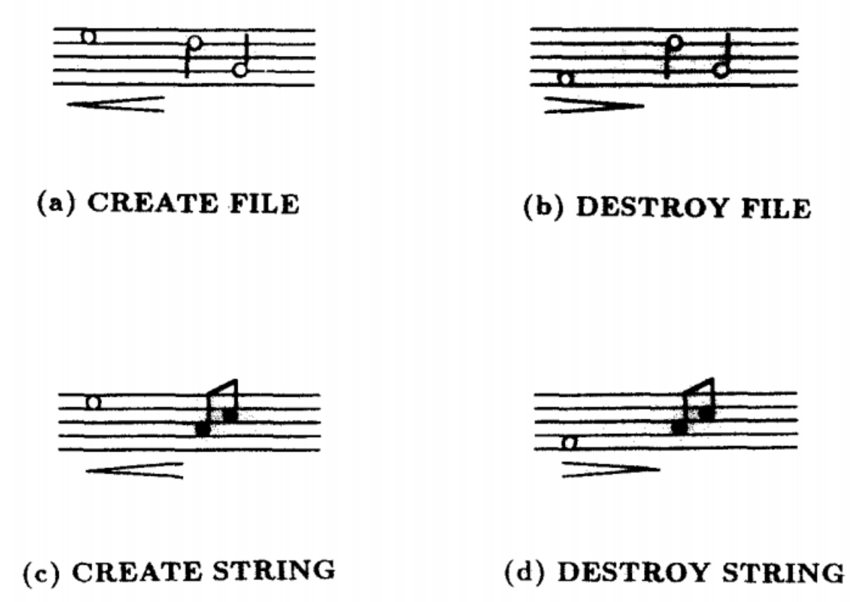
An earcon with dynamics that change from soft to loud.

Blattner, M. M., Sumikawa, D. A., & Greenberg, R. M. (1989). Earcons and icons: Their structure and common design principles. Human–Computer Interaction, 4(1), 11-44.

Combined Earcons

- “The three construction principles for compound earcons are combining, inheriting, and transforming.” p29
- “Combined earcons are formed by placing two or more audio elements in succession.” p29

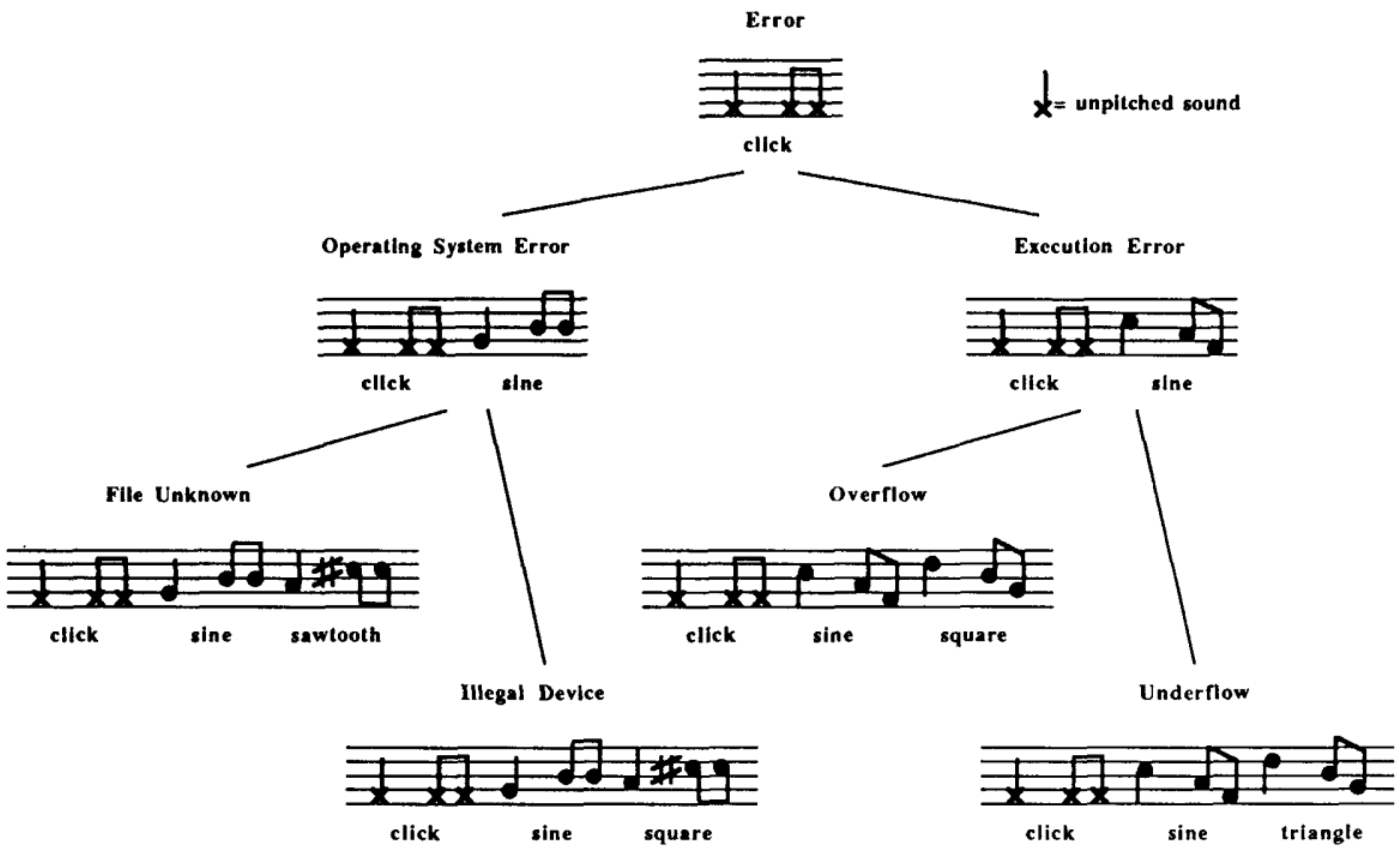




Blattner, M. M., Sumikawa, D. A., & Greenberg, R. M. (1989). Earcons and icons: Their structure and common design principles. Human–Computer Interaction, 4(1), 11-44.

Composed Earcons

Example Hierarchy – for Expert Users one?



Blattner, M. M., Sumikawa, D. A., & Greenberg, R. M. (1989). Earcons and icons: Their structure and common design principles. Human–Computer Interaction, 4(1), 11-44.

What do you hear?

Geiger Counter

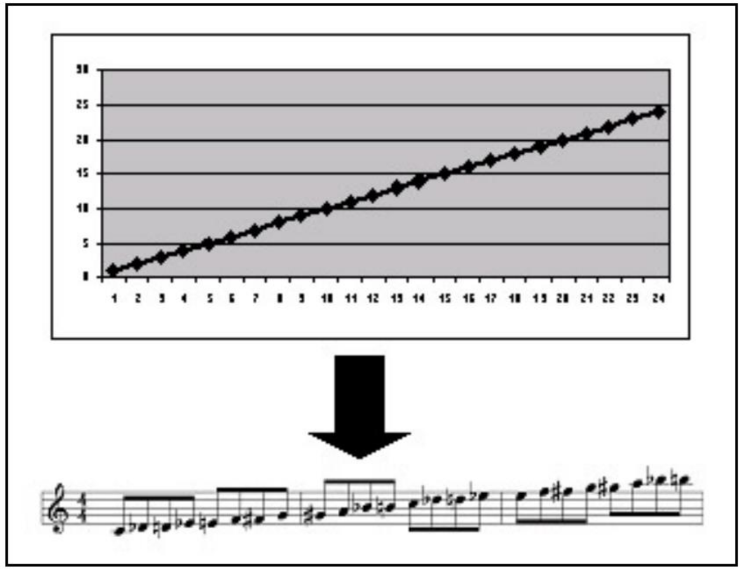
Sound of Radiation

Sound from BBC - http://bbcsfx.acropolis.org.uk/?q=geiger

Sonification

Basics

- non-speech audio
- convey information
- Make data / information audible
- alternative or complement to visualizations



As the y-value increases the pitch of the musical note gets higher

Brown, L.M. and Brewster, S.A. and Ramloll, S.A. and Burton, R. and Riedel, B. (2003) Design guidelines for audio presentation of graphs and tables. In.9th Int. Conf. on Auditory Display (ICAD), 2003, pp. 284- 287, Boston.

Sonification

Mapping Data to Sounds

- "which specific sound dimension is chosen to represent a given data dimension. […]"
- Typical acoustic dimensions:
  - Pitch / Frequency
  - Amplitude / Volume
  - Tempo / Duration
- Spatial arrangements

Brown, L.M. and Brewster, S.A. and Ramloll, S.A. and Burton, R. and Riedel, B. (2003) Design guidelines for audio presentation of graphs and tables. In.9th Int. Conf. on Auditory Display (ICAD), 2003, pp. 284- 287, Boston.

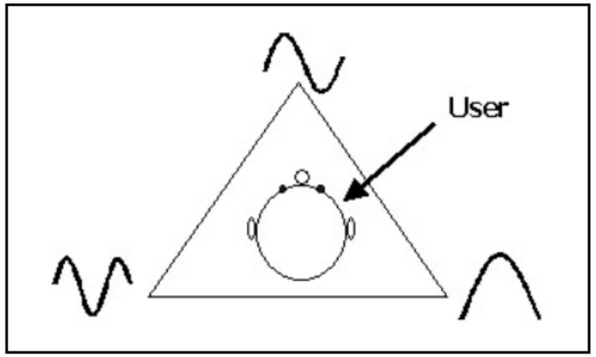


Figure 2: *One series is positioned at each corner of an equilateral triangle, with the user in the centre*

Walker, B. N., & Nees, M. A. (2011). Theory of sonification. The sonification handbook, 9-39.

Functions of Sonification

- Alerting functions
- Status and progress indicating functions
- Data exploration functions
  - Auditory graphs
  - Interactive sonification
- Art and entertainment

Walker, B. N., & Nees, M. A. (2011). Theory of sonification. The sonification handbook, 9-39.

Tasks supported by Sonification

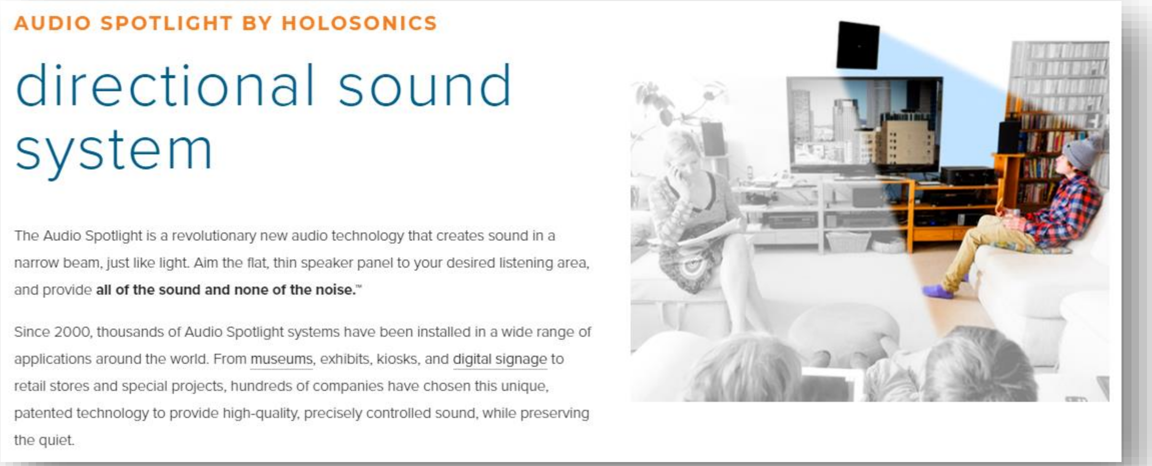
- Monitoring
- Providing Awareness of a process or situation
- Data exploration, exploratory inspection
- Point estimation and point comparison
- Trend identification
- Identification of data structure

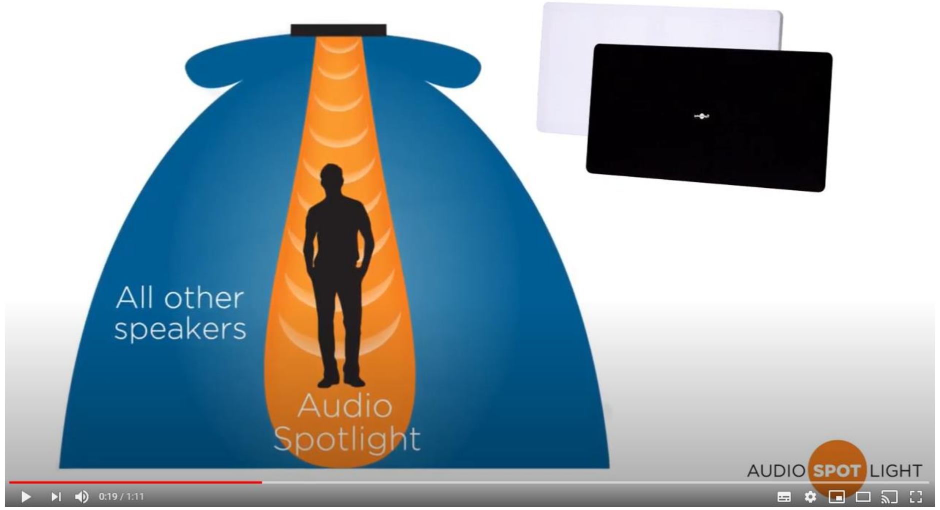
Walker, B. N., & Nees, M. A. (2011). Theory of sonification. The sonification handbook, 9-39.

Further topics in this space

optional

- Speech interaction and speech dialog system
- Spatial audio algorithms and toolkits
  - E.g. Omnitone (Spatial Audio Rendering on the Web) https://googlechrome.github.io/omnitone/
- Speaker systems that provided directed sound
  - E.g. Audio Spot lights, https://www.holosonics.com/





https://www.youtube.com/watch?v=lk7PVZYS_TQ

Did you understand this block?

Can you answer these questions?

- What technologies are available for presenting audio?
- Discuss how sounds can be used to convey information?
- What is the difference between auditory icons and Earcons?
- What is a combined Earcon?
- What are typical functions of sonification?
- What tasks can be supported by sonification?
- What auditory dimensions can be used to map data onto?

Reference

- Gaver, W. W. (1986). Auditory icons: Using sound in computer interfaces. Human-computer interaction, 2(2), 167-177.
- Brewster, Stephen A., Peter C. Wright, and Alastair DN Edwards. "A detailed investigation into the effectiveness of earcons." SANTA FE INSTITUTE STUDIES IN THE SCIENCES OF COMPLEXITY-PROCEEDINGS VOLUME-. Vol. 18. ADDISON-WESLEY PUBLISHING CO, 1994.
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- Sound library from BBC - http://bbcsfx.acropolis.org.uk/?q=geiger

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Printing and Physical Output

Albrecht Schmidt

Learning Goals

- Understand …
  - Available printing technologies
  - Advantages and disadvantages of different technologies
  - How to create 2D and 3D objects from a computer
- Know
  - How paper can be part of the user interfaces
  - The basics steps for 3D printing

Paper: Printing and Printers

- What to print?
  - Text, graphics, photos, books, objects
- On what to print?
  - Paper, special paper, cardboard, t-Shirt, …
- Where to print?
- How much to print?

- Total cost of ownership
  - dependent on usage/user profile
  - printer price (often insignificant compared to other cost)
  - materials (e.g. paper, ink, toner, energy)
  - maintenance (e.g. changing of paper in a ticket machine)

Paper: Printing and Printers

printing on paper

```php
<?php
require('fpdf/fpdf.php');

$pdf = new FPDF();
$pdf->AddPage();
$pdf->SetFont('Arial','B',16);
$pdf->Cell(40,10,'Hello World!');
$pdf->Output();
?>
```

FPDF example, https://ourcodeworld.com/

- Hardware
  - Print technology e.g. laser, dot-matrix, ink-jet, thermo
  - Media size and type, e.g. paper A4, CD, card board, envelops
  - Media handling, e.g. paper container, rolls and cutting
  - Speed – e.g. pages/minute, characters per second, sq ft/h
  - Resolution – typically dpi (dots per inch)
  - Colors
  - Connectivity e.g. network, WLAN, BT, USB, …
  - Size, weight, noise, …
- Software
  - Printer driver
  - Printer language, e.g. PS (postscript), HPGL (Hewlett-Packard Graphics Language, plotter), PCL (printer command language), GDI (Graphical Device Interface)
  - Libraries to create printed documents, e.g. FPDF, Apache PDFbox, OpenPDF

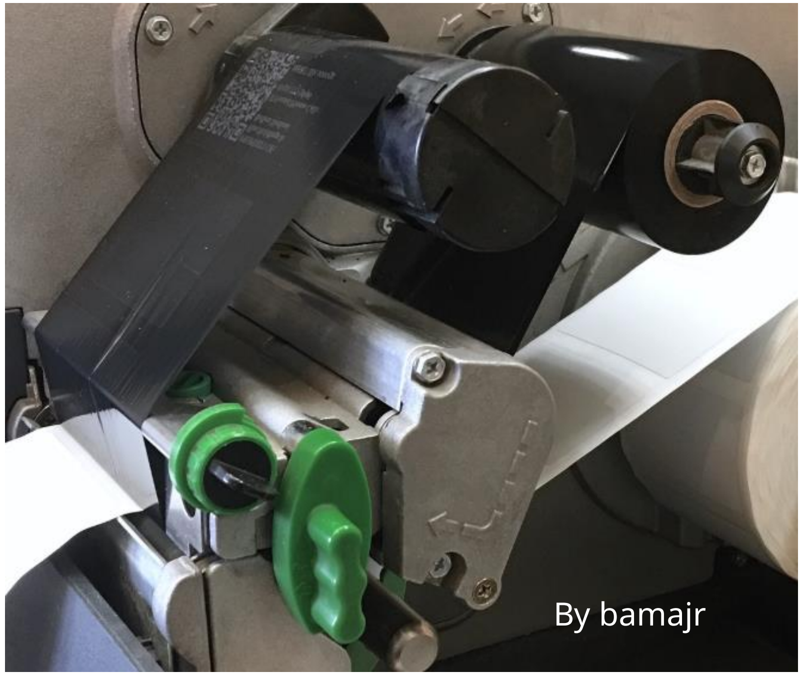
Paper: selected technologies

printing on paper

- Laser (black/white and color)
  - creating documents
  - office use
  - high resolution
- Plotter
  - Big drawings, posters
  - Endless printing
- Dot-matrix
  - Point of sale, Ticket printers
  - Multiple copies (e.g. carbon copy slip for credit card payment)
- Thermo printer
  - Point of sale, Ticket printers
  - Mobile printers


By Biswarup Ganguly

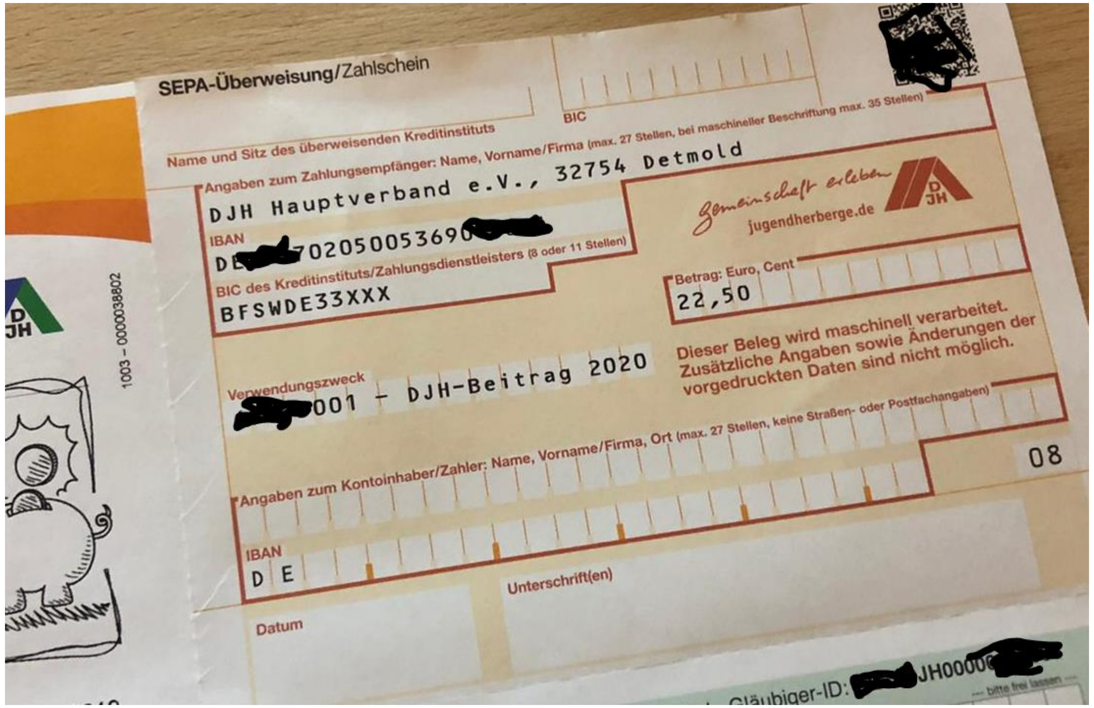

By Corvair


By bamajr

Paper: selected technologies

printing on paper

- Paperless office has not yet happened!
- Advances in technology makes it easier to use paper as interaction media
  - (fast) printing as output mechanism
  - Scanning as input mechanism
- Printing for reading, marking, commenting
- Paper as a temporary interface
  - Multi-step process, e.g.
    - print out a check list on paper
    - user interacts with the checklist on paper
    - scan & recognize interaction and create a database entry
  - for specific scenarios this can be a state of the art solution



2D output
On further materials

- Printing on different material (e.g. printing labels on a a DVD or printing on plastic sheets)
- Photo output on different materials, photo books
- **cutting plotter** (foil, stickers, paper), e.g. Brother ScanNCut
- Laser cutter for different materials such as paper, cardboard, wood, plastic, metal
- Engraving (laser, mechanical CNC)
- Sewing machine (fabric, stitching)

By O gerlach

2D output
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- Printing on different material (e.g. printing labels on a a DVD or printing on plastic sheets)
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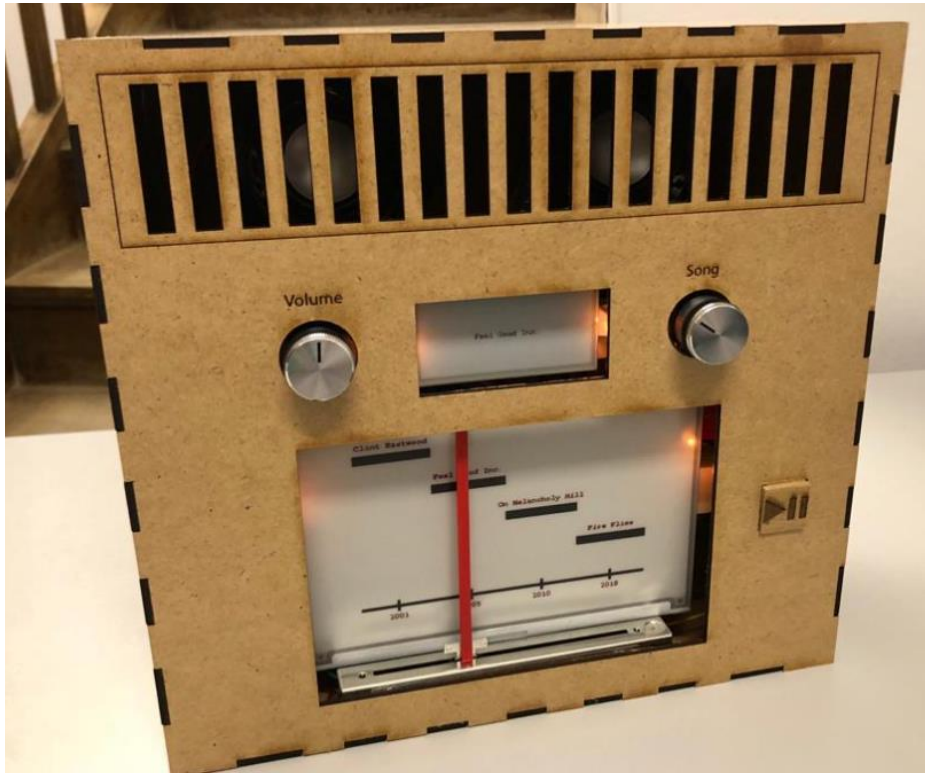

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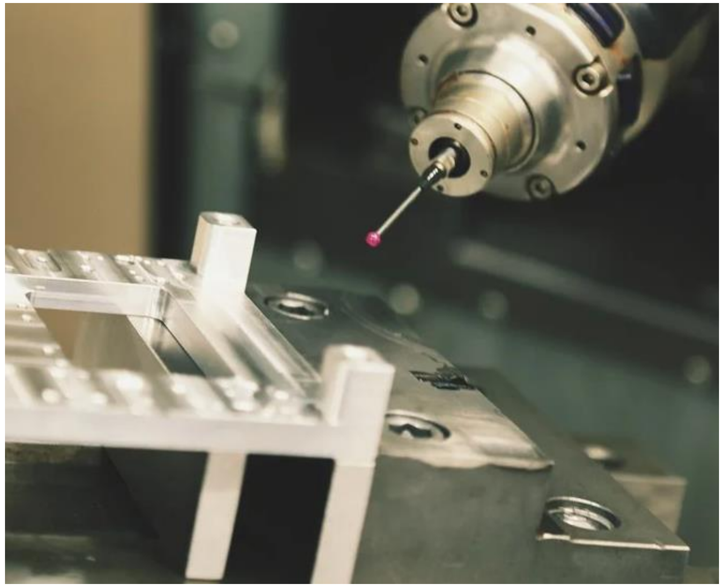
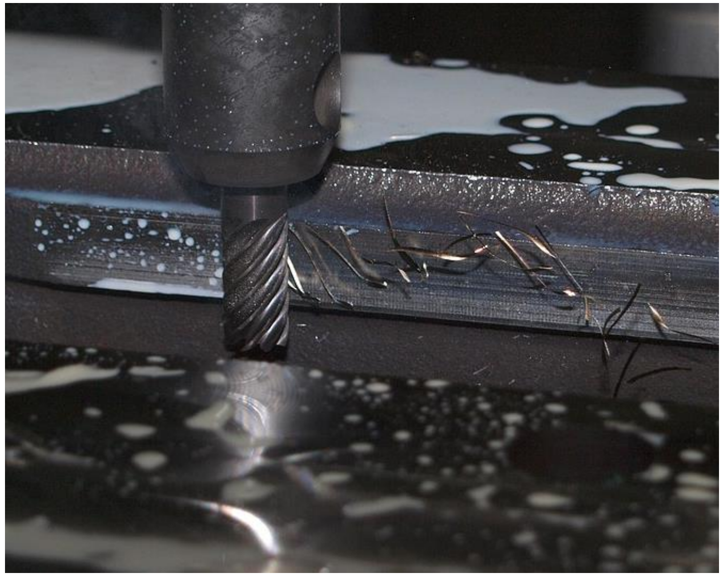
Creating Objects

“printing” things

- Subtractive, 3D
  - **CNC Milling**
  - Taking the material away to make the object
- Additive, 3D
  - 3D Printing
  - Building the object from material (e.g. layer by layer)
- Building from 2D parts
  - Laser cutting and assembly
  - Cutting sheets with connectors





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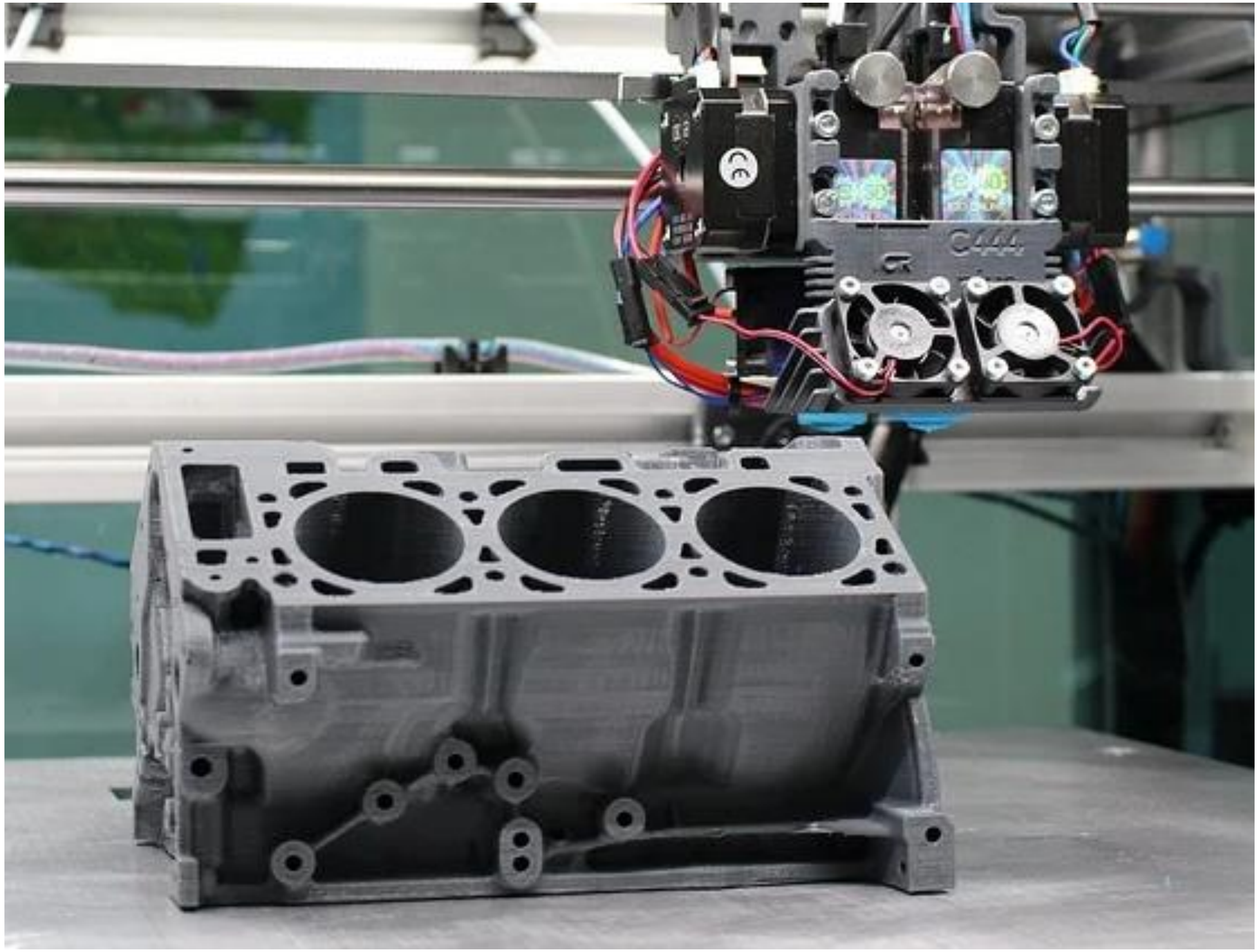
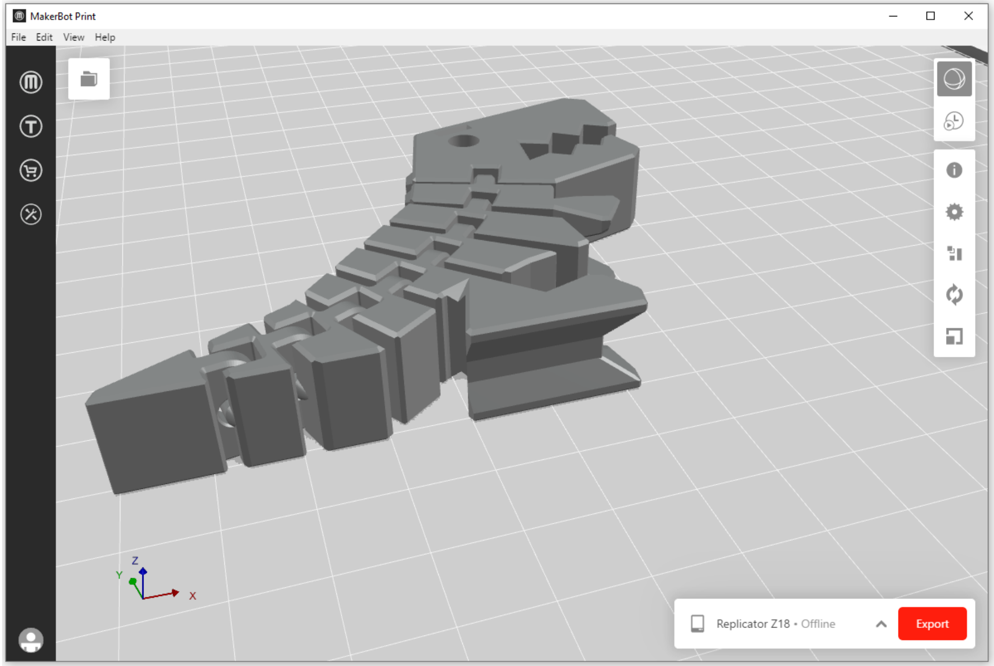


3D Printing Basics

From Idea to Objects – typical steps

- Create a Digital 3D Model
  - Scan from a real object
  - Model with a CAD / design software
  - E.g. Files in STL, OBJ, AMF, 3MF format
- Slice up the model into layers
  - Layer thickness is property of the printer (e.g. 0.1 mm)
  - Slicer or Slicing software
  - Create a representation that can be printed on a 3D printer (e.g. G code)
- Print layer by layer the object
  - Printing materials: object and if required support
  - Printing materials: metal, plastic, starch, …, chocolate
  - Support material will be removed



DrLex CC https://www.thingiverse.com/thing:2738211

More on 3D Printing

FORUM | INTERACTION TECHNOLOGIES

Envisioning, designing, and implementing the user interface require a comprehensive understanding of interaction technologies. In this forum we scout trends and discuss new technologies with the potential to influence interaction design. — **Albrecht Schmidt, Editor**

3D Printing for Human-Computer Interaction

Stefanie Mueller, MIT CSAIL

In the past five years, personal fabrication has become a major research area in human-computer interaction (HCI), with many new contributions every year. In this article, I explain one of its core technologies, 3D printing, with the goal of helping interested researchers get started. For a survey and roadmap of open research directions, please refer to [1] and to the corresponding website (http://hcie.csail.mit.edu/fabpub/), which provides a list of all the research papers published in the field.

3D PRINTING TECHNOLOGIES AND MATERIALS

A common misconception is that 3D printing is limited to the plastic extrusion process seen on today's popular consumer devices such as the MakerBot. In this process, plastic is extruded through a hot nozzle and deposited voxel by voxel (a physical pixel), layer by layer onto a build platform until the 3D object is complete. This is called *fused deposition modeling* (FDM).

The reason FDM technology entered the consumer market first is that its patents expired first: 3D printing is a technology developed in the 1980s with a variety of different processes and materials. In 2009 the first FDM patent ran out; only a few months later, the MakerBot Cubcake CNC appeared on the market. However, many more advanced technologies still have active patents and thus right now are available only in industry.

Another recently expired patent is that of *stereolithography* 3D printing, a process used, for example, in the Form2 3D printers. A liquid resin is poured into a tank. Then a laser (SLA 3D printing) or a projector (DLP 3D printing) selectively shines light onto the resin, which hardens it in these locations. Many other 3D-printing techniques will be available for startups soon. For instance, in inkjet 3D printing, an inkjet head releases a binder that selectively hardens powder in a powder bed. At the end of the process, users remove the object in a process that resembles an archaeological excavation. Metal printing works similarly: A laser selectively melts and fuses metal powder in a powder bed. Finally, layered-object manufacturing (LOM) can process materials that cannot be extruded, bound, or sintered. It takes entire sheets of material, such as a roll of fabric, cuts each sheet into a shape using a laser or other cutting device, and then stacks each layer to create the 3D object. Many more processes and materials exist (Figure 1), from machines that 3D print with felt to create entirely soft objects such as Teddybears, to 3D printers that can print glass.

Insights

- → Research on personal fabrication technologies such as 3D printing is increasingly contributing to the field of HCI.
- → Plastic is perceived to be the most common material for 3D printing, but the use of materials such as fabric, metal, and glass is now possible in industry.
- → Despite 3D printing's enormous potential, speed, especially for high-fidelity detailed prints, remains a limiting factor.

The words *3D printing* and *additive manufacturing* are often used interchangeably; however, they are not the same. 3D printing is a subcategory of additive manufacturing. Additive manufacturing is any process that creates objects by iteratively adding material until the object is finished. 3D printing is a specific additive manufacturing process in that it has full control over the placement of every voxel in the 3D object, which lends it unlimited degrees of freedom and thus unlimited complexity in the objects it can build. This makes it a very powerful tool.

THE PROCESS FOR CREATING PHYSICAL OBJECTS USING 3D PRINTING

The traditional workflow consists of three steps: 3D modeling, slicing (preparing a model for fabrication), and 3D printing.

3D modeling. There are many different 3D editors with different modeling processes. The most accessible ones for novice users, such as TinkerCAD, use a process called *solid modeling*, in which users combine primitive shapes, such as cubes and spheres, and use Boolean operations, such as intersect, join, and subtract, to create a 3D model.

Other editors, such as SketchUp, use a process called *surface modeling*, in which users manipulate the faces,

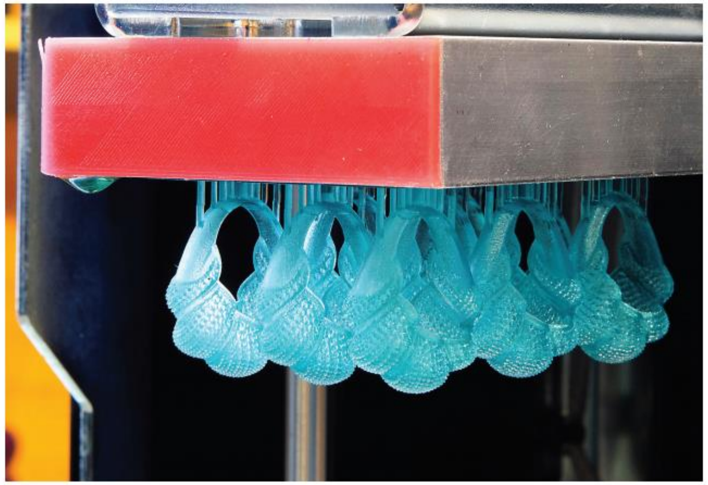


IMAGE BY MORENO SOPPELSA

edges, and vertices of a 3D model. This allows for more expressive free-form shapes but, there is a drawback: Users can accidentally create invalid geometry, for instance, by creating a hole in the surface geometry, which goes against the watertight requirement of 3D printing (i.e., the geometry needs to be "manifold"). In solid modeling, water-tightness is always guaranteed, as it is an inherent property of the modeling process. Many tools exist to help analyze 3D models for defects and repair them for 3D printing, either as additional plugins for 3D editors such as the SketchUp Manifold plugin, or as separate programs, the most popular one being Autodesk Meshmixer.

Slicing. To prepare a model for 3D printing, users have to open the 3D model in a separate program called a *slicer*. Preparing a model for 3D printing includes steps such as generating the support material that is printed below the model geometry that has nothing underneath it (called an *overhang*), splitting the model into layers that the 3D printer will print one at a time, and selecting the materials with which the object will be printed. Each of these attributes has additional parameters. For instance, there are different types of support structures for different use cases: Each layer consists of not only a height but also a number of outlines (so-called *shells*) and the percentage of *infill*, a honeycomb pattern used inside the object instead of solid infill to save printing time. The slicer typically imports the 3D model in .stl file format (but other formats, such as the recently developed .amf, exist). For most 3D editors that do not have an .stl export built in, there are additional plugins that can be installed (e.g., Sketchup provides an .stl extension plugin).

The words *3D printing* and *additive manufacturing* are often used interchangeably; however, they are not the same.

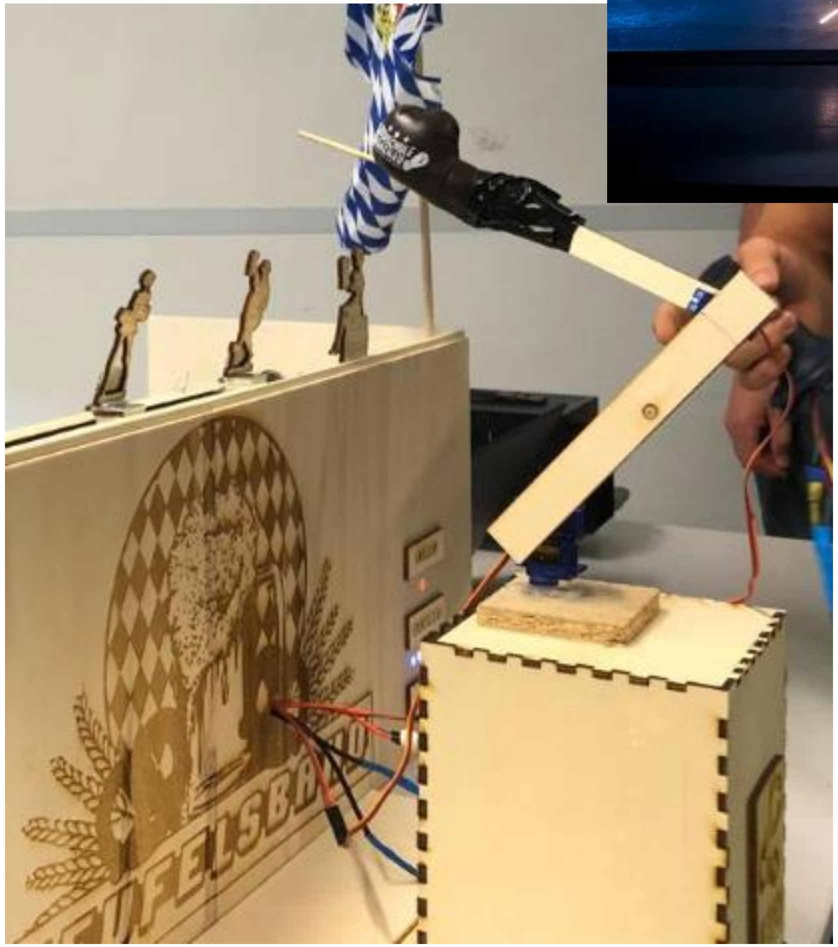
Fabrication. The slicer exports instructions to the 3D printer in so-called G-Code, which is the machine language for 3D printers. G-Code tells the print head where to move, how much material to extrude along the way, and how fast to move. Similar commands exist for leveling the print bed, warming up the extruder nozzles, and other parts of the printing process. Regular users will not have contact with low-level G-Code; however, many HCI research projects such as WirePrint [4] (Figure 2) leverage custom G-Code commands for their applications. Before printing, users typically must load the right materials into the 3D printer and level the printing platform to be the right distance from the extruder nozzle. However, more and more of these routines are becoming automated to make the process easier (e.g., via auto-leveling of the print bed).

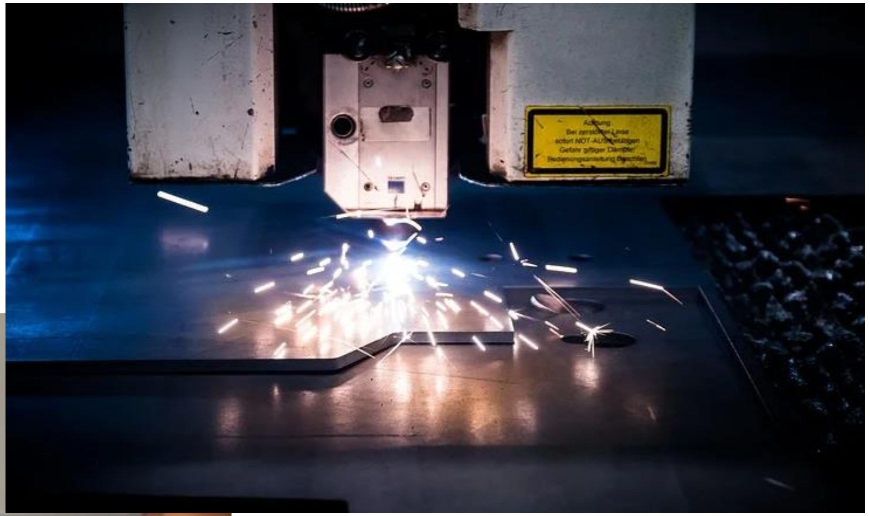
Mueller, S. (2017). 3D printing for human-computer interaction. interactions, 24(5), 76-79.

Creating Objects

“printing” things

- Subtractive, 3D
  - CNC Milling
  - Taking the material away to make the object
- Additive, 3D
  - 3D Printing
  - Building the object from material (e.g. layer by layer)
- Building from 2D parts
  - **Laser cutting and assembly**
  - Cutting sheets with connectors





Did you understand this block?

Can you answer these questions?

- What can a dot matrix printer do, that as laser printer can not?
- Discuss what different printing technologies are good for?
- What are cutting plotters used for?
- How can you use a laser cutter for creating 3D objects?
- What are the typical steps for creating a printed 3D object?
- How can paper be a part of a user interface design? In which use cases would this make sense?

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- Mueller, S. (2017). 3D printing for human-computer interaction. interactions, 24(5), 76-79.

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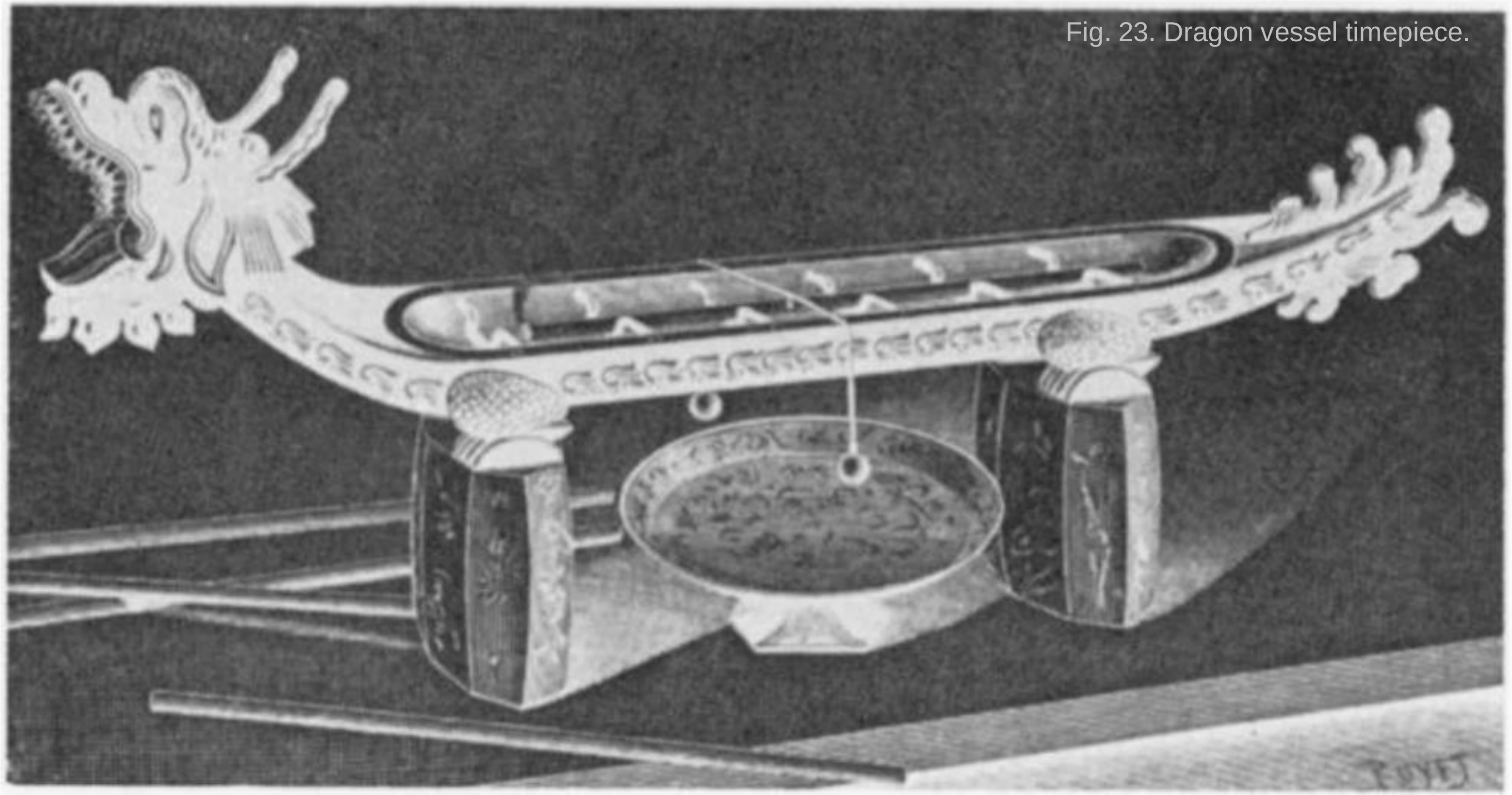


Fig. 23. Dragon vessel timepiece.

Olfactory Output

Taste Output

Learning Goals

- Understand …
  - The challenges of olfactory output devices
  - What parameters are used to create an artificial taste
- Know
  - Historic an example of using smell as information display
  - The basic components and functions of an olfactory output devices

Aromatic Output for Interaction


- Humans use their sense of smell
  - Is food save to eat?
  - Is there danger due to a fire?
  - Relationships


- Unexplored medium in human computer interaction
  - technical difficulties in emitting scent on demand
  - chemical difficulties in creating accurate and pleasant scents

Joseph "Jofish" Kaye, Making scents: aromatic output for HCI, Interactions, Volume 10, Number 1 (2004), Pages 48-61

Incense Clocks

Historic smell output devices: Dragon vessel timepiece

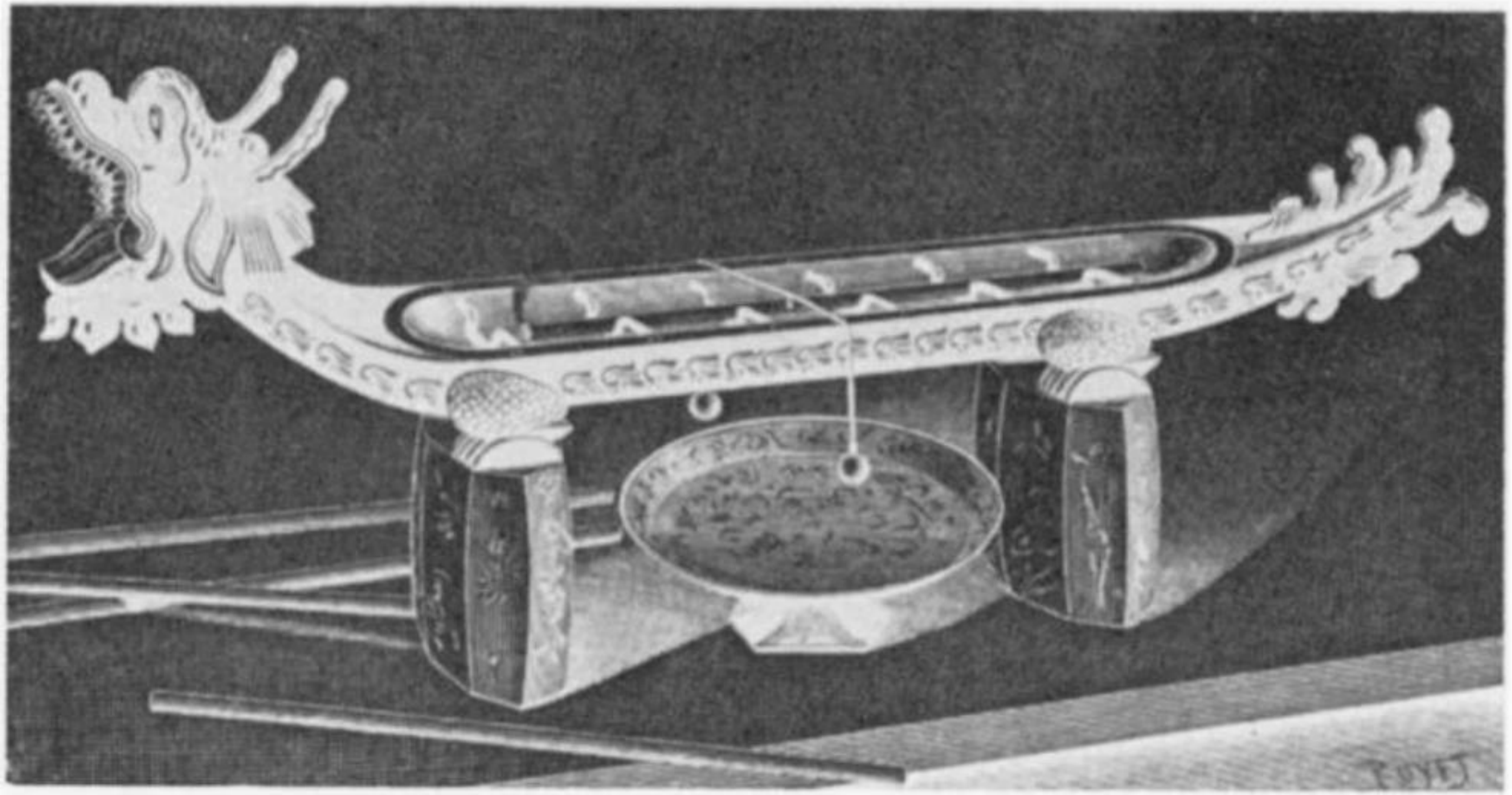


Fig. 23. Dragon vessel timepiece. Bedini, S. A. (1963). The scent of time. A study of the use of fire and incense for time measurement in oriental countries. Transactions of the American Philosophical Society, 53(5), 1-51.

Incense Clocks

Historic smell output devices

- timekeeping device (China, East Asia)
- Clock body holds incense sticks or powdered incense
- Different incenses along the body
- Calibrated brining rate to measure time
- Can include bells (auditory signal)
- Used in homes and temples
- New smell / other incense signals passage of time
- …you can smell the time

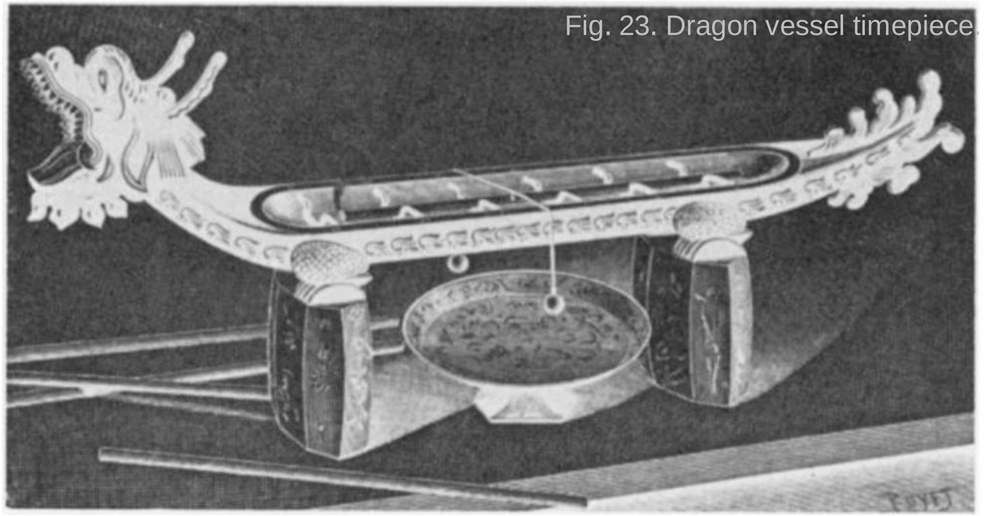


Fig. 23. Dragon vessel timepiece.

Bedini, S. A. (1963). The scent of time. A study of the use of fire and incense for time measurement in oriental countries. Transactions of the American Philosophical Society, 53(5), 1-51.

Physiology and Chemistry of Smell

- A thousand different kinds of olfactory receptors in our nose,
- each can sense a single kind of chemical bond in a molecule
- No abstract classification of smell
  - Examples: how does mint taste? It tastes like …mint
  - Compared to colors: green vs. spinach colored
- Rapidly acclimatized - Less than 1 minute
- Human Olfactory Bandwidth… … hard to tell
  - Perfumers and florist can distinguish many different smells - potentially thousands

Joseph "Jofish" Kaye, Making scents: aromatic output for HCI, Interactions, Volume 10, Number 1 (2004), Pages 48-61

Smell output

- Explored in movie theaters and VR… but so far not really successful
- Olfactory Icons
  - Smell a “shot” fired each time you press the trigger in your game
  - Ambient Notification, e.g. Smell of rose to notify you of a date or an incoming message
- What information should be displayed?
- **An Olfactory display is useful for slowly-moving, medium-duration information or information for which an aggregate representation is slowly changing.**

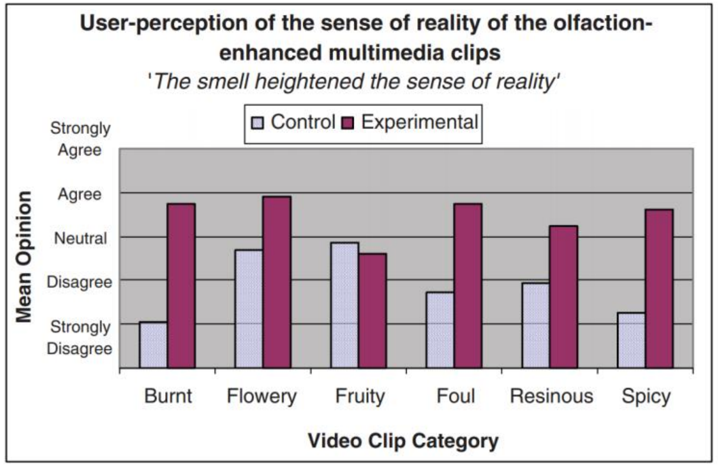
http://www.microfab.com/vapor-generation/aromajet

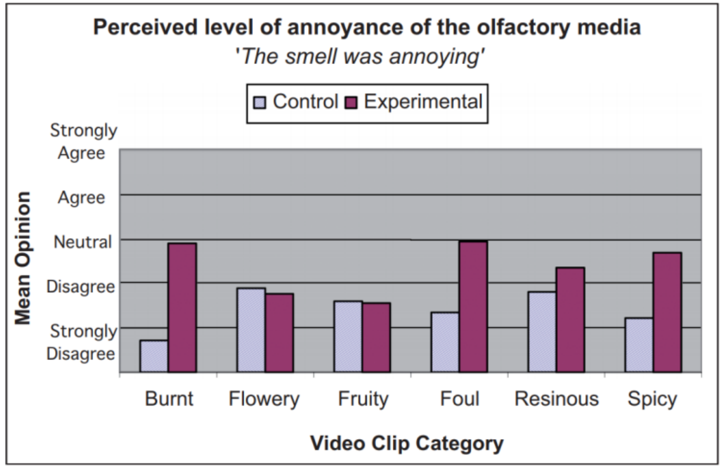
Joseph "Jofish" Kaye, Making scents: aromatic output for HCI, Interactions, Volume 10, Number 1 (2004), Pages 48-61

Multimedia Applications with Olfaction

Table I. Video Categories and the Smells Used

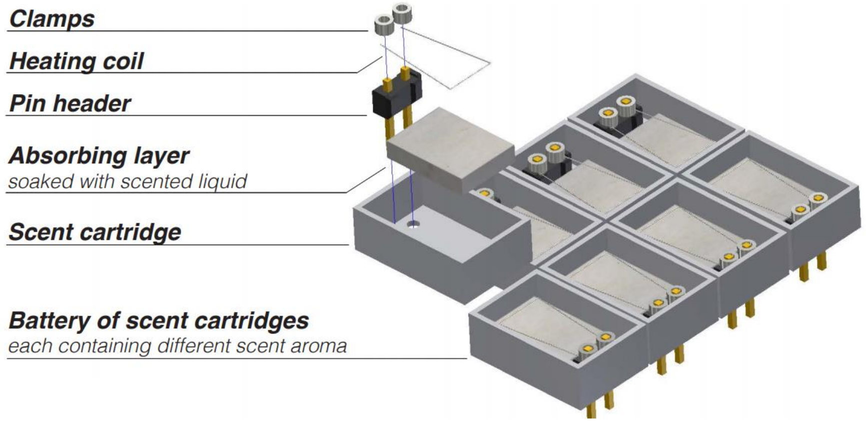
Video Name	Burnt	Flowery	Foul	Fruity	Resinous	Spicy
Video Description	Documentary on bush fires in Oklahoma	News broadcast featuring perfume launch	Documentary about rotting fruits	Cookery show on how to make a fruit cocktail	Documentary on Spring allergies & cedar wood	Cookery show on how to make chicken curry
Smell Used	Burning Wood	Wallflower	Rubbish Acrid	Strawberry	Cedar Wood	Curry
						

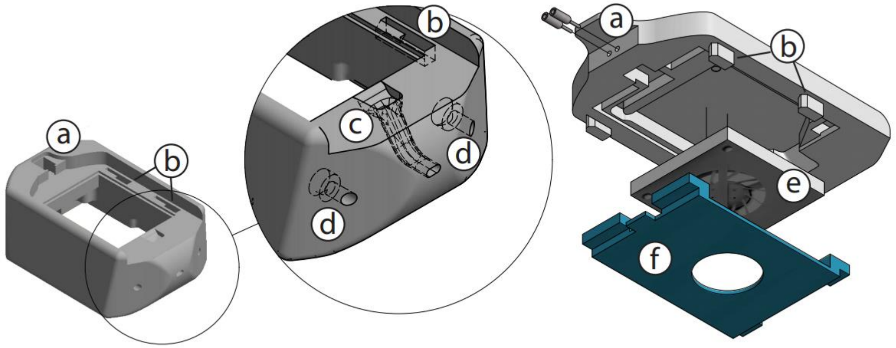




Gheorghita Ghinea and Oluwakemi Ademoye. 2012. The sweet smell of success: Enhancing multimedia applications with olfaction. ACM Trans. Multimedia Comput. Commun. Appl. 8, 1, Article 2 (January 2012), 17 pages. DOI:https://doi.org/10.1145/2071396.2071398

Wearable Olfactory Output Device (Research)

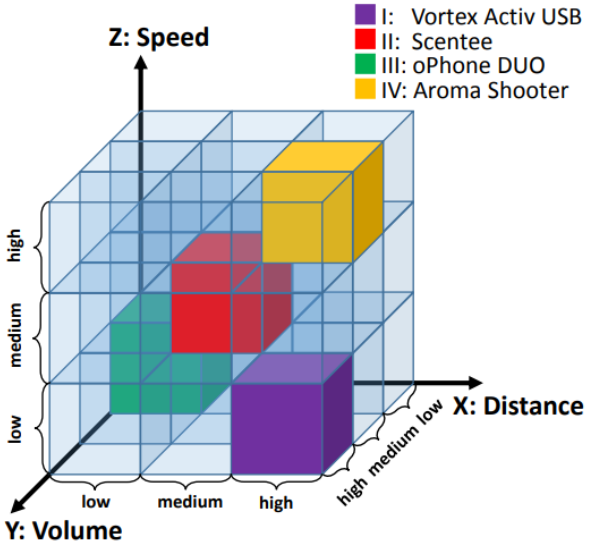




Dobbelstein, D., Herrdum, S., & Rukzio, E. (2017, September). inScent: A wearable olfactory display as an amplification for mobile notifications. In Proceedings of the 2017 ACM International Symposium on Wearable Computers (pp. 130-137).

Olfactory Output Device

- Key challenges
  - Creating a certain smell
  - Storing and providing the smell
  - Timed delivery of the smell to the user
  - Neutralizing / replacing the smell
- Parameters of scent delivery
  - Distance
  - Volume
  - Speed



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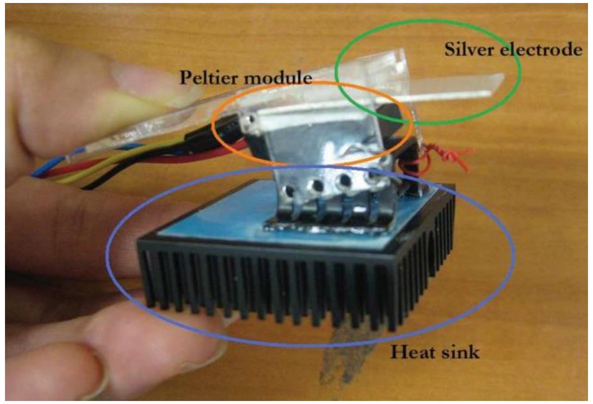
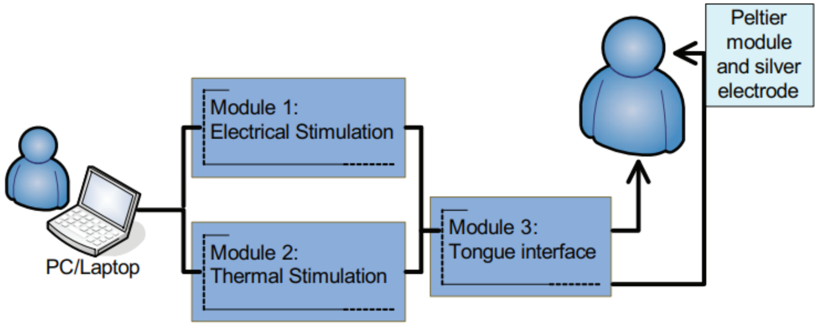
Taste Output Device (Research)

- Tongue interface
  - Peltier Element
  - Silver electrode
- Output Parameters
  - Electro stimulation (polarity, frequency, 0μA to 200μA, 50Hz to 1000Hz.)
  - Temperature (cooling/heating, 20°C to 35°)





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Did you understand this block?

Can you answer these questions?

- What are the key challenges when creating an olfactory display?
- What components do you need for outputting smell?
- What parameters are relevant for olfactory output devices?
- How is artificial taste created?
- Give a historical example of a smell output device and explain its basic function-

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- Joseph "Jofish" Kaye, Making scents: aromatic output for HCI, Interactions, Volume 10, Number 1 (2004), Pages 48-61
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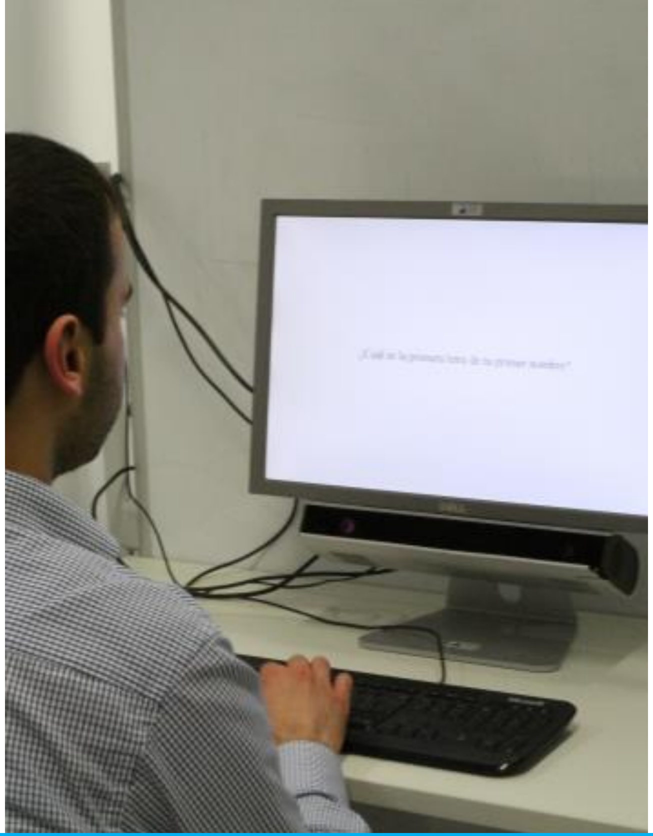

Image by Tschneidr (CC BY-SA)

Eye Gaze Interaction

Learning Goals

- Understand …
  - how gaze interaction works
  - what parameters can be measured from the eye
  - The Midas touch problem and implications for user interfaces
- Know …
  - what fixations, saccades, and smooth pursuit are
  - different types of gaze interaction and be able to give examples
  - about different applications of gaze interaction

The eyes show where you look

- Eye gaze is linked to seeing
- By looking at someone you can see what they look at
- What can we observe?
  - Fast eye movement (saccades) between objects of interest
  - Fixations on objects of interest
  - Following moving objects with gaze (smooth pursuits)
- Pupil dilation
  - Responds to light (a lot)
  - To cognitive load (a little)

Eye Movements

Person reading slowly

Gaze tracking

- What to meaure?
  - Gaze position/movement of the eye
  - Position/movement of the head
  - Relationship to the real world
- Typical API
  - Koordinates (x, y) in the world image as stream (e.g. 100 Hz)
  - Pupil dilation value (d)

Eye Tracker

- **Eye tracking glasses**:
  - Camera that looks at the users eyes
  - Camera that looks towards the environment
  - Mapping of the gaze position to a position in the real world (this is calibrated)
- Stationary eye tracker
  - Camera looking at the users face
  - Estimate gaze position
  - Estimate head position (or hold the head still)
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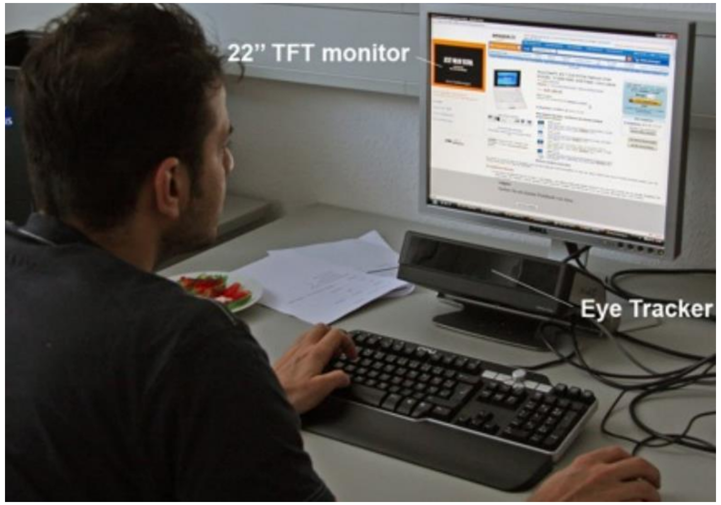
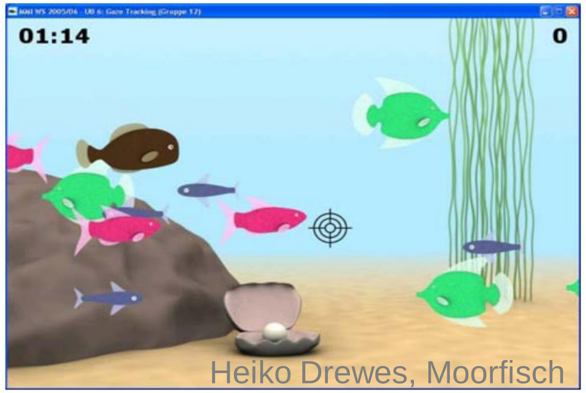


Gaze interaction

- **Fixations:** Use gaze to fixate a target
  - Select this after a certain time (dwell time), e.g. 2 second
  - Select this when a button is pressed
  - Requires calibration
- Smooth Pursuit: Use gaze to follow an objects
  - Several moving objects are presented on the screen
  - Follow with the case on of these objects
  - The object that is followed is selected
  - Can be done without calibration
- Gaze Gestures
  - Simple gaze gestures: Look right, look down
  - Complex gesture: look along a path / an outline
  - Can be done without calibration



Heiko Drewes, Moorfisch

Images by Tschneidr (CC BY-SA)

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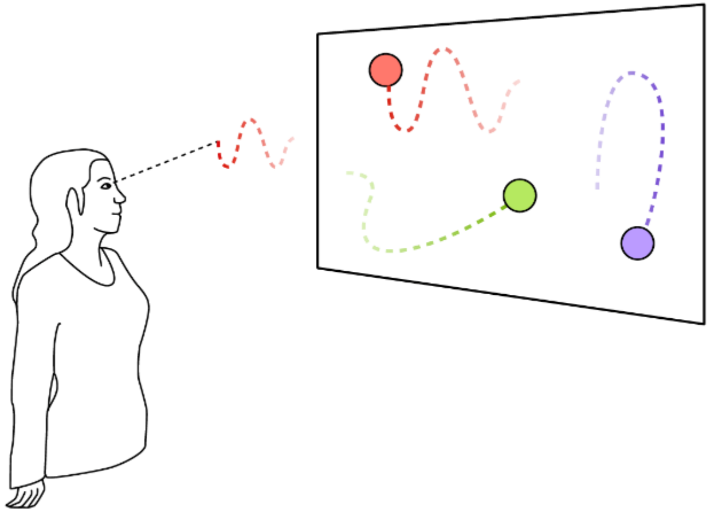

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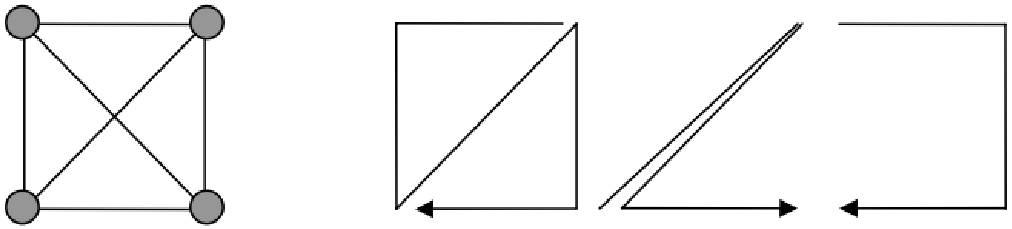
Gaze interaction



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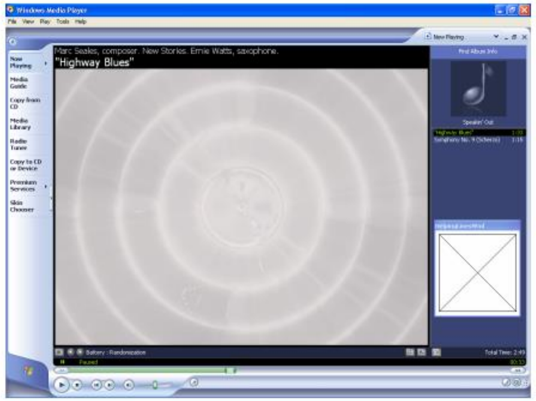

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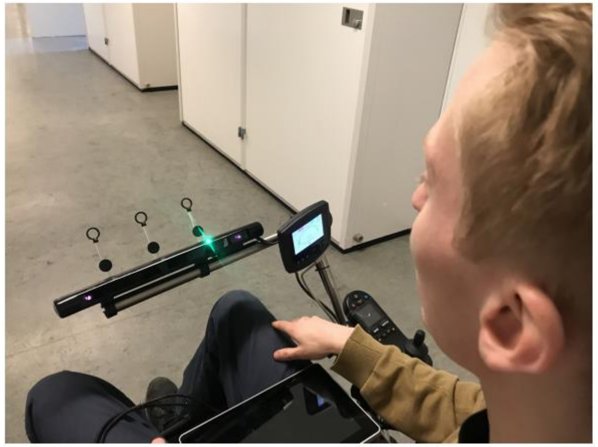
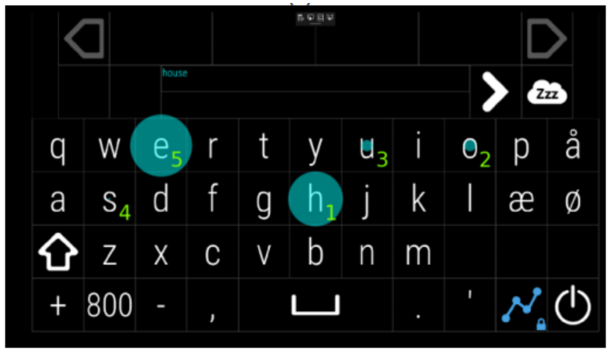
Gaze interaction Application

- **Accessibility**
  (typically fixations and dwell time)
  - Use case as alternative input
  - Operate buttons or menues
  - Gaze type
- Analytics
  - Understand what people look at
  - Usability research, market research
- Display adaptation
  - Automatically scroll when at the end of a display page
  - Marker on screen for faster resume
  - Pause media, when the user is not looking
- Image cropping
  - Crop based on where people look





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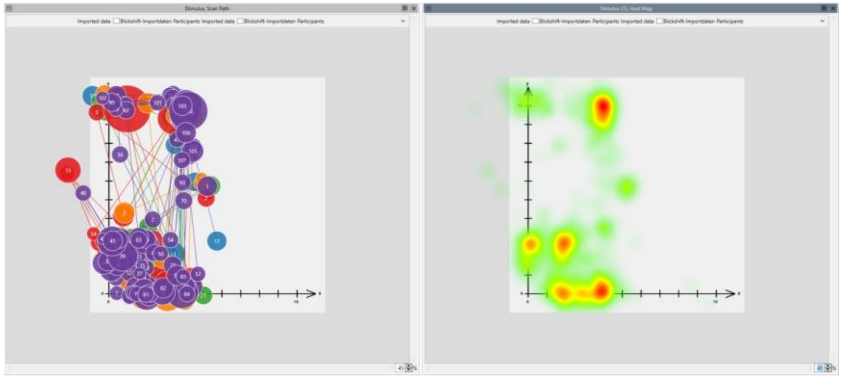

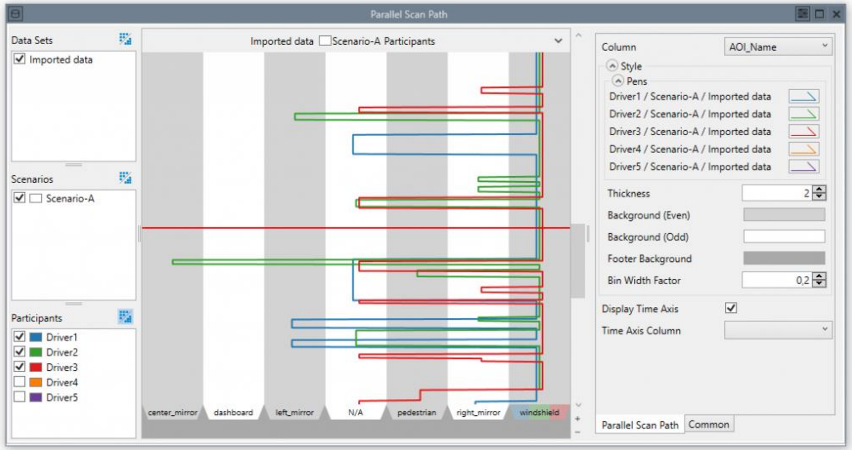

Photos from: https://www.blickshift.com/products-services/blickshift-analytics/

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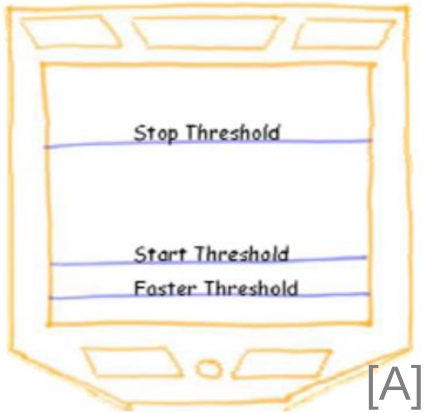
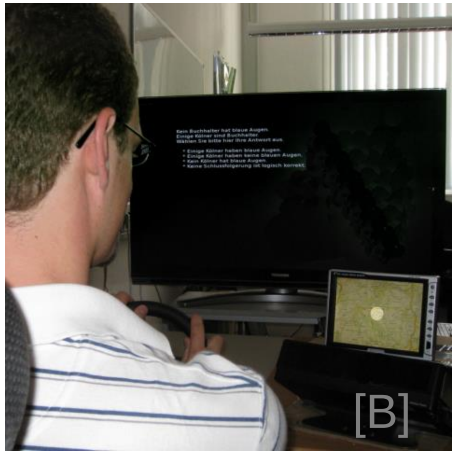
  - Pause media, when the user is not looking
- Image cropping
  - Crop based on where people look



[A]



[B]

[A] Kumar, M., Winograd, T., & Paepcke, A. (2007, April). Gaze-enhanced scrolling techniques. In CHI'07 Extended Abstracts on Human Factors in Computing Systems (pp. 2531-2536).
[B] Kern, D., Marshall, P., & Schmidt, A. (2010, April). Gazemarks: gaze-based visual placeholders to ease attention switching. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (pp. 2093-2102).

Gaze interaction Application

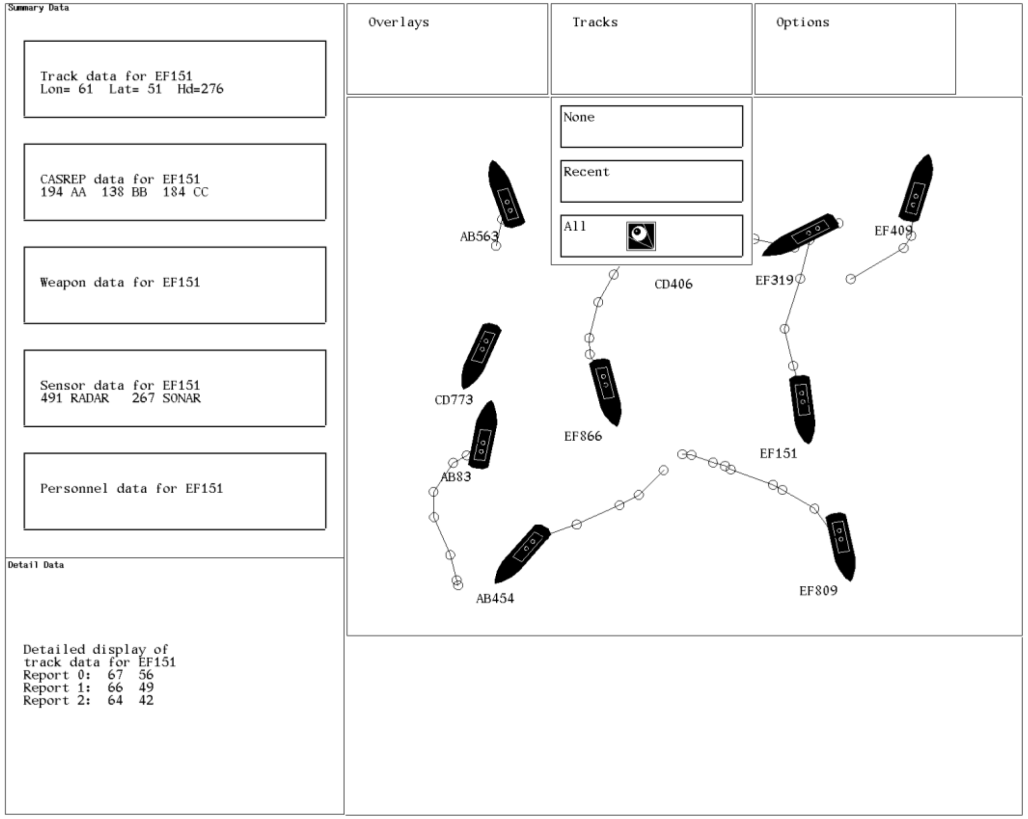
- Accessibility
  (typically fixations and dwell time)
  - Use case as alternative input
  - Operate buttons or menues
  - Gaze type
- Analytics
  - Understand what people look at
  - Usability research, market research
- Display adaptation
  - Automatically scroll when at the end of a display page
  - Marker on screen for faster resume
  - Pause media, when the user is not looking
- **Image cropping**
  - Crop based on where people look

Figure 6. Results for a set of representative images. (a) Original image; (b) fully automatic crop [Suh et al. 2003]; (c) gaze-based content map; (d,e) gaze-based crops to horizontal and vertical aspect ratios.

Santella, Anthony, Maneesh Agrawala, Doug DeCarlo, David Salesin, and Michael Cohen. "Gaze-based interaction for semi-automatic photo cropping." In *Proceedings of the SIGCHI conference on Human Factors in computing systems*, pp. 771-780. ACM, 2006.

Early Work on Eye-Tracking for HCI

- Object Selection
- Continuous Attribute Display
- Moving an Object
- Eye-controlled Scrolling Text
- Menu Commands



Jacob, Robert JK. "Eye tracking in advanced interface design." Virtual environments and advanced interface design (1995): 258-288.
Jacob, R. J. (1991). The use of eye movements in human-computer interaction techniques: what you look at is what you get. ACM Transactions on Information Systems (TOIS), 9(2), 152-169.

Midas Touch Problem

Fundamental Issue of Gaze Interaction

"The most naive approach to **using eye position as an input** might be to use it as a direct substitute for a mouse: changes in the user's line of gaze would cause the mouse cursor to move. **This is an unworkable (and annoying)** approach, because people are not accustomed to operating devices just by moving their eyes. They expect to be able to look at an item without having the look "mean" something. Normal **visual perception requires that the eyes move** about…[…]

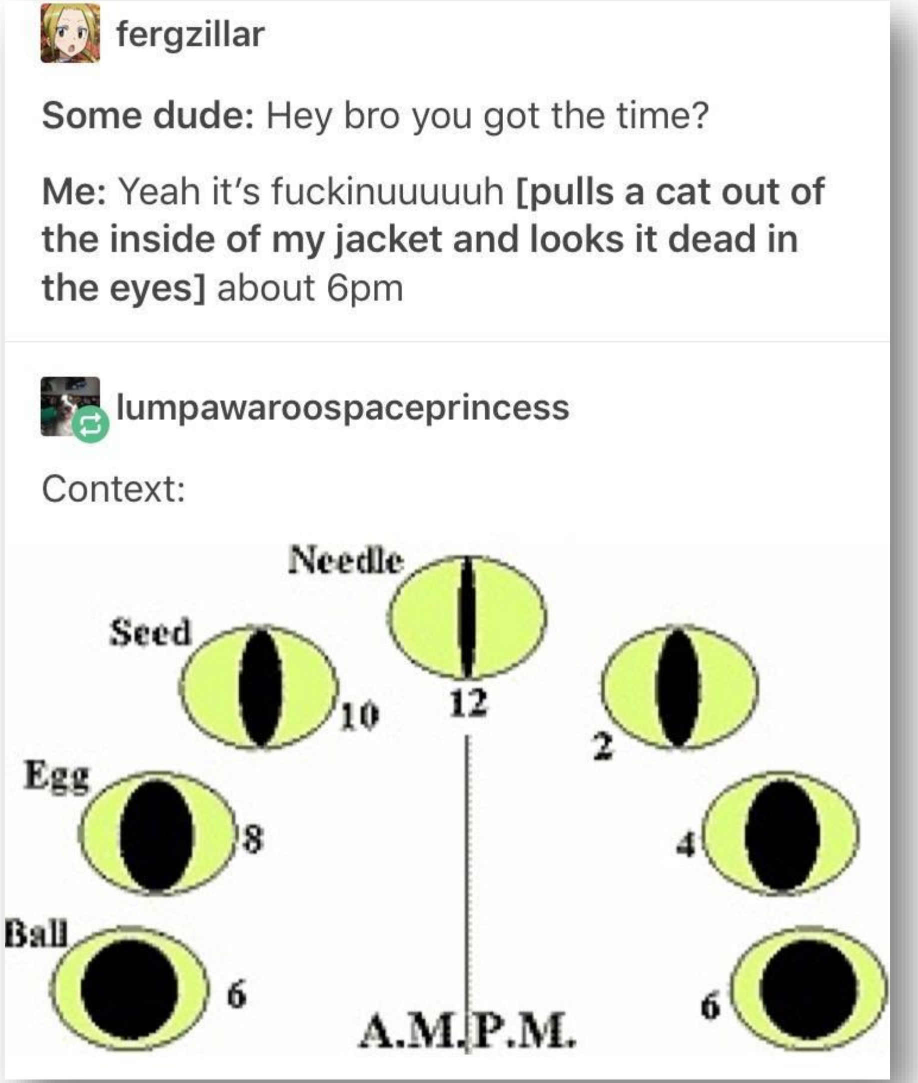
Before long, though, it becomes like the **Midas Touch. Everywhere you look, another command is activated**; you cannot look anywhere without issuing a command. […]

The challenge in building a useful eye tracker interface is to avoid this Midas Touch problem. Ideally, the interface **should act on the user's eye input** when he wants it to **and let him just look around** when that's what he wants, but the two cases are impossible to distinguish in general."

Jacob, R. J. (1991). The use of eye movements in human-computer interaction techniques: what you look at is what you get. *ACM Transactions on Information Systems (TOIS)*, *9*(2), 152-169.

Pupil size

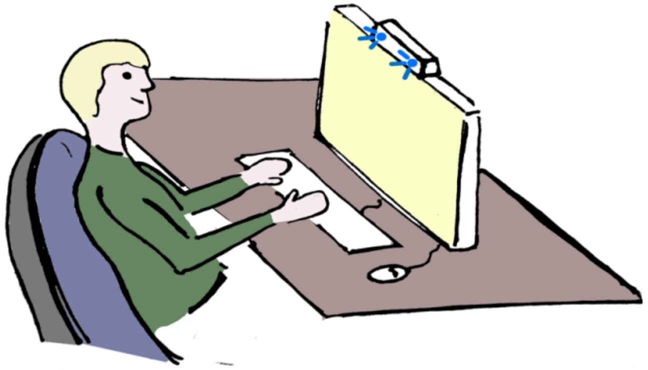
What does it tell us?



https://www.reddit.com/r/tumblr/comments/8cm6om/got_the_time/

Pupil size
Light and cognitive load

- Acts as the aperture of the eye
- Pupil size change with the light level
  - bright – smaller pupil – smaller opening
    - less light to the eye
  - Dark – wider pupil – larger opening
    - more light to the eye
- Mental workload will also impact pupil size
  - If the light is constant, and the task is
    - Difficult: wider pupil
    - Easy: smaller pupil



	Light (large impact)		Task (small impact)	
	low	high	difficult	easy
Pupil diameter	↗	↘	↗	↘

Model: $PD = PD_{light} + PD_{task}$

$PD_{task} = PD - PD_{light}$

Estimate: $mental\ workload \approx f(PD_{task})$

Bastian Pfleging, Drea K. Fekety, Albrecht Schmidt, and Andrew L. Kun. 2016. A Model Relating Pupil Diameter to Mental Workload and Lighting Conditions. In Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI ’16). Association for Computing Machinery, New York, NY, USA, 5776–5788. DOI:https://doi.org/10.1145/2858036.2858117

Did you understand this block?

Can you answer these questions?

- What information will a gaze tracker provide?
- What are basic measures we can take from the eye for interaction?
- What is the advantage of using smooth pursuit instead of fixations in an interface?
- What is the Midas touch problem? What are common solutions?
- Give examples for gaze interaction user interfaces?
- Give examples of applications of gaze tracking?
- What can pupil size tell you?

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