Friedrich-Alexander-Universität
Department Artificial Intelligence
in Biomedical Engineering | AIBE

Chapter 9:

Different Technologies for HCI

Overview

This chapter on technology should provide a basic understanding of the available technologies and can be used to create a suitable interaction mechanism between humans and computers. You need to understand the pros and cons of technologies to assess the current interaction you're designing for. Only if you have available technologies and their characteristics in mind you can choose the appropriate technology for your interaction. Also, keep in mind whom you are designing for!

Computer to Human

Output (Computer to Human)

In this chapter, we will cover output technologies and devices used in the context of HCI. The chapter is subdivided into devices for the human senses regarding:

- Vision
- Audio
- Haptic
- Smell/Taste

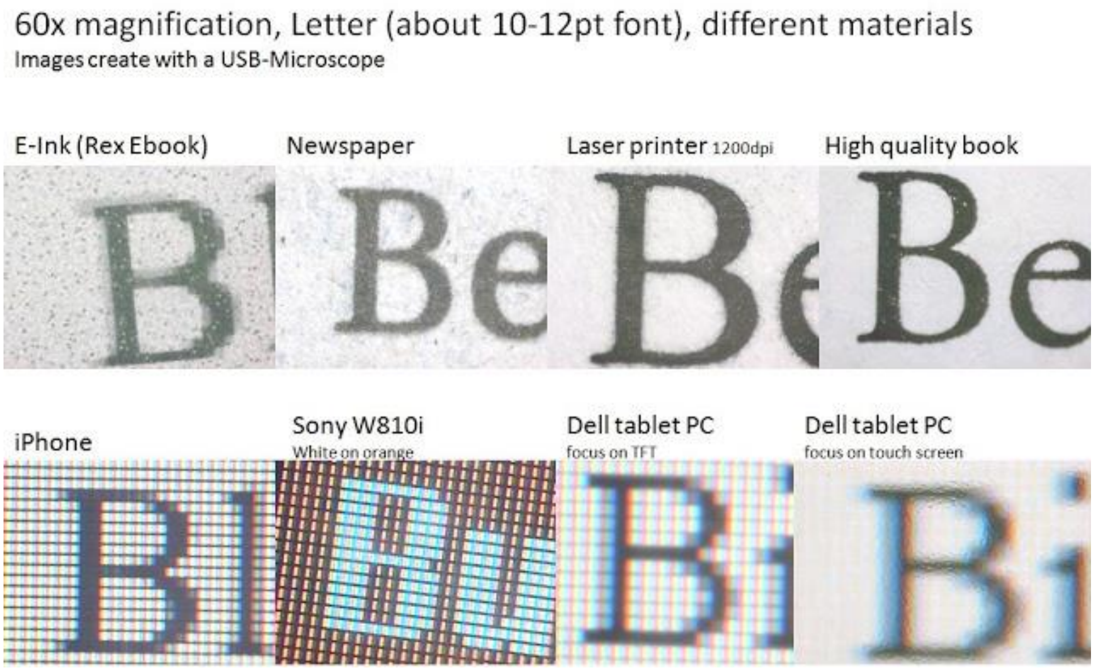
There will be an additional chapter in which alternative output methodologies play a role, like activating the human body from an external source such that the human body becomes the output device itself.

Also, there will be a short chapter on output devices that cover more than one human sense.

Vision

First, visual output can be characterised into **static** and **animated** types. If you think of static, it might be printed text, images, or data graphics. But there can also be animated text, graphics, or videos. So over time, the respective element can change.

Second, based on the type of visual input, you choose the appropriate (or feasible) technology. Technology types include **prints to paper, displays, or projections**. For example, high-quality static text would rather be printed on paper. Still, a lot of people prefer reading from paper instead of displays. The main reason is that the quality of printed text can be very high compared to the discretised pixel grids of display technology which is shown in the following image:



No paperless offices yet.

This depends on the printer hardware's quality (Resolution – typically dpi (dots per inch)). But how is HCI related to paper? The paperless office does not yet exist! Still, printing can serve as an output mechanism and scanning as an input mechanism that relates to an interaction between humans and computers. So, in most offices, paper is still a temporary interface that is often used. Imagine you print out a checklist on paper. The user interacts with the checklist on paper by checking all the elements that are done. After checking all elements, the list will be scanned and archived somewhere digitally.

A more convenient way would be to show a document – you're currently working on something like a checklist or similar – on display for further and continuous modification. Especially when using the animated type, the output device implements specifications that should adhere to the physiological limits of the user's (human's) visual system. So important factors for the output devices are (for example):

- **Update rate**
  too low → annoying
  too high → increased costs without further visual improvements
- **Spatial resolution**
  too low → not usable
  too high → increased cost without further visual improvement
- **Dimensions**
  too small → cannot see anything
  too large → human starts to turn head, which increases discomfort when using the device
- **Colour representation**
  colour-blind users?

Common and well-known visual output devices:

Upper Left: TFT LCD Screens (Typical color resolution 640x480 to 3840x2160 (and increasing) 80 - 300 pixel/inch (and increasing) Viewing angle to 170°) **Right:** Hi-Resolution Color Displays by Apple 2732x2048 pixel, 12.9", 264 pixels/inch **Lower Left:** Projectors with similar specifications. Additional criteria for projectors: Weight, Noise, Lens, Image correction, Projection distance, Connections, Lamp life time

Application-specific displays:

Hi-Resolution Grayscale Displays

- Use for medical imaging, radiology
- Calibration software
- E.g. Eizo RadiForce RX1270
  - 4200 x 2800 pixel
  - 10-Bit simultaneous grayscale display (1.07 billion from a palette of 543 billion colors)
  - 30.9" monochrome LCD
  - 12 mega pixel

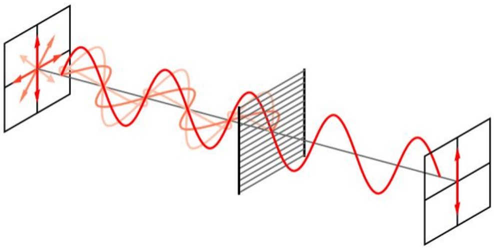
All these technologies are 2D screens and projections, capable of only showing 2D content, which is sufficient for most applications or use cases. However, especially for the medical application (body volume reconstruction of MRI scans) or in general, when creating 3D content (machine parts in CAD, game objects, and characters in blender), it might get difficult to work on a 2D screen.

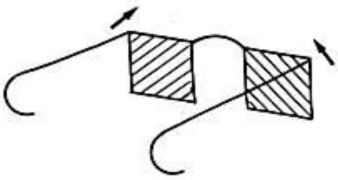
Because of that, 3D visual output devices are on the rise, which will be explained in the following.

3D-technology and output devices:

There are different ways to show 3D content. A well-known one are **shutter glasses.** The glass for each eye can be closed (shut) separately, which is done alternately at very high speeds. This means at a time, only one eye perceives an image. Alongside the eye, a screen or projection is synchronised so that each eye perceives two different images. Because the optical shutter switches at a very high speed, the illusion of a continuous image is perceived. However, each eye gets only "half" the time of a projection. This technique requires good synchronisation and very high speeds (>120Hz), which requires high computational power.

Shutter glasses with optical shutter system





Polarization filters and polarization glasses

Another technology are **polarisation filters**. This is still used in cinema today. The image for the left eye is encoded in a different wave direction than the image for the right eye. The polarisation filter aligns with the desired image wave direction to pass through the filter. The other image decoded in a different wave direction is blocked. Thus, only the image for the desired eye is perceived.

A modern technology becoming more and more present are **Virtual and Augmented Reality Headsets**. There we have a display for each eye. This requires a high refresh rate and thus computational power.

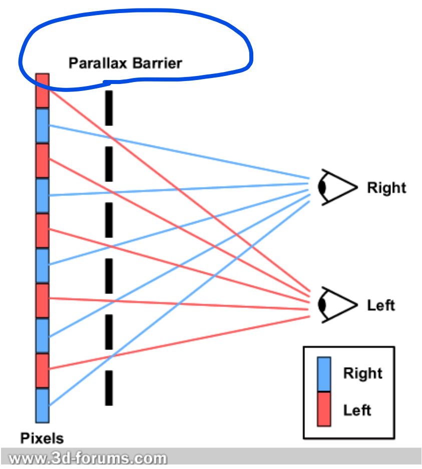
Virtual Reality Headset with a display for each eye.

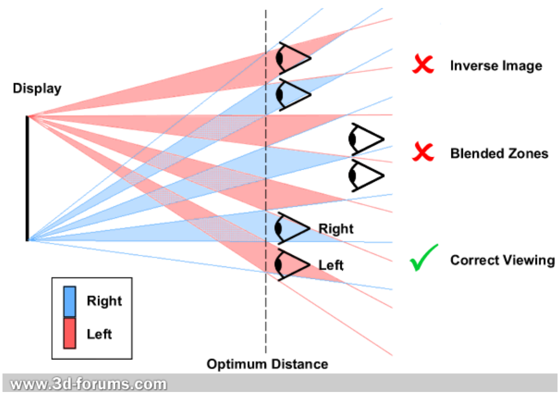
These technologies all require glasses that someone needs to put on. However, in some scenarios, that was not feasible. Furthermore, before the success of VR/AR headsets, the above-mentioned glasses reduced the perceived image quality. Therefore, **auto-stereoscopic 3D Displays** were developed that allowed seeing 3D content without special glasses in high resolution and with full brightness. The same technology was used in the Nintendo 3Ds.

red - left blue - right.

The image is again split so that some pixels (red) only show the image for the left eye and the other pixels (blue) show the right eye's image. To ensure that only the correct image travels to the respective eye, a parallax barrier is added. This barrier is blocking the left image from the right eye and vice versa. The issue is that the user must be in the exact position in front of the screen. Changes in position and distance to the screen will break the illusion of 3D.

Medical applications for auto-stereoscopic 3D displays.

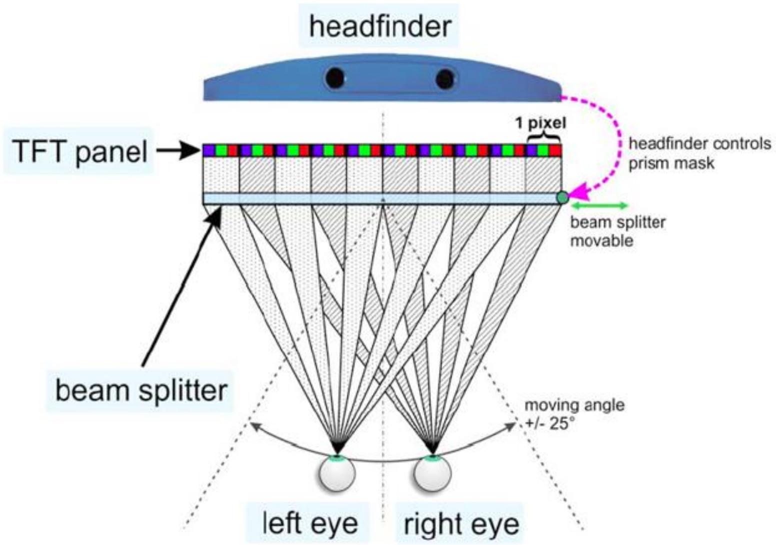




Left: Parallax barrier for image separation

Right: Only very limited viewing angles possible

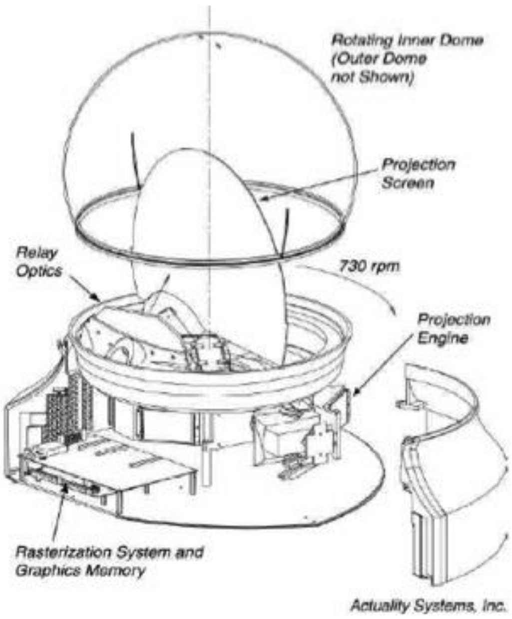
For the problem of limited viewing angles, the **headfinder** was added. The headfinder tracks the user's position. Based on this position the parallax barrier (here the beam splitter) is moved to the correct position. In that way it was possible to create the illusion of depth in multiple viewing positions. The image above for medical applications for auto-stereoscopic 3D displays actually has a headfinder on top of the screen.



Head finder moves parallax barrier

Headfinder (IR or camera based) tracks the user's position and moves the parallax barrier (beam splitter) accordingly

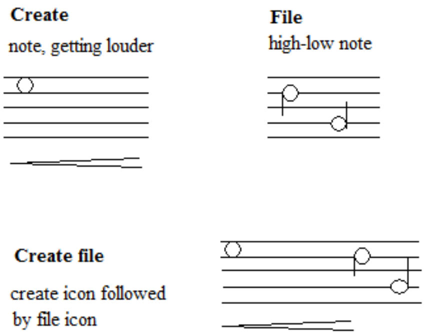
Finally, we want to show a volumetric 3D display which consists of a very fast rotating projection screen. The rotating projection screen is too fast to see, however, the image created can be perceived. The projection engine (projector) is rotating alongside the screen. Thus, a new perspective of the 3D object can be created on every frame that is drawn (5000 fps for smooth simulation). This allows to move around the object within the sphere and see the object "from behind". And it allows multiple viewers at the same time. For further inspiration look here: https://voxon.co/



Volumetric 3-D Display. The object consists of 2D slices. The projector and projection screens are rotating fast so that all the individual 2D slices together form a 3D object.

Audio → auditory icons → earcons ; teams sound.

Auditive output can also be characterized into different types. Like icons stand for small images that lead to a certain association (trash can on the desktop for deleting files), **auditory icons (also earcons)** can be used to associate a short melody or sound with a certain action (incoming emails). You could argue that the opposite would be real **music** with multiple instruments and perhaps also someone who sings. Both earcons and music can be composed of **synthetic sound**. So, sound that does not appear in the real world. But synthetic sound could at least imitate real sounds like **spoken text**. Synthetic sounds could in this case be created with a text-to-speech app. The classification of auditory output is not trivial.



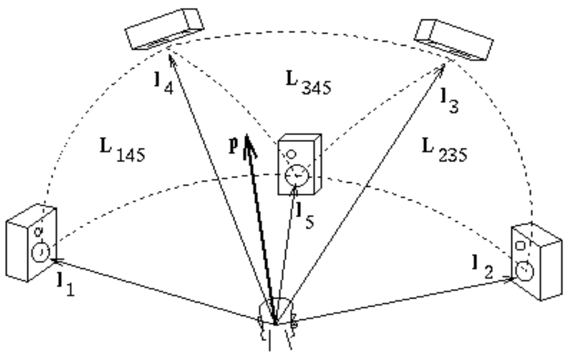
Earcons for two different actions (create and file). Both earcons together again form an earcon.

The principle of sound and audio for output is rather easy. We can provide information (success of certain action), ease the use (screen reader with text-to-speech apps), and simply play media (music).

However, a more interesting concept in terms of HCI is **spatial audio**. The idea is to modify the audio in a way that it supports the two channels we have (two ears on each side of the head). As you should know from the chapter "Humans", we can determine a Head-Related-Transfer-Function (HRTF). Now we again apply this HRTF to modify audio. The best experience is achieved when using headphones. Headphones are used because they fix the geometric relationship between the physical sound sources (the headphone drivers) and the ears. Headphones also eliminate crosstalk between the binaural signals. With additional signal processing, we can conceivably compensate for these effects, allowing spatial audio to be presented over free-field speakers. However, to compensate for the effects of speakers, the spatial audio system must have knowledge of the listener's position and orientation with respect to the speakers. This often leads to complex room setups for a limited number of listeners as shown here:

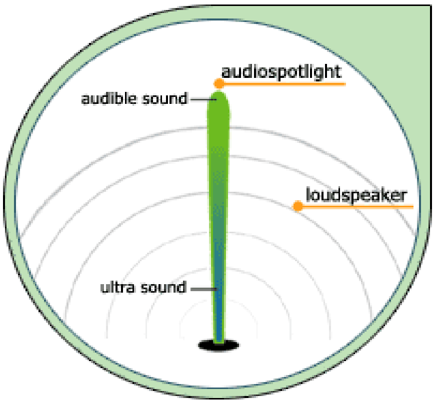
binaural signals

When you don't want to wear headphones and don't want to disturb others around you, **audio spotlight** might be



Spatial audio room setup. Lots of speakers are required and the user's position must be known.

an interesting approach. It is used in museums to create audio effects just at one specific location (in front of a picture). Thus, the audio guides we use to know from museums (worn headphones with an mp3 player attached) can be replaced by audio spotlights that provide the information at a specific location. The visitor does not have to use additional hardware. For further information: http://www.holosonics.com/



directed.
ultrasound

Audio spotlights: Directed ultrasound is generated, transformed in the air in audible sound, generates a sound only at a predictable location

Haptic

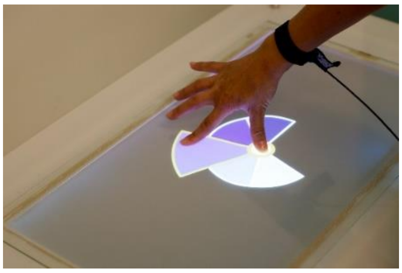
Again, we start with the characterization of the output methodology. This is rather a listing (not conclusive) of different types we came up with: **Vibration, Mechanical forces / motion, Shape change, Stroking motion, Temperature change, Air pressure / flow, and Electrical signals**.

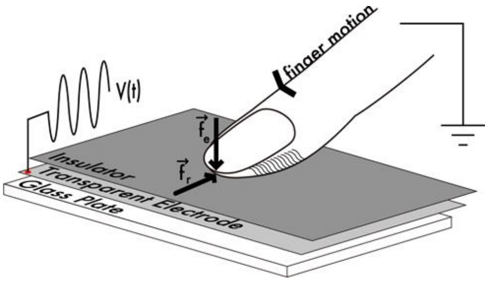
All these different types can be used for haptic output. The usage is just like icons or earcons. The rhythm of the vibration associates a certain action. A prominent example is this computer mouse:

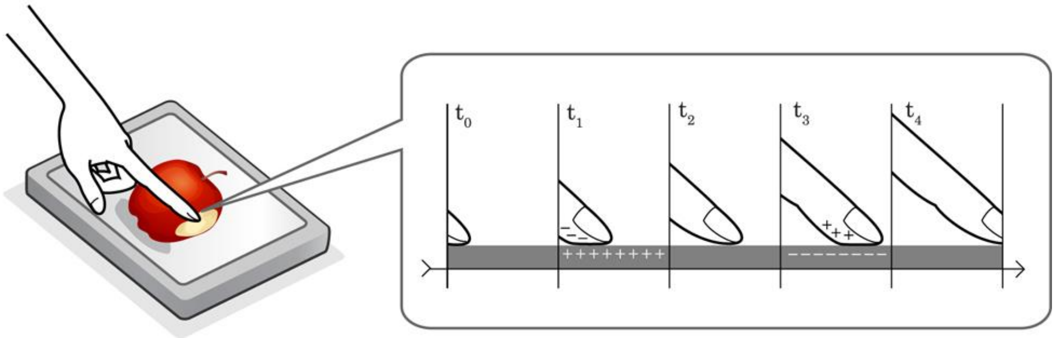
Force feedback mouse:
The vibration is used in:
- Menu slots that snap in
- "Feeling" icons
- Feel different surfaces
- Increase accessibility for visually impaired
- Gaming

The last point of gaming is of course not well supported by the mouse because only the thumb receives haptic feedback. This issue is tackled with full-body suits equipped with small air cushions. The cushions can be filled with air. In a kickboxing simulation, a blow to the body can be simulated by inflating the cushions at the respective position.

The point of feeling different surfaces is today also applied to touchscreens using electrostatic vibration.



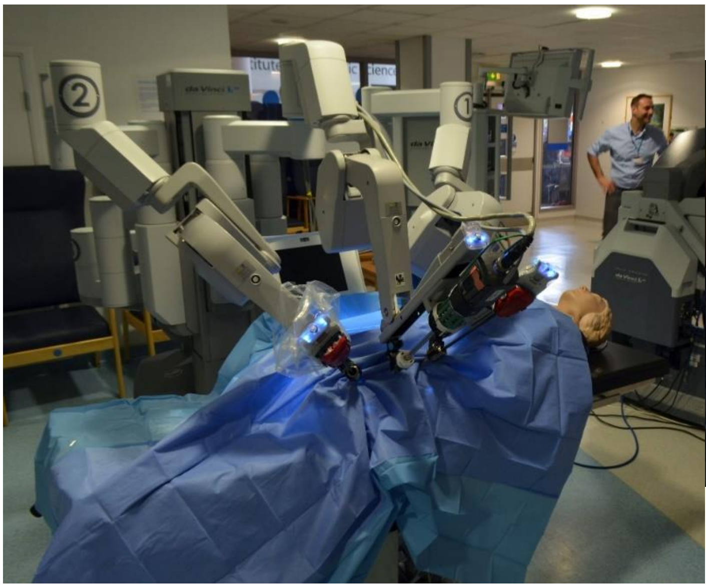


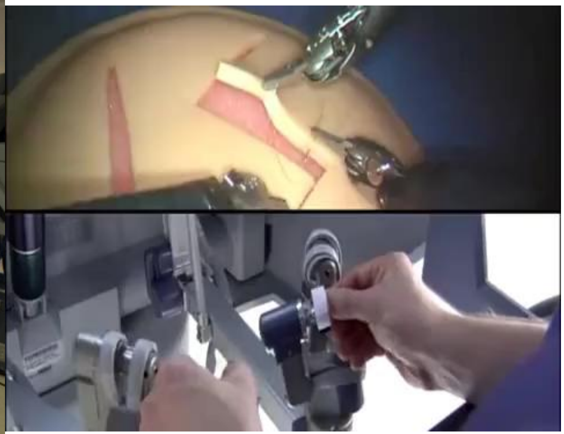


Olivier Bau, Ivan Poupyrev, Ali Israr, and Chris Harrison. 2010. TeslaTouch: electrovibration for touch surfaces. In Proceedings of the 23nd annual ACM symposium on User interface software and technology (UIST ’10). ACM, New York, NY, USA, 283-292.

Haptic output is not only used to provide information and improve our user experience. It can also be used in **therapy** when recovering from a stroke. Some people must learn again how to write. The device to the right is a 6degree freedom pen with force feedback. So, people can learn what different resistance feels like and learn again to react accordingly. This helps to identify how much pressure is required or if the applied pressure is too much.

The same idea is thought further in the **Da Vinci Surgical System**.
It was the first remote-controlled surgical system specifically designed for use close to the battlefield. The surgeon is located somewhere safe (USA) but the wounded soldier can be treated near the battlefield in foreign and distant countries. The force feedback is required to simulate the resistance of tissue when cutting through it and it also helps to stabilize hand movements. In the images below you see the system in action. The left image shows the patient and the robotic system. This robotic system is controlled by the doctor (lower right image). The surgeon sees the patient as shown in the upper right image.





By now all the shown systems and haptic output devices are supportive systems with a specific purpose. Another interesting system is rather for fun. However, it is a haptic output device and thus we want to present it: **The pain station**

Pain station: A Pong like game that is enhanced with pain when failing.

https://www.youtube.com/watch?v=AmFPURsKKh8

Smell / Taste

And again, smell and taste can be used to associate actions (olfactory icons, pull trigger → smell of gun powder). In the 19th century, the Chinese fire clock (a slow fuse that lights successive compartments, one at a time with a new smell) is an incense clock. Each new smell (another incense) marks a passage of time. So, you can "smell" the time.

Smell and taste are very important senses because we learned to make use of them to survive. Joseph "Jofish" Kaye wrote an article about that:

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

In that article he wrote about how humans use their sense of smell:

- Is food safe to eat?
- Is there danger due to a fire?
- Relationships

However, he stated that this is an almost entirely unexplored medium in HCI. There are reasons for this:

- Technical difficulties in emitting scent on demand
- Chemical difficulties in creating accurate and pleasant scents

acclimatize.

We have a thousand different kinds of olfactory receptors in our nose, and it is thought that each can sense a single kind of chemical bond in a molecule. It is also very hard to classify scents. Examples: how does mint taste? It tastes like …mint. Furthermore, we rapidly acclimatize to a scent (less than 1 minute) and we will no longer smell the scent.

Although it is very hard to design for these senses there are technologies supporting them. They are often explored in theatres or cinema:


Left: Armrest with olfactory module. **Right:** Scents in ampules.

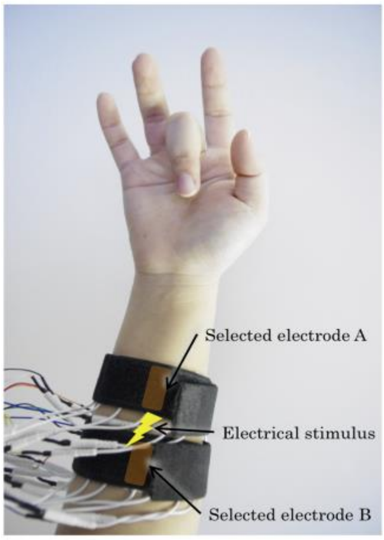
Still, there are not many technologies and those available only support a very limited number of scents. With the rise of Virtual Reality, research is done to include smell into our virtual experience. There are a few new companies trying to explore the olfactory medium for their VR experience (https://feelreal.com/, https://ovrtechnology.com/)

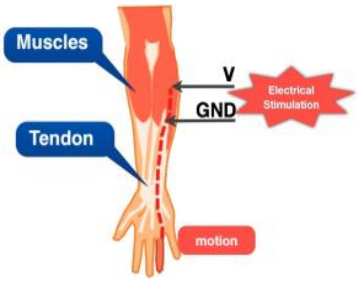
Activating the human body

The human body itself can be used as an output device. We would like to introduce two techniques:

- Possessed Hand
- Controlling Walking

Possessed Hand is a technique for controlling human hands using electrical muscle stimuli. The use-cases are therapy or also learning. If you image a patient after a stroke, you will be able to guide hid hand to accomplish certain actions. But also, someone who wants to learn an instrument could benefit from expert guidance that directly influences the hand movement. Thus, the perfect way of moving your hand/fingers can be learned directly.





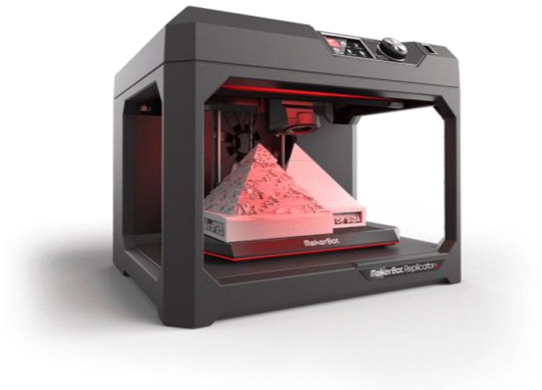
Controlling Walking is a similar technique for a different application. You can give impulses via an app to create a navigation system that directly influences the walking direction. This can help disabled people to cross the street or it could simply be a novel navigational system.

M. Pfeiffer, T. Dünte, S. Schneegass, F. Alt, and M. Rohs. Cruise Control for Pedestrians: Controlling Walking Direction using Electrical Muscle Stimulation. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, New York, NY, USA, 2015. Pages 48-61

Other output devices involving multiple human senses

We already talked about printers that create 2D images and text on paper. However, there are "printer" that also create output that not only supports the visual sense but also the haptic sense like a laser cutter or even a sewing machine. The output has a visual component, but you can also grab it and feel it. You can even build a 3D object out of the "2D" cuts of a laser cutter.

This also holds for 3D printing technology which today is advanced. You can use different technologies, e.g., Stereolithography, Fused Deposition Modelling, and Selective Laser Sintering. These different techniques allow different Materials like: Metals, polymers, ceramics. The output is visually appealing and haptically perceivable. The applications are manyfold, for building component replacements for machines to new production lines for on-demand production. But also, medical applications for individualized therapy and bone reconstruction (patient-specific implants). And archaeology to safe and exhibit endangered buildings and monuments.



https://www.stratasys.com/medical

https://www.noaraviv.com/

https://all3dp.com/2/3d-scanning-3d-printing-in-archaeology-paleontology/

Input (Human to Computer)

In this chapter we will cover input technologies and devices that are used in the context of HCI. The chapter again will be subdivided into devices for the human senses regarding:

- Vision
- Speech
- Haptic

There will be an additional chapter in which alternative input methodologies play a role like affective computing which means that we connect our body to the computer and control it by our thoughts and the resulting changes in EEG signals or muscle tension and also other physiological measures.

Vision

Modern eye tracking systems can track the eye movements and output information about where someone was looking at and how the pupil dilation behaves. In lots of applications this information is used for analysis. Especially in psychology, specific search strategies or memory workload specific changes in pupil dilation can lead to new models of human behavior and thus help to better understand human behavior.

However, eye tracking systems can also be used as input system. For example, a button can be "clicked" by looking at it. Also, a log-in methodology could be implemented by simply following a pre-defined path like a circle or an infinite loop. The individual jitter of a person helps to identify the person using the device and thus chooses the correct account to log-in.

The issue of using eye trackers is that they are still expensive. Especially the stand-alone devices that have a high sampling rate. With the rise of VR new headsets evolved that have in-built eye tracking systems that have a lower sampling rate.

Stationary eye tracking system (indicated by yellow circle) placed underneath a monitor. The red overlay on the monitor shows where the person was looking at.

Left: Early mobile eye tracking systems.

Right: Modern built-in eye tracking system. The eye tracking system consists of IR-lights and cameras placed around the eyes.

→ Gold touch.

When using eye tracking for input, an issue arises called the **Midas Touch Problem.** The name refers to Kind Midas (Greek mythology). King Midas asked for the ability to turn everything he touches into gold. However, this was a bad idea because he no longer was able to eat, and he also killed people by simply touching them and turning them into gold. This story was taken for naming the selection interaction problem in eye tracking. When someone is looking at a button, how will you know that the person really wanted to select/click that button or was simply looking there? There are multiple different techniques how to avoid this. A quite recent one is explained here:

Video Link: https://www.youtube.com/watch?v=kD-q1AzIlek

Speech

Speech recognition has become a popular research field. Today there are already a lot of products on the market that can understand us by listening to us and interpret our intention. Speech can thus be used as input. May it be for commands like adding apples to the grocery list or a doctor dictating a patient diagnosis that will automatically be put into writing.

Below you will find a few images of products that have in-built speech recognition for speech input:



Haptic

Haptic can be put into three main categories:

touch
kinesthetic

- Touch (the body feels different objects and feels where it was touched)
- Kinesthetic (the body feels itself and its own relative position of body parts in space)
- Locomotion (the body can move)

Da Vinci Surgical

locomotion.

These categories can also be applied to input devices. **Touch devices** are well known, because almost everyone at least uses one of these devices daily. May it be the touch screen or a mouse when operating a tablet, smartphone, or computer:



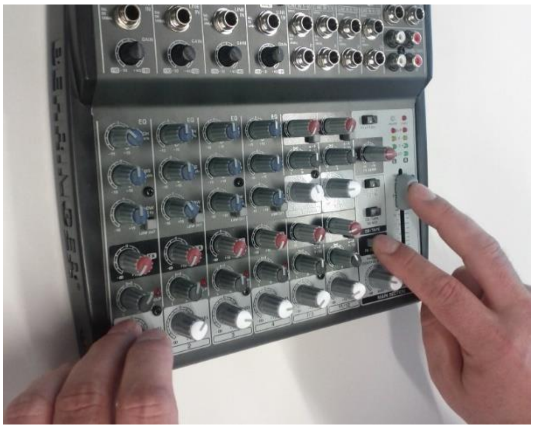
Thereby, touch screens are a special case because they seem to combine output and input. Of course, the conductive material is a different layer next to the actual screen with illuminated pixels, however, the screen shows icons that can be pressed. The software of the device interprets the touched position in x and y direction and checks if a clickable icon is located at that position. If so, the app is executed.

Kinesthetic input devices may be less popular. We already learned about a kinesthetic input device, namely the **Da Vinci Surgical System**. We defined it as output device because of the haptic feedback for the doctor when operating the system and for example cutting through tissue. However, the system is also an input device for the actions and movements the doctor performs. These movements must be transferred to the remote system part which conducts the surgery. This is possible because the tools of the doctor are connected to robotic arms that know their position relative in space. This information can be transferred to the remote system part and thus an exact copy of the actions and movements of the doctor can be achieved. The input parts of the system are again depicted on the images below:

Mouse

Locomotion devices probably need no further explanation. Everyone knows a mouse that recognizes relative changes in x and y positions. These changes are transferred to the cursor on the screen. Thus, you can move the cursor to the desired location on the screen.

Most often analog input devices also have a digital representation. For example, a mixer console with multiple channels and knobs to modify a specific channel.



Affective Computing

Brain Computer Interaction

Affective computing comprises Brain computer interaction (BCI) from neural signals. So, the human body is no longer part of the interaction but solely the brain and more specifically the brainwaves are used to initiate the action. Further signals to be used for affective computing could be muscle tension or other physiological measures like pulse, galvanic skin response or the like. Further research is done to identify Emotions based on facial expressions and adapt a system accordingly.

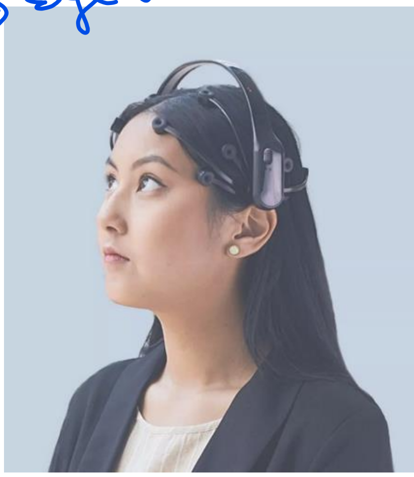
Brain waves.

An early BCI example was the **Brain Ball** (picture to the right). The idea was to relax. Only in a relaxed state the user could move the ball closer to the opponent. This should help people to learn how to relax. Thus, stressed people can willingly relax in stressful situations and better cope with them.

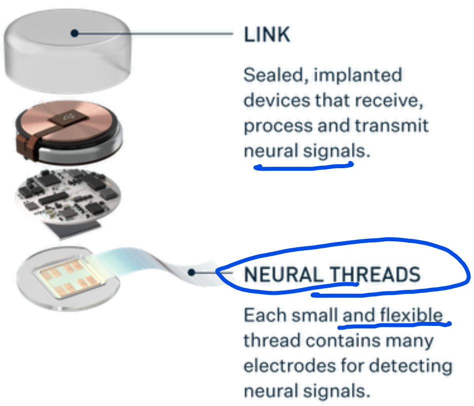
https://www.wired.com/2007/09/buzz-aldrin-bea/

Today mobile EEG headset can be bought and used in all kinds of applications. Emotiv's Epoc system has an impressive resolution for a mobile device http://www.emotiv.com/. At our lab we also conducted experiments with BCI. We implemented an interaction in which the user should think about pressing a button. The basic interaction worked; however, the specific button selection is tedious. When combining eye tracking and BCI you could also avoid the Midas Touch Problem.

→ eye tracking + BCI



Neuralink is currently going a step further. They build implantable electrodes to receive signals from within the brain. The reason is that head-worn EEG sensors are prone to artifacts from different sources (movement, bad conduction, hairs, …). Thus, a signal from within the brain is clearer and less distorted. The Neuralink device consists of a link part, that sends the collected signals to the device that should be controlled and the neural threads which are micro-scaled threads distributed over the brain and connected to the implanted link part.



Taxonomy

We presented a lot of input devices but in contrast to the presented output devices we did not characterize the input devices. We only mentioned the three main categories we expect input devices to appear. The reason is that the Taxonomy of input devices is very well elaborated. In the following we will present two taxonomies defined by **Bill Buxton** and **Stuart Card**.

Taxonomy for Input Devices (Buxton)

physical properties to logical parameters

> *'…basically, an input device is a transducer from the physical properties of the world into the logical parameters of an application.'*
> *(Bill Buxton)*

Bill Buxton defined four criteria to assess input devices:

- **Is the input continuous or discrete?**
- **What is the Agent of control?** → hand, foot, voice, eyes ...
- **What is being sensed?** → position, motion, or pressure
- **What is the number of dimensions being sensed?** → 1, 2 or 3

Also, he separated devices that are operated by touch (T) vs. those that require a mechanical intermediary between the hand and the sensing mechanism (M). With these characteristics he compiled a table containing example combination of these characteristics:

		Number of Dimensions							
		1		2				3	
Property Sensed	Position	Rotary Pot	Sliding Pot	Tablet & Puck	Tablet & Stylus	Light Pen	Isotonic Joystick	3D Joystick	M
					Touch Tablet	Touch Screen			T
	Motion	Continuous Rotary Pot	Treadmill	Mouse			Sprung Joystick Trackball	3D Trackball	M
			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	

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Taxonomy for Input Devices (Card)

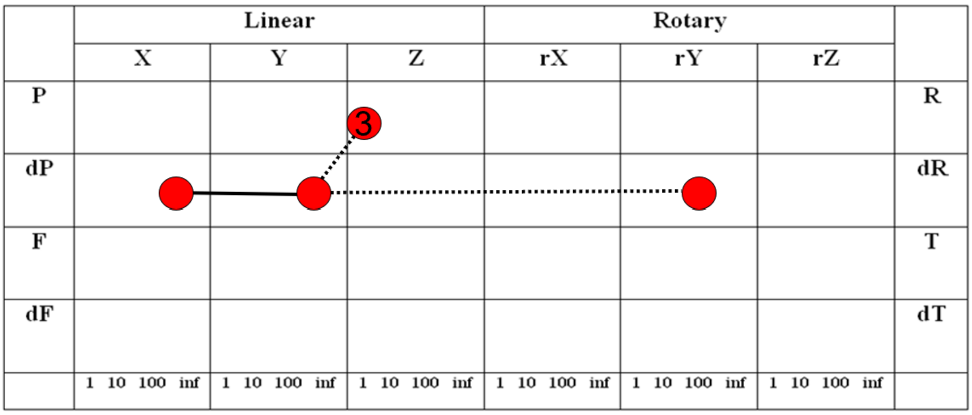
Stuart Card later defined a similar model taking the physical properties into account that are used by the input device. The two channels that are sensed are position of the device or the force applied to the device. The two sensing channels can be modified linearly (move mouse from one position to another) or rotary (positional change along a rotation point). A different concept that Bill Buxton did not consider is the type of modification. There are two types of modification: an absolute and a relative modification.

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

modification.

A mouse for example is a position sensed device with linear and relative modification. Card also developed a table that could be used to visualize an input device.

Let's stick to the mouse example:
This shows a mouse with a wheel and 3 buttons. The points in X and Y show that the relative position (dP) change is sensed on potentially infinite scale. You could infinitely continue to move the mouse to either side. The relative position is used because although the mouse can be moved infinitively to the right the cursor on the screen won't do



the same. The cursor will stop at the border of the screen. Whenever we change the direction of the mouse the cursor will immediately also change the direction and again follow the relative positional change. Buttons are commonly absolute positions in a range of 1, meaning they are either pressed or not. Only buttons which required a lot of force would be listed in the rows F or dF. The mouse wheel is a rotary modification. The reason for being a relative type is the same as for the positional change.

A touch screen is an example for absolute positions. You can only touch the screen within its own dimensions. If you click next to the screen nothing happens. So you can only touch the specific X and Y position on the screen. In Card's table this would look like this:

	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	

The red dots are no longer on infinite scale because the screen is limited. There is no infinite screen built yet.

To get to know more about the taxonomy and why some connections in the wheel mouse example are dotted, please read:

Card, S. K., Mackinlay, J. D. and Robertson, G. G. (1991).
A Morphological Analysis of the Design Space of Input Devices.
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