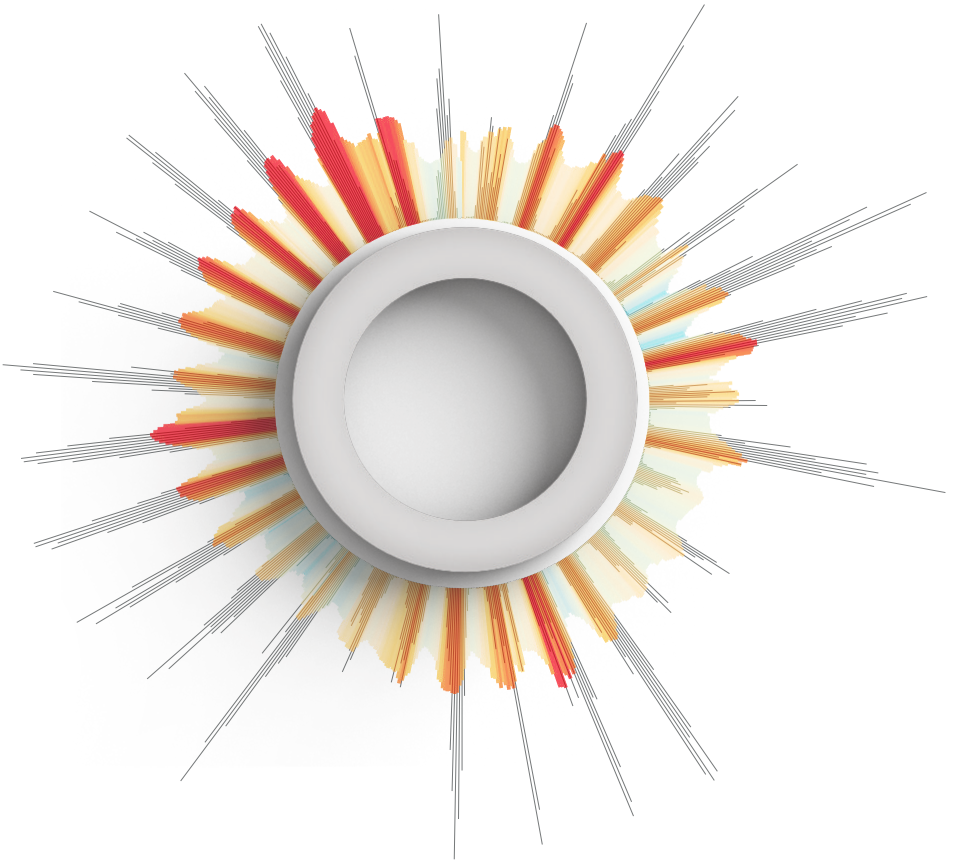
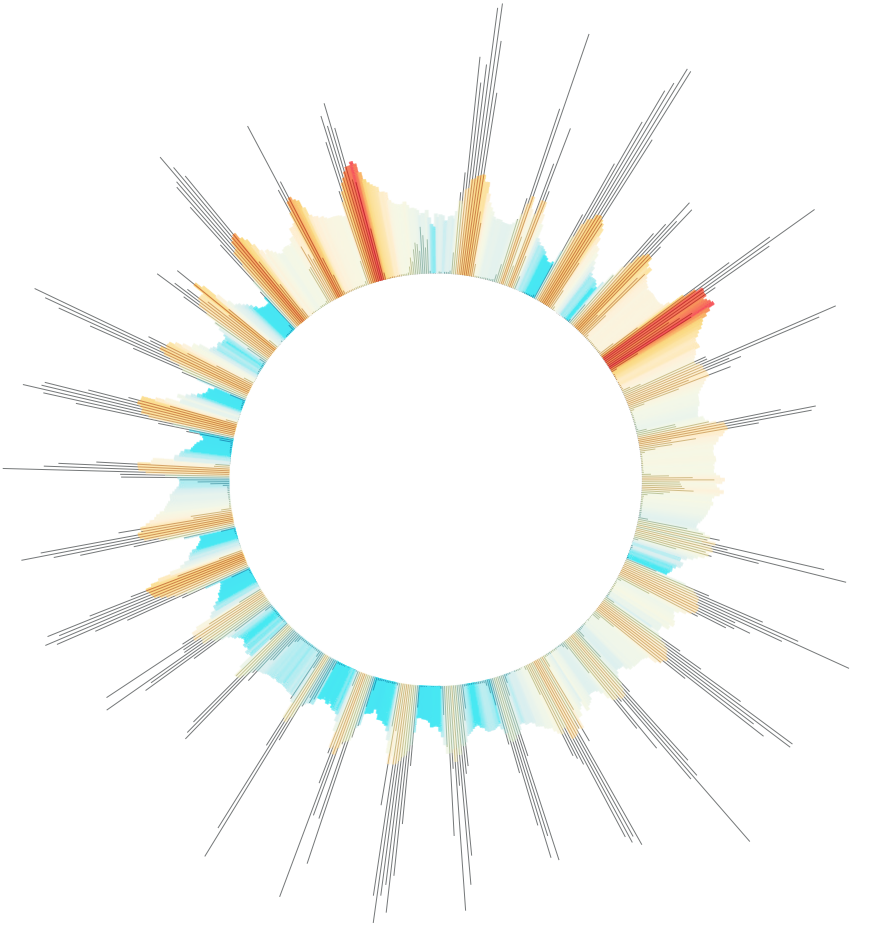




This is a revised and corrected version. In respect of content no changes were made.

FH Aachen
FB04 | Gestaltung
Kommunikationsdesign

Bachelorarbeit zum Thema :

Explorative Erprobung haptischer Elemente für grafische Benutzeroberflächen auf Multitouch Displays

Explorative evaluation of haptical elements for graphical user interfaces on multitouch displays

Zur Erlangung des Grades Bachelor of Arts

Vorgelegt von Laura Wagner
Abgabe: 04.07.2019

1. Introduction.....13

1.1 Tangible user interfaces.....16

1.2 Why write a BA thesis about tangible interfaces?.....18

2. Input devices and their degrees of freedom.....21

2.1 Classifying “tangibles”.....23

2.1 Degrees of freedom definition.....24

2.1 One degree of freedom (binary).....28

2.2 One degree of freedom.....29

2.1 Two degrees of freedom.....30

2+1 degrees of freedom.....32

3+ degrees of freedom.....34

2 + 3 + 1 degrees of freedom.....35

3+ degrees of freedom.....38

6+ Degrees of freedom.....39

3. Digital interface metaphors.....43

3.1 Sensual metaphors.....44

3.2 Affordances and affordance signifiers.....45

3.3 Information visualisation and visual metaphors.....47

3.4 Information sonification and auditory methaphors.....48

3.5 Information tactilization and tactile metaphors.....49

4. Visionaries of gestural and multi-modal interaction

4.2 Beginnings of multi-touch technology.....54

4.3 tangible bits and radical atoms.....56

4.1 Rich Gestures.....58

5. Tangibles in research

5.1 Slab Widgets.....64

5.2 Flexibles.....65

5.3 Eugenie and Eugenie++.....66

5.4 Plankton Explorer.....67

5.5 FlowBlocks and System Blocks.....68

5.6 Comparing TUI and GUI.....71

6. Commercialised tangible user interfaces

6.1 Surface Dial.....80

6.2 The Touch™.....82

6.3 3D Connexion....83

7. Touch-input technologies

7.1 Basic components of a touch screen.....87

7.3 Resistive.....91

7.4 SAW (Surface Acoustic Wave).....93

7.5 Multi point vs. multi touch (capacitive).....94

7.6 Single touch vs. dual touch (capacitive).....95

7.7 Multi hand vs. multi user interaction.....96

7.8 Multi point object interaction vs. TUI object interaction....97

7.9 multi touch vs. 3D touch (capacitive).....99

Computer–human human-computer modalities

8.1 Modality in human–computer interaction.....103

8.2 Computer–Human modalities.....104

8.3 Human-computer modalities.....106

9. Feedback

9.1 Counter-intuitive and opposite feedback.....116

9.2 Unhelpful, arcane or “rude” feedback.....116

9.3 Superfluous and annoying feedback.....117

10. Visualising weather and energy data

10.1 Visualisation goals.....122

11. Data visualisation

11.1 Visual encoding for Data Visualzations.....130

11.2 Encoding additional quanititative variables.....132

11.3 Visualising x-y-relationships.....134

11.4 Visualising x-y-relationships.....136

11.5 Visualising proportions.....138

12. Interface design

13. Tangible design

13.1 Tangible design principles.....152

13.2 designing tangibles with CAD.....155

13.3 3D printing tangibles.....156

13.4 Conductive ABS.....157

13.5 Tangibles made from wood with conductive coating.....163

14. Conductive materials for tangible coating

14.1 Experience with “Bare Electric Paint”.....167

14.1 Experience with Graphene coating.....169

14.2 Experiences with copper-based coating.....169

15. Preliminary results

15. 1 RGB colour mapping.....187

16 Outlook

16.1 Next goals.....227

1. Introduction

“all digital information [will have] **physical manifestation so that we can interact directly with it—as if the iceberg had risen from the depths to reveal its sunken mass.” []**

Hiroshi Ishii

1.1 Tangible user interfaces

Devices with **interactive multi-touch surfaces** are ubiquitous and are getting more and more sophisticated in terms of providing experiences that, thanks to ultra-low latencies and prediction algorithms, are smooth and have a natural feel to them. Gesture systems have been designed that don't have to be laboriously learned, but are discovered by intuitive means. Touch-screens are not only an adequate replacement for user interfaces with knobs and sliders, but are more efficient and universal in most cases. The graphical interfaces carry skeuomorphisms, metaphors and digital representations of old and known means of input, like knobs and sliders in order to help the user to instantaneously understand how to use them.

Multi-touch surfaces provide universal means of input, for almost all digital applications.

But there is an (apparently) strong human need that gets satisfied by worry stones and prayer beads, and more recently knobs, buttons and sliders: the need to fidget. This might be the reason why Matthew and Mark McLachlan had such a success with **FidgetCube** (a small cube that carries all kind of tangible and 'fidgetable' attachments) when 54,926 backers pledged $6,465,690 more than 431 times as much as the initial goal of 15.000 to help bring this project to life on Kickstarter. [1]

FidgetCube's success: one prove for the human need to fidget.

Tangible User Interfaces (TUI's) in the configuration explored in this thesis, consist of physical tokens that are

"Fidget Cube – Antsy Labs." https://www.antsylabs.com/products/fidget-cube. Accessed 24 Jun. 2019. [1]

placed on top of a surface and allow for manipulation of the digital world beneath them, which can distinguish them and recognise their orientation and translation (and depending on the setup also deformation and acceleration). **TUI** are an interface type, that interlinks the digital and physical worlds, and allows for exploration of digital content through manipulation of physical objects. Tangibles are not only mere input devices, but they can **superimpose** elements of the graphical user interface or become fused with it. In other words: they are - **part of the interface brought to life.**

Hiroshi Ishii of the MIT Tangible Media Research lab, who also coined the term 'tangibles' mentioning them in his research more than 20 years ago, defines the **"Tangible user interface"** as interim step before user interfaces will have been completely merged with, and be indistinguishable from our reality. He envisions a future of interaction, in which

"all digital information has physical manifestation so that we can interact directly with it — as if the iceberg had risen from the depths to reveal its sunken mass." [2]

[2] "Tangible Media Group - MIT." https://tangible.media.mit.edu/. Accessed 25 Jun. 2019.

1.2 Why write a Bachelor's thesis about tangible interfaces?

It may - at first seem arcane, to add tangible objects to a sleek and extremely well-designed, touch-enabled and self-sufficient surface that can fully be operated with the hands alone and seems to have already overcome any additional peripherals attached to it. A touch enabled surface, carefully developed and designed to understand human gestures in order to afford a seamless, and enjoyable interaction that works universally across a broad variety of applications created for it.

So why bother and spend time placing objects on top?

First of all, research about interfaces with tangible, especially research comparing graphical user interfaces with tangible-enabled counterparts suggest, that at least in some situations and in some aspects the performance of the latter is superior. I extensively analysed and compared studies dealing with this topic in chapter 5. As Bill Buxton of Microsoft points out in his paper "Multi-Touch Systems that I have Known and Loved":

"Everything is best for something and worst for something else. The trick is knowing what is what, for what, when, for whom, where, and most importantly, why." [3]

Universal vs. bespoke

Also, in the studies I've compared, some applications are very bespoke to one particular problem or subject. Like for example in **Flow Blocks** [4] by Oren Zuckerman (more thoroughly looked at chapter 5), where physical tokens can be stacked together in order to model a dynamic system. For a bespoke system, tangibles might add unique value.

"Multi-Touch Systems that I Have Known and Loved - Bill Buxton." http://www.billbuxton.com/multitouchOverview.html. Accessed 30 Apr. 2019. **[3]**

"(PDF) Flow blocks as a conceptual bridge between understanding the ...." https://www.researchgate.net/publication/234828457_Flow_blocks_as_a_conceptual_bridge_between_understanding_the_structure_and_behavior_of_a_complex_causal_system. Accessed 3 Jul. 2019. **[4]**

There also might be hope in the aspect, that physical control elements get advantage of the fact, human hands are very good at **high precision tasks** when presented with physical control elements, a claim which may be supported by the fact that DJ's still prefer physical channel faders to virtual ones as control elements.

Also the possibility for **collaborative interaction** and exploration, where markers are shared and exchanged is promising. A User interface with tangibles may promote collaboration and bi-manual interaction.

collaborative and bi-manual tasks

At last: Judging by the amount of research interest evaluated with google trends [5] TUI experiences seem to be a niché topic and may still hold some advantages that are not discovered yet.

Google trends suggests, there is comparatively low research interest in the field of tangible user interface compared to its bigger sister the GUI graphical user interface. (Comparing interest worldwide over the past year)

[5] Google Trends "https://trends.google.com/trends/?geo=EU. Accessed 30 Apr. 2019.

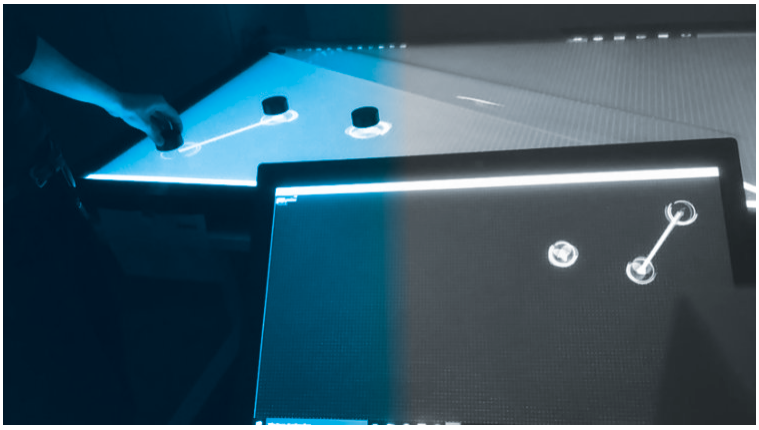
2. *Input devices and degrees of freedom*

"Tangibility is the property that a phenomenon exhibits if it has and/or transports mass and/or energy and/or momentum."

Piyush Mathur (2017)

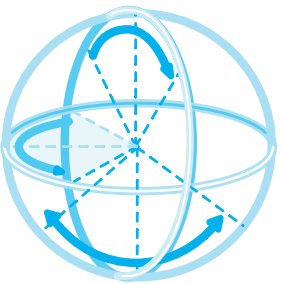
2.1 Classifying “tangibles”

In chapter 1 I will classify the tangible in context with other input devices, comparing their degrees of freedom. The number in degrees of In chapter 2 I will classify the tangible as input device and compare it to other common peripherals with a focus on their number in degrees of freedom. The Number in degrees of freedom are an essential aspect, that can contribute (depending on the application) to affording a more natural, life-like and intuitive interaction with the digital world. In computer aided design, it is necessary to at least emulate degrees of freedom in order to navigate and manipulate objects in a virtual 3D-space. The type of tangibles used in the prototype for this thesis, interact with the surface of a touch screen and at first glance they don’t seem to contribute to experience, nor provide any usability benefits as they are in default configuration not capable to provide more than 2+1 degrees of freedom (free translatory movement and one rotational axis) also: they always cover a certain amount of pixels. However, when the tangible is classified as an alternative input device, it can improve experience and workflow in **conjunction** with other input devices.



2.1 Degrees of freedom defintition

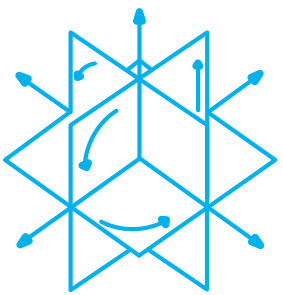
"In physics, the number of degrees of freedom (DOF) of a mechanical system is the number of independent parameters that define its configuration. It is the number of parameters that determine the state of a physical system and is important to the analysis of systems of bodies in mechanical engineering, aeronautical engineering, robotics, and structural engineering." [6]



For input devices the number of degrees of freedom is the number of different independent values that can be processed by the peripheral input device at the same time.

The richness and versatility of interaction is highly related to the richness/numbers of degrees of freedom (DOF), and in particular, continuous degrees of freedom, supported by the technology.

An example is the manipulation and translation of a 3-dimensional object in a 3D space, as it is done in Computer aided design. The position and orientation is defined by three components of translation and three components of rotation. The combined means of input have to afford 6 degrees of freedom to afford usability in a CAD-application. As most users use a common mouse-keyboard configuration, a combination of different shortcuts (switching between modes) and mouse-movement combinations are used in order to emulate degrees of freedom.



"Degrees of freedom - Wikipedia." https://en.wikipedia.org/wiki/Degrees_of_freedom. Accessed 3 Jul. 2019. [6]

The six degrees of freedom required in order to afford 3D movement/ manipulation of 3D-objects:

Moving up and down	**(elevating/heaving)**
Moving left and right	**(strafing/swaying)**
Moving forward and backward	**(walking/surging)**
Swivels left and right	**(yawing)**
Tilts forward and backward	**(pitching)**
Pivots side to side	**(rolling)**

Also a regular virtual reality headset provides 6 degrees of freedom as it reacts to all movements of the head and body movements that inadvertently affect the position of the head in 3D space.

In the context of this thesis **n+n DOF** means, that the object can be manipulated on different axes, however not all axes at a time. For example the scroll-wheel of a mouse adds an additional degree of freedom (up-and-down translation), however it can't be used in combination with the other two translational axes that allow free movement on a x-and-y plane. It has to be used independently from x-and-y translation. Hence it is categorised as **2+1 DOF** with the additional degree being restrained to One degree at a moment.

High-degree-of-freedom-input-devices are classified here as devices that provide more degrees of freedom as the classic pointer-device (computer mouse) + computer keyboard affords.

Comparison of common input devices by DOF

No. of DoF	1 (binary)	1 (binary)	2	2	2	2	2 + 1	2 + 1
Input device	Knobs (binary)	Knob (Rotary binary switch)	Computer mouse (No scroll-wheel)	Multitouch Tangible	TouchStyk, Joystick	Trackpad Digital-stylus	3D Touch	Computer mouse (With scrollwheel
Δx	○		●	●		●	●	●
Δy			●	●		●	●	●
Δz							+ ◗	+ ◗
Θx		○			◗			
Θy					◗			
Θz								

2 + 1	3	2 + 3 + 1	2+2	5	6	6	6
Tangible (additional rotary DoF)	Trackball device	Spaceball mouse	game controller	Anarkik 3D	3D Connexion	VR Glasses	VR Controller
●		●	●	●	●	●	●
●		●	●	●	●	●	●
		+ ◗			●	●	●
	●	+ ●	+ ●	●	●	●	●
	●	+ ●	+ ●	●	●	●	●
◗	●	+ ●	+ ●		●	●	●

2.1 One degree of freedom (binary)

Push-button

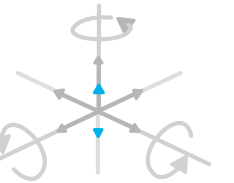
simple binary switch mechanism for changing a state of a machine or a process, that is generally made out of hard material, typically plastic or metal.[7] The surface is usually flat or shaped to accommodate the human finger or hand, so as to be easily depressed or pushed. Buttons are most often **biased switches**, although many **un-biased** buttons (due to their physical nature) still require a spring to return to their un-pushed state. The "push-button" has been utilised in calculators, push-button telephones, kitchen appliances, and various other mechanical and electronic devices, home and commercial.

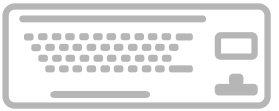
simple binary switch mechanism for changing a state of a machine or a process.

[8]

Computer Keyboard

The computer keyboard uses an arrangement of buttons as keys that are registered by the controller in a binary fashion by being manually pushed down. The development of the keyboard is a direct inheritance from the invention of the typewriter, therefore the keyboard is classified as a typewriter-style device. Initially the computer user interface relied on text entry interface for typing text and numbers into a word processor mechanical switches. in the 1970s there was a move to command style interfaces where interaction was primarily with mono-coloured text screens and a keyboard. [9]





"Push-button - Wikipedia." https://en.wikipedia.org/wiki/Push-button. Accessed 3 Jul. 2019 [7]

[IMAGE] https://www.ase-supply.com/Pollak_Ball_Switch_p/po-21-437-p.htm [8]

"The History of the Computer Keyboard - ThoughtCo." 24 Jun. 2019, https://www.thoughtco.com/history-of-the-computer-keyboard-1991402. Accessed 3 Jul. 2019. [9]

2.2 One degree of freedom

Rotary potentiometer / Knobs

Passive element continuous physical manipulation in the rotational axis results in different levels of resistance. Electromotive force gets measured by balancing it against the potential difference resulting from passing a known current through a known variable resistance. [10] The potentiometer is the underlying part that gives functionality to many devices and appliances that carry haptic interfaces and surround us in our daily lives: car dashboard, radio, white goods, stove, heater, gradient light switches, microwave, vacuum cleaner, kitchen devices and many more.

[10]

Linear potentiometer/ Channel Fader

[11]

Linear potentiometers follow the same principle as rotary potentiometers linear faders seem to be less common in household devices even though the radio-wave spectrum finds its representation on a linear scale while 'travelling through' it - the control mechanism is translated to rotary. The reason for this might be, that space allocation for an haptic interface is more efficient when designers decide for instead of sliders.

synthesizer and electronic music instrument makers used touch-sensitive capacitance-sensors to control the sound and music being made and their devices pre-date the age of the PC.

[10] [Image]"WH148 20K Ohm Variable Resistors Single Turn Rotary Carbon Film Taper Potentiometer"https://www.overstock.com/Home-Garden/WH148-20K-Ohm-Variable-Resistors-Single-Turn-Rotary-Carbon-Film-Taper-Potentiometer/25414933/product.html

[11] "Robotdyn Analog Slide Potentiometer 10K ohm - Addicore." https://www.addicore.com/Robotdyn-Analog-Slide-Potentiometer-10K-ohm-p/ad487.htm. Accessed 31 May. 2019."

2.1 Two degrees of freedom

2-Button computer mouse

Since the early days of personal computers, the Windows, Icons, Menus, Pointing device (WIMP) interface, invented at Xerox PARC, has been dominant in many of the digital devices we use. This interface has been developed around the input devices, Keyboard and Mouse which remain the most widely used input devices until this day. [12]

[13]

A simple two button or three button mouse without scroll wheel allows for unconstrained movement on a two axis plane, resulting in two degrees of freedom.

One-touchpoint track-pad

A one-touch-point track-pad is a track-pad which recognises only one touch-point at a time and therefore isn't gesture enabled. It follows exactly the same principles as a computer mouse and allows for controlling the position of a pointer on a two-axis, two-degrees-of freedom virtual surface plane.

Joystick

A simple joystick has two degrees of freedom. It can be used to translate input to translational or rotational movement. This type of control is often used in combination with other conrols on game controllers.

[16]

"The History of the Computer Mouse - Computing History." https://www.computinghistory.org.uk/det/613/the-history-of-the-computer-mouse/. Accessed 31 May. 2019. [12]

[IMAGE] "HP USB 3 button mouse" 573077-001 https://pc24.cn.com/mouse/hp/573077-001.html?lang=en_US [13]

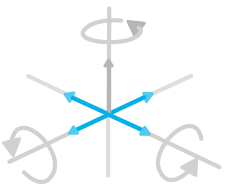
The synaptics TouchStyk finds great enthusiam among some users.

[14]

TouchStyk Pointing Stick

The Pointing stick or commonly better known as “nipple mouse” allows for 2 DoF navigation through push and tilt movements. This input device follows the very same principle as a Joystic does and is operated with one finger only. It’s a technology special to IBM devices and developed by Synaptics Inc.

Opinions on the subreddit r/thinkpad [15] suggest, that many owners of IBM Laptops don’t know the function and among the ones who do, not many are using it. The obstacle of learn how to operate it seems high, however there is also enthusiasm among people who mastered this input device.



Two degrees of freedom results in free movement on both translatory axes Δx and Δy.

Digital Pen

Input from a digital pen works like input from a mouse, just, that the interaction happens on the surface of the screen. There are multi-modal pens, carrying buttons that can be programmed to activate certain functionalities.

[14] [IMAGE]”mouse pointing stick” https://en.wikipedia.org/wiki/Pointing_stick#/media/File:Mouse_pointing_stick.jpeg

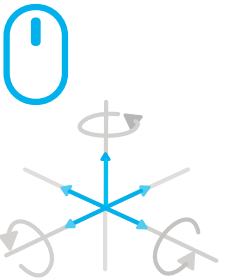
[15] “r/thinkpad”https://www.reddit.com/r/thinkpad/comments/aeu4n1/whats_your_view_of_the_thinkpad_nipple/

[16] [IMAGE] “http://www.cctvdiscover.com/accessories-ptz-controller-c26_28/control-key-plug-and-play-usb-ptz-keyboard-controller-p208.html" https://www.addicore.com/Robotdyn-Analog-Slide-Potentiometer-10K-ohm-p/ad487.htm. Accessed 31 May. 2019.”

2+1 degrees of freedom

Computer Mouse with zoom-wheel or ball

Two positional degrees of freedom, controlled as usual, and a third, but separate, rotational degree of freedom - the zoom-wheel controlled by a finger. As the zoom-wheel is separated from the translational degrees of freedom and can't be used in direct combination, the mouse with zoom-wheel is categorised here as a 2 +1- degrees of freedom input device rather then a 3 degrees of freedom device. The zoom-wheel can move the x-y plane up and down enabling translation, in other applications the zoom-wheel will zoom in and out.



Two degrees of freedom results in free movement on both translatory axes Δx and Δy.

Multi touch tangibles

Tangibles on a multi-touch-surface can be moved freely on the xy-surface plane and also be rotated, if the interface affords this interaction. The rotation can be mapped to a zoom scale, but it could also be used for changing parameters and navigation. In the prototype for this bachelor's thesis, the rotation is used to navigate through time, to change month and date of a year.

Multi touch tangible magnifying glass

Tangibles can add a +1 degree of freedom when rotated. A 'magnifying glass' setup could allow for zooming in selective details.

[17] "Wacom Pro Pen 2 with Pen Case" https://eu-store.wacom.com/Product/wacom-pro-pen-2-with-case#/undefined1

[18] [IMAGE]"Wacom pro 2 Pen"https://eu-store.wacom.com/Product/wacom-pro-pen-2-with-case#/undefined1

[19] Battery-free Pen PW500 https://www.huiontablet.com/battery-free-pen-pw500.html Accessed 31 May. 2019."

[20] "Wikipedia- Force Touch"en.wikipedia.org/wiki/Force_Touch

[21] "What Is 3D Touch? A Webopedia Definition." https://www.webopedia.com/TERM/3/3d-touch.html. Accessed 2 Jul. 2019.

[22] [IMAGE] https://www.iculture.nl/gids/force-touch-uitleg/

Two-finger or multi-finger track-pad

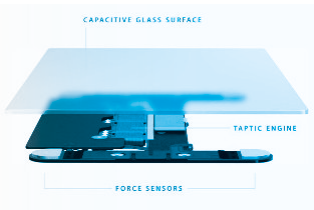
A two finger track-pad is a track-pad which recognises two touch-points at a time and therefore has the capability of recognising zoom and pinch gestures and distinguish between a two-finger-swipe and a one-finger-swipe. For translated movement on the virtual surface displayed on the screen, it follows exactly the same principles as a computer mouse and allows for controlling the position of a pointer on a two-axis, two-degrees-of freedom virtual surface plane.

pressure sensing active Digital Pen

[18]

Passive pens carried out by manufacturers such as Wacom [17] and Huion PW500/PW507 can support 8,192 levels of pressure sensitivity and tilt recognition with accuracy. [19] Tilt feature of the passive pen aims to create natural-looking pen, brush, and eraser strokes in applications that support tilt sensitivity.

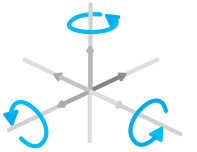
Force touch track-pad Apple



[22]

Force Touch is a technology developed by Apple Inc. that enables track-pads and touchscreens to distinguish between various levels of force being applied to their surfaces. It uses pressure sensors to add another method of input to Apple's devices. The technology was first unveiled on September 9, 2014, during the introduction of the Apple Watch. [20] Starting with the Apple Watch, Force Touch has been incorporated into many products within the lineup of Apple's Products including notable MacBooks and the Magic Trackpad 2. The technology is based on and superseded 3D Touch (Apple on its 2015 iPhone 6S and iPhone 6S [21]. The technology brings usability enhancements to the software by offering a third dimension to accept input. The 3D-Touch controller is part of the taptic engine which also provides the user feedback on her touches: In the engine there is a kind of mechanical drum, that gives more sophisticated and nuanced feedback than common devices from other manufacturers.

3+ degrees of freedom



Trackball devices

“A trackball is a pointing device consisting of a ball held by a socket containing sensors to detect a rotation of the ball about two axes. [...] Large trackballs are common on CAD workstations for easy precision. Before the advent of the touch-pad, small trackballs were common on portable computers, where there may be no desk space on which to run a mouse. Some small "thumb-balls" are designed to clip onto the side of the keyboard and have integral buttons with the same function as mouse buttons.” [23]

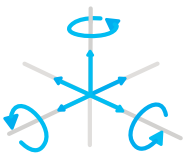
[24]

As the trackball is a stationary device, it lacks translational degrees of freedom. To move the pointer using a trackball, you rotate the ball with your thumb, fingers, or the palm of your hand. In addition to the ball, a trackball usually has one or more buttons that work just like mouse buttons. This input device is stationary and therefore cant track translation on a 2D-plane. The trackball however allows for pitch, roll and yaw - potentially affording 3 degrees of freedom.

"The GlobeFish and the GlobeMouse." https://www.uniweimar.de/fileadmin/user/fak/medien/professuren/Virtual_Reality/documents/publications/GlobeFish.GlobeMouse-TalkCHI2006.pdf. Accessed 1 Jun. 2019 [23]

[IMAGE]”CH Products Wired PS/2 Trackball” https://sg.rsonline.com/web/p/trackballs/4646082/ [24]

2 + 3 + 1 degrees of freedom



Logitech MX Ergo Wireless Trackball

A computer mouse with an integrated spaceball provide 3 Rotational degrees of freedom (Spaceball), plus the translatory degrees of freedom provided by the design of the mouse and the additional, but independent degree provided by the zoomwheel. This device expands traditional mouse functionality and may be useful in computer aided design or games. According to Logitech, using the **MX Ergo Wireless Trackball** will cause “20% less muscular strain compared to a regular mouse.” [25] The Mouse can be moved on the x-y axis like a usual **2 degees of freedom** mouse pointer device and also has a trackball that allows for pitch, roll and yaw (**2 Dof**). In addition to that it has a zoom-wheel typical for contemporary computer mice. In total that makes **five degrees of freedom**, however they cant be moved altogether, therefore here they are classified as 2+3+1 DoF.

[26]

[25] "Logitech MX Ergo Wireless Trackball Designed for Comfort and ...." https://www.logitech.com/en-us/product/mx-ergo-wireless-trackball-mouse. Accessed 1 Jun. 2019

[26] [IMAGE] "Logitech MX Ergo Plus Advanced Wireless Trackball for Windows PC ...." https://www.walmart.com/ip/Logitech-MX-Ergo-Plus-Advanced-Wireless-Trackball-for-Windows-PC-and-Mac/980404339. Accessed 1 Jun. 2019”.

Game controllers

Game controllers are devices used with games or entertainment systems to interface for human interaction in a video game, typically to control an object or character.

The Google Stadia game controller carries a joystick for walking (2DoF) and for view orientation (2 DoF). Because they can be used simultaneously, this and similar controllers can be categorised as a 4-DoF controller. Similar to the X box One X [28] or Playstation 4 [29] controller and to the majority of contemporary game controllers.

[27]

High degree of freedom devices for CAD

There are a lot of applications that require more than the two degrees of freedom (free movement on a x-y plane) a touch sensor provides, and where there is a need for options to switch fast between modes. Computer aided design for example requires the engineer, designer, architect or artist to navigate in at least six degrees of freedom and fast switch between different tools and modes. This cannot be performed with a flat-surface multi-touch sensor alone. There are a few commercial input devices that exactly tackle on the question how to make the workflow in CAD more efficient and also the process of creating more realistic in adding haptic force feedback.

[30]

[Image]"With Google Stadia, Gaming Dreams Head For the Cloud | WIRED." 19 Mar. 2019, https://www.wired.com/story/google-stadia-cloud-gaming/. Accessed 1 Jun. 2019" [27]

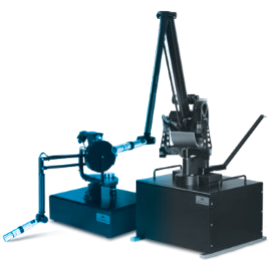
"Xbox - Wikipedia." https://en.wikipedia.org/wiki/Xbox. Accessed 1 Jun. 2019." [28]

"PlayStation - Wikipedia." https://en.wikipedia.org/wiki/PlayStation. Accessed 1 Jun. 2019. [29]

[IMAGE]"anarkik 3D contoller" http://anarkik3d.co.uk/ [30]

3D Connexion space navigator SpaceMouse Pro and SpacePilot Pro are human interface motion control devices intended for manipulating and navigating computer-generated 3D imagery. [32] The product is aimed at engineers, architects, designers and other creative professionals that work mainly with CAD and 3D Simulation environment. The manufacturers claim, that the 6 degrees of freedom in navigation can effectively speed up the workflow. The SpaceMouse Pro and SpacePilot Pro extend the navigation functionality and carry additional programmable buttons for shortcuts and saved view angles.

[31]



[31] [IMAGES] https://www.3dconnexion.de/index.php?id=13&redirect2=www.3dconnexion.de “SpaceMouse

[32] Pro”https://www.3dconnexion.de/index.php?id=13&redirect2=www.3dconnexion.de accessed 7 Apr. 2016,

3+ degrees of freedom

Myo Gesture

Myo Gesture Inertial measurement unit, was marketed (discontinued) with 9 DoF it has actually only 6 DoF effective in reality. The 9-DOF sensor, it carries, is made up of three 3-DoF sensors: (accelerometer, gyroscope and magnetometer) all three sensors overlap in measuring the orientation however and they can't measure translation. This makes the Myo Gesture wristband very effective in recognising gestures. It was never advertised [33] to replace traditional input devices such as mouse or keyboard, but to compliment them. It was mainly marketed for interfacing contact-less to external devices for example to facilitate hands free power point presentations.

[34]

VR controller + VR headset

For a virtual reality experience that is truly immersive, the orientation of the visual field should behave according to reality. If the head or whole body gets moved up or down, left and right, forward, backward, tilt, swivel or pivot, the virtual environment needs to adjust itself to the new position and orientation. The higher the delay or discrepancy, the less natural the experience and the higher the risk of motion sickness will be the case, because a discrepancy is created between the vestibular, kinaesthetic and the visual senses. [35]

[VIDEO]"The Myo Armband: The Future of Gesture Control." https://www.youtube.com/watch?v=jOEcsNmTk7g&t=13s. Accessed 31 May. 2019. [33]

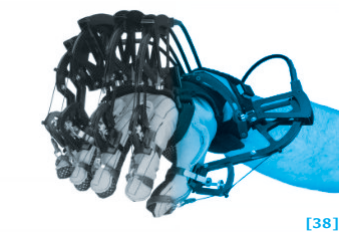
[IMAGE] Myo-2-900x789.jpg. "https://www.gadgetreview.com/myo-armband-2" [34]

"Virtual reality sickness. Wikipedia" https://en.wikipedia.org/wiki/Virtual_reality_sickness [35]

6+ Degrees of freedom

Exoskeleton gloves for VR

these devices take the experience one step further, sensing input through max 27 channels for the number of degrees of freedom of the human hand. [37] In the near future, the user may be able not only to move around in a natural manner, but use her hands and manipulate objects in the virtual realm. If these gloves are also equipped with haptic feedback actuators, objects touched and manipulated could also 'feel' natural and characteristics like friction resulting from texture and weight of an object could be simulated. Force feedback provides direct perception of three-dimensional (3D) objects and directly couples input and output between the computer and User.



[38]

Force feedback exoskeleton suits

A vision system with a camera could potentially translate captured movements into input channels for all 244 degrees of freedom of the human body - and exoskeleton suits could provide force feedback for the whole environment in the virtual world. A user could sit on a chair and feel its support or pick up a stone in VR and actually feel it's weight, temperature and texture. The startup Tactai [40] is working on an approach to record textures of the natural world in order to reproduce them in VR through vibrations.

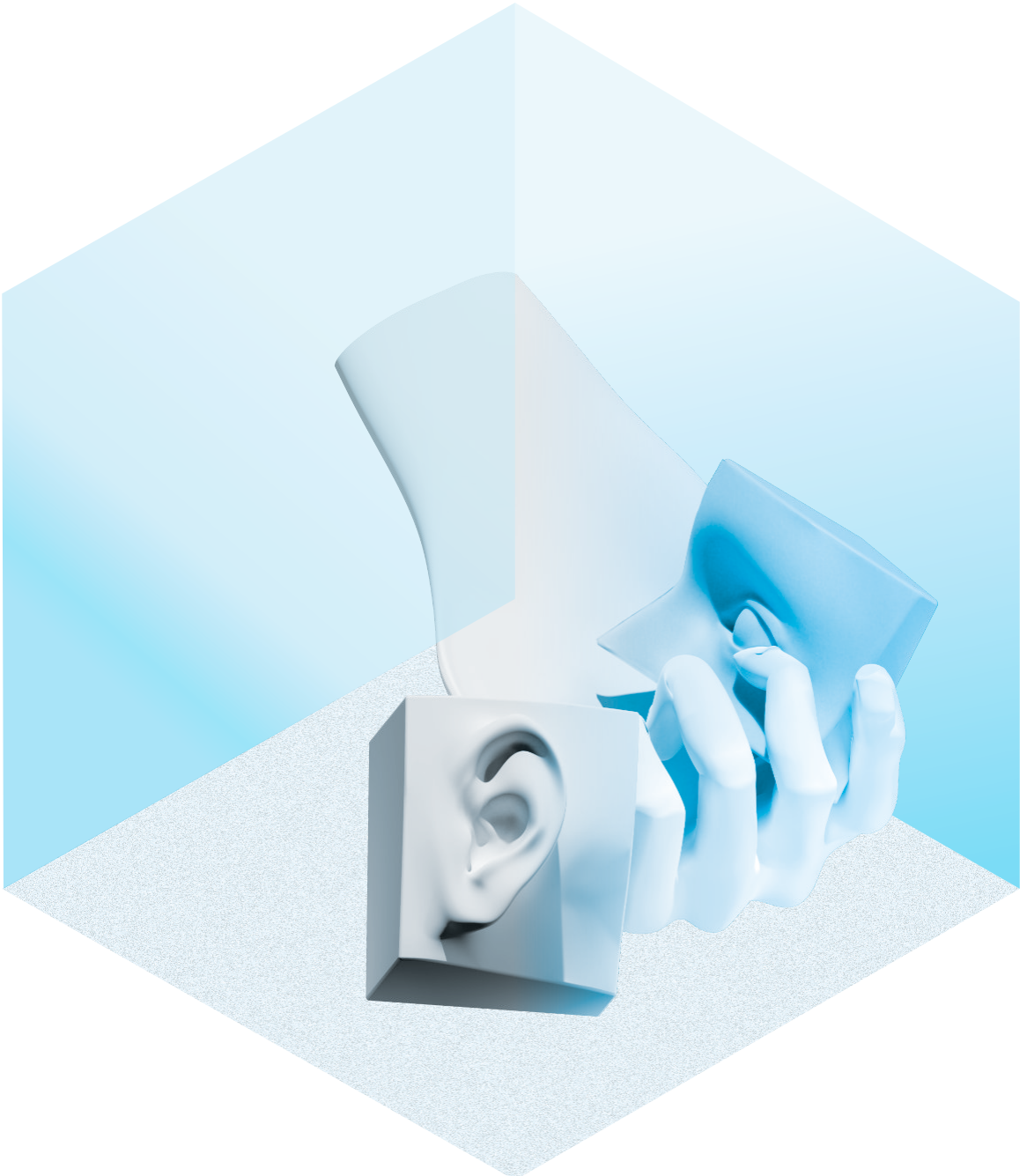
[39]

[38] "Understanding Hand Degrees of Freedom and Natural Gestures for ...." https://link.springer.com/chapter/10.1007/978-3-642-40483-2_20. Accessed 3 Jul. 2019.

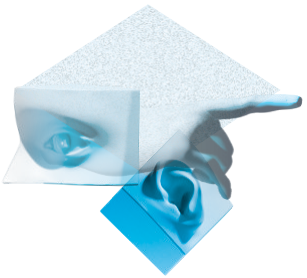
[39] [IMAGE] "CyberGloveSystems-CyberGrasp.png." http://djrobinsimmons.com/CyberGloveSystems/cybergrasp.html

[40] "On eve of VR launches, hands-on with a new haptic ideal" https://www.polygon.com/virtual-reality/2016/3/25/11306368/tactai-haptics-vr-virtual-reality-touch Accessed 31 May. 2019."

A tangible, can be designed in a way that the user intuitively understands how to use it. In the prototype for the thesis a circular tangible was developed that is supposed to resemble a magnifying glass and also indicates that the user can turn the tangible. Around the tangible weather data of a whole year can be visualised. In the inner circle of the tangible there is a day/week section providing a more fine grained look at the data. Sensual metaphors can also act as affordance signifiers - signifying to the user what can be done with it - which affordances it provides.



3. Digital interface metaphors



3.1 Sensual metaphors

A metaphor is a figure of speech that, for rhetorical effect, directly refers to one thing by mentioning another." [41]

In user interface design, an interface metaphor is a set of user interface visuals, feedback and feedforward, or events that draw on knowledge that are a priori to humans or were aquired previously in other domains. Interface metaphors allow for instantaneous knowledge about how to interact with the user interface. Concepts like files folders stacks or the tree view representation of a file system, as in a file manager. Interface metaphors draw on existing **cognitive models** as well as experience-based perceptual skills. [42]

Making the unfamiliar familiar through the familiar

Sensual interface metaphors can be auditory, visual, haptic, olfactory, gustatory, kinaesthetic and vestibular. [43] This thesis will only focus on the first three named senses and how they can be addressed with an multi-sensory interface. Research suggests that these sensual metaphors are not strictly independent from each other and may have synaesthetic influence on each other, yet these synaesthetic effects may vary strongly from person to person and through factors like ethnographic background. Sensual perceptive metaphors are not universal. Green signifies a right answer, as do certain auditory signals. Blue and red might have universal meanings for cold and hot but all of that is tied to the background of a person. [44]

Interface metaphors

Metaphor. Wikipedia "https://en.wikipedia.org/wiki/Metaphor" [41]

Cooper, Alan. About Face: the Essentials of Interaction Design ; Wiley, 2014. Chapter 13 Metaphors, Idioms and Affordances [42]

Sense. Wikipedia "https://en.wikipedia.org/wiki/Sense" [43]

losely based on: CULTURAL RELATIVITY Do You See What I See? https://www.sapiens.org/language/color-perception/ [44]

3.2 Affordances and affordance signifiers

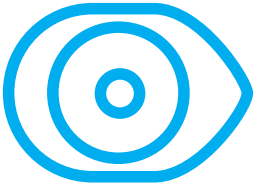
In his book “the design of everyday things”, Don Norman defines the term affordance as the “**relationship between a physical object and a person.**” A chair affords (“is for”) support and, therefore, affords sitting. “Knobs afford turning, pushing, and pulling” [48]

Physical objects are familiar and humans know how to manipulate them. Synthetic or digital objects carry certain characteristics, that draw on our prior knowledge and tell us how we can use them. Being manipulated by us, they usually behave in an expected manner: We can predict where objects will fall, how well known shapes look from other angles, and how much force is required to push objects against friction.For example the symbol of an arrow might tell us about the degrees of freedom of an object. These clues are what Don Norman defined as “**affordance signifiers**” partly to counteract the incorrect use of the term affordance by designers.

Tangibles can afford a natural way of interaction with the digital realm

Through their familiar characteristics, tangibles promise a chance to bridge the gap to the more abstract, the more unfamiliar world of digital data and may offer us an opportunity to design more playful interactions that promote engagement on the one hand, enable a deeper and more intuitive understanding of complex data on the other. A Tangible object intrinsically promotes grasp, while a screen can only promote abstract interactions.

Norman, Donald A. The Design of Everyday Things. - Revised and Expanded Edition Basic Books, 2013. **[48]**



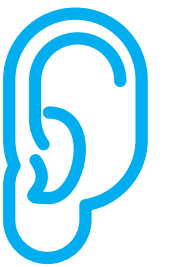
3.3 Information visualisation and visual metaphors

Digital user interfaces are generally ocular-centristic - centeres around the human visual sense. If they would mainly use audible human computer modalities, they would be phono-centristic. This suggests a ocularcentric predisposition of humans, or at least a cultural predisposition in western cultures. This might be the reason why displays are the most mature computer-human modality and our computational devices are (computers, phones) are screen based. In his research paper “Subjective User Experience and Performance with Active Tangibles on a Tabletop Interface”, [45] Alexander Toet compares the performance of tangibles that give either visual feedback, auditory or haptic (vibrotactile) feedback in order to guide the user to relocate them to a certain position on the screen. The visual feedback yields the fastest task completion times and the highest ratings for personal preference from the users. The experiments conducted in the study also tested, if visual feedback is more effective and preferable when emitted from the display or directly from the tangible. The latter was preferred and the hypothesis was stated that this setup reduces “clutter and occlusion on the display surface”.

[45] "Subjective User Experience and Performance with Active Tangibles ...." 30 Jul. 2015, https://www.researchgate.net/publication/280562129_Subjective_User_Experience_and_Performance_with_Active_Tangibles_on_a_Tabletop_Interface. Accessed 3 Jul. 2019.

3.4 Information sonification and auditory methaphors

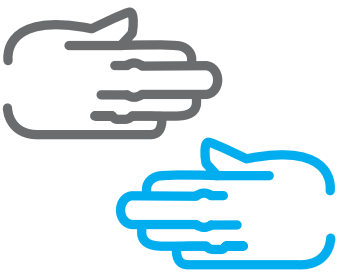
Sound can provide feedback on the user's action or change of her system status. Sounds can build a context and are also used to draw attention to warnings or can signify affordances. Sound is also used to establish a brand personality and recognition. For example the 158 Marimba sound, every iPhone ships with by default. [46] The new iPhone X ships with the new default ringtone REFLECTION, [47] as it is the 11th generation of iPhone and marks a new era. As Don Norman mentions in his book "the design of everyday things" a sudden necessity to add sound to electric vehicles that don't have a combustion engine and therefore lack the sounds of cars that we are accustomed to came up. Inside the car, a lack of sound is a lack of feedback for both drivers, passengers and pedestrians, which will create a need for designing new sounds i.e a sound pitch goes up with increasing velocity. Car manufacturers are currently using this problem as an opportunity to add sonic branding to their products. In this case the sound itself is an idiomatic digital metaphor at first and and will get associated with the certain brand over time.



[46] "Marimba IOS 6" - https://www.youtube.com/watch?v=gtWFGRmhAF8

[47] "iPhone X Reflection Ringtone" https://www.youtube.com/watch?v=JVrpZauQtls

[48] Norman, Donald A. The Design of Everyday Things. - Revised and Expanded Edition Basic Books, 2013.



3.5 Information tactilization and tactile metaphors

Bimanualism conventionally refers to two hands interacting with one object. Research [49] suggests that active inquiry and exploration using the hands can deepen investigative exploration and reflection, promote social interaction, and has the potential to enhance learning and retention. Tangibles invite to treat an experience interactively, rather than as a simple information delivery system. Through vibrotactile feedback, tangibles could convey information. An example for Information haptilization would be small vibrations, that indicate whenever a grid-line of a virtual grid is passed. Also if the user performs a desired action with the marker, this action can be confirmed. A tangible object intrinsically promotes grasp, while a screen can only promote abstract interactions.

[49] "(PDF) Tangible interaction and learning: The case for a hybrid approach." https://www.researchgate.net/publication/225776146_Tangible_interaction_and_learning_The_case_for_a_hybrid_approach. Accessed 3 Jul. 2019.

4. *Visionaries of gestural and multi-modal interaction*

The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it.

Mark Weiser

4.2 Beginnings of multi-touch technology

In 1965 **E.A. Johnson** creates the first finger-controlled touchscreen at the Royal Radar Establishment in Malvern, UK. In his article "Touch Display – a Novel Input/Output Device for Computers" (paywalled - here cited from article [58]), Johnson described a touchscreen mechanism employed by many modern smartphones – **capacitive touch**. A capacitive touchscreen features an insulator, such as glass, coated with a transparent conductor like indium tin oxide. A human finger coming into contact with it acts as an electrical conductor. Yet this type of technology was only able to process one touch at a time.

The first multi-touch device was developed in 1982, Nimish Mehta at the University of Toronto. It was made of a frosted-glass panel with a camera behind that could scan for fingers being pressed against the surface of the glass. This technology is similar to infrared multi-touch technology which can detect as many fingers as the camera vision algorithm is able to handle and also QR codes and objects.

However projected **capacitive multi-touch-displays** are much more common today. This type of technology is now used in almost every touch-screen device and the company **Synaptics** sells a great share of its sensors. Synaptics is a publicly owned San Jose, California-based developer of human interface (HMI) hardware and software. Chipmaker for Apple including touchpads for computer laptops; touch, display driver, and fingerprint biometrics technology for smartphones; and touch, video and far-field voice

"A Brief History of Touchscreen Technology" https://www.acante.co.uk/a-brief-history-of-touchscreen-technology-part-one/

--> Cites: "Touch display--a novel input/output device for computers - IET ...." https://ieeexplore.ieee.org/document/4205802. Accessed 3 Jul. 2019. [58]

[ARTICLE]"from touch displays to the Surface: A brief history of touchscreen technology" "https://arstechnica.com/gadgets/2013/04/from-touch-displays-to-the-surface-a-brief-history-of-touchscreen-technology/ [59]

"Kapazitiver Touchscreen funktioniert trotz Handschuhen" https://www.golem.de/1102/81428.html [60]

[WIKIPEDIA] "Synaptics" https://en.wikipedia.org/wiki/Synaptics. Accessed 5 May. [61]

technology for smart home devices and automotives. Synaptics primarily sells its products to original equipment manufacturers (OEMs) and display manufacturers.[61]

Since its founding in 1986, the company's notable innovations include the first ever computer touchpad, touch technology for the click wheel on the classic iPod, touch sensors used in numerous Android phones, touch and display driver integrated chips (TDDI), and biometrics technology for fingerprint sensors. All touch and fingerprint technology was based on capacitive sensing up until the introduction of optical fingerprint sensing in late 2016.

"[...]Machines will fit the human environment, instead of forcing humans to enter theirs."

Mark Weiser

ubiquitous computing

The term ubiquitous computing was coined and introduced by Mark Weiser, former computer scientist and Chief Technology Officer at XEROX PARC (1952-1999). XEROX PARC was the birthplace of many technologies that marked the PC era, such as the computer mouse, windows-based user interfaces, and the desktop metaphor. [62]in his 1991 paper "The Computer for the 21st Century" [63] he envisions a world where digital devices have become part of our environment, are everywhere and merged with our reality. They will have overcome their frustrating obstacles of communicating and communication modalities will be so intuitive, that humans can interact completely fluently. He envisions that ubiquitous computers will help overcome the problem of information overload and Machines will "fit the human environment, instead of forcing humans to enter theirs."

[62] [WIKIPEDIA] "Parc company" https://en.wikipedia.org/wiki/PARC_(company)
[PAPER]"The Computer for the 21st Century."

[63] https://www.ics.uci.edu/~corps/phaseii/Weiser-Computer21stCentury-SciAm.pdf. Accessed 3 Jul. 2019.

4.3 tangible bits and radical atoms

The Tangible Media Group at MIT Media Lab, does pioneering work in the field of tangible interfaces. According to their approach, the TUI is just an interim step before user interfaces will have been completely merged with, and be indistinguishable from our reality. The ***'Radical Atoms'*** stage represents the labs vision for the future of interaction, in which **"all digital information has physical manifestation so that we can interact directly with it—as if the iceberg had risen from the depths to reveal its sunken mass."** [64] Professor Hiroshi Ishii, the founder of the ***Tangible Media Group*** also was the one to coin the term 'tangibles' mentioning them first in his 1997 published work about 'tangible bits' where he defines the tangible-ui and exemplifies it with different research prototypes. "Tangible Bits" is an attempt to bridge the gap between cyberspace and the physical environment by making digital information (bits) tangible. This will bridge "the gap between the worlds of bits and atoms."

Interactive Surfaces
Transformation of each surface within architectural space (e.g., walls, desktops, ceilings, doors, windows) into an active interface between the physical and virtual worlds;

Coupling of Bits and Atoms
Seamless coupling of everyday graspable objects (e.g., cards, books, models)with the digital information that pertains to them

Ambient Media
Use of ambient media such as sound,
light, airflow, and water movement for background
interfaces with cyberspace at the periphery of human perception.

"Hiroshi Ishii - MIT Media Lab." http://web.media.mit.edu/~ishii/. Accessed 25 Jun. 2019.. [64]

GUI

“A graphical user interface only lets us see information and interact with it indirectly, as if we were looking through the surface of the water to interact with the forms below.”

TUI

“A tangible user interface is like an iceberg: there is a portion of the digital that emerges beyond the surface of the water—into the physical realm—so that we may interact directly with it.”

[65]

Radcial Atoms

“describes our vision for the future of interaction, in which all digital information has physical manifestation so that we can interact directly with it—as if the iceberg had risen from the depths to reveal its sunken mass.”

[65] [SCREENSHOT] "Tangible Media Group - MIT." https://tangible.media.mit.edu/. Accessed 25 Jun. 2019.

4.1 Rich Gestures

The “Pioneer of Rich Gestures” Myron Krueger built the very first prototype implementing among a rich set of gestures a pinch-to-zoom gesture in the mid-70s. [50]

[51]

Wayne Westermann, [52] co-founder of FingerWorks and after their acquisition through Apple, employee of the latter, built up upon this groundwork in his PhD dissertation with the title “**Hand Tracking, Finger Identification, and Chordic Manipulation on a Multi-Touch Surface**” [53] - the foundation on which Apple will later built their great invention narrative. The most name-worthy of the products FingerWorks came up with was The iGesture Pad.[54] Marketed with the (not so catchy) slogan: “better than a mouse”. The iGesture Pad was a trackpad with multi-touch implementation, that enabled the user to perform interactions like dragging sliders and browsing.

The **Magic Trackpad** is a multi-touch trackpad produced by Apple Inc. Announced on July 27, 2010, it is 80% larger than the trackpad found on the current MacBook family of laptops. [56] A new version called the **Magic Trackpad 2** [57] came out on October 13, 2015. It can be used as a button: pressing down on it puts pressure on two circular feet below to register a click

[55]

[WIKIPEDIA] “Myron Kruger Wikipedia" https://en.wikipedia.org/wiki/Myron_W._Krueger Accessed 5 May. [50]

[VIDEO]“Videoplace, Myron Krueger (1985)” https://www.youtube.com/watch?v=YyIWzapmOLI [51]

[WIKIPEDIA] “Wayne Westermann" https://en.wikipedia.org/wiki/Wayne_Westermann [52]

Accessed 5 May.

[DISSERTATION PDF] "HAND TRACKING, FINGER IDENTIFICATION, AND CHORDIC ...." https://resenv.media.mit.edu/classarchive/MAS965/readings/Fingerwork.pdf. Accessed 3 Jul. 2019 [53]

[54] “iGesture Pad” https://www.microsoft.com/buxtoncollection/detail.aspx?id=213. Accessed 17 Jun.

[55] [IMAGE] IMG_0579.png https://www.microsoft.com/buxtoncollection/detail.aspx?id=213. Accessed 17 Jun.

[56] “Magic Trackpad ”https://en.wikipedia.org/wiki/Magic_Trackpad. Accessed 17 Jun. 2019.

[57] "Magic Trackpad 2" https://en.wikipedia.org/wiki/Magic_Trackpad. Accessed 17 Jun. 2019.

First finger-driven touch-screen invented by E.A. Johnson

1965

Myron Kruger - "the pioneer of rich gestures" introduces a system incorporating pinch and zoom gestures.

1983

Apple relases its touch-capable Newton PDA

1993

1970

Dr.G.Samuel Hurst Invents the first resistive touchscreen by accident

1983

HP releases the HP-150, one of the first touch-screen computers.

1991

Mark Weiser envisions ubiquitous computing in his paper “The Computer for the 21st

1992

IBM Simon Personal Communicator- the first phone interfacing with a touch-screen

Wayne Westerman and John Elias found FingerWorks

1999

October 26, 2012 the Microsoft surface gets introduced

2012

On October 2, 2018, Microsoft announces the surface dial as accessory for the Surface Pro

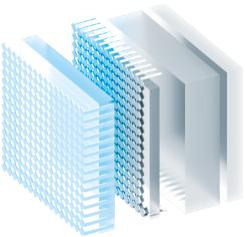
2018

2007

January 9, 2007 Apple announces the iPhone

2011

Samsung SUR40 a multi-touch Monitor with PixelSense technology is



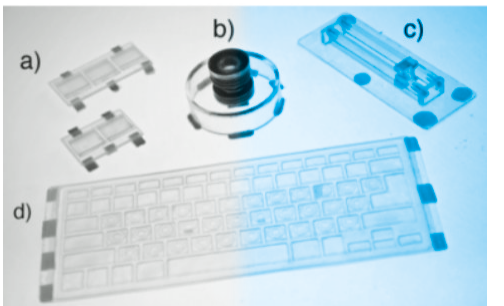
2014

19. September 2014 Apple announces taptic engine to be implemented in the MacBook and MacBook pro

5. Tangibles in research

5.1 Slab Widgets

In the research project “Bridging the Gap Between Virtual and Physical Controls on Tabletops” students of RWTH Aachen University and the University of California, developed and explored physical peripheral controls for the use on the surface of touchscreens:



[66]

“Silicone Illuminated Active Peripherals” (SLAP), are tangible, translucent widgets to ‘slab’ onto the surface of multi-touch tabletops. The sliders, knobs, keyboards, and buttons are aimed at improving input accuracy, by allowing the user to make use of fine human motor skills. The slab widgets are cast from flexible silicone and acrylic and they don’t carry any electrical components, which makes them simple, affordable, flexible, and robust. The students conducted user studies and set up a performance task, where users were to interact with a video player using a SLAP-widget-knob setup and an equivalent setup with virtual controls. It was hypothesised that users would navigate much faster when using the SLAP-Widget setup, because “Video navigation and annotation require users to manipulate controls while visually attending to video.” The results yielded that “Video navigation to specific target frames was “significantly faster using the Slab Interface, yet users “felt more comfortable with the virtual version”. [66]

"SLAP: Silicone Illuminated Active Peripherals - University of California ...." http://hci.ucsd.edu/hollan/Pubs/SLAP.pdf. Accessed 3 Jul. 2019.

[CONFERENCE PAPER] Malte Weiss, Julie Wagner, Yvonne Jansen, Roger Jennings, Ramsin Khoshabeh, et al.. SLAP Wid- [66]

gets: Bridging the Gap Between Virtual and Physical Controls on Tabletops. CHI ’09 SIGCHI

Conference on Human Factors in Computing Systems, ACM, Apr 2009, New York, United States.

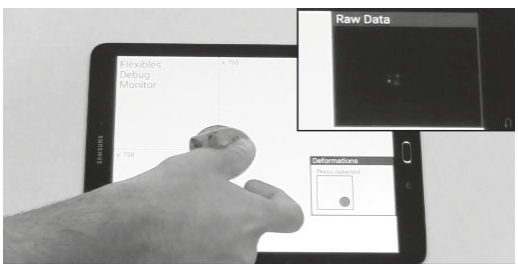
5.2 Deformation-Aware 3D-Printed Tangibles

Students from the human computer interaction department (HCI) of TU Darmstadt developed 3D-printed flexible tangibles for capacitive touchscreens that are printed or cast from soft materials and recognise deformations as an input modality. The design of the tangibles is based on different types of deformation mapping, and incorporates 3D-printable mechanisms that capture pressing, squeezing, and bending input with multiple intensity-levels and location information. The Project aims to incorporate deformation into the variety of interaction with tangibles as this is "a very common and intuitive interaction in everyday life, such as bending a handle, squeezing a tube, or folding a sheet of paper." [67]

[67]

For the design of the tangibles, embedded conductive sensing structures and deformable pads are arranged in specific geometries that are able to transmit physical manipulation data such as bending to the capacitive sensor. The project aims to [...] "enrich interactions via physical manipulation of digital content, for instance, to provide faster, more fine grained, or eyes-free input control on capacitive touchscreens."

In this setup, 3D-printable mechanisms detect multiple levels of pressing, squeezing, and bending input on passive 3D objects. Mechanisms can be combined in an object.



[67]

[PAPER] "Deformation-Aware 3D-Printed Tangibles for Capacitive Touchscreens." https://hci.cs.uni-saarland.de/files/2017/03/TUD-CS-2017-0028.pdf. Accessed 3 Jul. 2019.

[67]

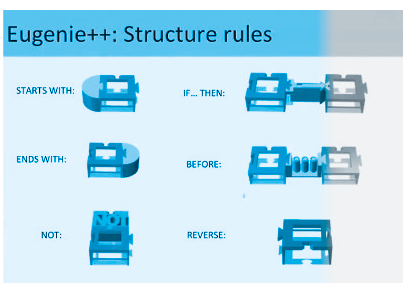
Flexibles: Deformation-Aware 3D-Printed Tangibles for Capacitive Touchscreens

Martin Schmitz , Jürgen Steimle, Jochen Huber, Niloofar Dezfuli, Max Mühlhäuser

5.3 Eugenie and Eugenie++

Eugenie is a Multi-touch GUI for working with the principles of Eugene, a language developed for describing **Biological Parts, Devices, and Systems** via **"BioBricks"**[97] - sequences of DNA that have certain characteristics can be assembled and thus act as biological devices.

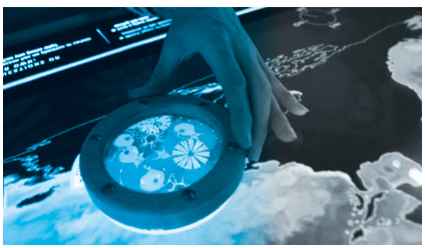
Based on Eugenie, ***Eugenie*++** was developed. The multi-touch application was extended with tangible active tokens - micro-computers with sensing capabilities - such as shaking tilting and touching. A synthetic biological device could be engineered by connecting active and passive tokens assembling a physical structure of tangible blocks. The sequence could then be "stamped" on the multi-touch surface copying the sequence to the GUI and creating a digital representation for the rules. [68]



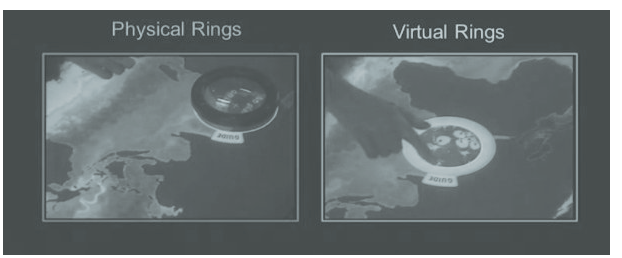
[VIDEO] "TEI 2015 - Eugenie: Multi-Touch and Tangible Interaction for Bio-Design" https://www.youtube.com/watch?v=pL5oWWUNWvo [68]

[WIKIPEDIA] "Bio Bricks" https://en.wikipedia.org/wiki/BioBrick - Accessed 5 May. [97]

5.4 Plankton Explorer



Plankton explorer is an interactive demonstrator of San Francisco's **Exploratorium** science museum. Plankton populations in waters around the world can be revealed and explored through a tangible 'magnifying glass. The system was designed in a graphical user interface version and a version with tangible markers. Both versions were compared in a between-subjects experimental design study, with the means of wiretapping and video surveillance. The percentage of visitors that touched the virtual/physical rings was evaluated, as well as the holding time. The tangible markers yielded a wider distribution of movement on the screen. It was hypothesised that the tangibles will be used more collaboratively and will be shared often, which didn't prove true. A very significant result was, that the multi-touch screen in the TUI version (carrying tangibles) was much better in initiating a first contact - more visitors were drawn to it.

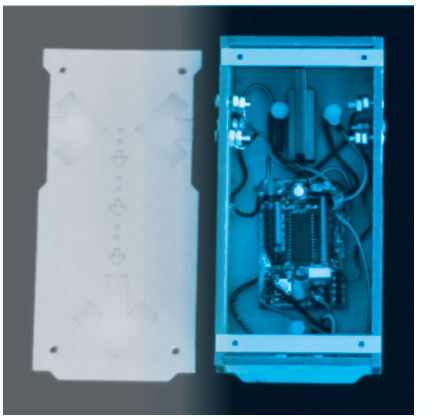


[69] **[VIDEO] "TEI 2015 - Using a Tangible Versus a Multi-touch Graphical User Interface to Support Data Exploration at a Museum Exhibit" https://www.youtube.com/watch?v=ffnEh2EGA1I&t=756s**

5.5 FlowBlocks and System Blocks

FlowBlocks (2013) by Oren Zuckerman and Ayelet Gal-Oz The Interdisciplinary Center of Sammy Ofer School of Communications is an interactive tangible application enabling the user "to model and explore **dynamic systems**" [70] and develop an intuitive approach to system dynamics and causalities.

The wooden, computationally enhanced blocks are representing stocks, flows, variables and constants. The set of Blocks consisting of a "Discrete Sender Block, a Continuous Sender Block an Accumulator Block a Multiplier Block a Subtraction Block and an Addition Block" can be connected on their output side via a magnetic connector to an input of another block in order to model a dynamic system.



[70]

The tangible ***FlowBlock***-set contained a custom designed PCB and potentiometer, lights, switches and displays depending on the function.

FlowBlocks was based on ***System Blocks*** [71] (2003), an earlier work of Oren Zuckerman and Mitchell Resnick developed in the MIT Media Laboratory that was targeted at elementary grade children to convey the basics of system dynamics at an early age. FlowBlocks however is targeted at all age groups as according to a studies cited by the authors, "misconceptions regarding system dynamics concepts are not limited to children" and "even elite business school students demonstrated a poor level of system dynamics understanding".

[PAPER]"Flow blocks as a conceptual bridge between understanding the ...." https://www.researchgate.net/publication/234828457_Flow_blocks_as_a_conceptual_bridge_between_understanding_the_structure_and_behavior_of_a_complex_causal_system. Accessed 3 Jul. 2019. [70]

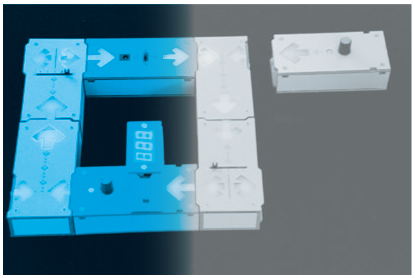
[MASTER'S THESIS] System Blocks: Learning about Systems Concepts through Hands-on Modeling and Simulation - Oren Zuckerman [71]

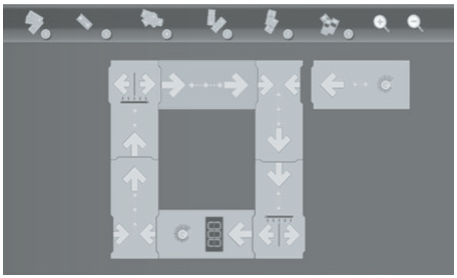
[RESEARCH PAPER]To TUI or not to TUI: Evaluating performance and preference in tangible vs. graphical user interfaces Oren Zuckerman, Ayelet Gal-Oz [72]

Furthermore FlowBlocks was created in a TUI and a GUI version in order to test the hypothesis that task performance would be enhanced in the TUI version and to test if usability would be perceived higher in the TUI-version or it's GUI equivalent. A study [72] with 58 undergraduate communications students was done which showed a statistically significant preference for the TUI version over the GUI version, yet the usability of the latter was rated higher and when given a task, the completion took longer in the TUI version.

FINDINGS: Most participants preferred the TUI version over the GUI version. The preference was statistically significant. Interviews with users revealed that the TUI version was preferred over the GUI version because it (1) enables physical interaction (2) provides rich feedback (3) produces high levels of realism — properties that make the TUI version stimulating and enjoyable.

TUI and GUI versions of FlowBlocks. Task performance was quicker in the GUI.





“Everything is best for something and worst for something else. The trick is knowing what is what, for what, when, for whom, where, and most importantly, why.”

Bill Buxton

5.6 Comparing TUI and GUI

Based on users knowledge and skills of interaction with the non-digital realm, TUIs show a potential to enhance the way in which people extract and convey digital information. But do Tangible user interface systems perform better in terms of usability and enjoyment? In my research I came across many examples in which exactly this question is being examined and attempts are being made to prove or disprove the advantages of tangible user interfaces in comparison to more common and widely-adapted touch -and multi-touch interfaces. Evaluation of the existing body of knowledge with respect to designing, implementing, and evaluating tangible user interfaces, highlighting perspectives from human-computer interaction, design, engineering, psychology and cognitive sciences.

All studies that were found are summarised in the table of the next pages. They have **yielded very different results** concerning the question if tangible user interfaces perform better than graphical user interfaces. Some suggest indeed that tangible user interfaces have advantages over conventional single-touch or multi-touch interfaces, at least in the **initiation stage** of user and interface and in being perceived appealing and motivating than their GUI counterparts. [69] Some of the findings are contradictory however. Most of these comparisons are qualitative: they assess the **level of engagement,** how motivating or appealing the user finds the application and degree of enjoyment the interaction affords, also analysing the conversations a user has when interacting or after interacting with the user interface.

Examples for quantitative measurements are: comparison of the time it takes to finish a certain task, comparison of time the user spends with the GUI (free-choice learning environment) and likelihood of initiation and number of people engaging in the first place.

Examples for qualitative measurements: Subjective rating of usability and enjoyment.

Year	Authors	Title	Interface
2018	Wiktoria Wilkowska, Martina Ziefle, RWTH University	Requirements for tangibles on multitouch surfaces from the user's perspective	multi-touch TUI
2015	Jan B.F. van Erp 1,2(&) , Alexander Toet 1 , Koos Meijer 1 , Joris Janssen 1 , and Arnoud de Jong Human Factors, Kampweg 5, Soesterberg, The Netherlands Human Media Interaction, University of Twente	Comparison of visual, auditory and vibrotactile feedback as to what signifiers/cues are more effective.	TUI vibrotactile feedback Visual feedback Auditory feedback

"(PDF) Anforderungen an Tangibles auf Multitouch-Tischen aus der ...." 7 Nov. 2018, https://www.researchgate.net/publication/328782712_Anforderungen_an_Tangibles_auf_Multitouch-Tischen_aus_der_Nutzerperspektive. Accessed 3 Jul. 2019. [73]

"Subjective User Experience and Performance with Active Tangibles ...." 30 Jul. 2015, https://www.researchgate.net/publication/280562129_Subjective_User_Experience_and_Performance_with_Active_Tangibles_on_a_Tabletop_Interface. Accessed 20 May 2019. [45]

Study design	participants	Measuring critetria	Results
Not stated	Adult students	Survey How motivating, Intriguing, useful, effective, easy to use, reliable, appealing or innovative is the interface perceived	Among the students the TUI was rated more motivating, but less intriguing, useful, effective, easy to use, reliable, appealing and innovative.
Between subjects experimental design	N = 21 adults, students 10 female, 11 male, age-range 20-48, mean age= 36.7 yrs.	Movement Task which involved the displacement of the Sensators to different designated target positions, and a rotation task which involved adjustment of the orientation of the sensators to a single designated target site	all active feedback techniques increased accuracy in both tasks active visual (Visual and Tabletop) feedback yielded the highest accuracy in both tasks, fastest performance in the Rotation task, and overall highest subjective user experience and preference scores

Year	Authors	Title	Interface
2013	Joyce Ma, Lisa Sindorf, Isaac Liao, Jennifer Frazier	Using a Tangible Versus a Multi-touch Graphical User Interface to Support Data Exploration at a Museum Exhibit	Multi-touch GUI TUI
2015	Oren Zuckerman and Ayelet Gal-Oz	FlowBlocks	Multi-touch GUI TUI
2011	Bertrand Schneider, Patrick Jermann, Guillaume Zufferey, and Pierre Dillenbourg	Benefits of a Tangible Interface for Collaborative Learning and Interaction	“multitouch tangible interface”

[VIDEO] “TEI 2015 - Using a Tangible Versus a Multi-touch Graphical User Interface to Support Data Exploration at a Museum Exhibit” https://www.youtube.com/watch?v=ffnEh2EGA1I&t=756s. [68]

[RESEARCH PAPER]To TUI or not to TUI: Evaluating performance and preference in tangible vs. graphical user interfaces Oren Zuckerman, Ayelet Gal-Oz [45]

Benefits of a Tangible Interface for

[74]

“Collaborative Learning and Interaction" 9 Jan. 2019, https://dblp.uni-trier.de/pers/z/Zufferey:Guillaume. Accessed 3 Jul. 2019.

Study design	participants	Measuring critetria	Results
Wiretapping, Video Comparing GUI and TUI between-subjects experimental design	Visitors of the Exploratorium Museum	% of visitors that touched the virtual/physical Rings Holding time Distribution of movement on the screen	Physical rings were better in initiating contact n=253 No differences in holding time physical rings afforded a broader exploration
Between subjects experimental design	N = 58 adults, undergraduate communications students	Subjective rating of usability and preference Task completion time	Preference for TUI was significantly higher but usability was rated lower and task completition took longer
Between subjects experimental design	n = 82 apprentices, 9f, 73m aged between 16 and 40 yrs.	Task completition time: designing ware-houses - space optimisaztion, placement of accesible shelves efficiency of the layout	Participants performed significantly better with the TUI that multi-touch setup and produced more efficient layouts.

Year	Authors	Title	Interface
2010	Philip Tuddenham, David Kirk, Shahram Izadi	Graspables Revisited: Multi-Touch vs. Tangible Input for Tabletop Displays in Acquisition and Manipulation Tasks	M'touch Mouse and puck Tangibles
2011	Tess Speelpenning, Alissa N. Antle, Tanja Doering, and Elise van den Hoven	Exploring How Tangible Tools Enable Collaboration in a Multi-touch Tabletop Game	M'Touch GUI Physical
2009	Malte Weiss, Julie Wagner, Yvonne Jansen, Roger Jennings, Ramsin Khoshabeh, James Hollan, Jan Borchers	SLAP Widgets: Bridging the Gap Between Virtual and Physical Controls on Tabletops RWTH Aachen University University of California, San Diego	M'touch Slap Widgets

[RESEARCH PAPER]"Graspables Revisited: Multi-Touch vs. Tangible Input for Tabletop ...." http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.178.8321. Accessed 3 Jul. 2019. [75]

[CONFERENCE PAPER]"Exploring How Tangible Tools Enable Collaboration in a Multi-touch ...." https://link.springer.com/chapter/10.1007/978-3-642-23771-3_45. Accessed 3 Jul. 2019. [76]

[CONFERENCE PAPER] Malte Weiss, Julie Wagner, Yvonne Jansen, Roger Jennings, Ramsin Khoshabeh, et al..

"SLAP: Silicone Illuminated Active Peripherals - University of California ...." http://hci.ucsd.edu/hollan/Pubs/SLAP.pdf. Accessed 3 Jul. 2019. [66]

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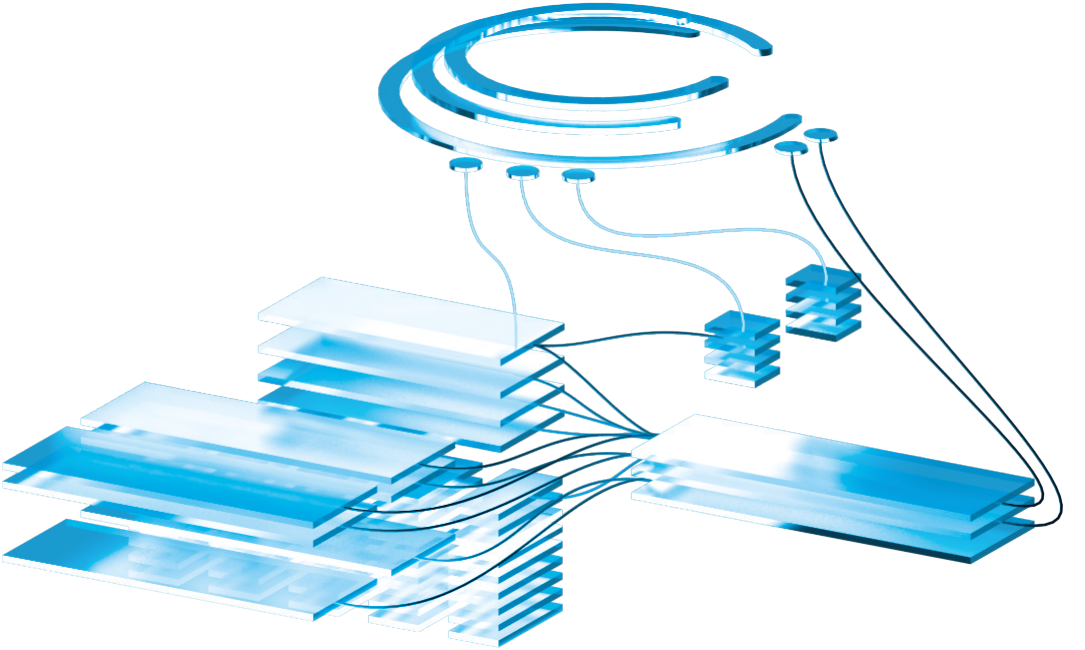
Study design	participants	Measuring critetria	Results
A within-subjects experimental design	n=12 adults	Task completion time	TUI outperformed Multitouch and Mouse and puck in task completion time, error rate and preference rates, but not in regard to ratings of comfort.
A within-subjects experimental design	45 participants, groups of three players = 15 different groups. Participants (26 male, 19 female) **University students**	Collaboration: access points, physicality and awareness.	**increased "tool usage announcing" when taking over physical tokens.** **preference for Tangibles among participants**
A between-subjects experimental design	n=21 adults, 19 male, 2 female ages of 22 and 36 with an average age of 25.7		"Video navigation to specific target frames was significantly faster" using the Slab Interface, yet users "felt more comfortable with the virtual version"



6. Commercialised TUI Products

6.1 Surface Dial

With the introduction of the Surface Studio on 26 October 2016, Microsoft announced a new type of computing device called the Surface Dial, mainly targeted to creative professionals. In the promo-video with the title “Put a new spin on your creativity.” [78] creative professionals and artists are shown engaging in aspects of their profession with their hands (drawing, sewing, composing music, sketching, pottery, and CAD design) - then the the Surface Dial's is introduced. According to unboxing and review videos [79] The Surface Dial is set with standard commands that can be used with app, but need to be laboriously configured by the user for each and every software she wants to use.[80] These commands include toggling sound volume, scrolling, zooming, brightness, and undo/redo.

However, app developers can customise the wheel's abilities, when developing apps and if more developers will choose to do so, there will be more apps with useful preconfigurations. [81] Some third-party applications that were included in the Surface Dial launch include Drawboard PDF, Sketchable, StaffPad and Mental Canvas Player. Surface Dial, like the Surface Pen, utilise non-rechargeable batteries, though the Dial **requires two AAA Alkaline batteries**, and the Surface Pen requires a single AAA battery.

A huge drawback is that the surface dial needs to be configured with each and every app it's supposed to be used with.

The fact that the device requires AAA-Batteries and doesn't come with a docking station to place it on for charging when not in use might also deter potential users from buying in.

"Five things you need to know about Surface Dial" https://blogs.windows.com/devices/2017/02/15/five-things-need-know-surface-dial/#4p9kggIpsebYq2ba.97 Accessed 17 Jun. 2019. [78]

[VIDEO] "Microsoft Surface Dial Review 2019 - Must Have Or Gimmick?" https://www.youtube.com/watch?v=4xmuKhgaT7s&t=187s Accessed 17 Jun. 2019. [79]

[VIDEO] "SURFACE DIAL - eine runde Sache? | Review" https://www.youtube.com/watch?v=axFSpyDGo9Q Accessed 17 Jun. 2019. [80]

Tutorial: Support the Surface Dial (and other wheel devices) in your UWP apphttps://docs.microsoft.com/en-us/windows/uwp/design/input/radialcontroller-walkthrough [81]

6.2 The Touch™

The Touch™ is a commercial force-feedback devices for CAD and 3D Modelling (NURBS). It allows for interactions that enable zoom pinch and orbit, 3D sculpting in translating movement to additive and subtractive virtual brushes and movements like torque and bend - while giving motorised force feedback. It's intended use is 3D sculpting, CAD-Design and even medical training. [82]

The device aims to improve the NURBS curve modelling workflow, as they are very difficult to edit in a free form manner and to provide a more organic modelling workflow overall.

Using Computer aided design applications with a common pointer device and a keyboard requires not only precise motor control and dexterity, but also fluency in keyboard shortcuts and keystroke scroll-wheel combinations to navigate: pinch, zoom, orbit and pan.

As these shortcuts are always a reduction and abstract translation of the degrees of freedom of the physical world, this interaction is counter-intuitive and has to be trained in order to develop a fluent workflow. Because Computer aided design is about representations of 3D objects and surface textures, adding more degrees of freedom and haptic feedback could potentially enhance the design workflow.

"The Touch™ Haptic Device." https://www.3dsystems.com/haptics-devices/touch [82]

6.3 3D Connexion

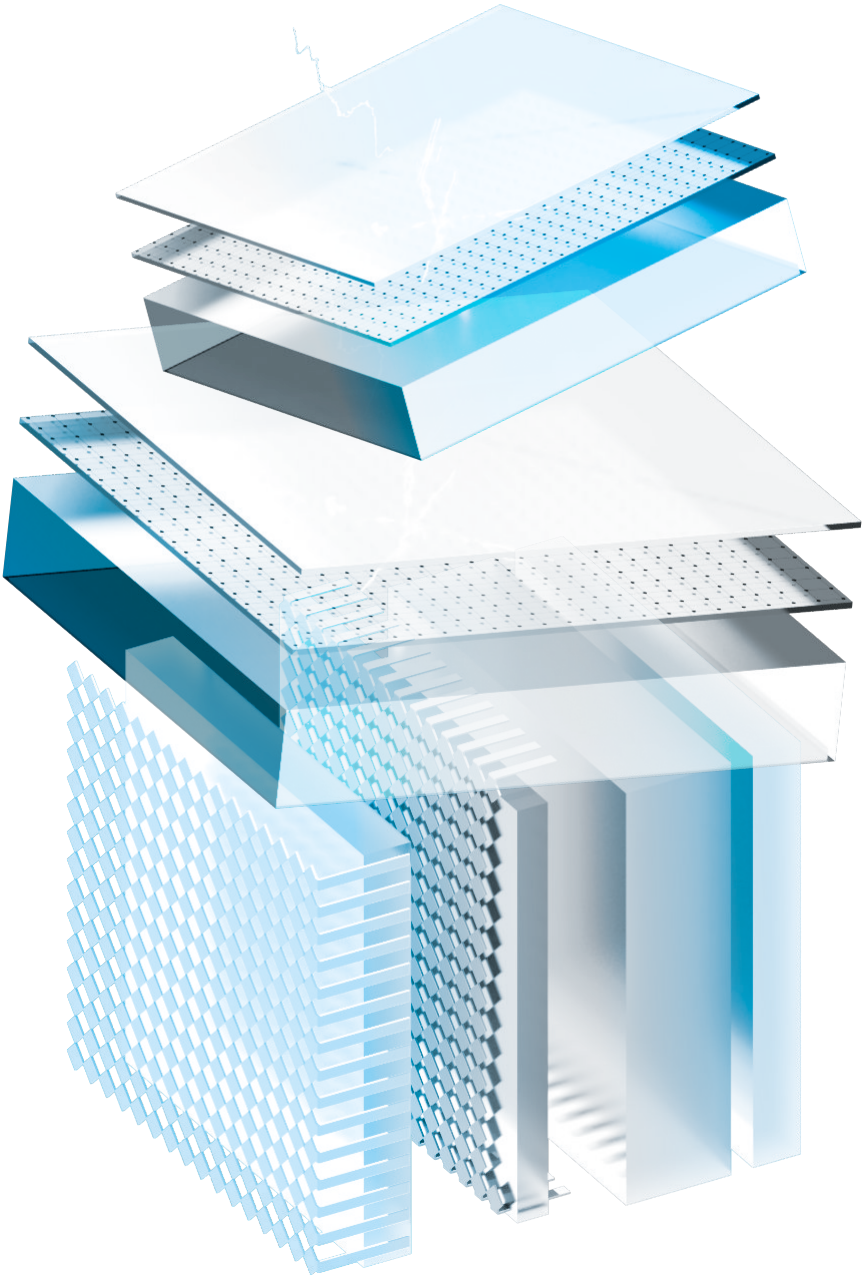
3Dconnexion manufactures a line of human interface devices for manipulating and navigating computer-generated 3D imagery. These devices are often referred to as 3D motion controllers, 3D navigation devices, 6DOF devices (six degrees of freedom) or a 3D mouse.

Commonly utilised in CAD applications, 3D modelling, 3D Simulation environment, animation, and product visualisation, users can manipulate the controller's pressure-sensitive handle (historically referred to as either a cap, ball, mouse or knob) to fly through 3D environments or manipulate 3D models within an application. The appeal of these devices over a mouse and keyboard is the ability to pan, zoom and rotate 3D imagery simultaneously, without stopping to change directions using keyboard shortcuts or a software interface. 3Dconnexion devices are compatible with over 100 applications including Autodesk Inventor, Solid Edge, Blender, Google Earth, Second Life, NASA World Wind, Virtual Earth 3D, Geomagic, Google SketchUp 6, Cinema4D, Maya, SolidWorks, T-FLEX CAD, Photoshop, etc.

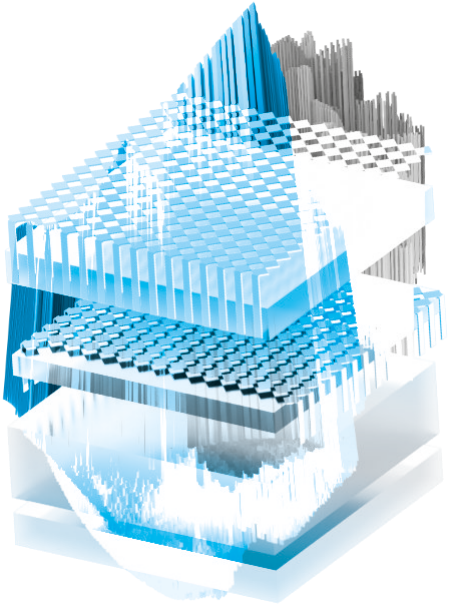
[83]

[83] **[IMAGE]** https://www.konstruktionspraxis.vogel.de/erweiterte-unterstuetzung-von-3d-maeusen-in-rhino-v5-a-398453/

[32] "SpaceMouse Pro"https://www.3dconnexion.de/index.php?id=13&redirect2=www.3dconnexion.de accessed 7 Apr. 2016,



7. Touch-input technologies



7.1 Basic components of a touch screen

A basic touch has a touch sensor, a controller, and a software driver as three main components. The touch screen is needed to be combined with a display and a PC to make a touch screen system.

Touch sensor:

The sensor generally has an electrical current or signal going through it and touching the screen causes a change in the signal. This change is used to determine the location of the touch of the screen.

Controller:

A controller will be connected between touch sensor and PC. It takes information from sensor and translates it for understanding of PC. The controller determines what type of connection is needed.

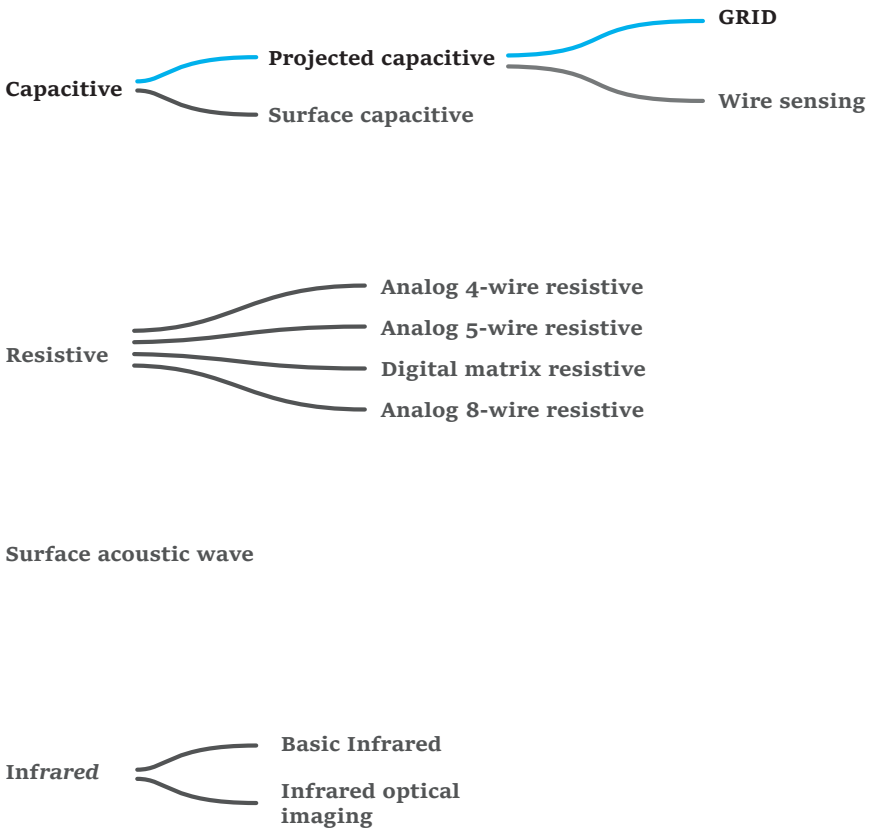
Software driver:

It allows computer and touch screen to work together. It tells OS how to interact the touch event information that is sent from the controller.

[86] [87]

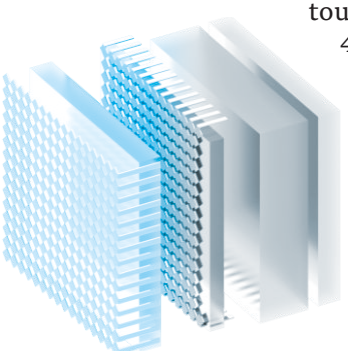
[86] **"The touchscreen technologies guide" https://www.dmccoltd.com/english/museum/touchscreens/idea.html**

[87] **[WIKIPEDIA] "Touchscreen." https://en.wikipedia.org/wiki/Touchscreen**


Capacitive
Projected capacitive
Surface capacitive
GRID
Wire sensing
Resistive
Analog 4-wire resistive
Analog 5-wire resistive
Digital matrix resistive
Analog 8-wire resistive
Surface acoustic wave
Infrared
Basic Infrared
Infrared optical imaging

7. 2 Projected capacitive

According to Geoff Walker the Senior Touch Technologist of the Intel Corporation, in the year 2007 93% of touchscreens shipped were resistive and only 4% were Projected Capacitance. In 2013 3% of touchscreens shipped were resistive and 90% were Projected Capacitance. [88] Projected Capacitive is similar to Surface Capacitive, but it offers two primary advantages: in addition to a bare finger, it can also be activated with surgical gloves or thin cotton gloves; and it enables multi-touch activation (simultaneous input from two fingers). [89]



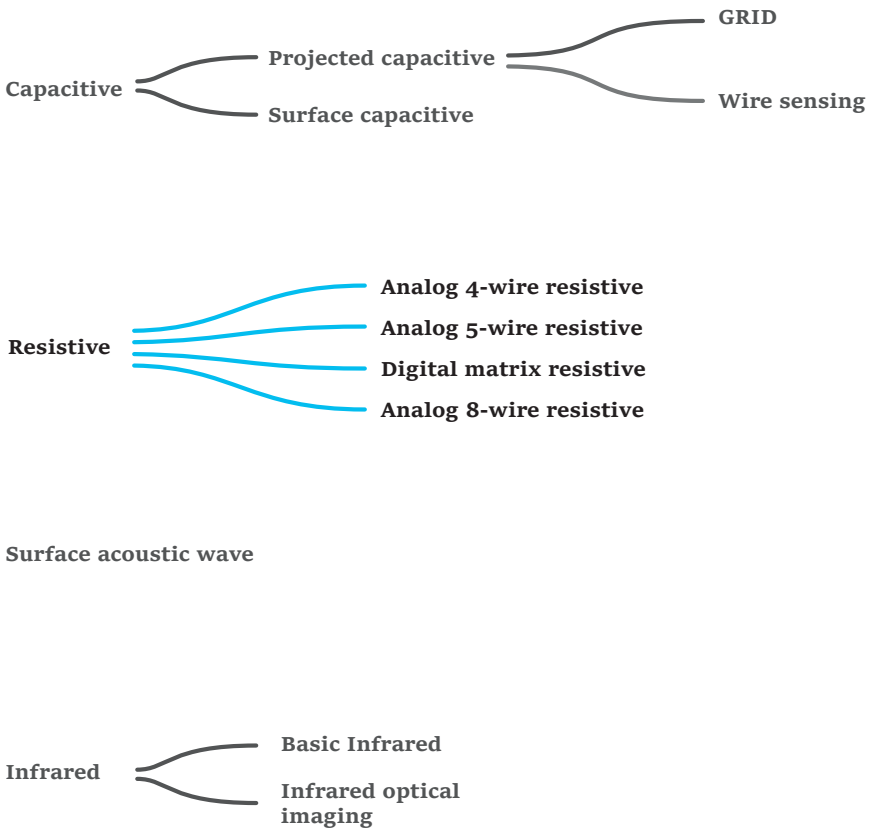
Capacitance coupling makes the electrostatic capacitance between the x and y electrodes change

A projected capacitive monitor is composed of a sheet of glass with embedded transparent electrode films and an IC chip, which creates a three dimensional electrostatic field. When a finger comes into contact with the screen, the ratios of the electrical currents change and the computer is able to detect the touch points. When touched, a charge is drawn to the point of contact and circuits located in the panel measure that charge and then send the information to the controller to process it thus using humans as real life capacitors. Both resistive and capacitive touch screens use indium tin oxide (ITO) sensors and it will use in totally different ways.

Projected capacitive grid sensing is used in neary all Smartphones and tablet devices of recent technology

[88] [PRESENTATION SLIDES](PDF)"Fundamentals of Projected-Capacitive Touch Technology" - Geoff Walker http://www.walkermobile.com/Touch_Technologies_Tutorial_Latest_Version.pdf

[87] [WIKIPEDIA] "Touchscreen." https://en.wikipedia.org/wiki/Touchscreen

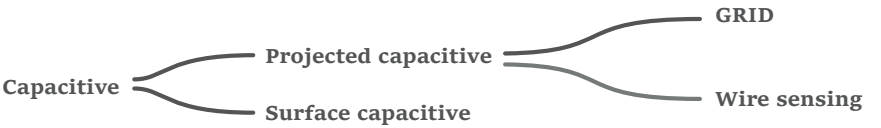

Capacitive
Projected capacitive
Surface capacitive
GRID
Wire sensing
Resistive
Analog 4-wire resistive
Analog 5-wire resistive
Digital matrix resistive
Analog 8-wire resistive
Surface acoustic wave
Infrared
Basic Infrared
Infrared optical imaging

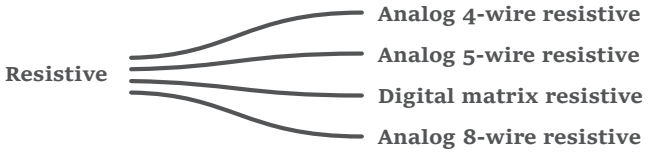
7.3 Resistive

Resistive touch screens are still widely used in medical devices, scientific instruments, military, industrial environments where it's users have to wear gloves. There are clear instances where they are no doubt better suited for low-cost designs . Resistive touchscreens work on the basis of pressure applied to the screen. A resistive screen consists of a number of layers. When the screen is pressed, the outer later is pushed onto the next layer — the technology senses that pressure is being applied and registers input. Resistive touchscreens are versatile as they can be operated with a finger, a fingernail, a stylus or any other object. There are two different types of metallic layers. The first type is called matrix, in which striped electrodes on substrates such as glass or plastic face each other. The second type is called analogue which consists of transparent electrodes without any patterning facing each other. As of 2011 analogue offered lowered production costs.[citation needed] When contact is made to the surface of the touchscreen, the two sheets are pressed together. On these two sheets there are horizontal and vertical lines that, when pushed together, register the precise location of the touch. Because the touchscreen senses input from contact with nearly any object (finger, stylus/pen, palm) resistive touchscreens are a type of "passive" technology.

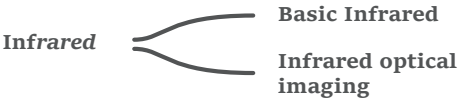
[88] [PRESENTATION SLIDES](PDF)"Fundamentals of Projected-Capacitive Touch Technology" - Geoff Walker http://www.walkermobile.com/Touch_Technologies_Tutorial_Latest_Version.pdf

[87] [WIKIPEDIA] "Touchscreen." https://en.wikipedia.org/wiki/Touchscreen

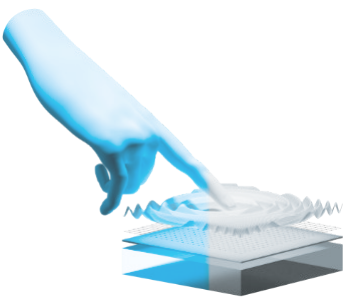




Surface acoustic wave



7.4 SAW (Surface Acoustic Wave)



A SAW touch screen is made up of a glass sheet with three components: piezoelectric transmitting transducers, receiving piezoelectric transducers, and reflectors. The transmitting transducers produce ultrasonic waves that skim over the surface of the screen, get reflected and are captured by the receiving transducers. A portion of the waves is absorbed when the panel is touched. This allows the receiving transducer to locate the touch point and transmit its coordinates to the computer. When a soft matter like human skin, touches the screen, the surface acoustic waves are absorbed, and the receiving transducers do not register any input. Based on this lack of sound the sensors can calculate the location of the touch event. [87] This also means, that SAW touch screens can't detect a touch by hard materials which do not absorb pulse.

[88] [PRESENTATION SLIDES](PDF)"Fundamentals of Projected-Capacitive Touch Technology" - Geoff Walker http://www.walkermobile.com/Touch_Technologies_Tutorial_Latest_Version.pdf

[87] [WIKIPEDIA] "Touchscreen." https://en.wikipedia.org/wiki/Touchscreen

7.5 Multi point vs. multi touch (capacitive)

As Bill Buxton of Microsoft Research points out in his article multi-touch systems I have known and loved, an important distinction to make: “Many, if not most, of the so-called “multi-touch” techniques, are actually “multi-point”. Double clicking, dragging, or working pull-down menus, for example, are the same interaction technique, independent of whether a touch pad, trackball, mouse, joystick or touch screen are used.” [3]

If the touch sensor controller gives information about the area that is being touched, it is possible, to distinguish different fingers or as fingerSense technology does: fingers and knuckles. Information about the area being touched can convey information about the **angle of approach** - the **pitch and yaw** of fingers relative to a touchscreen surface. An example is FingerSense [90] developed by Robert Xiao, Julia Schwarz and Chris Harrison of Qeexo and described in their paper ‘Estimating 3D Finger Angle on Commodity Touchscreens’. [91] This technology was later implemented on on Huawei Phones which for example allows for several different screenshot options and broadens the variety of gestures with pitch and yaw detection and distinguishing knuckles, nails and fingers.

"Multi-Touch Systems that I Have Known and Loved - Bill Buxton."http://www.billbuxton.com/multitouchOverview.html.Accessed 30 Apr. 2019. [3]

[RESEARCH PAPER]TapSense: Enhancing Finger Interaction on Touch Surfaces “https://juliaschwarz.net/assets/tap-sense/harrison-uist11-tap-sense.pdf” [89]

“Finger Sense - Queexo ”https://qeexo.com/fingersense/ [90]

“Estimating 3D Finger Angle on Commodity”Touchscreenshttp://chrisharrison.net/projects/3dfingerangle/Qeexo3DFingerAngle.pdf [91]

7.6 Single touch vs. dual touch (capacitive)

Dual touch devices are limited to the use of two concurrent contact points - usually two fingers. Dual touch interaction allows for gestures like pinch and zoom and can distinguish between a one or two finger swipe. The behaviour of a dual touch device can become erratic and give weird results if more than two contact points are used. As a result, dual touch devices are limited for for single user interaction and not suited for multi-user interaction. [92]

[92] "What's the difference? Single, Dual and Multi Touch Monitors" http://www.appliedart.com/blog/whats-the-difference-single-dual-and-multi-touch-monitors

7.7 Multi hand vs. multi user interaction

Multi touch user interfaces, that allow for multi user interaction should support at least ten touch points in order to afford two hands to independently interact. However the capacitive sensor will never convey enough information to distinguish the hands of different users. In the default configuration there are limitations for collaborative tasks with multi touch screen systems.

DiamondTouch was a multi touch input technology which was capable of allowing multiple people to interact simultaneously while identifying which person is touching where. Licensed in 2008 to Circle Twelve Inc, it was originally developed by Mitsubishi Electric research Laboratories (MERL) in 2001. The system configuration contains a camera mounted on top of the monitor and facing straight down, where the users hands would interact. It is very likely that a camera recognition algorithm was used to assign the additional information to the touch points.

[94]

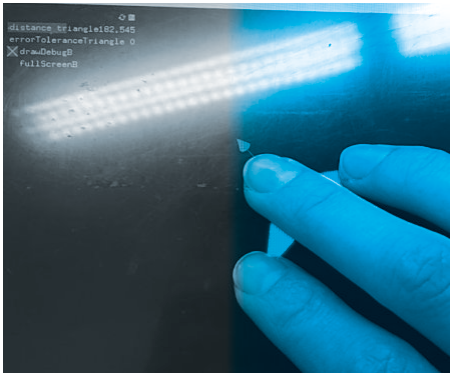
The Touch-Table configuration was intended for collaborative tasks such as brainstorming and collaborative note-taking. Tangible Objects were not part of the Prototype, but the approach could be used to couple a Tangible ID with a user ID and thus enabling more complex scenarios.

"Publications | Mitsubishi Electric Research Laboratories." https://merl.com/publications/?da=on&ps=20&idx=120. Accessed 1 May. 2019. [93]

[IMAGE] “1st_DiamondTouch_ws1.jpg” https://en.wikipedia.org/wiki/DiamondTouch [94]

7.8 Multi point object interaction vs. multi touch

Accessing the touch-controllers information about the area of touch makes it possible to develop applications with deformation aware tangibles like the Flexibles developed in HCI TU Darmstadt.



WinOfxTouch Windows 8 touch driver for OpenFrameworks using WM_POINTER events. This addon is the base for oscTouchObject; object interaction with a touch screen

Accessing the touch-controllers information about the area of touch makes it possible to develop applications with deformation aware tangibles like the Flexibles developed in HCI TU Darmstadt the

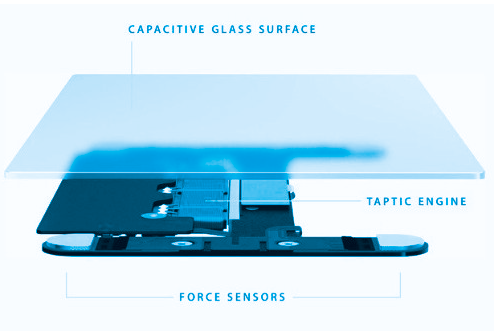
[67]

[67]

[PAPER] "Deformation-Aware 3D-Printed Tangibles for Capacitive Touchscreens." https://hci.cs.uni-saarland.de/files/2017/03/TUD-CS-2017-0028.pdf. Accessed 3 Jul. 2019.

Flexibles: Deformation-Aware 3D-Printed Tangibles for Capacitive Touchscreens

Martin Schmitz , Jürgen Steimle, Jochen Huber, Niloofar Dezfuli, Max Mühlhäuser



[22]

7.9 multi touch vs. 3D touch (capacitive)

3D-touch is a technology developed by apple and is the successor of force-touch. Both digital features are based on the same technology that utilises Apple's own proprietary **Taptic Engine**. Force Touch is capable of is capable of taps and multi-touch gestures like pinch and swipe as well as distinguishing a soft touch and a soft press. 3D touch adds functionality and allows for gestures with a broader context as it can distinguish between a soft and a hard press. [21] The following are examples of how apple archives a very natural way of letting the user interact trough 3D touch gestures:

1. **Quick Actions**: "Quick Actions let users do the things they do most often, faster and in fewer steps. Many of these actions can even be done with a single press, right from the Home screen." [95]

2. Peek and Pop: letting [...] "users preview all kinds of content and even act on it — without having to actually open it. Users can then press a little deeper to Pop into content in an app" [95]

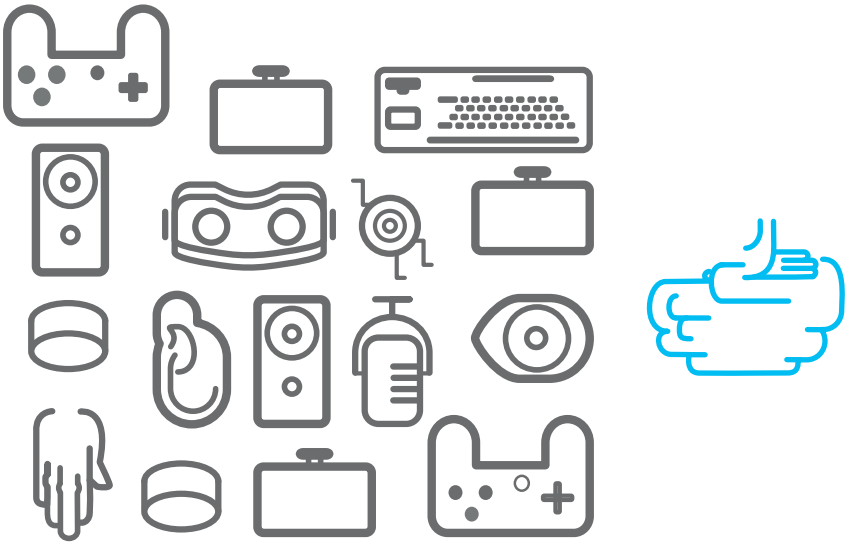
3. Pressure Sensitivity: "Creative apps can take advantage of the pressure-sensing display of iPhone in many ways. For example, they can vary line thickness or give a brush a changing style." [95]

[95] "Take Advantage of 3D Touch" https://developer.apple.com/ios/3d-touch/

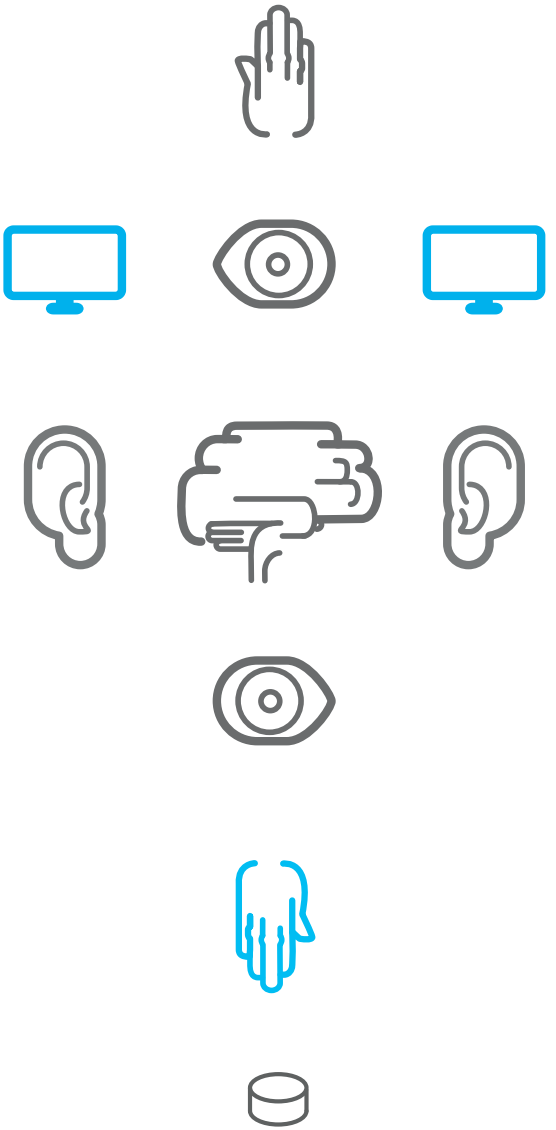
[20] "Wikipedia- Force Touch"en.wikipedia.org/wiki/Force_Touch

[21] "What Is 3D Touch? A Webopedia Definition." https://www.webopedia.com/TERM/3/3d-touch.html. Accessed 2 Jul. 2019.

[22] [IMAGE] https://www.iculture.nl/gids/force-touch-uitleg/



8. Computer–human human-computer modalities



8.1 Modality in human–computer interaction

"In the context of human–computer interaction, a modality is the classification of a single independent channel of sensory input/output between a computer and a human. A system is designated uni-modal if it has only one modality implemented, and multi-modal if it has more than one. When multiple modalities are available for some tasks or aspects of a task, the system is said to have overlapping modalities. If multiple modalities are available for a task, the system is said to have redundant modalities. Multiple modalities can be used in combination to provide complementary methods that may be redundant but convey information more effectively. Modalities can be generally defined in two forms: human-computer and computer-human modalities.

Multi-modal interaction can also be defined as interaction with environments, virtual and physical through natural modes of communication [999] body and hand Gestures, speech control, handwriting, graphics or eye movement." [96]

[96] [WIKIPEDIA] Modality (human–computer interaction)
https://en.wikipedia.org/wiki/Modality_(human%E2%80%93computer_interaction)

8.2 Computer–Human modalities

"Any human sense can theoretically be used as a computer to human modality. However, the modalities of seeing and hearing are the most commonly employed since they are capable of transmitting information at a higher speed than other modalities, 250 to 300 and 150 to 160 words per minute, respectively. Though not commonly implemented as computer-human modality, tactition can achieve an average of 125 wpm through the use of a refreshable Braille display. Other more common forms of tactition are smartphone and game controller vibrations." [96]

vision

Audition

Tactition

Uncommon modalities:

Gustation (taste), **Olfaction** (smell), **Thermoception** (heat), **Nociception** (pain), **Equilibrioception** (balance)

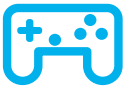
[WIKIPEDIA] "Modality (human–computer interaction)"
https://en.wikipedia.org/wiki/Modality_(human%E2%80%93computer_interaction) [96]

Typical peripheral hardware

Screen

Speakers

Vibration motors



8.3 Human-computer modalities

"Computers can be equipped with various types of input devices and sensors to allow them to receive information from humans. Common input devices are often interchangeable if they have a standardised method of communication with the computer and afford practical adjustments to the user. Certain modalities can provide a richer interaction depending on the context, and having options for implementation allows for more robust systems. With the increasing popularity of smartphones, the general public are becoming more comfortable with the more complex modalities. Speech recognition was a major selling point of the iPhone 4S and following Apple products, with the introduction of Siri. This technology gives users an alternative way to communicate with computers when typing is less desirable. However, in a loud environment, the audition modality is not quite effective. This exemplifies how certain modalities have varying strengths depending on the situation. Other complex modalities such as computer vision in the form of Microsoft's Kinect or other similar technologies can make sophisticated tasks easier to communicate to a computer especially in the form of three dimensional movement."[96]

Tactition

Non-touch gestures, motion

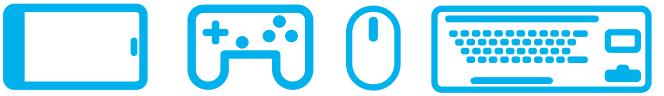
Speech Input

[WIKIPEDIA] "Modality (human–computer interaction)"
https://en.wikipedia.org/wiki/Modality_(human%E2%80%93computer_interaction)

[96]

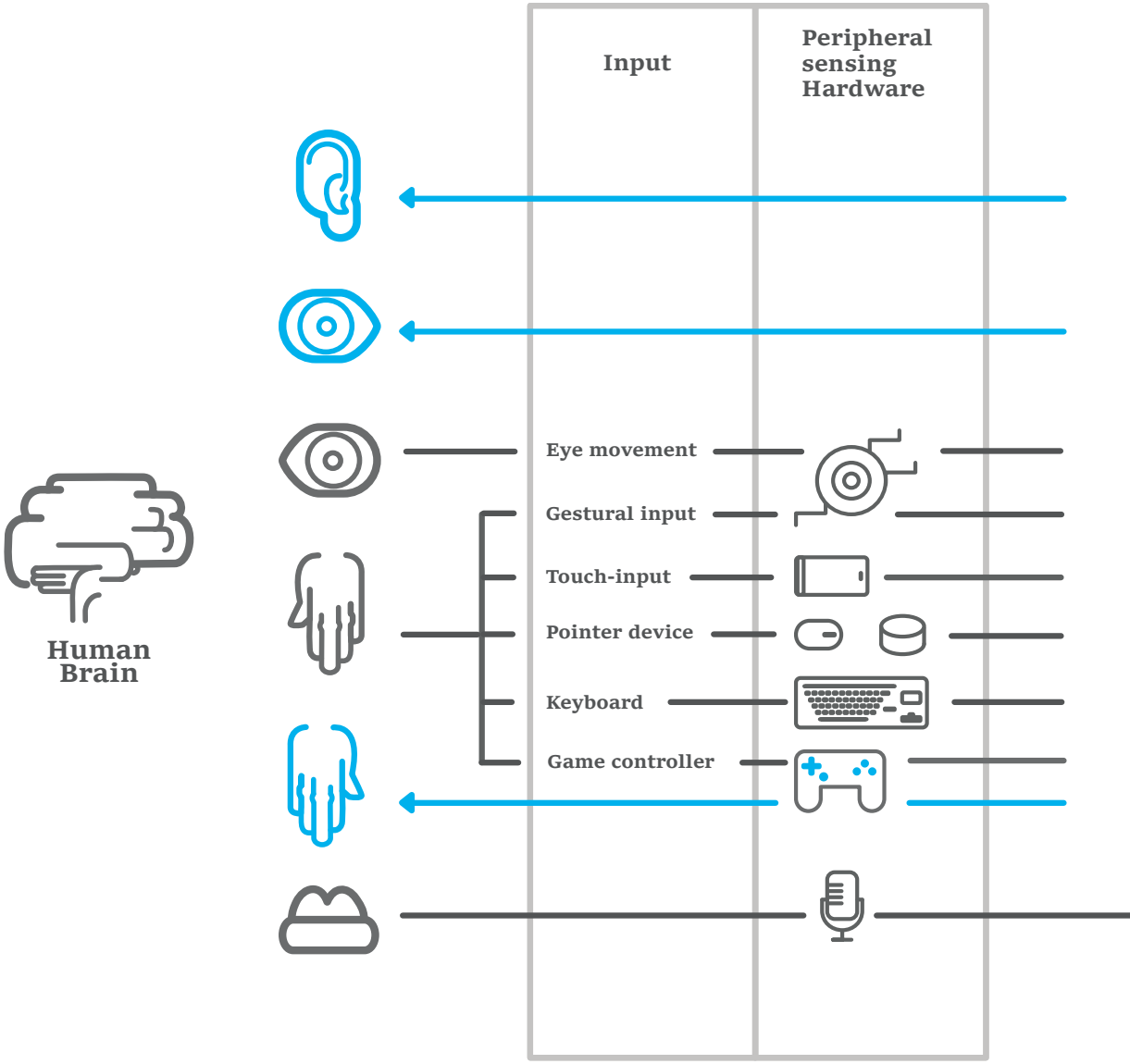
Typical peripheral hardware

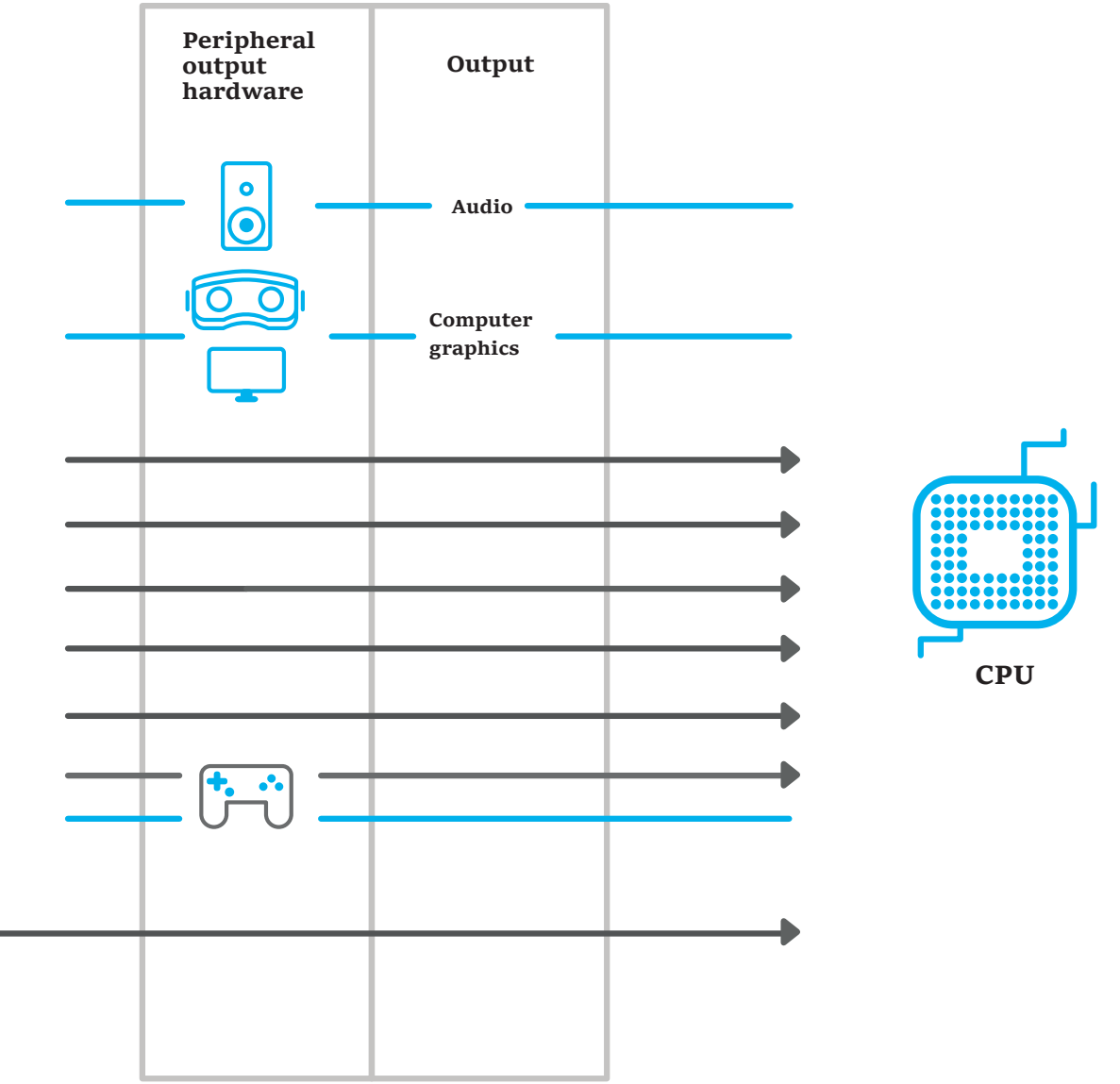
Touchscreen,Keyboard, pointer device



Computer vision system: Camera infrared etc.

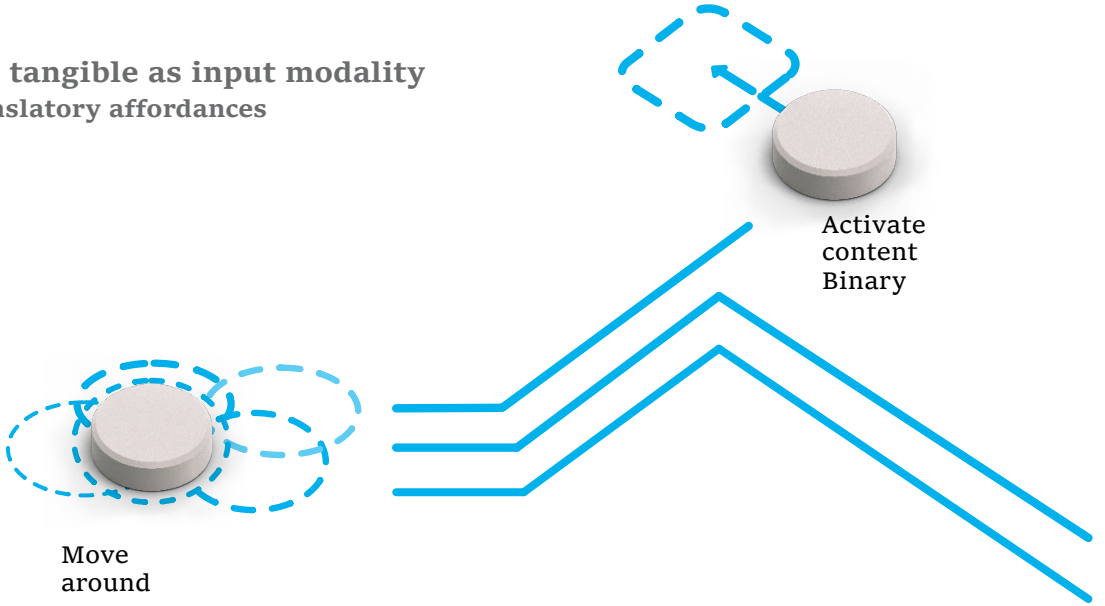
Microphone

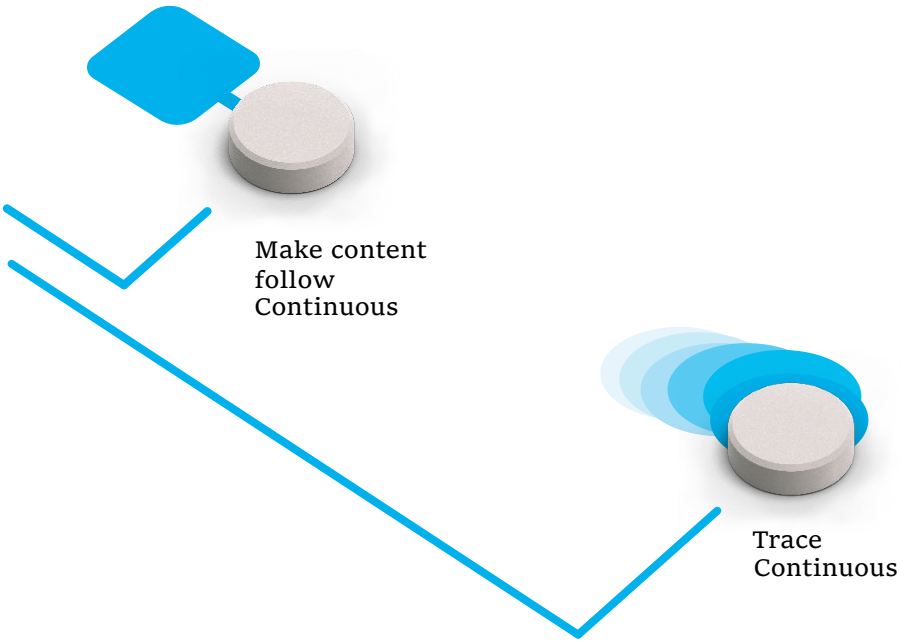

Input
Peripheral sensing Hardware
Eye movement
Gestural input
Touch-input
Pointer device
Keyboard
Game controller
Human Brain


Peripheral output hardware
Output
Audio
Computer graphics
CPU

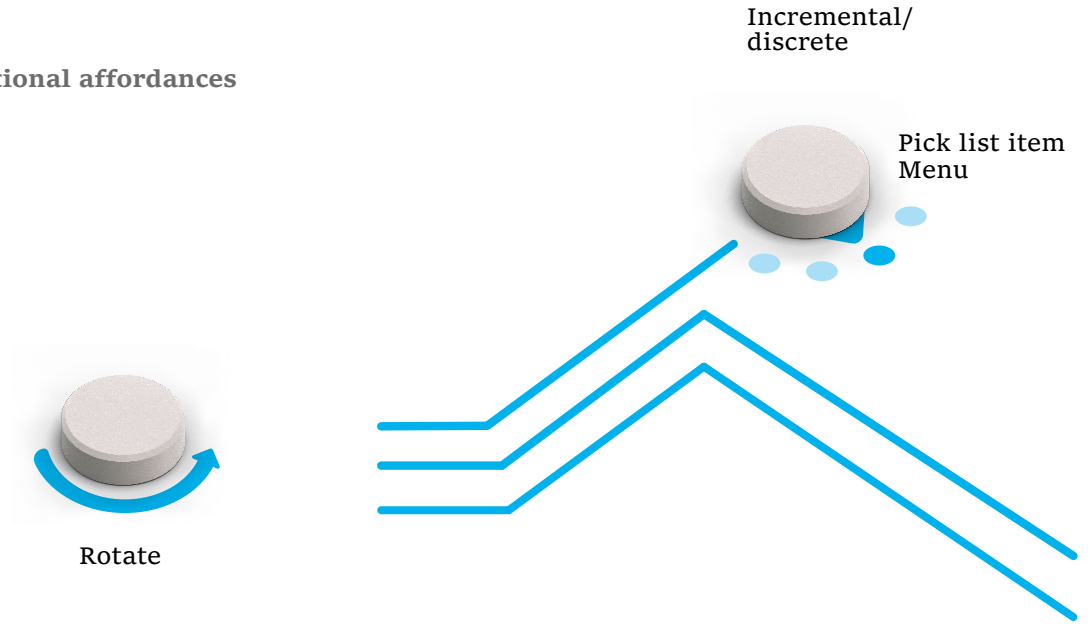
The tangible as input modality

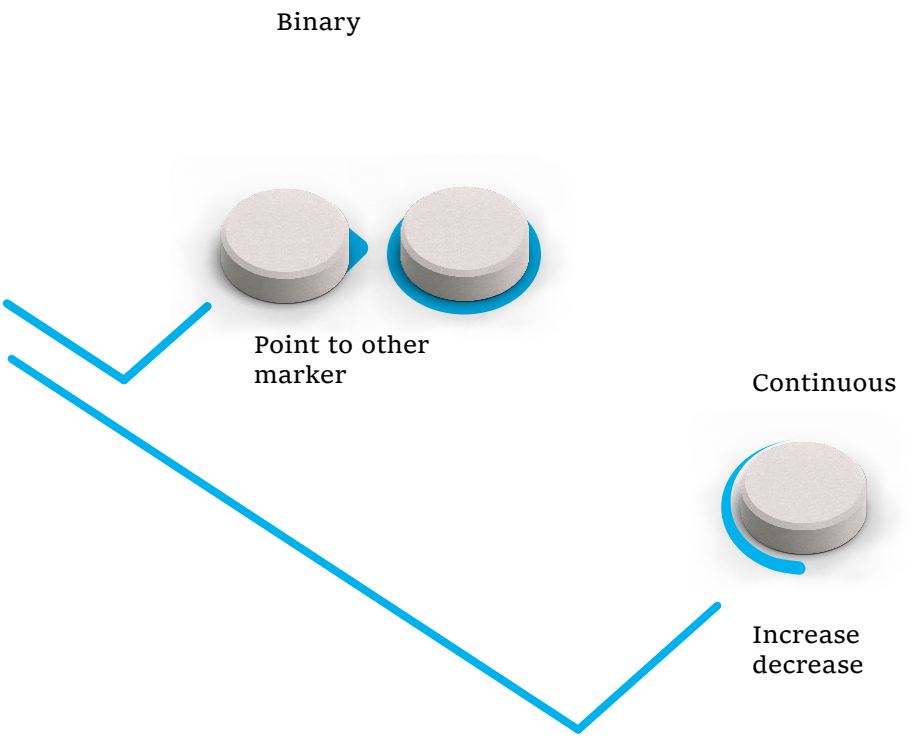
Translatory affordances




Make content
follow
Continuous
Trace
Continuous

Rotational affordances




Binary
Point to other
marker
Continuous
Increase
decrease

9. Feedback

“Poor feedback can be distracting, uninformative, and in many cases irritating and anxiety-provoking”

Don Norman

9.1 Counter-intuitive and opposite feedback

Feedback—communicating the results of an action—is a well-known concept from the science of control and information theory: Wrong counter-intuitive and opposite feedback can lead to complete frustration. This can be illustrated with mirror drawing tasks: a piece of paper is placed shielded from the view of the person that is instructed to draw on it. The only reference comes from a mirror, that is angled at the drawing surface such, that the participant can only see an inverted version of her hands and the resulting drawing. The visual feedback therefore is opposite and the person drawing cannot help to refer intuitively to what she knows of how the world works. It becomes an almost impossible task to trace a line of a simple shape like a star. If user-interface elements are not in a place where the user might expect it, they can lead to errors, disruptions and potentially unleash feelings of frustration.

9.2 Unhelpful, arcane or “rude” feedback

Error messages that often contain messages that seem arcane to a user that is not an it-professional, sometimes error messages in windows systems will be like: “ a problem caused the program to stop working correctly...[...]” without stating what the problem is or how to solve it. In windows 7 this had to be confirmed by a user with “OK”, even if most likely the user was not OK with the application

failing. This kind of feedback isn't helpful for the user and sometimes can be interpreted as plain rude. In windows 10 there are improvements in communicating with the user: when an error message pops up, the user has a button that closes the application and sometimes is promoted with the decision to 'debug' or 'close the program' which is for most users the same thing, only that the latter will more time.

9.3 Superfluous and annoying feedback

Inflationary: If feedback like warning messages come up too many times, they might be ignored the next time.

Redundant: If a user's action causes an error, it might be helpful to inform her about measures to prevent it from happening in the future. If the same error however causes multiple error-messages, and therefore results in multiple boxes popping up, it will be very disruptive and seem redundant to the end-user that just wants to continue with what ever her goal is at the moment.

Cacophonous: Feedback can be too loud, to colourful or worse: both at the same time. Don Norman compares inappropriate and unintelligible Feedback to the phenomenon of the annoying backseat-driver.

Feedback that is actually helpful

Adequate feedback should be none of the above stated things and it must be immediate, should convey information about what has happened and it should be unobtrusive and not inflationary.

[48] Norman, Donald A. The Design of Everyday Things. - Revised and Expanded Edition Basic Books, 2013.

9.4 Haptic force feedback devices for computer aided design

For CAD design it is safe to say that a certain degree of realism is not required and in many cases even not desirable. Different behaviour in responsiveness in order to represent the weight of an object in the material world- for example a model of an iron bar behaving more sluggishly than a counterpart made from a lighter material- could very much encumber a users workflow. More realistic shading, given that it doesn't slow down the application would most probably not add value and could potentially be a distraction or even interfere with standardised labelling. A certain **level of abstraction** is required for efficient computer aided design.

Different tasks in a virtual environment require different levels of abstraction

The Touch™ Haptic Device 3D Systems [82]

Using Computer aided design applications with a common pointer device and a keyboard requires not only precise motor control and dexterity, but also fluency in keyboard shortcuts and keystroke scroll-wheel combinations to navigate: pinch, zoom, orbit and pan.

As these shortcuts are always a reduction and abstract translation of the degrees of freedom of the physical world, this interaction is counter-intuitive and has to be trained in order to develop a fluent workflow. Because computer aided design is about representations of 3D objects and surface textures, adding haptic sense could potentially enhance the design workflow.

[30]

Anarkik 3D controller

[IMAGE]"anarkik 3D contoller" http://anarkik3d.co.uk/ [30]

"The Touch™ Haptic Device." https://www.3dsystems.com/haptics-devices/touch [82]

9.5 Haptic force feedback devices for VR

Exoskeleton gloves for VR

[39]

these devices could potentially take the VR experience one step further sensing input through a maximum of 27 channels for the number of degrees of freedom of the human hand. The user may be able not only to move around in a natural manner, but also use his hands naturally and manipulate objects with them. If these gloves are also equipped with haptic feedback actuators, objects touched and manipulated could also 'feel' natural and characteristics like friction resulting from texture and weight of an object could be simulated. Force feedback provides direct perception of three-dimensional (3D) objects and directly couples input and output between the computer and User.

Force feedback exoskeleton suit

An Exoskeleton suit could not only provide a high number of degrees of freedom close to the 244 of the human body, but also provide force feedback for the whole environment in the virtual world. A user could sit on a chair and feel its support or pick up a stone in VR and actually feel it's weight, temperature and texture.

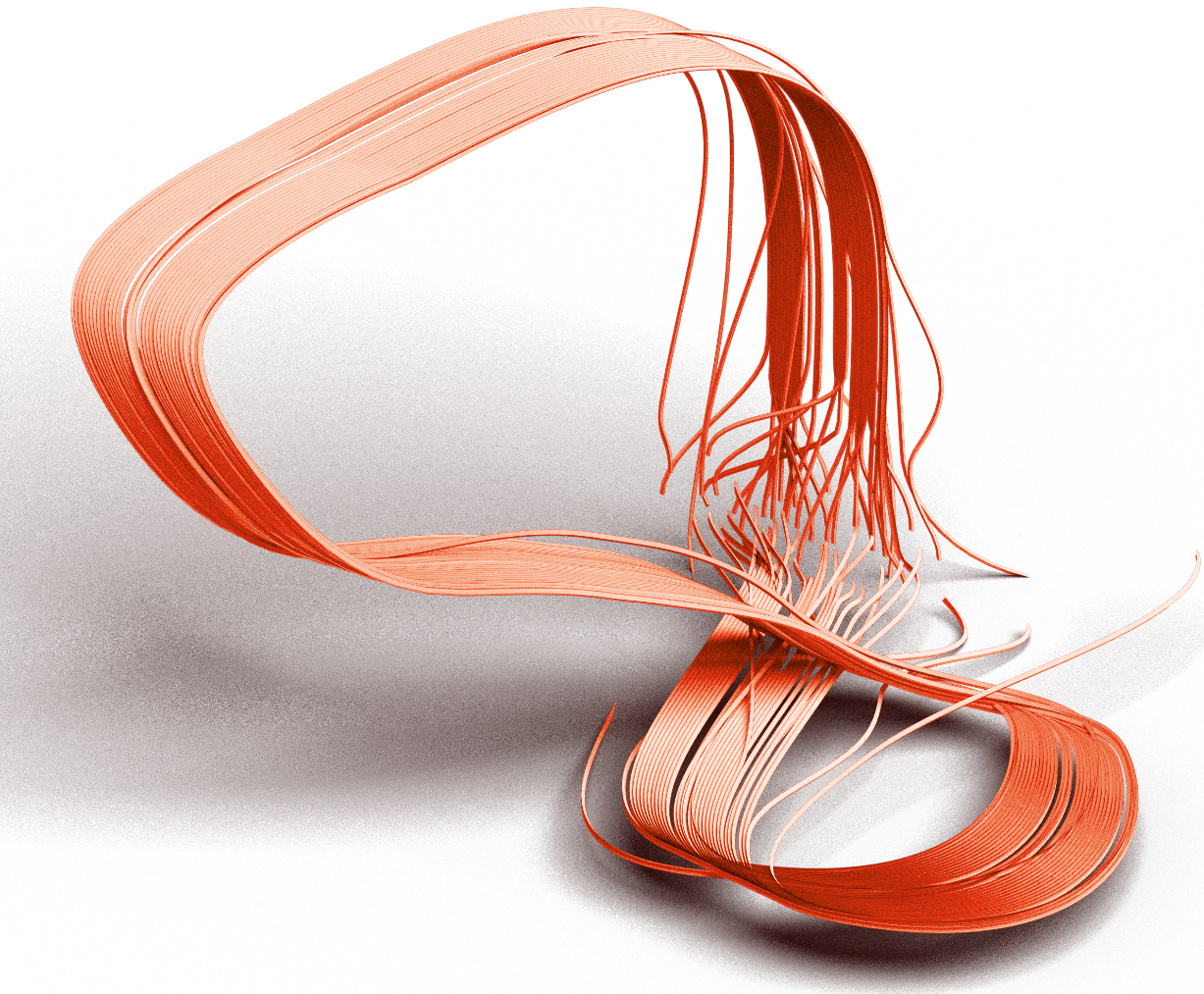
Haptography

The Startup Tactai **[99]** aims to record textures of almost anything and translate them into vibration that mimic the surface texture. They call this approach digitising our sense of touch or haptography. The startup released a developer kit Tactai TouchTM. This technology could, in conjunction with exoskeleton gloves add touchable surface textures to VR.

[38] "Understanding Hand Degrees of Freedom and Natural Gestures for ...." https://link.springer.com/chapter/10.1007/978-3-642-40483-2_20. Accessed 3 Jul. 2019.

[39] [IMAGE] "CyberGloveSystems-CyberGrasp.png." http://djrobinsimmons.com/CyberGloveSystems/cybergrasp.html

[40] "On eve of VR launches, hands-on with a new haptic ideal" https://www.polygon.com/virtual-reality/2016/3/25/11306368/tactai-haptics-vr-virtual-reality-touch Accessed 31 May. 2019."



II

Developing a prototype

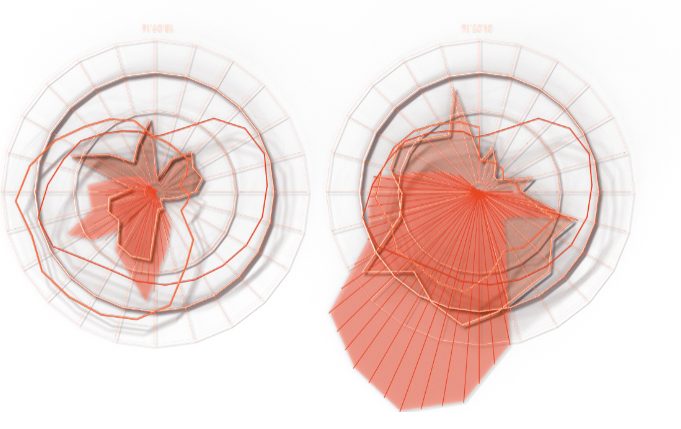
15.1 Visualisation goals

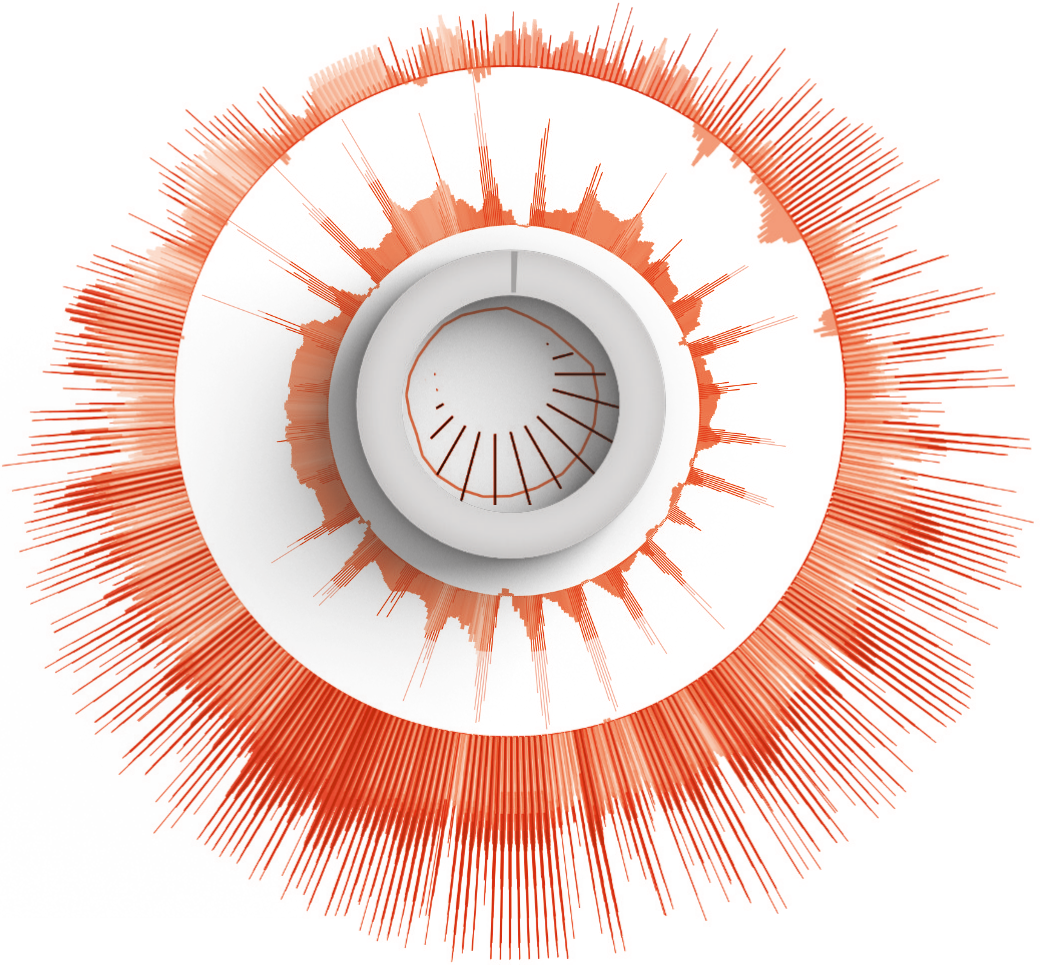
the prototype for this thesis is intended to serve as means to evaluate how a setup with interactive tangibles can provide interaction with large data-sets, while making them easier to navigate through, compare and more visually appealing. As an example weather data was obtained from Solar-Institute Jülich (SIJ), an institute that is mainly involved in the development of application-oriented, technical solutions in the fields of renewable and efficient energy use. The data covers the entire years 2017 and 2018 and contains hourly values for temperature, humidity, wind direction, wind speed, air pressure, irradiance, global radiation and direct radiation. For the visualisation temperature and global radiation were picked, as the year 2018 was significantly hotter than the year before and it was hypothesised that this would already be an interesting aspect to visualise as an example.

Secondly the combination of global radiation in conjunction with wind speed is interesting, because it can be the basis for a simulation that can show, how much of this energy could potentially be harvested when more electricity is being produced than needed and stored in an energy storage system, in order to be used later on. This visualisation would be more complex and an algorithm from would be needed. In order to sketch and experiment how a possible result could potentially look like , hourly load values from 2017 and 2018 were downloaded provided publicly by entso-e, the European Network of Transmission System Operators.

SIJ | SOLAR-INSTITUT JÜLICH
FH AACHEN
UNIVERSITY OF APPLIED SCIENCES

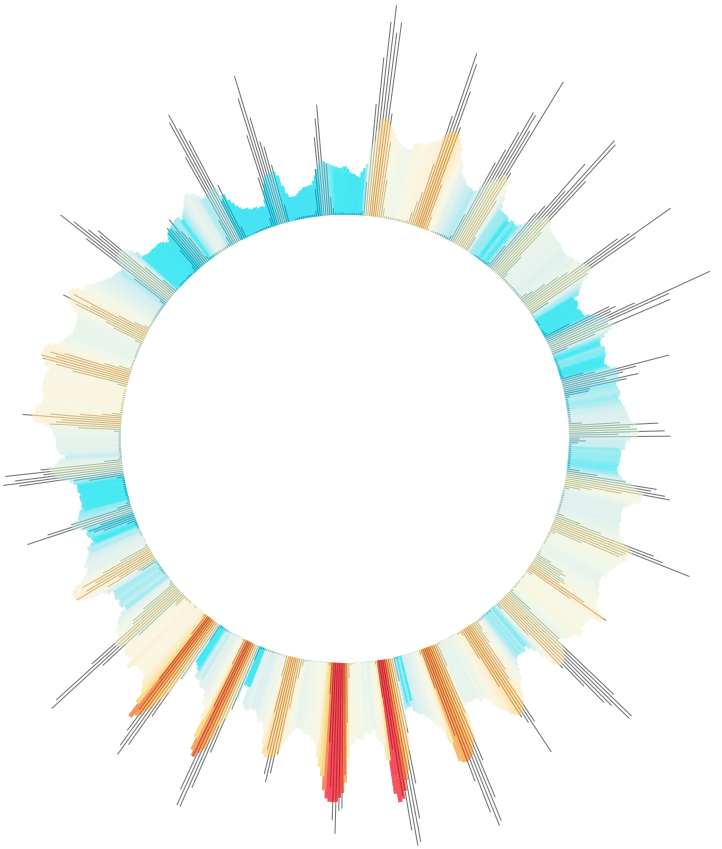
entsoe



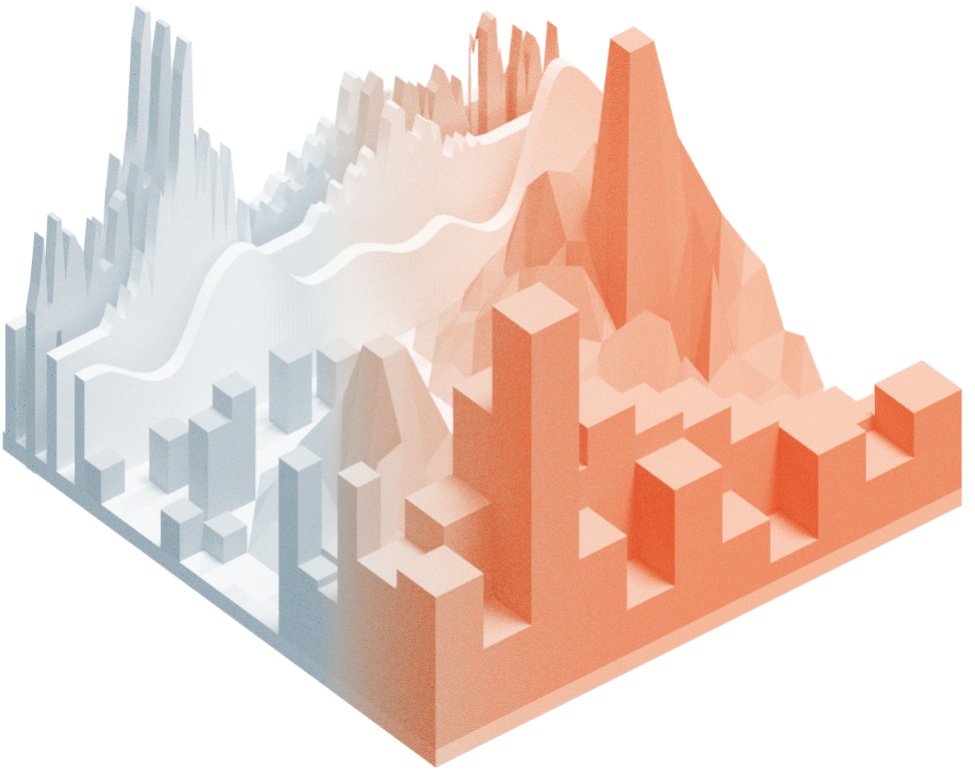


10. Visualising weather and energy data

new_date_series	Temperature_degC	RelativeHumididty_percentage	Wind_direction_deg	Wind_speed	Amient_pressure_hpa	Irradiance_klx	Global_radiation	Direct_radiation
01/01/2018	8.976	82.877	256.581	5.286	985.801	0	5.517	123163.977
01/01/2018 01:00	6.422	91.718	242.005	4.515	987.165	0	6.418	123166.375
01/01/2018 02:00	6.941	86.601	242.996	5.164	987.261	0	6.779	123166.977
01/01/2018 03:00	6.667	83.772	225.489	4.147	987.224	0	5.811	123167.172
01/01/2018 04:00	7.492	78.369	228.614	4.821	987.531	0	4.482	123167.172
01/01/2018 05:00	7.431	77.219	240.364	5.497	987.969	0	4.174	123167.172
01/01/2018 06:00	6.724	80.047	242.838	4.729	988.703	0	5.104	123167.172
01/01/2018 07:00	6.446	81.492	236.063	4.627	989.355	0	4.551	123167.172
01/01/2018 08:00	6.645	80.007	241.463	4.373	990.066	0	3.993	123167.172
01/01/2018 09:00	6.667	79.515	237.566	4.373	990.631	0.29	11.215	123167.172
01/01/2018 10:00	5.564	87.904	227.389	3.101	990.984	1.897	36.889	123167.172
01/01/2018 11:00	7.359	78.585	222.92	3.847	990.526	7.217	140.177	123167.172
01/01/2018 12:00	8.303	72.949	223.837	4.664	989.254	9.665	195.814	123167.172
01/01/2018 13:00	9.226	67.409	215.68	3.746	988.01	6.736	215.07	123167.172
01/01/2018 14:00	7.979	72.584	188.31	2.475	986.741	5.327	86.772	123167.172
01/01/2018 15:00	8.282	73.82	183.994	2.104	985.449	3.828	63.454	123167.172
01/01/2018 16:00	7.912	76.485	153.187	2.205	984.235	0.667	15.087	123167.172
01/01/2018 17:00	7.245	79.352	145.365	2.82	982.743	0.073	6.275	123167.375
01/01/2018 18:00	6.075	84.949	147.67	2.956	981.871	0	5.217	123168.375
01/01/2018 19:00	5.171	93.538	142.829	1.656	981.733	0.002	6.173	123170.375
01/01/2018 20:00	4.949	94.563	240.721	1.203	982.174	0.002	6.294	123171.172
01/01/2018 21:00	4.725	95.877	273.44	1.411	983.072	0	6.513	123171.375
01/01/2018 22:00	4.864	97.677	286.382	3.879	984.863	0	6.574	123172.172
01/01/2018 23:00	4.856	96.724	289.311	5.057	986.791	0	6.675	123172.773
02/01/2018	4.64	95.415	287.333	5.051	988.572	0	6.691	123173.375
02/01/2018 01:00	4.733	95.968	266.77	3.329	989.869	0	6.646	123173.375
02/01/2018 02:00	5.229	93.634	263.342	3.637	990.646	0	6.813	123173.57
02/01/2018 03:00	5.232	93.963	270.58	3.44	991.393	0	6.524	123173.977
02/01/2018 04:00	5.709	92.989	259.55	3.683	991.705	0	6.501	123174.57
02/01/2018 05:00	5.59	93.147	265.436	4.862	992.109	0	6.531	123174.773
02/01/2018 06:00	5.5	94.654	279.677	5.048	993.255	0	6.682	123175.172
02/01/2018 07:00	5.644	94.121	288.699	5.198	994.742	0	6.63	123175.172
02/01/2018 08:00	5.708	91.876	279.346	4.507	995.929	0	6.405	123175.172
02/01/2018 09:00	5.771	87.112	281.031	4.244	997.206	0.16	8.783	123175.172
02/01/2018 10:00	5.877	87.731	262.347	3.397	998.264	1.481	30.094	123175.172
02/01/2018 11:00	5.941	86.794	248.828	2.949	998.793	2.405	44.649	123175.172
02/01/2018 12:00	6.338	83.679	248.293	2.961	999.069	4.393	77.47	123175.172
02/01/2018 13:00	6.91	77.713	253.187	3.529	999.189	8.424	145.518	123175.172
02/01/2018 14:00	7.094	74.909	242.286	2.742	998.417	9.015	149.834	123175.172



October 2017



11. Data visualisation

11.1 Visual encoding for Data Visualzations

Magnitude

Encoding by position

Position on monodimensional scale

Position within a 2D plane

by angle

Force vector

Magnitude or multitude

by Color

Luminance/hue/ saturation

by Size

Length (1D)

Area (2D)

Identity

Color

Luminance/hue/ saturation

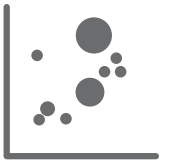
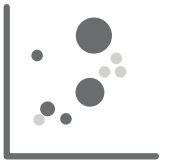
Pattern

Shape

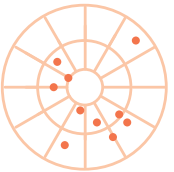
Tag/label

11.2 Encoding additional quanititative variables

Cartesian

	Encoding	
2 Variables	X-y relationship/polar coordinates	
3 Variables	X-y relationship/polar coordinates Colour hue/ saturation/ Luminance	
	X-y relationship/polar coordinates Size	
4 Variables	X-y relationship/polar coordinates Size Colour	

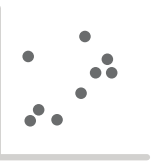
Polar



11.3 Visualising x-y-relationships

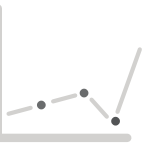
Cartesian

Scatter Plot



Scatter-plots are mainly used to emphasise on correlation. collection of points generated by correlating x-values mapped into a system of a two axes Cartesian coordinate system. Data points are primarily encoded by position. Secondarily they can be encoded by colour, shape and size as discussed in the previous chapter on data encoding.

Line graph

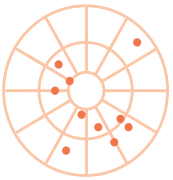


Line Graphs are used to display quantitative values over a continuous interval or time period in an x-y-relationship. A Line Graph is an efficient way and mostly used to show trends, an overall context of development and analyse how data has changed over time.

Simple Stacked bar chart and normalised Stacked bar chart

A stacked bar chart is used when volume is emphasised together with trends and developments over time covered mostly by line graphs. Unfortunately due to the overlapping, some of the data points might not be visible and due to the overall discrepancy between visible and actual proportions, this kind of mapping can be misleading. If the values are normalised and stacked on top of each other, it could be even more misleading, the areas beneath other data-points could actually be interpreted as accumulated.

Polar



Scatter plots mapped onto polar coordinates don't pose a particular advantage. The same counts as for the other linear to radial conversions: An additional cognitive load is inflicted on the user by the need to decode radial back to linear, if a non cyclic interval is depicted.

Mapping a linear graph onto polar coordinates most likely will not have a benefit. If a linear time interval is mapped, it is essential to efficiently mark the beginning of the time interval. Polar coordinates however have an advantage when it comes to cyclic events that repeat.

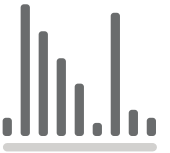
A huge drawback with the stacked bar chart in general, is that the visible area size is not proportional to the actual values. The polar mapping doesn't solve the misleading proportions of the area mapping, but could even adding the confusion by an additional decoding process by the human user from radial back to linear if a time interval. is displayed.

[100] "datavizcatalogue" https://serialmentor.com/dataviz/directory-of-visualizations.html. Accessed 14 Jun. 2019.

11.4 Visualising x-y-relationships

Cartesian

Bar chart



"The classic Bar Chart uses either horizontal or vertical bars (column chart) to show discrete, numerical comparisons across categories. One axis of the chart shows the specific categories being compared and the other axis represents a discrete value scale. [...] Bar Charts are distinguished from Histograms, as they do not display continuous developments over an interval. Bar Chart's discrete data is categorical data and therefore answers the question of "how many?" in each category." [100]

Histogram

"A Histogram visualises the distribution of data over a continuous interval or certain time period. Each bar in a histogram represents the tabulated frequency at each interval/bin. Histograms help give an estimate as to where values are concentrated, what the extremes are and whether there are any gaps or unusual values. They are also useful for giving a rough view of the probability distribution." [100]

Polar

Bar chart

Bar Charts are distinguished from Histograms, as they do not display continuous developments over an interval. Bar Chart's discrete data is categorical data and therefore answers the question of "how many?" in each category.

Histogram with polar coordinates

Histograms help give an estimate as to where values are concentrated, what the extremes are and whether there are any gaps or unusual values. They are also useful for giving a rough view of the probability distribution.

[100] “datavizcatalogue” https://serialmentor.com/dataviz/directory-of-visualizations.html. Accessed 14 Jun. 2019.

11.5 Visualising proportions

Linear

Simple stacked bar chart

Simple Stacked Bar Graphs place each value for the segment after the previous one. The total value of the bar is all the segment values added together. The stacked bar graph is an ideal way of visualising proportions and for comparing the total amounts across each group/segmented bar. It has the same anatomy and can be used interchangeably with the pie chat.

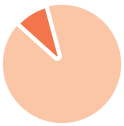
Set of normalised stacked bar charts

A 100% stacked or normalised stacked bar graph is a simple bar graph with the values all normalised to 100%. This mapping emphasises on the **relative differences** between quantities in each group. If the normalised stacked bar graphs are confused however with ordinary stacked bar graphs, for example due to misleading or ambiguous scales, the information can be misinterpreted. They also become harder to read the more segments each bar contains. Comparing each segment to each other is difficult, as they lack a common baseline for alignment.

Set of stacked bar charts

Simple stacked bar graphs place each value for the segment after the previous one. Like in a single ordinary stacked bar chart, the total value of the bar is all the segment values added together. This type of visualisation is mainly used for comparing the total amounts across discrete values and groups.

Polar



Simple polar chart

The simple polar chart is one of the most widely used charts and there a are default functions for it in PowerPoint and Excel. Polar charts are a simple and easy to understand way to visualise proportions. This type of visualisation is the radial equivalent of the stacked bar graph.

Nightingale rose chart
Also: Coxcomb Chart, Polar Area Diagram

Florence Nightingale was as a manager and trainer of nurses during the Crimean War, in which she organised care for wounded soldiers. In her official reports she used various data visualisations - most famously the Nightingale rose where she underlines preventable deaths among soldiers, showing that they mostly dies from disease than battle wounds.

The Nightingale rose chart is a variation of stacked charts with the main purpose of showing proportions. The polar coordinates Nightingale Rose Charts are drawn on a polar coordinate grid. Each category or interval in the data is divided into equal segments on this radial chart. How far each segment extends from the centre of the polar axis depends on the value it represents. Misleading can be the fact, that the outer segments are given more emphasis because of their larger area size and increases in value are

11.6 Proportions and data flow

Linear

Parallel sets

"Parallel Set charts are similar to Sankey Diagrams in the way they show flow and proportions. However, Parallel Sets don't use arrows and they divide the flow-path at each displayed line-set."[100]

Gant chart

"A Gantt chart is a type of bar chart, that visualises various categories into time series. Gantt charts illustrate the start and finish time in time period blocks. A Gantt chart is often used in project management as one of the most popular and useful ways of showing activities (tasks or events) displayed against time. On the left of the chart is a list of the activities and along the top is a suitable time scale. Each activity is represented by a bar; the position and length of the bar reflects the start date, duration and end date of the activity." [100]

Treemap

"Treemaps are an alternative way of visualising the hierarchical structure of a tree Diagram while also displaying quantities for each category via area size. Each category is assigned a rectangle area with their subcategory rectangles nested inside of it. When a quantity is assigned to a category, its area size is displayed in proportion to that quantity and to the other quantities within the same parent category in a part-to-whole relationship. Also, the area size of the parent category is the total of its subcategories. If no quantity is assigned to a subcategory, then it's area is divided equally amongst the other subcategories within its parent category."[100]

Polar

Chord Diagram

This type of diagram visualises the inter-relationships between entities. The connections between entities are used to display that they share something in common. This makes Chord Diagrams ideal for comparing the similarities within a data-set or between different groups of data.

Nodes are arranged along a circle, with the relationships between points connected to each other either through the use of arcs or Bézier curves. Values are assigned to each connection, which is represented proportionally by the size of each arc. Colour can be used to group the data into different categories, which aids in making comparisons and distinguishing groups.

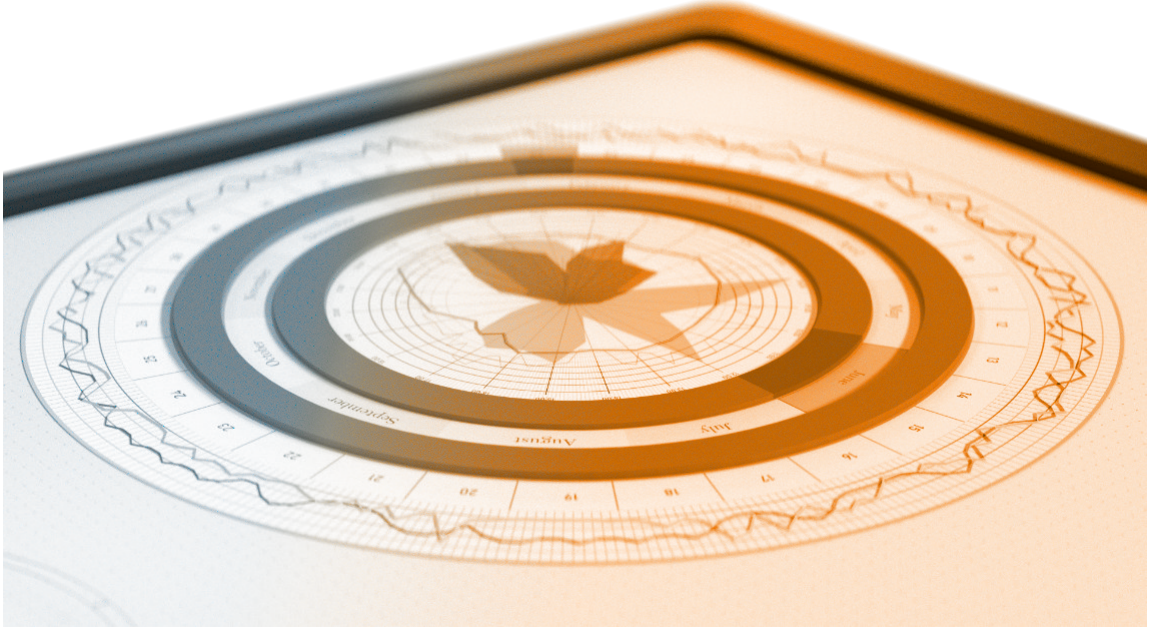
Simple polar chart

Simple Stacked Bar Graphs [100] place each value for the segment after the previous one. The total value of the bar is all the segment values added together. Ideal for comparing the total amounts across each group/segmented bar.

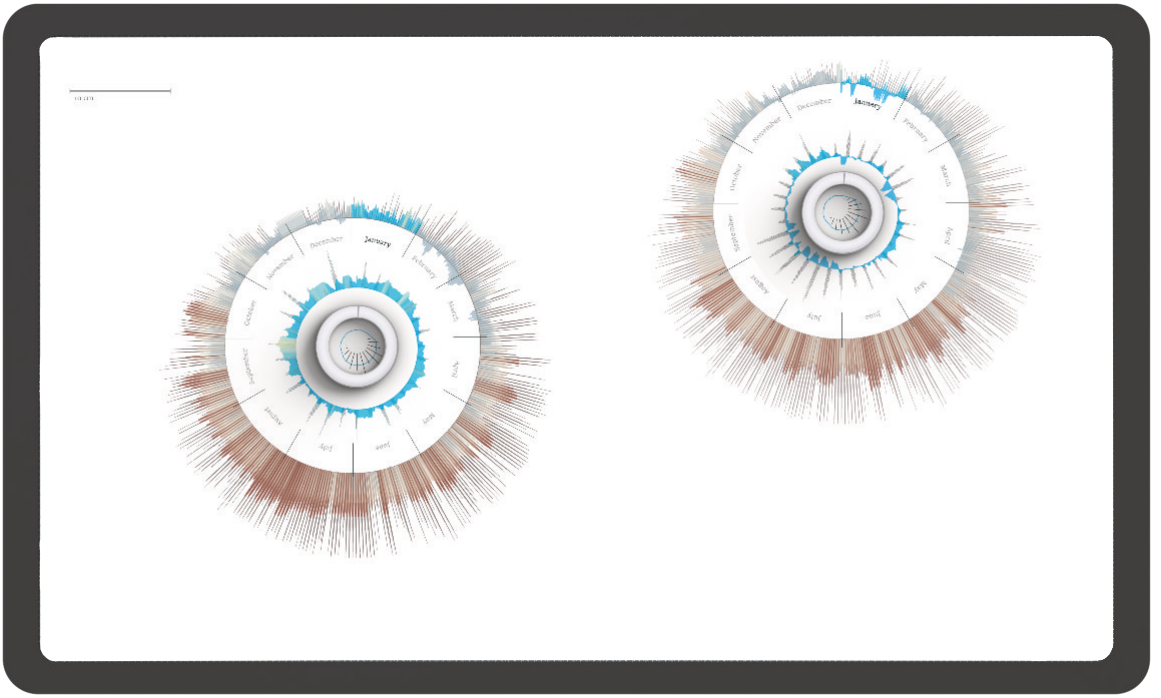
Sunburst Diagram

This type of visualisation shows hierarchy through a series of rings, that are sliced for each category node. Each ring corresponds to a level in the hierarchy, with the central circle representing the root node and the hierarchy moving outwards from it..Rings are sliced up and divided based on their hierarchical relationship to the parent slice. The angle of each slice is either divided equally under its parent node or can be made proportional to a value.

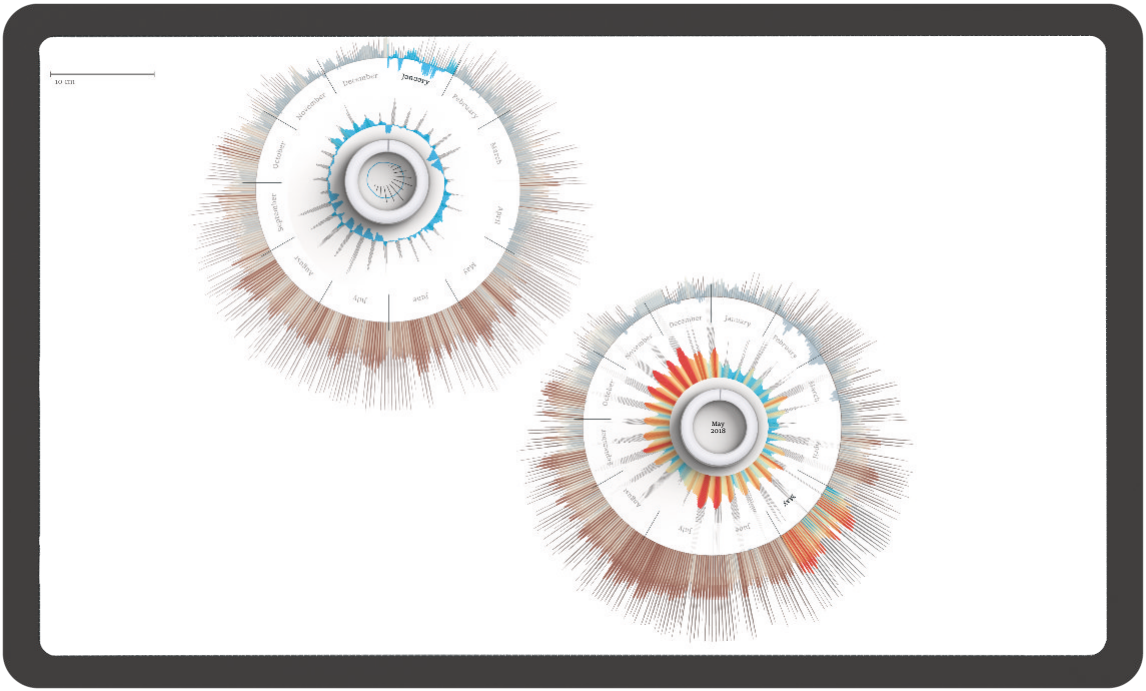
[100] "datavizcatalogue" https://serialmentor.com/dataviz/directory-of-visualizations.html. Accessed 14 Jun. 2019.



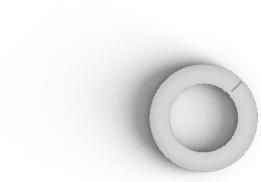
12. *Interface design*



Comparison of January
2017 and January 2018



Comparison of January
2017 and May 2018



Marker diameter 5.5 cm

(3840 x 2160 4K UHD)
65” diagonal equals 165.81 cm
Width : 44 heigth 81 cm

Marker diameter 8.5 cm

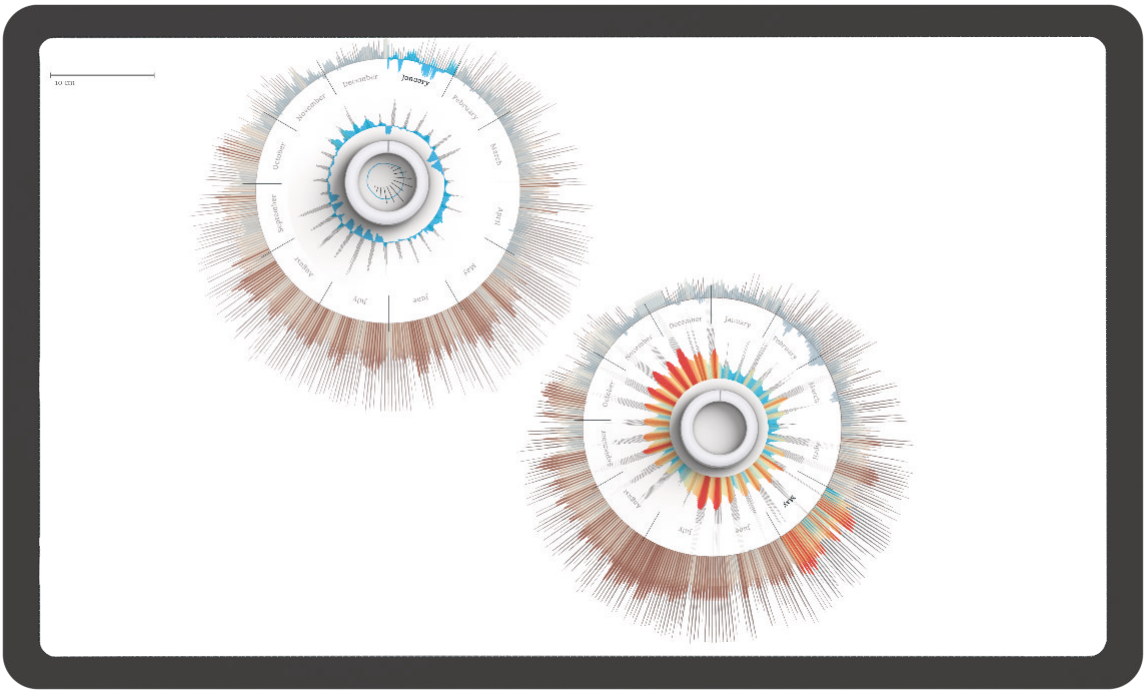
(3840 x 2160 4K UHD)
65” diagonal equals 165.81 cm
Width : 44 heigth 81 cm

Iiyama ProLite TF6537UHSC-B1AG

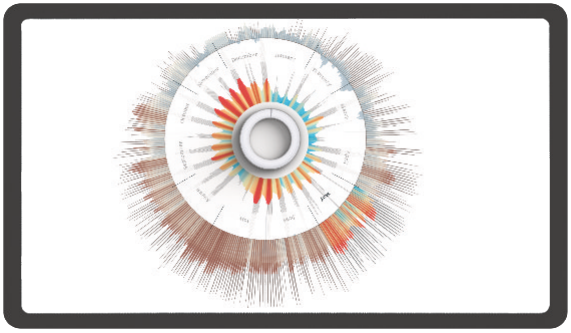
The application it intended for a comparatively big screen like the Iiyama ProLite TF6537UHSC-B1AG, a capacitive touch screen with the capability of 50 touch-points and a 4K-resolution. A small drawback of the screen is, that its LCD and not LED. This means that it cannot operate displaying the same image over a long period of time without the risk of that image being burned in. This also has to be taken into account when designing an application for this particular model.

ThinkPad Yoga S1, 10 Touchpoints

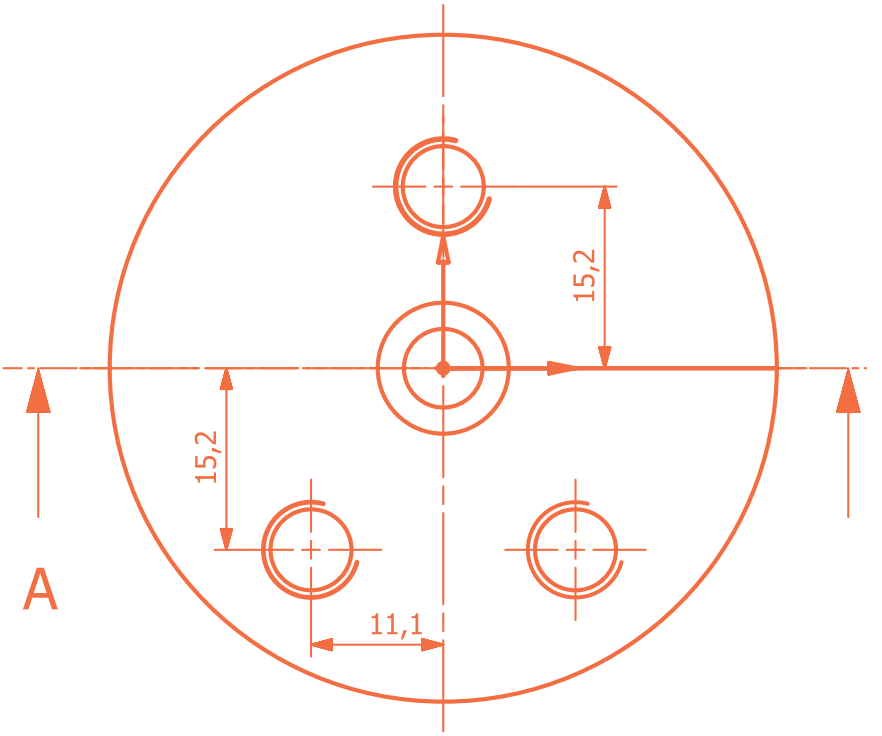
The application for the prototyped using a Lenovo Yoga S1 laptop that has a 12.5” touchscreen that provides 10 touch-points. With this small size it’s not possible to compare two of the weather data visualisations simultaneously.



(3840 x 2160 4K UHD)
65” diagonal equals 165.81 cm
Width : 44 height 81 cm



(3840 x 2160 4K UHD)
65” diagonal equals 165.81 cm
Width : 44 height 81 cm


15,2
15,2
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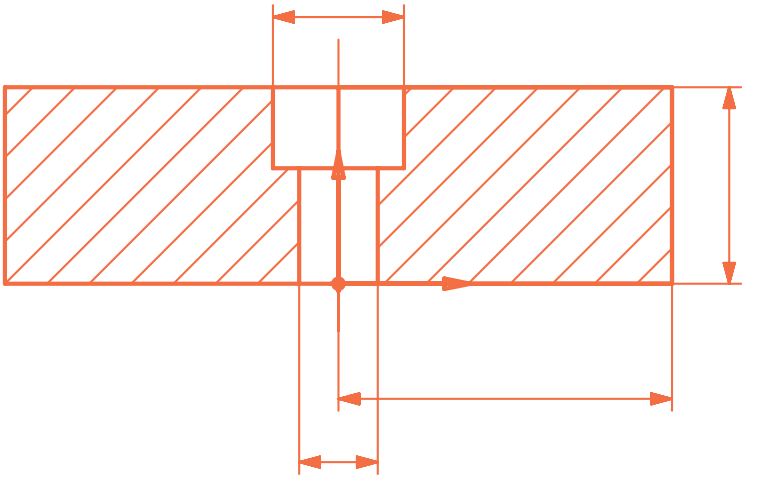
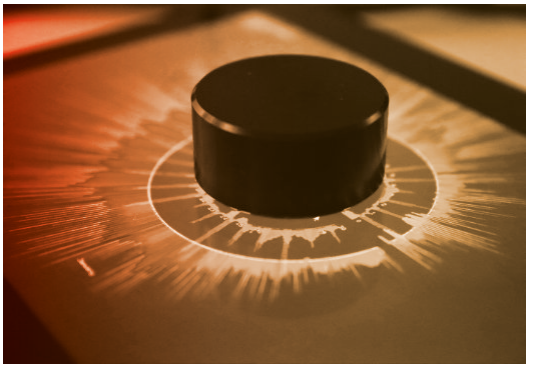
11,1



13. Tangible design

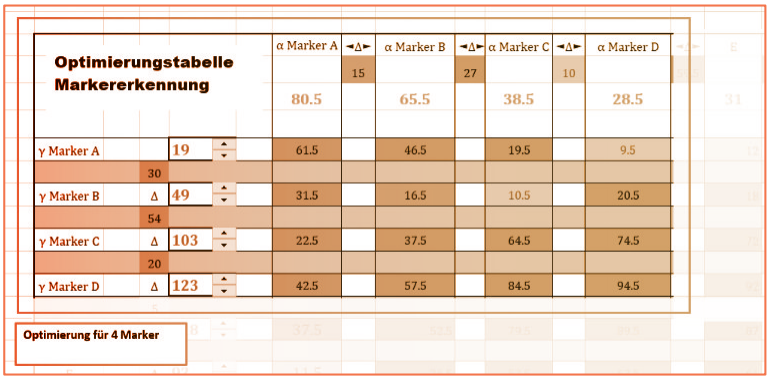
3.1 Tangible design principles

The system used for the prototype looks for all simultaneous touch events and measures their proximity. If three adjacent touch-points have a proximity of a certain tolerance threshold, they get identified as a cluster. The apex angle of the resulting triangle gets determined by mathematical means. This information of adjacent touch points is used for distinguishing the markers. Every marker carries a structure underneath that consists of three points of conductive material that trigger a capacitive sensor by means of capacitance coupling, the same way human fingers do.



Essential for this approach is, that the points have adequate spacing (if touch points are too close, they get merged by the Windows touch handler) and that there is enough contrast between the angles of the different markers so they don't get confused which each other, as moving them around causes slight variations in the angle being recognised. For the prototype of this thesis I made a table in excel that indicates the contrast of markers and works as a useful tool for optimisation.

the prototype for this thesis uses three points and the apex angle of the resulting triangle for recognition, translatory and orientation tracking. the touch points are placed at a pre-defined distance and angle to make the patterns distinguishable from human gestures. This approach is possible on any capacitive multi-touch device that carries at least 3 touch-points and no hardware modifications are



Optimierungstabelle Markererkennung			α Marker A	◄Δ►	α Marker B	◄Δ►	α Marker C	◄Δ►	α Marker D
			80.5	15	65.5	27	38.5	10	28.5
γ Marker A		19	61.5		46.5		19.5		9.5
	30								
γ Marker B	Δ	49	31.5		16.5		10.5		20.5
	54								
γ Marker C	Δ	103	22.5		37.5		64.5		74.5
	20								
γ Marker D	Δ	123	42.5		57.5		84.5		94.5

Optimierung für 4 Marker

required. As the tangibles are not equipped with electronics or mechanical parts, their design follows a **passive approach**.

active design approaches

High precision active Digital Styluses owe their accuracy to their active approach. It uses modulation circuits to generate high-frequency touches to encode object IDs in the time domain. That is the reason, why these styluses only work with the system they are shipped with. A Wacom Pen for example will only work on a Wacom-enabled surface. Capacitive sensors, that are not “tuned” for the touch screen will not work. [84]

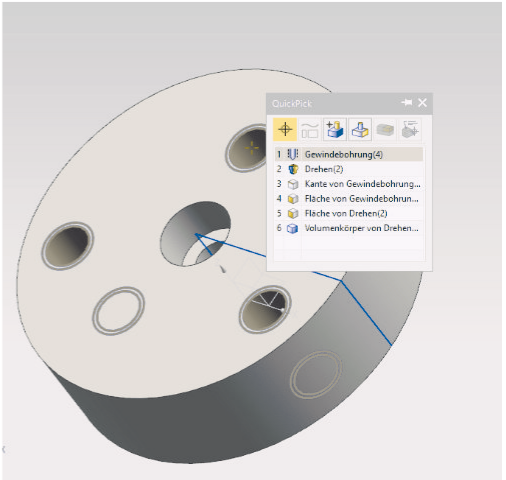
In his master’s thesis [85] at **RWTH** Media Computing Group, Jan Thar developed active tangibles,that use a combination of an integrated light sensor and a Bluetooth sensor to communicate its position to the touch screen.

[84] https://www.howtogeek.com/177376/not-all-tablet-styluses-are-equal-capacitive-wacom-and-bluetooth-explained/

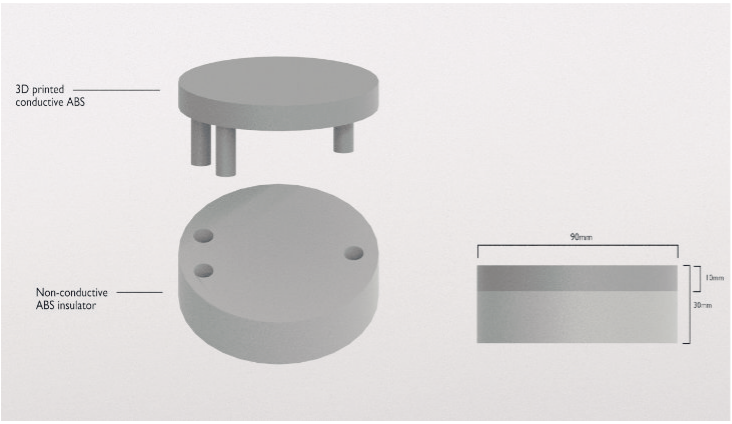
[85] [MASTERS THESIS] “APUCS:Active TangibleInput Devices for Capacitive Multitouch Surface Jan Thar - Media Computing Group - RWTH Aachen." 5 Jun. 2019, https://hci.rwth-aachen.de/thar. Accessed 3 Jul. 2019.

b98=53'0
b96=125
b93=60°

3.1 designing tangibles with CAD



3D printing of tangibles requires a CAD design. The STEP-Files have to be exported into the *.stl or .obj format in order to be imported into an application like Cura and then be printed with common FDM-printers for example Ultimaker. For this bachelor thesis, attempts have been made to print on an ANET A8, but failed due to the conductive ABS material seems to have different requirements for printing than the common ABS which was used for (successful) test prints. The CAD-Design was made in Siemens NX, and Blender. For the CAD-design the most efficient combination of markers (highest contrast among marker angles) was determined and the CAD Models designed according. The makers were supposed to be made up of two parts that would be stacked together later on. The upper part was to be printed with conductive ABS-material with three elevated tips, that would form the contact points on the surface of the sensor of the multi-touch monitor.



3.1 3D printing tangibles

3D printing enables designers to prototype 3D objects fast and at a low cost. Conductive ABS and PLA promises to also prototype conductive components and anti-static containers for protection of static sensitive devices like PCB's. The conductive ABS I used in order to build my first prototypes performed well, but the 3D printed tips of the contact points were making scratching noises on the surface screen. The 3D printed tangibles had an uneven surface as its typical for 3D prints. I attempted to smooth the surface with acetone but had unsatisfying results.

Conductive ABS

This type of filament is ABS mixed with pure carbon and therefore conductive. Exchange on internet Forums suggest, that it is more difficult to print. If there is a need for the Tangible to have a specific custom made shape, the whole Marker could be printed from conductive ABS, but as the material is apparently hard to print, a better approach might be to print with standard non-conductive materials such as PLM and ABS and then apply a conductive coating to the print afterwards. I've also prototyped 3D printed conductive markers, but found a weaker performance compared to my prototypes painted with Bare conductive Ink. This might be due to lower conductivity.

Advantages:

low cost - 1 KG of the filament costs about 30 €

High flexibility in custom shaped tangibles

Relatively low effort - if there are no complications while printing.

No smudges on the screen, low risk of contamination, causes no scratches on the screen.

Disadvantages:

ABS is the **least environmentally friendly** 3D printing Material.

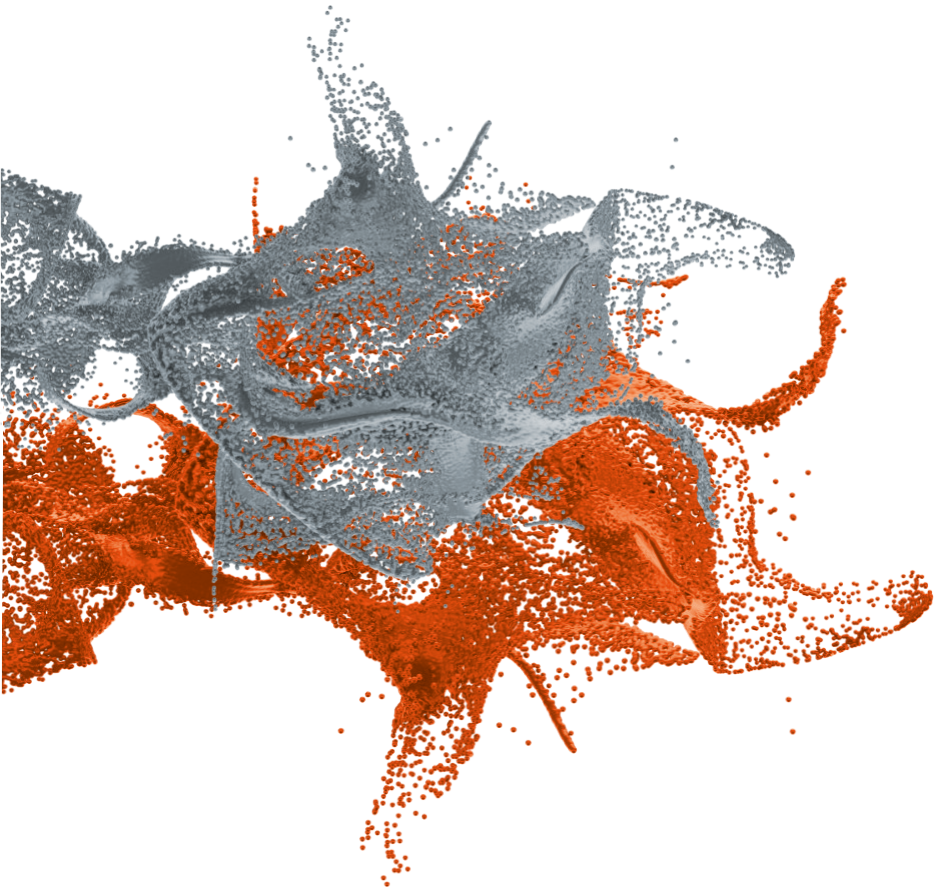
The Surface of the 3D prints isn't smooth

The 3D printed Tangibles performed less reliably. Touch-Point detection was not continuous when moving the marker and angle misinterpretation was more frequent.

13. Tangible prototypes

13.1 Tangibles made from wood with conductive coating

As the conductivity of the anti-static ABS material, apparently was not sufficient with the capacitive touch sensor of the Lenovo Thinkpad Yoga S1 where the prototype was developed on, The decision was made to manufacture the tangibles from wood and coat them with conductive paint. While building and evaluating various prototypes, Bare conductive ink as well as copper and graphene spray was tested.



14. Conductive materials for tangible coating

For the first Prototypes a conductive paint based on charcoal was used. Unfortunately its water soluble and leaves traces on the hands when touching the tangible and smudges on the surface of the multi-touch screen.

14.1 Experience with “Bare Electric Paint”

Advantages:

low cost - a DIY version of the paint can be made from scratch very easily with charcoal and paint.

The paint doesn't contain substances that could harm human health or the environment - the conductive ink is by far the most **environmentally friendly** of the proposed solutions.

The paint will not leave scratches on the surface of a touch screen.

Disadvantages:

Ink will get contaminated over time when touched by human hands. Dust will stick to the surface very fast. The dried paint can develop cracks and break apart - all factors that will lessen conductivity relatively fast.

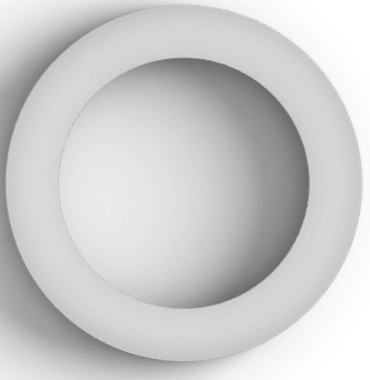
14.1 Experience with Graphene coating

A dispersion of fine, pure, colloidal graphite in a specially formulated solvent mixture with an organic binder, which gives an electrically conductive coating to non-conductive media. Graphene has very high electron mobility ≈105 cm2/Vs at room temperature. The graphene spray dries evenly creating a smooth surface. The conductivity seems to be excellent for the use of touchscreens and overall the graphene spray yielded the best results. The graphene can have a light smudging effect, when touched with sweaty hands, but with dry hands there was no problem.

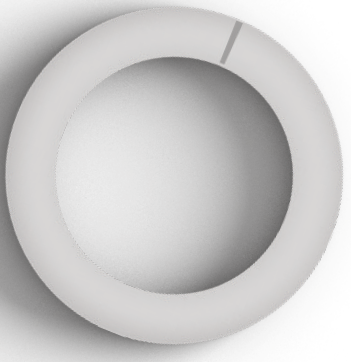
14.2 Experiences with copper-based coating

It was very difficult to apply the copper spray evenly. With 29.90€/200 ml it comes with a much higher price than graphene. Graphene was much easier to apply and dry evenly. Both coatings were polished in the end which gave them a shiny finish. Air bubbles caused the copper spray coated tangibles to have a slight uneven surface. Graphene coating seems to be a better and cheaper alternative.

A tangible, can be designed in a way that the user intuitively understands how to use it. In the prototype for the thesis a circular tangible was developed that is supposed to resemble a magnifying glass and also indicates that user can turn the tangible. Around the tangible weather data of a whole year can be visualised. In the inner circle of the tangible there is a day/week section providing a more fine grained look at the data. Sensual metaphors can also act as affordance signifiers - signifying to the user what can be done with it, which affordances it provides.

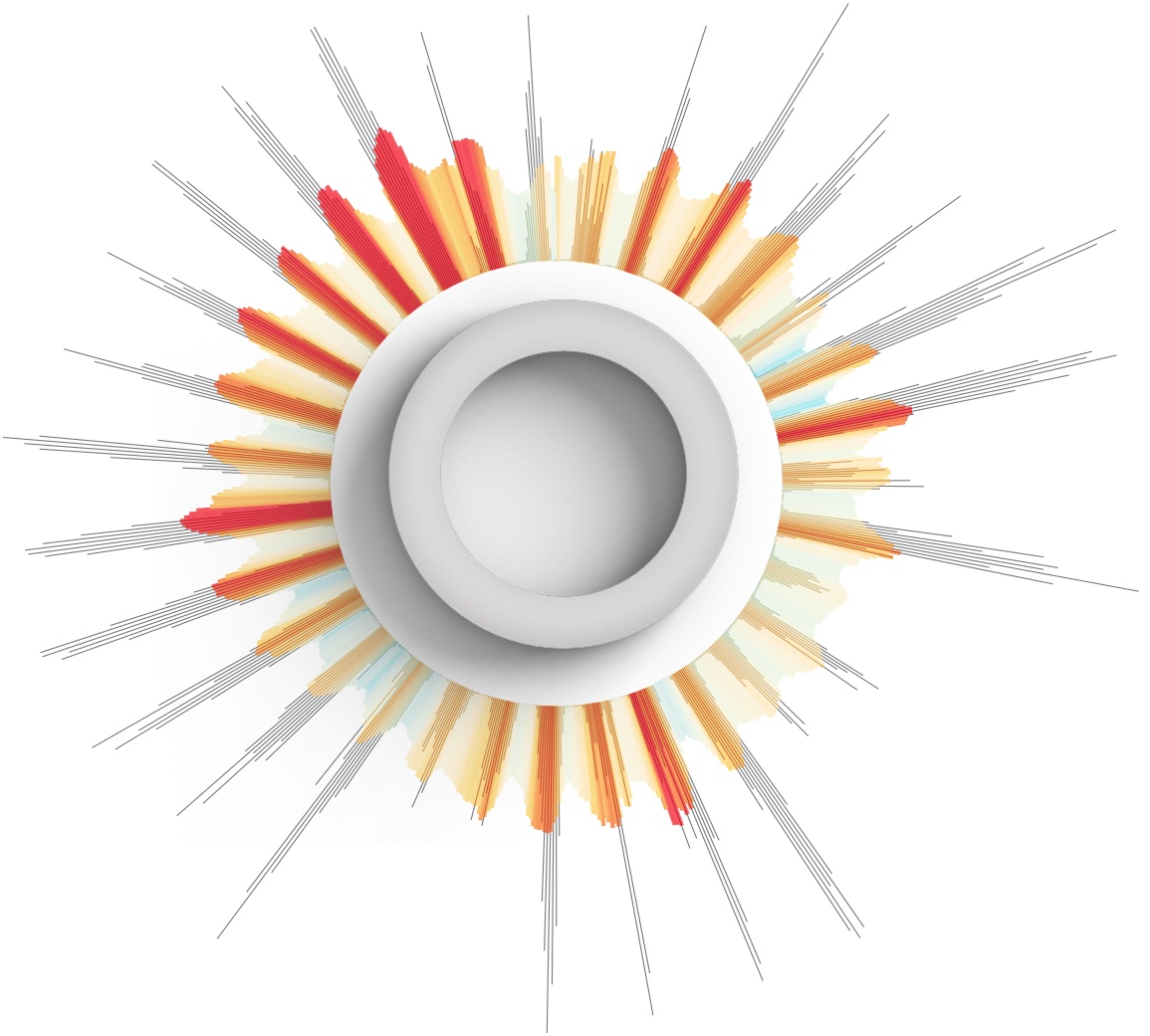


A blank ring can be used as a magnifying glass in order to magnify the image beneath it.



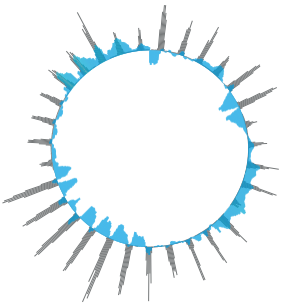
A simple ring with a pointer, allows for one-directional navigation through the data.

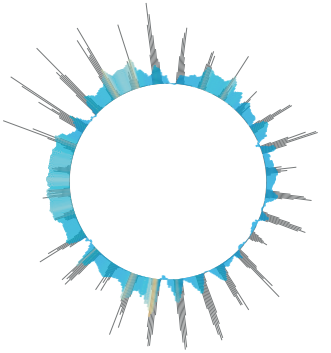
Two rings stacked into each other were the originally intended design, which would provide the possibility to navigate through the days and months simultaneously. Unfortunately the design of the markers doesn't allow for this variation as the angles for the recognition system would interfere.



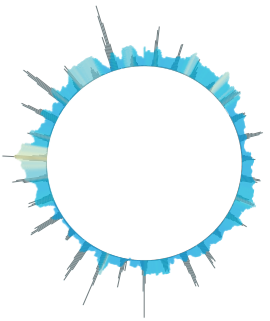
15. Preliminary results

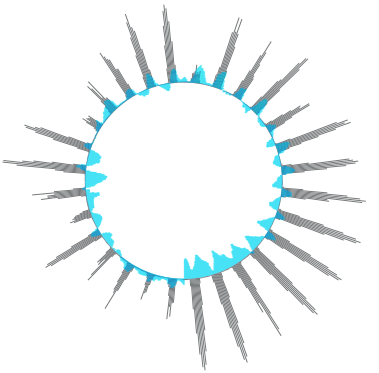
2017





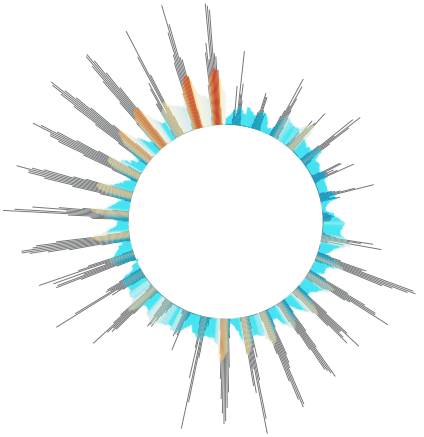
2018

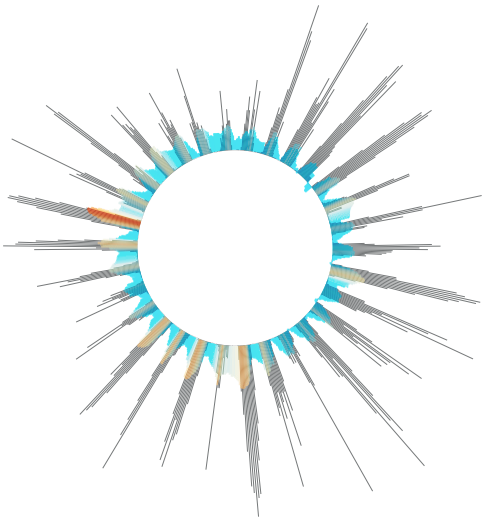


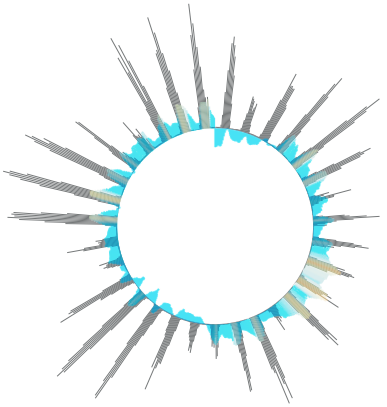


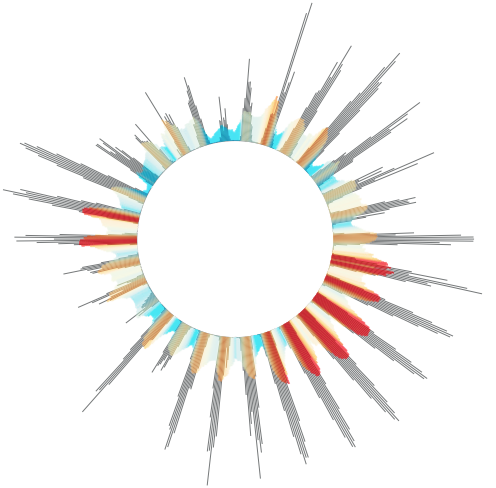
January

February



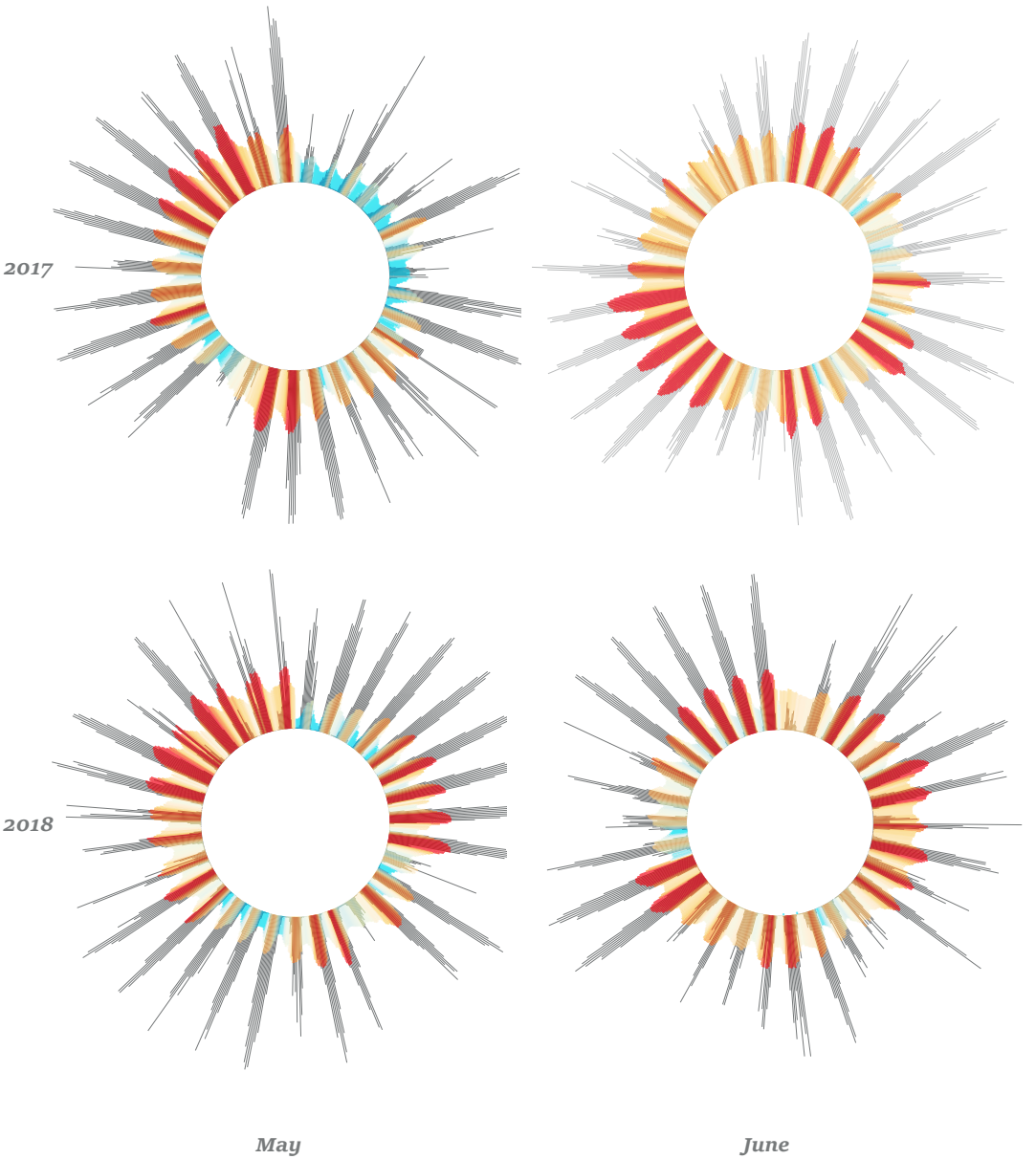


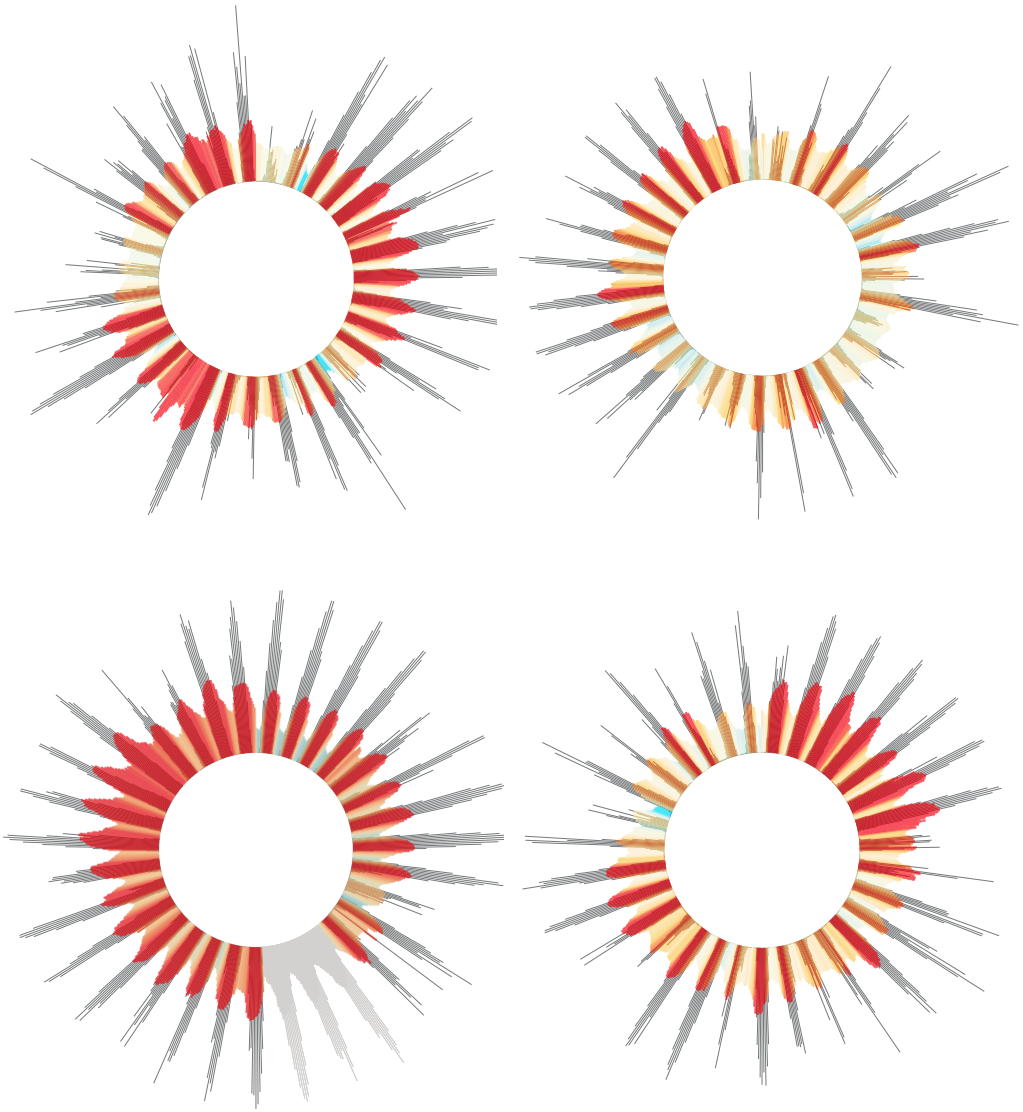




March

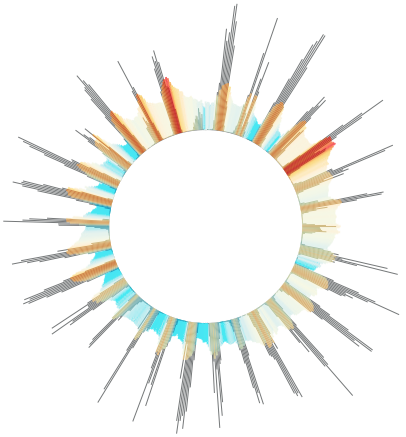
April

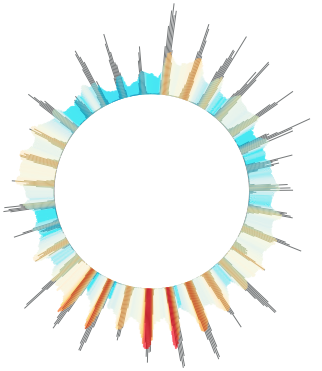

2017
2018
May
June



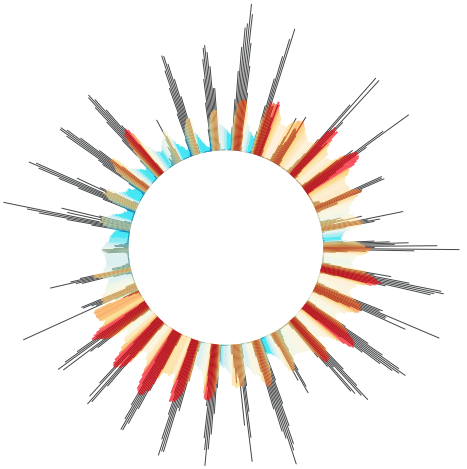
July *August*

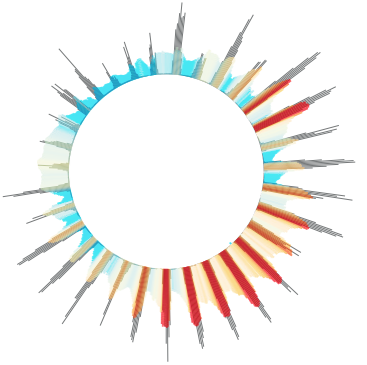
2017





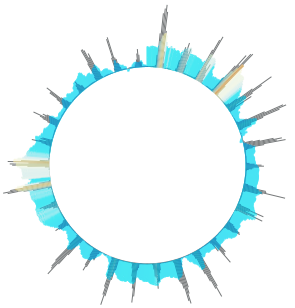
2018

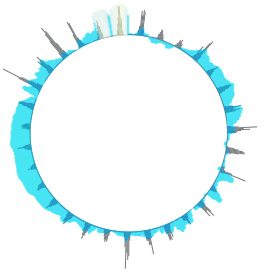


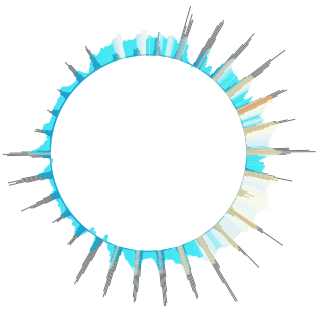


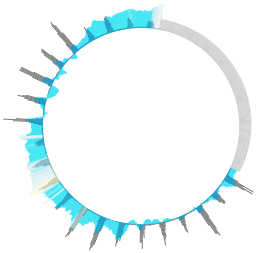
September

October



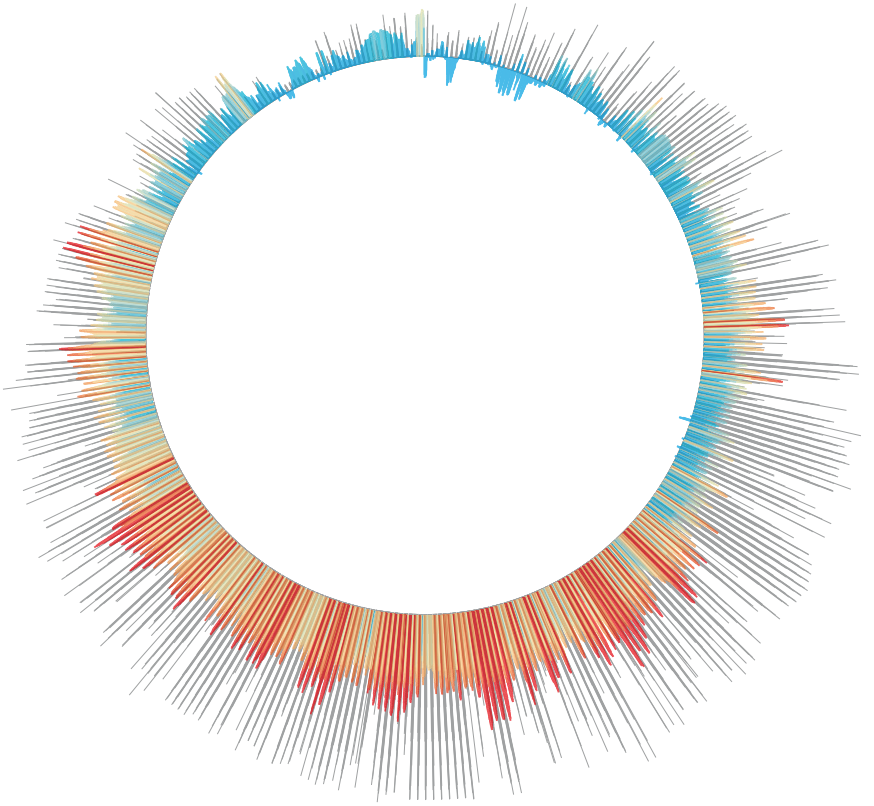




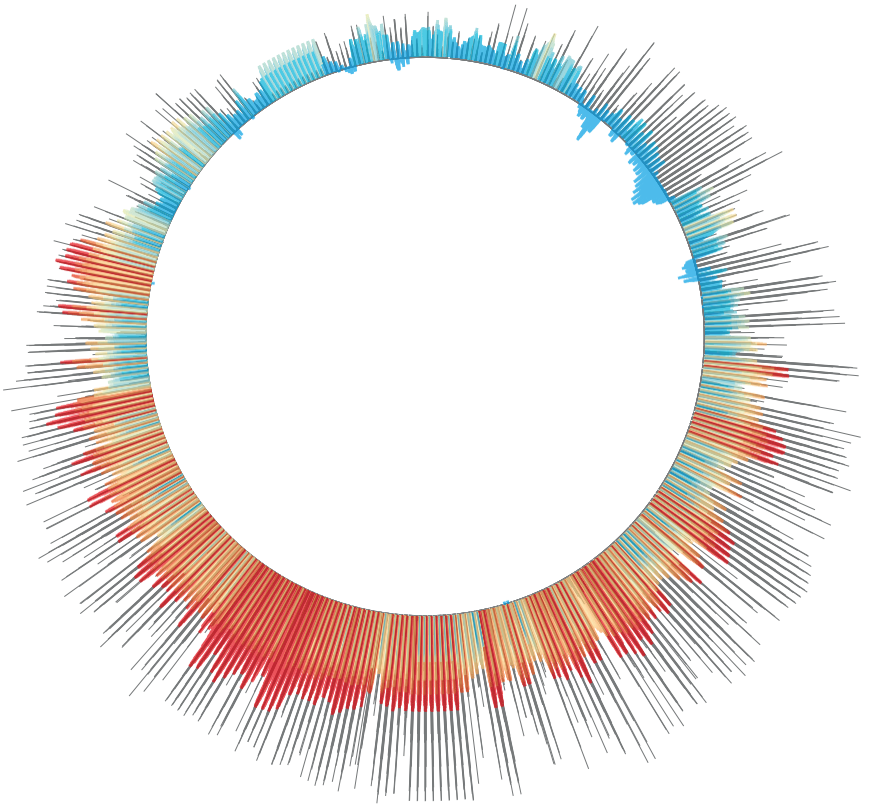


November

December



2017



2018

```
std::vector<std::string> lineSplitted17;
std::vector<std::string> lineSplitted18;
std::vector<std::string> lineSplittedSun;
std::vector<float> allTemperatures18;
std::vector<float> allGlobalRadiation18;
std::vector<float> allWind18;
std::vector<float> allTemperatures17;
std::vector<float> allGlobalRadiation17;
std::vector<float> allWind17;



std::vector<std::string> split(const std::string& s, char
{delimiter)
   std::vector<std::string> tokens;
   std::string token;
   std::istringstream tokenStream(s);
   while (std::getline(tokenStream, token, delimiter))
   {
      tokens.push_back(token);
   }
   return tokens;
}
```

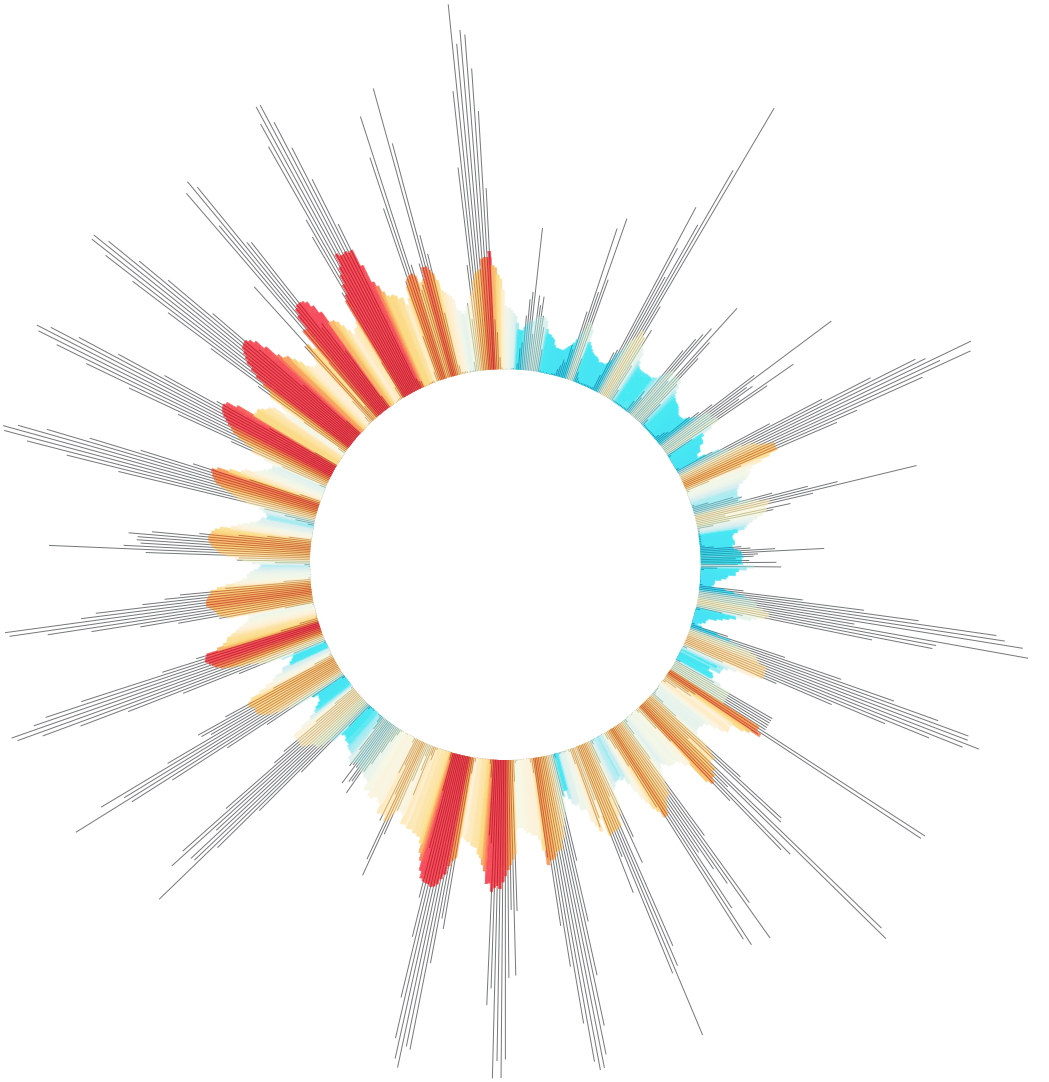
Creating dynamic vector variables

```
void touchObject::setup() {

ifstream ip18("data/data2018b.csv");
   if (!ip18.is_open()) std::cout << "ERROR: no file" <<
'\n';
   for (int i = 0; i < 8760; i++)
   {
      getline(ip18, line18);
      lineSplitted18 = split(line18, ',');
      //cout << lineSplitted[0] << endl;
      wind18 = stof(lineSplitted18[3]);
      temp18 = stof(lineSplitted18[0]);
      globalRadiation18 = stof(lineSplitted18[6]);
      allTemperatures18.push_back(temp18);

allGlobalRadiation18.push_back(globalRadiation18);
   }
```

open CSV file

Reading in data values for 8760 hours in a year

Append data values into array

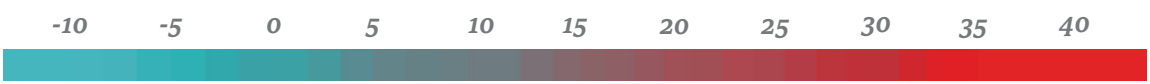


May '18

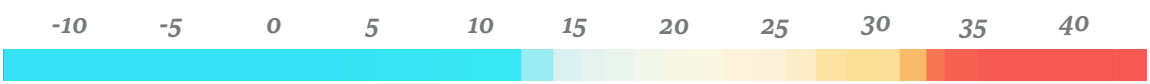
15. 1 RGB colour mapping

```
void touchObject::draw() {

float r_T = 255 / 33 * Temperatur17[m][j17][i17] + 235 * 2 /
float g_T = 255 / (-45.00)*Temperatur17[m][j][i] + 245 * 2 /
float b_T = 255 / (-45.0)*Temperatur17[m][j][i] + 255 * 2 / 3;
float a_T = 255 / -66 * Temperatur17[m][j][i] + 255 * 2 / 3;

output.setColor(r_T, g_T, b_T);

}
```

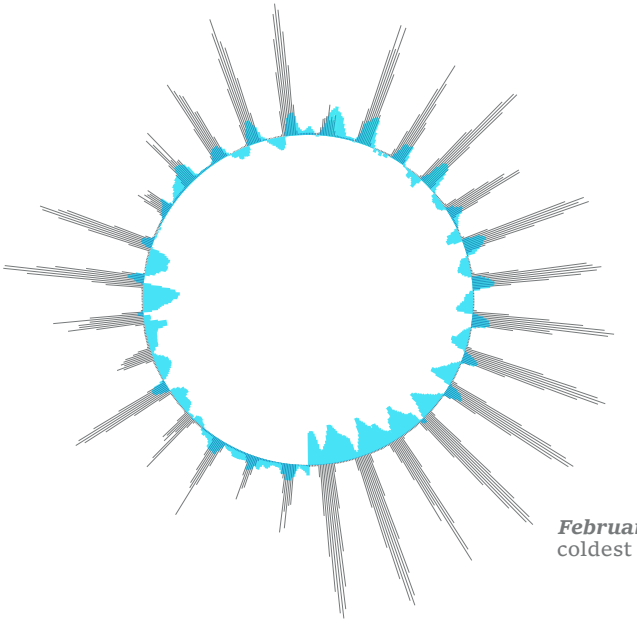
red
green
blue
alpha



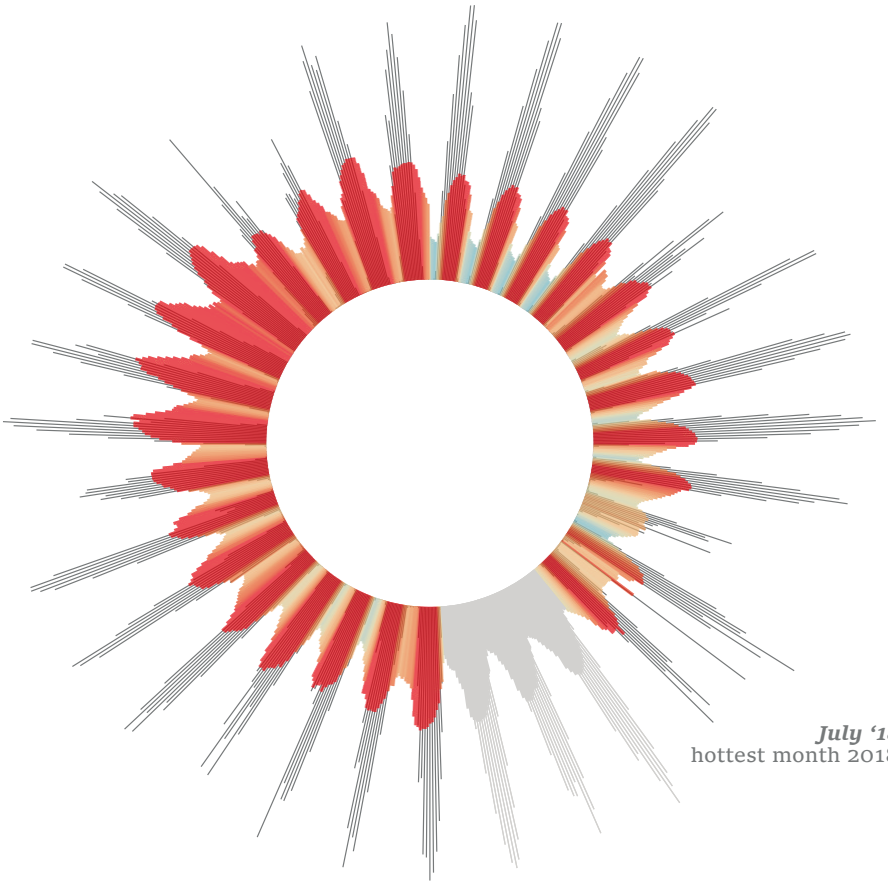
Resulting colour spectrum (RGB)



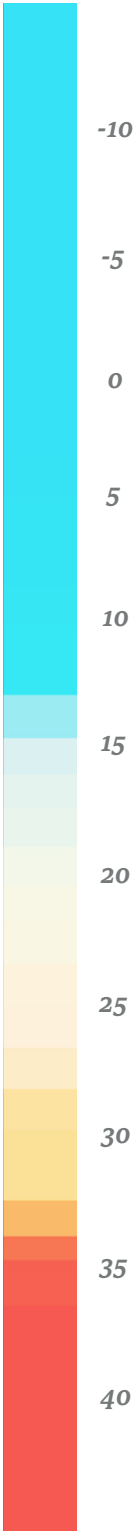
Resulting colour spectrum (adjusted for CMYK Print)



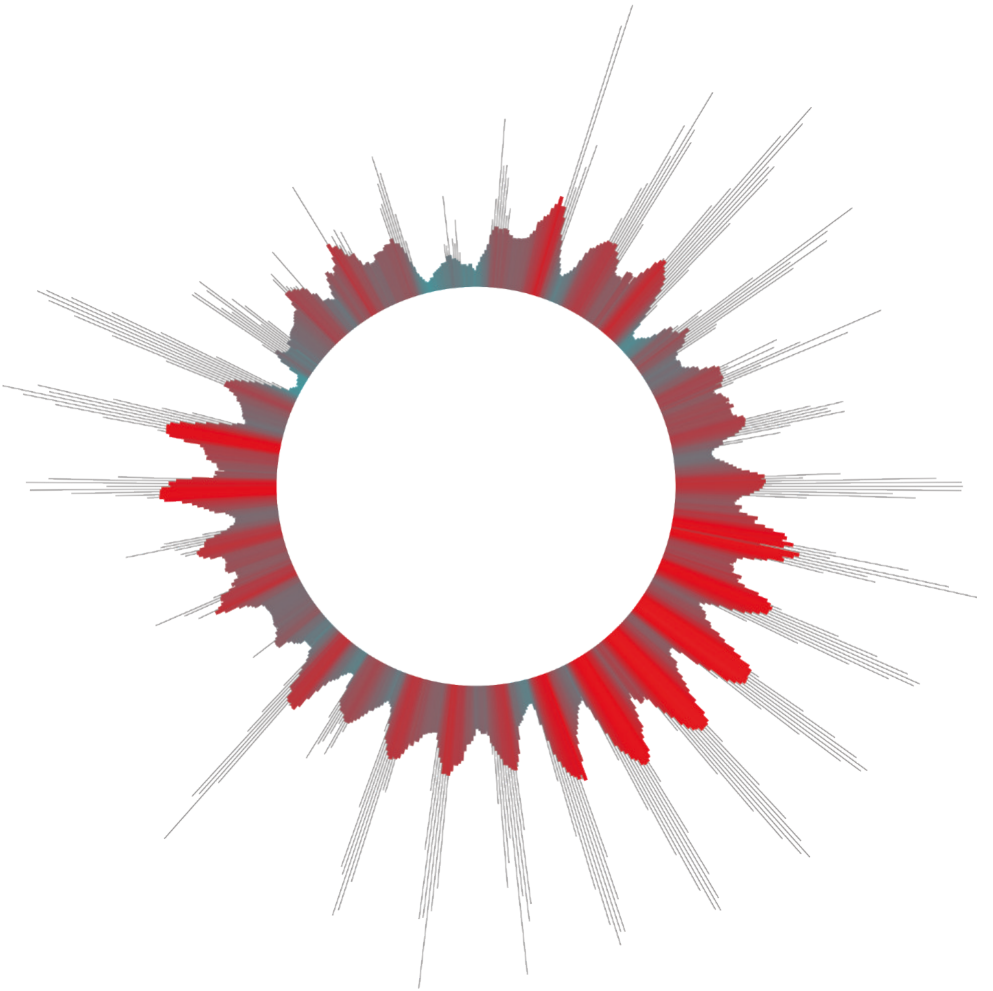
February '18
coldest month 2018



July '18
hottest month 2018

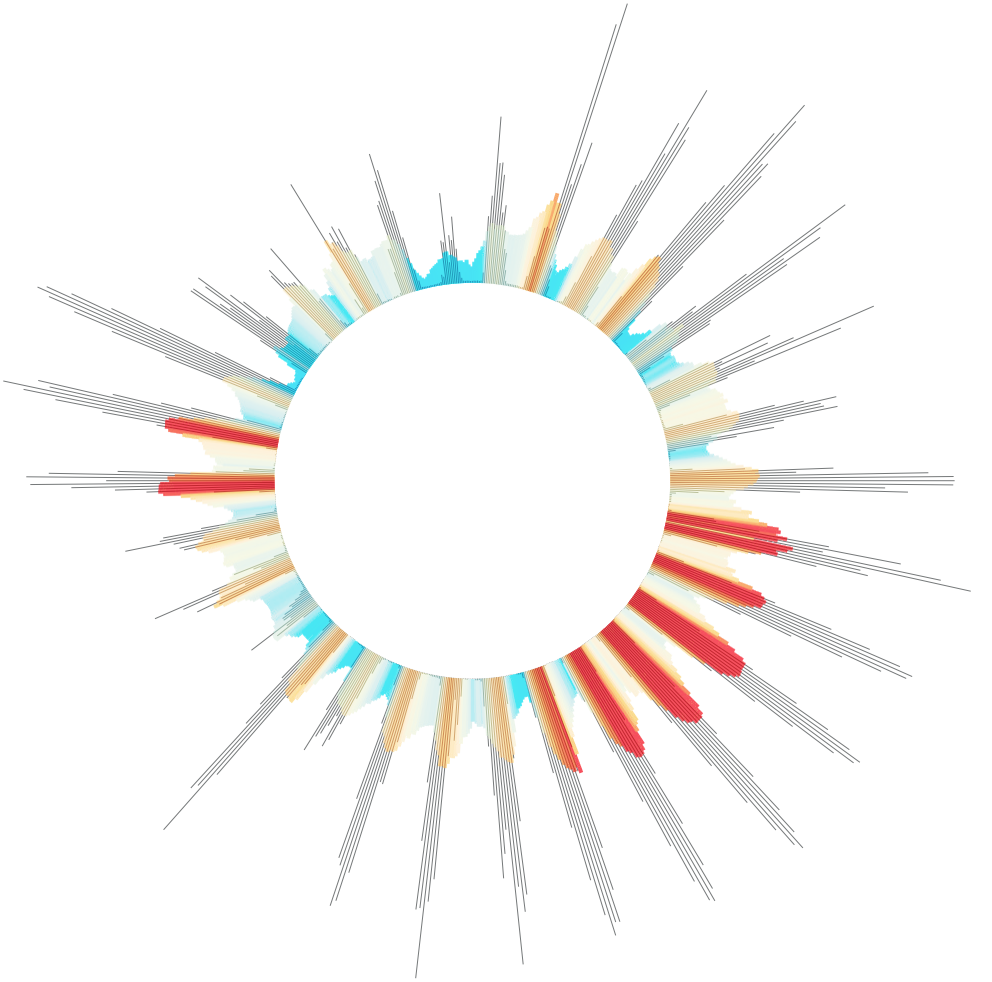

-10
-5
0
5
10
15
20
25
30
35
40

Unadjusted color scale (RGB)



April '18

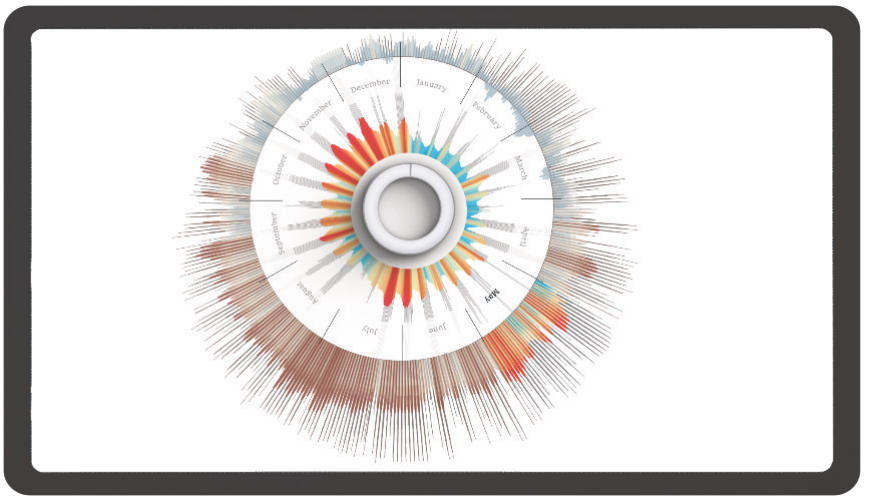
Target color scale (not implemented yet)



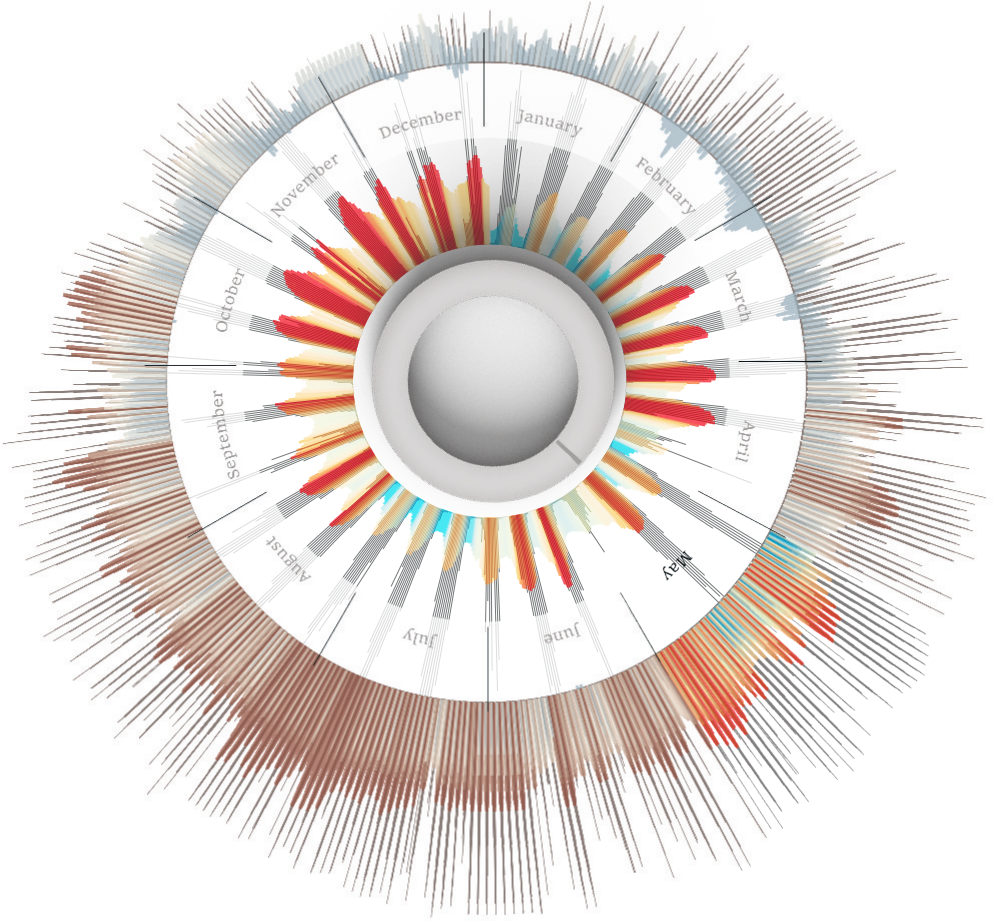
April '18

Unadjusted color scale (RGB)

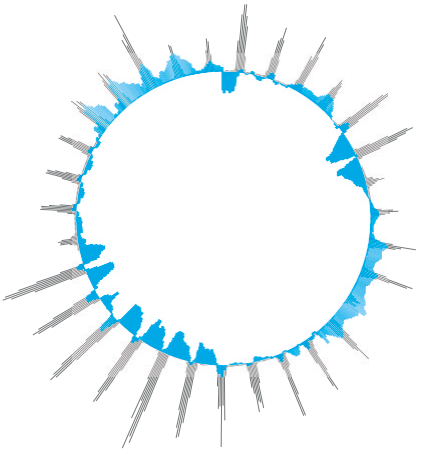
Target color scale (not implemented yet)



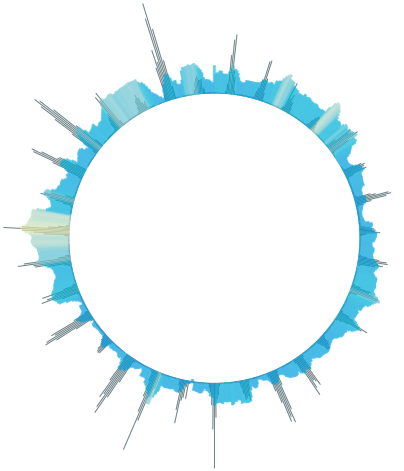
May 2017
dark mode



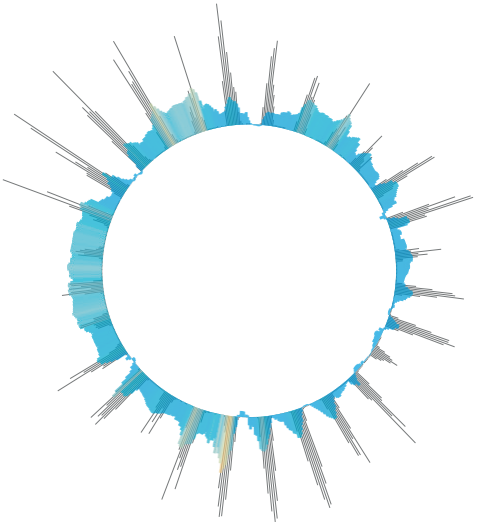
May 2018
bright mode



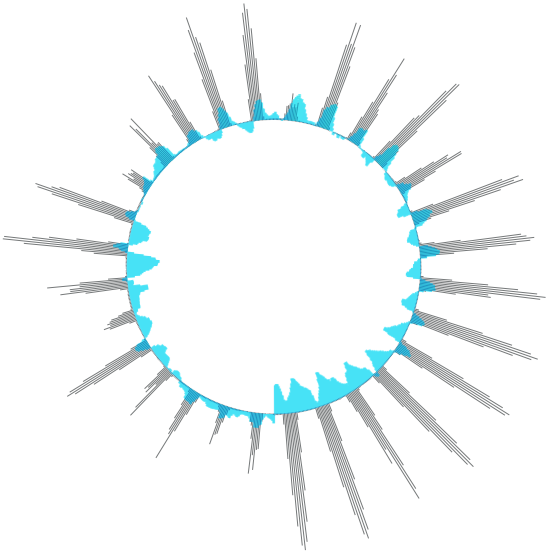
January 2017



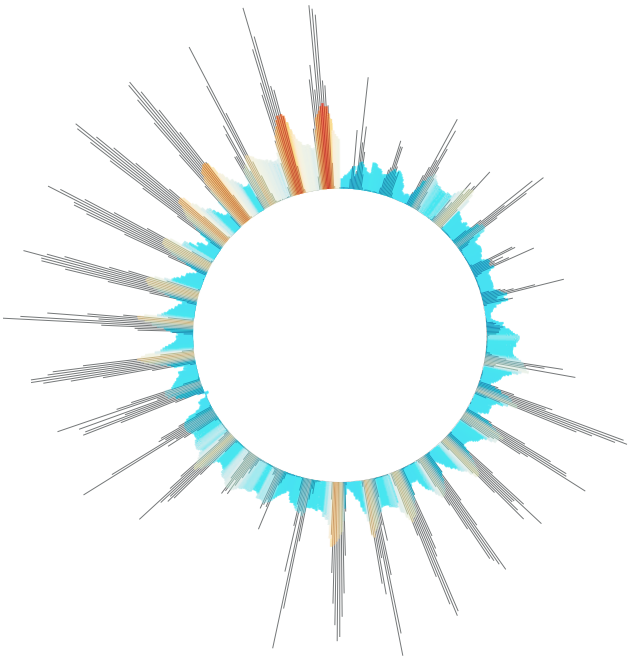
January 2018



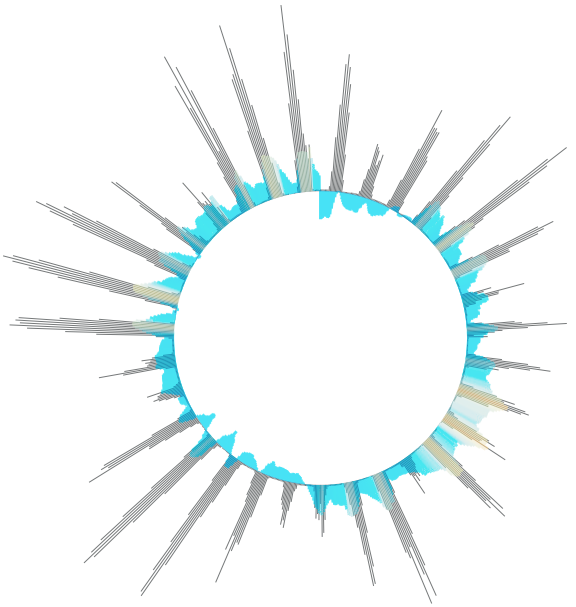
February 2017



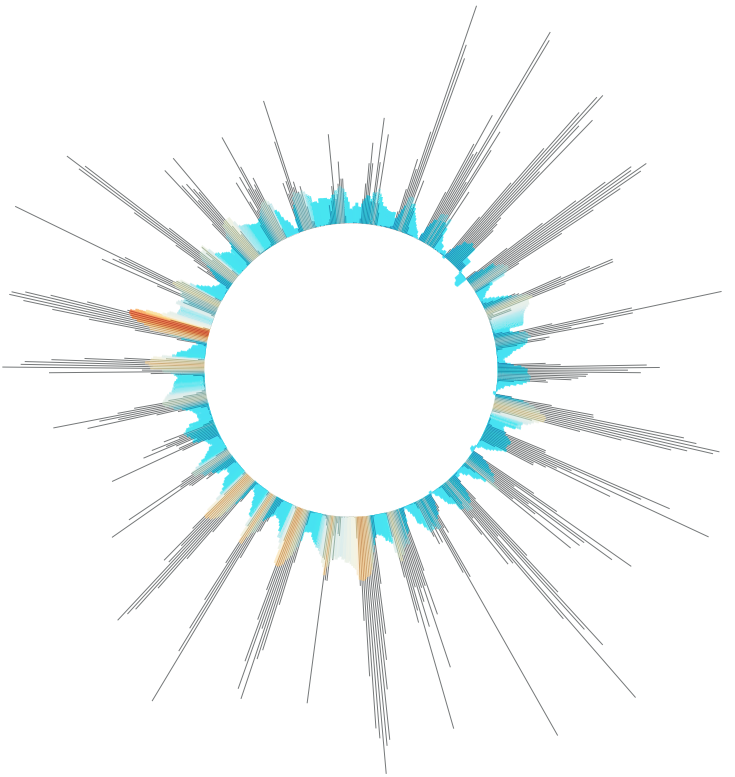
February 2018



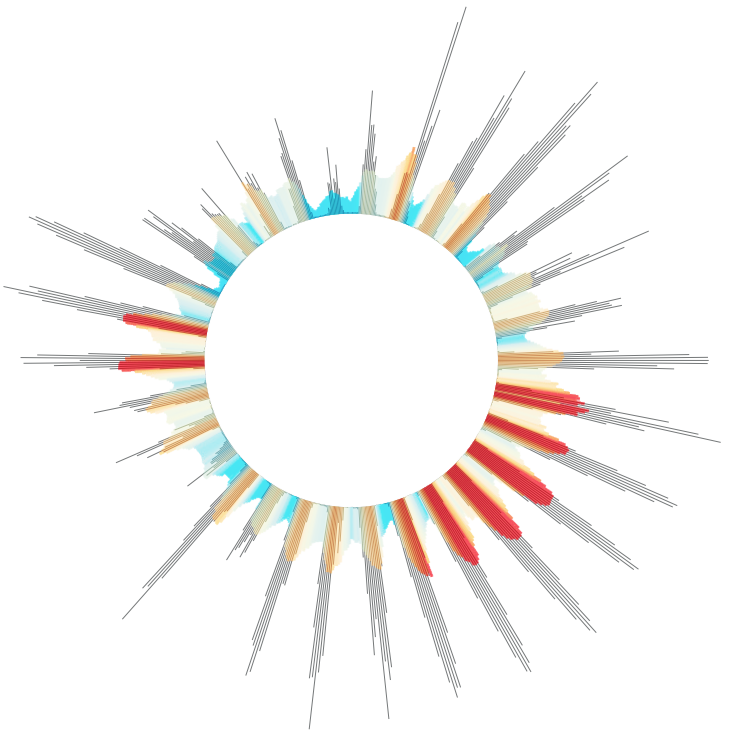
March 2017



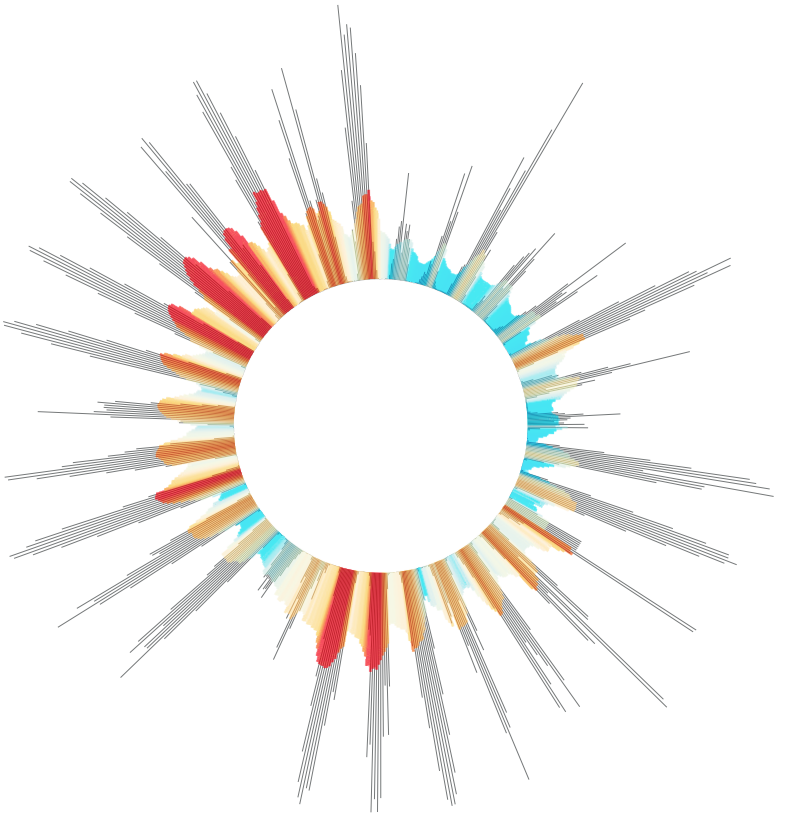
March 2018



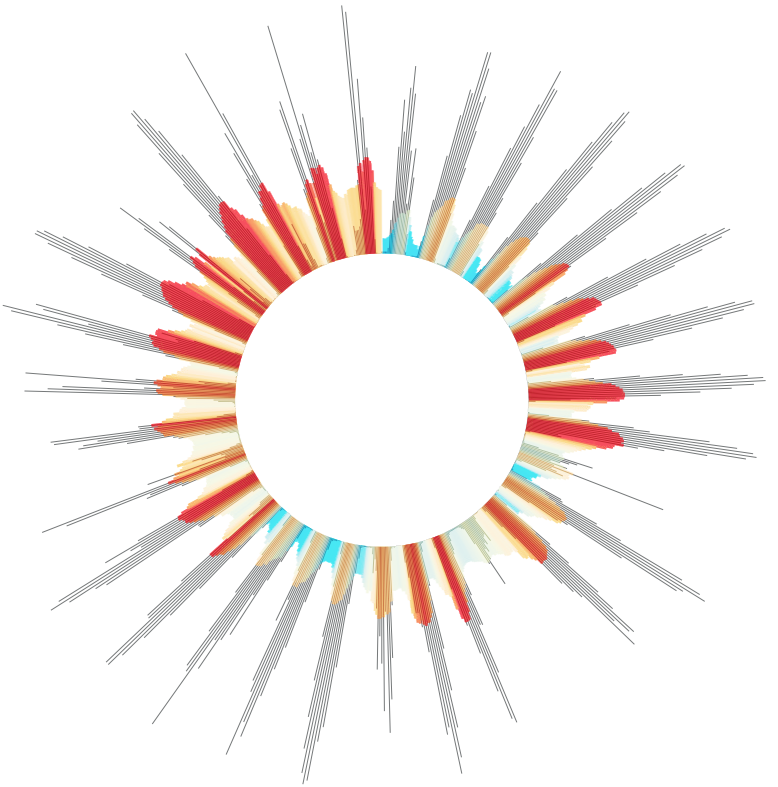
April 2017



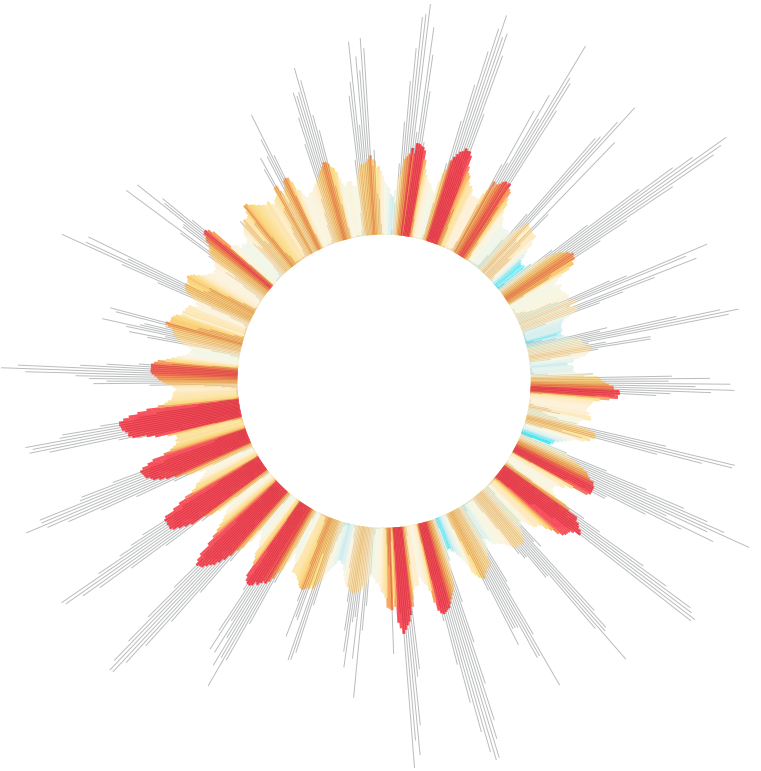
April 2018



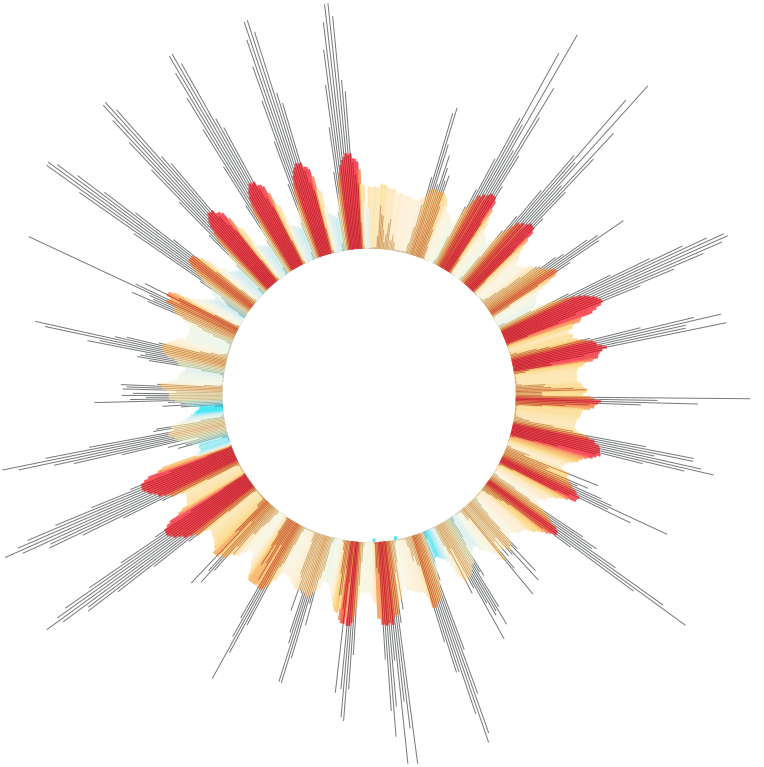
May 2017



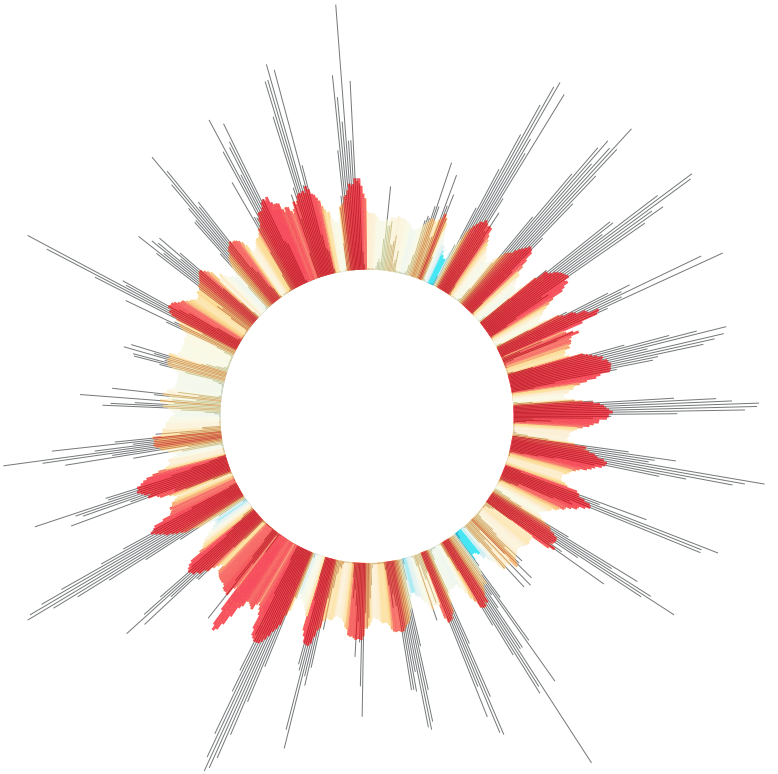
May 2018



June 2017



June 2018



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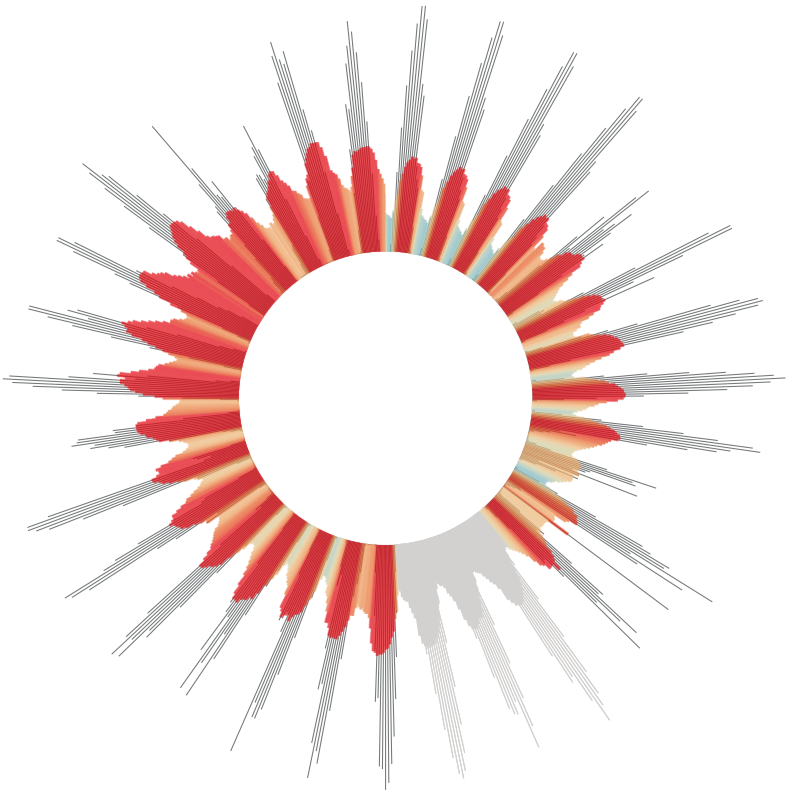

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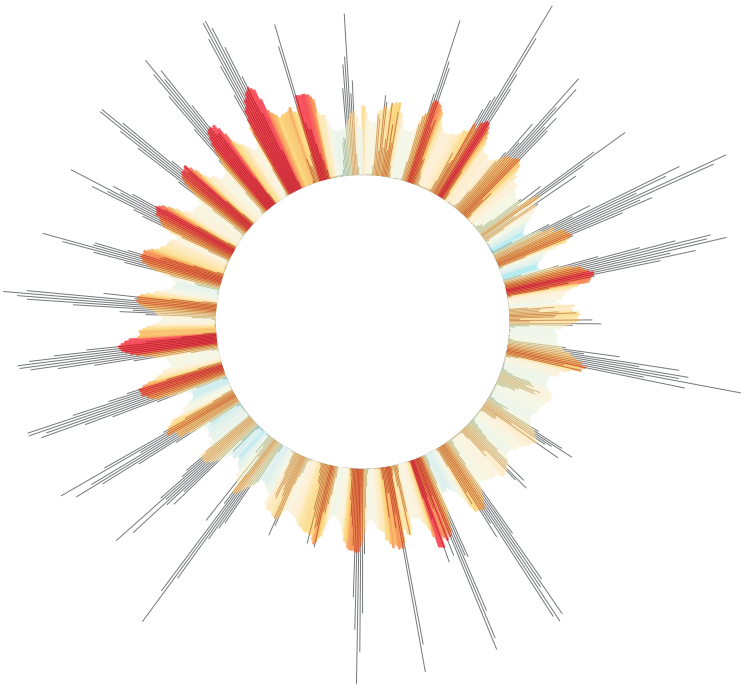

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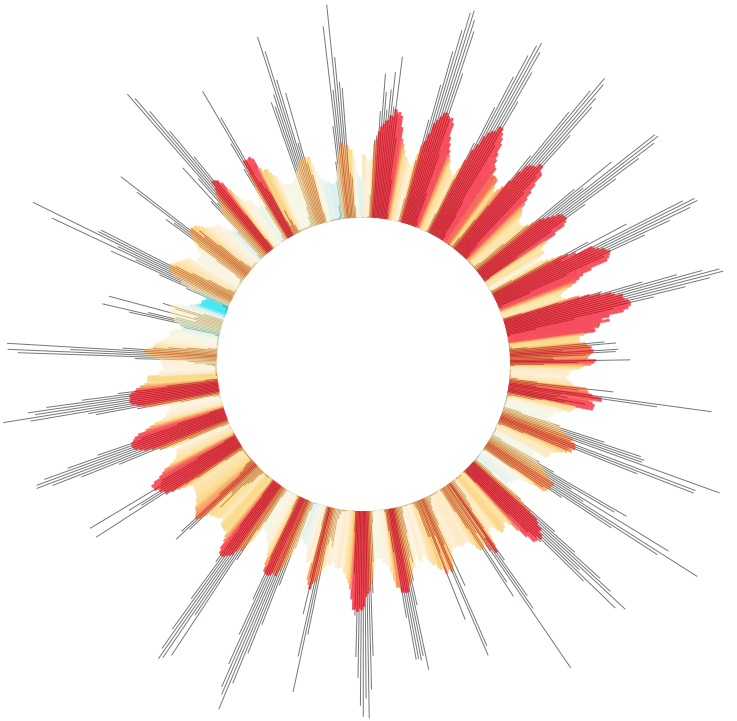

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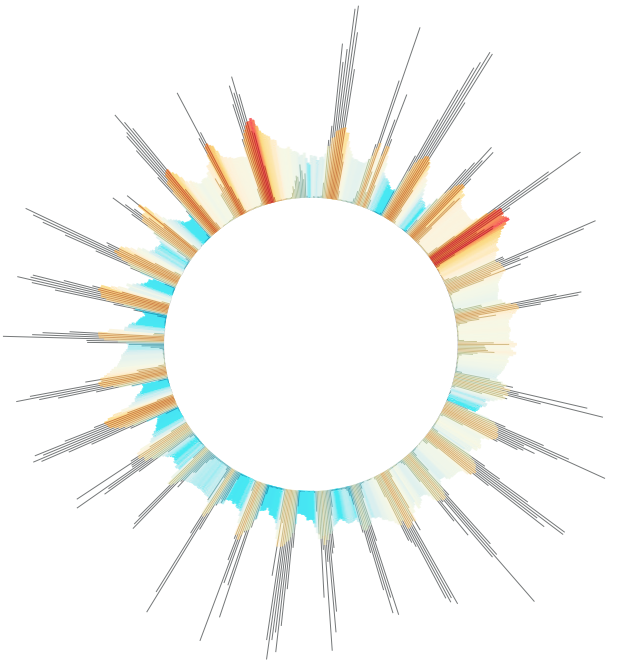

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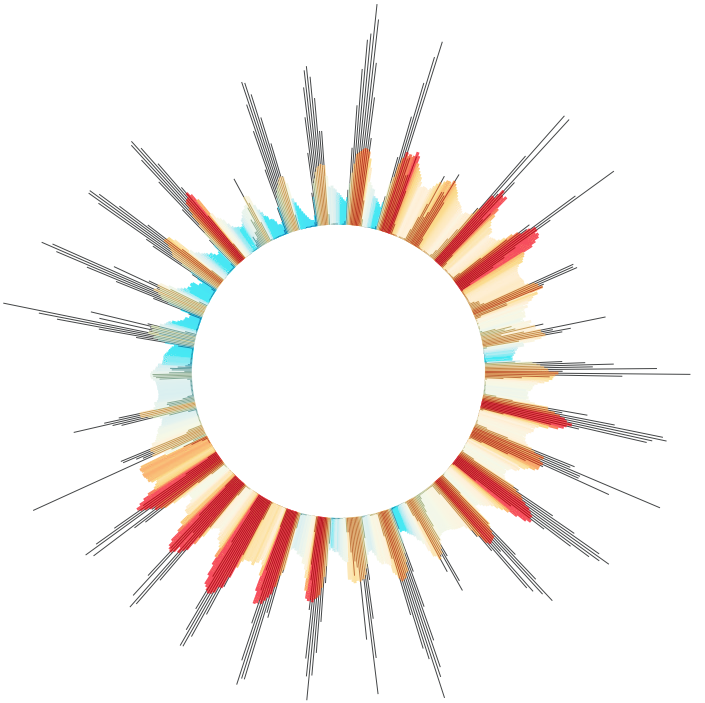

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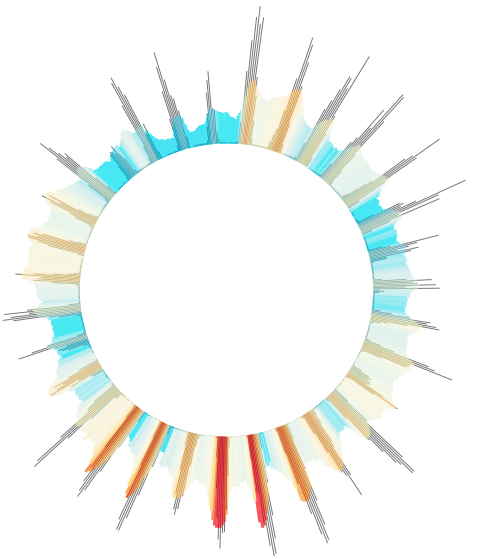

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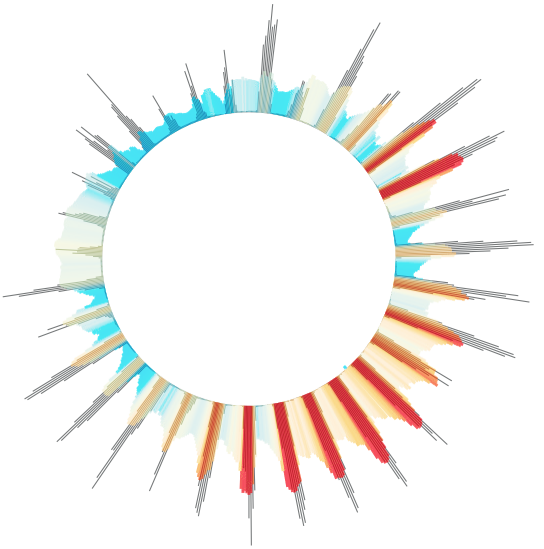

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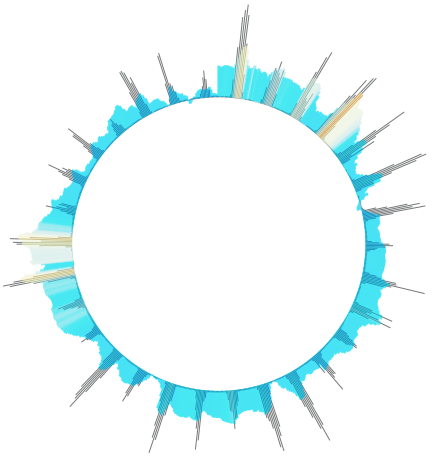

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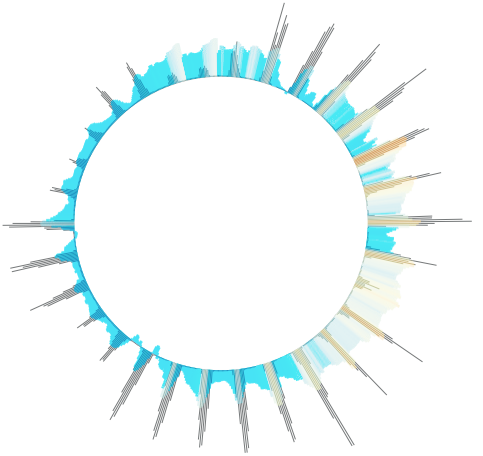

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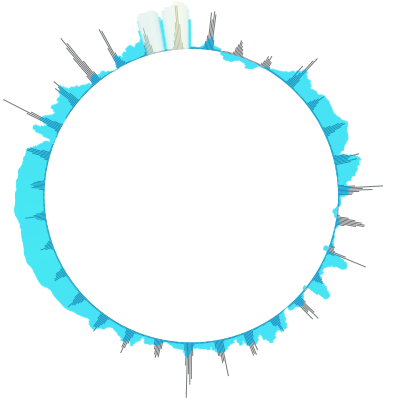

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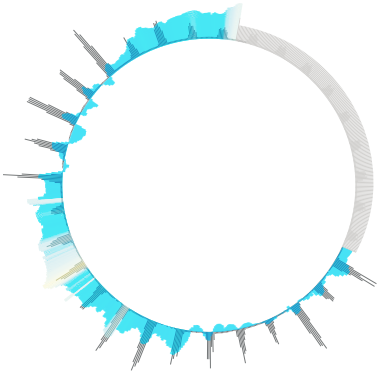

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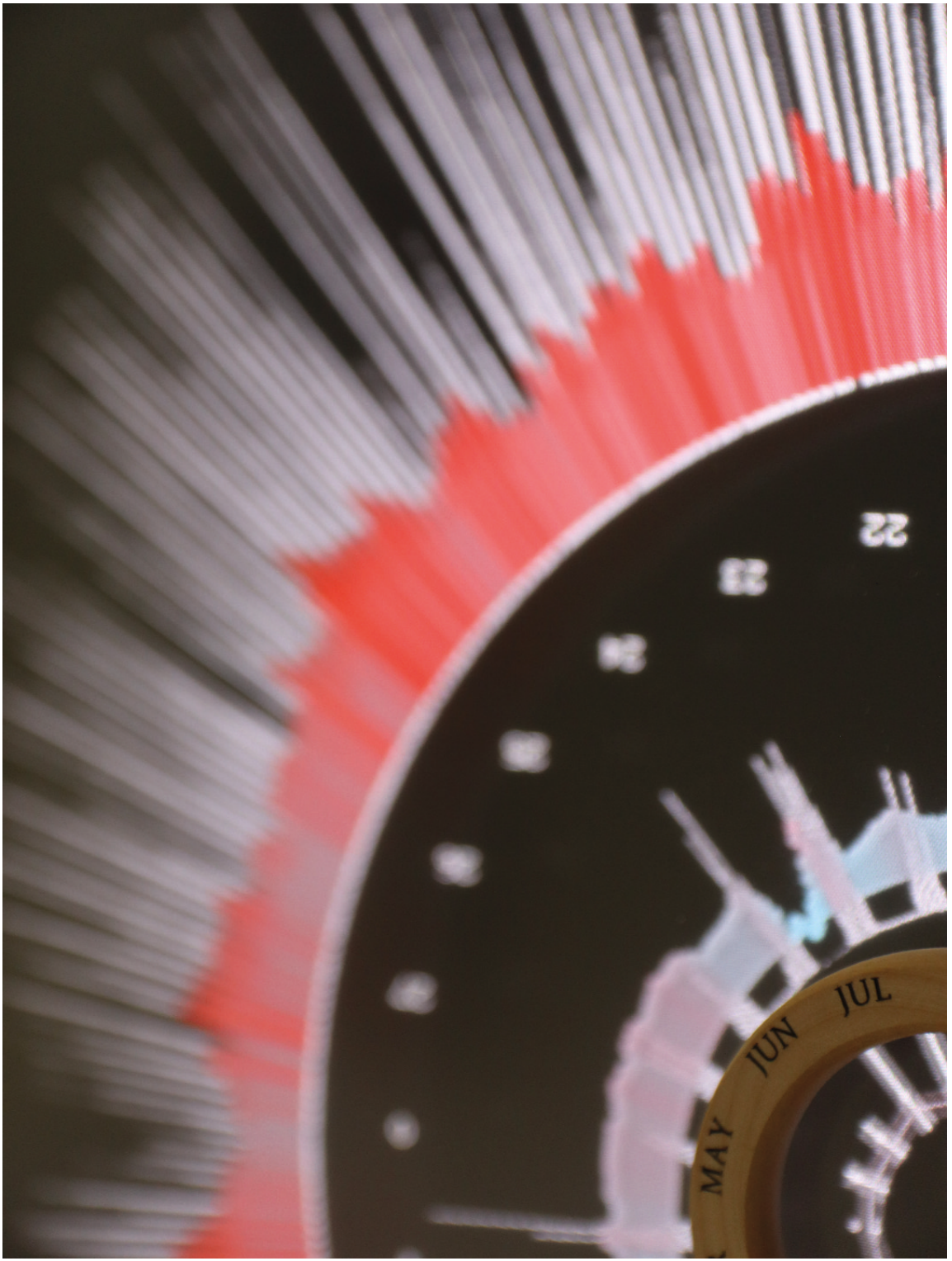
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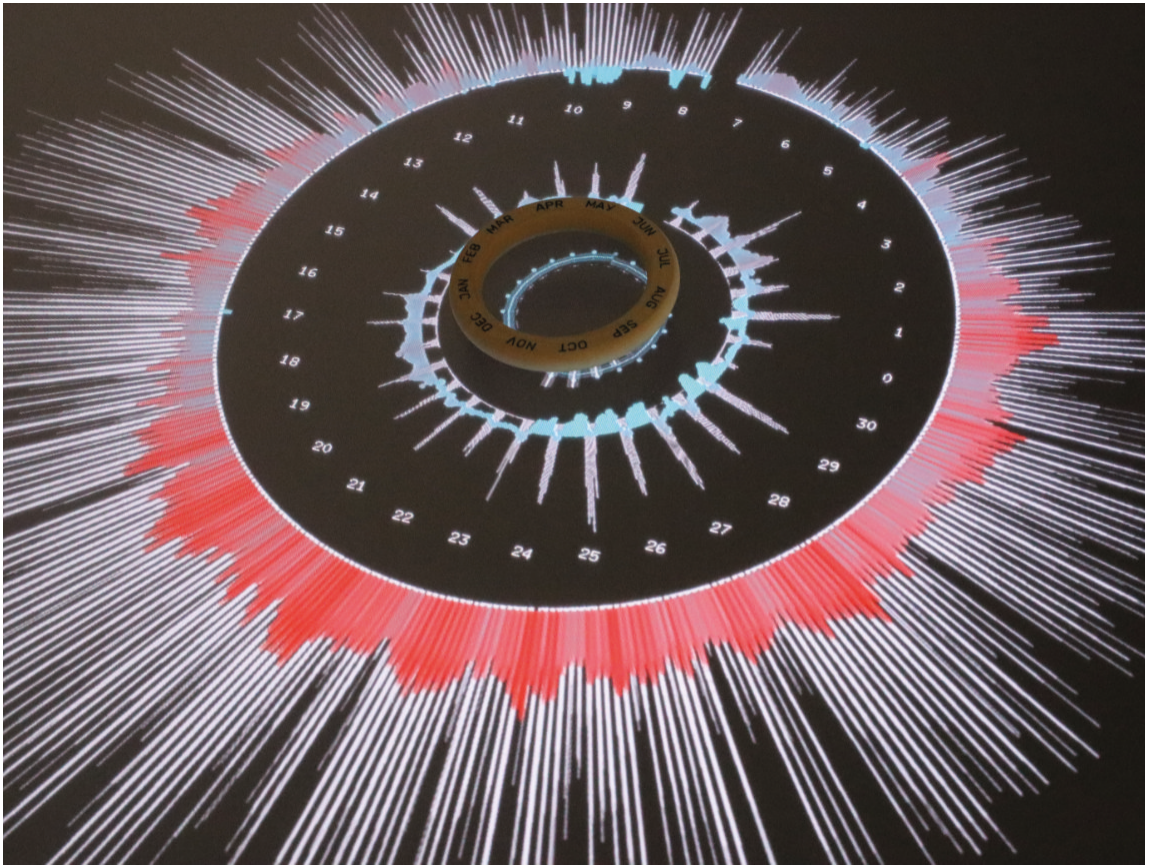
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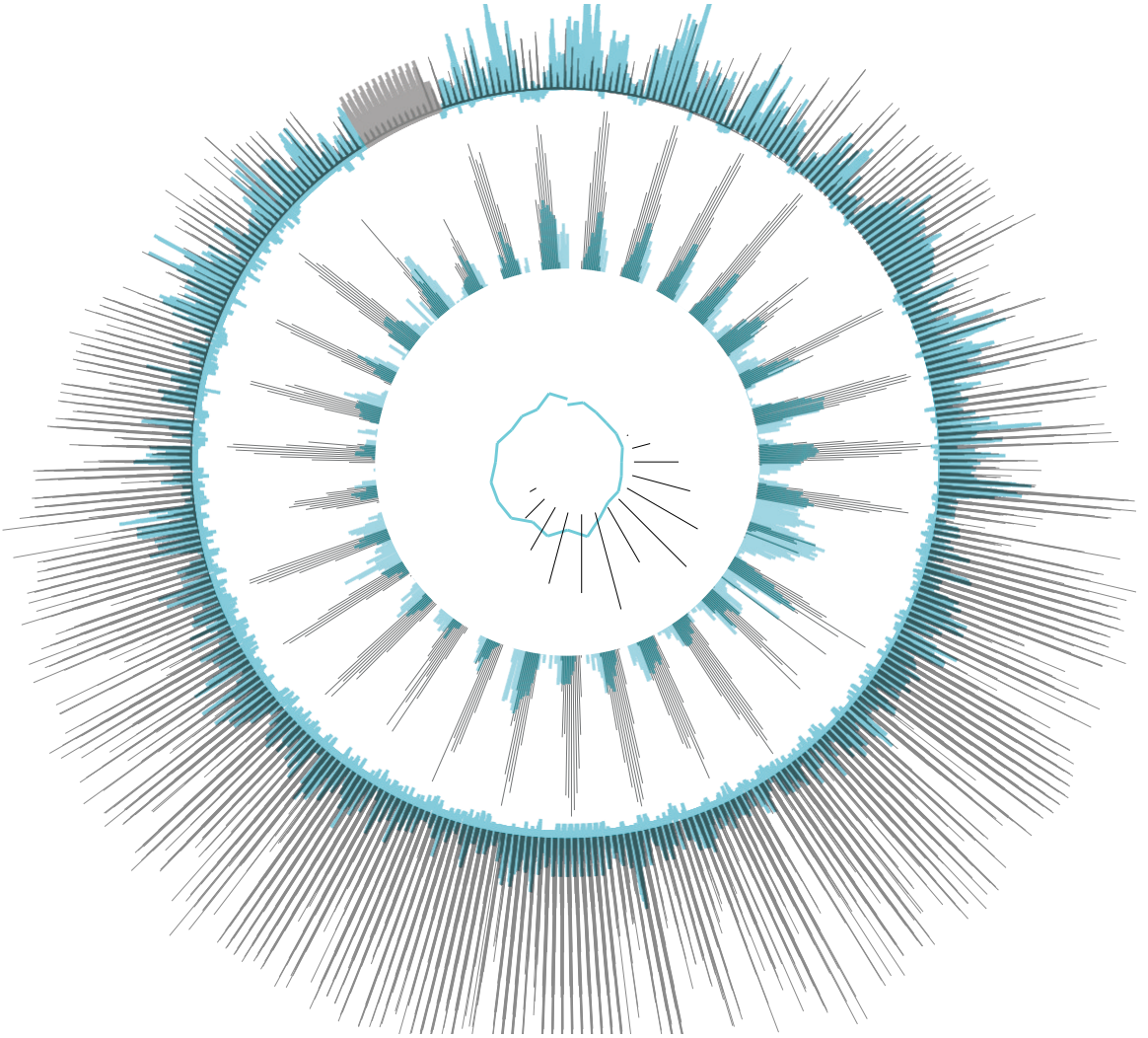
15. Outlook

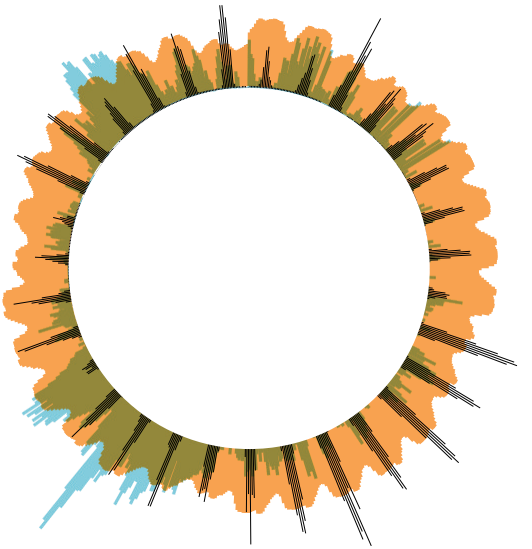


Windspeed and global radiation 2018

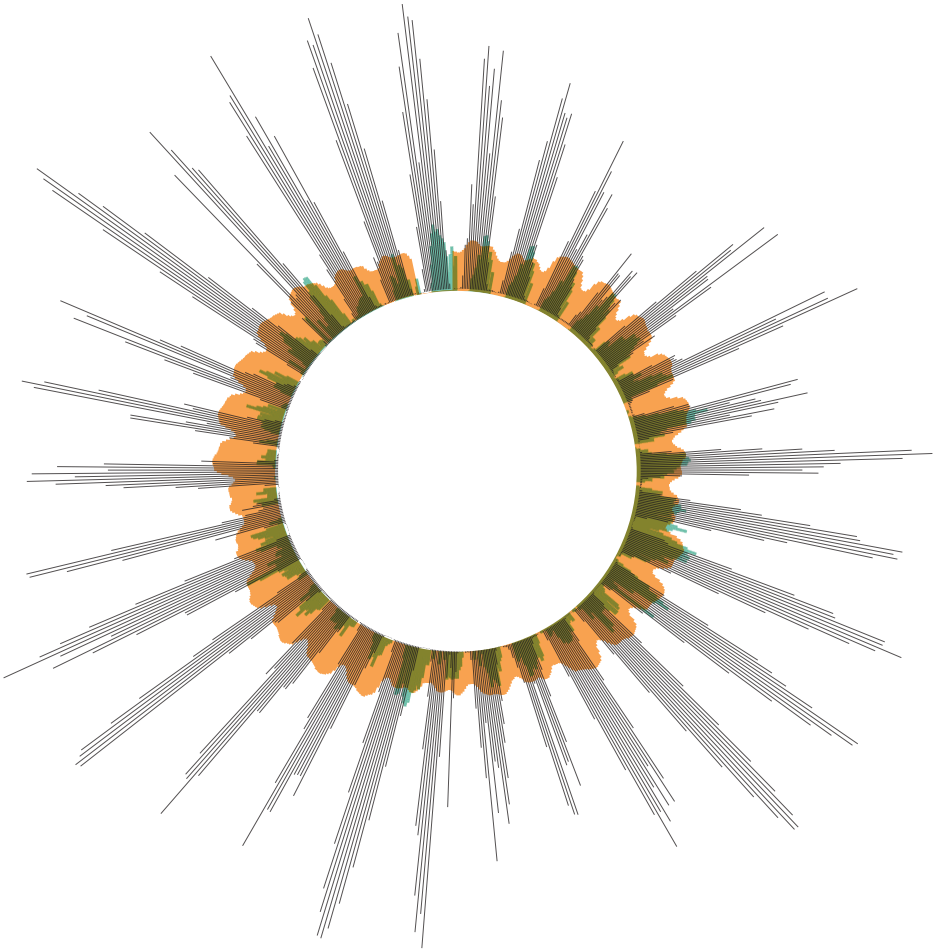
15.1 Next goals

If layers of visualisation get stacked onto each other, sometimes they can complement each other providing useful insights. Unfortunately more than two layers are often already too many and cause visual cluttering. Therefore in order to improve usability of the visualisation, the possibility to **switch on and off layers** should be implemented. want to switch on and off different layers.

The combination of visualising global radiation in conjunction with windspeed is interesting, because it can be the basis for a simulation that can show, how much of this **energy could potentially be harvested** when more electricity is being produced than needed and stored in an energy storage system, in order to be used later on. This visualisation would be more complex and an algorithm would be needed in order to simulate when and how much energy goes into and out of an energy storage system. In order to sketch and experiment how a possible result could potentially look like, hourly load values from 2017 and 2018 were downloaded provided publicly by entso-e, the European Network of Transmission System Operators and combined with the data from Solar Institute Jülich.

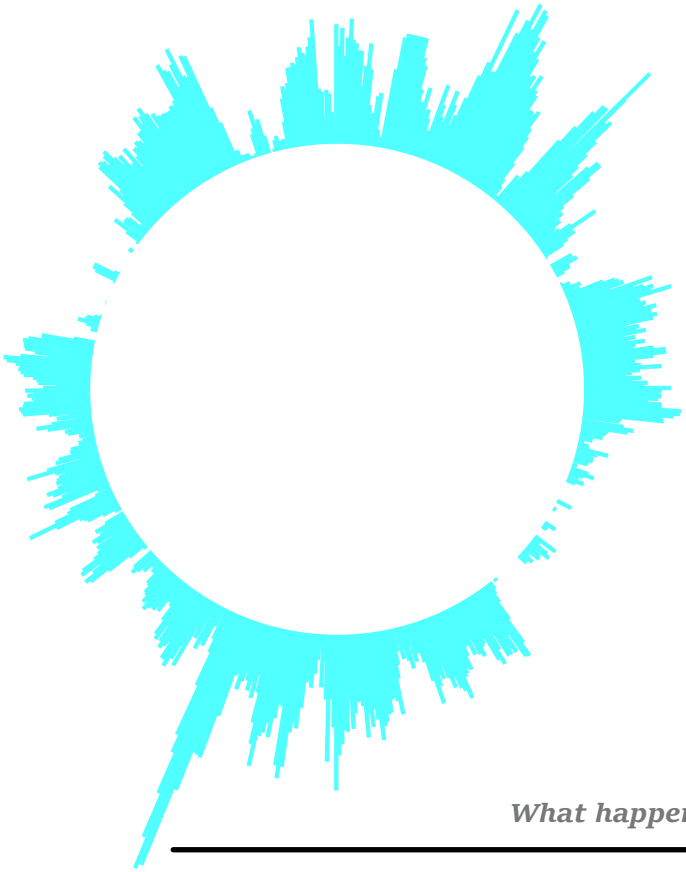


January 2017



July 2017

Windspeed January 2018



What happened here?