Expanding the Information Fidelity of Calm Technology Devices Through Techniques of Information Visualization.

by
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Abstract

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MDes, 2016
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This thesis explores the creation of ambient data visualisation devices that keep

users informed via their use of colour and light to convey information. It is an

exploration into how the principles of information visualisation can be applied to

the design of "calm" devices in order to enhance their features as well as expand

their information fidelity. This exploration builds on the concept of "calm

technology", coined by Mark Weiser and John Seely Brown of XEROX PARC

(1996) which describes unobtrusive, informative technology. Calm technologies

should exist mostly in the periphery, continuously relaying information in a non-

intrusive manner. The research employs iterative prototyping and reflection to

explore was to improve information delivery within calm technology. The project

demonstrates several opportunities to enhance visual-based calm technology

devices by incorporating principles of information visualisation in order to expand

the information fidelity of these devices.

Keywords

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Chapter 1: Introduction

This thesis explores how to apply the techniques and concepts comprising the field of information visualisation to the design of calm technology devices. The goal of this research is to expand information fidelity and in doing so, augment the principles of calm technology embodied within these devices. The project is primarily organized around the development and analysis of a series of prototypes. Weather forecast information is used as the proof-of-concept dataset of commonly sought-after information in order to develop a visual language for the prototypes.

"Calm Technology" is a term first introduced by Mark Weiser and John Seely Brown from XEROX PARC (Wieser, Brown, 1995). It refers to technology that has been designed to be informative yet non-disruptive; technology that does not demand the user's direct attention, but rather remains in the periphery (Wieser, Brown, 1995). This project explores the role of colour, light and motion in developing a light-based calm technology. Sounds and other forms of stimuli are beyond the scope of this thesis.

Currently, the way most of us access information is through smart devices (phones, laptops, and tablets). They require our active attention while we interact with them. They either refocus our attention to them via notifications or we request information directly from them and receive it on demand. In both scenarios, we are required to take action in order to open up the exchange of information, however, in human history information has, most often, been passively embedded in one's surroundings. For example, discerning the time of

day roughly based on the location of the sun in the sky. The ancient Egyptians were able to predict the flooding of the Nile by the position of the star Sirius in the night sky. These are just two examples of how we are able to extrapolate information from our environment by pairing visual stimulus with other attributes. In this era of information technology, can we re-infuse our living and work environments with such ambient, implicit information?

We are at the start of a real world progression from smart search devices to smart environments. During my undergraduate studies, I created a piece of art/ device that visually represented local area network (LAN) traffic via illuminated fibre strands.

Figure 1 - Visualisation of Different Types of local Internet Traffic, An undergraduate project.

The colours of the strands varied to indicate the nature of the traffic, for example, blue for social network activity, red for torrents, yellow for email, and purple for regular website activity, such as when using Google. The idea was to make unseen data visible, to occupy some of a person's physical space with an aesthetically interesting and pleasing piece. While I did not realize it at the time, that project was an example of information visualisation presented in line with the principles of calm technology: It was able to enrich a user's peripheral environment with information that could be internalized in a non-interruptive manner. The motion of the colours was subtle enough not to be distracting, yet when observed, the user could interpret the gist of the information that the device was visualizing (network traffic, in this case).

After learning about the concepts behind calm technology, I continued to research the topic. After taking a class on information visualisation, I recognized the similarities between the two fields: calm technology and information visualisation. They are motivated by the same goal: reducing cognitive overload. Calm technology is concerned with the reduction of unnecessary interruptions in order to help becalm the user, while still providing information in the periphery. Information visualisation is concerned with the externalization of cognition through visual representation. It seems that both strive to alleviate stress while reinforcing cognition. This prompted my interest in exploring the two fields in tandem.

The objective of this thesis is to explore potential design principles for light-based, calm technology, through the development of "calm" prototypes. The prototypes incorporate aspects of my two primary fields of interest: calm

technology and information visualisation. They apply techniques found in the field of information visualisation to calm technology devices, to explore the extent to which the devices' information fidelity can be improved. The prototypes invite comparison among properties of the various information visualisation concepts incorporated into their designs.

Using light as a medium for information transmission provided a robust and limited set of conditions as a framework for testing. By manipulating aspects of projected light-namely colour, intensity and motion—in different configurations, I was able to explore the effect of various information visualisation techniques. The prototypes are devices inspired in their design by the concepts of calm technology. Weather information and forecasts serve as a dataset that is consistent between the prototypes.

Several research questions guide the exploration:

- How might properties of light (intensity, colour, motion) effectively be used to represent changes in values of data?
- What properties of light (intensity, colour, motion) might be used to shift a device into the users' focus and back to the periphery of their attention?
- To what extent do the prototypes successfully exhibit the principles of calm technology?

This thesis document begins with an analysis into the two main fields of interest: calm technology and data visualisation. Attributes and concepts from each are unwrapped for analysis and discussion regarding their implications for the

prototypes' design considerations. Biological and cognitive aspects of human vision and attention are also explored in relation to the principles of calm technology and information visualisation.

I then examine the context within which my project is being developed. This section explores the current state of related, existing products and devices that embody principles of calm technology. This marks the end of the foundation research; project development follows.

The prototype development section is comprised of two main parts: production research and prototyping. Production research outlines the ideation and initial research into the hardware, software and design aspects of the prototypes. The weather is introduced as the content that the prototypes are developed to communicate. Methods of visualizing the weather are explored, as is the significance of using the weather as a dataset.

The prototyping section details the process of developing and reflecting upon each prototype, evaluating each against the principles outlined in the earlier sections. A large portion of this section details the development of the visual language that the prototypes use. A comparison of the results and a reflection of each prototype's development complete this section.

This is followed by the findings section, which relates the findings from the prototyping development to the foundation research. In it, I discuss the successes and failures of each prototype in relation to the concepts of calm technology and information visualisation.

Finally, the conclusion summarizes the findings and reflections on the project exhibition. The thesis concludes with a discussion about how this work could be continued, possible applications, and opportunities for further research.

Design Research Methods

This thesis project is an exploration of the design that can enhance the information fidelity of calm technologies through the techniques of information visualisation. Due to the explorative nature of the research performed, "Research through Design" was chosen as the main research methodology.

Research Through Design

Engaging in research through design is an interesting, generative endeavour, you aren't working in an exact science. The process involves applying design practice to particular situations in an attempt to gain theoretical knowledge by the development and reflection upon the artefact or system created (Gaver, W, 2012). Reflection is key to gain conceptual insights into the theories explored. In the case of this thesis, the prototypes developed are means to an end, the end being the knowledge gained through the experience of developing and reflecting upon them. The insights gained into calm technology and how the principles of information visualisation may augment it, are the real results.

Chapter 2: Foundation Research

Calm Technology

It is no secret that our obsessive use of communication technology plays a significant, integral role in generating stress in our daily lives. In modern times, humans have been increasingly reliant on the very technologies that regularly irritate us. Communication technologies are an essential component of modern social life; they have revolutionized the ways in which humans communicate with one another and have changed the ways we access and obtain information. The merits of our technological grandeur are undeniably immense, though even here we might say, "Everything in moderation." Our frequent use of communication technologies, particularly the actions we must take each time we engage with them, can have negative effects on us cognitively, emotionally and physically. With more of the world's population gaining access to these technologies, it is important to understand the impacts of communication technologies on society as a whole.

The pervasive use of Information Communication Technologies (ICT) and the resulting negative impacts on human well-being has been termed "technostress". Craig Brod, a clinical psychologist, first coined the term technostress in 1984, it is described as a "modern disease caused by one's inability to cope or deal with information communication technologies in a healthy manner" (Ayyagari, Grover & Purvis, 2011). Technostress in large numbers of individuals inevitably makes an impact on the communities in which they live and

work and on society as a whole. With the meteoric rise of Internet-enabled devices, it behooves us to identify and put in place design solutions to alleviate technostress. The design principles of calm technology may be just one of these solutions.

Since the advent of the modern Internet in the mid-twentieth Century, researchers have given much thought to the potential futures that this powerful invention could give rise to. It's impossible for researchers to be able to predict exactly where technologies will lead us but two researchers in particular - John Seely Brown and Mark Wieser of XEROX PARC, made a particularly prescient prediction back in the 90's. The prediction was that between the period of 2005-2025 we would begin to live in a world that was more connected than it has ever been before; the era of ubiquitous computing was around the corner and that couldn't have been more true as we now live in the age of what we call the "Internet of Things" (IoT).

The era of Ubiquitous computing (UbiComp) and IoT describe one and the same thing, that is, a world interconnected by networks of sensors, actuators, computers and pretty much any type of electronic device able to share data with other electronic devices. IoT is simply the more modern name given to the phenomenon. Infrastructures in modern, developed countries, have arisen that allow a multitude of electronic devices to transmit data from all ends of the globe (and beyond, thanks to NASA). This has given us an abundance of data about our world. When Mark Wieser and John Seely Brown began to think about this potential future, they also predicted an unfortunate side effect of living in this interconnected world, that being what Wieser called "information

overload" (Wieser, 1996), which we would now consider to be a contributor to modern daily stress.

We human beings are only able to consciously process so much information at a given time and with so much information being available to us, not to mention our obsession and rapid adoption with communication technologies, there is a lot of information being thrown at us on an hourly basis. A text message, an app notification, a Skype call or upcoming meeting, hundreds of emails, Instagram and Facebook updates are some examples of the sources of bombardment we experience from our connected world. Having the foresight to predict this future back in the 90's Wieser and Brown proposed a design philosophy to mitigate the effects of "information burnout", they coined it as "Calm Technology". (Wieser, 1996.)

Principles of Calm Technology
Calm Technology is a term the researchers used to describe technologies created with specific goal of enriching a user's periphery with information while not contributing to "information overload". They defined a set of principles that describe Calm Technology:

-Technologies encalm as they empower our periphery. This happens in two ways:

-A calming technology may be one that easily moves from centre to the periphery and back.

-The Technology may enhance our peripheral reach by bringing in more details into the periphery and in doing so, create a sense of "locatedness".

"This is encalming, when the enhanced peripheral reach increases our knowledge and so our ability to act without increasing information overload. " (Wieser & Brown, 1995b, Pg 4)

Peripheral reach refers to the amount of information that we can obtain from our immediate surrounding space as suggested by Wieser & Brown (1995b). There are areas in the human brain that are responsible for the mapping of our external world, the majority of this map is built up from two of our primary sense, sight and sound (Kalat, 2007). While touch, taste and the sense of smell obviously factor in here, they aren't quiet as critical as the former two in regard to periphery. This thesis is centred around the sense of sight, as such the remaining senses are beyond the scope of the research. Additionally, vision impairment is not addressed within the scope of this thesis.

Our senses of sight and sound have the important role of alerting our attention to any significant changes that we can perceive in our surroundings, bringing objects from the periphery into our focus, as suggested by Wieser and Brown (1995b). A lot of that information processing of the periphery remains unconscious up until the point that there is a change in the environment that triggers our attention to be reassigned to that stimulus. In order to enhance peripheral reach, there must be sources of information embedded in the user's surrounding environment so that they can perceive it. For the user to quickly interpret and absorb the information, it should be presented in a way that optimizes the interpretation of the data so that it can be quickly incorporated into the user's conscious mind as suggested by Wieser & Brown (1995b). By doing

this, the user's periphery is now enriched by that information, effectively extending their peripheral reach to include information that was not present prior.

The switching between a stimulus being in our periphery and being the centre of our attention is a key feature of what would be considered calm technology. Even while a stimulus remains in the periphery we aren't completely unaware of it. Brown gives a great example of this in a 2014 interview: Calm Tech, Then and Now, where he goes on to demonstrate this phenomenon in a relatable way to anyone who drives a car. We can always hear the engine, feel it even but we aren't constantly given it our attention, while driving there is large amount of information that the driver has to process on-the-fly, this stimulus preoccupies us from the sound of the car, to many the sound disappears all together. However, in the unfortunate instance that something goes wrong with the vehicle, in most cases the driver will become aware of this due to a change in the engine's sound. Although the driver wasn't actively listening to the car, any abrupt changes will cause the driver's attention to shift to the sound. This is a great example of how audio plays a role in our peripheral reach.

The other factor that Wieser and Brown talk about is "locatedness". Locatedness refers to the user's position in relationship to the data or information that they are perceiving. This perception is in regard to past, present and future states of the data as suggested by Wieser & Brown (1995a). The technology serves as an anchor to the data and when the user's attention is once again placed on the device, this anchoring occurs.

Information Visualisation

The field of information visualisation ("Infoviz") has developed over the last half-century or so with increasing significance. In this age of big data, the significance of data visualisation and information design is more relevant than ever. From early cartography and disease vector maps to 3D digital representations, a variety of information visualizations exist and have developed alongside the technologies that have been used to create them as suggested by Skaggs (2014). As new visual display technologies become available, they have allowed for the creation of new forms of data visualisation.

While there are far too many different forms of data visualisation to mention in the scope of this thesis, all of them strive to achieve the same thing: compress their information and present it to the viewer using the smallest amount of visual information possible as suggested by Skaggs (2014). The success or failure of the visualisation is determined by certain factors, nicely summed up by Edward Tufte in the following quote from his seminal writings on information design:

"Graphical excellence is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space" (2001, Pg. 51)

Breaking this down, we can see what Tufte posits is the basis for a successful visualisation. The goal is to compress information, encode it efficiently with minimal complexity, and facilitate quick interpretation of the information by the viewer. Good data visualisation offers what is called external cognition, the inclusion of visual designs that mirror the human cognitive process in how the information is represented. For example, consider a pie chart versus a spreadsheet of values. The pie chart has several values indicated visually within the total available value (pie), whereas the spreadsheet offers lists of values and their totals. In order to achieve the same level of comprehensive understanding as we gain by glancing at the pie chart, we would have to read through each line of the spreadsheet's values, and then work out percentage values for the amount out of the total. Even if that author did that for you, you would have to read and understand an additional column if information. The humble pie chart conveys all that information in a way that feels intuitive and eliminates several steps of cognitive work. External cognition outsources human cognitive features into Infoviz designs in order to facilitate understanding while decreasing cognitive load as suggested by Skaggs (2014). It overlaps nicely with the concepts of calm technology, in that both fields aim to reduce cognitive load while being informative.

As mentioned there are numerous types of data visualizations, far too many for the scope of this thesis. Below is a breakdown of the types of data visualizations employed in the prototypes developed, namely: pie charts, ring charts, histograms and heat maps.

Pie Charts

One of the most widely used forms of data visualisation, pie charts are a frequently used technique in a variety of fields. Sometimes called a circle chart, pie charts consist of a circular body representing the whole, which is subdivided into sectors that demonstrate numerical proportions. The length of each sector is proportional to the value it represents. Pie charts are best suited to display the relative quantities of values within a total and are not well suited to display exact figures. The first known example of the pie chart appeared in a publication called Statistical Breviary, Written by William Playfair, who is also credited with the development of the technique during the late eighteenth and early nineteenth century as mentioned by Skaggs (2014).
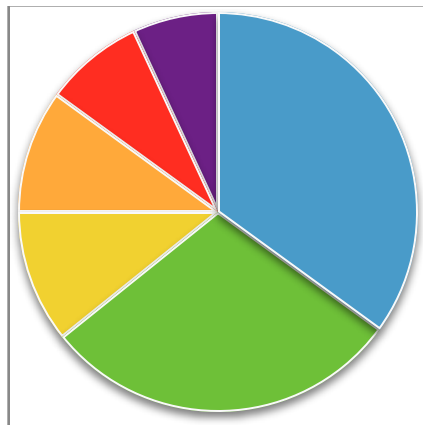
Figure 2 - Example of Pie Chart

Ring Charts

A more advanced pie chart, also known as a sunburst chart or radial tree-map, the ring chart consists of concentric circles that visualize hierarchical data. The ring chart looks like a pie chart within a pie chart. Each succeeding segment of concentric circles represents not only composition of the totals, but also the

composition of the previous layers' adjacent segment. Like pie charts, ring charts are not well suited to display exact figures, but rather are best used to present to the viewer a breakdown of compositions relative to each other out of a total.

Figure 3 - Example of Ring Chart

Histograms

Column or line histograms are a form of data visualisation with which many people are more familiar under the name for one type, bar graphs. Histograms plot numerical data by means of proportionally sized rectangles, in the case of column histograms, or by a continuous line plotted by a sequence of points, in the case of a line histogram. These visuals invite direct comparisons among separate values, as compared to pie charts and ring charts, which best display each value's relationship to the whole.
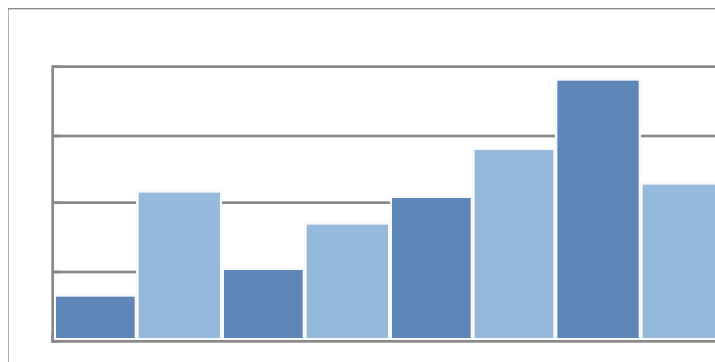
Figure 4 - Example of Histogram

Heat maps

Heat maps are graphical representations of a data set of values plotted over a 2D matrix and represented by colour gradients. The heat map has been widely adopted in a variety of fields. We are probably most familiar with them in weather reports online and on TV, another familiar example is election result maps. The colour gradients indicate numerical values while their location in the 2D matrix corresponds to a set of data points, such as geographic location in the case of weather maps or shelf height in the case of retail market research.
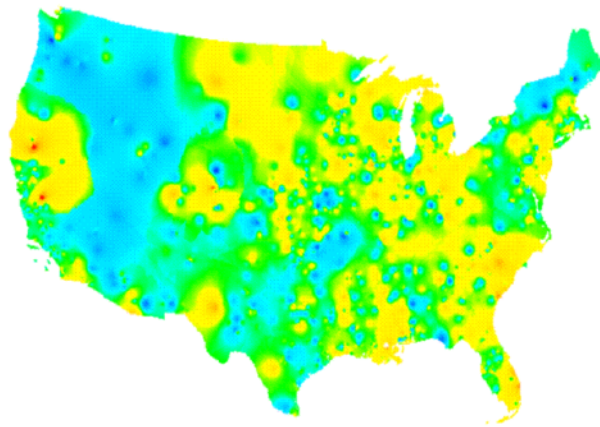
Figure 5 - Example of Heat Map (http://mappingcenter.esri.com/index.cfm?fa=ask.answers&q=319)

Visual Perception and Cognition

Visual perception is crucial to the interpretation of information visualizations. The way in which human visual processing handles content within our focal point differs from how it processes visual information from the periphery.

Objects that are seen in our focal point have a much higher resolution than objects seen in our peripheral vision. We are better, however, at detecting certain properties through our peripheral vision than in our focal point as suggested by Kalat (2007), such as movement, changes in degrees of luminance, colour, and properties of shape.The degree and pace at which these values change in the periphery often determine what gets called into our active scope or attention, shifted into our focal point. This evolutionary aspect of our brains' visual processing cortex, helped us be aware of our surroundings for the sake of survival in humanity's early years. With it we could "sense" a lion barely creeping into view as she stalked us, or a bison we were hunting heading down a different path than we predicted.

It is these biological features of human vision that will be exploited for this thesis and the accompanying prototypes. Along with sound, which is outside the scope of this thesis, vision-based stimuli are some of the more direct ways to become informed about changes in our surroundings. When objects are in our peripheral vision, they do not require our active attention or conscious focus though their state is perceivable to a degree, and we are able to detect significant changes and when called for, shift our attention. These properties make peripheral vision a prime test site for weaving together the principles of calm technology with the concepts of information visualisation. It should be noted that in regard to accessibility, the sense of sight is not a consistent experience for everyone. Individuals with vision impairments such as colourblindness and complete blindness require special design considerations that are beyond the scope of this thesis.

Pre-attentive Features

There has been significant research into methods of encoding information into visual form in a manner so that the viewer can quickly, and with little guidance, interpret the visualisation. While colour and light play a crucial role in information visualisation, several theories are currently in play regarding our vision processing system. The trichromatic theory, opponent process theory, and retinex theory are the prevalent theories into colour perception. Although their details are beyond the scope of this thesis, certain implications of these theories are relevant to the development of the prototypes. Building from understandings of the human visual processing system, certain pre-attentive aspects of our vision have been discovered. The term pre-attentive describes qualities that we can sense with our vision that are not consciously processed as thought, but instead trigger specialized neural networks within the human brain as suggested by Kalat (2007). Suggested to be "feature detectors," these networks get activated by particular forms or visual stimulus such as borders of shapes, degrees of luminance, and colour. These qualities are then processed by higher levels of the visual processing system and eventually get incorporated with other components of our active, working, visual memory, which in turn further informs the visual system of more details of what we are perceiving (Kalat, 2007). It is a fascinating process, and one which Colin Ware, an authority on perception for design, has summarized quiet succinctly within his work on information visualisation in regard to cognition. As mentioned by Skaggs (2014), Ware divides the process into three stages:

Stage 1: Extraction of basic features by rapid parallel processing (pre-attentive properties).

Stage 2: Patterns and structures are extracted next by slower, serial processing.

Stage 3: Goal-oriented processing reduces the information to a few objects, which are held in the working visual memory.

The pre-attentive features are of greatest relevance to this thesis; when accounted for in visual design, they can improve the speed of the following tasks: detection of target, detection of boundaries, tracking region, and most importantly for this thesis, estimation and counting (Skaggs, 2007). By incorporating this knowledge into the prototype design, my hope is to maximize efficiency and "glanceability" of the visualizations.

Context Review

This context review of related devices has been conducted to provide an

overview of the current state of calm technology principles being implemented in

existing devices and consumer products, particularly within the realm of ambient

data visualisation, below.

Tempescope

The Tempescope is an ambient weather visualisation devise that uses water to

create conditions within an enclosure to represent the following day's forecast. By

manipulating water vapour within the device's sealed chamber, it can create rain,

clouds and even lightning with the built-in LED light source. A Japanese software

developer, Ken Kawamoto, who wanted to bring the thunderstorms of the Okinawa Isles indoors, created Tempescope employing interaction design principles of calm technology for a novel expression of information visualisation.

The use of a physical medium is powerful in that the representation closely mimics the weather phenomena. However, the reliance on a physical medium, in this case, water, does impose some limitations not present with virtual representations. For example, the device cannot represent weather conditions beyond the scope of its hardware's capacity. Tempescope, for instance, cannot produce hail or snow. Its information fidelity is also narrow, as the device only displays one data point at a time. Notwithstanding these limitations, Tempescope succeeds in conveying information with a nice ambient effect.

Violet Dal

Figure 7 - Dal Lamp, http://archive.linuxgizmos.com/device-profile-violet-dal-the-first-emotional-lamp/

Encompassing the principles of calm technology, the Dal lamp, which is touted as the first consumer product of its kind, is a Wi-Fi-connected device that responds to real-world events through a display of gentle colour. The device is also called the emotional lamp; data is subtly diffused in a room setting through colour displays of varying rates and rhythms. The lamp can be customized to convey one of several areas of information: long range weather forecasts; stock market updates; local traffic conditions; responses to changes in ambient noise; and email alerts. The Dal lamp also has a special feature with which two people can create a shared language through programming that is expressed as colour

animations representing specific emotions as identified by the users. This makes ambient and non-intrusive an aspect of their communication with each other.

The two-way communication feature of the Dal Lamp is a very interesting step for calm technology devices, though bi-directional communication is beyond the scope of this thesis. The lamp's diffused LED light matrix, its means of visualisation, emphasizes the ambient nature of the device, with having only a 9 LED matrix, the device seems to lack the flexibility to display less ambient information, should it be required in the moment.

Air Quality Egg

Figure 8 - Air Quality Egg, http://airqualityegg.com

The Air Quality Egg, available for purchase as a do-it-yourself kit, is designed to detect air quality in home or work environments, using visual displays to represent the data collected. The Air Quality Egg is completely open source; individuals can buy the components and build it themselves. It targets gasses related to urban air pollution, providing users with visual data to help them comprehend and plan for current air quality conditions. An electronic sensing system connected to a USB transmits data over Wi-Fi, providing indoor and outdoor detection of airborne pollutants. An objective of the device is to engage society in a critical discourse about air-pollution, so the company invites users to both store and retrieve data from its free web-based archive service, providing access to current and historical information on air quality.

In order to visualize the aggregated information, the device uses two approaches. A single RGB LED indicator light is embedded within the device, and provides the user with a simple current status report of the current air quality. Due to the limitations of using a single LED, the Egg's collected information is also made available via the website's archive of aggregated data. This is an appropriate approach, though it would be interesting to see the re-developed with greater capability for information fidelity, so that it could further inform the user without turning to a web portal.

GlanceClock

Using LED displays, the GlanceClock, a yet-to-be released product, provides
alternative visual representation of data, as opposed to screen-based methods,
in a user's home or office. With the help of application program interfaces (APIs),
the GlanceClock obtains data from archives, which is then displayed through
representations of colour. It was intentionally designed around the principles of
calm technology to emphasize its "glanceable" nature. Algorithms recognize user
interaction, which overtime tells the clock what information to display and when it
would be most appropriate. Information such as personal schedule, personal
physical activity, household energy consumption and even health information
such as current blood pressure are examples of what the device can display.

Users choose the represented data and control the device's many functions and displays through GlanceClock's free mobile app.

The GlanceClock is a great example of a soon-to-be real world product specifically designed to apply calm technology to information visualisation. The product was announced at the end of 2015, with hopes for a 2016 release. (As of March 2016, it is yet unreleased.) The design promises to strike a good balance between being informative and ambient, and to have the flexibility for shifting between the two. Two features may be found to reduce its ambient effect: traditional, physical components for the clock and the use of text for read-outs both require a user to interrupt their activity and look directly at the device to acquire the time and other information.

Chapter 3: Project Development

The Weather

There are a variety of reasons for choosing weather as the primary data set for these prototypes, the most obvious of which is relevance. For some weather is a matter of what clothing to wear that day or if an umbrella will be required. For others it is a critical factor in their livelihood, such as in the case of farmers. While the degree of significance varies from person to person, the weather has an impact on each of our daily lives, regardless of where we live.

An unfortunate reality of contemporary times is that the weather is becoming increasingly unpredictable due to our overheating climate. Freak storms, floods and intense heat waves are among the more inclement weather phenomena that are becoming common as our environment reacts to the damage we have caused. Increasing weather unpredictability is a good indicator that humans need to become increasingly awareness of the current weather and updated forecasts. The principle of providing increased information awareness, without adding a burden of effort or stress, makes calm technology well suited to weather information applications.

A simpler reason for my selection of weather as a dataset is my desire to abate an aspect of the daily discomfort in waking up early in Toronto, Ontario, during the deep winter months. With the sun rising late, it is often too dark outside for me to see what is happening weather-wise. The current options are to turn on the TV for the local news or weather channel or most likely, to unlock my

phone and check the weather via an app, both of these require direct

engagement of my attention. The weather is something that is naturally

"glanceable", that is, you can pretty much determine what is happening simply by

looking at it, no extra attention is required apart from a glance. I believe that it is

possible to use colour and light in a user's space to recreate this more natural

experience in a manner that requires less attention. The experience could even

improve upon the original, natural inspiration of the sky by providing the user an

up-to-date forecast of the next 11 hours opposed to the much shorter forecast

one can glean from a single view of the sky.

In those dark winter mornings, information that would otherwise be easily

attained in a natural manner, glancing outside, must be sought through alternate

methods, many of which require our direct attention to access, such as when

using a smartphone app. Residents of underground apartments, or where

window views are obscured by other buildings, and those who work in

windowless facilities, face this annoyance daily, regardless of the month or time

of day. The prototypes I developed were inspired by this experience. With them, I

strive to recreate the calm and ease of glancing outside to get a sense of the

weather, something we humans have been doing since we began living in

shelters.

Weather Instruments

There are many existing analogue technologies used for measuring and

visualizing the properties of the weather. My interest lays in the analogue weather

measuring instruments that have historically been kept in a domestic setting:

barometers, thermometers and hydrometers. These instruments measure air

pressure, ambient temperature and air moisture (humidity) respectively and were

often found in businesses and private dwellings. Temperature, humidity and air

pressure form the basis of weather; it is by measuring changes in these values

that one can predict storms, rain or fair weather. Those who had this measuring

equipment inside their living and working spaces, and knew how to read and

interpret them, could plan around nature's offerings for the day. However, with the

advent of radio weather forecasts, then TV weather forecasts, and then,

eventually, online access to accurate weather information, the need or desire to

have one's own weather measuring equipment fell away. As is often true of

trends, this one seems to be in a reversal: personal weather stations that relay

information to the consumers' smartphones are becoming quite popular.

Barometers, thermometers and hydrometers were, and in some cases still

are, beautifully made and displayed proudly on a home's or business's wall or

counter top. They occupied a part of the shared space among colleagues or

family members and made their information known to anybody who glanced at

them. This kind of relationship between user and device is what my prototypes

strive to achieve: weather forecast information that is not relegated to

representations on a smartphone or other LCD displays, but rather, exists as an

ambient, pleasing, part of the physical space.

Digital Weather Devices
Why develop a digital version of these classic devices? A device that can

access weather information from reliable, accurate and powerful weather

services has the potential to be even more informative than the analogue devices of the past. These devices often relied on indoor measurements and as a result, would be less than fully accurate. That said, when devices rely on the Internet for information, there is always cause for concern should the Internet go down or the device be unable to access its online resources, perhaps due to API protocol changes. In most cases where Internet access is ubiquitous, I believe, the increase in information fidelity, due to a richer source of data, outweighs the risks of relying on the Internet not to fail.

Another benefit of using a digital device is that it can communicate weather information through an array of elements – in the case of my prototypes, light, colour and motion. Unlike the physical dials and measuring rules of the past, a device based on colour can amplify information fidelity by indicating fine distinctions between and the relationships among data points through, by varying or aligning hues or brightness, for example.

Visualizing the Weather

In addition to the domestic weather instruments mentioned above, humanity has historically come up with other inventive ways to visualize the weather in order to better comprehend its behaviour and communicate that behaviour to others. New technologies often make it possible to develop new means of visualizing the weather. For example, the familiar, multi-coloured map overlay that we see on modern TV weather reports is a result of advancing computer graphics technology. Previously, most weather maps relied on simple symbols, lines and

text to convey their data. This new type of map is actually an example of the data visualisation "heat map" technique.

Process

Fabrication

I chose 3D printing as my fabrication method in order to rapidly produce custom components for each prototype and to allow for precise design of these components. The 3D printing technology used was that of fused filament fabrication (FFF) - a process involving thermoplastics being liquified and then extruded into the pattern of a 3D model, layer by layer.

I used the 3D modelling software Rhino to create all the non-electronic components for both prototypes. The ability to rapidly iterate the design allowed for a more generative process, as turn-around time for making adjustments was insignificant. The actual 3D printer used for this project was an Ultimaker 2, printing with a polylactic acid (PLA) filament.

Hardware

Based on my goals of creating a stand-alone device, I needed to select a platform that would be easy to develop on and would enable wireless communication via Wi-Fi. I considered several options: the Intel Edison, the Raspberry Pi, the Arduino with WLAN shield, and the Wi-Fi-enabled Arduino Yún.

Ultimately, I decided to prototype with the Arduino Yún because it offered the hardware features I needed and was the most user-friendly.

The Arduino Yún combines an Atmel ATmega 32U4 processor and an Atheros AR9331, which runs an embedded version of Linux. The Linux side runs an operating system called OpenWrt-Yún and is responsible for interacting with the Wi-Fi radio hardware and the Ethernet communication. The Arduino (ATmega) side is responsible for the familiar hardware I/O's of an Arduino Uno, this is what controlled the LED configuration and colours. A bridge is created that allows messages, data, to be sent between the two chips. This bridge consists of a combination of hardware and software; it requires certain code libraries to be implemented. For the majority of the prototyping process, testing and development did not take advantage of the more advanced features of the Yún, but rather, used the Arduino side to relay instructions from a computer running a Processing sketch.

Another major component of building the prototypes was finding solutions for creating the light patterns and animations I had set out to implement. Initially, I had planned to explore using LCD display technology but decided that using patterns of LEDs would be better for creating a more ambient experience. After researching the potential options for the LEDs, I decided to use the well-documented and popular NeoPixel line from Adafruit. These RGB LEDs come in a variety of configurations are controlled via a library NeoPixel provides for Arduino; these LEDs are individually addressable, allowing me to have precise control over each light's brightness and colour. Their variety of sizes and different forms granted the flexibility I had in developing my prototypes.

Software

Before getting too far into physical prototyping, I created a representation that would allow me to prototype possible LED configurations and patterns virtually, prior to committing to a specific form for the device. This allowed me to practice with and learn the idiosyncrasies of the Arduino Yún, while continuing to progress with the other aspect of the project: data visualisation.
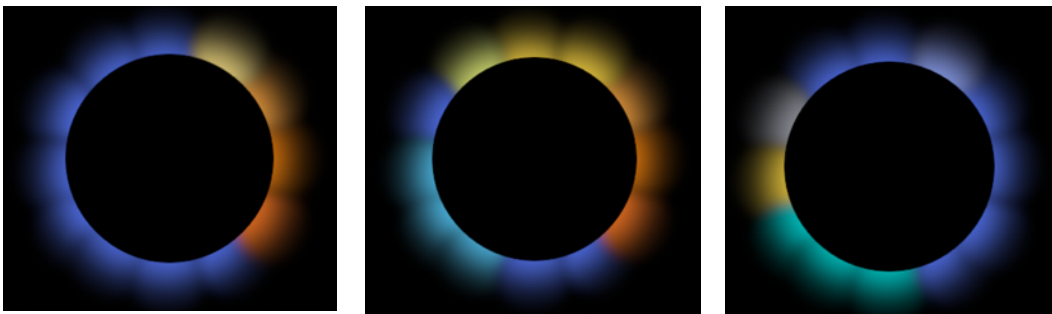

Figure 10 - Software Exploration of LED Configuration

Using Processing, I created a series of functions and classes that could configure the virtual LEDs arrangement. I assigned colours to them individually, or by set grouping. This allowed for some early comparative testing of the potential configurations, to see which offered more options for creating interesting patterns. This helped inform my decision to use the Adafruit NeoPixel range of LED products for further prototyping.

With that decision made, I began work on allowing my Processing sketch to control the physical LEDs via an Arduino. This gave me a good idea about what the lights would look like in different lighting conditions and with different colours assigned at a variety of intensities.

During the initial prototyping phase, I searched for a reliable source for the weather information I planned to use as the prototypes' dataset. There were many options, each having particular limitations. After researching the variety of offerings by each API provider, I decided that forecast.io would be my project's best option: it offered a thousand free API calls per day, more than I required to maintain up-to-date information for each hour throughout the day.

Prototyping: EXOSPECTRA

For this thesis, I developed and compared two information visualisation device prototypes: EXOSPECTRA Circle and EXOSPECTRA Cube. The devices created, coalesce the principles of calm technology and information visualisation (Infoviz), both outlined above in order to explore ways to increase the information fidelity—in this case, about the weather—of a device designed using calm technology principles.

The chosen name, EXOSPECTRA (outside spectrums) was selected to emphasize that the devices are representing external information within the user's space. The inclusion of the spectrum reference is to highlight the variety of combination of hue's that the devices are able to represent. This also thematically

ties into the the fact the devices are representing weather properties visually, something that we are familiar with by looking at the natural spectra of the sky.

Each prototype applies Infoviz principles differently. EXOSPECTRA Circle reflects upon radial techniques, such as pie charts and sunburst charts, whereas EXOSPECTRA Cube reflects upon the information visualisation techniques possible with a 2D grid matrix, specifically: histograms, heat maps and even basic pixel art-like representations. Each device went through two iterations of development, with time devoted in between for reflection and further development of the concepts to better meet the goals. Finally, I compared user observations of each prototype in the context of the Infoviz and calm technology principles. The axes of comparison are: the device's effectiveness in terms of being informative while not distracting; its ability to gain the user's attention when important; and the degree to which it is otherwise ambient, remaining in the user's periphery. The exploration begins with EXOSPECTRA Circle.

Prototype A: EXOSPECTRA Circle

Figure 11 - EXOSPECTRA Circle In-Situ

Description

I began developing the first prototype, EXOSPECTRA Circle, using, as the name
suggests, a circle as its base shape. The motivation for using a circle was to
mimic one of the Western culture's most familiar forms of calm technology, the
analogue clock. I wanted to provide a platform for exploration that built on the
comfort people have with "reading" (gaining information from) a round, 12-hour
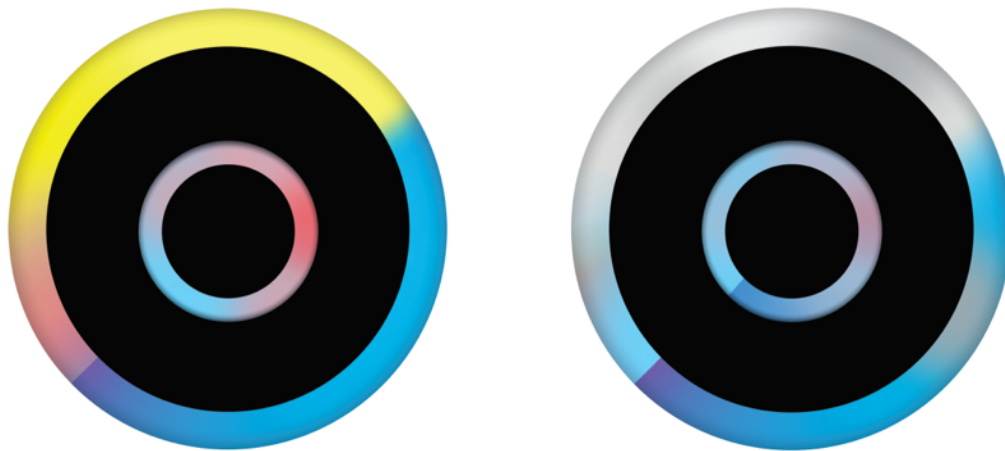clock.

Figure 12 - EXOSPECTRA Circle, Summer Day (left), Winter Day (right) Example.

By providing weather information within the familiar organization of a clock, I
hoped that users would easily and comfortably come to "read" weather
information in relation to time of the day. In the context of weather, a circle also
made sense, in that the circular form was often present in the analogue versions
of domestic barometers and hydrometers, usually as dials contained within a
circular enclosure. Even prior to these relatively modern devices, the circle was

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used as the form for many sun dials.

A ring of LED lights, mounted on EXOSPECTRA Circle's back surface, emits light around the device's circumference and illuminates the white wall or other mounting surface (room divider, etc.). I chose to mount the lights to be seen in reflection rather than directly in order to create a soft, calming, ambient effect. The specific hues and behaviours (pulsing, flashing, or flickering) of the LED-generated light represent weather conditions for the current hour and the next eleven hours.
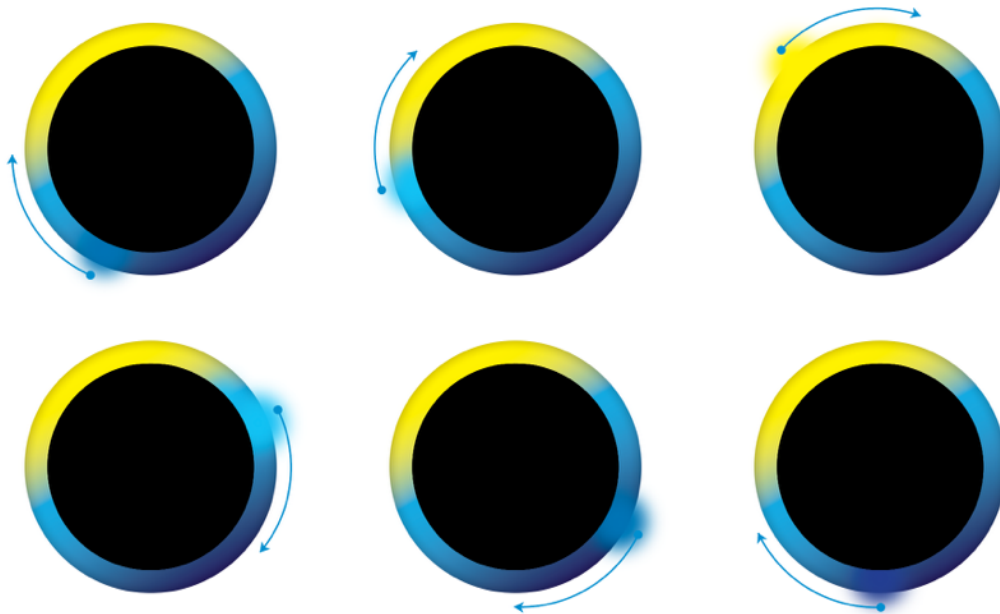

Figure 13 - Sweep motion that indicates current time.

Current time is indicated by the starting position of a sweep animation, where the LEDs gently pulse their light in sequence around the circle and briefly stop at the original start position, indicating the current hour, the effect then repeats (see

Figure 13). The sweep itself is inspired by a Doppler radar sweep, an effect often seen in TV newscast weather reports. Representationally, and I believed, very intuitively, the clockwise sweeping motion indicates the passage of time.

Precipitation is one of the conditions the device is encoded to communicate information about. It is represented by pulsing light intensity, with the speed of the pulse indicating the percentage chance of precipitation. LED colours change to represent different weather conditions such as rainstorms, thunderstorms, clear skies, and snow. Temperature, too, is represented by a colour gradient. A more detailed look at the visuals used can be seen below (Figure 14).

Mapping weather conditions over the familiar 12-hour clock face allows for quick associations between conditions and the time that they are occurring, as most people know the position of the 12 hour markings of a clock.

Figure 14 - Sample of changing colours throughout the day. See Appendix A for full diagram.

Iteration 1

Figure 15 - Mockup of EXOSPECTRA Circle Iteration 1

After designing the virtual prototype during the production research phase, the next step was to design the hardware system and assemble the electronics. For the initial iteration, the device is attached to a computer, which does all the hard work, such as changing colours and intensities and generating patterns. It is also responsible for fetching up-to-date weather information via the Internet. This all occurs within a Processing sketch, running on the computer, which in turn feeds the updated LED information to the Arduino via serial communication. The Arduino simply updates the LEDs with the new RGB values. The reasoning for this arrangement was to speed up development and allow for rapid prototyping of the visuals before having it all working on the Arduino itself. Debugging and working within the memory restrictions of a low powered micro-controller can be
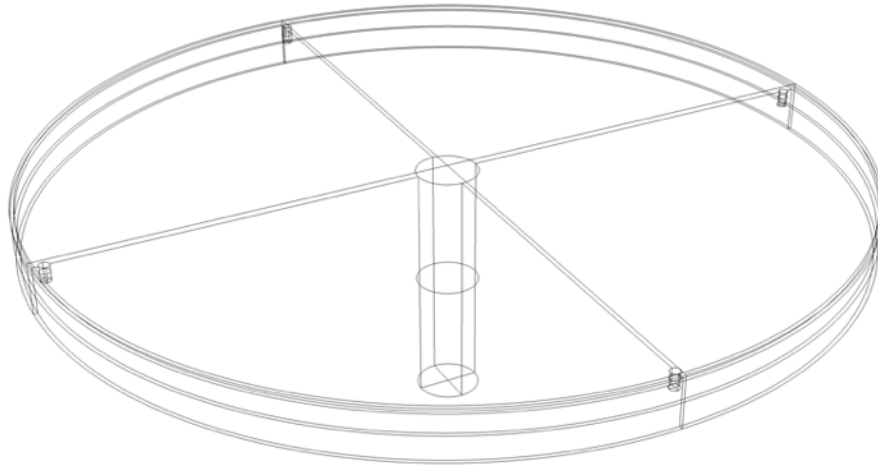
time consuming.

Figure 16 - 3D Model of EXOSPECTRA Circle iteration 1 enclosure.

After establishing the circle as the base of the design, some logistics

needed to be worked out in order to successfully mount the Neopixel LED ring.

The ring used consists of 60 uniquely addressable RGB LEDs. The enclosure

had to accommodate the large ring while maintaining its simple form. The very

simple enclosure in the first prototype provided a jumping off point for the second

iteration.

Reflection

Initially, EXOSPECTRA Circle could only display one weather dataset at a time,

for instance rain, or thunderstorms, or a clear sky. Testing the device in Toronto

made obvious the limitations of this configuration. Conditions about which a Canadian needs information to prepare for the outdoor portions of their day are multifold. Skies may be clear with the sun shining while it is -15° Celsius and in an hour, windy as hell. A sweltering August noontime may lead into a late afternoon rainstorm. It became clear that showing one condition at a time, while somewhat useful, could be radically enhanced by showing more than one together, a representation of the temperature gradient simultaneously with wind and precipitation forecasts, for instance, giving the user a more complete picture.

A second design consideration that became clear with EXOSPECTRA Circle's first iteration was the prototype's dependence on a white wall or surface for reflectivity of the LED lights in all their hues. If a user was to place the EXOSPECTRA Circle on a surface of any other coloured surface, the colour balance of the entire device would be off and, in some cases, certain colours would become invisible. With this in mind, and the goal of adding a second layer of data to the visualisation, I began developing the next iteration.

A revised version of the EXOSPECTRA Circle, Iteration 1 was created for the purposes of the defence exhibition, details and design documents for this iteration can be found in Appendix B.

Iteration 2

Figure 17 - EXOSPECTRA Circle Iteration 2 Mockup

Adding a 2nd ring of LEDs to represent temperature required some significant

rethinking of the design of the structure of the device. Whereas the first version of

EXOSPECTRA Circle was a basic structure that did not conceal its electronic

components, the second iteration of the prototype included design refinements to

neaten this up, such as a hollow support rod to allow wires to pass concealed

from base to LED ring. A more complicated layout was designed to accommodate

a second ring of LEDs and their connections to the Arduino, these

accommodations had to be designed around the structural limitations of 3D printing with a FFF approach, so the device was now designed to be broken up into strategically planned, interconnected layers. A large white reflector panel was added to the rear of the device in order to mitigate the reliance of a wall surface for the back reflection. In addition to this, I incorporate a smaller reflector on the front side of the base, providing a reflective surface for the smaller, inner circle of LED's.
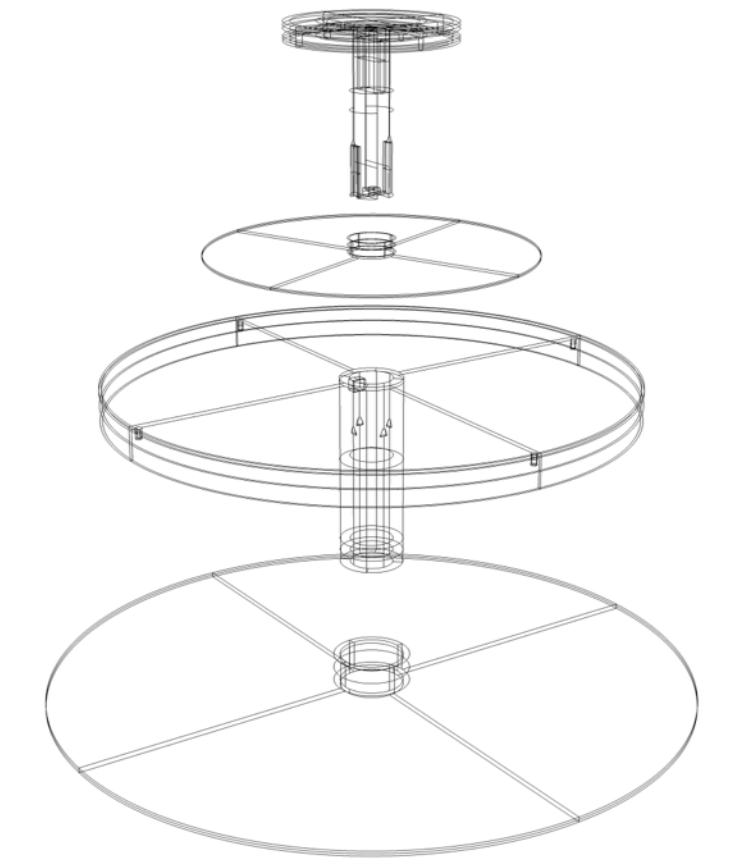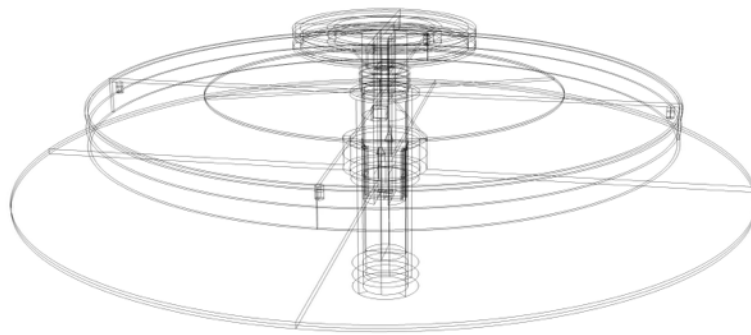

Figure 18 - EXOSPECTRA Circle, Iteration 2, Parts

Figure 19 - 3D Model, EXOSPECTRA Circle, Iteration 2, Complete

Reflections

The addition of the second ring of lights, allowed for encoding of two separate data sets simultaneously – in this case temperature and weather conditions. Delegating the inner ring to the temperature gradient seemed to make the most sense, as temperatures usually shits less dramatically throughout the day when compared to weather conditions which in some areas can change rather rapidly as in the case of torrential rain in tropical climates. Having less individual points of lights, due to less LEDs, the information fidelity of the inner ring is less that of the outer ring which has 60 LEDs, allowing for more points of data to be plotted.
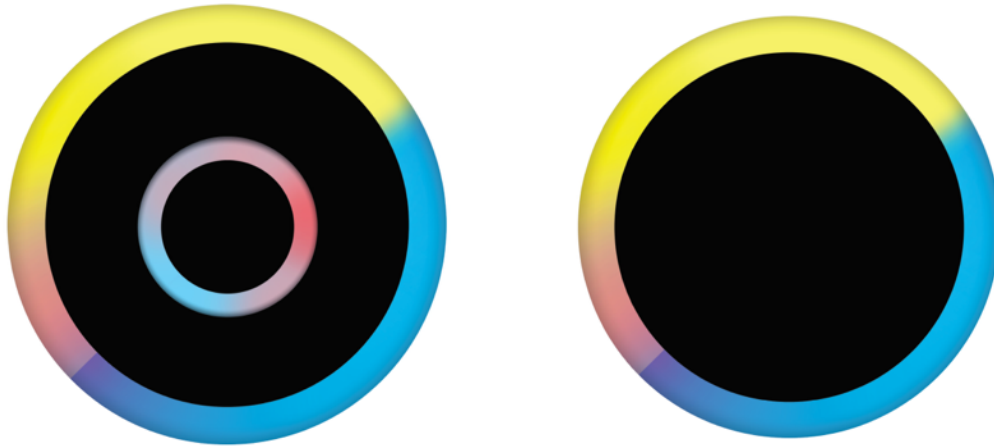
Figure 20 - EXOSPECTRA Circle Iteration 2 vx 1 Comparison

By changing the number of LEDs that are grouped together in the visualisation,
the fidelity of the information visualized can be adjusted. More LEDs grouped
together, less information fidelity; less LEDs grouped together, greater
information fidelity. This grouping of LEDs and the subsequent changes in
degree of information fidelity can be dynamically changed on-the-fly depending
on the current goal of the device and in balancing its ambient nature with being
informative. This provides a practical way to shift the nature of the visualisation in
order to suite the context.

Prototype B: EXOSPECTRA Cube

Figure 21 - EXOSPECTRA Cube, In-Situ

Description

The second prototype, named EXOSPECTRA Cube, was designed to facilitate comparison to the EXOSPECTRA Circle. Departing from a circular shape, this prototype uses a square as its base shape. The visuals are produced by a matrix of 64 individually addressable RGB LEDs. They are placed behind a diffuser that softens their light and generates more consistent colours. The device is intended to be placed on a surface, such as a kitchen counter, desk or bedside table. It is intended to be positioned closer to the user when compared to the wall-mounted EXOSPECTRA Circle.

The square grid configuration provides a two-axis coordinate system to facilitate a variety of different visualisation techniques that EXOSPECTRA Circle was unable to achieve with its circular design. The coordinate system allowed me to plot information along the two axes, such as with line charts and histograms. While these shapes, arguably, are not organic or ambient, they are ideal for representing changing values, and are at least somewhat familiar to most adults. Another great quality of the grid configuration is that it opens up the possibility of displaying basic images or sprites. This seemed like a perfect opportunity to develop some representational pixel-art.

The visuals explored can be seen within the breakdown of visual language in appendix A.
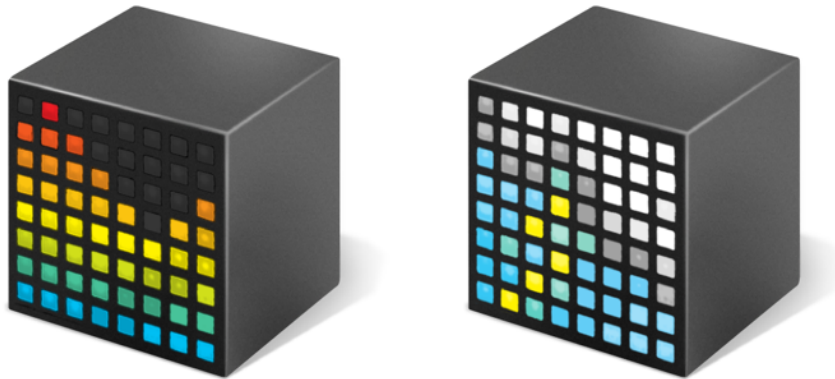
Iteration 1

Figure 22 - EXOSPECTRA Cube Iteration 1 Mockup

Production of the EXOSPECTRA Cube began with the goal of making a table-top friendly version of an ambient visualisation device comparison to the wall-hanging EXOSPECTRA Circle. Whereas the EXOSPECTRA Circle was designed around the format of a circular wall-mounted clock, the EXOSPECTRA Cube was designed, for intended contrast, using a square base form and a grid LED configuration. This design afforded me a different set of available information visualisation techniques than the first prototype.

Modifying the initial Processing sketch provided a quick way to start development of the visuals. However, since the LED configuration was different, the colour patterns and logic applied to the EXOSPECTRA Circle would not translate to the cubic form. Without the circular, clock-like shape, I excluded a time marker from this prototype. With this prototype, I would have users find out

the time through any of the other ubiquitous means in their environment. Not relying on the circular format with time awareness built in, forced me to rethink ways for the device to represent current weather and upcoming weather forecasts.

Two potential approaches stood out early in the development, both influenced by the form of the LED configuration. Having a 2 axis coordinate system allowed for graphing of information into organized columns and rows. Although not the most exciting method of visualizing information, graphs have been used for decades to illustrate data, especially in demonstrating progressive changes in values. The second approach that this LED configuration facilitates is that of communicating through low resolution pixel art, much like an LCD display but with much lower resolution.
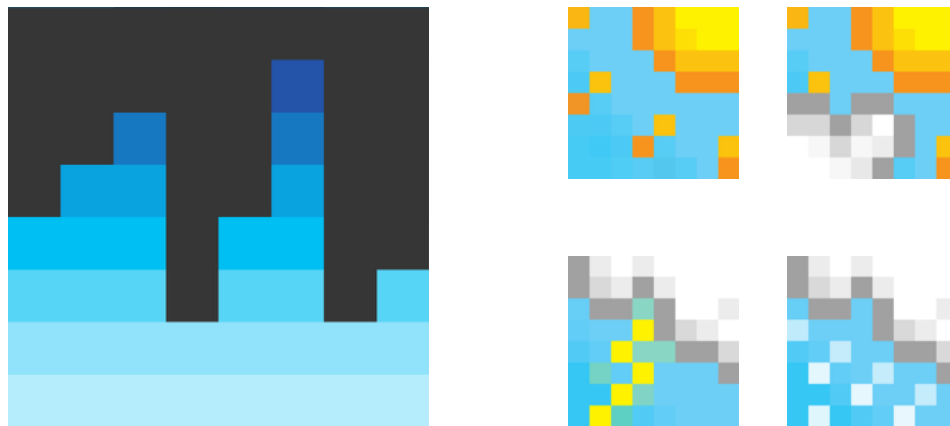

Figure 24 - EXOSPECTRA Cube Iteration 1 Visuals (see Appendix A)

Reflection

Upon reflection of the first iteration and its possible configurations, two major observations arose. Firstly, the use of histograms, in the bar chart approach, seemed overly analytical in the context of this project, where the goal is to convey information calmly and "glanceably" The visuals lacked an ambient quality. I tried a design to communicate through pixel-art representations. While I found these images were indeed more ambient in nature compared to the histogram chart, they could only represent only one data point at a time, for instance, the current weather condition. They were less informative since they lacked the ability to provide an hourly forecast. Since this thesis explores ways in which techniques of information visualisation can enhance information fidelity within calm technologies, and this iteration of the prototype limited it, I needed to find a different approach.

The second observation was that neither approach taken with EXOSPECTRA Cube addressed one of the principles of calm technology, that of facilitating "locatedness," situating the user within the data stream so that they have a sense of what has passed and what will come. With these observations, the direction for the next iteration came to be.

Iteration 2

Figure 25 - EXOSPECTRA Cube Iteration 2 Mockup

The second iteration of EXOSPECTRA Cube began with the goals of encoding more information into its visualisation while providing a more ambient visual experience than that of the very literal approaches in the first iteration. I achieved this in two ways. First, I applied the Infoviz heat map technique. Heat map data visualisation allows for the plotting of numerical values over a 2D coordinate system. The numerical values are represented by colour gradients. Second, I included a method for the user to interact with the device. By adding a simple capacitive touch circuit, I created a mechanism by which the user could touch the top of the cube to cycle through various layers of the weather forecast information. For example, one touch might switch the display from visualizing temperature gradients to displaying degrees of precipitation.

Figure 26 - EXOSPECTRA Cube Iteration 2 Heat Maps

This iteration works as follows: The device acquires its geographical location via the Wi-Fi it is connected to. A heat map of the current geographical area is downloaded from an online resource, such as the weather channel. This map is scaled and reduced to the 64-pixel resolution of the cubes display. With the centre of the cube being the user's current position, the heat map is then projected on the surrounding space by the LEDs. The familiar arrangement of the cardinal directions of a compass is used: the top of the cube is north, the bottom is south, left side is west and the right side is east. This provides reference points for the visualized weather and its direction. The heat map for each dataset (temperature, precipitation and cloud cover) is represented by unique colour gradient, so that the user quickly understands which weather condition is being represented. The user can switch among the visualized information by tapping the cube's top, thereby activating a capacitive touch sensor located beneath the surface of the top of the cube. Should an extreme weather event occur, EXOSPECTRA Cube will switch itself to the most relevant dataset, in an attempt to notify the user. For example, if there is a large thunderstorm approaching the user's location, the device will automatically transition to the precipitation heat map. A more detailed look at the visuals used to encode the information can be seen below in the visual language breakdown (Appendix A).

Figure 27 - EXOSPECTRA Cube Iteration 2 Temperature Heat Map Over Time

Reflection

Although not as precise as the histogram version from the first iteration of the EXOSPECTRA Cube, the second iteration seemed to offer a just-right balance between being ambient and informative. The overlaying of the heat map representation over the user's current geographical location achieved the desired effect of situating the user so they could see the past and future of the information, creating that sense of locatedness. Inviting the simple interaction of a touch helped alleviate problems I faced in trying to encode multiple types of data into a single visual representation.

Figure 28 - EXOSPECTRA Cube Iteration 2, Temperature, Precipitation, Cloud Cover

Comparative Summary of Prototypes

Each prototype, while displaying the same information regarding the current and forecasted weather, does so by different means. Different approaches to information visualisation manifested in unique designs and outcomes. EXOSPECTRA Circle incorporates radial, or sunburst, charts, an Infoviz type

best suited for demonstrating composition (pieces of a whole), in order to display

weather conditions and daily temperature changes around a 12-hour clock-face.

This was made possible by the circular LED rings used. EXOSPECTRA Cube, on

the other hand, utilizes a 2D matrix of LEDs to accommodate its method of

visualisation: a heat map or choropleth map, a method best suited to represent

changes in values mapped over a 2D coordinate system, such as a geographical

map. EXOSPECTRA Cube maps weather information not against a clock face,

but rather, against the also-familiar orientations of the compass: north, south,

east and west. It calculates the user's position as the centre of the matrix.
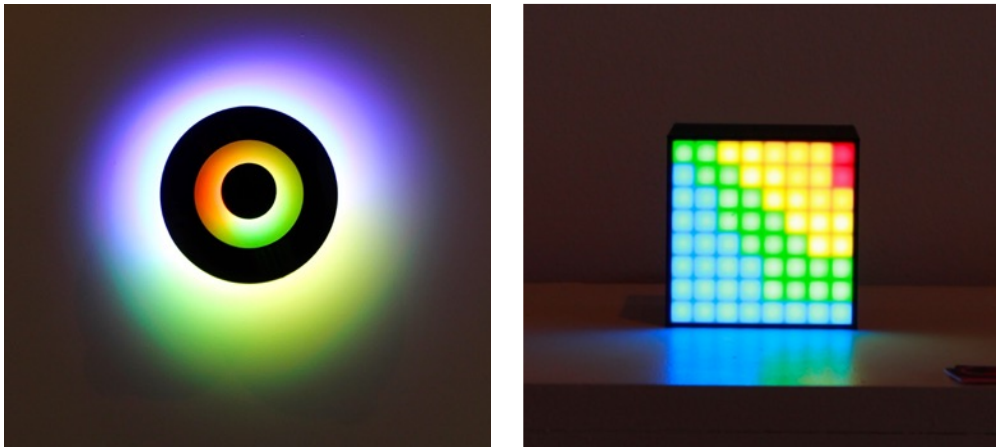
Figure 29 - EXOSPECTRA Circle Vs. EXOSPECTRA Cube, Defence Exhibition

In regard to information fidelity, both devices are able to represent many

data points simultaneously with varying degrees of success. In EXOSPECTRA

Circle, the current time is encoded through the sweeping Doppler-like effect,

letting users know when – visually, where on the circle – the forecast begins.

Within the inner circle of light, the device is able to represent hourly temperature

shifts across a hue gradient, informing the user whether the day will be getting

hotter or colder. The outer circle of light encodes weather conditions by means of

variations in colour intensity, and even in motion in the case of pulsing/flashing

effects. The weather conditions encoded in these visual effects include likelihood,

type and amount of precipitation, be it rain or snow, thunderstorms, clear skies, or

overcast but dry conditions. Overall, EXOSPECTRA Circle is capable of encoding

more information in a single visualisation than EXOSPECTRA Cube.

EXOSPECTRA Cube, on the other hand, is able to separately represent data

across more visualisation types. The cube includes a map for temperature,

another for precipitation, and a third for cloud cover.

        Whereas EXOSPECTRA Circle relies on the familiar clock design to map

other data values against an axis of time, EXOSPECTRA Cube focuses more on

relative location and distance from weather events. Different approaches, both of

these visualizations seem to facilitate the sense of "locatedness" that Brown and

Wieser put forth (1996), being situated within the flow of information.

        Designed to be mounted on a wall or vertical divider, EXOSPECTRA

Circle has a greater chance of being further out within the user's peripheral space

than EXOSPECTRA Cube, which sits on a desk or table, nearer the user's focal

point. In order for EXOSPECTRA Circle to direct the user's attention to particular

information, light effects were used, such as flashing or pulsing. This effect may

arguably be distracting and stress-inducing to the user. As such, a method of

user interaction may be necessary, so the person can acknowledge receipt of the

notification, and mute the visual effects. EXOSPECTRA Cube's effects more

subtly convey important information and signal for the user's momentary direct

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attention. It smoothly transitions to the appropriate visualisation so that at the next glance, the user is made aware of the information, for example, that a thunderstorm is approaching.

The different approaches led to EXOSPECTRA Circle being designed and built as a less abstract, more precise tool for visualisation than EXOSPECTRA Cube. Its method of acquiring the user's attention reduces its "calmness." EXOSPECTRA Cube is the more abstract of the two, and less precise. It does a better job at remaining "calmly" in the user's periphery, even when calling attention to a new piece of information.

The prototyping process was invaluable as I strove to deepen my understanding of Infovis and calm technology design principles, and identify and overcome some of the challenges of designing calm yet highly informative devices. Diving head first into creating the prototypes allowed me and test users to make practical observations right from the start. Each iteration and prototype resulted from and in my clearer insight into employing information visualisation techniques to enhance information fidelity within light-based calm technologies while maintaining their "calm" effect.

Chapter 4: Findings

For this thesis, a preliminary exploration into how the concepts and techniques of information visualisation can be applied to calm technology devices in order to enhance their information fidelity, I used a framing process of rapid prototyping, reflection and iteration. Far from an empirical process under lab conditions, this may have mimicked a consumer tech company's' product development process, and provided some valuable insights into the concepts and ideas explored.

Light and Colour as a Medium for Calm Technology

The usage of light and colour as the primary method of representation proved to be effective. The wide variety of colour choices available accommodated the various nuances of the information being represented. That said, one of the obvious limitations of using colour and light as the means of communication is that not everyone has the same ability to interpret colours, particularly those who suffer from colour-blindness or full blindness. There are potential design interventions that can mitigate this in the case of colour-blindness, for example, using certain colour gradients and avoiding others such as the green-red gradient. This, however, is beyond the scope of this thesis.

Colour palettes chosen to represent the information should be selected with respect and adherence to cultural norms. By referencing existing colour palettes used by weather representations in western culture, I was able to use familiar gradients that didn't require excessive learning on part of the user. It helped make the visualizations as intuitive as possible to interpret. While cultural

variation of colour representation was not within the scope of this thesis,

culturally appropriate colour palettes could be offered through changes in

software implemented in devices available in various regions.

The Use of Motion/Animation as an Indicator

During the prototyping process, it became clear to me that motion, or animation,

can play a key role in the balance between a non-intrusive design and a

distracting one. The Doppler sweep effect within the EXOSPECTRA Circle

prototype illustrated this effect: I found that if the motion was paced too quickly,

the device lost its ambience and became more of a distraction when in the user's

focal point. Slowing the effect down, making it subtler, predictably made the

device less distracting, and allowing it to more "calm" and in the periphery. This is

in line with my foundation research into how our biology is adapted to focus our

attention best to moving objects in our periphery.

The use of effects such as flashing and pulsing also gave rise to some

interesting observations. Flashing lights, in the case of thunderstorms, were quite

distracting when observable, however the slow, medium and fast pulse effect of

the degree of precipitation indicator was not nearly as distracting. My thoughts

are that the softer fade is a gradual change that is within the threshold of being

ambient (it does not trip our peripheral attention), whereas in the case of the

sharp, irregular flashes of the thunderstorm, the sudden change in luminance

triggers a refocusing of our attention onto the device. This is not necessarily a

negative attribute; the intention was to be able to notify users of inclement

weather conditions. However, once the user has been notified, it would be best to have a way for the user to acknowledge receipt. Implementing a simple method of interaction to dismiss inclement weather alerts, such as waiving one's hand in front of the device, could be a potential solution. Using luminance effects such as flashing or pulsing to represent values or changes in values should be done with prudence as to not compromise the "calm" nature of the technology being developed.

Enhancing Information Fidelity

By implementing the techniques of information visualisation within the prototypes developed, I made some key observations about information fidelity. Most important would be that the goal of a calm technology device should directly inform the choice of type of data visualisation technique to employ. For example, when aiming to create a more abstract visualisation, as opposed to precise one, certain techniques are more applicable, as was demonstrated in the negative within the EXOSPECTRA Cube prototype, where the usage of histograms proved to detract from the calm nature of the device. The method of visualisation chosen can have a significant impact on the aspects of legibility and ease of interpretation by the user.

To assist the user with interpretation of the visuals, a familiar, pre-existing form can be selected on which to map the visualisation. This also assists in enhancing the fidelity of information, as it provides a structure or axis for the user to plot the information. In some cases, the form itself encodes some of the information. This is demonstrated by the prototypes developed: The

EXOSPECTRA Circle is based around the clock form, which helps users interpret the time at which certain weather conditions will occur; the EXOSPECTRA Cube device uses the familiar, cardinal directions of the compass to allow the user to sense the source and direction of the weather conditions' movement.

When considering the key principles of calm technology as outlined by Wieser and Brown, we can establish the success and failure of the prototypes and information visualisation techniques used:

Technologies encalm as they empower our periphery. This happens in two ways:

-A calming technology may be one that easily moves from centre to the periphery and back.

A key factor into the degree of which the prototypes were successful at this was the difference in the manipulation of colour and luminance to represent changes in data. Sudden changes in luminance or extreme changes in colour, proved to be too distracting and in so incongruent with this principle of calm technology. Slower animations such as pulsing, proved to be non-interruptive yet informative, allowing for easier shifting in to the periphery.

-The Technology may enhance our peripheral reach by bringing in more details into the periphery and in doing so, create a sense of "locatedness".

The type of data visualisation used to convey the information in the prototypes and have a bigger role in the success or failure of the devices being able to enrich the periphery. Histograms seem to require extra attention while the user is trying to interpret the data being represented. The use of familiar

organization of information, such as the use of the clock face in EXOSPECTRA

Circle with use of the cardinal directions in EXOSPECTRA Cube, seems to

greatly promote interpretation.

Both of these designs contribute to situating the user within the flow of

information creating a sense of "locatedness," which I consider to provide an

extra layer of information fidelity.

Chapter 5: Conclusions

This thesis demonstrates how the application of information visualisation techniques on calm technologies could help enhance the information fidelity of the technology, and in so doing, amplify the "calm" aspects of these devices while making them more practical.

Through explorative prototyping, comparison and reflection of two devices, EXOSPECTRA Circle and EXOSPECTRA Cube, which I designed applying the principles of information visualisation and calm technology, I was able to explore the ways in which colour, light and light in motion can play a potentially significant role in the representation of information within our living and working environments. The exploration gave just a glimpse into the ways the principles can complement each other and in many ways, when used appropriately, can augment each other. Most importantly, I was able to observe ways in which the principles of information visualisation can, indeed, enhance information fidelity within light-based calm technologies. Key findings include:

- The type of data visualisation techniques used can have an impact on ambience of calm devices. More analytical techniques, such as histograms, seem to be less ambient than that of heat maps or radial graphs.
- Light and Colour are effective means of representing information in a user's space, that being said, due to a variety of vision impairments existing in individuals, it is not always a viable option.
- Special consideration must be given to lighting effects. Sudden changes in hue or luminosity can prove to be distracting. However, slower, gradual

lighting effects can be effective status indicators while not being
interruptive, maintaining the "calm" nature of the device.

Further Research

An immediate next step following this thesis would be formal user testing. Ideally,
each prototype would be put through several phases of user testing, with the
researcher collecting data on, analyzing and comparing the subjective
experiences of quite a number of participants. One major area of focus would be
the relative ease of interpretation of the visuals by participants. Another area of
testing would be the degree to which the devices are found to be distracting or
interruptive. In-situ testing would be ideal, with the final iterations of each
prototype being placed in the users' homes or workplaces for a week or more to
gain a greater understanding of the effects each has in a user's familiar
environments. Of particular encouragement for product development would be a
noted uptake in users' awareness of the dataset being visualized when having
the device present than when they sought such information through other means.
Other signs of potential marketability would be if users seem to enjoy
experiencing the devices' ambient presence, and if they feel reassured, rather
than stressed or irritated, by those occasions when the device called attention to
itself to convey significant changes in the weather. I am sure that, through such
testing, many refinements could be made to the design, bringing one or the other

of the prototypes closer to achieving high information fidelity within a highly calm device.

Due to time limitations, only two devices were prototyped. There are many more physical forms that can be explored and data visualisation types to incorporate for comparative analysis. This is something that additional research could, and probably should, address. These additional iterations could perhaps better explore some of the concerns not addressed within the scope of the thesis as it currently stands. Two main limitations I would hope to address with further research are: How can the design of these devices and visualizations in general account for the variety between individuals visual perception, such as in the case of being colour blind? The second area for a potentially large chunk of research could be done into devices of this nature that explore more than just our sense of sight. The sense of hearing and touch could prove to be viable candidates for calm technologies to engage users through.

Further development of the current prototypes could also include a more finalized version of the software that runs each device. Development of a user-friendly front end would be a top priority, followed by the ability to represent or customized visualisation of different types of data, such as stocks, calendar notifications, and fitness tracker activity. When different types of data are applied to these types of devices, it becomes clear that their practicality could be extended into many other applications. This is the most exciting aspect of the future research I hope to explore.

The Future

As the potential problem of information overload becomes more apparent with each new mass-used technology, the need for design interventions becomes more urgent. The principles of calm technology should be considered when designing for the future. Not every new device needs to be "calm," but more of them should be. Likewise, as calm technology devices become more ubiquitous, it is important to identify ways in which they can be made highly informative while maintaining their calm effect. The application of information visualisation techniques within light-based calm technologies could help make that a reality.

My hope is that more manufactures and designers will incorporate the principles of calm technology into their information visualisation products, so that we will eventually live in a world full of aesthetically pleasing, non-disruptive, easy-to-interpret information in our surroundings. Lowering reliance on user-initiated programs and devices for information and help, the consumer technology industry can ease the stresses of technology-related stress and information overload, and at the same time usher in a more universally informed world, where information is available everywhere and to all.

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Appendix A - Visual Language Breakdown

Clear Sky, Sun is out.

Rain in the afternoon.

Dawn

Current time, 7am -dawn

11 hours into the future

Dusk

Clear Sky, Sun is out.

Rain in the afternoon.

Warmer in the afternoon

Dawn

Current time, 7am -dawn

Cooler in the evening

11 hours into the future

Dusk
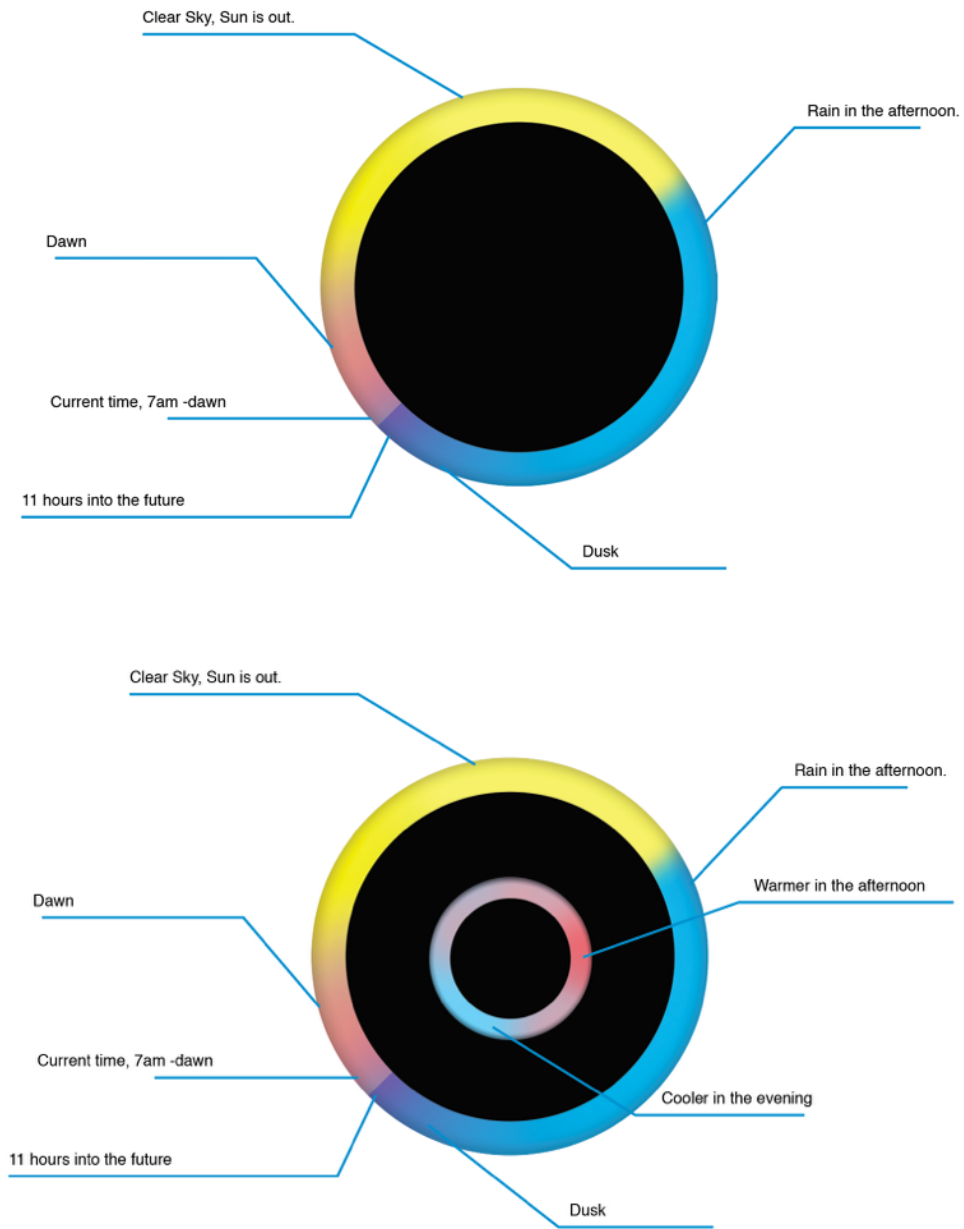
Figure 30 - EXOSPECTRA Circle V1, V2 - Visual Breakdown

Current Time: 7PM
11 Hours Ahead

Current Time: 7AM
11 Hours Ahead
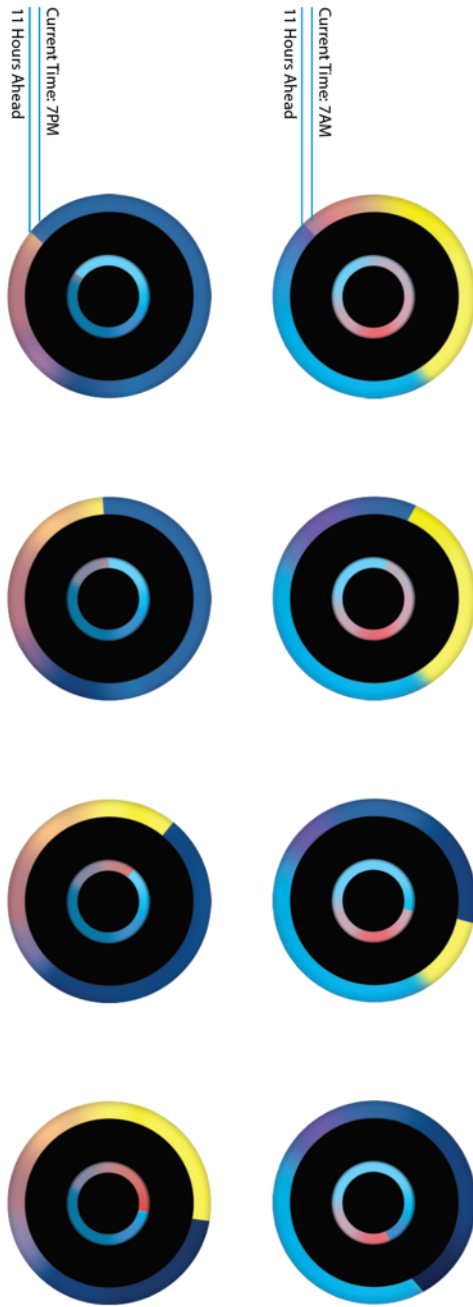
Figure 31 - EXOSPECTRA Circle 2.0, Daily Transitions

Temperature
Histogram
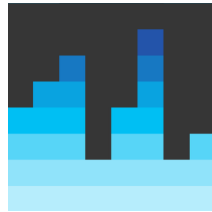
Precipitation
Histogram
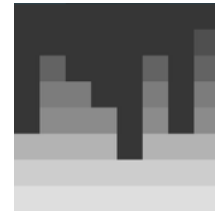
Cloud Cover
Histogram

"Sunny"
Icon

"Partly Cloudy"
Icon

"Overcast"
Icon

"Raining"
Icon

"Lightning Storm"
Icon

"Snow"
Icon

Figure 32 - EXOSPECTRA Cube, Visuals

Appendix B - Exhibition and Install Materials
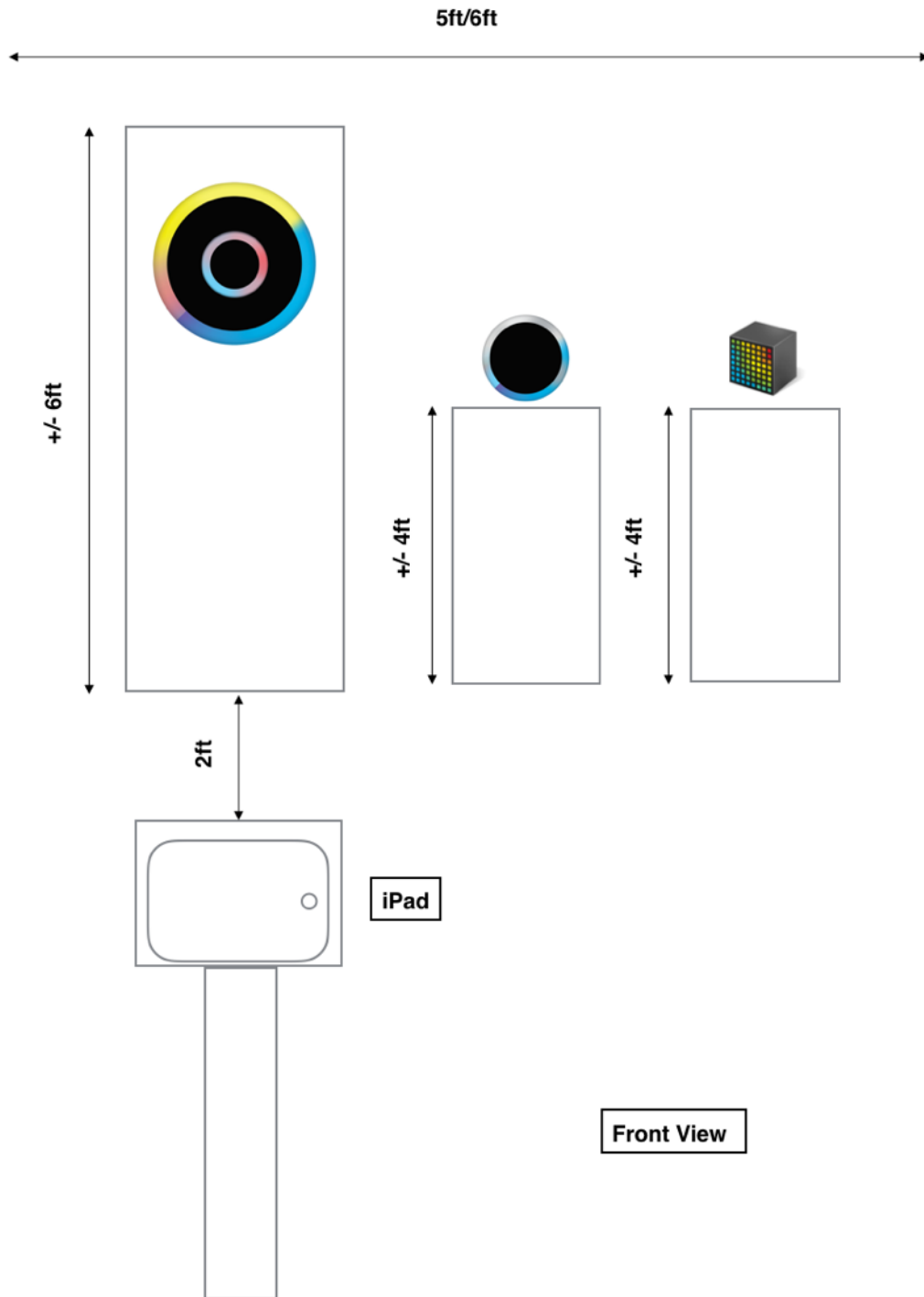
Figure 33 - Exhibition Plan, Front view
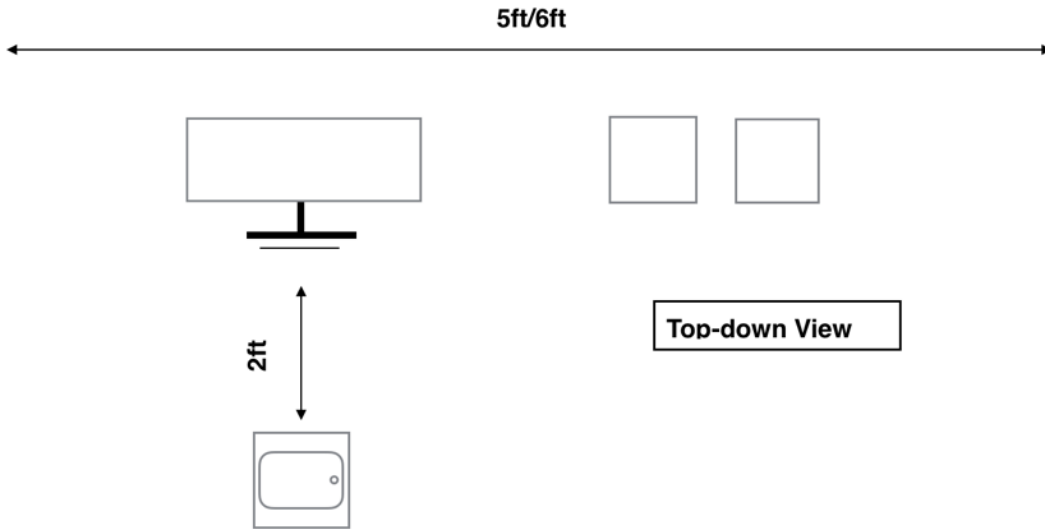
Figure 34 - Exhibition Plan, Top-down view
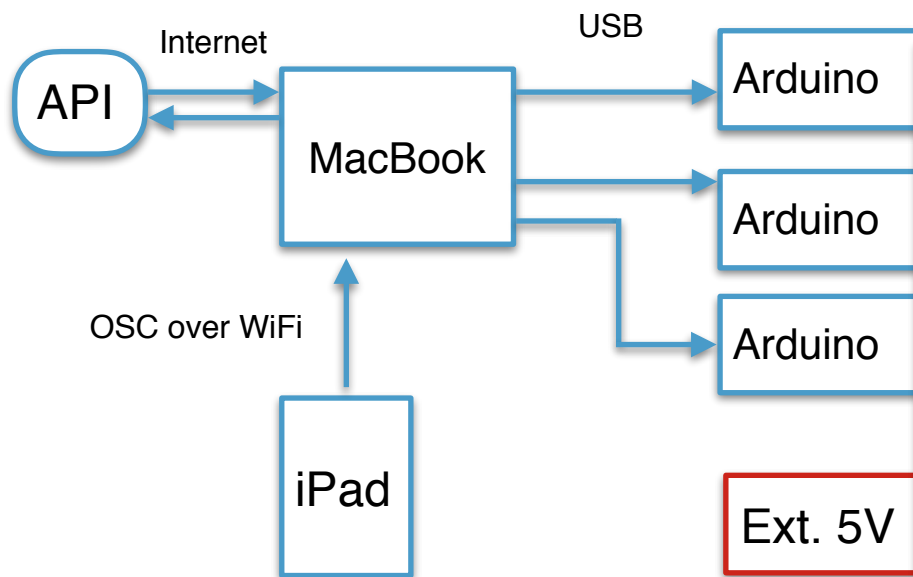
Figure 35 - Exhibition system diagram

Figure 36- Exhibition
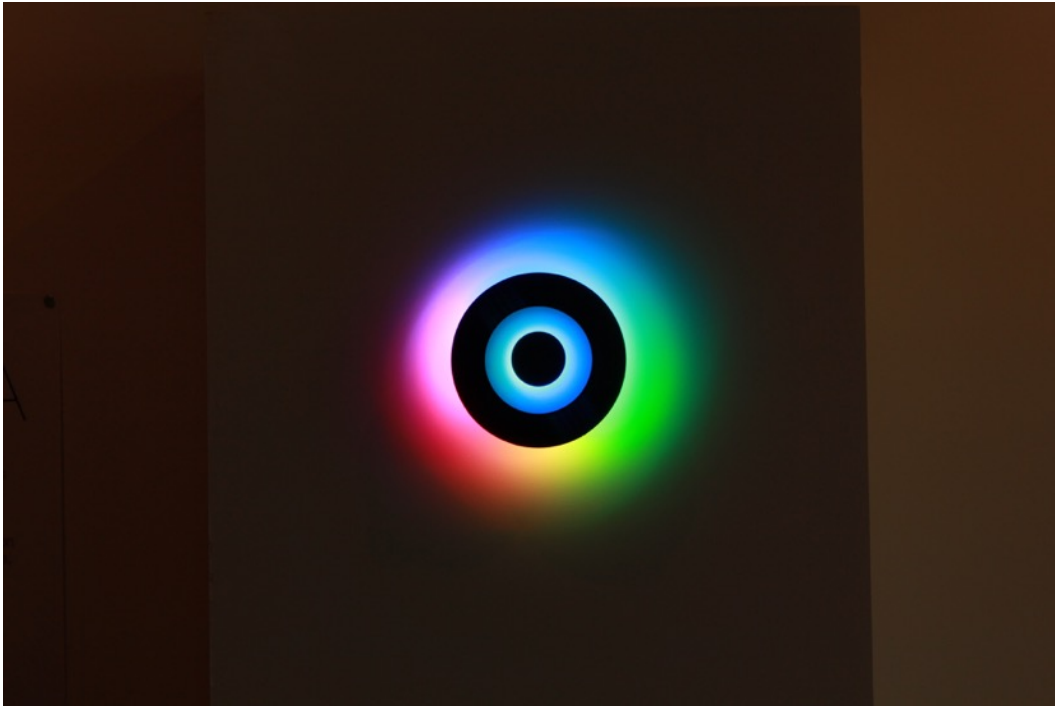
Figure 37 - EXOSPECTRA Circle 2.0 at Exhibition.
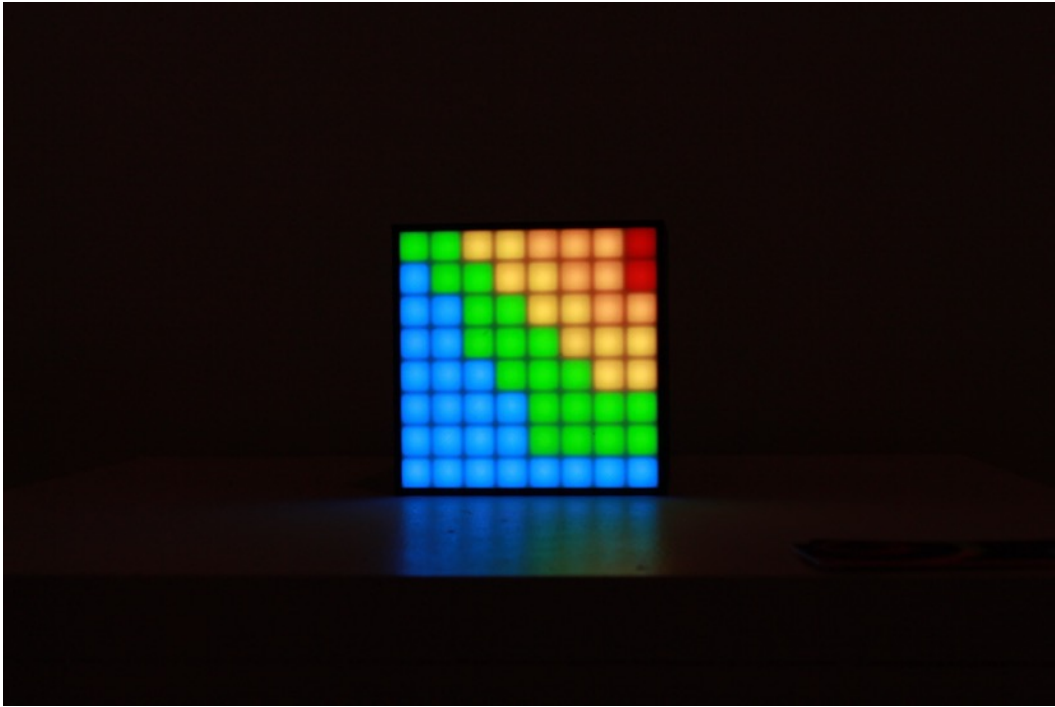
Figure 38 - EXOSPECTRA Cube at Exhibition

Figure 39 - EXOSPECTRA Circle 1.0 Revised at Exhibition

Redesign of EXOSPECTRA Circle for Defence Exhibition

For the purpose of demonstration, a more compact version of the first iteration of EXOSPECTRA Circle was designed and fabricated. The form allowed for a more side-by-side, visual comparison of the two smaller prototypes while the larger, more complete, second version of the Circle could be presented with greater emphasis. The design incorporated elements from the larger Circle based versions. I was able to reuse parts by tweaking their design for the smaller form. In order to house the Arduino, a body was created with an angular shape.

Reflector

LED Concealer

Main Body
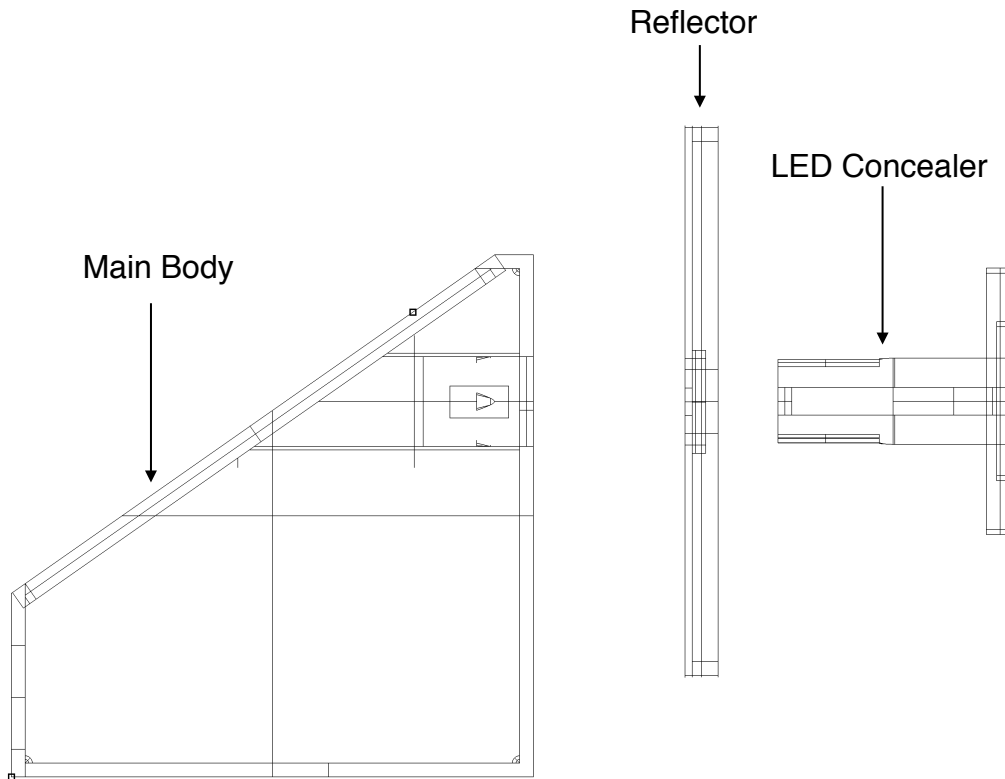
Figure 39 - EXOSPECTRA Circle 1.0 Revised Design diagram (side)
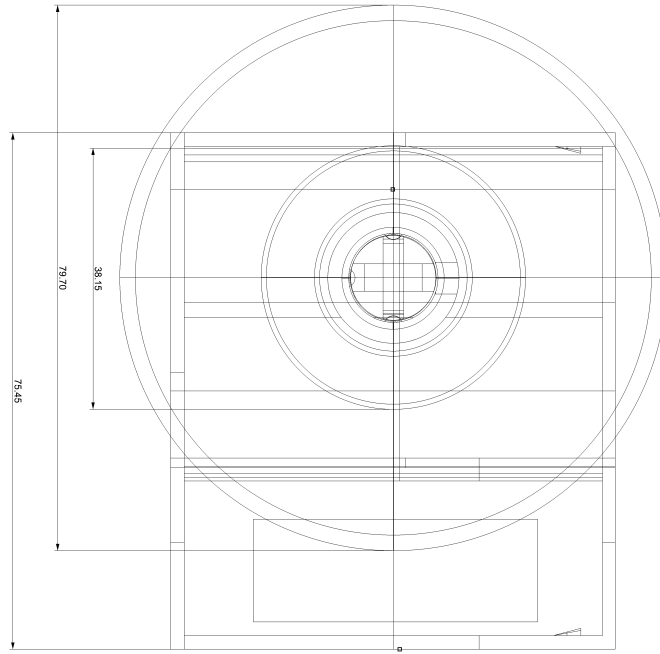
Figure 40 - EXOSPECTRA Circle 1.0 Revised Design diagram (front)

Figure 41 - EXOSPECTRA Circle 1.0 Revised Design

**Information Posters from Defence Installation**

Figure 42 - EXOSPECTRA Poster

EXOSPECTRA
cube

This prototype explores ways in which a 2D grid can be used to visualize weather forecast. In particular, iterations involved using histogram charts as well as pixel art.

Later iterations use a heat map visualization technique that provides an overlay of the surrounding weather properties in relation to the geographic location of the user.

The final version includes a touch sensor that allows the user to switch between different modes.
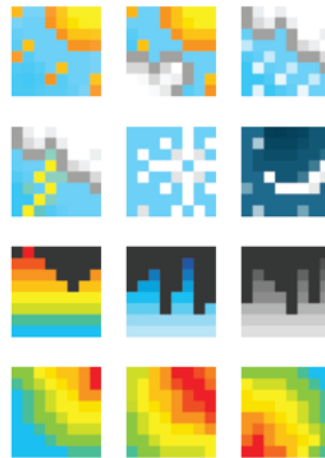
Representational pixel art, graphs and heat map iterations

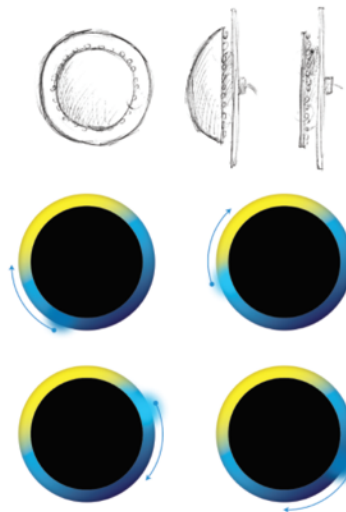*Three modes: temperature, precipitation and cloud coverage*

Switch modes by touch

User location in the center

Colour gradients indicates changes in values
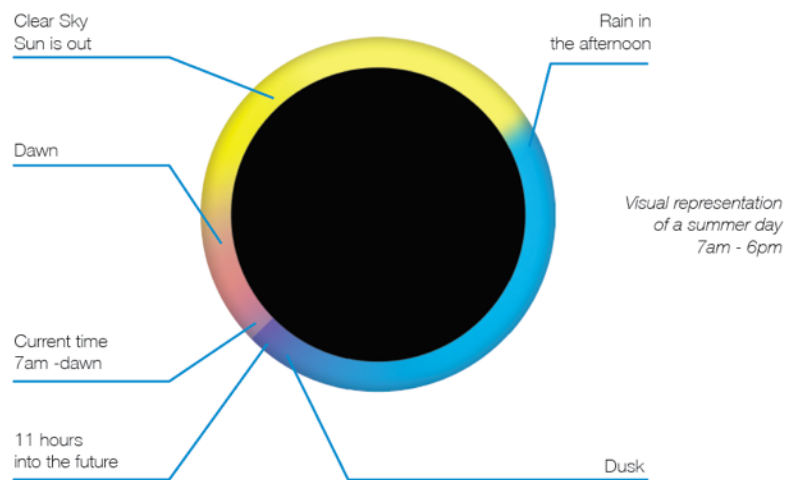
Visual representation of surrounding weather
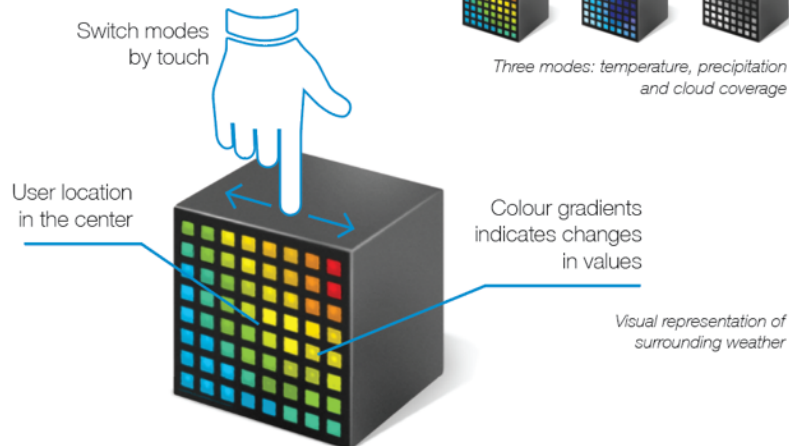
Figure 43 - EXOSPECTRA Poster

Figure 44 - EXOSPECTRA Poster