The Timestreams Platform: Artist Mediated Participatory Sensing for Environmental Discourse

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ABSTRACT

Ubiquitous and pervasive computing techniques have been used to inform discourses around climate change and energy insecurity, traditionally through data capture and representation for scientists, policy makers and the public. Research into re-engaging the public with sustainability and climate change issues reveals the significance of emotional and personal engagement alongside locally meaningful, globally-relevant and data-informed climate messaging for the public. New ubiquitous and pervasive computing techniques are emerging to support the next generation of climate change stakeholders, including artists, community practitioners, educators and data hackers, to create scientific data responsive artworks and performances. Grounded in our experiences of community based artistic interventions, we explore the design and deployments of the Timestreams platform, demonstrating usages of ubiquitous and pervasive computing within these new forms of discourse around climate change and energy insecurity.

Author Keywords

ubiquitous computing, artistic engagement, climate change

ACM Classification Keywords

H.3.5 [Online Information Services]; H.3.2 [Information Storage]; J.5 [Arts and Humanities]

General Terms

Design, Experimentation, Human Factors, Measurement

INTRODUCTION

Although the risks related to energy and climate change are as great as ever, a wide range of causes are seen to impact on societal interests [29, 30, 4]. There is also, however, a general degree of public apathy which initially was believed to arise from low levels of scientific comprehension by the public [18]. Kahan et al. found no support for this belief.

Instead, they found that those members of the public with the highest levels of scientific and technical literacy have little concern for climate change. Amongst these factors cultural conformance (conforming one's beliefs to those prevalent in one's group) is seen as a factor governing behaviours in these matters. People tend towards beliefs that maintain healthy peer relations over those that benefit the environment. Alongside this, media, reporting often through an emphasis on fear and threat [27], a lack of access to information that explains the complexity of climate change and sustainability [4], and a broader need for a local and personal connection to this information [32] can also contribute to public disengagement. Working with communities, through data-rich art and citizen science activities and interventions is increasingly being seen as a positive contribution to tackling energy and climate change issues [28, 23, 22].

Our project team formed as an interdisciplinary collaboration between artists, scientists, technologists, communities and researchers to investigate these issues, reach communities, and engage them in culturally-meaningful ways. As a research tool, we have designed and deployed Timestreams[1], a self-service platform capable of local disconnected operation and global cloud logging. The platform provides capabilities to sense, monitor, interpret, represent and then *perform* [33] time-series data through various artistic forms.

In this paper we report on the technical platform and case studies from events for artists and hackers. Our findings offer views into the expansion of the pervasive computing vision to encompass playful forms of collection and *performance* of data.

RELATED WORK

Previous work shows that research into novel forms of climate change and energy use communication are urgently required for diverse and remote communities, and that

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[1] The term Timestreams is primarily used throughout to describe the platform, however, it is also used in places to describe views into time-series data streams that are central to the service that the platform offers

ubiquitous computing platforms need to be developed to facilitate this communication through data collection, visualisation and interpretation [17, 2, 14].

Ubiquitous computing technologies, such as sensors and crowdsourcing data regarding climate change issues and sustainability have been developed for scientific analysis or physical system monitoring. These technologies have tended to focus on directly providing sensor data to researchers [3, 34], or using citizen science principles to provide data collected by volunteers to researchers [19], rather than for artistic performance and interpretation. Although not primarily designed for this purpose, Timestreams has been used to support researcher-oriented data collection in the currently unpublished work, described at the website of [9]. However, the chief purpose of Timestreams is to support various project designs consisting of participatory styles of data collection and analysis from a wide range of types of sensors, for use by non-researcher users of differing technical abilities.

Previous work within sustainable HCI has considered how communities have engaged with artistic interpretations of environmental data, raising questions around the relationships between public engagement, technology and the environment [11] and how the public takes responsibility for interpreting scientific data [1, 10]. Other related work investigates the role of artistic interpretations through *eco-visualisation* [16, 20] and *eco-feedback technology* [12], yet much of this work focuses on behavior change, usability and the display of information and less on how meaningful engagements with the data can be supported [5].

As noted in [19], however, citizen science has been slow to use pervasive computing, with relatively few examples being found that make use of mobile phones, let alone other non-phone based sensors. The main difficulties users have with citizen science platforms, also reported in [19], has to do with the technical skills required to get up and running with existing systems. They attempted to address this by simplifying study authoring, data collection and data management. With Timestreams we similarly tried to simplify these areas, however, we incorporate non-phone based sensors in the collection, and provide more freedom for artists to interpret the data, but require some additional programming.

Another service that provides sensor data to blogs is described in [13], however it focuses exclusively on reporting mobile phone data. Alternative collaborative approaches to sensor data collection and dissemination are described in [8, 31, 24, 35], with key differences between Timestreams and these systems emerging from the ways that communities engage with blogs versus wikis or other social networks.

The importance of maintaining data credibility for such systems, especially when they are to be used primarily for scientific purposes, is highlighted in [6]. They have designed a system presuming always-on networking and continuous access to GPS or cell towers. Timestreams, on the other hand, is designed to support grassroots participation in pervasive computing for gathering data for artistic rather than scientific purposes. As such Timestreams emphasises disconnection survival and simplified data gathering procedures over data provenance.

The value of artistically engaging members of the public with scientific climate data was discussed in [17]. Timestreams was designed in line with the principle highlighted in that paper of promoting dialogue and interpretation around the data rather than informing or persuading users to take a particular view.

Previous works have suggested that artistic domains require alternative approaches to the design and deployment of pervasive or ubiquitous systems than do more traditional ones such as for environmental monitoring or healthcare [7, 11]. A key difference is that the deployment model of artistic pervasive computing requires staged delivery of incompletely specified systems to be operated and critiqued by end users as part of their performance or artefact creation endeavours.

A pervasive artistic framework intended to control multimedia outputs based on sensor data is described in [7]. Our approach differs from theirs in that they presume to have continuous network access, whereas Timestreams was expected to be capable of disconnected operation as well. They also attempt to control multimedia authoring packages such as Max/MSP from within their framework, whereas Timestreams provides an API for use by such authoring packages allowing artists to continue to work in familiar environments. Our approach therefore can have built in support beyond the notion of eco-visualisation [15], enabling artists to create artistic time-series eco-feedback [12] in the physical world, as performative artifacts [25, 26, 36] and immersive environments.

TIMESTREAMS PLATFORM
The Timestreams data publishing platform was designed to
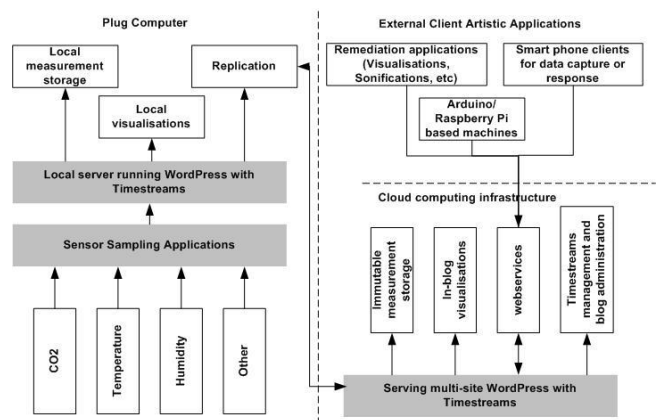
Figure 1. The Timestreams network consisting of plug computer servers, cloud computing infrastructure and external client applications.

help artists interact with communities and school groups to collect, view and respond to local and global data including from environmental sensors and media (such as audio, pictures and text) from fixed locations or in mobile situations. It also facilitates the general public to experience artistic interpretations of the data.

Timestreams is delivered as a plugin that extends the functionality of the WordPress content management system to store, communicate and share data through plugin features and a RESTful API. WordPress was chosen for its large number of users, ease of use, user management, theme support, plugin architecture, and its open source license. We have also attempted to lower the barrier of entry, by placing Timestreams in the familiar context of WordPress, and by building up communities through blogs that can communicate about data collection and visualisation

The Timestreams platform plugin is available as a free and open source download. WordPress is used in two settings for the delivery of Timestreams, pictured in figure 1. Firstly, the Timestreams platform plugin adds functionality for local data capture hubs running WordPress to support mobile sensing and data capture, whether or not they are network connected, and to report this data to a cloud computing-based social platform when network services become available. Secondly, Timestreams is deployed as multi-site WordPress networks in cloud computing resources as the basis for social collaboration amongst federations of communities. The Timestreams platform adds functionality to such WordPress installations for mobile sensing and logging, synchronising mobile instances with external services, displaying and communicating about data, and federating data between communities. Figures 2 and 3 show some functionality extensions to WordPress from the Timestreams platform plugin.

Timestreams explicitly separates and foregrounds three core concepts to the user; reporting or uploading of sensor measurements, manipulation of the playback of these sensor measurements via the Timestreams metaphor, and representation and performance of the measurements in the
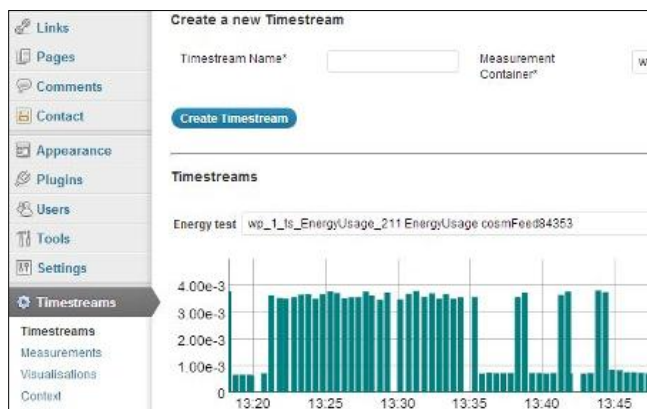
Figure 2. Timestream interface in the WordPress dashboard requires filling in the name and selecting a corresponding measurement container.

form of digital web-based interpretations or physical artefacts.

Measurements can be uploaded into Timestreams from various data sources including sensors, historical data, modeled data, or predicted values. Readings from individual sources are stored in measurement containers, which are defined by the user. In Timestreams we have generalized the notion of a sensor to include traditional sensor devices, such as those for capturing numeric data regarding CO_2 levels, temperature or humidity, as well as those that record images, videos, audio or anecdotal textual accounts or recollections.

Users create measurement containers for each data source that they wish to use (such as a sensor readings or historical records), specifying expected maximum and minimum values, and the form of the data that will be recorded, which automatically creates appropriate storage in the underlying database. Once created, measurements can be uploaded to the measurement container via the Timestreams API.

On top of this sensor measurement uploading and storage system we have developed time-based views of these measurement containers. Such views are known as Timestreams within the platform (from which the platform derives its name). A Timestream is analogous to tape-based playback of data, consisting of a play-head continuously moving through a measurement container and playing out measurements as if they were live. The play-head has a number of configurable behaviours, including the rate at which it moves, looping between specified start and end time, or continuous playback.

The third major component of the Timestreams platform is the support for visualisations (and other media outputs such as sonifications) to create performances of sensor data. A visualisation may take the form of a widget embedded within a Timestreams-installed WordPress blog, a standalone graphical application, or dedicated hardware driving a physical actuator or installation. A Timestream acts as an abstraction of the underlying measurement container, with a visualisation revealing a particular Timestream's time-based playback of the measurements. A visualisation is time independent in that a Timestream play-head appears to continue to move with its configured behaviour regardless of how many identical or different visualisations are connected to it, implementing a data-streaming metaphor.

Artists can create multiple, different Timestreams to modify the display of measurements in a visualisation without having to manipulate a visualisation directly. Through Timestreams controls, such as skipping to different periods of time, or selecting alternative measurement containers, users create relatively generic visualisation widgets that transparently support both the display of live or historic sensor measurements.
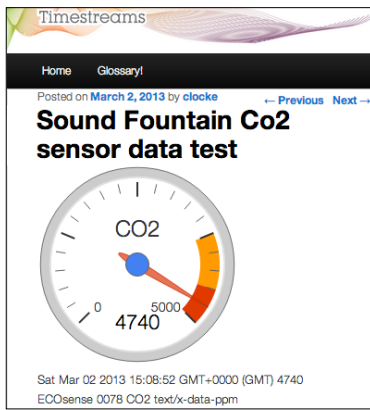
Figure 3. A blog post containing a sample Timestream guage view visualisation created by our team.

Figure 2 shows the interface for creating and manipulating Timestreams. Users name their Timestreams and specify which measurement container the Timestream should play data from. This can be changed at any point to another measurement container that holds similar data – where in this case similarity relates to the kind of measurements that it would make sense for a visualisation to display. The Timestreams interface displays a section of measurements from an underlying measurement container, allowing the user to page through larger data sets, or to zoom in and out to inspect particular measurement trends or periods of time. Users may view media files where relevant. The interface allows the user to set the start and end time of the Timestream if looping behaviour of the play-head is required, to directly manipulate the position of the play-head and to review how it is moving through the measurement container.

The plugin makes significant use of the WordPress user management functionality in order to support the sharing of measurement containers. We run WordPress on cloud servers using multi-site functionality allowing various projects to share the same deployment infrastructure. We developed functionality in the Timestreams plugin to allow project blog users to share their measurement containers with other blogs in the multi-site network. In addition we have developed replication functionality in Timestreams to allow users to share measurement container data between WordPress installations running on independent servers.

The primary mechanism for creating a visualisation of a Timestream is to embed it into a blog post or a page, either with surrounding commentary and with WordPress support for comments and sharing, or as a Timestream page, that strips theme styles and menu items in order to create a plain backdrop for the visualisation. Timestreams provides an interface integrated into the WordPress post authoring system that allows a user to quickly embed a visualisation by way of WordPress short codes, and to connect this visualisation to an existing Timestream. The system provides a library of generic visualisations, including a gauge for displaying numeric measurements that is

automatically configured to the appropriate range specified by the measurement container, and an image viewer for creating a slideshow of image measurements.

These WordPress visualisations are implemented with JavaScript and the D3.js library, however the system also provides a generic JavaScript interface for developing new visualisations. Visualisations, such as the example gauge view shown in figure 3 (developed by our team), poll the Timestreams API regularly in order to receive new measurements according to the current time of the Timestream play-head. Bespoke applications can also query the API over HTTP, enabling the construction of visualisations, for example using Unity or Processing, or that are not embedded within the WordPress blog structure, for example supporting the development of physical actuators built using Arduino.

Timestreams can be installed as a local sensing platform to maintain long-term archives of data for future review and data replication to cloud-based servers. The local sensing platform is made up of small form factor servers (plug computers), and sensors that transmit data to them. For mobile use, the plug computers may be battery powered (such as is illustrated in figure 4).

The plug servers run specially configured WordPress instances with the Timestreams plugin installed. The plugin provides capabilities for sensor data capture and dissemination within WordPress. The plug computers are also configured with sensor drivers to adapt data formats that off-the-shelf sensors may use to relay data.

CASE STUDIES

The following case studies describe how artists and hackers have responded to the Timestreams platform at three separate events that took place during the Relate project: artist residencies on a farm in the Atlantic Forest in Brazil, and at an artist studio in Rio de Janeiro, and a hackday event in Nottingham. The purpose of the events was to assess how individuals from these target groups related to the platform. The event participants were given brief platform training and platform developers were on hand to answer questions and aid with the artists visions in response to the platform.

Figure 4. Mobile server and sensor collecting data in a tree for a short experiment in a Brazilian forest.

Each case study provides a brief description of the event, the participant's persona and background, what they attempted to achieve, a description of the resulting artefact, their insights and challenges in working with Timestreams, and how these inform a set of design implications which will be discussed further in our conclusions. Note that neutral names and random genders are assigned to hide the identities of the participants.

Artist/Hacker living in Brazil (Ali) who worked on climate data driven record player

Event Description
Members of our team were invited to spend one week in residence at Barracao Maravilha, an artist studio and gallery space in Rio de Janeiro. Ali is an artist from Barracao who we introduced to Timestreams.

Participant's Persona and Background
Ali has an existing interest in data, technology and electronics. Ali's background comes from studying sculpture but describes his work as exploring "sound and presence in 3D space". Much of Ali's work has involved hacking electronics and he has some programming knowledge as well.

Participant's Goal
Ali wanted to control a record player using data from the Timestreams. Towards this, Ali reports:

"I imagined the variations (drawings) of data being made visible by an object that could reverberate and make evident the variations into another audio-visual experience. The data varied the frequency, which turned the record player. Translating the data into energy, intensities of rotations and in a very simple way, almost rudimentary the vinyl. I chose a record, The Rite of Spring and placed a needle over it which would play the music according to the rotation, fed by the data."

Resulting Artefact
Ali used Timestreams to access a data set containing historic levels of CO_2 in the Earth's atmosphere since 1970 recorded at Mauna Loa, Hawaii [21]. This data set is one of the key records of CO_2 increases used by climate scientists to model and understand climate change. The data was used to control the playing speed of a record player, shown in figure 5, playing Igor Stravinsky's *The Rite of Spring*, chosen for the season the residency was taking place in.

Ali described the significance of the data in the artwork he created with Timestreams as:

"There is a significance in dealing with important data such as CO2 or Decibels or Humidity etc. How to articulate this thinking within the arts, it's obvious, extreme, the work with the record player allows one to experience exactly that, the scientific data. There is an importance of the data and the opportunity here is to throw these into the campus of art as material. Provoking and perceived in some way, it points to the difficulty of the understanding of data, but transforming it into a poetic construction."

Insights and Challenges
Ali's case study reveals ways that artists played with scientific data as a type of *performance of data*, and exposed some of the ways they attempted to make meanings from data through Timestreams. Ali sought to re-visualise the data in a familiar way – using a record player, with the artwork informed by platform data, which in turn created a new set of *artistically informed data*. For Ali access to non-live or pre-recorded sources of environmental data on the platform was key to his engagement with the platform, which he described as a type of 'new material' to create artwork with:

"It enriched my practice yes, to work with such abundant and accessible data, to offer this to our group was very positive."

In this case the live experience of the audience watching and listening to the record player was more significant in creating a sense of a *performance of data* than the liveness of the actual data itself. The way the music on the record responded to the data was what was specific to the time and place, and therefore the audience's understanding of the data would have had less meaning in a different context.

Ali suggests that he welcomed the challenges posed by using scientific data and saw the technology as a tool that could support interdisciplinary within his practice:

"My practice lends itself to what is understood as scientific perhaps by the tools and objects that I use. The distance feels more related to the technology; it points to the possibilities of articulating this conversation between practices."

Ali suggests that there are issues around how the Timestreams Platform was experienced by artists as a tool, the issues of integrating technology into artistic practice and the context in which the platform used. Despite feeling that his artistic process lends itself to working with the platform he exposes issues around how artists see tools differently from programmers.

Artist/Hacker living in UK (Bobby) who integrated Timestreams with a sound fountain during our hackday event

Event Description
Our team hosted a *hackday* (collaborative workshop and

Figure 5. A climate data driven record player which adjusts its playing speed in reaction to data from a Timestream.

making session) that brought together artists, designers, coders and makers to explore ideas at speed and make experimental projects with the Timestreams platform.

Participant's Persona and Background
Bobby is an artist with programming experience, who creates her own artistic projects, as well as collaboration on other artists' work. She noted:

"My own practice is mainly working for other people and often it is when they want to work with data from external sensors… [My] standard operating procedure is more building sensors or finding sensors to capture the type of data that's needed and then making an interface to turn that into useful data for digital artists or whoever needs to work with; rather than making the end product I tend to be the person building the thing that gets them to the end product."

Bobby shows us that there is already a specific role for creative programmers within the arts who use tools, such as Timestreams in order to enable artists like Charlie who have less technical, programming skills to develop sensor based work.

Participant's Goal
Bobby attended the hackday as it offered an opportunity to apply her skills on using the Timestreams platform to transform data and make it, as she said:

"…useful for digital artists to whoever needs to work with."

Resulting Artefact
Bobby used Timestreams to access CO_2 data recorded from a sensor in the room. The sound fountain, shown in figure 6, is a large cistern filled with water, placed above a speaker. The pattern on the surface of the water changes according to frequencies determined by the Timestream that are played through the speaker.

Insights and Challenges
Bobby was excited by the idea of translating the CO_2 data as it occurs, while further communicating it in an engaging way. She was particularly interested in the temporality of the data, specifically visualizing live data and recreating this as a live performance of the data through the sound fountain. She was interested in how the liveness of data transforms the perception that one has about it, enabling new forms of interpretation of the data, by creating stronger memories and consequently stronger attachments with the environment and the data itself: "So like I use live sensors

Figure 6. Timestreams driven sound fountain.

more than captured data, which, you know, it's just that feedback I think people love, love to see something happen that correlates with something they did gives people a strong memory of that thing."

Bobby described how the *liveness* of data is directly linked to the *reality* of the data. In other words, in order for data to be real and authentic, it has to be live and this needs to be accommodated by the Timestreams platform for two main reasons: firstly, for maintaining authenticity of the data and its visualisation and secondly, for making it flexible for use by both pure scientists and artists. Bobby notes:

"I don't think all artworks should be interactive and this probably more applies to the data side of things but I think the more you can allow people to kind of get in there and do some of the work themselves make them feel like they're doing something with the data then that gives them more of a understanding to it."

Artist residing in Brazil (Charlie) who produced "Beyond Light" piece

Event Description
Members of our team worked for a week in residence at a farm in the mountains of the Mata Atlantica (Atlantic Forest) outside Rio de Janeiro to advance the Timestreams prototype and explore artistic ways to engage with it, whilst testing the concept and technology *in the wild*. It was during this time that Charlie, who had previously consulted with us about how Timestreams might be used in Brazil, engaged with an early version of the platform.

Participant's Persona and Background
Charlie is an artist and producer of cross-cultural arts who had worked previously on projects with some of our team.

Participant's Goal
Charlie describes the work she does as spontaneous and wanted to:

"Experiment individually and as a group towards creative responses to energy within the context of climate change and produce artworks that respond to environmental data."

Resulting Artefact
Charlie produced *Before Light*, a video performance of six rooms in a farmhouse filmed at night. Inspired by the CO_2 data captured using the Timestreams platform and sensors at the same location on a previous date, Charlie calculated a binary representation of this for the purposes of the piece. 6 people were given a print out of these numbers and they used a metronome to keep in time whilst turning the lights on or off to represent the binary conversion of the data. Music was created to accompany the video, by transforming the binary numbers into a set of musical notes (shown in figure 7). She suggests that she was able to create an artwork that not only responded to the farm and environment that she was in but also in response to the platform and through access to the data captured through the platform. She describes this process:

"It took a little while for everyone to understand oh ok this is what [I'm] doing, it was a bit like trying to understand what R [one of the programmers] does, but using zeros and ones, using us and our life energy and our intelligence and our ability to co-operate and our language."

Insights and Challenges

Charlie had some challenges using Timestreams, raising some important issues around how we develop tools for artists and communities, the context of their use beyond the basic functionality of the tool, and how the technology potentially intervenes with, and can hinder, existing artistic processes.

She describes Timestreams positively as "accompanying a general kind of moment, a global moment", but raises concerns about technical issues of working with the platform. She explains that for her "the creative practice isn't just about the tools that you use but it's about your attitude and it's about how you take those tools to wherever you're going and that can be totally part of the everyday."

During a system review Charlie discussed usability issues regarding the mapping between what she called the 'scientific' or 'technical' terminology of the system and the impact her understanding has an artist on her ability to use the tool within her creative practice:

"But the language isn't an artist language at all. We're having to use a programmer's language to understand. There's going to be some sort of handover to an artist, (to use) a programmers' language to be able to engage with this."

She also described how setting up a new sensor in Timestreams felt like a test, showing how these technical issues could begin to inhibit her interest and confidence in working with the data:

"'What's the symbol of your measurements?', that's becoming like a test. Someone who doesn't know perhaps or who has forgotten temporarily that temperature is Celsius or perhaps in fact they work in Fahrenheit, and don't even know there's Celsius. It starts becoming like *aghh* I'm not intelligent enough for this."

She showed concerns over the need to include a programmer in her artistic process and questioning how she

Figure 7. Composing the binary musical score for Before Light.

could incorporate the platform into her existing processes without learning to program first: "So that's the bit of data we're observing and I'm trying to connect with this. I'm trying to think about how I'll visualize it or put it through a performance I'm going to document… So how am I going to start approaching this data in a way and start using my tools or to deal with this?"

Challenges aside, Charlie is interested in how other artist groups and communities may be able to experiment with the platform. She noted:

"…there's a bunch of artists there, you know, interested in the environment and climate change and data and I can't see that they would have anything like Timestreams, you know, to play with. So these kinds of resources would be really wonderful to kind of open out to those people to then see what they kind of come up with. … and it's not exclusive to artists, you know. I think other disciplines as well, you know, I think, but artists, it's almost a, it kind of opens a door to everyone else you know if artists can do it, so can everyone else…"

Hacker living in UK (Danny) who used Timestreams to control a light with CO2 data during our hackday event.

Event Description
Same as for Bobby.

Participant's Persona and Background
Danny is an electrical engineer with some programming experience working in a multi-disciplinary capacity in the renewable energy field. Danny has a particular interest in revealing the physicality of energy in a variety of ways, including mechanical or pedal-powered devices, and integrating weather data. He explains:

"I am very interested in the boundary of people's perception of power and energy. I do quite a lot of stuff with pedal power … the kind of engaging education side of stuff that's very important."

Participant's Goal
Building on his experience and interests Danny wished to create an actuator that took data from Timestreams and manifested the measurements physically in some way, with the aim of recreating the environment from a geographically remote area to give a sense of presence, by replaying measurements captured by sensors.

"The project that I was interested in was sending data from one side of the world to the other… about getting that data interactive and being able to do something with it in the physical environment rather than on a computer screen."

Resulting Artefact
Danny developed a visualisation using Arduino and Processing that connected to the Timestreams platform and made use of the Mauna Loa data series, in lieu of a significantly remote sensor, in order to control a potentiometer connected to an incandescent light bulb (shown in figure 8). The Timestream played out the

measurements at a rate of approximately 1 year every 10 seconds.

Insights and Challenges

Danny highlighted the need to manipulate or scale measurements to support a performance of data, understanding that the measurements would ultimately be interpreted by an audience, not to distort the data but in order to make it accessible or tangible to the viewer:

"First of all I built a kind of [servo controlled] pointer which showed the carbon dioxide quantity in the air. If I just set it to show the data as a scale of 0 to 1000, or whatever it would have been, the arrow wouldn't have moved so I had to expand the scale until it showed from400, 420 massively expanding in that bit. It massively improves the visibility of it… It's going too slowly; I need to make time go faster… now it's going around at the rate that I've set."

Danny highlights the issues around mediating data for this kind of performative experience. He describes how he walks the line between scaling data to give it clearer meaning for an audience, and maintaining scientific authenticity:

"…it massively improves the visibility of it but you're not skewing the data because the data is still there, you can play the data, so you are just making it readable by someone in a more obvious way as long as the data isn't kind of messed around with in any way that would be my one thing, so with climate change data, again you do need, not massage the data but scale it, make it obvious to people what it is."

Danny worked directly with the Timestreams Platform and API in order to build the application that controlled his visualization and support these issues of scaling, revealing how he came to understand the concept of a 'Timestream' as a single authored dataset, in contrast to a more traditional, queryable, static database of measurements:

"When I restart the application where is the pointer? … Oh it's looping regardless of the application… You are just getting any data that that thing points to, which is actually quite a nice way of doing it"

Figure 8. Incandescent light visualisation. The lightbulb's luminescence corresponds to CO2 data from a Timestream.

In contrast to the previous case study, Danny was already a skilled programmer and engineer and so was able to bypass many of the issues raised earlier about how using the platform might intervene with existing artistic processes. This enabled him to quickly begin thinking about scale, authenticity and sense making in relation to the tools available within the platform, and therefore begin to play directly with the data in a more detailed way.

CONCLUSIONS

We have determined the following key insights from our work with the Timestreams platform and case studies.

Artist Tools and User Context

User context is an important factor in the development of ubicomp tools for artists. Technology has the potential to intervene with existing artistic processes both positively and negatively. Artists' processes and potentially the communities that they work with can be hindered by contexts of working with these tools, and levels of additional technical support required. Both their ability and desire to access this support needs to be considered in the expectations of use of the tool - as well as within the system design.

As we saw from the first case study, artists may have different interpretations of what a tool should provide. In the case of Charlie, she talked about tools needing to be integrated into 'everyday use'. Ali suggested that artists require tools that are hidden and don't simply provide literal visualization opportunities, but enable opportunities for thinking and questioning.

There were also issues raised around how the use of a tool can be supported through collaborations between artists, programmers and artist/hackers. Bobby provides an example of an artist/hacker who regularly works with artists to link between tools such as Timestreams and the artistic processes of non-technical artists. As we saw, in response Charlie also raises issues around whether the need for this role can hinder artistic processes, and suggests that the tool needs to be designed in a way that can be more open to everyday uses.

Artists and hackers tended to approach Timestreams either as a tool to be inspired by as part of their creative practice, as Charlie did, or as a functional tool with a particular goal in mind as Bobby did. Different levels of interaction with the platform suggest that there is a need for creating different forms of accessibility, or user profiles that might enable artists to be able to use the platform in both functional and inspirational ways.

Considering Scientific Data

Each of the case studies reveals different ways that the artist considered the scientific data within the artworks they created. Ali suggests that the platform enabled him/her to consider data as new material whilst still recognizing its scientific significance, which raised issues around how artists can maintain scientific authenticity when using

scientific data; this was also raised by Bobby. Each artist attempted to create meanings from the data in reference to the themes of energy and climate change. This was done through playing with temporality and the scale of the data. They each had different rationales for why they used either the historical data made accessible through the platform, or captured live data and how they mediated the data to create the meanings.

Some of the case studies suggested that there was significance not only in the temporal elements of the data itself but also in their presentations of the data within a specific time and place. This wider context of how data was composed or experienced as part of an artwork or visualization suggests that considerations of time and space beyond the platform add meaning and opportunities for **sense making**. Each of these artists used the platform to create connections between the data, and the time and space in which it was *performed*.

Access to different forms of data
Following on from the ways that the artists and hackers considered the scientific data within their approaches, the case studies provide us with insights into how the pervasiveness of data is not limited to the here and now. This reveals important implications in the ways that they each showed interest in working with the different forms of data, as either historical, live or modeled data or potentially a juxtaposition of all three.

In terms of the artists/hackers who were comparing, contrasting and mediating live data it has revealed opportunities for interaction, feedback and as Bobby described, finding ways to *embed data into our memories*.

Others, such as Ali were interested in data that is historic, creating experiences of data to expose *meanings* we may not have otherwise understood (in this case the speeding up of CO2 increases since 1970). Connected to the space and time in which this data is performed these meanings are further revealed – as with the nostalgic nature of listening to classical music on vinyl, through a record player.

Temporality and Performing Data
Despite using different forms of data, an element of liveness appeared to be a central consideration for most of the artists/hackers. For Bobby, a creative loop of action-reaction is fundamental for the enrichment of experiencing the data and the world, while live feedback links people and objects. Each of the case studies suggested that the performance of data over time, rather than a static visualization or infographic, was an important part of how artists make sense of ubicomp data and consider how an audience would also create meanings from their experience.

The significance of time and space in the way each of the case studies used or responded to the data has interesting implications for the design of such systems. The importance of location, temporal scaling and enabling different forms

of data within the Timestreams platform provided insights into how artists can begin to play with scientific data.

This issue of temporality suggests these tools can enable the creation of performative experiences. This offers new perspectives on how the artists or makers that use the tool can walk a line between finding creative ways to mediate the data and maintain authentic representations of the data from an empirical scientific perspective. These issues are supported by previous work on how artists and the public interpret scientific data, walking the line between veracity and meaning [1, 17].

The context of how the artists used and accessed the tool exposed some significant issues around our assumptions of how artists might access the platform. Issues around the technical language and access to programming support may hinder artists' use of the platform as a tool for making work and quite possibly how they then engage other communities with the tool through their artworks.

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