Smart cities and the digital geographies of technical memory

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Abstract

This paper interrogates the concept of technical memory in relation to smart city systems. Using the example of the UK air pollution monitoring system AURN (Automatic Urban and Rural Network) and how information from this system is displayed in smart phone air monitoring apps, the paper theorises the memory of smart systems. Developing the work of Tristan Garcia, the paper rethinks Bernard Stiegler's retentional accounts of technical memory, which suggests that memory is held or inscribed on or within a particular technical object. To do this it argues that technical memory can be productively considered as a form of artificial comprehension. Here, the memory of smart systems are analysed through a variety of logics that disclose particular qualities of objects for particular purposes, which shapes how people make sense of and respond to their environment. Through the example of AURN, the paper suggests that the concept of artificial comprehension is useful for digital geographers studying a range of smart and non-smart technical systems.

Key words: Smart City, Smart Phones, Air pollution, Apps, technical memory

1. Introduction

Digital networks brought with…[them]…a new kind of economy, based on personal data, cookies, metadata, tags and other tracking technologies…These traces constitute hypomnesic tertiary retentions. Having become digital, they are today generated by interfaces, sensors and other devices, in the form of binary numbers and hence as calculable data (Stiegler 2017 p19-20).

For Bernard Stiegler (2017), sensor enabled and internet connected 'smart' technologies such as autonomous vehicles, intelligent lighting systems, phones and watches are primarily forms of tertiary retention, which work to exteriorise various aspects of human experience into tools and machines (Stiegler 1998, 2009a, 2010d). Here technical memory is understood as a kind of archive or recording that is materially retained in a specific location through a process of 'grammatization' (Stiegler 2017 p19), where thoughts, sounds and other objects are converted and spatialised into discrete marks, such as letters, pictures or binary code. In relation to smart objects and systems specifically, these tertiary retentions are traces of human action, such as data captured through GPS on smart phones and stored in cloud servers (Garde-Hansen 2011; Thatcher 2014; Amoore 2018). In Stiegler's (2017 p15) terminology, the retentions of smart objects create 'habitats' that can be used to model and predict behaviour forming a 'society of hypercontrol' (Stiegler 2017 p16). As a result, smart systems work as tools of hypomnesis, by standing in for and in turn reducing the capacity of humans to remember and experience environments without these systems (Stiegler 2009b, 2010a, 2010b, 2010c). Smart systems thus form part of a broader process of 'smartification' which 'hegemonically serves a hyper entropic functioning that accelerates the rhythm of the consumerist destruction of the world while installing a structural and unsustainable insolvency, based on a generalized stupefaction and a functional stupidity' (Stiegler 2017 p19-20).

A number of geographers have explicitly drawn upon Stiegler's theory of retention to theorise socio-spatial relations in a range of objects as diverse as social media (Kinsley 2014), escalators (Bissell 2014), geovisualisations of motorways (Bissell and Fuller 2017), community mapping exercises (Wilson 2014) and videogames (Ash 2012, 2013, 2015), alongside broader issues around automation (Bissell and Del Casino 2017) and smart cities in general (Rose 2017). This work forms part of a broader literature in geography that explicitly theorises the memory of smart systems as a kind of archive or trace. For example, work on spatial media regularly considers technical memory as retention when it suggests that digital memory are 'fumes' (Thatcher 2014) that are 'left' within an app, platform or space (Kitchin, Lauriault, and Wilson 2017; Leszczynski 2014; Wilmott 2016a, 2016b; Galloway 2004; Dodge and Kitchin 2007a; Verhoeff 2012). As Elwood and Mitchell (2014 p148-149). put it:

[a]pplications such as Facebook store and organize our activities into 'timelines' and circulate these digital histories of our lives to others in our online social networks. Digital histories are constituted through the traces left in databases and websites as we use geosocial applications such as FourSquare to "check in".

In turn, this work regularly links definitions of technical memory as a trace or archive to smart technologies capacity to control and survey human activity (Gabrys 2015; Kitchin 2014; Batty et al. 2012; Frith 2015; Kuniavsky 2010; Strengers 2013; Pink and Fors ; Pink et al. 2017). For instance, Lupton (2013, 2016) argues that smart objects such as health tracking watches result in a form of 'dataveillance', where events of a person's life are 'archived' and can be used to discipline and control that person (on digital surveillance also see: Adey et al. 2013; Andrejevic 2007; Bennett 2001; Ellis, Tucker, and Harper 2013; Leszczynski 2015; Leszczynski and Crampton 2016; Wilmott, Fraser, and Lammes 2017).

Rather than tertiary retentions, which act as an archive or log that work to control what humans can do, the paper draws upon the thought of Tristan Garcia (2013, 2014a, 2014b) to consider the memory of smart systems as a form of artificial comprehension. Distinct from retentional perspectives, which consider technical memory in terms of inscriptions or traces left in the world, the concept of artificial comprehension sees memory as an ongoing process, whereby smart objects are designed to disclose different qualities of the objects they encounter (Ash 2017). In doing so, the specificity of these qualities alter the appearance of environments and how they are experienced and understood. This perspective suggests that smart systems are not monolithic entities that inevitably give way to corporate control, 'forgetting' or 'stupidity' as Stiegler puts it and neither do these systems just enable a complete or total form of archiving of human experience that is ripe for data mining (Beer and Burrows 2013). Instead, the multiplicity of ways that technologies can artificially comprehend objects provides the possibility for new ways of sensing, thinking and knowing environments, which exceed the corporate or governmental intention of the design and implementation of these systems. This is important because it highlights the fragility of smart systems and provides a starting point for interrogating and remaking them for more inclusive and civic purposes (Marres 2007).

To demonstrate how the memory of smart systems can be theorised as forms of artificial comprehension and the ways these artificial comprehensions affect how environments appear to users, the paper draws upon the example of the UK air monitoring system AURN (Automatic Urban and Rural Network). Specifically it explores how air samples from particular AURN monitoring stations are collected and then made differently present via two air pollution monitoring apps for smart phones: Plume and London Air. AURN is an interesting smart system and Plume and London Air are interesting apps to discuss in this paper, because they are designed to address the increasing problem of air pollution in the UK, which causes serious health problems including breathing issues such as asthma and has led to increased mortality rates. The World Health Organisation (2014) now estimates that over seven million people a year die as a result of exposure to air pollution, which accounts for one in eight of total global deaths. Utilising the publicly available data from AURN, a range of software developers have produced apps that work in conjunction with smart objects such as smart phones to enable individuals to monitor air pollution levels in the spaces of their everyday lives. As such, AURN forms a useful counterpoint to discussions of smart systems and objects that tend to emphasise the way they work as technologies of surveillance (Kember and Zylinska 2015; Best 2010; Bogard 2015; Crawford, Lingel, and Karppi 2015; Rosenblat and Stark 2015). Rather than simply recording or retaining information, I argue these apps operate according to a variety of logics and in doing so generate potentially different ways that air pollution can become intelligible. In turn, these apps enable alternate modes of addressing the environmental, social and political issues that surround air pollution.

To illustrate how the memory of smart systems and objects can be understood as sets of artificial comprehensions, the rest of the paper is structured into four main sections. In the next section, I utilise the work of Garcia to define air pollution as sets of objects that comprehend one another. Section three defines artificial comprehension and demonstrates how air pollution is artificially comprehended by the AURN monitoring stations. In the fourth section, I discuss the Plume and London Air apps, and how they artificially comprehend data from the AURN stations to show how smart objects alter the way air pollution appears to the users of these apps. To conclude the paper suggests that the concept of artificial comprehension is useful to understand digital memory and spatial experience beyond the specific example of smart systems and objects.

2. Comprehending Air pollution

Kampas and Castanas (2008 p362) define air pollution in the following way:

an air pollutant is any substance which may harm humans, animals, vegetation or material. As far as humans are concerned an air pollutant may cause or contribute to an increase in mortality or serious illness or may pose a present or potential hazard to human health. In the context of human health, ‘‘risk’’ is the probability that a noxious health effect…may occur.

In turn, they identify four main types of pollutants: ‘1. Gaseous pollutants (e.g. SO2, NOx, CO, ozone, Volatile Organic Compounds). 2. Persistent organic pollutants (e.g. dioxins). 3. Heavy metals (e.g. lead, mecury) 4. Particulate Matter’ (Kampa and Castanas 2008 p362-363). From this position, air pollution is defined extensively in terms of the number of these particles in the air, which can be affected by a range of factors, including wind direction and speed, natural topography and the presence, type and density of buildings in an area (Hatzopoulou and Miller 2010; Biggeri et al. 1996). Broadly speaking, the more particles in a particular area, the greater the amount of pollution there is said to be and the fewer the particles, the lower the amount of pollution. Here, pollution is understood to amass and travel over or through time, with temporality used as a quantitative marker to denote changes in pollution levels (Schwartz and Marcus 1990; Dominici et al. 2002; Niska et al. 2004).

Modifying the work of Tristan Garcia (2014b) we can define air pollution quite differently, not as an extensive mass of individual particles that gather and travel, but as a comprehension. The notion of comprehension is based upon Garcia’s desire to produce an anti-substantialist, anti-reductionist notion of objects. As Cogburn (2017 p11) outlines, anti-substantialism attempts to avoid explaining objects by recourse to smaller or more fundamental objects or forces:

if we could explain a putative kind of thing (say, chemical compounds) entirely in terms of another kind of thing (say sub-atomic particles composing the compounds and the fundamental forces to which they are subject), then there would be no reason to be ontologically committed to chemical compounds any more. All that would really be there would be the subatomic particles and the fundamental forces.

To avoid a reductionist notion of objects, Garcia suggests that an object is ‘that which differentiates what it comprehends from what comprehends it’ (Cogburn 2017 p111). Or in other words an object is the difference between what it contains (its parts or pieces) and what contains it (other objects). Garcia formally names what an object contains, its being and what contains that object, its comprehension. Comprehension thus refers to how an object is defined by the way it is located and situated within a broader category, which gives it a sense of its being. ‘Comprehension is having something inside itself…[It]…is also comprehending an element by being a set; comprehending one quality by being a substrata of qualities’ (Garcia 2014b p107). Garcia gives the example of being in a room to explain this model of comprehension:

I am present in this room when I am in the room and the room comprehends me. I am absent from the room when this room comprehends me in some way (the room comprehends my memory, the fact that I was there, my footprints, the possibility that I could be there, for my thought or for that of another), though I am not inside the room (Garcia 2014b p169).

From this position, any particular object is not reducible to an innate substance, but is the tension between what that thing is (its being) and how this being is comprehended by a category or object that contains it. Modifying Garcia's account of comprehension somewhat we can state that air pollution cannot be reduced to its quantified amount, but is better defined by the way it is comprehended by other things. In my definition comprehension refers to the qualities of an object that are disclosed to another thing (human or non-human) through the specificity of its relation with that thing. These relations are private, non-totalisable and can't necessarily be viewed, observed or recorded from outside of that relation. Take sulphur dioxide (S02), a key air pollutant. From the perspective of chemistry, sulphur dioxide is a compound composed of two oxygen atoms and one sulphur atom. But, understood as a comprehension, sulphur dioxide is a different kind of object depending on what it is comprehended by and may only appear that way to that particular object. A human tongue might comprehend a high concentration of sulphur dioxide through the qualities of acidity, while a fish in a body of water might comprehend it through the quality of choking. From this position analysing air pollution means investigating the different objects that comprehend it and identifying what qualities they disclose. In this case, these objects include the AURN monitoring station and humans whose health is negatively affected by the pollutants.

3. Artificially comprehending air pollution

In the UK, air quality monitoring has been conducted by the Department for Environment, Food and Rural Affairs (DEFRA) using a network of automatic recording stations (called AURN) since 1972. Prior to this, manual forms of air monitoring have been conducted since 1961. The daily air quality index that is used by DEFRA to provide air quality information is based upon measuring the presence of five main pollutants: ozone (03), nitrogen dioxide (N02), sulphur dioxide (S02), particulate matter (PM10) and fine particulate matter (PM2.5). These pollutants are created from different sources and tends to have different health effects. For example, nitrogen dioxide is created from combustion, including heating and electricity generation and contributes to the development of asthma, while particulate matter is generated through traffic and can create nasal allergies and increase the risk of lung cancer (Samet, Marbury, and Spengler 1987; Smith et al. 2000; Turner et al. 2011).

Each AURN station contains a range of different sensing devices that utilise a variety of techniques in order to measure the presence of these pollutants. For instance, nitrogen dioxide is usually measured through the technique of chemiluminescence, using a device such as a Chemiluminescent Nitrogen Oxides Analyzer, whereas ozone is measured via the technique of UV absorption, using a device such as a UV-VIS Spectrophotometer. Through these devices, information about the presence of pollutants is monitored constantly and collated on an hourly basis, which can then be accessed by the public through a range of interfaces, such as the DEFRA website, DEFRA telephone line and a range of third party smart phone apps.

We can draw upon Garcia’s work to claim that the AURN monitoring stations do not represent or retain a memory of a past or absent event of air pollutants presence in an environment. Rather, the AURN stations work to artificially comprehend pollution in a variety of ways. To explain Garcia’s account of memory as a kind of artificial comprehension, he discusses his childhood : ‘my childhood is present in me and in the rest of the world, in the traces that I have left of it, in objects, photographs, imprints, and changes that I have caused; the past is not an absolute non-being, but a fading presence, which withers and passes’ (Garcia 2014b p183). Here memory refers to a kind of negative of an object : ‘absence is the event of the withdrawal of thing from its form, its negative, which persists in objective form (as a sign, an imprint, a fragrance, a memory, an image, and so on)’ (Garcia 2014b p47). In this account, memory becomes a kind of ‘artificial comprehension’. To explain this Garcia offers the example of remembering a lover. He suggests:

By accumulating the memory of my lover, which is with me, and the fact that my lover is currently elsewhere, I create the chimera of an absence, an emptiness, or a being that I comprehend within me, but which is not with me. In reality my lover is not absent, since I must relate to her memory, or to the projection that I make of her actual distant being: her memory or image is present for me. Strictly speaking, of course, my lover is neither her memory nor her image. But since I can identify my lover with what she is in my memory or in my imagination, I can lack her, *I can artificially comprehend her*, *contain her inside me without being there inside me* (Garcia 2014b p171 emphasis added).

Here memory operates as a device of comprehension that takes one of two forms. Either an object can contain something inside it, without that object actually being there (which Garcia terms emptiness) or an object can be contained in something, without being comprehended by it (which Garcia terms exile). Developing Garcia’s idea of memory, we can modify his notion of artificial comprehension to theorise a non-human memory of smart systems and objects. Simply put, artificial comprehension refers to the way technologies are designed and manufactured to disclose particular qualities of objects for particular purposes. Here artificial comprehension is not just about the absence of objects, but about comprehending those objects using a distinct set of methods, techniques or logics and thus disclosing qualities from the form or negative of previous objects. In the case of the air pollution monitoring networks, artificial comprehensions work to change how air pollution appears through the way particular instruments are designed to comprehend particular kinds of object.

For instance, consider how many AURN stations monitor nitrogen dioxide, through the deployment of devices such as a Chemiluminescent Nitrogen Oxides Analyzer. The analyser uses the chemiluminescence technique to comprehend the concentration of Nitrogen dioxide in the air. The most basic form of

chemiluminescence describes the process of fluorescence resulting from a chemical reaction. The chemiluminescent sampler for the measurement of NO2 relies on the reaction of NO with O3 to produce an “excited” form of NO2. As the excited molecule returns to its ground state, fluorescent radiation is emitted, the intensity of which is proportional to the concentration of NO (AQEG 2004 p114).

Depending on the particular device used, this reaction is enabled by introducing a sample of nitrogen dioxide collected from the air into a reaction chamber. Ozone is then added into the chamber creating a chemical reaction that produces a quantity of light for each nitrogen dioxide molecule that is reacted. The fluorescent radiation given off by this reaction is then measured by a component such as a photomultiplier tube. According to Abramowitz and Davidson (2015 n.p.), photomultiplier tubes are a ‘photo emissive device in which the absorption of a photon results in the emission of an electron. These detectors work by amplifying the electrons generated by a photocathode exposed to a photon flux’. More specifically,

[p]hotomultipliers acquire light through a glass or quartz window that covers a photosensitive surface, called a photocathode, which then releases electrons that are multiplied by electrodes known as metal channel dynodes. At the end of the dynode chain is an anode or collection electrode. Over a very large range, the current flowing from the anode to ground is directly proportional to the photoelectron flux generated by the photocathode (Abramowitz and Davidson 2015 n.p.).

When the nitrogen dioxide is introduced into the reaction chamber, we could suggest that the reaction chamber comprehends it, which in turn discloses different qualities of the nitrogen dioxide's being. Here, being refers to 'belonging to something…having a quality…being situated in something' (Garcia 2014b p107). Belonging to the reaction chamber, the nitrogen dioxide becomes a different thing when the ozone is introduced into the chamber. The ozone works to comprehend the nitrogen dioxide by placing it within the newly formed environment of the reaction chamber plus ozone and in doing so alters the object itself. This is because the new environment alters the tension between what the nitrogen dioxide is (the particular arrangement of particles of nitrogen and oxygen) and what that nitrogen dioxide enters into (a sealed chamber with ozone). By altering the relation and tension between the nitrogen dioxide's being and comprehension, new qualities of these objects are disclosed, and in this case the new quality becomes an object itself: light.

In the same way, the light is then comprehended by the photomultiplier tube, which alters the tension between 'what enters into the thing, and what the thing enters into' (Garcia 2014b p122), which in turn discloses different qualities of the light. For instance, the photons of light are comprehended by the photo cathode, which are then comprehended by the dynodes and anodes, which are then comprehended by an output meter, through which the electrons are comprehended within a broader category of mathematical units that allow recording, measurement and comparison. Through these multiple acts of artificial comprehension, particular objects come to be named and identified as a specific concentration of nitrogen dioxide.

In each of these artificial comprehensions, the object itself changes, while being informed by the negative of its previous form. Referring to form, Garcia (2014b p139) suggests: 'a form is a things negative, reverse side and condition. My hands form is everything except my hand'.

This account is quite distinct from Stiegler (2017 p31), who argues a smart system 'whatever its form or material may be, artificially retains something through the material and spatial copying of a mnesic and temporal element'. From a Garcian perspective, the form of the previous object is not retained as a presence, copy or even translation of that object, but as an absence, or negative of an object. Once the nitrogen dioxide has been exposed to ozone and the light generated by this reaction measured by the photomultiplier tube, there is not a material trace or retention of this reaction in the measurement output. Rather, the output measurement is predicated upon the disclosure of a series of qualities of previous objects as they comprehend one another. These previous comprehensions are not present in the comprehension that becomes registered as the output measurement because the quality of that object is specific to the comprehension in question. Previous comprehensions therefore become the condition of possibility of the output measurement while remaining absent from the comprehension itself.

This account is useful because it enables a more open and transformational mode of analysis than Stiegler's account of memory can sometimes imply. For Stiegler, the tertiary retentions of smart systems are so problematic because they narrow and limit consciousness by creating increasing numbers of automated processes that stand in for human thought. In his words: 'understanding has been automatized as the analytical power delegated to algorithms executed through sensors and actuators operating according to formalized instructions that lie outside…intuition' (Stiegler 2017 p27). As a result, 'the…automatic society consists sets up a new mental context – stupefaction – within which systematic stupidity proliferates. The result is a significant increase in functional stupidity, drive-based capitalism and industrial populism' (Stiegler 2017 p30). But, in developing the concept of artificial comprehension we can suggest that smart systems do not just convert analogue lived experience into reductive digital data. Instead the artificial comprehensions of smart objects alter the intelligibility of an environment by altering which objects appear and how they appear. In doing so, the logics of artificial comprehension can inform how people move through, experience and understand space and can potentially alter the way air pollution appears as a social and political issue in ways that are far more ambivalent than Stiegler might suggest. To illustrate this point, we can now discuss the way artificial comprehensions gathered at the AURN monitoring sites are also artificially comprehended by air pollution monitoring apps, which present air pollution in a variety of ways to smart phone users.

4. Air pollution apps and the logics of artificial comprehension

In response to concerns about falling levels of air quality in the UK, a number of smart phone apps have been released that present regularly updated data regarding air pollution from AURN monitoring stations in a range of formats. The following section examines two of these apps in particular: Plume and London Air. Each app artificially comprehends the data from the monitoring stations and works to modulate how pollutants appear in an environment according to different logics, which exceed an account that focuses on hypomnesis or total surveillance alone. In doing so, these logics produce different ways of thinking about and experiencing air pollution and the spaces in which air pollution exists. We can term these logics dispersal and delimitation.

a) Dispersal

Dispersal refers to the way air pollution is artificially comprehended as an abstract unit that creates a vague sense of the presence of pollutants that are hard for the user to locate in their environment. In Plume, dispersal is achieved through a core dashboard that displays the Plume Index for a given city. The Plume index is built on the Air Quality index and the AURN monitoring stations used by DEFRA in its air quality reports. The Plume index is displayed graphically and numerically. When opening the app, you are greeted with a circle and a white bar that wraps around the circle. Next to the white bar is a series of colours that line the interior of the circle. These colours range from blue (clean air) to pale pink (moderate pollution) to brown (high pollution) to grey (very high pollution) to black (extreme pollution). Depending on where the white bar stops, one can ascertain the current level of pollution. The bar is supplemented by a stylised anthropomorphic cloud that has eyes and a mouth. When the air is clear the cloud is smiling, when moderate pollution is detected the cloud has a straight mouth and so on. If you swipe right within the circle this gives you the Plume index in relation to the yearly average for your city or region and swiping right again gives you levels of ozone, nitrogen oxide, and particulate and fine particulate matter in a numerical format. Below the Plume index a line graph displays levels of pollution across time. Swiping right, the temporal scale can be altered. Data can be presented at hourly intervals across the space of one week or monthly across the space of one year. Swiping right also provides advice about the type of activity it is safe to undertake at different times of the day, given the pollution level. There are four types of activity listed: outdoor sports, cycling, bring baby out and eating outside. Depending on the pollution index, the app will suggest to 'Enjoy it!' 'Take it easy' or 'Take Care'.

Through the construction of this interface, Plume artificially comprehends air pollution data in different ways. For instance, take the Plume index score and the graphical dial that surrounds it. By splitting the dial using white lines and colouring the interior of the dial, the pollution data from the monitoring sites is artificially comprehended as a new object: a bar that moves from zero (fresh air) to one hundred and fifty (extreme pollution). This dial works 'through a law of exchange…the absenting of something present entails the presentation of something absent'

(Garcia 2014b p250). In this case, the dial works to present something absent (the air pollution measured at the monitoring station), but in doing so absents the very presence of this pollution (the pollutions form in the air, prior to its artificial comprehension by the monitoring station). In doing so, Plume generates an artificial comprehension of the region or area that the user is monitoring as an abstract and undifferentiated entity through this interplay of presence and absence. For example, there are around two hundred and twenty air quality monitoring sites across the UK. Two of these are located in Newcastle Upon Tyne, where I am currently located. One is on Cradlewell roadside and the other is in Newcastle city centre. According to the Plume app, the current pollution levels, at the time of writing, are moderate and it recommends that if I wanted to partake in outdoor exercise or take a baby outdoors that I should 'take it easy'. However, I am in Gosforth, two miles north of the Cradlewell roadside monitoring station. As the information page of the app itself recognises, air quality is highly localised, with micro variations in air temperature, positioning of buildings and so on leading to radically different levels of air quality only metres apart. In Plume's (2016 n.p.) words:

add a little gust of wind or a ray of sunshine, a morning traffic jam, a residential heating peak…and air quality is turned upside-down in a matter of minutes, for better or worse! Hence the importance of following its evolution closely. Obviously, you don't have time to keep checking pollution indexes…but thanks to Plume you can get real-time notifications :-).

As such the way Plume artificially comprehends air pollution creates quite a vague sense of where the pollution is located because it is based on a set of comprehensions between a small number of technical objects (two monitoring stations for a whole city, the servers at Plume and the users smart phone). In turn, this comprehension creates a vague sense of Gosforth as an environment for the user. Sitting in Gosforth I can either uncritically accept the pollution index

Plume provides or I can recognise its limitations. If I uncritically accept that the pollution is actually moderate today in my location, this shapes how space appears for me. Following the apps suggestions, I choose to take it easy and cycle one mile rather than four. I may not choose to take the baby for a walk. I may keep the windows of my house shut and so on. If I choose to critically reflect on how closely the pollution index ties to my particular locality, relations of near and far become indeterminate to me. Where exactly is the pollution moderate? Is there a way for me to avoid the pollution? In doing so, Plume discourages the user from becoming sensitised to the micro ecology of objects that shape how pollution amasses and travels. The degree of abstraction that the logic of dispersal enables, could be considered both productive and problematic. Productively, Plume might encourage users to take action over what they see as unacceptable levels of pollution that the app makes intelligible for them. Problematically, the app makes it difficult to make informed decisions that are sensitive to the actual location of the user at the time. In either case, the way Plume artificially comprehends air pollution can have important consequences for how the user's environment appears to them.

b) Delimitation

Delimitation refers to the way the temporality of air pollution is spatialized and in doing so appears to be differentially present in an area. The logic of delimitation is particularly evident in the London Air app. The London air app draws upon the Automatic London Network (ALN), a subset of the wider AURN network. The ALN consists of 14 monitoring stations across London, enabling a much more detailed artificial comprehension of air pollution than other cities, which might only have two AURN monitoring stations in total. The greater number of monitoring sites, in concert with computational modelling creates an artificial comprehension of air pollution that is overlaid onto a cartographic map of London. While Plume provides one overall score for a whole city, London Air offers a micro differentiated colour coding system that visualises pollution on a more local scale. Using London Air, the user has to rely on their own interpretations of different coloured rectangles that overlay the map, ranging from blue to denote ‘low’ levels of pollutants to orange for ‘moderate’, red for ‘high’ and black for ‘very high’. Together these shades form a heat map of the presence of pollution on screen.

The space that appears for the user is then partially constructed by the sample resolution of the data and how this data is artificially comprehended as a coloured rectangle and how these rectangles relate to one another to form a heat map. The London Air app cuts London into rectangular units of around 5 meters square. Of course, these rectangles provide approximations of the presence of pollutants, but due to pollutants necessarily diffuse nature and the predictive nature of the app’s comprehension of the data, such approximations are never completely accurate. For example, as I write, London Air shows that that there are ‘moderate’ levels of pollutants at the corner where Oxford Street meets Bayswater Road, while the immediate areas surrounding Oxford Street have low levels of pollutants. In doing so, the heat map produced by the app acts as a kind of artificial comprehension, giving the air pollution its supposed form. For example, the heat map itself acts as a kind of negative of the pollution, much like a photo negative. ‘In photography, the fixed light on a surface…appears as a hole…which gives form to faces, streets and landscapes which we know are absent’ (Garcia 2014b p250). As a kind of negative or form of a presence that is absent (the air pollution), the heat map in turn enables specific pollutants that are undetectable to the human senses to become present and thus intelligible in particular locations.

In other words, the way London Air artificially comprehends the air pollution alters the intelligibility of London as a city. For example, perhaps a user might consult the app and decide to cross the street to avoid what the app considers to be a particularly polluted area. Rather than nearness and farness being organised around the objects that make up the urban street scene, such as roads, pavements, traffic lights and so on, near and far become organised around the assumed presence of pollutants, as denoted by the heat map in the app. In doing so, the user may have to work against the objects that make up the street scene to avoid these pollutants. Perhaps they walk along a bike lane to stay within green quadrants or cross the road at a non-pedestrian crossing point to move from a red to an orange zone. In either case, the way the app artificially comprehends the air pollution through the heat map potentially encourages different forms of engagement and response than when a user engages with the street without the app.

London Air also artificially comprehends air pollution through its ability to send notifications to a user's home screen. Users can subscribe to be updated regarding the pollution levels at specific sites and receive text notifications and alerts through the app when pollution levels become moderate or high. Imagine receiving a notification every day at 8am that particulate pollution has increased from low to moderate or from moderate to high on a junction that you regularly walk through on the way to work. Perhaps over time the notifications come to jar you enough to change your habits and take a different route to work to avoid this pollution black spot. In doing so the artificial comprehension of the app has constructed a form in which the presence of a space and distinctions between near and far have altered. What was once simply a part of an everyday journey takes on a new form. Suddenly the space of the city is cut and split into different quantities of air pollution that are defined by the pollution's extensity on the heat map and through which the city is comprehended by the user. In other words, London Air makes particular points of the city intelligible as an environment that is associated with potentially negative health effects in ways that would remain unintelligible without the app.

5. Conclusions

This paper has used the example of air pollution monitoring stations and air pollution monitoring apps to think through the question of memory in relation to smart systems and objects. Rather than defined as a retention, the paper suggests the memory of smart systems can be understood as a form of artificial comprehension. This account challenges a notion of retention as a static store or archive that is imprinted into a material thing. Instead, the notion of artificial comprehension allows us to consider memory as a dynamic form of absence, which actively alters what objects and qualities appear as they become comprehended by other objects in a smart system.

The concept of artificial comprehension thus allows us to consider how the technical memory of smart systems is both subject to change and also contains a kind of durability. Technical memory changes as the very object of that memory is comprehended by other objects. But, the artificiality of its comprehension ensures that the previous object's form is maintained as a condition of possibility for the next artificial comprehension to occur. In the case of air pollution monitoring apps, these artificial comprehensions begin when the instruments at the monitoring site comprehend various particles and end when these measurements are comprehended as visualisations on a screen that a user engages with. Understanding technical memory as artificial comprehension thus provides a mode of analysis that allows us to trace how smart systems have effects through the way they actively shape the kinds of object that appear to users and in turn how these users comprehend the environments they move through.

In demonstrating this argument, the paper points to an alternative way of thinking about the social and political problems that Stiegler (2017) and other critics of smart technology such as Dodge and Kitchin (2007b) suggests emerge when human memory is exteriorised into smart objects and systems. For Dodge and Kitchin, one political response to the problems with smart systems is to design in 'forgetting', understood as a periodic wiping of data, which enables people to not be entrapped by the archives of information stored about them. In their words, 'memory should always be complemented by forgetting…[F]orgetting is not a weakness or a fallibility, but is an emancipatory process that will free…[users]…from burdensome and pernicious disciplinary effects' (Dodge and Kitchin 2007b p441). Understanding the memory of smart systems as a form of artificial comprehension suggests that there can be no total store of memory about an individual, because each comprehension is always selective and based upon the form or absence of a previous comprehension. In doing so, the concept of artificial comprehension offers a more hopeful account for challenging smart systems and objects, because it points to the fragile and contingent nature of their memory and their fundamental incapacity to retain a complete or total record of the past.

In other words, the power of smart systems and objects is not the way they automate, monitor or stand in for human memory alone. The power of these systems are also about how they actively alter human intelligibility in ways that exceed exteriorisation and data capture. As a discussion of Plume and London Air demonstrate, understanding the way these apps operate can reveal the contradictions and tensions of these systems in ways that avoid simple narratives of outright denunciation or celebration. A Garcian reading of air pollution monitoring systems and apps would suggest that the artificial comprehensions of these devices alters how air pollution appears and in doing so open new domains to understand and contest the objects that generate this pollution. Indeed, it is only by focusing on the specificity of smart systems and the way particular objects generate artificial comprehensions that we can begin to understand the role they might play in helping to solve societal problems such as air pollution (Marres 2007). As Gabry's (2014; 2016) suggests, these solutions can include the development of citizen science projects and activist campaigns that work to change policy and law around the kinds of vehicles that are allowed to operate in a space or the concentration of pollutants factories are allowed to emit.

In summary, the concept of artificial comprehension provides us analytical purchase to trace the memory of smart systems and interrogate and contest the way they alter how environments come to be registered, experienced and sensed. While the paper has identified two logics through which smart systems operate to alter the intelligibility of objects (dispersal and delimitation) in relation to the AURN network in particular, this is not to say that these are the only two logics at work. Neither is to say that the concept of artificial comprehension can only be used to analyse air pollution monitoring systems. Indeed, I would encourage those interested in smart systems to study their artificial comprehensions and identify other logics through which objects come to be comprehended. For instance, one might wish to analyse automated traffic light systems to understand how cars or traffic jams come to appear as objects and how this alters human comprehension around road planning or driver decision making in relation to journey routes. As spaces become increasingly filled with such smart systems and objects, it is important to identify these logics and the artificial comprehensions linked to them. In doing so we can alter these systems to generate comprehensions that enable social and political responses to the problems they are implicated in.

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