What Lies Above: Alternative User Experiences Produced Through Focusing Attention on GNSS Infrastructure

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ABSTRACT
This paper describes a study in which participants were made aware of the presence of Global Navigation Satellite Systems (GNSS) infrastructure (often colloquially known as GPS) through an exaggeration of its breakdowns and a defamiliarisation of its use. We found that, by drawing attention to satellites and their signals, participants began to feel part of a larger system and to reflect on their sociotechnical practices within that system. These reflections included playful exploration and an interrogation of power relations made invisible by the blackboxing of GNSS infrastructure. Despite these shifts from established practices, smartphone visual interfaces continued to be a powerful arbiter of how participants situated their experience. Drawing on the experience of this study, we suggest ways for designers and researchers using Location Based Services (LBS) to inspire critical relationships with infrastructure which circumvent dominant design inscriptions. We also offer these techniques for others working more broadly in the fields of participatory and critical design.

Author Keywords
Critical design; Location Based Services; Infrastructure; Inventive Methods; Human Factors

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H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous;

INTRODUCTION
Although the first phones that supported a Global Navigation Satellite System (GNSS) appeared in the mid 1990s, we can trace the dramatic rise in everyday use of GNSS technologies and Location Based Services (LBS) to the introduction of 3G-enabled smartphones in the late 2000s. This shift allowed mobile devices to displace dashboard mounted satnav devices as the most common GNSS-enabled technology. Currently, it is extremely common for multiple applications on mobile devices to request access to the device's location. Such a request may be related to an app's functionalities, including navigation (*Citymapper* [14]), social media geotagging (*Instagram* [25]*, Facebook* [21]*, Foursquare* [22]), ordering a car and driver (*Uber* [47]) or gaming (*Pokemon Go* [37]). Equally, the establishment of location may be implicated in the ambient data-gathering performed by many applications during their use. Through these cases, we can say that the use of technologies which identify our location has become deeply embedded in our sociotechnical practices. Although many devices also use Wi-Fi and cellphone towers in supporting location capabilities, the best-known means of identifying device location is through Global Navigation Satellite Systems (GNSS), often colloquially known through the name of the longest standing GNSS, the American Global Positioning System (GPS). Currently, most mobile devices are equipped with a GNSS antenna and sensor, forming a vast collection of sensors which orient themselves using signals from the GPS satellite network operated by the US military, GLObal NAvigation Satellite System (GLONASS), a system operated by the Russian military, and, increasingly, the Chinese-operated service BeiDou. Besides user-facing consumer functions, GNSS is used in military operations and a diverse range of industries including logistics, high-frequency financial trading, earthquake prediction and weather forecasting.

Our primary concern here is smartphone user driven cases. We note that for most users, the complex infrastructure which determines a device's location is frequently rendered invisible. For example, *Google maps* [35] shows a flashing blue dot which denotes 'You are here', not 'This device has received a minimum of four time-stamped signals from satellites in medium earth orbit and, despite the possibility of environmental disruptions, has estimated that you are here.' The infrastructure is blackboxed. Its existence and operation is concealed and thereby made invisible. Such blackboxing is by no means unique to GNSS technology, it

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is consistent with Mark Weiser's influential claim that, in ubiquitous computing, the user's attention should be on the task at hand rather than the tool [38, 51, 52]. However, while such a design approach may create smoother user experiences, it also works to determine the paths and aims of such experiences. Blackboxing may also conceal certain attendant operations and effects of a technology which are relevant to users. For LBS these may include on what terms nearby businesses are deemed relevant to a user or what is happening to their personal location information further up the data chain. In pursuing this line of research, we were interested in whether drawing attention onto the presence of GNSS infrastructure would make users critique their own sociotechnical practices. The ability to make such critiques and gain awareness of the ways practices are formed and maintained has benefits for both designers and users.

It should be noted that we deploy the term 'users' with a pinch of salt. This research argues that there is nothing fixed or rigid about such a term. Rather, users emerge from sociotechnical practices which are enacted in response to the uses inscribed by designers [2], often with strong measures of translation and friction [3]. However, we continue to use this term as a shorthand, while exploring how it and its attendant infrastructures are constructed and made durable.

As a technique to make infrastructure more visible and less naturalised, we take a lead from Bowker and Star's proposal for "infrastructural inversion" [11]. It should be noted that we do not focus on historical inversion approaches, where researchers study the development of a technology, exploring contingencies and how certain formations were made durable [10]. Rather, we concentrate on the phenomenological experience of having infrastructure revealed. This is done through exaggeration of points of infrastructural breakdown and defamiliarisation of sociotechnical practices during a task at hand. Through this, we create a more immediate sense of a participant's place within GNSS infrastructure as it acts.

In developing this technique, we also drew on art based walking practices, particularly the influential situationist proposal for derives (directionless walks which render a familiar cityscape new and unusual) [17].

We framed the inquiry with the research question: 'What alternative user experiences emerge when we foreground the infrastructure which supports LBS?' During the study, we found that participants were able, to some extent, to shift their familiar user position, and see themselves as part of a wider system in emotional, ontological, social and material terms. These new positions opened possibilities for playful interaction with GNSS technology and an ability to question the distribution of power within that system. We also note that established means for shaping sociotechnical practices remained strong, with the visual interface of the research app and ideas of mapping remaining powerful in forming experiences.

We begin the paper with a review of some theoretical understandings of infrastructure and blackboxing, along with our reasoning for challenging the established practices which lead to infrastructural invisibility. We then orient our methodology alongside some complementary practices. We describe our study; a series of walking workshops which took place around the Barbican Estate in London, a building complex with features which disrupt the smooth operation of GNSS. After describing the outcomes of the research, we discuss the alternative user experiences produced and consider their potential to inform surrounding research and design.

WHAT IS HIDDEN

It is difficult to pin down what an infrastructure 'is'. The term describes diverse formations of technical and organizational objects. In their influential article, Star and Ruhleder instead argue that "infrastructure appears only as a relational property, not as a thing stripped of use" [42: 113]. As such, we can understand it through "changes in infrastructural relations" rather than the causal agency of people or things. For Star and Ruhleder, infrastructures may vary in type and scale. Historic examples include the electrification of a town or the uptake of the file folder in the management of American industry. In these examples, both a power grid and a means of organising information are understood as infrastructures through the impact they make on surrounding relations. Infrastructures can be said to emerge with eight dimensions: Embeddedness; Transparency; Reach or scope; Being learned as part of membership; A link with conventions of practice; Embodiment of standards; Being built on an installed base; and becoming visible on breakdown [42]. In relation to our study of GNSS infrastructure, we reflect in detail on three of these dimensions: Embeddedness; Transparency and Visibility through breakdown.

Within the realm of this study, GNSS is embedded into the smaller, user-facing structure of the smartphone. The actions of the wider system are collected and re-interpreted by a sensor within the device. This sensor works with other structures to inscribe actions for users. Examples of such structures are the operating systems which support smartphone applications. The Android operating system (latest version at time of writing: Nougat 7.1) [4] allows developers to call a breadth of information from the device's GNSS sensor, including the number of satellites in view, the signal to noise ratio of their communications and the azimuth of their trajectory. Apple's iOS operating system (latest version at time of writing: 10.3) [26] on the other hand only allows developers to call information about the accuracy of the location fix. In this way, the presence of the infrastructure is embedded to the point of transparency. For Star and Ruhleder, transparency means that the infrastructure does not need to be reconstituted for each task, but rather "invisibly supports those tasks" [42:113]. This transparency is true of both Android and iOS's support of LBS, but something more radical is happening in

Apple's case. Here, invisibility becomes paramount because the presence and operation of the infrastructure is blackboxed. Even if they have need to, developers are unable to request information relating to operational components of the infrastructure. All they can tell is how well it is working (how accurate a fix can be established). This brings us to the dimension of visibility upon breakdown. In iOS development, the only pertinent information has been judged to be the degree of breakdown; in other words, to what extent has the tool become visible and, presumably, in turn, what solutions can the developer find to mitigate that visibility.

Blackboxing, or the making invisible of infrastructure, is frequently understood as something desirable within HCI. Weiser famously claimed that: "A good tool is an invisible tool. By invisible, I mean that the tool does not intrude on your consciousness; you focus on the task, not the tool" [52]. Bakke identifies a trend in HCI such that "the cultivation of an [information infrastructure] would benefit from hiding the infrastructural complexity beneath an easily comprehendable user-interface" both to make an interface easy to learn for new users and to offer quicker ways for experienced users to complete their tasks [7]. Weiser also argued for a type of ubiquitous computing which should recede into the background, ultimately becoming an ambient part of the environment [51]. Such invisibility, however, may emerge less from its physical placement and more through the aspects of its use. For Latour, blackboxing is understood as the way in which "scientific and technical work is made invisible by its own success" [28:304]. In the same way the use of a device like a refrigerator might become so widespread that we cannot imagine life without it, information infrastructures have the potential to "become tacit in thought and action for human users" [24]. When such developments become tacit they gain an aura of inevitability, as if their development could not have taken any other course [10].

Blackboxing may ultimately be realised by the proliferation of a particular infrastructure, but is also the result of a series of inscriptions from designers. Akrich notes that the affordances of a system or object work to try and define which tasks are possible, which in turn defines the nature of the user [2]. The complexity of this process has been emphasised in empirical studies of inscription in information infrastructures [1, 23]. At the same time as uses are inscribed by designers, alternative practices emerge through the ways in which those inscriptions are received [3]. GNSS infrastructure offers an interesting example of these processes because it has been leveraged by multiple communities of use. Besides familiar examples of finding your position on a map, or a route to your destination, practices such as weather forecasting leverage the relative speed of satellites' signals in different air humidities. High frequency financial trading uses the satellites' atomic clocks to synchronise trades. Establishing device location, while a more familiar use, also supports a complex set of practices including tracking pets and prisoners, finding potential sexual partners or providing metadata for photos or *Twitter* [47] posts. The emergent map of GNSS use shows it is not limited to any single practice. However, all these various uses rely on a shared material base, the largest parts of which are developed and maintained by the militaries of the United States and Russia. For Callon and Latour, blackboxing is a fundamentally asymmetrical process. It allows a micro-actor to become a macro-actor, which "bends space around itself, makes other elements dependent upon itself and translates [its] will into a language of its own" with a greater degree of success [12:286]. The crux of this power lies in invisibility; many actors become understood as one object or system. It therefore becomes more difficult to imagine how things could have developed in a different way. This process has implications for the way our surroundings are understood, both in spatial and political terms [34].

Stepping outside the historical inevitability which emerges through blackboxing is desirable for several reasons. For ethnographic research, which seeks to understand how sociotechnical practices are formed and enacted, it offers the possibility of a deeper level of engagement. Within participatory design practices, respondents and designers could be more empowered to think through how their sociotechnical practices are formed and could be reformed [43]. It would allow people (in various often overlapping roles as users and designers) to reflect critically on the unconscious values embedded in computing [8, 19, 41]. In more pragmatic terms, attention to the seams and points of breakdown in infrastructure may hold great potential for generating new and innovative designs [13]. Before these benefits can be reached, a way must be found to invert our usual practices and make what is hidden visible. In the following section, we describe the methodology we developed for making GNSS infrastructure visible by leveraging and exaggerating moments of breakdown

TURNING AN ICEBERG UPSIDE DOWN

Our aim in this project was to ask what alternative user experiences emerge when we foreground the infrastructure which supports LBS. To explore this question, we first needed to challenge the invisibility of blackboxed infrastructure. Our approach follows the principles of infrastructural inversion laid out by Bowker and Star. There are many ways to apply infrastructural inversion, but all share a drive to recognise "the depths of interdependence of technical networks and standards, on one hand, and the real work of politics and knowledge production on the other" [11:34]. This work is often done historically, unearthing the contingent preceding and parallel infrastructural conditions through which, "the initial claim came a posteriori to be seen as reasonable" [10:235]. In our case, rather than taking a purely historical approach, we chose to foreground "the sequencing of events in the present" [11:46]. We wanted to explore contemporary experience more directly to stage a more dramatic inversion of participants' usual practices.

This process is analogous to the taking the visible part of an iceberg and turning it upside down to expose its hidden, supporting depths. We brought this visibility about by defamiliarising GNSS technology through our experiment design, at the same time as using the affordances of a particular site to stage exaggerated moments of breakdown. Once the infrastructure is brought into focus in this way, we encouraged participants to explore it through movement and exploration, then to reflect on this experience through writing, drawing and discussion.

The act of making what has become naturalised strange and unfamiliar finds resonance in critical art practices going back at least a far as the situationists in the 1950s [17]. Here, practitioners would walk freely, without direction in the city, exploring what emerged when the familiar was made strange or 'detourned'. Indeed, situationist practices of re-configuring the city, or adding extra layers of meaning to it were influential in the first wave of locative media art projects that emerged in the early 2000s [46]. Such practices are, however, perhaps limited through the faith they put in distinct objects such as user and city. Such an understanding leaves little room for macro-actors such as blackboxed infrastructure to shape what lies around them [45]. Nevertheless, the principle of defamiliarisation has potential to be a useful one for critical work in design. Bell et. al. argue that such an approach "provides a lens to help us see our own design practices in a new light" [9:154]. We would go further and invoke critical design discourses [8, 19] to argue that it also has the potential to interrogate practices of use as they are experienced as well as designed. Such approaches may not uncover the totality of what is specific to the infrastructure in that moment, but rather provoke wider reflections on what lies beneath familiar tasks and what new understandings that knowledge can provoke.

The idea of making communications infrastructure visible also resonates through a number of contemporary design and art projects. Julian Oliver's *Border Bumping* project has interrogated moment of cellphone network switch and breakdown at national borders [36], while Martinussen, Knutsen and Arnall's *Satellite Lamps* installation uses lamps to alert people to the nearby presence of GNSS satellites [32]. Network visualization app, *The Architecture of Radio* uses static datasets to depict a realm of signals, including nearby cellphone towers, Wi-Fi routers and communications satellites [49]. These projects all share a desire to make communications infrastructures visible and thereby provoke reflection in the viewer.

Such reflection on the presence and operation of infrastructure can, in turn, generate new approaches for design. Chalmers and Galani argue that the disappearance of computing proposed by Weiser fails to recognise the everyday negotiations made at seams which become exposed during moments of breakdown or translation across different software or platforms. The negotiations which take place at such moments can be productive for designers to explore [13]. Infrastructural inversion, where one looks beyond those moments of breakdown to what they can reveal about the infrastructure, also has the potential to generate new systems or practices of use. While such approaches have not yet extensively explored in the literature, examples do exist of the generative potential of infrastructural inversion in digital humanities [27], sensors in field based scientific research [33] and climate science [20]. While the present study did not foreground the generation of new designs, we intend that it can be useful to critical design communities by providing techniques for making infrastructures visible and inspiration for designers to explore.

STAGING A STUDY

The experiments described here were undertaken as a series of three walks around the Barbican Estate in spring and summer 2016. We focused on the Barbican because its distinctive architecture often blocks GNSS signals, making breakdown more likely. An additional walk took place around Manchester city centre in August 2016. The walks were simultaneously understood as art and research projects, a formulation reinforced by their promotion with partner organisations. One Barbican walk was arranged with the Culture Capital Exchange, an organisation which focuses on "knowledge exchange, collaboration and wider engagement between the research base and the arts" [44]. Another was organised with Antiuniversity Now who aim to challenge existing structures of knowledge production "by inviting people to organise and share free learning events in public spaces" [5]. The event in Manchester was organised in association with the Loitering with Intent exhibition at Manchester Peoples' History Museum. The other walk around the Barbican was organised by the authors. Undoubtedly, as a result of our framing and choice of collaborators, the majority of our 26 participants identified as being from an arts or research background. For us this was an advantage. Respondents from these backgrounds had proven more willing to engage with the possibility of re-conceptualising GNSS in preliminary studies which also involved respondents from computer science and engineering backgrounds.

Figure 1. A Participant moves through the monolithic architecture of the Barbican Estate.

Besides attracting certain participants, the use of an art context to stage our research was motivated by a desire for the flexibility and freedom which art practices can provide for thought experiments [29]. By situating our study within this context, we also invoked a lineage of art practices around locative media and the act of walking. In this way, we acknowledge that we constructed a site in which to stage the research.

Interrogating what it means to site research, Dilley draws attention to the influence of the particular research questions being posed: "contexts are sets of connections constructed as relevant to someone, to something or to a particular problem, and this process yields an explanation, a sense, an interpretation for the object so connected." [18:2]. Law and Urry make a stronger claim that methods "can help to bring into being what they also discover" [30:395]. So, in this way, we are aware that we have made a conscious intervention in the participants' relationship with technical objects and the infrastructure which lies behind them, but we have done this to bring into existence a set of conditions which helps to probe our area of concern. This acknowledgement invites the kind of complexity described by Lindstrom and Stahl as "entanglements in multiple temporalities" [31]. We accept this and, in the analysis of our data, seek to include the attendant specificities of staging, site and technical tools.

After looking for an appropriate architectural site, we decided to stage the walks primarily in the Barbican Estate, a collection of concrete buildings, comprising a residential estate and an arts centre. The estate is built in the brutalist style and has many architectural features which block lines of sight with the sky (covered underpasses, extensive underground car parks, indoor public spaces (see figure 1)). These structures also have the potential to produce multipath errors as signals travel from satellite to device, bouncing off large-scale, reflective concrete surfaces on the way. Indeed, owing to its often obscure design, the complex is notoriously difficult to navigate, to the extent that *Googlemaps* offers an indoor navigation service for the arts centre. Our participants were given a commercial app developed by Chartcross called *GPS Test* which uses the affordances allowed by the Android operating system to plot a compass-style map of GNSS satellite positions in relation to the device (see figure 2). The app also offers a bar chart of relative signal to noise ratios for transmissions from the satellites in view (see figure 3) and information relating to the device's velocity and height relative to sea level. To give the participants some idea what they were seeing on the app, we gave them a brief explanation of the way location is established through the triangulation of time-stamped satellite signals and compared to the known trajectories of individual satellites within an almanac database.

We focused on the importance of lines-of-sight with the sky to allow reception of broadcast signals. We also gave them some very brief history of the development of the GPS and GLONASS systems. We ran the app on Yuntab K03-7 7-inch tablet devices using the Android 4.2 operating system. The app only takes GNSS signals into account, so there was no need to disambiguate from other modes a device may use to establish location. Participants walked freely around the Barbican site for 30 minutes during which time they were observed. After returning to the meeting point, they were given pens and paper and asked to reflect on their experience through drawing and writing. They did this for around 20 minutes after which the group came together for a discussion. Transcripts of the discussion formed the backbone of our data, while the drawn and written material was intended to allow participants to reflect individually before contributing to the discussion. Individual written and drawn responses were therefore read alongside the discussion as supporting material and to mitigate against the possibility of participants being shy or reserved in the discussion context.

We coded the data using grounded theory principles [16] to establish themes and then used the themes as part of a situational analysis [15] which also allowed for the influence of the physical site, art staging and surrounding sociotechnical practices. We chose this approach to be "accountable to the complexity" [15: 559] we were producing both through the conscious staging of our research and the problemetization of familiar technologies and practices. We would like to think that situational analysis also offers steps towards an infrastructural inversion of the research process itself, allowing us to probe what is assumed both in attendant sociotechnical contexts and our own theoretical assumptions.

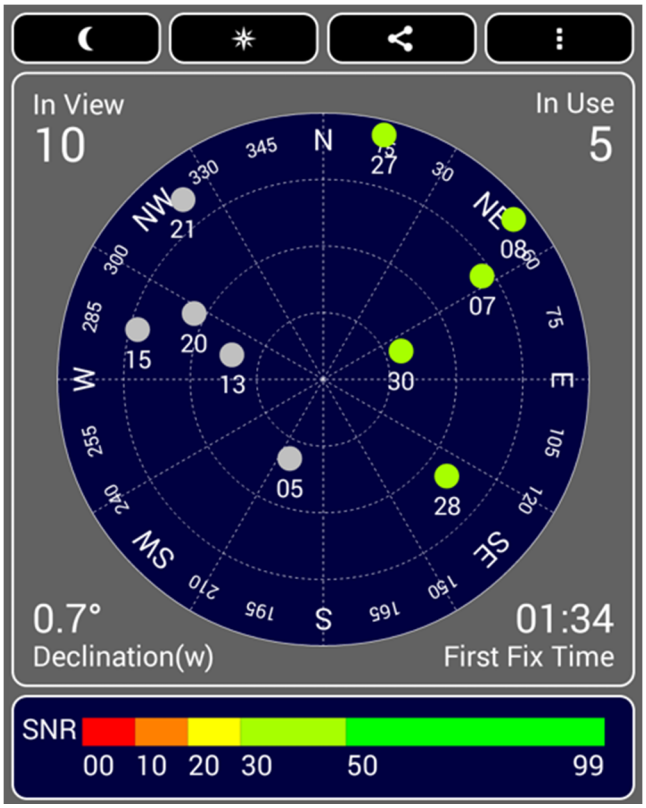

Figure 2. The compass-style display showing satellite positions in *GPS Test*. Here the device can only establish connections satellites to the east of its position.

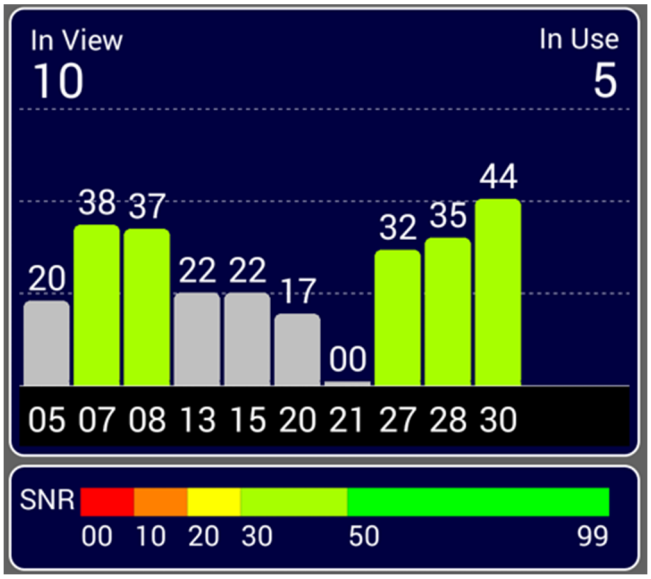

Figure 3. The bar chart display showing relative satellite signal to noise ratios in *GPS Test*.

ALIENATION / ENVIRONMENT / DYNAMICS

Our first question for the data generated by the workshops was whether we had succeeded in making GNSS infrastructure more visible. In three different workshops participants identified an "inversion" of the usual operation of the technology. The change was understood as a shift in what was being located by whom, so "you could see them [satellites] rather than being seen":

"I'm used to me on *Googlemaps* being a little blue dot, so in a strange way I thought there's something quite subversive about the satellites being located by me… locating the satellite rather than locating yourself was fun to play with".

The position of the satellites provided the point of contact with GNSS infrastructure. Other physical elements of GNSS infrastructure such as ground antennas and control stations remained concealed, as did the techniques and standards which fed into the design and testing of the satellites. These elements were embedded within the satellite, which was understood as a coherent and distinct object. This understanding was supported by the placement of satellites as separate dots of the visual interface.

Despite these caveats, the exercise did allow participants to think beyond conventional user experiences and, as we shall see, use satellites as prompts to reflect on their sociotechnical practices. This manifested in several ways. In the following section, we describe participants' responses beginning with alienation, moving through awareness of an infrastructural context, to reflection on some of the dynamics at work within that awareness. We conclude the section by noting the persistence of certain familiar aspects such as the power of a visual interface and the idea of GNSS as a tool associated with mapping.

Alienation

A sense of removal from usual tasks was experienced by several participants. This was felt through a re-orientation, where "the whole sense of direction became a bit more abstract and didn't seem to include me in it", or, in broader terms, everything on the site became "surreal". The participant who noted the "surreal" also stated that "this could be what it's like inside a computer game - a pixel slowed down to the speed of snails". This sense of disassociation was interpreted in terms of size and scale by another participant:

"The experience of reminding myself of the relationship between device and satellite had the same impact as when I'm in a space where I can see the stars. I often forget that I'm on a planet… one of many in a much bigger space, and whenever I see the stars it has an impact… so for me it's a slightly humbling experience… this experience has just reminded me of this scope of things, the ecosystem that is my life, the universe… and that came off very powerfully when I sat down and started to look up"

Here the scale of the infrastructure sparked a removal from everyday concerns and created reflection back on the profoundly large space and time of the universe. For him, stars acted as a point of comparison for the presence of satellites, indeed, the comparison also exists in the design nomenclature where an array of satellites is called a 'constellation'.

We would also reflect that, although the aspects specific to GNSS infrastructure (such as scale) certainly contributed to a sense of alienation, the staging of the exercise undoubtedly had an influence. One participant wrote that the exercise felt like a 'techno-derive', betraying knowledge of the work of the situationists. He described how wandering without a task emphasised his sensory experience:

"The thing was, not having to go from 'A' to 'B', it made me acutely aware of my body in relation to the temperature, humidity, sound. All of which could change with the pungent smells from the kitchen air extractors. The magnified distant booming of vehicles unloading, trolleys on prams bashing over textured flooring."

This enhanced sensory experience is similar to that which lead one participant to report an experience felt "at the speed of snails" and betrays the art staging of the experiment, especially to those in the know. Although it may be from a mix of causes, responses of alienation from usual practices were widespread, thereby laying the groundwork for more nuanced engagement with infrastructure.

An Environment of Signals

In taking their attention away from their usual practices, several participants were provoked to think about the presence of electromagnetic signals in their surroundings. This feature of the infrastructure was, again, partially driven by the experiment design and use of *GPS Test*. Through the app, the presence of satellites was revealed, but a secondary effect was the awareness of signal paths which allowed a given satellite to be designated 'in use'. The presence of GNSS signals made participants also consider how rich the air might be with Wi-Fi, cell phone and radio transmissions. Signals became a dominant theme in one of the discussions and appeared in two others. One participant "wonder[ed] what else was around", while another questioned the nature of those signals as a surrounding medium: "the question of how ethereal is this, it's like what are we actually moving through? What's the world that we're existing in and how much of it are we aware of?" For both these participants, the revealed presence of infrastructure raised questions, both of what was there and how it affects them. Another participant made a stronger claim, positing a whole ecosystem, which they, themselves were part of:

"So, you've got like universal background static all the way down to these super-precise signals and very short range signals which are probably coming from like Wi-Fi routers in the building or peoples' phones and it's this whole nested scale of like different kinds of signal which are penetrating your body, your phone, the building around you, and you're also part of that structure in a way, you know, you're accepting, receiving, deflecting all this stuff as well."

This understanding of oneself as a reflective and receptive body within a structure of signals marks something different from initial experiences of alienation. The participant has proposed an alternate system in which the user's body, phone, Wi-Fi and long-range signals are understood as an overlapping and interacting web. It is not clear in what sense this participant would or would not understand this structure as an infrastructure in the terms proposed by Star and Ruhleder [42], but the possibility of placing oneself within a system of ambient, ongoing interactions, leads us to think about what sociotechnical dynamics might emerge out of such an infrastructural awareness.

Dynamics

If it is possible to imagine a wider system of interactions between body, device, a scale of signals and technical objects, we can then ask what dynamics exist within that system. Those dynamics were surely experienced differently by each participant, but nevertheless some common themes emerged.

Every discussion exhibited a strong theme of play and experimentation. Participants chose to describe the activity variously as "hide and seek" or "like walking a puzzle". The process reminded another participant of "not stepping on the cracks when you're a kid". Within the app, when a location fix was possible, all the satellites in use would light up, when it was not, all the satellites would be greyed out. As a location fix provided strong visual feedback to participants, it is unsurprising that they would focus on this action. What does require more explanation, however, is that many of them understood this as play. In some ways, this aspect suggests a more open interaction with the infrastructure, one distinct from typical task-based practices. However, as a game, hide and seek does come with some basic roles and structures around the visibility of the participants.

This act of hiding can be understood in part as testing or, in the words of one participant, "probing" the infrastructure, but it also resonates strongly with another theme which was present throughout all the discussions; the position of GNSS infrastructure within a wider system of surveillance and privacy concerns. While it was noted in the workshops' technical introduction that the satellites themselves are merely emitting signals and they do not 'see' activity on the ground, the trope of spy satellites with observing eyes was persistent (see figure 4). Even without a direct link from satellite to surveillance, participants were aware of the collection of personal data by corporate and state actors further up the data food chain. The asymmetry of power implied by an infrastructure on such a scale did not escape the notice of one participant who referred to the satellite constellation as "the imperial grid" and "the all-seeing eye". While another described it as "kind of scary", reflecting on "possibilities for control and writers like Orwell and how it can be used for good or bad". Another participant voiced more specific concerns, stating that:

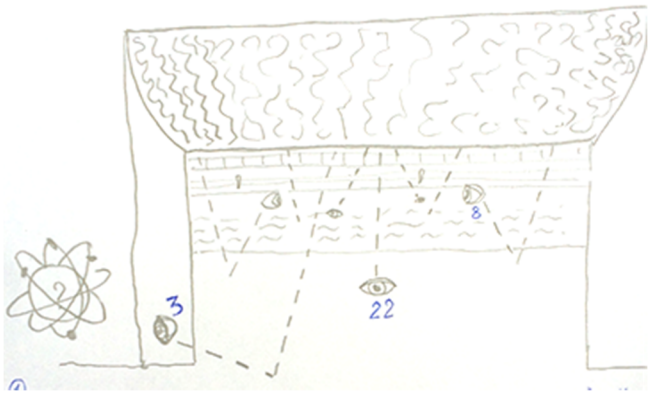

Figure 4. Participant drawing showing satellite signals descending as observant eyes.

"While I don't feel like I do anything where I would be surveilled for that thing, I know that information is used beyond its descriptive capabilities, and so that exercise of state or corporate power is not just in the hands of people who understand the specific limitations of the technology, but also people who have had it explained to them third hand… so I'd rather not leave a trail of breadcrumbs anywhere."

This comment betrays a lack of confidence in both the limits of explanatory power of location data and the ability of data-handlers to recognise those limits. Several other statements were made along these lines including one participant who described a privacy calculus she makes between giving up personal information and having the convenience of a locative service like *Googlemaps*. For her the experiment made her "think about it the other way", that "even though I'm using a service, the service is using me, just as… probably more than it's used by me." The trigger for this reflection was "the visual nature of having something like that in the sky… it brings it home to you, that they're really up there." Here, GNSS infrastructure acted as a stand in, an implicated composite part of a wider infrastructure concerned with tracking the movement of people and devices. The making visible of this infrastructure led her to reflect on the way she forms her usual practices around personal information.

Although this participant experienced the presence of GNSS infrastructure in an unsettling way, others responded to the satellites differently. During the Manchester study, several participants noticed that, despite their best efforts to "hide" from satellite signals, one satellite was more persistent than the others. Number 26 (named from its Pseudorandom noise (PRN) code) was described as "the plucky satellite that was still holding when all the others were vanishing". The persistence of this one satellite, while likely more the result of its position in the sky than any property specific to it, allowed the experience to "become personal", inspiring one participant to report:

"I was almost I don't know, really surprised about how it felt inside, rather than this kind of scientific gadget, cos I'm not a particularly gadget-y person, and I found myself completely transfixed by it."

What is perhaps most noteworthy here is that a "personal" relationship with a satellite can become possible. This is, in part, a result of the power of the visual interface which depicts satellites as distinct, numbered moving dots on a chart. While, strictly speaking, the satellites act primarily in concert, with four signals needing to be received to establish a reliable location fix, the design of the app presents satellites as discreet objects. This reveals the interface's continuing ability to inscribe user responses. Indeed, both the visual interface and other lingering established sociotechnical practices proved influential in other ways.

Visual Interface and Mapping

Features of the app's interface were recreated in several participants' drawn responses to the walk. In one case, the app's bar chart took on other potential meanings, with this participant likening it to a city skyline. Far more common was the presence of numbers in drawn responses. GPS Test's interface features a wealth of numbers, from the PRNs of individual satellites to the tickers for how many satellites are in view and in use. Numbers influenced user experiences to the extent that one participant wrote: "the space becomes a patchwork of numbers". This resulting space was variously understood as meandering (see figure 5) or part of a more ordered mapping process (see figure 6). Indeed, the mapping of space through the permeability of GNSS signals emerged in every discussion. This took slightly different forms, with some shift over whether the mapping would be done for the benefit of users who wanted to "escape" from GNSS signals or, perhaps, as a means for the satellites themselves to map and read the city. In this later case, one participant offered the concept of the "city as braille", a physical language to be read through the touch of signals. In practice this is not possible within the scope of current technology, but it does represent a very interesting dynamic where the user is removed and the focus of sociotechnical practice shifts to the possibility of GNSS infrastructure's actions on other, architectural infrastructures.

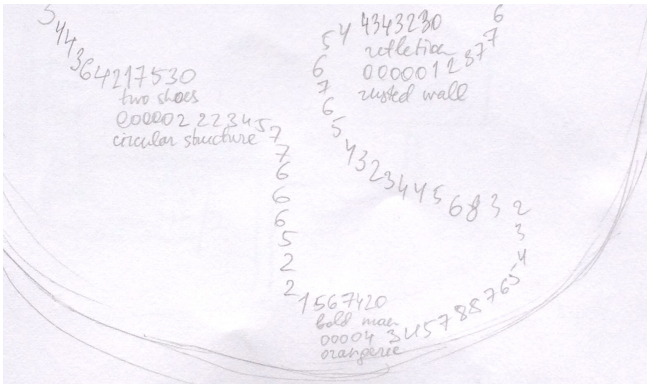

Figure 5. Participant drawing featuring numbers following a rambling route through the site.

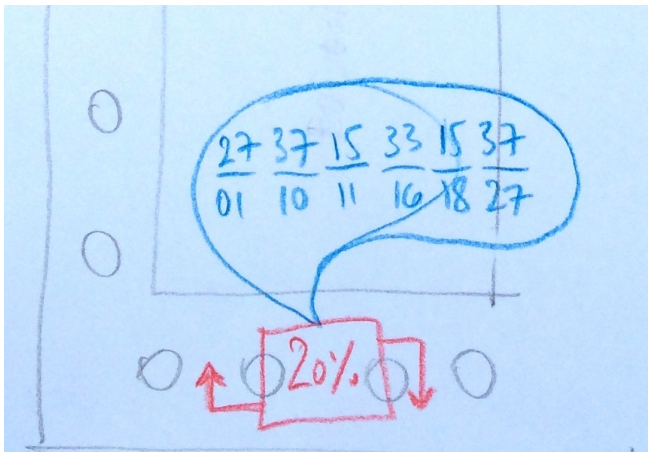

Figure 6. Detail of a participant drawing with an ordered use of numbers and a percentage sense of signal coverage.

DISCUSSION

Throughout the research activities, several alternative user experiences emerged. In this section, we briefly summarise them, reflect on the success of the experiments and discuss their implications for designers.

Firstly, the experiments did alienate participants from their usual sociotechnical practices, in the sense that it reversed the 'gaze' of the infrastructure. Typically, satellites and the technical objects which support them are concealed, but *GPS Test* allowed the satellites' presence to be revealed. This gave participants a new perspective on both the task at hand and the space around them. The experiment allowed participants to explore the effects of architecture on the functioning of GNSS infrastructure through moments of breakdown. As such, movement became a strong interaction mode, participants explored the site, testing different locations for signal strength, an interaction which was frequently described as a game of "hide and seek". This represents a type of the infrastructural inversion proposed by Bowker and Star, although it is limited by certain factors. The full infrastructure was not made visible. Rather, the app reported the presence of satellites and, through that visualisation, implied the presence of GNSS signals. The existence of ground antennas, control stations and the historical development of GNSS systems were not directly revealed through the experiment. Their existence was explained to participants in the introduction to the experiment, but they were certainly less present than other elements. The infrastructural inversion achieved here was, then, not complete, but was strong enough to create affective experiences of embeddedness within an ecosystem of signals and a profound sense of the scale of the infrastructure. Deeper and more wide-ranging infrastructural inversions would likely take considerably more time and commitment from participants. The use of a satellite-focused inversion is therefore incomplete, but offers a type of experiential immediacy which we found to be productive.

The inverted sense of space and practice achieved through the experiment allowed participants to begin to explore themes related to the process of blackboxing. The strongest among them was the idea of privacy. Participants were aware that "state and corporate" actors would be able to track them in their daily movements, but that knowledge had been parsed into the background. When participants stated "this really brings it home that they're up there", or drew a network of eyes coming down from the sky, they were referring to the satellites, but the satellites were acting as a symbol of wider interconnecting infrastructures of location tracking. Participants offered nuanced critiques of such infrastructures and the role their own practices play in them. They mentioned a privacy calculus between being provided with a service and giving up one's information. They also mentioned the ways in which the frequent use of such a technology can lead to "dependency", an interesting acknowledgement of the ways an infrastructure can become invisible through its successful adoption. Participants also acknowledged what Callon and Latour called the "asymmetries of power" [12] around macro-actors, while exploring the ways such asymmetries are negotiated by different groups in different contexts. One participant mentioned the work he undertakes as a researcher using GNSS to track migration patterns of birds, speculating on how the data models he develops could also be used to track humans. In response, another participant noted how, during the recent large-scale migration of refugees across eastern Europe, GNSS had proved very useful to allow people to navigate successfully through an unfamiliar environment. This discussion suggests that the experiment provided a successful prompt for critical engagement with themes generally made invisible by blackboxing. Participants could see the presence of macro-actors and reflect on their influence. As such, our findings suggest that practices which invert infrastructure would be useful in both "empowering" users in participatory design practices [43], while the staging aspect of the work may also provide inspiration for designers working with improvised theatrical approaches [39,50]. The project also points to ways through which designers can reflect on hidden critical issues at play in the design process [9, 41].

The experiment also points to the possibility of conceptualising experiences which do not centre around the user. Participants reflected on possible interactions between GNSS infrastructure and architecture, where, within an ecosystem of signals, the city emerged as "braille", a language of touch which could be explored by signal penetration. If we think of elements of the infrastructure as discreet entities, then satellites could not 'read' the city through this touch as no information is fed back to them. However, if we consider the process of knowing as something which can emerge across an infrastructure, then this proposition makes more sense, providing a way of conceptualizing practices which do not rely on users. The techniques to allow such a shift in thinking are likely to

prove productive in fostering both critical reflection and inspiration as technologies develop which requires less human intervention.

Following Chalmers and Galani, we suggested that seams and moments of breakdown may offer generative potential for designers. From this work, we can offer some thoughts for designers of LBS interested in creating alternative and reflective experiences. We note that the visual interface remained extremely influential in participants' responses. In some cases, they copied elements for their drawings, and in many cases borrowed the trope of numbers to express the operation of GNSS. It may be that an experience design which takes the user away from the smartphone object and its visual interface would offer a more profound alternative to familiar user experiences. Indeed, another interaction dynamic which came through strongly was movement. Participants explored the site by moving between different locations. Nikki Pugh's *Landscape Reactive Sashes* project (discussed in [40]) may provide a useful counterpoint. Pugh had participants walk with two GPS devices. Owing to differences in site and sensor, each produces slightly different location readings. The readings are compared with a high-quality GPS sensor which has a clear view of the sky and participants are informed when accuracy drops by a vibrator attached to a sash hung over their bodies. This project leverages contingencies in the infrastructure to demonstrate that location is not a given and the processes used to establish it have a materiality formed variously from the nature of the sensor and the interplays between sensor, satellite and site. It also offers a promising alternative to the use of a screen. The use of vibration provides the user with less diagnostic information, but arguably offers an experience more distant from their usual practices.

Critical designers may also be interested to note the persistence of ideas of mapping. Participants suggested developing a graded topography of GNSS signal strength as a means of "hiding" from satellites. With dominant sociotechnical practices positioning GNSS as a spatial technology, mapping offers a useful point of leverage for critical designers interested in developing locative experiences which are challenging, yet contain a 'conceptual bridge' [6], to more familiar practices.

Finally, we acknowledge the specificity of our particular method to GNSS infrastructures. We hope however that our experiences will not just inform designers and researchers working with LBS, but rather provide encouragement to those working with other infrastructures. In particular we would reflect on the usefulness of casting attention onto infrastructure as a prompt for reflection on concealed aspects of the design and use of familiar technologies. We would like to see future work which applies and develops these techniques with a wider range of user groups than our useful, but narrow sample of artists and researchers, perhaps combining our approach with other participatory design techniques.

CONCLUSIONS

GNSS technology represents a pervasive, yet embedded and invisible infrastructure for the majority of users. As the infrastructure is blackboxed, power relations become concealed, design inscriptions become stronger and potential for both critical reflection and imagining alternative uses becomes more difficult.

Using a technique built on infrastructural inversion, we offer a potential route for designers and users interested in exploring what lies behind the veil of invisibility cast over GNSS infrastructure by dominant design processes. In applying our technique, we note the persistence of the visual interface in defining practices and modes of use. We also acknowledge practical limits to making extensive aspects of the infrastructure visible. In our case, we concentrated on the positions of satellites which were able to represent themselves and to act as a stand-in for attendant infrastructures already known to participants.

We conclude that, despite its limitations, our technique was successful in alienating participants from their usual practices and providing new perspectives and experiences. We note the specificity of our method to GNSS infrastructures, but encourage researchers and designers interested in exploring the hidden influence of infrastructures to leverage techniques of infrastructural inversion to their case-specific needs. In this spirit, we offer the limitations and successes we experienced as some signposts to all those interested in circumventing processes of infrastructural blackboxing.

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