Seeing the Invisible

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Abstract. In this article we attempt a closer examination of the notion of invisibility as it has been used within the ubiquitous computing community. We seek to tease apart various understandings of invisibility as an emergent attribute of technology use, examining what true "invisible technology" might be, in what ways it is beneficial, and how it might be designed for. We propose a theoretical model consisting of two complementary concepts: invisibility-in-use, the experience of direct interaction with artifacts and tools largely free of conscious monitoring, and infrastructural invisibility, the capacity of physical, organizational, or technological infrastructures to become tacit in the thoughts and actions of human actors. Underlying our approach is the belief that invisibility is fundamentally a phenomenological human construct, an experience of being in the world that is socially and psychologically created by humans as they go about their various activities.

1 Introduction

The last decade has witnessed the emergence of ubiquitous computing, a research effort seeking to make technology "disappear," for it to become "invisible" or "fade into the background." Some researchers address these goals more or less literally, embedding computation into the environment and attempting to make human-computer interaction less apparent, or more "calm" and "natural." Other researchers treat this metaphorically, talking about designing technologies that fade into our conceptual background, the goal being the construction of tools that we work through rather than work with. Still others conflate both these approaches.

Mark Weiser referred to invisible technology as that which is "so imbedded, so fitting, so natural, that we use it without even thinking about it" [20]. Satyanarayanan [15] interprets invisibility as a "complete disappearance of pervasive computing technology from a user's consciousness." Fishkin, Moran, and Harrison [4] envision "a progression towards a more real-world interaction style, where there is no perceived mediation, *i.e.*, an invisible user interface." Norman [13] writes "The computer is really an infrastructure, even though today we treat it as the end object. Infrastructures should be invisible … A user-centered, human-centered humane technology where today's personal computer has disappeared into invisibility."

While in many ways inspiring, these concepts, when taken in aggregate, are ripe with inconsistency. There is a distinct aesthetic appeal to rendering systems physically invisible, but total invisibility, and the lack of feedback and control that implies, is obviously undesirable. From the psychological perspective, designing calm or ubiquitous technologies is clearly a valuable goal, but just what factors are involved in creating and learning such systems are often not elaborated – many times it seems assumed that these technologies will be amenable to a simple walk-up-and-use paradigm. Presumably these technologies will leverage our tacit knowledge[1], but it is unclear how much consideration has been given to the nature and sources of such knowledge.

In this paper we attempt to elaborate two forms of invisibility that lie at the heart of the ubiquitous computing agenda: invisibility-in-use, in which we are "freed to use technologies without thinking and so to focus beyond them on new goals," and infrastructural invisibility, "everywhere computing that does not live on a personal device of any sort, but is in the woodwork everywhere." Underlying our approach is the belief that invisibility is fundamentally a phenomenological human construct, an experience of being in the world that is socially and psychologically created by humans as they go about their various activities. As such, our approach is rooted in phenomenological philosophy, including the works of Heidegger [8] and Merleau-Ponty [12], as popularized within human-computer interaction by authors such as Suchman [18] and Dourish [3]. After introducing these concepts and means by which they can be studied, we present a series of examples to make these concepts concrete and relate them to the ubiquitous computing agenda. We then conclude by dispelling some common misconceptions about invisibility and consider how our framework might be applied to the design of ubiquitous computing systems.

2 *Invisibility-In-Use*

Ranging from pencils to computers, invisibility-in-use refers to the phenomena in which people directly employ tools or concepts without consciously monitoring them; when people work *through* their tools rather than *with* them. These notions have been the object of philosophical and psychological study at least as early as Heidegger's *Being and Time* [8], in which Heidegger uses the terms *zuhanden* (ready-to-hand) and *vorhaden* (present-at-hand) to describe the unconscious and conscious use of tools. The relevance of these concepts to Human-Computer Interaction has been elaborated in works by both Winograd and Flores [21] and Dourish [3]. In a modern adaptation of Heidegger's hammer, Dourish gives the example of computer mouse use: when the mouse is used to complete some task, it becomes an extension of the body used largely unconsciously. However, as soon as the mouse runs off the pad or the wire obstructs motion, it is present-at-hand, becoming consciously present as an artifact in use.

2.1 Studying Invisibility-In-Use

Studies in psychology provide scientific evidence for the phenomena of invisibility-in-use, suggesting tools can cause a fundamental remapping of how action in the world is perceived. In a study of subjects with near-space visual neglect [1], Berti and Frassinetti found that the task of bisecting a line in space could highly depend on the tool used. Participants were told to bisect a line in near-space using a laser pointer

[1] Tacit knowledge: our knowledge and abilities that enter into the production of behaviors and/or the constitution of mental states but are not ordinarily accessible to consciousness. (Adapted from the Dictionary of Philosophy of Mind, http://www.artsci.wustl.edu/~philos/MindDict/)

and were unsuccessful, but succeeded at the task when performing it in far-space. However, when subjects were asked to bisect the line in far-space using a stick, they suffered a similar inability as the near-space case. This suggests that use of the stick caused a fundamental, unconscious remapping of subjects' perception of space. Similarly, psychologist J.J. Gibson, originator of the influential notion of affordances, states in his Field of Safe Travel theory [5] that automobile drivers undergo a perceptual remapping of their mechanisms of obstacle avoidance, normally developed for bipedal motion, to suit the increased size and velocity of automobiles.

A framework for further study of invisibility-in-use can be drawn from existing disciplines such as distributed cognition [14], and valuable insight can also be gained from the psychology of flow [2] and relevant literature in expertise [10]. As ubiquitous computing involves interaction with multiple devices, objects, and other people, holistic psychological frameworks such as distributed cognition will undoubtedly prove useful. In addition, the psychology of flow might better elucidate the loss of conscious attention that is central to invisibility-in-use and the psychology of expertise may suggest how invisibility-in-use arises as a result of learning and practice.

3 *Infrastructural Invisibility*

Computation is already an infrastructural service. The average computer user, whether she is surfing the web, editing a spreadsheet, or playing a 3D video game, is rarely thinking in terms of electrons, logic gates, or machine instructions—computation is effectively invisible. Continuing along these lines, a primary aim of ubicomp is to better infrastructuralize ever higher-level computing services, moving them out of the desktop and directly into more diverse and immediate contexts of use. Yet the challenges of building effectively invisible infrastructures, especially on the grand scale envisioned by futurists and ubicomp researchers alike, have social and psychological as well as technical aspects, all of which are inextricably interrelated.

By infrastructural invisibility we mean the capacity for infrastructure, whether physical, technological, or organizational, to become tacit in thought and action for human users. Creating such infrastructures is not just a function of technological design and engineering feasibility. Standardization bodies [7], negotiation, and (often implicit) categorization structures [17] are all part of crafting an infrastructure. Infrastructures are never completed works, but living, evolving bodies requiring regular maintenance and development. Furthermore, infrastructure and its effects must be adequately understood and leveraged by those within its sphere of influence if it is to be of benefit to society, let alone invisible.

3.1 Studying Infrastructural Invisibility

Historical analysis provides one avenue for studying infrastructure, as done by Thomas Hughes in his study of the rise electrical networks [9] and by Clay McShane in his study of the intertwined history of the automobile and urban America [11]. Two useful concepts to arise from such historical analyses are those of *reverse salients* and *network externalities*. Reverse salient points are "technological, social or political sticking points which can slow the development and design of infrastructure" [17], the solutions of which may cross disciplinary boundaries (e.g., a social solution to a technological problem) and whose resolution can have a defining effect on the infrastructure and its usage. For example, privacy issues present a particularly troublesome reverse salient for context-aware computing. Network externalities concern how the value of an infrastructure (or access to that infrastructure) varies as a function of the number of users, and thus relates to the critical mass problem described by Grudin [6].

While historical analysis can unearth larger trends and events, qualitative fieldwork seems particularly attractive as a means for unearthing the invisible in infrastructure use. Though the use of ethnographic techniques is well known to the HCI community, infrastructure presents some unique challenges worth considering. S. L. Star considers some of the methodological issues in studying infrastructure [16]. Of note is the problem of scale. Ethnographic practices can provide the qualitative results necessary to reveal the mundane and largely invisible interactions with infrastructure that occur, but infrastructural use and development also occurs at a much larger scale, across peoples, organizations, and disparate geographical locations. While logging technologies can collect a wealth of observational data, tried and true techniques for reducing this data into useful, manageable collections have yet to emerge. In light of these difficulties, Star offers advice to the infrastructural ethnographer, including identifying master narratives embedded in the infrastructure and surfacing "hidden" work (*e.g.*, the influence of secretaries in the publishing practices of scientists).

4 Seeing the Invisible

The discussion up to this point has been largely abstract. In this section we present examples describing invisibility-in-use and infrastructural invisibility in real-world contexts. We also discuss how these concepts interact: individual artifacts, potentially experienced as invisible-in-use, can serve as interfaces to an underlying infrastructure.

Weiser's example of reading and literary technology [20] as the most powerful "invisible technology" in use today is a perfect example. Every day, people of modern societies are saturated with text without giving it a second thought, often effortlessly processing and absorbing the surrounding information. This ability, however, is predicated on over a decade of schooling and countless hours of practice. The invisibility of literary technology was achieved over centuries, enabled by numerous innovations (*e.g.*, Gutenberg's invention of the printing press) and maintained today by a vast institutionalized education system. For the educated, reading is a largely invisible activity belying a staggeringly large infrastructure.

Of a more clearly technological nature are the electrical and plumbing systems enjoyed by first-world residents. Both constitute cases of invisible infrastructures—the world of wires, voltage conventions, power plants, pipes, and sewage treatment centers being largely removed from people's daily life. Instead, people interact with such technological infrastructures through interfaces: electrical outlets, light switches, faucets, and toilets. These artifacts are the entry points through which people access the infrastructure, each of them sites at which invisibility-in-use may be experienced. The flip of a light switch can be performed effortlessly, without conscious apprehension of the switch itself, let along the vast infrastructure of power production and management underlying this simple action. Moreover, both electrical and plumbing infrastructures become quite visible upon breakdown, power outages and poor water pressure bringing infrastructural processes and limitations to the forefront of consciousness.

Wireless 802.11 networks provide an example of a successful ubiquitous computing technology already out in the wild. The deployment of such systems requires the installation of access points, management of network access and encryption keys, and user interaction with 802.11 cards and software drivers. Furthermore, these systems are often overlaid upon an existing infrastructure for wired networks, illustrating the layered nature of most successful infrastructures [16,17]. The experienced invisibility of such systems depends on a number of factors, including the available coverage of the network and the amount of user configuration required. For example, the introduction of software that automatically detects local wireless networks, no longer requiring users to know network IDs ahead of time, better facilitates infrastructural invisibility.

Electronic card key readers, increasingly being used in lieu of keys and locks, are another example of a successfully deployed ubiquitous technology. As infrastructure, these systems involve the deployment of RFID readers, connection to a centralized access database, management of permissions, and dispersion of credit-card-sized RFID cards to authorized individuals. This entails not only the requisite technological infrastructure and maintenance, but social structures as well, including bodies responsible for managing access privileges and for approving and funding such systems. This infrastructure carries over into user experience at multiple points: the bureaucratic process users must navigate to acquire card keys and access, and actual physical interaction with the cards and readers.

For example, many of the card readers on our campus are located just below the average waist level, leveraging cultural convention to allow people with the card keys in their pockets (or in a wallet in a pocket) to unlock the door by appropriately walking by the reader. A short period of observation will reveal that this practice is quite common, done habitually and unthinkingly—an invisible infrastructure accessed using cards and readers which are effectively invisible-in-use. On other locations on campus, however, card readers are placed at less convenient heights (such as chest level), requiring one to retrieve the card key and hold it up to the reader. In this case, the difference between visible and invisible technology is about 3 inches.

5 Implications and Conclusion

At this point our discussion still raises as many questions as it has set out to answer. One outstanding issue is how our model of invisibility can be translated into fruitful practices for design. Additionally, a rigid scientific account of the invisible eludes us, and will continue to do so for the foreseeable future. Still, the continuing confluence of psychology and neuroscience and the sustained efforts of concerned social scientists will undoubtedly unearth new understandings relevant to the issue.

The discussion above, though far from comprehensive, helps to dispel a number of common misconceptions about invisibility. First, as convincingly demonstrated by Tolmie *et al.* [19], the concept of invisible interfaces does not in any way imply literal physical invisibility. Such an approach would eliminate the control and feedback mechanisms that are at the heart of good user interface design. Instead, judicious design of appropriate feedback mechanisms and affordances for further inspection and control are needed. The design challenge is to achieve this without unduly overwhelming or unnecessarily distracting users. Second, true phenomenological invisibility, a socially and psychologically constructed experience, cannot be designed into a system. To speak of designing invisible interfaces as such is a misnomer. As in the card key example above, experienced invisibility can be facilitated by design, but its actual achievement is a construct of the human mind, influenced by numerous contextual factors. Third, "invisible" technology does not imply "walk up and use" systems. As in the case of reading or driving automobiles, practices that are effectively invisible-in-use may require long periods of learning and practice. Finally, as presented here, invisibility is an experienced relationship between humans and their tools, whether they are physical or conceptual. Within this relationship there is no inherent value judgment—the tool may be a creative instrument, or it may be a weapon. Rather, it is through the achievement of invisibility in the context of beneficial actions—beneficial independent of their experienced invisibility—that ubiquitous computing hopes to improve the quality of life of technology users.

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