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INVISIBLE COMPUTING

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Abstract

The computer is no longer a tool solely used for enhancing the productivity of organizational tasks. Rather, computing capability now is embedded into our everyday artifacts, enabling our daily activities to become smarter and easier. As a result, the way we interact with computers has radically changed in the past few years: computing is now being designed for activity-oriented users. Thus, as IS and HCI scholars have discussed, computing should be designed to be invisible. By invisible we mean the phenomenon that users are not conscious of the computing that they are using. The degree of invisibility largely depends on user interfaces of computing. The concept of invisibility has been used among IS and HCI scholars. However, detailed analysis on invisibility as a construct has not been conducted. Therefore, in this paper, we will investigate 1) where and how the concept of invisibility has been used in the literature, 2) a new theoretical framework for the concept of invisibility in computing, and 3) how this concept can provide practical implications by applying it to a related case. In this paper, we focus on the relation between computing devices and users at the individual level with respect to degrees of invisibility.

Keywords: Invisibility, Computing, Physical Invisibility, Psychological Invisibility.

1 INTRODUCTION

The computer is no longer a tool solely used for enhancing productivity of organizational tasks. Rather, computing capability is now embedded into our everyday artifacts, enabling our daily activities to become smarter and easier. As a result, the way we interact with computers has radically changed in the past few years. Traditional input and output tools such as the keyboard and the mouse are no longer necessary for interacting with computing devices such as smart phones and tablet computers. Rather, the use of more intuitive interface tools is enabling use to become less conscious (Heer and Khooshabeh 2004). Examples include the use of the stylus or of hands via touchscreen or motion-sensing wireless for more seamless interacting with computing devices. Furthermore, users can interact with computers everywhere, not only via miniaturized, mobile computing artifacts such as smart phones and laptops, but also via everyday artifacts such as smart televisions, music players, and automobiles where computing capabilities (i.e. microprocessors) are embedded.

With this rapid change of human interaction with computers, we are now entering a new computing era where, drawing from Shneiderman (2003), it does not matter what the computer can do, what matters is what users can do through computing. In other words, computing is no longer computing-oriented but activity-oriented. Therefore, computing artifacts for activity-oriented computing should be designed to help users focus on their everyday activities where computing is blended into the unconscious background. Thus, in this paper, we argue that activity-oriented computing devices should be designed *invisible*.

This invisibility concept within the ubiquitous computing stream is found in a handful of literature related to IS or human computer interaction (HCI) (Abowd et al. 2002; Heer and Khooshabeh 2004; Norman 1998; Russell et al. 2004; Weiser 1991; Weiser 1993). These studies argue that as computing becomes smaller, cheaper, and more capable, it should more seamlessly fit the human environment, rather than humans needing to adapt to the computing world. Thus, computing is evolving to the invisible artifacts from the direct, conscious sight of the user.

This process can be applicable for all technologies. For instance, electric power was a highly visible infrastructural technology when first invented (Carr 2003) requiring a large amount of space for its own physical forms wherever it was applied (e.g. huge, localized electric generators). However, as these technologies advanced, they became more ubiquitous, no longer requiring a large amount of space or their own physical forms co-located at the user level. As a result, we no longer directly "see" the infrastructure of generating, transmitting, and distributing electricity even though we rely upon it continuously in everyday actions in, for example, turning on a light, a laptop, or a thermostat. Thus, the "most profound technologies are those that disappear (Weiser 1991, P94)" and now computing is rapidly evolving to being such a "most profound technology".

But then what does it mean for computers to be invisible? The concept of invisibility of computers has been used widely in the field of IS and HCI (Dourish 2004; Streitz and Nixon 2005; Weiser 1993). However, the meaning of invisibility has not been clearly defined in past research. Thus, in this paper, we investigate: 1) where and how the concept of invisibility has been used in the literature, 2) a new theoretical framework for understanding the meaning of the concept of invisibility in computing, and 3) how this concept can provide practical implications by applying it to a related case.

We next introduce dictionary meanings of invisibility and then show how the concept of invisibility is used in three different fields: communication, sociology, and modern art. This is followed by a detailed process developing and presenting the concepts of physical and psychological invisibilities which we present in our framework. Finally, we use our framework for analyzing a case demonstrating invisibility applied to computing.

2 THE CHARACTERISTICS OF INVISIBILITY

2.1 Invisibility in Dictionary

Invisibility is defined in various dictionaries as having a strong relation with vision and perception as shown in Table 1.

Dictionary	Meaning	Relation with
Merriam Webster	Incapable by nature of being seen	Vision
	Inaccessible to view	Vision
	Imperceptible, inconspicuous	Recognition, identification
Oxford Dictionary	Unable to be seen	Vision
	Concealed from sight; hidden	Vision
	Treated as if unable to be seen; Ignored or not taken into consideration	Recognition, identification
Dictionary.com	Not visible; not perceptible by the eye	Vision
	Withdrawn from or out of sight; hidden	Vision
	Not perceptible or discernible by the mind	Recognition, identification
	Concealed from public knowledge	Recognition, identification

Table 1. Dictionary Meaning of Invisibility

From Table 1, the first meaning of invisibility from the three dictionaries is related vision. "Incapable by nature of being seen", "unable to be seen", and "not perceptible by the eye", are all from the perspective of vision relating to the inability to be seen. A second meaning of invisibility refers to something or somebody that is visible but hidden from view. A third meaning of invisibility is that something or somebody is ignored regardless whether it is visible or invisible, which is related to the recognition ability of the viewer rather than being related to vision. In sum, invisibility has two overall meanings: 1) a physical invisibility by not being visible by nature or hidden from the viewer, and 2) a psychological invisibility in not being aware to a viewer due to lack of awareness.

2.2 Invisibility in Three Different Fields: Communication, Sociology, and Modern Art

In this section, we introduce and review the literature from three different fields where the concept of invisibility is applied: communication, sociology, and modern art. Drawing from the dictionary meanings of invisibility, commonalities of how invisibility is applied among these different fields are identified and explained. We focus on the most relevant cases in the three fields that most clearly illustrate the transition of invisibility from physical to psychological dimensions.

In the field of communication, the concept of invisibility is strongly related to visibility with both concepts dependent on information asymmetries. Specifically, information asymmetries between two parties make particular information more visible by one party compared to the other. At the same time, the party may hide some information (i.e. making the information invisible) from the other party to modify its image. Usually, in such situations, the party modifying its images is outnumbered by the many other parties observing these modified images (Brighenti 2007). Thus, the modified visibility/invisibility forms the public images of the party.

As media technologies (e.g. television, Social Network Service (SNS), and radio) have advanced, the observing party has grown to large numbers of people, sometimes reaching into the millions and beyond. Therefore, invisibility/visibility has now become a supply & demand market. In such a market, invisibility/visibility is strategically modified taking into account the value of the content. In other words, invisibility/visibility is now liberated from "spatial-temporal properties of here and now" thanks to the use of media technologies (Thompson 2005, p.35).

An example of invisibility/visibility modification is as follows. In South Korea, when the presidential election-day approaches, it is common that the candidates go to the market places and eat cheap food, while chatting with ordinary people in order to attract voters. These images are then delivered to the

viewers via media technologies such as SNS, television, and the Internet, while other information (e.g. their privileged life style) is hidden from the viewers. This simple approach is usually successful. As Goodwin (1994) argues, now the invisibility/visibility is socially crafted by particular ways of seeing. Furthermore, once the public image is formed and shared in society, it can be lasting. To summarize the process, viewers first physically see the modified information without seeing the invisible information (i.e. physical invisibility/visibility). This modified information then forms the public perception of the politician (i.e. psychological invisibility/visibility).

Sociology is another field that has used the concept of invisibility/visibility, particularly, dealing with problems of ethnicity (Bryce-Laporte 1972; Johnson et al. 1971; Pagallo 2010; Wing 2007) and social identity (Brighenti 2007; Edwards 1999; Simpson and Lewis 2005). Here, the concept of invisibility mainly means a minority group's lack of recognition from the larger society. We believe that the invisibility/visibility in these fields also has the same kind of pattern as that in communication field. In the 1960s and 1970s in the United States, African Americans were segregated from white people in most settings including education, occupation, and housing. The opportunities for this minority group to get higher education were rare. The occupations of African Americans, therefore, tended to be lower paying and of lower status, and the demand for these jobs could not be met without them being filled by minorities. In addition, residential areas were segregated. As shown in this example, the majority group wanted the minority group to be invisible, so that the former group could function in a segregated society.

Therefore, in sociology, particularly focusing on racial problems, invisibility first occurs with physical discrimination. African Americans have low status jobs, while majorities have high status jobs. Thus, they were systematically prevented from attaining higher positions in society. In higher education, the participation rate of white students was far higher than that of African American students. Also, African American neighborhoods were physically isolated from white neighborhoods. All of these components resulted in the social perception that African Americans were hidden minorities in society, creating the perception of being invisible. The same overall process is observed here, as in the previous example: 1) African Americans were physically discriminated (i.e. physical invisibility) and 2) in the larger society, they were perceived to be invisible (i.e. psychological invisibility).

In the field of modern art, the concept of invisibility/visibility has also been studied. Klee and Klee (1968) argued that "art does not reproduce the visible; rather, it makes things visible". The purpose of art in this view is not to reproduce the visible, but to make visible the invisible that exists in the between-dimension of observer and the art being observed. For instance, a modern sculpture of a small rectangle that is made of wood is exhibited with the artist's explanation. The artist has a particular interpretation about the sculpture. Art viewers observe the piece and read the explanation, which is the only visible explanation of the work that is available. They, therefore, interpret the invisible part of the art piece as it is related by the artist. This process allows the viewers to see the invisible created between the viewers and the art. Careful observation of this process shows that the invisibility is not the opposite concept of visibility. Merleau-Ponty (1969), a French philosopher, argued in his work "the Visible and the Invisible" that what Klee and Klee meant was that the invisible is not an opposite concept of the visible. Rather, the invisible is the depth of the visible. In other words, the invisible functions as a fundamental source for the visible. The same recognition process occurs in this modern art example as in the previous examples. The art is first exhibited to the viewers (physical invisibility/visibility). Then, another dimension of invisibility/visibility is formed internal to the viewer, which is much more psychological (i.e. psychological invisibility).

After careful observation of these invisibilities, we realized that physical invisibility occurs first, followed by the formation of psychological invisibility resulting in our Characteristics of Invisibility Framework shown in Table 2. For instance, in the field of communication, the modified physical invisibility/visibility of someone/something is first observed by communication media, and then the perception of someone or something is formed. In Sociology, physical discrimination leads to the psychological perception of being a minority. In Modern Art, the physical invisibility/visibility are sources of psychological invisibility/visibility. In the next section, we apply the definition of invisibility to computing and provide specific examples.

Field	Characteristics of Invisibility Framework	
	Physical Invisibility	Psychological Invisibility
Communication	Modified images via communication technologies	Perception formed among viewers
Sociology	Physical discrimination of minorities	Perception of minority formed in the larger, majority society
Modern Art	Art exhibited to the viewers	Viewer's perception about the art is formed internal to each viewer

Table 2. Characteristics of Invisibility Framework

2.3 Invisibility of Computing

We next explain the concept of the invisibility of computing. As observed in the development of our framework in the previous section, invisibilities of other fields including communication, sociology, and modern art can experience the same patterns where physical invisibility develops first, followed by psychological invisibility. We, therefore, expect the invisibility of computing to follow the same process

Using examples from Polanyi's tacit dimension, in this section, we explain how 1) physical invisibility, and 2) psychological invisibility of computing occurs. As mentioned in introduction, IS and HCI scholars have studied the notion of invisibility (Dourish 2004; Heer and Khooshabeh 2004; Norman 1998; Weiser 1991; Weiser 1993). However, as far as we know, detailed analysis on invisibility has yet to be conducted. In the field of IS, Yoo (2010) explains the concept of invisibility with the notion of embodiment that roots from the philosophy of phenomenology (Heidegger 2008; Merleau-Ponty 1996). The author argues that the embodiment relationship means that technology that comes between users and the world mediates experiences of users. Thus, the user directly experiences computing as an end in itself, or as part of an end rather than as representational objects of something else real, or experiences it in the virtual world (i.e. in the realm of the imagined). Directly experiencing technology means that technology itself is the end through which users are mainly focused. Yoo (2010) calls this "experiential computing" and argues that, to be an end, the technology should be embodied in our everyday lives. That is, technology mediates the everyday experience of users in four dimensions including time, space, other actors, and things. We believe this embodiment concept is the essential part of computing design that leads to the invisibility of computing. To summarize, when computing is perfectly embodied in all or part of the four dimensions (i.e. time, space, other actors, and things) of our everyday lives, computing becomes invisible to the users.

We next explain the process of invisibility forming between users and computing devices in more detail. For this purpose, we will use the concept of the tacit dimension that explains well the invisibility forming process in great detail. The tacit dimension was coined by Polanyi (1969; 2009). According to the researcher, the tacit dimension consists of three coefficients including the person (let's call it A), the activity (C), and something (B) that is endowed to give meaning to, or integrated to give meaning to the activity (C). Thus, when A endows B with meaning to bear on C, the integrated B loses its bodily characteristics and, thereby, becomes transparent (i.e. invisible). This simple pattern, we argue, can explain the process of the formation of invisibility.

Polanyi considers the activity (C) as the focal activity, and B as subsidiaries of this focal activity. The B coefficient is not necessarily one subsidiary but usually more than one. Therefore, the actor still needs to focus on each subsidiary, but the focus is to manage the focal activity as a whole, rather than to perform each subsidiary well. Thus, in order to perform the joint performance (C) well, the actor's attention should stay on the joint activity (C), rather than on each subsidiary (B). For instance, when a pianist (A) performs, he or she focuses on whole performance (C) rather than separately on each of her fingers (B), the score (B), or the audience (B). That is, the attention to each subsidiary such as her fingers, the score, and the audience should be in his or her tacit dimension. Therefore, the training for each subsidiary activity should be done before the joint activity (C) starts. Unless subsidiary activities are trained well before the performance, the pianist would have to think about each of the subsidiaries (B) such as her fingers touching the keyboard, reading the score, and the audience during the

performance (C). Hence, the pianist would have a hard time focusing on her performance jointly, which would likely result in an overall unsuccessful performance.

When users (A) perform activities with computing devices, the same pattern takes place. Their activities (e.g. reading, listening to music, and gaming) via computing devices are the focal activities (C) and manipulating computing devices including hardware, operating system, apps and all other things are subsidiaries (B). As Polanyi argues, each subsidiary needs to be a tacit dimension of users. That is, users should not pay much attention to manipulating them, because that interrupts their focal activities such as reading, gaming or listening to music.

Here, the physical interaction with computing devices is what determines the degree of physical invisibility. Since user interfaces are where the physical interaction occurs, we believe the design of user interfaces is an important part of study on invisibility. The computing device includes hardware, software, operating system, and apps, and each of them has a user interface that also needs to be closely bundled with each other.

Once physical invisibility forms, regardless of whether it is a high or low degree of invisibility, it transforms into psychological invisibility. As users are more trained to use computing devices, the actor (A) does his or her own activity (C) without focusing on each subsidiary (B) including manipulating hardware, software, or the operating system. That is, the users psychologically do not see the computer that they are using because the subsidiaries of manipulating computing devices are in the tacit dimension. Therefore, as Yoo (2010) argues, computing devices will be perceived by users as an end object or part of an end.

To summarize, the development of physical invisibility is followed by the development of psychological invisibility. When users first interact with interfaces of computing devices, physical invisibility forms. At this stage, users need to learn how to manipulate these interfaces. As they become familiar with the interfaces, psychological invisibility occurs. That is, users feel that they are performing their activities, in which computing is perceived as part of the end object or end object itself.

3 A CASE OF INVISIBILITY OF COMPUTING

3.1 User's Two-Phased Invisibility Process

We next provide a specific case of computing invisibility that shows how physical and psychological invisibilities forms per our framework. When a person buys an iPad, he or she first learns how to use the tablet (B) including turning on the device, getting familiar with the touchscreen, downloading apps, etc. Then, the user, which is the actor (A), downloads apps from the App Store. For simplicity, we assume that the user uses the iPad for reading books, which is here the focal activity (C). Thus, the user downloads a Kindle app and learns how to use the app (B) once he or she finishes learning how to use the iPad (i.e. hardware). Since the Kindle app coupled with the iPad is designed to help users to easily and intuitively manipulate the app, users are likely to learn how to use it without much difficulty.

In this scenario, the user's feeling with respect to each component of the computing device determines physical invisibility. By user's feeling, we mean the degree that the user consciously thinks of each component needed for computing. Therefore, physical invisibility forms with the user's feeling with the computing device at a relatively early stage. After all of these processes are done, the user now reads books that actually consists of several subsidiaries (Bs) including manipulating the iPad (i.e. hardware), manipulating the Kindle app (i.e. software), and reading letters in a book. When the user becomes familiar with all of these subsidiaries, he or she is able to mainly focus on the focal activity, while subsidiaries are being operated in the user's tacit dimension; that is, they are unconsciously operated. As the user (A) reads books (C) with the iPad over time, he or she starts to see the iPad not as a computing device, but as a reading tool that is an end object in this context. That is to say, psychological invisibility forms with the user who psychologically perceives the iPad as his or her reading tool. In this stage, the subsidiary activities including manipulating the iPad as hardware,

manipulating the Kindle app as software, and reading letters in the book are integrated seamlessly in the user's tacit dimension so that the user is unconscious of them.

Thus, this example demonstrates that physical invisibility develops first which is the result of not only the experience of using the computing device, but also the user's physical interaction with the iPad, (i.e. hardware), the Kindle app (i.e. software), and operating system.

3.2 Increasing Physical Invisibility on User Interfaces

Having analyzed the general process of forming invisibility that consists of physical and psychological invisibility through our framework, we now explain how the degree of physical invisibility forms in more detail. As previously explained, what determines the physical invisibility of computing devices is the user interface perception. All digital products, including the computer, consist of four layers containing hardware, network, operating system, and applications (Yoo et al. 2010),. Since we are dealing with the interaction between computing devices and humans at the individual level, we will focus on hardware, applications, and the operating system. Each of these components has a user interface. First, hardware is where the user enters input into the system and displays output in readable forms. For instance, a mouse and keyboard are input tools and monitors and speakers are output tools. Second, applications are designed for particular tasks, for which users manipulate the application with specified input and output interfaces that are usually bundled with hardware interfaces. For instance, Microsoft Word shows its output via monitors and the letters need to be typed by input tools such as a keyboard, which is a hardware interface. Finally, the operating system also has an interface to manage computer hardware resources.

To be invisible, interfaces should be designed to help users focus on their own activities rather than spending energy to manipulate the computing devices. That is, the interface has to be more intuitive and directive. Computing interfaces have been developed over the decades. When personal computers first became popular, command-line interfaces were mainly used requiring commands to be typed using a keyboard. With command-line interface, users had to focus on typing the input, hence computers were clearly visible to the users. What followed was the graphical user interface (GUI) that uses the metaphor of real world objects. With GUI, the real world object is graphically represented in the output tool such as monitor. And, input tools such as keyboards and the mouse are used to manipulate the object. Since GUI is limited to two dimensional representations, users have to focus on the output tools like the monitor, which in turn prevents them from focusing on their subsidiary activities.

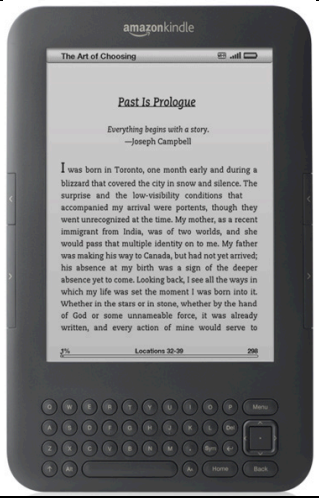
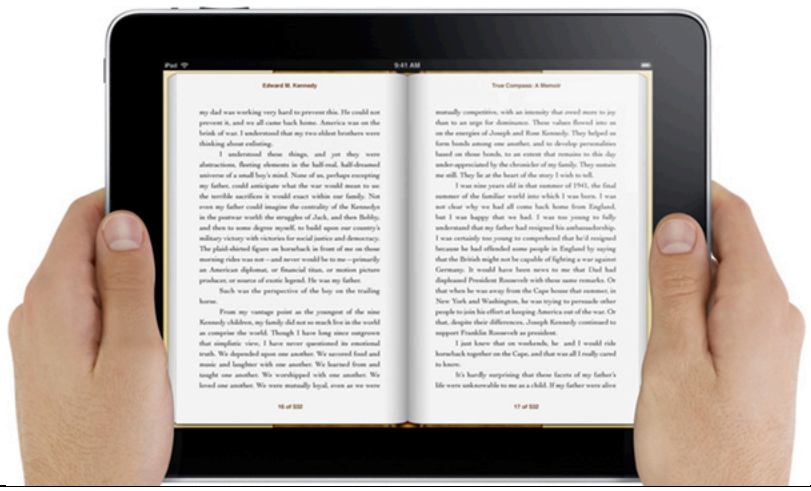
Kindle Keyboard	iPad with Kindle App
	

Figure 1. Kindle Keyboard and iPad with Kindle App

The natural user interface (NUI) is being developed and applied to portable computing devices that are more intuitive and directive than previous types of interfaces. NUI does not use the metaphor of

objects but becomes the object itself. Intuitive input tools such as touchscreen and stylus are good examples of NUI. For NUI allows the users to manipulate the computing device in the same ways as we do our everyday artifacts. Also, the input and output tools are designed to function together with an end object, which is usually the computing hardware itself. Thus, users are able to focus on their activities rather than spending energy to consciously manipulate the computing devices. The Kindle keyboard and iPad are good examples to compare NUI with GUI. As shown in Figure 1, the Kindle Keyboard requires the user to use input tools like the keyboard and some buttons on the device for manipulating the device; the output is represented on the screen. Thus, users are likely to perceive the Kindle device as the computer. In contrast, the iPad with the Kindle App allows users to manipulate it in the same manner as they do for paper books. For instance, users turn pages using their fingers on the screen, and the device itself through the Kindle application and iPad hardware are closely coupled functions as a book (i.e. the object). Users are therefore able to feel that they are reading a "real" book rather than thinking that they are manipulating a computing device. As a result, computer is invisible to the users.

In summary, this paper examines the concept of invisibilities in different fields including communication, sociology, and modern art. The findings from reviewing the literature in these fields show that invisibility physically forms first and then psychological invisibility follows. The case comparing iPad with Kindle Keyboard explains the process of how invisibility forms in detail.

4 FUTURE RESEARCH PLAN

In this paper, we investigate the concept of invisibility by first describing how physical and psychological invisibilities form drawing from the three fields of communication, sociology, and modern art. From this investigation, we develop a new theoretical framework for analyzing the concept of invisibility in computing. We will next apply our framework in order to further develop the concept of invisibility in computing. Specifically, we will conduct an empirical study by measuring physical and psychological invisibility in order to show how these two invisibilities influence each other as well as other IS constructs. In addition, for greater depth of understanding invisible computing, we will compare this concept with such analogous aspects as 'ease of use' and 'habit'.

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