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Making ubiquitous computing available

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The field of ubiquitous computing was inspired by Mark Weiser's [11] vision of computing artifacts that 'disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it'. Although Weiser cautioned that achieving the vision of ubiquitous computing would require a new way of thinking about computers, that takes into account the natural human environment, to date no one has articulated what this new way of thinking is [3]. Here we address this gap, making the argument that ubiquitous computing artifacts need to be physically and cognitively available. We show what this means in practice, translating our conceptual findings into principles for design. Examples and a specific application scenario show how ubiquitous computing that depends on these principles is both physically and cognitively available, seamlessly supporting living.

The term 'ubiquitous computing' has been used broadly to include pervasive or context-aware computing, anytime-anywhere computing (access to the same information everywhere) and even mobile computing. Work on this 'ubiquitous computing' has been largely application driven, reporting on technical developments and new applications for RF(Radio Frequency)ID technologies, smart phones, active sensors, and wearable computing. The risk is that in focusing on the technical capabilities, the end result is a host of advanced applications that bear little resemblance to Weiser's original vision. This is a classic case of not seeing the forest for the trees.

In this article, we want to take a walk in the forest, that is, to suggest a new way of thinking about how computing artifacts can assist us in living. In doing this, we draw on German philosopher, Martin Heidegger's, analysis of the need for equipment to be 'available' [1]. While several influential studies in Human-Computer Interaction (HCI) have also drawn on Heidegger and the concept of availability, these studies have focused on *physical* availability. While going some way to identifying and addressing the problems that Weiser identified with traditional computing, they have not gone far enough. Delving deeper into Heidegger's analysis, we can explain why artifacts designed using the traditional model of computing tend to get in the way of what we want to do. This leads us to refine the concept of *physical* availability and identify the need for computing artifacts to also be *cognitively* available.

We will first draw on Heidegger to explain why it is that computing artifacts designed according to the traditional model are often a hindrance rather than a help. The traditional conception of how we use computing is based on a particular understanding of human action, which we have referred to elsewhere as the 'deliberative theory of action' [2]. According to this deliberative theory of action, humans reflect on the world before acting. Traditionally computing artifacts are designed to assist us through providing a representation of the world which we can reflect on before action [10]. In other words, the traditional computing artifact requires us to move away from acting in the world to 'use' the computer. In the case of the desktop computer, there is an obvious physical move away from acting in the world to 'using' the computer. Mobile technology can bring the computer to the person in the form of laptops, handhelds and so on. However, as Figure 1 illustrates,

mobility, in and of itself, does nothing to remove the dichotomy between reflecting *on* the world and acting *in* the world.

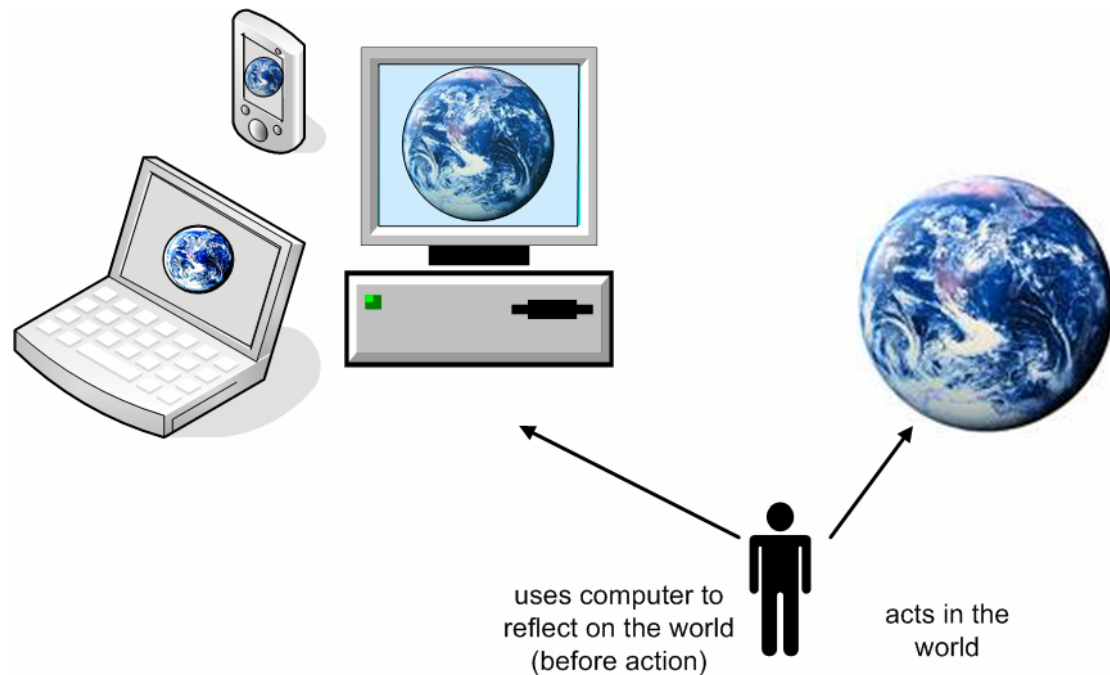


Figure 1: Traditional model of computing takes us away from acting in the world

We consider that Heidegger's account of how we act in the world is a truer account of everyday activity than the deliberative theory of action implicit in Figure 1. According to Heidegger's situated theory of action, we are already thrown into the world, continually responding to the situations we encounter. This means that in everyday activity we seldom achieve the level of detachment that allows us to make reflective decisions before we act. Suchman [7] implicitly draws on Heidegger to argue that, because we are absorbed in coping with the present, we do not have time to form a mental model about how to use technology. This analysis has strongly influenced HCI; however, it does not fully address the problems with the traditional model of computing. In order to articulate a model of computing appropriate for the task of achieving Weiser's vision of ubiquitous computing, we need to probe further into the situated nature of action and draw explicitly on Heidegger's characterization

of equipment that is 'available' [1]. (The original term 'zuhandenheit' is sometimes translated as 'ready to hand'.)

Heidegger describes as 'available' that equipment which helps us to deal with the present without interrupting the flow of absorbed coping. Equipment that is available disappears from our awareness. It is only when the equipment doesn't work as expected that it is noticed. Heidegger gives the example of a hammer that is too heavy for the task of nailing a piece of wood. In this case, the user's attention is drawn away from the task and to the hammer itself; in particular, the fact that the hammer is too heavy. Because the hammer is no longer 'available', the user has to find another hammer or find some unfamiliar way of using this heavy hammer before they can proceed with the task of nailing a piece of wood. Whether equipment is 'available' or not depends on a combination of the design and location of the equipment, the user's familiarity with it and what they want to use it for; in other words, the term 'available' describes a relationship between the equipment, the user and the task. Although availability requires physical proximity to the user, it is much more than this. Equipment that is available as we use it allows us to focus on what we want to do. This is in contrast to equipment that gets in the way of what we want to do, so that we have to deal with the equipment first.

When the activity involves the need to know about something, for example, knowing what to do next, then a new aspect of availability is involved. Whereas *physical* availability depends on a combination of the physical design and location of the equipment, the user's familiarity with it and what they want to use it for, *cognitive* availability depends also on the amount of interpretation required to use the

equipment. This is trivial in the case of a hammer, but not so in the case of computing artifacts. In order for computing artifacts to support our focus on what we want to do, they need to be both *physically* available and *cognitively* available.

As the following discussion shows, those within HCI have recognized that the level of availability of the traditional computer is a problem that needs to be addressed. However, because no distinction has been made between physical and cognitive availability, the proposed solutions do not adequately address the issue of designing to improve *cognitive* availability.

Both Weiser and Norman have criticized the design of the traditional computer as getting in the way of acting in the world. Weiser says that the traditional computer ‘fails to get out of the way of work.....Rather than being a tool through which we work, and so which disappears from our awareness, the computer too often remains the focus of attention’ [12:76]. As Norman comments in his book The Invisible Computer, ‘I don’t want to use a computer, I want to accomplish something’ [6:75].

Norman’s focus, and that of HCI in general, is on *physical* availability and how the physical availability of artifacts can be increased through exploiting physical affordances in the design of the computing artifact [5]. Exploiting physical affordances goes some way to increasing *cognitive* availability, but it does not go far enough.

Furthermore, approaches under the rubric of ‘ubiquitous computing’ have generally also failed to address the issue of improving *cognitive* availability. For example,

'anytime anywhere' computing is a literal translation of ubiquitous computing, emphasizing access to the same information everywhere, whether by computers located everywhere or users carrying a mobile device. It is basically the traditional model of computing on a grand scale.

Lyytinen and Yoo [4] consider that the problem with anytime, anywhere computing is that the computing model does not update as we move location. In their work on pervasive computing, they suggest that the way to make the computer invisible is for the computer to automatically update its model of the world from information it obtains from the environment in which it is embedded. However, although this overcomes the need for unnecessary data entry, it still does nothing to increase cognitive availability. A computing artifact is still not available if we have to turn our attention away from what we are doing to using the computing artifact.

In particular, having to interpret a model of the world is disruptive to the flow of situated action. It takes the user's attention away from what they are doing to a model of the world. This means that the user has to do interpretive work to extract the relevant information before proceeding with what they were doing. Computing artifacts that rely on a representation of the world are, by their nature, not cognitively available. Delving more deeply into Heidegger's analysis of how we are dynamically situated in the world assists us to conceptualize more fully how we can design technologies that are cognitively available.

We have characterised Heidegger's analysis of the situated nature of action as describing our state of being thrown into the world and coping with the present.

However, as Figure 2 shows, there is also a *future* aspect to our dealing with the present. According to Heidegger, we as human beings, are simultaneously:

- a) already existing in the world with particular interests (often translated as ‘thrown’);
- b) absorbed in coping with the present (often translated as ‘amidst’);
- c) pressing forward into future possibilities (often translated as ‘projecting’).

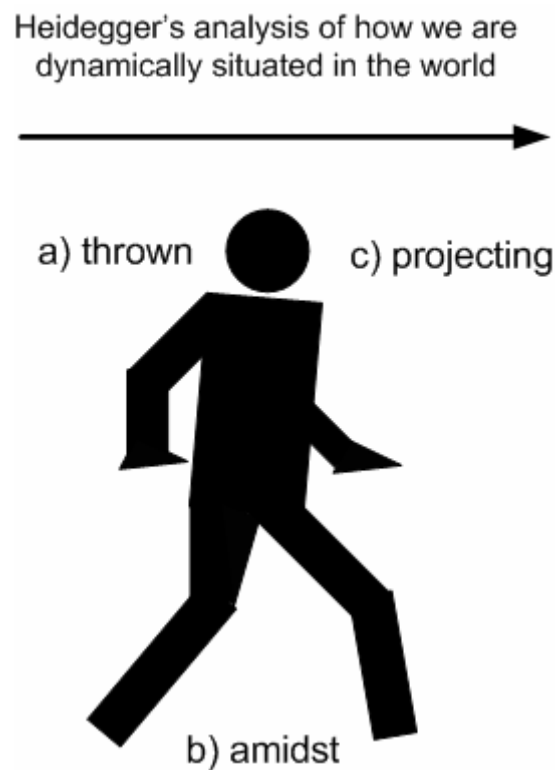


Figure 2: Three aspects of how we are situated in the world

This orientation towards the future means that our everyday action in the world is guided by what we perceive to be the opportunities for action. We will now show how we can build on this idea to suggest a way of increasing the availability of computing artifacts. In this, we draw from the findings of our project to develop a radically new approach to information system analysis and design, which is informed by the situated theory of action [2, 8]. This work shows how a situated approach to systems analysis

and design demands a focus on action and how this focus on action leads to a different understanding of how best to provide information support. Unlike traditional systems which are designed first and foremost to provide information for managing, the primary purpose of situated systems is to support routine action in work systems.

Unlike traditional systems, the situated systems approach does not propose to support action by providing a representation of the world. Rather it supports action by providing the actor with direct access to the possibilities for action (affordances) present in the actor's environment. Of course, in this context, the affordances relate to actions which will help achieve the goals of the work systems. There are two aspects to this support: making the affordances present and making the affordances known. The first aspect is realized through manipulating environmental structures to control which actions are actually feasible for the actor. The second aspect is realized through indicating what actions are feasible. In other words, the environment of the actor is manipulated so that only relevant actions are possible and the actor is informed that an action is possible without needing to refer to a representation of the state of the world.

The following applies these insights from situated information systems to the design of computing artifacts and applications in order that ubiquitous computing can be truly available to the user. Rather than making the computing artifact/application itself the focus of attention, design of ubiquitous computing should centre on the following two principles: making the possibilities for action present and making them known. On the one hand, making the possibilities for action present increases *physical* availability. In contrast to previous work in HCI which has focused on designing the artifact so that it is likely to be more physically available in use, this principle

involves manipulating environmental structures to control which actions are actually feasible for the user (so as to facilitate achievement of their purpose). On the other hand, making the possibilities for action known increases *cognitive* availability. It involves indicating to the user what actions are possible in that place and that moment. In this way, the attention of the actor remains attuned to the action rather than being diverted to a model of the world.

Some examples should make these two principles clearer. Indeed, as mentioned at the start of this paper, this new way of conceptualising how computing artifacts can best support activities is already implicit in the design of some applications considered to be part of the ubiquitous computing vision. For example, the first principle of the computing artifact altering the structures of the environment to control possible actions is implicit in the design of smart spaces which manipulate the action possibility space. These smart spaces can adjust the lighting, temperature, and airflow in response to the numbers of people in the room and so facilitate particular activities in the room. Similarly smart security systems respond to the detection of authorized human beings and unlock doors to enable entry or exit.

The second principle of computing artifacts indicating the possibility for action is evident in a handheld navigational aid that tells the user when to turn (in other words, indicates the possibility for a relevant action). Such a navigational aid is likely to be more cognitively available for a user who wants to know when to turn than a handheld navigational aid that depicts a map which the user must interpret. Similarly, there have been projects to develop artifacts which alert the user when an opportunity arises to interact with a person who has similar interests.

When the two principles are applied in a coordinated way, they have the greatest effect in increasing the availability of ubiquitous computing. We will base an illustration of this on Eric Dishman's work at Intel concerned with finding ways to support people with cognitive impairment [9]. In this example, the ubiquitous computing artifacts assist through application of the two principles: indicating the possibility of action and manipulating the space of possible actions.

Imagine an older person is suffering episodes of mental confusion but wants to remain living independently. Active RFID technology can be used to detect discrepancies in the execution of simple tasks such as making a cup of tea. When apparent that the person is having trouble, the system provides voice assistance as to what to do next. Depending on the extent of confusion inferred, further stages of assistance can reduce the opportunity for dangerous actions; for example, automatically locking kitchen cupboards that contain household poisons.

As we have discussed, making ubiquitous computing available is not limited to a single user. The concept can be applied to the design of systems; through informing and enabling action, a network of devices can support the coordination of time-constrained operations in enterprises [8].

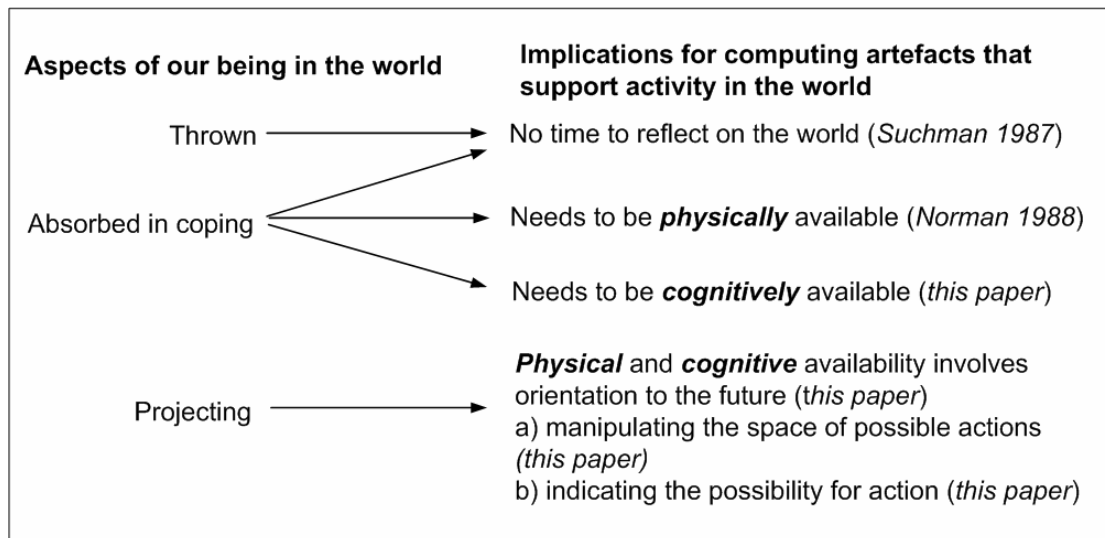


Figure 3: Implications of the nature of being for the design of computing artifacts

Figure 3 summarises what is needed in order to achieve Weiser’s vision of ubiquitous computing artifacts that disappear from our awareness as we use them. Because we are absorbed in coping with the situations we encounter, ubiquitous computing artifacts need to be designed for both physical and cognitive availability. Because our way of being orients us towards future possibilities, physical and cognitive availability involve an orientation towards the future.

In the absence of articulation of these conceptual guidelines to increase the availability of computing artifacts, research in ‘ubiquitous computing’ has proceeded in an ad hoc way and in a variety of directions. Although increasing cognitive availability is already implicit in the design of some new technologies, other ubiquitous computing technologies involve merely extending the representational capabilities of the computer. For example, despite the potential of RFID technologies to inform users about possible actions, there is much work on RFID applications which merely has the goal of widespread use of RFID tags to associate objects with a representation.

Existing technological capabilities provide the potential to fulfil Weiser's vision. What has been needed is articulation of concepts that will enable designers to consciously design for physical and cognitive availability. Drawing from our work on developing a situated approach to information systems analysis and design, we have presented two ways that ubiquitous computing can be truly available – firstly, through manipulating the space of possible actions and secondly, through indicating the possibility for action. Only when there is a conscious effort to design ubiquitous computing to be both physically and cognitively available, will ubiquitous computing seamlessly support our everyday activities.

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