A Cognitive Meta-Analysis of Design Approaches to Interruptions in Intelligent Environments

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ABSTRACT
Minimizing interruptions to users is a crucial and acknowledged precondition for the adoption of new intelligent technologies such as ubiquitous and proactive computing. This paper takes a step toward achieving a consensus among the numerous existing approaches addressing the challenge posed by interruptions. We start by explicating why interruptions are considered important. We then reveal similarities and differences among the approaches from a cognitive viewpoint. It appears that the approaches draw from different assumptions about human cognition. Some of the approaches contain inconsistencies. The cognitive analysis also inspires directions for future work.

Categories & Subject Descriptors: H5.2 [**User Interfaces**]: Theory and methods.

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INTRODUCTION
After over 10 years of research in intelligent environments (IE) [13], the field now seems to be in a state of conceptual balkanization. Currently, there are at least 15 named *design approaches*. Consider, for example, proactive, ubiquitous, pervasive, mobile, situated, wearable, ensemble, invisible, context-aware, peripheral, and calm computing, ambient intelligence, disappearing computer, attentive and intelligent user interfaces, and personal technologies, each having their proponents. Consequently, it is difficult for us researchers to get an overall grasp of the field.

In this paper, we argue that designing disruption-free interaction is a central *design problem* for IE and "technology beyond the desktop" in general [13]. The problem is shared by many of the approaches but also allows for distinguishing between them. In this paper, we first explicate the problem of interruptions and then investigate and evaluate, from the point of view of cognitive psychology, how some of the most prominent approaches have addressed the problem.

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What We Mean by Intelligent Environments?
By *intelligent environments* we mean technological augmentation of user's physical surroundings with systems or devices that are able to respond to user activity. This technology aims to provide services and control over processes, and support decision-making and other cognitive needs. Responsiveness and adaptation are based either on preprogrammed heuristics or real-time reasoning capabilities. All the approaches mentioned in the introductory paragraph fit at least partly into this characterization. For the purposes of this paper, intelligent environment serves as an umbrella term for talking about the approaches with one term.

WHY INTERRUPTIONS IS AN IMPORTANT DESIGN ISSUE FOR INTELLIGENT ENVIRONMENTS?
IE will be in homes, lecture halls, gardens, schools, city streets, cards, buses, trams, shops, malls etc. In other words, elsewhere than at the desktop. As these use contexts inherently involve many sequentially and simultaneously performed tasks, they can be called *multitasking contexts*. *Frequent task-switching* is an unavoidable implication of such multitasking. Because the resources of attention are limited, we must switch back and forth between tasks and information sources, leaving the switched-from tasks temporarily on hold. Successful multitasking is a complex cognitive achievement, requiring planning, timing, monitoring, and control of action. Sometimes we cannot know, without task-switching, whether the switched-to task is worth switching to. These temporary shifts of attention to irrelevant or unimportant sources of information (from the user's point of view) are here called *interruptions*.

The costs of interruptions to social and cognitive performance are somewhat known. In social interaction, interruptions not only delay and distract the fluent course of *turn-taking* in human–human conduct, but also can render actions of people incomprehensible for others [11]. In cognitive psychology, it is known that there is cost of switching *attention* between information sources or tasks that is in the magnitude of seconds. Interruptions also hamper *memory* by making memories more susceptible to omissions and distortions. Interruptions are most harmful for higher-level thought processes involving heavy load for working memory, for example when solving novel problems. Looking at the social and cognitive costs of interruptions, it becomes understandable why interruptions are associated with all kinds of negative consequences: delays, errors, mistakes, frustration etc (see [6]).

Whereas desktop-based applications can mainly interrupt only other computer-based tasks, *in intelligent environments the to-be-interrupted tasks are related more to the psychosocial well-being and life-management of the users.* The tasks carried out at a desktop computer are but a minor subset of the spectrum of life-management tasks and the larger hierarchy of human and social needs. A justified and often heard fear is that interrupting these activities can easily lead to rejection of the interruption-causing technology. The remedy is wise design that minimizes the costs and negative effects of interruptions.

To summarize, the logic is that interruptions are an unavoidable feature of interaction in intelligent environments, and if not carefully designed, they hamper our psychosocial well-being, which can lead to dismissal of the technology more easily than in the traditional desktop-based HCI. Therefore, it is justified to claim that the problem of interruptions is highlighted in intelligent environments.

REVIEW OF CONTEMPORARY APPROACHES FROM THE POINT OF VIEW OF COGNITIVE SCIENCE

In the following, contemporary solutions to the problem are analyzed from the point of view of how they map to different aspects of the human cognition.

Invisibility

According to an interpretation of Weiser championed by Philips (as cited in [9]), computers at the age of ubiquitous computing should be invisible. Weiser's "disappearance" is here taken literally to mean perceptual invisibility.

Perceptual disappearance, if it worked, would, by definition, solve the problem of interruptions. Invisibility of a user interface, however, is in many respects a non-goal and a paradox in design. At the time of interaction, the user interface must become perceivable somehow.

Progressive Negotiation

Mixed-Initiative Interfaces (MIIs) assume that "intelligent services and users may often collaborate efficiently to achieve the user's goals" [1, p. 159]. Instead of immediately taking the foreground – interrupting the ongoing activity of the user, a MII *progressively* signals requests for attention. Initially this may happen through a channel peripheral to user's activity, but can then be achieved in turns with the user. This is a step towards the kind of deepening and progressive turntaking in human-human interruption management. The main idea is a promising one: the first steps in interaction are very non-disruptive and will not create a feeling of being interrupted, and only upon negotiation with the user will the interaction be taken further. A small signal from the user is enough to terminate the turntaking if the interrupting task seems irrelevant or unimportant, thus making interruption negotiation more human-like.

Preattentive Processing

In *Peripheral Computing*, the interface attempts to provide peripheral awareness of people and events (e.g., [3, 10]). Ambient channels provide a steady flow of auditory cues (such as a sound like a rain) or gradually changing lighting conditions. According to Hiroshi Ishii, "The smooth transition of users' focus of attention between background and foreground using ambient media and graspable objects is a key challenge of *Tangible Bits*" [3].

In practice, the promise of peripheral interfaces lies in our capacity to preattentively and unconsciously process peripheral stimulus sources (i.e., stimuli that are not in the center of conscious attention). By *habituation* to irrelevant ambient stimuli, and *sensitization* to relevant and important ambient stimuli, the subconscious cognitive system is capable of learning what is worth bringing to conscious attention and what is not. Sudden or abrupt changes in soundscapes, for example, typically receive immediate attention and thus create an interruption. The amount of information that can be conveyed in such a manner is relatively small, which limits its generality. Moreover, internalizing the meanings of ambient signals takes considerable time.

Change Blindness

Stephen Intille at MIT has examined how to exploit a cognitive phenomenon called *change-blindness* in designing ambient displays embedded to user's environment. The idea is to minimize the *perceived change* by eliminating all attention grabbing cues [2]. If a change occurring on a display is not perceived, it cannot capture attention and interrupt the user. Changing information very slowly, blanking the image, changing the view very rapidly, displaying "mud splashes" to distract the user from noticing changes, utilizing eye blinks and saccades, and using occlusion are some of the proposed methods.

A limitation in the approach is that it cannot be used to convey critical information to the user. That is, it can be used to decrease the possibility of uninteresting information grabbing the attention, but not for designing how the interruption should take place.

Unreserved Modalities

The idea in *Multimodal Interfaces* is to use unreserved modalities for interaction. This obviously calls for understanding what modalities are typically reserved in a use situation.

For example, in mobility, our visual attention is mostly reserved for orienting ourselves to others and navigating through the environment. *Nomadic Radio* [7] addressed this problem by creating a messaging service that instead of visual modality required only auditory attention and speech for interaction. This made it possible for the users to not interrupt the navigation task while doing messaging.

A limitation for the approach is posed by the fact that although our attentive capacity is modular in respect to modalities, the central executive is a serial processing unit. This implies that when the automated control within modality-specific subsystems is not possible, as in novel and unpracticed situations, processing the task requires our conscious attention and thus creates an interruption.

Attention and Task Preferences

Attentive User Interfaces (AUIs) are based on the idea that modeling the deployment of user attention and task preferences is the key for minimizing the disruptive effects of interruptions [11]. By monitoring users' physical proximity, body orientation, eye fixations, and the like, AUIs can determine what device, person, or task the user is attending to. Knowing the focus of attention makes it possible in some situations to avoid interrupting users in tasks that are more important or time-critical than the one interrupting.

Before taking the foreground, AUIs determine whether the user is available for interruption, given the priority of the request, signal the user via a non-intrusive peripheral channel, and sense user acknowledgment of the request. AUIs are focused on facilitating user's attention efficiently, but do not say that interruptions should be minimized. They only need to be introduced at a right time and in a right way, depending on the urgency, and determined partly by the importance of the user's present task.

Learning and Automatization

Ubiquitous Computing (ubicomp) aims to "activate the world" with hundreds of wireless computing devices per person, ranging in size from tiny to wall-sized. According to its founder, Mark Weiser, ubicomp "takes into account the human world and allows the computers themselves to vanish into the background. Such a disappearance is a fundamental consequence not of technology but of human psychology. *Whenever people learn something sufficiently well, they cease to be aware of it*" [13, p. 66, italics added].

The idea that interaction with technological artefacts becomes automatized, and thus an unconsciously performed skill, is based on a psychological fact. Well-learned routines do not require conscious control but can be unconsciously carried out, ballistically from the beginning to the end. When the user learns to use an artefact well enough for a meaningful goal-pursuit, the interruptions it makes become a natural, or unconscious and thus not disrupting, part of interaction. In selecting this road for design, we need to know preconditions for a skill becoming automatized. Studies of automatization offer starting points for this (e.g., [5]).

Augmenting Everyday Skills

Unremarkable Computing is an approach to the design of ubicomp suggested by the Xerox Research Centre Europe. The focus is on designing domestic devices that are "unremarkable" to users. Here invisibility is understood as the use of a device being a *part of a routine*, since "routines are invisible in use for those who are involved in them" [9, p. 403]. Then, technology is subservient to routines and actions: "…the key point is that the computation is in service of actions – everyday actions – which themselves have a significance" [9, p. 404].

Interruptions caused by a device should be designed to be a part of a routine. "Things with a routine character may then have many of the qualities we are aiming for by being tacit and calm in that they are not 'dramatic' and do not command attention except when they need to. They are seen but unremarked, used as resources for action" [p. 403].

The authors are sympathetic to the *Tangible Interfaces* approach (e.g., [3, 10]) that augments traditional artifacts with functionalities that fit to everyday routines. "Manipulating physical objects is one of people's everyday competencies and more generally available than, say, abstract computer commands and software applications" [9, p. 404]. Here the authors, however, fail to notice that the use of abstract computer commands can be automatized as well as any other everyday skill. Thus, they can be unremarkable as well.

Augmenting routines may not always work as intended. When a new tool is introduced, its adoption is bound to affect the routine. If the technology does not introduce a change, what is its benefit for users? On the other hand, people are known to be clever at inventing opportunistically new uses to artifacts, which alter the nature of routines in unexpected ways. It can be that Unremarkable Computing, by concentrating on augmenting present-day routines, misses the potential of IE technologies and actually weakens Weiser's point of harnessing automatization.

Delegating Decision-Making Responsibility

Proactive Computing was recently introduced by Tennenhouse and colleagues [8, 12]. The enabling technologies include sensors and actuators intimately connected to the physical world, processors with faster-than-human operating speed, and autonomous software programs assembled to form "knowbots" assigned for helping the user. The key idea is using simulations of the real world to make inferences and predictions that anticipate and prepare for events.

User's role in a proactive system is to monitor and steer processes, without actively intervening in decision-making situations that may arise. The user is relieved from making decisions every time when the system encounters a branching point in its activity. Thus, interruptions that would normally require decision-making are minimized and the user is raised above the traditional interaction loop by letting him/her take a monitoring role.

A somewhat similar approach that also attempts to delegate decision-making responsibility to intelligent systems is taken by the *Ambient Intelligence* (AmI) technology programme of the European Union. One part of the AmI vision entails intelligent agents that assume some of the control responsibility from users, as in the following example of a call-mediating intelligent agent: "With a nice reproduction of Dimitrios' voice and typical accent, a call from his wife is further analysed by his D-Me. In a first attempt, Dimitrios' 'avatar-like' voice runs a brief conversation with his wife, with the intention of negotiating a delay while explaining his current environment [since Dimitrios had some pressing tasks to do. After a while] his wife's call is now interpreted by his D-Me as sufficiently pressing to mobilize Dimitrios. It 'rings' him using a pre-arranged call tone" [4, p. 5]. Using human-like agents like D-Me may prove fruitful for the delegation approach, because in the IE use contexts we are accustomed to collaborate with humans in pursuing our goals.

NEW DIRECTIONS FOR RESEARCH

The cognitive scientific framework that was used for analyzing the approaches above, also inspires novel approaches that have not been yet explored.

One such approach is that of *memory*. Whereas perception, attention, and decision-making have been addressed in the existing approaches, memory has not been. The idea in memory-based approach would be to design interruptions that impair our ability to remember the interrupted task as little as possible. For example, presenting interruptions during low working memory load would be one step towards this goal. Another one would be providing retrieval cues adaptively in the UI to help the user to mentally restore the cognitive state to resume the interrupted task. The memory-based approach builds on the AUI approach, and would require extensive tracking of user's perception, attention, and interaction history to track the contents of user's memory and the development of memory skills.

Another approach inspired by the framework relates to *stress* and *inference*. A possibility for designing less disruptive interruptions is to make them more *predictable*. It is known from the cognitive studies of stress that events that are both unpredictable and uncontrollable cause stress. Thus, instead of tracking users and predicting their interruptability, the system could try to predict and visualize *to* the user when it is going to interrupt him the next time. This is largely a problem for UI design and the psychology of inference, as the user employs his/her mental models to draw inferences from the cues available at the user interface.

A third, and probably the most promising approach inspired by the framework relates to *human needs and preferences*. As common sense reveals us, some tasks are more important than others, and just those tasks are the ones that deserve our attention and are thus not considered as interrupting or disrupting. Getting a call from a dear friend is usually delightful, were we in a meeting or not. Thus, interrupting user can and should be beneficial, and one can ask if the quest for minimizing interruptions is a solution without a problem. Innovating more meaningful design concepts for the technology of future would solve part of the problem.

CONCLUSIONS

HCI research has been criticized for being *a*theoretical. This is definitely true of research in intelligent environments. The only way to systematize and bring consensus to this *a*theoretical and balkanized field is by constructing concepts and theories. As shown in this paper, interruption is such a concept. It makes visible similarities and differences among research approaches, and helps future work by revealing possibly important omissions. The cognitive scientific approach to interaction and interruption is, of course, but one conceptualization of only one key problem in intelligent environments. Future research must search for similar emerging frameworks elsewhere and attempt to explicate and evaluate them.

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