1 Introduction

Claudia Roda

In recent years it has been increasingly recognized that the advent of information and communication technologies has dramatically shifted the balance between the availability of information and the ability of humans to process information. During the last century information was a scarce resource. Now, *human attention* has become the scarce resource whereas information (of all types and qualities) abounds. The appropriate allocation of attention is a key factor determining the success of creative activities, learning, collaboration and many other human pursuits. A suitable choice of focus is essential for efficient time organization, sustained deliberation and, ultimately, goal achievement and personal satisfaction. Therefore, we must address the problem of how digital systems can be designed so that, in addition to allowing fast access to information and people, they also support human attentional processes. With the aim of responding to this need, this book proposes an interdisciplinary analysis of the issues related to the design of systems capable of supporting the limited cognitive abilities of humans by assisting the processes guiding attention allocation. Systems of this type have been referred to in the literature as Attention-Aware Systems (Roda and Thomas 2006), Attentive User Interfaces (Vertegaal 2003) or Notification User Interfaces (McCrickard, Czerwinski and Bartram 2003) and they engender many challenging questions (see, for example, Wood, Cox and Cheng 2006).

The design of such systems must obviously rest on a deep understanding of the mechanisms guiding human attention. Psychologists have studied attention from many different perspectives. In the nineteenth century, when attention was mainly studied through introspection, William James (considered by many the founder of American psychology) devoted a chapter in his *Principles of Psychology* to human attention and observed:

> Everyone knows what attention is. It is the taking possession by the mind, in clear and vivid form, of one out of what seem several simultaneously possible objects or trains of thought . . . It implies withdrawal from some things in order to deal effectively with others (James 1890: 403–4).

However, as for many other *things* that 'everyone knows', such as rationality, intelligence, memory and love, attention escapes a precise definition, and more than a century after James' writing, its mechanisms still generate debates and controversy in the scientific community.

Since the mid-twentieth century, attention allocation has been viewed as the process of *selecting* stimuli for processing, and research has focused on the question of *when and how* this selection takes place. Proponents of *early selection theory* (Broadbent 1958) argue that stimuli are filtered early, at the perceptual level, on the basis of their physical properties so that irrelevant (unattended) stimuli are not further processed. Proponents of the *modified early selection theory* (Treisman 1960) maintain that the early filter is not just *on* or *off* but that some stimuli are just attenuated rather than completely filtered out, so that some irrelevant stimuli may reach consciousness. Proponents of *late selection theory* (Deutsch and Deutsch 1963) argue that all stimuli are analysed (i.e., there is no filter at perceptual level) but only pertinent stimuli are selected for awareness and memorization. More recently some of the fundamental assumptions of the early/late selection dichotomy have been questioned (Awh, Vogel and Oh 2006; Vogel, Luck and Shapiro 1988) and the debate over early and late selection has directly or indirectly raised many other related questions: e.g., does attention modify the manner in which we perceive the environment, or does it impact on our response to what we perceive? This is an important question for the design of attention-aware systems. For example, Posner (1980) suggests that cueing facilitates perception and that different cues activate brain areas devoted to alerting and to orienting attention (Posner and Fan 2007). This implies that it is possible to help the user redirect attention, maintain attention on a certain item, or simply alert him to possibly relevant stimuli. However, psychological literature also tells us that certain stimuli may be perceived if uncued and even if they are actively blocked. For example, in a noisy environment such as a cocktail party we are able to block out noise and listen to just one conversation amongst many (Cherry 1953), but why will some of us very easily and almost necessarily notice our name if mentioned in a nearby but unattended conversation? In trying to address this question, Conway and his colleagues showed that 'subjects who detect their name in the irrelevant message have relatively low working-memory capacities, suggesting that they have difficulty blocking out, or inhibiting, distracting information' (Conway, Cowan and Bunting 2001: 331). Similar results, relating working-memory capacity and the ability to block distractors, have been reported in the visual modality with experiments employing neurophysiological measures (Fukuda and Vogel 2009). A better understanding of these mechanisms could help us design systems that help users who have more difficulties in maintaining focus with obvious applications in, for example, in-car support systems, technology enhanced learning applications, control room systems, etc. The study of this very close relationship between attention and working memory has been a very active area of research (Awh, Vogel and Oh 2006; Baddeley 2003; Buehner *et al*. 2006; Engle 2002; Shelton, Elliott and Cowan 2008). However, both attention and working memory realize multiple functions implemented by a variety of processes that physically correspond to multiple areas in the brain and therefore the interaction between attention and working memory is difficult to grasp. Some of the chapters in this book take different stands on this interaction. In chapter 4, Low, Jin and Sweller base their analysis of the relationship between attention and learning on an assumption of 'equivalence between working memory and attentional processes'; in chapter 5, Bowman and his colleagues see attention as a mechanism that mediates the encoding and consolidation of information in working memory; in chapter 9, Stojanov and Kulakov indicate that activated items in working memory guide the perception processes.

Another area of research in cognitive psychology that has had a significant impact on the field of human–computer interaction addresses the question of whether all types of stimuli are treated by a central system or, instead, several different systems manage different types of input. The organization of attention over several channels associated with different modalities was first proposed by Allport, Antonis and Reynolds (1972), who suggested that a number of independent, parallel channels process task demands. Users' responses to messages in different modalities have consequently been studied in relation to the optimization of interaction in various applications (see, for example, chapters 4 and 7 of this volume). The interaction between, and the integration of, these different channels has not yet been extensively studied. The large majority of the studies of attention have concentrated on either the sound modality or the visual modality. Recent research, expecially when related to human–computer interaction, is for the most part focused on visual attention. This greater focus on visual attention is reflected in this book, with many chapters (3, 5, 7, 10) reporting results in this modality.

A final important issue, recurrent in this volume, addresses how to facilitate the user in his perception and understanding of messages coming from digital devices. It is commonly accepted that two types of processes, bottom-up and top-down, guide attention and visual attention in particular. Bottom-up processes, also called exogenous processes, guide attention to *salient* elements of the environment; and top-down, or endogenous, processes guide attention to elements of the environment that are relevant to the current task. The definition of what determines the saliency of elements of the environment, and the creation of models that integrate both bottom-up and top-down processes, has been a very active area of research (Cave 1999; Itti 2005; Peters and Itti 2007). These issues are central to chapters 3 and 5 of this book.

A challenge that this book aims to address is the creation of a bridge (or a set of bridges) between the research work carried out in cognitive psychology and neuroscience, which reports fundamental results on specific aspects of attentional processes, and the work carried out in human–computer interaction that endeavours to apply these results. The difficulty of this effort is mainly due to the fact that, in the former work, experiments are carried out in controlled environments where the conditions under which subjects are working are known, and effects are observed over periods of time that are often very short (down to the millisecond). Instead, in real-world situations, such as the ones addressed by research in human–computer interaction, there is very little or no control over the conditions under which users are working, and the time lengths are much longer with effects that may span hours, days or even months. To make things worse, addressing the problems faced by human–computer interaction would require a holistic theory of attention, which is still far from being achieved. As a result, the tools and systems proposed in the chapters of this book necessarily focus only on some aspects of attention. For example, chapter 8 focuses on the effects of contextual information, chapter 10 on the conspicuity of visual information, and chapter 12 on social aspects of attention. Nevertheless, attention-aware applications have been shown to be greatly beneficial in several areas, including the control of appliances and desktop interfaces (chapter 7), robotics (chapter 9), visualization for decision making (chapter 10), learning and training (chapters 8 and 11), and online collaborative environments (chapter 12).

The book is organized in three parts, with chapters that focus mainly on concepts in part I, chapters that focus mainly on theoretical and software tools in part II, and chapters describing applications in part III.

Part I (Concepts) introduces the conceptual framework of research aimed at modelling and supporting human attentional processes. The chapters in this part analyse human attention in digital environments, integrating results from several different disciplines, including cognitive psychology, neuroscience, pedagogy and human–computer interaction.

Chapter 2 sets the scene by providing a broad overview of the main issues addressed by attention research in cognitive psychology and neuroscience, and their relevance for the design of digital devices.

In chapter 3, Ronald Rensink reviews one of the prevalent areas of attention research, vision science. Drawing on his vast experience in this subject, Rensink guides the reader through an exploration of visual attention and the many processes involved in scene perception. Based on this knowledge of scene perception, Rensink proposes that displays may be designed so that they elicit particularly efficient users' responses.

John Sweller, who co-authors chapter 4 with Renae Low and Putai Jin, has developed *cognitive load* theory, one of the most influential theories relating attention and learning. Cognitive load theory was originally designed 'to provide guidelines intended to assist in the presentation of information in a manner that encourages learner activities that optimize intellectual performance' (Sweller, Merrienboer and Paas 1998: 251). In chapter 4 the authors discuss the impact of cognitive load theory on the design of digital tools supporting learning.

Part I closes with a chapter by Howard Bowman, Li Su, Brad Wyble and Phil J. Barnard. The authors report on the results obtained in the Salience Project,[1] and elegantly analyse some aspects of attention that have been the focus of recent research, including its temporal organization, its redirection, and the role of long-term goals and emotional significance in determining saliency.

Part II (Theoretical and software tools) analyses the theoretical and computational mechanisms currently available for supporting human attentional processes. These tools span very different areas of attention-related services to users.

Chapter 6, contributed by Benoît Morel and Laurent Ach, focuses on the design of artificial characters that adapt to the attentional state of the user. On the strength of over a decade of practice in creating 3D embodied agents, the authors explain the role that attention plays in creating engaging agents 'that are capable of natural, intuitive, autonomous and adaptive behaviours that account for variations in emotion, gesture, mood, voice, culture and personality'.

In chapter 7, Kari-Jouko Räihä, Aulikki Hyrskykari and Päivi Majaranta discuss eye-tracking technology based on their long experience of leading some of the most successful research endeavours in this field, including the European Network of Excellence COGAIN and the EYE-to-IT project. Eye-tracking technology has historically been central to the development of attention-aware applications because of the very close relationship between gaze direction and attention. After reviewing the psychological foundation of visual attention, the authors

[1] www.cs.kent.ac.uk/~hb5/attention.html.

address the question of the relation between attention and the point of gaze as well as the use of the latter for the implementation of adaptive applications.

Chapter 8, authored by Hans-Christian Schmitz, Martin Wolpers, Uwe Kirschenmann and Katja Niemann, proposes that metadata about attention allocation can be captured and exploited to personalize information and tasks environments. Significantly, on the basis of their extensive application studies, the authors argue for the important role of attention metadata for the support of cooperative work.

In chapter 9, Georgi Stojanov and Andrea Kulakov analyse how attention may be modelled within a complete cognitive architecture. After reviewing how attentional processes are represented in several known cognitive architectures, the authors present their own cognitive architecture, founded on robotics research, and they highlight the role played by attentional processes.

Part III (Applications) presents several computing applications designed to support attention in specific environments. The applications presented in this part cover a wide variety of fields, showing the relevance of attention-aware systems to fields as different as command-and-control displays, technology-enhanced learning, and the support of online communication and collaboration.

The application described by Frank Kooi in chapter 10 is the result of the author's very long experience in researching and implementating visual displays. The objective of the two-depth layer display presented by the author is to increase the amount of information available to the user without increasing clutter. Based on knowledge of visual attentional processes, Kooi proposes that, by using dual layer displays, search may be made much more efficient in command-and-control displays.

Chapter 11, authored by Inge Molenaar, Carla van Boxtel, Peter Sleegers and Claudia Roda, reports on a system designed to supply adaptive and dynamic scaffolding through the analysis and support of learners' attentional processes. The experimental results clearly show the potential of the application of attention management in technology-enhanced learning environments.

Finally, in chapter 12, Thierry Nabeth and Nicolas Maisonneuve propose an implementation of the general attention support model originally proposed by Roda and Nabeth (2009). This model is based on four levels of support: perception, deliberation, operation and metacognition. Chapter 12 explains how this model may be implemented to support social attention and describes the attention-aware social platform AtGentNet.

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More Information

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Part I

Concepts

2 Human attention and its implications for human–computer interaction

Claudia Roda

Remembering planned activities, resuming tasks previously interrupted, recalling the names of colleagues, sustaining focused performance under the pressure of interruptions, ensuring that we don't miss important information . . . these are only a few examples of critical activities whose performance is guided by attentional processes. This chapter proposes that knowledge about attentional processes can help us design systems that support users in situations such as those described above. The first part of the chapter gives an overview of some of the essential theoretical findings about human attention. The second part analyses attentional breakdowns and how those theoretical findings may be applied in order to design systems that either help avoid attentional breakdowns or assist in recovering from them.

2.1 Introduction

Current information and communication technologies concentrate on providing services to users performing focused activities. However, focused activity is no longer the norm. Users are often interrupted, they switch between the contexts of different devices and tasks, maintain awareness about the activity of distant collaborators and manage very large quantities of information. All this results in high cognitive load that may hinder users' overall achievements.

In order to address interaction in a more realistic manner, we have been working on the development of systems that are capable of supporting the processes that govern human cognitive resources allocation: attentional processes.

Attention plays an essential role in task performance and interaction. It enables us to act, reason and communicate, in physical or virtual environments that offer us stimuli exceeding, probably by several orders of magnitude, what we are actually capable of processing. Attention makes it possible for us to pursue goals without being distracted by the immense variety of available alternative stimuli and actions and undeniably mediates our interaction with the world.