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Dimensions of Attentional Processing

Abstract This paper explores the role of cues in manipulating attention with the purpose of understanding their potential value to attention aware systems design. Four dimensions of attentional processing are presented along which recent findings in the attention literature can be conceptualised: (1) Locus of control; (2) Spatial cue information; (3) Semantic cue information; (4) Timing of the cue. We suggest that they provide a useful framework for understanding the complexity of attention processing for the attention design community.

Keywords attention design · dimension · cue · attention aware systems

1 Introduction

The focus of our work on attention management has been to apply the findings of visual attention research from psychophysical studies and cognitive science to 'Attention Aware Systems' design [18].

A key feature of attention management in relation to visual displays is to guide the user's attention to relevant screen events to support effective task based activity (cf. [13,18]). Often the event is unanticipated by the user and therefore pertinent information available from an unexpected source may go unobserved. This is especially the case when the user is engrossed in their task, leading to even quite dramatic and significant events being completely ignored (cf. [16]).

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A possible technique for managing attention may be to alert the user to pertinent information through the use of cues (or primes, flags, signals, alerts). This paper explores the role of cues in manipulating attention with the purpose of understanding their potential value to attention aware systems design. It is a well-recognised phenomenon in psychophysical visual attention studies that introducing a 'cue' or 'prime' prior to presentation of a 'target' results in a reduced 'reaction time' (RT) in response to the target (e.g. [15]). Understanding the nature of 'priming' and its role in manipulating attention may guide us in harnessing the power of priming as a useful technique for managing attention. As part of this endeavour, useful insight may be gained from work, which does not treat attention as a unitary process, but instead identifies various stages and/or aspects of processing. However, interpreting the literature appropriate for attentional management implications is problematic for a number of reasons. Firstly, there is a wealth and diversity of technical terminology that is not always used consistently and unambiguously. Second, there is a wider variety of attentional studies that are potentially instructive, but drawing valid implications from the diverse tasks used and broad range phenomena investigated in a systematic fashion is a substantial challenge. Third, attentional processes can be characterised at different time scales ranging from tens of milliseconds through to activities that endure over periods of minutes or even hours. Unfortunately, analyses of attentional processes often fail to clearly identify over what timescale they hold (cf. [1, 10]).

Our approach initially takes a step back from interpreting the literature directly in attentional management terms. Rather we ask the question what are the underpinning features that can be used to characterise cued attentional episodes. In particular, 'dimensions' of attentional processing are presented in order to promote a deeper appreciation of the underpinning structure of attention related phenomena and processing. We anticipate that such dimensions provide a productive framework in which to consider design issues from a process orientation. Four dimensions of attentional processes have been identified and will be discussed in the following sections: (1) Locus of control; (2) Spatial cue information; (3) Semantic cue information; (4) Timing of the cue.

2 Locus of Control: external, internal and mixed

The locus of control dimension identifies the source that drives changes of attention. The source may be external to or internal within the cognitive system. An external source will be a cue in the external environment, an exogenous signal that interrupts otherwise ongoing cognitive processing. The cue information is received through the senses, typically visual or auditory, and processing will progress in a bottom-up fashion. Within an internal source, the endogenous processing will be driven by the current goals of the cognitive system. Such processing is top-down in character and various levels of processing may be distinguished on different time scales and in relation to the aspect of attentional processing considered. At the lower level there are basic attentional processes occurring over short periods of time concerned with a particular attentional or sensory event. At a higher-level, meta-attentional processes are concerned with the management of a number of successive attentional events. Pure internal and external sources for the locus of control for attention are best considered as the ends of a spectrum, with typical events being more complex mixes of both top-down and bottom-up processing, happening perhaps in parallel, or occurring in quick succession.

For example, Posner and Fan [11] have recently identified specific neural pathways associated with different aspects of visual attention. Through studies involving fMRI scanning and neurotransmitter drug manipulation, they identified three distinct networks within the brain associated specifically with processes they refer to as: 'alerting', 'orienting', and 'executive control'. They describe each in turn as "achieving and maintaining an alert state", "orienting to sensory events" and "controlling thoughts and feelings" (p2). They further describe orienting as a three step sequence of 'disengaging' with the current focus of attention, 'moving' to a new focus of attention and then 'engaging' with that new focus of attention. In terms of the present locus-of control dimension, the Posner and Fan alerting network appears to deal with external sources and their orienting network a mixture of the two: 'disengaging' being a bottom-up process and 'engaging' top-down, whereas executive control is associated with internal sources of meta-attentional processing. A process termed 'executive attention' is described by [7]. This is a top-down control system for flexibly modulating lower level processes which tend to be stimulus-bound. Executive attentional processes are required to resolve conflicts, correct errors and plan ahead, and in particular to make appropriate, non-habitual responses to the target [11]. Brain imaging studies suggest that these attention regulating networks are located in mid-frontal brain areas. These areas have been shown to be activated strongly by tasks that require very high levels of executive attention such as the Stroop task (naming colour-name nouns printed in conflicting ink colours eg. "blue" printed in red ink).

A more specific and also interesting type of meta-attentional process has been termed 'inhibition of return' (IOR) [12]. A more recent review is provided by [9]. The term refers to a reduced probability, lasting several seconds, for attention to return to a previously attended location - a mechanism designed to privilege new search locations over old. Following visual attention to a stimulus at a peripheral location, the processing of other targets around that location is facilitated. However, when attention shifts from that peripheral location, return of attention is delayed relative to 'fresh' locations. It has been postulated to be a mechanism that facilitates efficient food foraging, and IOR affects both motor and attentional components of responding [9].

3 Spatial cue information: direct, indirect and none

A cue may, or may not, provide information about the spatial location of the target to which attention should be switched. 'Flagging' can consist of a simple binary indicator (e.g. on screen) which does not signal the location in which the target will subsequently appear. Such a flag might consist just of a transient colour change of the display background, or in the form of a particular object that appears briefly at centre screen. When that information is given it may be direct, in that the precise location of the target is explicitly shown using some spatial technique in the direct vicinity of the target location. Intermediate cases can occur when the spatial information is presented but in an indirect fashion. A flagging cue may (imprecisely) 'point to' the general area in which the target will appear - this type of cue might, for example, be similar to the 'xeyes' feature of the UNIX X-windows operating system. The spatial information may even be given in linguistic form, such as 'bottom left, to indicate the position on a page.

Consider the study of [11] again. Because "all sensory events act both to contribute to a state of alertness and to orient attention" (p3) their studies involved a test designed to separate these two elements of attention in subjects performing a single integrated reaction time task. The 'attention network test' (ANT) involves presenting a cue prior to a target event to which the user responds. "Some cues provide information on *when* the target will occur. The warning signals lead to changes in a network of brain areas relating to alerting. Other cues provide information on aspects of the target such as *where* it will occur and lead to changes in the orienting network." ([11] p3, *italics added*). By contrasting the effects of the different types of cues, they were able to derive findings which revealed those aspects of brain activity associated specifically with being alerted (by any cue) to a subsequent target event, compared to those aspects of brain activity associated with orienting (by a spatial cue) to a specific spatial location for the subsequent target event.

4 Semantic cue information: linguistic, iconic, deictic and none

The cue may provide information that can help the processing of the target. In effect, the cue can be used as a semantic prime (cf. [15]). The semantic information may be presented in linguistic form, "low fuel", or in iconic form, such as a graphic showing a empty tank. Deictic semantic cues are most vividly exemplified by physical pointing by people, or by the most ubiquitous metaphor, the arrow [8,14].

Knowledge serves to bias information processing to be more selective of, or prepared for, the primed attributes. For example, being prepared for a red object ensures a more efficient response to the (red) target when it appears. Similar processes appear to be active for advance information on direction of motion, shape and even familiarity with the target [5]. These top-down processes overlap in functionality with working memory [4].

5 Timing of the cue: anticipatory, concurrent and retrospective

The timing of when the cue is presented in relation to the occurrence of the target is the fourth dimension. The cue may be anticipatory, concurrent or retrospective, occurring before, at the same, or after the onset of the target. The timing of the cue will affect the nature of the attentional processing that occurs but also provides alternative means to engage attention under different circumstances. For example, in tasks with high cognitive load, retrospective cues may be more useful than anticipatory cues. For adaptive attention management systems, lack of a user's response to the occurrence of the target may be an effective way to detect failure to attend to the target.

The effect of cuing a target prior to target onset is that it is processed more efficiently than if no cue had been presented [3,6]. Presentation of the target following a spatial cue further decreases response times [3,6]. It appears that, in the absence of a cue, the presentation of the target corresponds to a novel sensory event involving both the alerting and orienting networks. In contrast, presentation of the target following a cue involves just the orienting network [3,6,11]. Shorter reaction times in cued conditions reflect a saving on activation of alerting to presentation of the target. But also the alerting network appears to effect the orienting network by accelerating its functioning and thus reducing response time [2].

Presentation of the target following a spatial cue facilitates the shift of attention further still by enabling the current focus of attention to be disengaged prior to a voluntary shift of attention to the target location. This aspect of orienting network functionality is also involved in voluntarily moving attention "from location to location while searching for a visual target." ([11], p5). A non-spatial cue, on the other hand, requires the current focus of attention to be disengaged prior to reorientation to the target following its presentation [6,11]. Responding to an unexpected or novel event also activates brain areas associated with disengaging from a current focus of interest to a new event, as does monitoring for infrequent events, such as for vigilance [3].

6 Conclusion

We have presented four dimensions along which recent findings in the attention literature might be described. They may provide a useful framework for understanding the complexity of attention processing for the attention design community.

The insight these studies afford into the faciliatory role of cues, and especially spatial cues, suggest ways in which attention might be managed more effectively. Resource intensive task-focussed top-down processes essentially screen out bottom-up activation of attention, leading to sensory events being effectively ignored, a phenomenon highlighted through recent work on 'change blindness' and 'inattentional amnesia' [16,17,19]. By engaging the user in a voluntary shift of attention to important screen events through the use of cues or primes, we may hope to overcome this fundamental limitation in users' ability to attend to novel events.

7 Scenarios

This paper discussed dimensions of attentional processing in order to promote a deeper appreciation of the underpinning process micro-structure of attention related phenomena. The three imaginary scenarios we present are different cases where attention switching occurs in different circumstances. They are plausible from an attentional processing perspective. Readers are invited to interpret each case in terms of the dimensions discussed above, before reading our interpretations. We claim that such dimensions provide a productive framework in which to consider design issues from a process orientation.

7.1 Scenario One: Search in a spreadsheet

Jamie is inspecting a spreadsheet for errors, which has items distributed rather randomly in about one third of the cells. The spreadsheet should contain only three digit numbers but unfortunately two names, 'WALDO' and 'BOB', have accidentally been inserted. Jamie knows there are two errors that are names but does not know precisely what they are. As the entries in the cells seem randomly distributed, Jamie decides to quickly scan over the spreadsheet rather than do a systematic row or columnwise search. However, before even getting started, Jamie immediately notices WALDO but then continues with the process of scanning. Although the search is not systematic and rather like a random walk, Jamie typically does not return to cells that have previously been examined. The content of each cell with an entry is individually but quickly examined to check whether it contains an entry that seems to resemble a number. However, after exhausting all the potential cells, Jamie is puzzled not to have found the name, so decides to do a systematic row-wise search and carefully inspects each cell. Eventually BOB is found.

In terms of the dimensions of attentional processing, what is happening? [1] In this task there are no general explicit flags ***(no direct or indirect spatial cues)*** indicating when and where the target occurs. However, Jamie's attention is drawn to WALDO immediately the task begins, because the size of the target compared to the background field of smaller constant size numbers means it stands out and acts as a de facto flag ***(direct iconic spatial cue)*** that the sensory system automatically identifies in a bottom-up (exogenous) processing fashion ***(external locus of control)***. Initially, Jamie's quick scanning search for the other name relies on the expectation that the overall shape of the name will be different and that it will be noticed as the eye skims over the cells, without the contents being fully processed semantically ***(internal locus of control)***. Because BOB looks superficially like a number, Jamie misses it in the first fast pass. Although not deliberate and conscious, the process of inhibition of return means that Jamie did not return to previously examined cells even though no explicit visual search strategy has been adopted. The scanning search process involves repeated cycles of noticing adjacent targets in peripheral vision, attending to one of them and then orienting the focus of attention to that target.

7.2 Scenario Two: . Automated support for monitoring in a control room

Alexis is an officer in a traffic management control room. There is a bank of eighteen screens taking input from different cameras at multiple road junctions. To assist Alexis, the system has novel software that analyses the images for any signs of unusual activity and provides an alert in the form of a spoken recording of the number of the screen ('one' to 'eighteen') plus a phase summarizing the system's interpretations, such as stationary traffic, break down or accident. On hearing the alert, Alexis looks at the appropriate screen and decides whether there is a substantial problem.

In terms of the dimensions of attentional processing, what is happening? The audio announcement produced by the system is a synchronous alert ***(concurrent timing)*** that fully interrupts Alexis's ongoing activity ***(external locus of control)***. The number of the screen is an ***indirect spatial cue*** given in ***linguistic*** form that requires switching to an ***internal locus of control*** in-order for Alexis's orientation of attention, and direction of gaze, to be moved to the target screen. The alert phrase primes Alexis to attend to those things that are germane to particular types of problems.

7.3 Scenario Three: Following an explanation of a diagram in a lecture

Sam is sat in an HCI lecture given by Kim. A flow diagram is projected on the screen whilst Kim is explaining the process depicted by the diagram. As each new subprocess is introduced, Kim indicates the relevant icon in the diagram using a laser pointer. As Sam is taking notes and looking away, Kim's pointing actions are sometimes missed, but at other times Sam looks up just at the time the pointing happens. Sam manages to continue following the explanation even when the pointing is missed, because the icons can be found when Kim mentions the text labels associated with them. In some cases Sam correctly identifies the next icon before the pointing occurs from what Kim is saying, even though Kim does not explicitly say the label for the icon.

In terms of the dimensions of attentional processing, what is happening? Kim's pointing to the icon in the diagram serves both as an alert to disengage attention from somewhere else on the diagram and also provides directly the new spatial location for the new focus of attention ***(external locus of control with concurrent spatial deictic cue)***. The pointing action is silent, so when Sam is looking away it will fail to work as an alert. However, the context of what Kim is saying may provide Sam with a synchronous cue ***(anticipatory cue timing, external locus of control)*** that some shift of attention is needed and serves to prime the likely location of where Sam should attend ***(indirect spatial cue)***, so enabling Sam to look up and anticipate the laser light spot just at the right time ***(anticipatory timing)***. When Sam misses the pointing completely, the icon can be found by explicitly searching for the icon ***(internal locus of control)***, either using its name when explicitly mentioned by Kim, or by Sam's knowledge of relevant synonyms, or context, such as spatial adjacency to icons just previously mentioned.

[1] Explicit reference to dimensions in text shown in bold italicised font.

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