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The effect of four user interface concepts on visual scan pattern similarity and information foraging in a complex decision making task

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A B S T R A C T

User interface (UI) design can affect the quality of decision making, where decisions based on digitally presented content are commonly informed by visually sampling information through eye movements. Analysis of the resulting scan patterns – the order in which people visually attend to different regions of interest (ROIs) – gives an insight into information foraging strategies. In this study, we quantified scan pattern characteristics for participants engaging with conceptually different user interface designs. Four interfaces were modified along two dimensions relating to effort in accessing information: data presentation (either alpha-numerical data or colour blocks), and information access time (all information sources readily available or sequential revealing of information required). The aim of the study was to investigate whether a) people develop repeatable scan patterns and b) different UI concepts affect information foraging and task performance. Thirty-two participants (eight for each UI concept) were given the task to correctly classify 100 credit card transactions as normal or fraudulent based on nine transaction attributes. Attributes varied in their usefulness of predicting the correct outcome. Conventional and more recent (network analysis- and bioinformatics-based) eye tracking metrics were used to quantify visual search. Empirical findings were evaluated in context of random data and possible accuracy for theoretical decision making strategies. Results showed short repeating sequence fragments within longer scan patterns across participants and conditions, comprising a systematic and a random search component. The UI design concept showing alpha-numerical data in full view resulted in most complete data foraging, while the design concept showing colour blocks in full view resulted in the fastest task completion time. Decision accuracy was not significantly affected by UI design. Theoretical calculations showed that the difference in achievable accuracy between very complex and simple decision making strategies was small. We conclude that goal-directed search of familiar information results in repeatable scan pattern fragments (often corresponding to information sources considered particularly important), but no repeatable complete scan pattern. The underlying concept of the UI affects how visual search is performed, and a decision making strategy develops. This should be taken in consideration when designing for applied domains.

1. Introduction

The manner in which people visually sample information presented on displays through eye movements is important to the design of user interfaces (UIs), allowing to evaluate, for example, whether all information sources on the display are attended to or whether shortcuts are developed. To date, the quantitative literature on the subject is sparse, although computer interfaces are a ubiquitous part of everyday life. Further, in the age of Big Data, visualisations containing sometimes hundreds of variables become ever more prevalent (Turkay et al., 2017; Sagiroglu and Sinanc, 2013), where visualisation design can improve the decision quality (Savikhin et al., 2008). The question motivating the current work was whether and how four conceptually very different data presentation strategies affect information foraging.

The analysis of interactions with visually displayed information has a rich history for consumer testing, where visual scanning of UIs can be investigated through eye tracking (Jacob and Karn, 2003; Poole and Ball, 2006) to get an insight into ease of information acquisition (Pohl et al., 2009) for example. Despite these efforts, our understanding of principles underlying visual interaction with UIs is considered underdeveloped (Ehmke and Wilson, 2007), and comparatively little work systematically investigates the effect of data presentation on visual scanning approaches and information foraging. In a field study investigating visual sampling across multiple displays in a road traffic control room (Starke et al., 2017), we recently showed that search activity was idiosyncratic (with individuals adopting different patterns of

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search) but also preferential (with some information displays being attended to more often than others). With the work reported here, the role of preferential information selection was tested in a controlled task.

1.1. Information foraging in visual displays: explore-exploit trade-off and effort

In this study, we explored the effect of data presentation on visual information foraging in context of the effort involved in accessing information. This effort of information access becomes important in the 'explore-exploit' trade-off/dilemma in multi-source decision making, where decision correctness (exploitation) is balanced against search time (exploration of further sources) depending on the task and learning effects (Wilson et al., 2014; Kaelbling et al., 1996). In line with this well explored phenomenon, using cognitive modelling we have recently shown that an optimum number of attended regions of interest (ROIs) can be predicted for efficient information extraction (Chen et al., 2017), where efficiency is determined by an optimum trade-off between the correctness of decisions and the time taken to make it.

Generally, effort of information access can be controlled along two dimensions: data representation and time to access data. First, in a simple decision scenario which might involve a binary choice (such as "good/bad"), data can be represented in two ways: alpha-numerically (requiring a person to read and interpret information in context of known classification parameters, where e.g. for a £0 account threshold, £100 means good, -£100 means bad), or through colour blocks (pre-interpreted data visualised through colours: e.g. green means good, red means bad). The latter transforms the task from reading and interpreting the information to a simple act of colour decoding and is exploited in the use of colour maps/colour representations (Carlsson, 2017; Yau, 2011; Turkay et al., 2017; Lurie and Mason, 2007). Second, time spent accessing information indicates the user's willingness to increase decision time while sampling more information. The importance of decision time has been widely demonstrated in the psychological literature, where humans may use heuristics and other approximations to make decisions faster without attending all available information (e.g. Gigerenzer and Gaissmaier, 2011; Mousavi and Gigerenzer, 2014).

Considering the factors above, different UI designs could create trade-offs leading to different information foraging strategies. To explore this, we quantified visual scan patterns for four conceptually different UI designs (2 × 2 design along the above two dimensions of data representation and information access time) to understand how the presentation of visual information influences visual scan patterns and information foraging.

1.2. Scan pattern similarity: evidence and open questions

Scan patterns are commonly defined as the sequence in which people attend to different regions of interest (ROIs) in a given display (Holmqvist et al., 2011). There is much evidence that such visual attention shifts are guided 'top-down' in goal directed tasks, where eye movements are strategically directed towards relevant information sources (Hayhoe and Ballard, 2005; Henderson, 2003): i.e. people simply look where they expect to find information relevant to their agenda or question. This consensus roots in classic work which demonstrated that attended ROIs depend on the viewer's intention (Borji and Itti, 2014; Yarbus, 1967). The definition of 'viewer intention' could relate to the mental model that the viewer has of the structural relations between information sources and decisions, but could equally relate to the probability that a given information source contributes to a given decision.

To date, it remains ambiguous whether people develop systematic scan patterns when examining familiar information sources. There is mounting evidence for the development of repeatable sequences of attended regions within a scene. During repeated viewing of natural images, scan patterns are reasonably consistent (Foulsham and Underwood, 2008; Laeng and Teodorescu, 2002; Pieters et al., 1999; Underwood et al., 2009). In air traffic monitoring, visual scanning shows a tendency towards repeatable patterns independent of changes in the locations of points of interest within a stationary display (Ellis and Stark, 1986). When looking at websites, there is evidence for similarity in (preferred) scan patterns for some participants (Josephson and Holmes, 2002). However, no study has yet found evidence for perfect scan pattern repeatability; generally, humans retain a (sometimes high) level of variability. Familiarity and expertise may affect the consistency of scan patterns: in dynamic tasks, scan patterns can vary in consistency between novices and experts, when judging fish locomotion (Jarodzka et al., 2010). The same holds true for static stimuli such as dermatology slides (Vaidyanathan et al., 2014). Ultimately, the similarity of scan patterns depends on the study design and may – in part – arise from the consistency of image characteristics (Josephson and Holmes, 2002). The latter usually results in scan patterns which are similar between participants.

At present, some of the open questions in scan pattern analysis concern the meaningful comparison of scan patterns, the consistency of scan patterns, as well as the relationship between scan patterns and cognitive processes (Holmqvist et al., 2011). Here we address some of these issues, applying conventional and recent methods to the visual interaction with user UIs.

1.3. Scope

The motivation for performing the work reported here was to examine a) whether people spontaneously develop systematic scan patterns during feedback-based information foraging, and b) whether different user interface concepts would lead to differences in information foraging and task performance. The work was performed in context of the current discussion about the integration of human and machine intelligence in the age of Big Data, with a view of establishing whether UI design can affect visual information sampling when humans work in tandem with computers.

2. Experimental design

2.1. Participants

This study was approved by the University of Birmingham Ethics Panel (Reference Number ERN_13-0997) as part of the European Project SPEEDD. Thirty-two participants (mean ± SD age 28.9 ± 6.7 years; 21 male) were recruited from staff and students at the University of Birmingham, UK. No financial or other incentives were given for participation and written informed consent was provided prior to commencing the study.

2.2. Task

Participants were asked to take on the role of a credit card fraud analyst where they had to screen transactions flagged by an 'automated system' as suspicious. This task was chosen according to the use-case of credit fraud detection investigated through the SPEEDD project. The benefit of this task is a controlled environment consisting of simple cues that relate to a task of which people have a basic conceptual understanding. Similarly, previous seminal work used the financial scenario of share trading as the decision task (Newell et al., 2003; Newell and Shanks, 2003) to explore heuristics. The flow diagram in Fig. 1 illustrates the five steps which a participant completed when working through a transaction, namely 1) call up the transaction, 2) view information, 3) log decision, 4) view feedback and 5) close transaction. The speed-accuracy trade-off was left to the participants to decide by phrasing the aim as follows: "The aim is to correctly classify 100 transactions as quickly as possible while minimising the number of mistakes […]. Making many mistakes would be negative for the bank as