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Towards a Selection Mechanism Integrating Focal Fixations, Pupil Size, and Microsaccade Dynamics

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Abstract. The use of gaze promises fast and smart user interaction. Mimicking human gaze interaction, we suggest a framework based on the vision of integrating fixations, pupil size, and microsaccade dynamics. Recent work has shown that fixations can be differentiated between focal and ambient, where the former are important for further decisional processes, and the latter are rather used for orienting. Psychophysiological measures suggest that pupil dilation and microsaccades can reveal user intention in real time. We propose a selection mechanism that takes into account microsaccades and pupil diameter changes but only within focal fixations.

1. Introduction: the Power of Gaze

Gaze is one of the central means for human-human interaction. The vision for including gaze in human-computer interaction (HCI) is making the interaction smooth, natural, adaptive, and smart. Enabling gaze-based HCI thus requires an understanding comprising all factors involved in human-human gaze communication. In the following, we forward some ideas of how to integrate current knowledge of gaze behaviour with a framework integrating knowledge about fixations, pupil dynamics, as well as about motion dynamics (i.e., saccades and microsaccades).
2. Interacting via Focal Fixations

Gaze behaviour provides observers information about our moment-to-moment point of attentional interest and focus. Despite various suggestions for selection by gaze, dwelling on an object is still the most common approach.

There is a large body of literature relating fixation duration and cognitive and emotional processes. For example, a longer fixation duration can indicate depth of cognitive processing and problem-solving (Jacob and Karn, 2003; Eivazi and Bednarik, 2011). Just and Carpenter's (1976) eye-mind assumption states that gaze remains fixed on the stimulus so long as it is being processed. More recent studies show the active role of attention in constructing a decision (Krajbich et al., 2010; Shimojo et al., 2003).

The dynamic pattern of visual attention is very often, in different models, attributed to two modes of information acquisition, referred to as, e.g., exploring and inspecting (Velichkovsky et al., 2005), orienting and evaluating (Ingle, 1967). In all those models the first stage is related to ambient attention, which serves mainly for orientation within the visual scene, and the second stage is related to focal attention, suggesting deep information processing with high attentional processes involved (Trevarthen, 1968). Velichkovsky et al. (2005) related these two stages of information processing by fixation duration and saccade amplitude. Short fixation durations combined with long saccades are characteristic of ambient processing, while longer fixation durations followed by shorter saccades are indicative of focal processing (Unema et al., 2005). More recently, Krejtz et al. (2016) combined fixation duration and saccade amplitude giving the $\mathcal{K}$ coefficient, capturing the interplay of ambient and focal modes of visual attention as the single values string.

We posit that detection of ambient/focal fixations serves as a good first step for inclusion of additional indicators of decision-making. To our knowledge such an approach has not yet been explored previously in gaze-based human-computer interaction studies.

3. Interacting via Pupil Dynamics

Pupil diameter is a psychophysiological measure that may reveal much more about a user than just luminance or visual acuity, since it also changes in response to mental and attentional processes, as described by Bumke (1904). Hess and Polt (1964) rediscovered the indicative function of pupil size during mental problem-solving. Based on this finding, it is even possible to deliberately enlarge pupil diameter given that biofeedback is provided, opening a possible input to HCI (Ehlers et al., 2016). Today, beyond
mental effort, many more factors are thought to influence pupil diameter, including attentional processes (Einhäuser et al., 2008), covert attention, which can also be used for gaze based input (Mathôt et al., 2016), decision making, emotional arousal (Ehlers et al., 2016), and visual target detection (Privitera et al., 2010).

When comparing different map tasks employing the pupil, Kiefer et al. (2016) report the largest increase in pupil diameter during search tasks and focused search tasks. However, pupil dilation may not only reveal the kind of spatial task performed, but even predict its outcome: Privitera and colleagues found the pupil dilates when subjects fixate targets in visual search. Pupil dilation was observed even when subjects fixated but did not consciously recognize the target (Privitera et al., 2010). Moreover, the pupil diameter reportedly reflects binary decisional processes, even to the extent that their outcome is connected to a certain pupil dilation. In this context, de Gee et al. (2014) describe a larger pupil dilation accompanying decision for “yes” compared to decisions for “no”. However, by manipulating certainty during perceptual choice tasks, Urai et al. (2017) reported significantly larger pupil dilation after erroneous rather than correct choices and smaller dilations after correct decisions based on strong evidence.

Pupil diameter may reveal the user’s intention during, after, and perhaps even before a decision is made. While finding a target is consistently linked to a larger pupil dilation in visual search tasks than fixations on irrelevant parts of a scene, findings for decision paradigms are less consistent. While it is claimed that a positive decision leads to a larger dilation than a negative decision, this relationship may be affected and even reversed depending on the level of uncertainty. Bednarik et al. (2012) examined the role of pupil diameter changes in an off-line machine learning investigation of eye tracking data when selecting, but reported only a moderate classification performance. Strauch et al. (2017) revisited this question by assessing diameter changes accompanying object selection in a gaze-based interface. Blink-filtered pupil dilation emulated selection on-line when diameter exceeded a critical threshold. Taken together, pupil dilation may be a promising factor for gaze-based interaction augmenting fixational information.

4. Incorporating Microsaccades

Microsaccades are small movements of the eye made during fixations. Their primary role is said to be maintaining visibility by constant stimulation of retinal photoreceptors to generate a stable image (Martinez-Conde et al., 2009). Microsaccade rates may be moderated by both perception and cognition reflecting top-down and bottom-up processes (Engbert, 2006; Laubrock et al., 2005).
In the context of decision making, Privitera et al. (2014) conclude that microsaccade rate is highest during fixations on a desired target. Several studies show the role of the Locus Coeruleus (LC) in decision making and its link to pupil dilation e.g., Einhäuser et al. (2010). The Superior Colliculus (SC) is known to be involved in microsaccadic eye movement generation (Hafed et al., 2008; Otero-Millan et al., 2008), and is in turn linked to LC, indicating correlation between pupil dilation and LC activation during discriminant decision making. Microstimulated or spontaneous activity of the LC is followed by pupil dilation with a short latency (Siddhartha et al., 2016).

Combining and comparing pupil diameter with microsaccades seems appealing: measures of attention and decision in particular and arousal in general could be made more reliable. Variations as a result of factors selectively confounding microsaccades or pupil diameter could be reduced and the general understanding of cognitive processes could as well be improved as applications might benefit from fast and specific information on LC activity.

5. Vision: Total Gaze for Interaction

The envisioned concept combines focal fixations with pupil and eye movement dynamics, namely saccades and microsaccades. Our proposed multi-layer selection mechanism first determines whether fixations are focal or ambient. If the fixation is focal, psychophysiological indicators of intention should be tracked as a next step. We argue that alterations in pupil size and in microsaccade rate and magnitude are interesting in this regard. If critical thresholds are exceeded for any of these indicators, other selection mechanisms, e.g., dwell time could be dynamically adapted by a weight that is individually assigned to the psychophysiological measures, depending on their contribution to intention recognition. This proposed mechanism is presented schematically in Fig. 1.

Potential applications include gaze-based recommender systems which are designed to respond with information contingent on the viewer’s gaze, e.g., for geographic or location-based services, when directed to a specific point in physical or virtual space. Such gaze-based recommender systems have been referred to as gaze-informed location based services (Anagnostopoulos et al., 2017). As an example of a higher-level attentional approach useful in such a system, we propose to utilize one as demonstrated by Krejtz et al. (2014) showing the utility of $K$ during visual search over different geographic representations of two cities.
Figure 1. Envisioned selection mechanism based on a combination of psychophysiological indicators.

References


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