Visual Search of Computer Displays: Local Density Guides Visual Search

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Abstract

Visual search in an important aspect of human-computer interaction (HCI), but it not well understood how layout design affects visual search. Predictive modeling of visual search is useful to HCI, as it can help us understand how layout design affects visual search. This research reveals patterns of human performance in visual search and contributes to predictive analysis of visual search.

This research uses reaction time data, eye movement data, and computational cognitive modeling to investigate the effect of local density on the visual search of structured layouts of words. Layouts were all-sparse, all-dense, or mixed. Participants found targets in sparse groups faster, and searched sparse groups before dense groups. Participants made slightly more fixations per word in sparse groups, but these were much shorter fixations. The modeling suggests that participants may have attempted to process words within a consistent visual angle regardless of density, but that they were more likely to miss the target if the target was in a dense group. Furthermore, it was found that the participants tended to search sparse groups before dense groups, and roughly halfway through searching mixed layouts, participants appeared to switch search strategies with respect to the number of fixations per group of words and fixation duration. Implications for design layout are that when combining densities in a layout, it may be beneficial to place important information in sparse groups. Implications for predictive modeling in HCI are that density does not affect the region perceived during each fixation, but that higher densities affect the probability of detecting the target.

Introduction

Varying the density is one common design practice used to establish grouping and hierarchy in visual displays. The density of items in a display is one factor that has been shown to affect the number of items that can be perceived in a single fixation and thus search time (Bertera and Rayner, 2000; Ojanpää, Näsänen, and Kojo; 2002). Besides affecting the number of items inspected per fixation, local density may also affect the *order* of inspection.

Consider snippets from the NewYorkTimes.com home page, Figure 1, in which the density of link labels varies with spacing and font size.

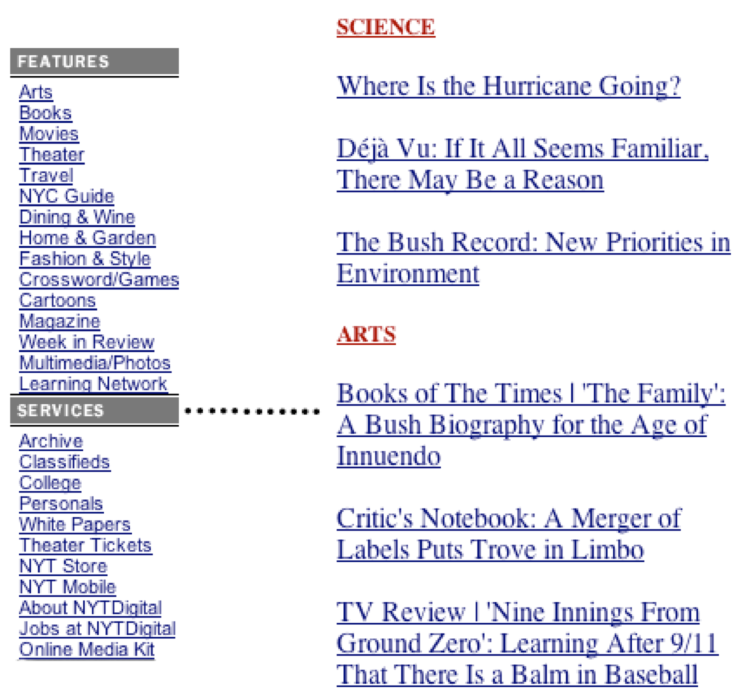


Figure 1. Snippets from the NewYorkTimes.com home page. The density of link labels vary across the page.

Predictive modeling of visual search rarely needs to account for the affects of density. An experiment was conducted to investigate how people search groups of words that vary in density. The results were used to build a model of visual search.

Experiment

An experiment was conducted to investigate the effect of local density, and the mixing of local densities, in the visual search of structured layouts where the stimuli were words. Twenty-four people, 10 female and 14 male, ranging in age from 18 to 55 years of age (mean = 24.5) from the University of Oregon and surrounding communities participated in the experiment.

Figure 2 shows a sample layout from one mixed-density trial. All trials contained six groups of left-justified, vertically-listed black words on a white background. The groups were arranged in three columns and two rows.

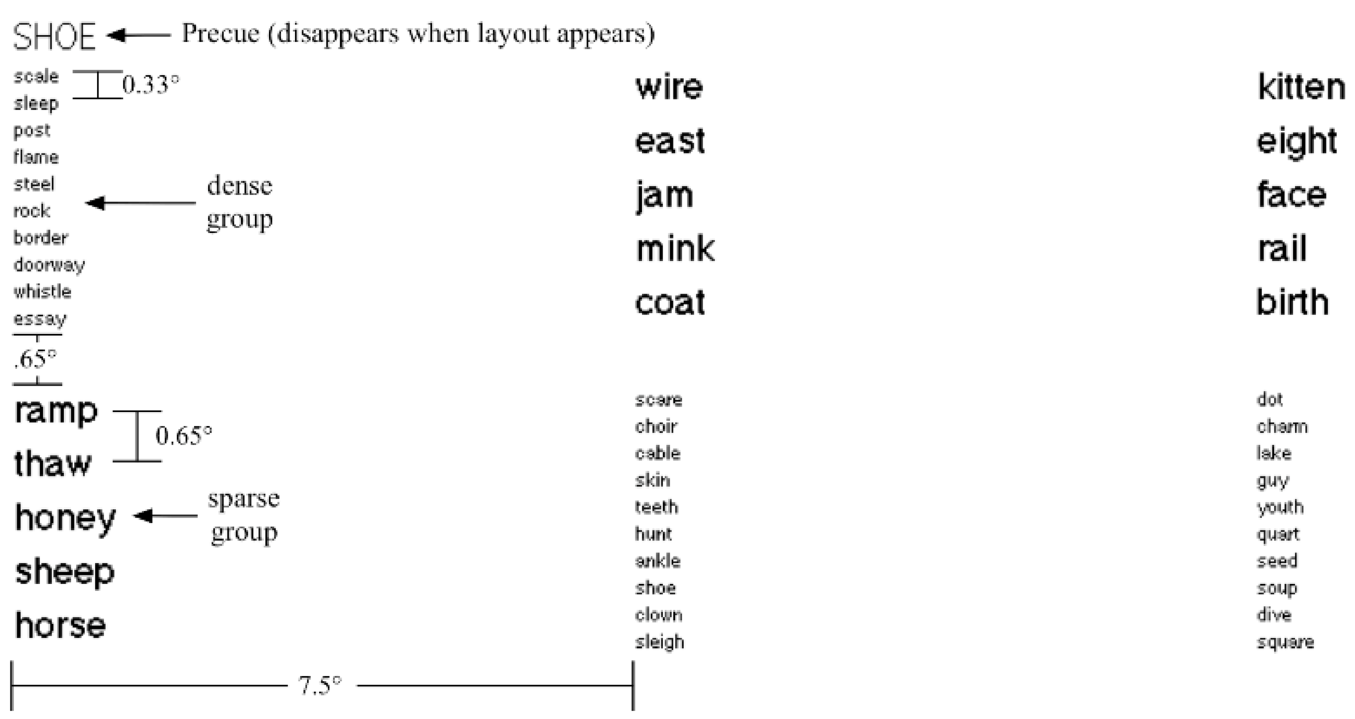


Figure 2. A example mixed-density layout. All angle measurements are in degrees of visual angle.

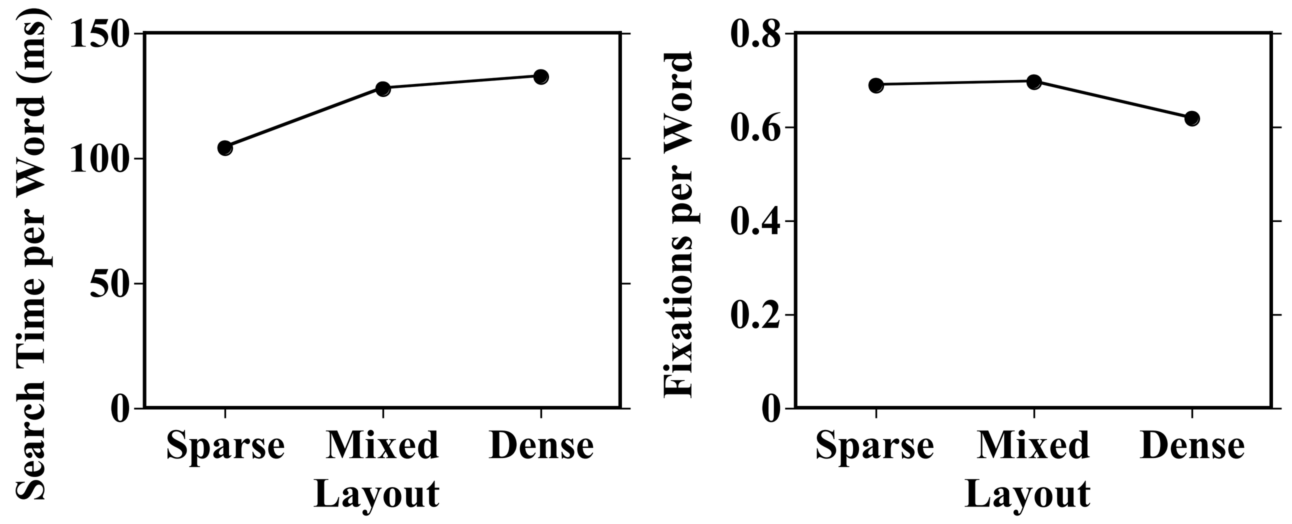
There were two types of groups with different local densities: *Sparse* groups contained five words of 18 point Helvetica font. *Dense* groups contained 10 words of 9 point Helvetica font. Both types of groups subtended the same vertical visual angle.

There were three types of layouts: *sparse*, *dense*, and *mixed-density*. Sparse layouts contained six sparse groups. Dense layouts contained six dense groups. Mixed-density layouts contained three sparse groups and three dense groups. The arrangement of the groups in the mixed-density layouts was randomly determined for each trial.

Each trial proceeded as follows: The participant studied the precue, clicked on the precue to make the precue disappear and the layout appear, found the target word, moved the cursor to the target word, and clicked on it.

Results and Discussion

Search time and eye movement data were analyzed.



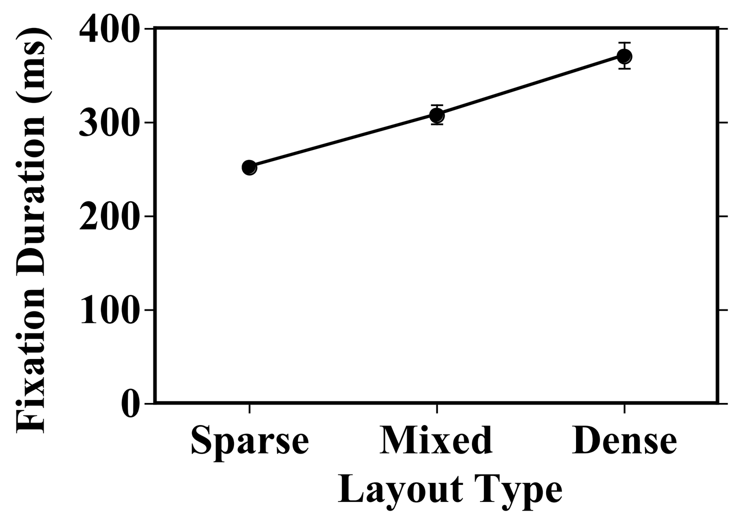


Figure 3. The mean search time per word (upper left), mean number of fixations per word (upper right), and mean fixation duration (lower left) by layout type.

Participants spent less time per word in layouts with fewer dense groups, $F(2,46) = 13.94$, $p < .01$. Participants made slightly fewer fixations per word in layouts with more dense groups, $F(2,46) = 3.25$, $p = .05$. Conversely, participants' fixations were much longer in layouts with more dense groups, $F(2,46) = 61.82$, $p < .01$.

As Figure 3 shows, the sparse layouts were searched faster per word. However, the number of fixations per word decreased with density, suggesting that more words were perceived on each fixation. Therefore, the increase in search time is most likely due to an increase in fixation duration as the density increased.

However, there is more to the story. The order in which the groups were searched was also affected by the density.

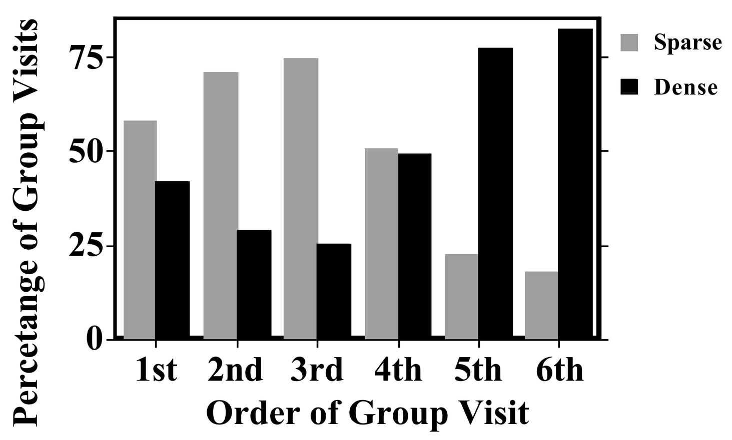


Figure 4. The percentage of visits in mixed density layouts that were to sparse or dense groups, as a function of the order in which groups were visited.

Analysis shows that participants tended to visit sparse groups before dense groups $X^2 = (5, N=24) = 500.04$, $p < .01$.

Sparse words were not only searched faster, they were searched first. Figure 4 shows that sparse groups were the majority of the first three groups searched. Looking at the order of search in greater detail reveals even more.

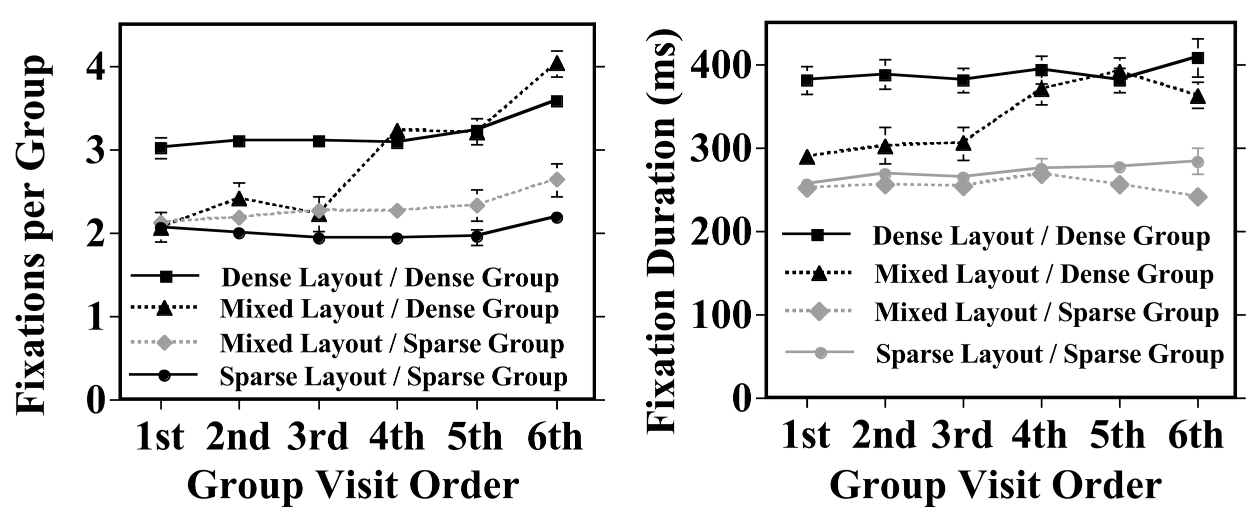


Figure 5. The mean number of fixations per group (left) and mean fixation duration (right) as a function of layout, the density of the group currently visited, and order of the visit.

The number and duration of fixations used to search each group was relatively constant in sparse layouts, dense layouts, and sparse groups in the mixed layout. However, dense groups in the mixed layouts were searched with fewer and faster fixations earlier in the search process. This suggests that the participants tended to rush the search process in dense groups until they were approximately halfway through the layout.

Modeling

Computational cognitive models were constructed using the EPIC (Executive Process Interactive Control) cognitive architecture (Kieras & Meyer, 1997). EPIC captures human perceptual, cognitive, and motor processing constraints in a computational framework that is used to build cognitive models. Into EPIC were encoded (a) a reproduction of the task environment, (b) the visual-perceptual features associated with each of the screen objects and (c) the cognitive strategies that guide the visual search, encoded as production rules. After these components were encoded into the architecture, EPIC executed the task, simulated the perceptual motor processing and interactions, and generated search timed eye movement predictions.

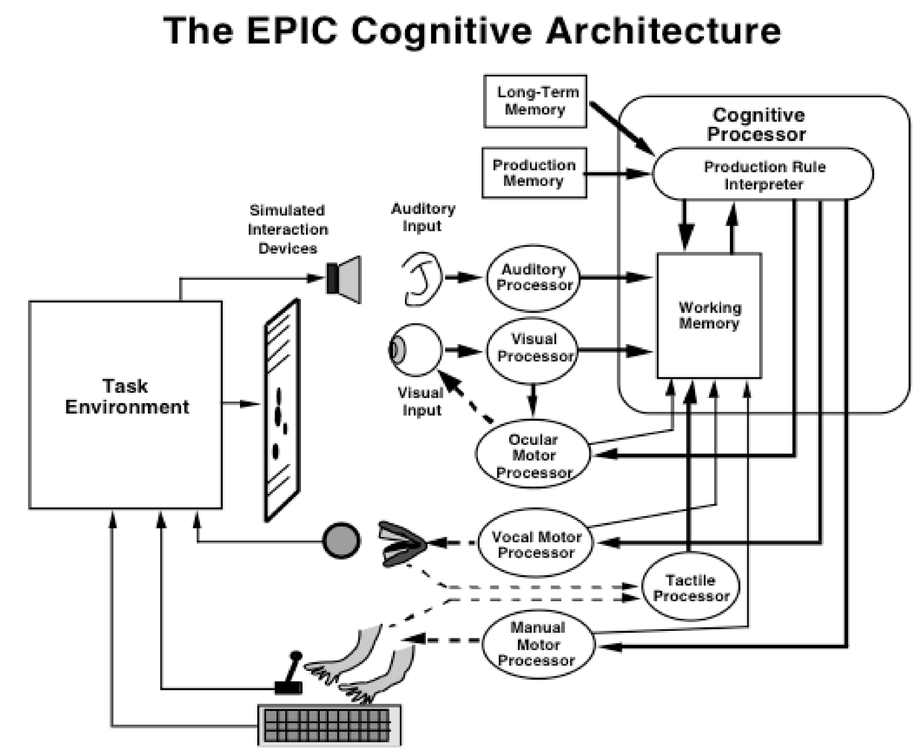
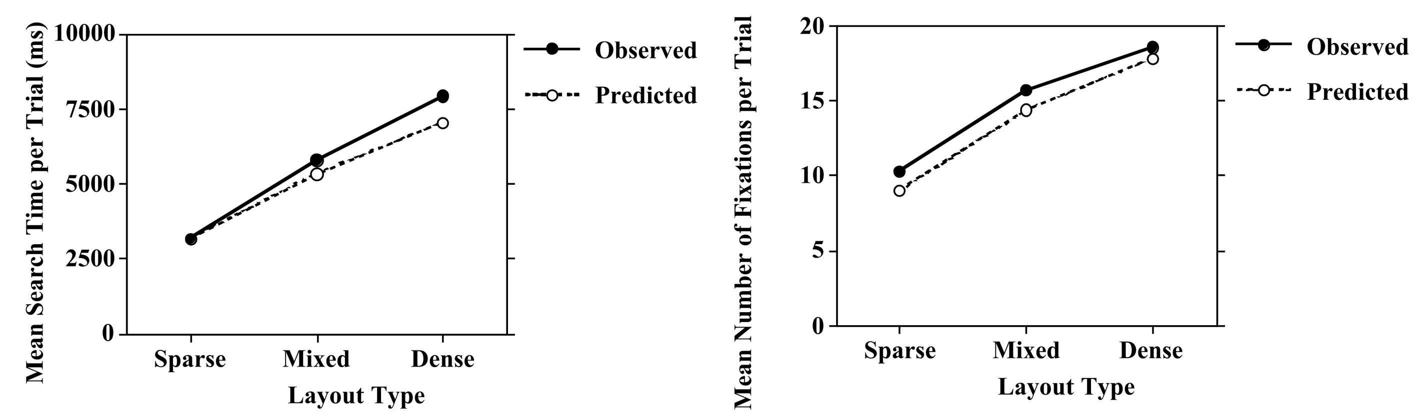


Figure 6. Diagrammatic representation of the EPIC cognitive architecture.

Four models were created in EPIC to account for the search time, number of fixations, and fixation durations. Each improved on the previous. All models are based on a purely random, without replacement, search strategy. While we do not necessarily assert that people move their eyes from item to item randomly, it may be that a random search strategy is a good first approximation for predicting mean layout search time without the need to specify complicated strategies or visual features beyond the locations of objects. Such a strategy has the added benefit for a priori engineering models, as each object need be coded with only it's location.

The best fitting model refrained from initiating a saccade until the text of the currently fixated words were perceived, but prepared the next saccade while waiting. In addition, the time and probability of perceiving the words was determined by the proximity of adjacent items. Dense words required a total of 200 ms to perceive and sparse words a total of 100 ms to perceive. The region from which text could be perceived was left at the EPIC default value of 1.0 dov. However, the probability of perceiving any given word was varied by local density: 90% for words in sparse groups and 50% for words in dense groups. As seen in Figure 7, this model explains the data very well.



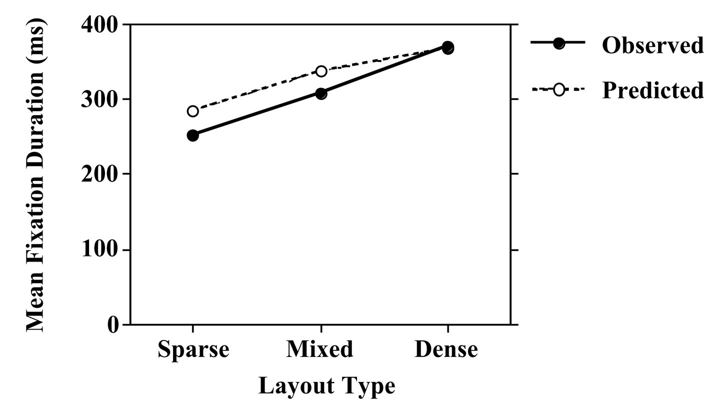


Figure 7. The mean search time (upper left), number of fixations per trial (upper right), and fixation duration (lower left) that were observed (solid lines) and predicted (dashed lines) by the best-fitting model. The average absolute error of the fit for each measure are, in order, 7%, 9%, and 8%.

Conclusions

This research investigates the effect of local density on visual search of structured, two-dimensional menus. It was shown that targets in sparse groups were found faster for two reasons. Participants were able to adopt a more efficient eye movement strategy for sparse groups that used slightly more, but much shorter, fixations. In addition, the participants tended to search the sparse groups first. Even when dense groups were searched early, the dense groups were searched in a less thorough manner (i.e. fewer and shorter fixations) than when searching dense groups alone.

The modeling results support those of Bertera and Rayner (2000). Bertera and Rayner estimated that the size of the region in which objects were processed was the same across layouts of different densities. The best fitting model based on our data also predicts that the region in which objects were potentially processed was the same across different densities. However, the model suggests it is likely that some items within that region were not perceived.

Implications for predictive modeling of visual search for HCI are that the effects of density will not only have to be accounted for at the perceptual and motor level, such as the number of items perceived in each fixaton and the fixation duration, but also at the cognitive or strategic level, such as the order of search and a shift in fixation strategy based on the density of objects.

References

Bertera, J. H., & Rayner, K. (2000). Eye movements and the span of effective stimulus in visual search. *Perception & Psychophysics, 62*(3), 576-585.

Kieras, D. E., & Meyer, D. E. (1997). An overview of the EPIC architecture for cognition and performance with application to human-computer interaction. *Human-Computer Interaction, 12*(4), 391-438.

Ojanpää, H., Näsänen, R., & Kojo, I. (2002). Eye movements in the visual search of word lists. *Vision Research, 42*(12), 1499-1512.