The VERP Explorer: A Tool for Exploring Eye Movements of Visual-Cognitive Tasks Using Recurrence Plots

Çağatay Demiralp, Jesse Cirimele, Jeffrey Heer, and Stuart K. Card

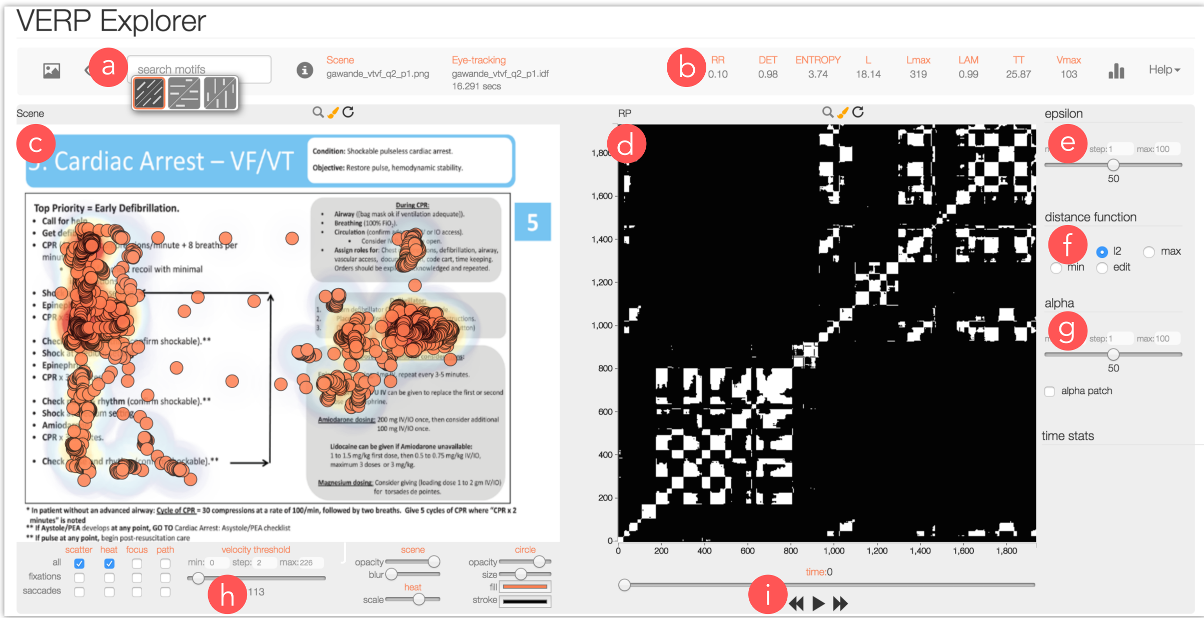

Fig. 1: The VERP Explorer has two main views: the scene view (c) and the recurrence plot view (d). The VERP Explorer combines spatial eye movement visualizations with recurrence plots to support the visual analysis of eye movements during visual-cognitive tasks. (See Section 2 for descriptions of the interface elements labeled above.)

Abstract—Evaluating the effectiveness of the visual design of an interface is an important yet challenging problem. In this paper, we introduce the VERP (Visualization of Eye movements with Recurrence Plots) Explorer, a visual analysis tool for exploring eye movements during visual-cognitive tasks. The VERP Explorer couples conventional visualizations of eye movements with recurrence plots that reveal patterns of revisitation over time. We contribute a set of methods for the analysis of eye movement sequences, including recurrence motifs for identifying behavioral eye movement patterns. We apply the VERP Explorer to the domain of medical checklist design, analyzing eye movements of doctors searching for information in checklists under time pressure. We use these results to introduce the notion of visual micro-foraging, which generalizes information foraging theory to visual design.

Index Terms—Visualization, HCI theory, visual search, eye movements, recurrence plots, time series, information foraging theory, study squares, micro-foraging, inadvertent detractors.

1 Visual-Cognitive Interaction

The purpose of visualization is to ease and amplify the work of cognition by re-coding information so as to exploit the perceptual abilities of the eye. To design for the eye, we have principles at a general level—the principles of perception, the gestalt laws, etc.—but to gain more insight, we need to understand the lower-level mechanisms forming these principles. Insights and models derived from lower-level empirical data can inform higher-level visual design principles [13].

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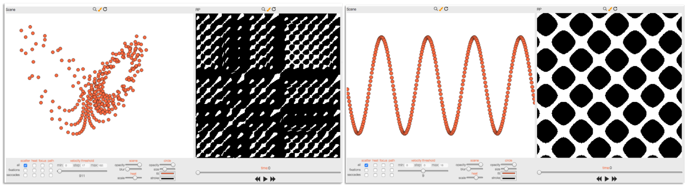
1.1 Visualizing Eye Movements

Fortunately, eye movements often track the sequential attention of the user, affording a unique window into visual-cognitive interactions. However, understanding eye movement trajectories is not straightforward. In this paper, we propose a set of analytical methods to improve visual design and evaluation of interfaces through eye movement based analysis, especially for the case where the design needs to facilitate visual search. Our work has two primary goals: (1) to improve the behavioral characterization of a design, and (2) to embed the methods in an integrated tool, so as to make them easy and rapid to use.

Advances in eye tracking technology have made eye movement data collection more practical than ever, increasing the need for developing better visual analysis methods [4]. There are several standard techniques for visualizing eye tracking data including heat maps, focus maps, and gaze plots (scan paths). Understanding differences and similarities in eye movements across subjects is an important goal in eye tracking studies. Earlier research introduces several techniques to reduce visual clutter and



Lorenz Sine

Fig. 2: Recurrence plots of the Lorenz function (left)—projected into the plane—and the sine function (right).

support multi-subject comparisons (e.g., [8, 22, 23, 29]). Experts often capture semantics of eye movements by tagging areas of interest (AOIs) on the stimulus and associating them with fixations. Typically borrowing from the text visualization literature (e.g, [19, 34]), prior work also proposes visualization techniques to support AOI-based analysis (e.g., [7, 32]).

The VERP Explorer couples several of the standard eye tracking visualizations, including heat maps, focus maps, gaze plots, with recurrence plots and alpha patches through interaction.

1.2 Recurrence Plots

Recurrence plots originate from the study of dynamical systems and were introduced for visual analysis of trajectories [14, 25]. Figure 2 shows the recurrence plots for the Lorentz (left) and sine (right) functions. Notice that the Lorenz function is a multidimensional function parametrized by time. To obtain the matrix $[r_{ij}]$ that is the basis for a recurrence plot, we compare each data value f_i (e.g., the eye tracking sample or value of a time-varying function at time i) to all the other values in the sequence, including itself. If the distance d_{ij} between the two compared values is within some small distance ε then we put a 1 at that position in the matrix, otherwise a 0. Formally,

$$r_{ij} = \begin{cases} 1 & \text{if } d_{ij} \leq \varepsilon \\ 0 & \text{otherwise} \end{cases}$$

Figure 3 illustrates how a recurrence graph for eye movements plotted over a scene (stimulus image) (Figure 3a) is constructed. The dotted circles represent the $\varepsilon/2$-distance regions around the locations of eye movements. To analyze a visual text search task, for example, we would set ε to be 3° as the foveal area in which a person can read the text is about /1.5°.

To construct the recurrence plot Figure 3g of Figure 3a, we start with a blank matrix Figure 3b. Eye fixation 1 is within its own circle so cell (1, 1) is white (Figure 3c). Likewise, all other fixations fall within their own circles, so the diagonal (i, i) is white (Figure 3d). No other fixations falls within the circle of fixation 1, so the rest of row 1 is black Figure 3e. Since the distance metric used is symmetric, the rest of column 1 is black as well (Figure 3f). Fixation 2 is also not quite in any other fixations circle, therefore, except for the cell (2, 2) on the diagonal, its row and column are black (Figure 3f). Fixation 3 is in the circle of both fixation 4 and fixation 5, so cells (3, 4) and (3, 5) are white, by symmetry, so are cells (4, 3) and (5, 3). Finally, fixation 4 is in the circle of fixation, so (4, 5) and (5, 4) are also white (Figure 3g).

Recurrence plots are particularly good at characterizing periodic and semi-periodic sequences. The recurrence graph of a sine wave shown in Figure 2, for example, exhibits strong periodic behavior.

Prior work applies recurrence plots to analysis of speaker-listener eye movement coordination [11, 30] and characterization of eye movements in viewing scenes [1, 36]. Facilitating both visual (qualitative) and quantitative analysis is a powerful feature of recurrence plots. Recurrence quantification analysis (RQA) [26] uses scalar descriptors such as Recurrence Rate, Entropy, Determinism, etc. to quantify different recurrence patterns. Anderson *et al.* [1] apply RQA to characterize the type of the stimulus scene viewed, finding RQA measures to be sensitive to differences between scene types (e.g., indoor vs. outdoor). Building on this work, Wu *et al.* find that differences in eye movement patterns as quantified by RQA correspond to scene complexity and clutter [36].

To our knowledge, our work is among the first to study the goal-oriented task of visual search using recurrence plots of eye movements. The VERP Explorer simplifies exploratory analysis by integrating spatial eye tracking visualizations with recurrence plots and quantified recurrence analysis.

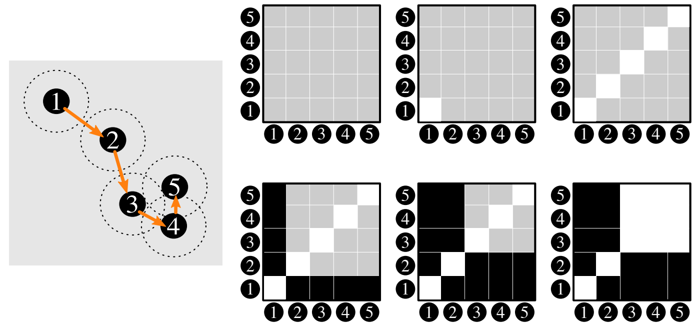


Fig. 3: Construction of a recurrence plot for the eye movements shown (a). The diameter of dotted circles around the points is ε. For every pair of points, we put 1 (white) in the corresponding matrix entry if they are within ε distance (i.e., their dotted circles intersect), otherwise we enter 0 (black).

2 Design of The VERP Explorer

The goal of the VERP Explorer is to support the interactive visual analysis of eye movements using recurrence plots. To this end, the VERP Explorer couples several spatial eye movement visualizations with recurrence plots through brushing and linking (Figure1). The VERP Explorer is a web based application and we implemented it in JavaScript with help of D3 [6] and Angular JS [2] libraries. The source code and a deployed copy of the VERP Explorer can be accessed at `https://www.github.com/uwdata/verp/`.

We now briefly discuss the visualizations and interactions that the VERP Explorer supports.

2.1 Heat Maps, Focus Maps, and Scatter Plots

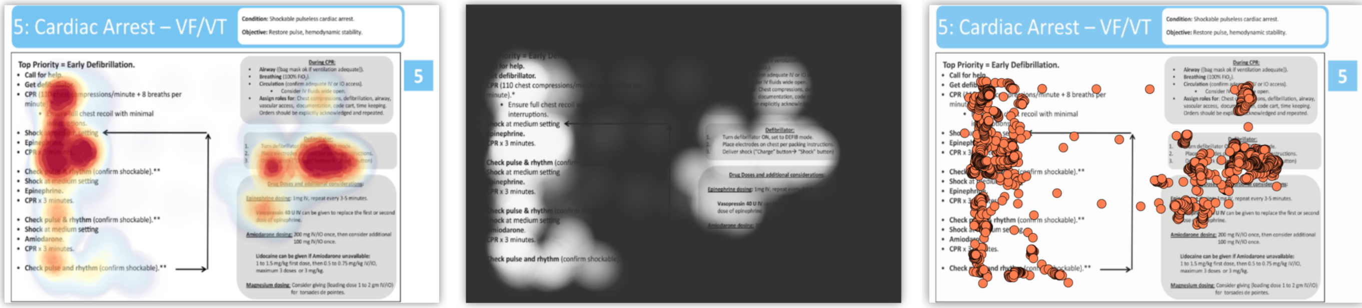
The VERP Explorer enables users to visualize eye tracking positions as heat maps, focus maps, and scatter plots. The three have complementary strengths. *Heat maps* and *focus maps* are two related standard techniques that are useful for providing a synaptic view of eye movements aggregated over time and subjects. The VERP Explorer creates the heat map visualizations by drawing semi-opaque disks centered at eye tracking positions. The disks are filled with a color gradient and their opacity is modulated (decreased) with the distance from the disk center (Figure 4). By painting eye movement point densities, heat maps obscure, however, the areas of attention when overlaid on the stimulus image. Focus maps visually "invert" heat maps to enable the visibility of the areas of viewer attention. To create a focus map, we first create a uniform image (mask) that has the same size as the underlying stimulus image. We then vary the opacity at each pixel inversely proportional to the opacity of the corresponding heat map pixel. Focus maps are essentially negative space representations, visualizing the negative space of the corresponding heat maps (Figure 4).

Heat maps and focus maps support visual aggregation while visualizing eye movements indirectly. On the other hand, *scatter plots* provide a discrete view by representing eye movement positions directly, enabling the inspection of patterns and outliers at the level of individual points. The VERP Explorer creates scatter plot views by drawing each eye tracking position as a circular node in the plane (Figure 4).

2.2 Scan Paths

In their basic, static configuration, neither heat maps nor focus maps convey the temporal order of eye movements. The VERP Explorer uses scan paths (gaze plots) to provide an aggregate temporal view of eye movements. It creates scan path views by drawing circles centered at the centroids of fixation clusters and connecting two consecutive clusters with arrows. The VERP Explorer numbers the nodes sequentially. It also encodes the temporal order of fixations by coloring the nodes and the arrows using a color map ranging from dark blue to red [18] (Figure 5).

Note that the VERP Explorer does not assume the eye tracking data is already classified. It identifies fixations and saccades using the velocity-threshold fixation (I-VT) algorithm [31]. I-VT is a fast and robust algorithm for classifying fixations and saccades based on thresholding



Heat map Focus map Scatter plot

Fig. 4: Three spatial eye tracking visualizations from the VERP Explorer: Heat map (left), focus map (middle), and scatter plot (right). The three visualizations have complementary advantages. Heat maps and focus maps are particularly useful for providing a continuous aggregate view of eye movements and their negative space. Scatter plots directly encode eye movements (as circular nodes here), enabling the exploration of the data patterns at the level of individual eye movements.

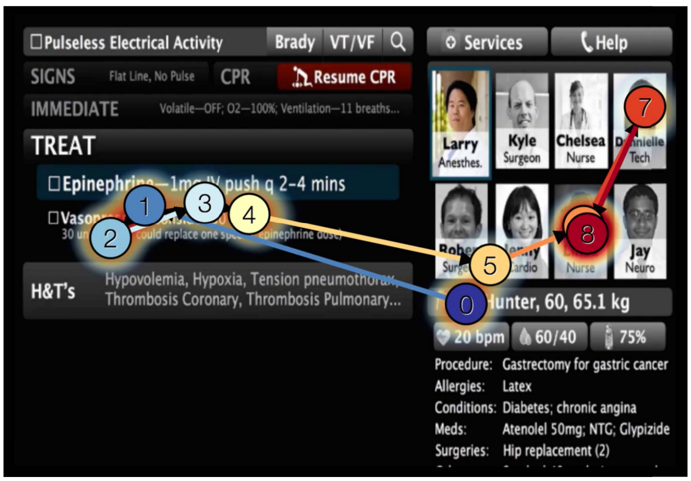


Fig. 5: Scan path visualization of fixation points. The VERP Explorer uses text, shape, and color to encode the temporal order of fixations. It sequentially numbers the nodes that represents fixation clusters, puts an arrow between consecutive nodes, and colors the nodes and the arrows using a color map ranging from dark blue to red.

point-to-point velocities of eye movements. The VERP Explorer gathers consecutive fixation points into clusters and computes associated measures such as centroid, geometric median, and duration. More importantly, it enables users to modify the velocity threshold of classification using a sliding bar (Figure 1h) and view the changing scan path visualizations interactively.

2.3 Alpha Patches

Visual clutter is often a concern in analysis of eye tracking data. We introduce *alpha patches*, alpha-shapes [15] of fixation points, to provide a cleaner view of underlying fixation areas through filled polygonal patches.

The alpha shape is a generalization of the convex hull of a point set [15]. Unlike the convex hull, the alpha shape can recover disconnected, non-convex spaces with holes. Crucially, it provides a control over the specificity of the polygonal approximation of the underlying points through a parameter $\alpha \in [0,\infty)$ (Figure 6). The VERP Explorer enables users to automatically create alpha patches of fixations with a dynamic control over the α parameter (Figure 1g).

2.4 Interaction Techniques

The visualizations we have described are interactive, giving rise to a number of exploration techniques:

Zooming & Panning. The VERP Explorer provides zooming and panning interactions on all of the visualizations that it generates. Both zooming and panning are forms of dynamic visual filtering and essential for exploring dense eye movement datasets.

Brushing & Linking. We use brushing & linking in the VERP Explorer to coordinate the scatter plot of the eye tracking data with the recurrence plot view. This is the main mechanism that allows users to inspect recurrence space and spatial eye movements simultaneously. Brushing over a location on the scene highlights all the corresponding entries in the recurrence view. Conversely, brushing on the recurrence plot highlights corresponding eye movement positions represented as circular scatter plot nodes.

Epsilon Filtering. Epsilon filtering enables the interactive exploration of range of epsilon values for recurrence plots (Figure 1e). Users can also select different distance measures (Figure 1f). We provide the Euclidean (L_2-Norm), the city block (L_1-Norm), the maximum (L_∞-Norm) and the minimum of the absolute differences along data dimensions and the edit distance.

Alpha Filtering. Similar to epsilon filtering, alpha filtering allows users to dynamically change the α parameter of the alpha patches. This enables creation of a multi-scale, coarse-to-fine, view of the underlying eye tracking data (Figure 1g).

Dynamic Fixation-Saccade Classification. The VERP Explorer also enables users to change the threshold for fixation-saccade classification dynamically. This is particularly useful when angular velocity calculations are not possible or reliable (Figure 1h).

Motif Search. Recurrence plots facilitate pattern-based analysis of time varying data. One of the motivations of the current work is to help relate behavioral eye movement patterns to visual design through recurrence patterns. In addition to computing several well-known descriptors of recurrence plots such as Recurrence Rate (RR), Determinism (DET), Entropy (ENTROPY), etc. (Figure 1b), the VERP Explorer enables users to search for predefined patterns in the recurrence plots (Figure 1a). Currently users can search for diagonal, vertical and horizontal structures in recurrence plots.

Timeline Animation. While the scan path visualization provides an aggregate temporal view of the eye movement, it is desirable to be able to directly examine the timeline of the complete data. The VERP Explorer enables users to animate the appearance of eye tracking points using the scatter plot visualization (Figure 1i).

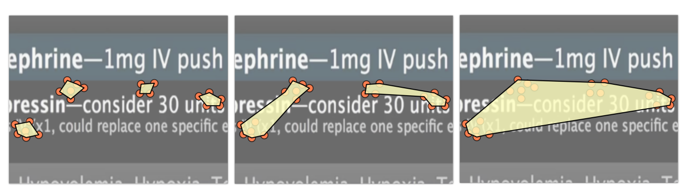


Fig. 6: Three alpha patches with increasing α values from left to right. Notice that, when α is sufficiently large, the alpha patch is the convex hull of the points (right).

3 Illustration of Use: Visual Search in Emergency Medical Checklists

To illustrate the use of the VERP Explorer for exploring a cognitive-visual task, we use the task of designing visual displays for emergency medical checklists. In U.S. hospitals, it is estimated that medical errors cause in excess of 100,000 deaths per year, half of which are thought to be preventable [21]. Checklist use has been found to improve performance in aviation [5, 9, 12] and medicine from surgery to intensive care and crisis response [3, 16, 17, 20, 24, 28, 37]. However, checklists have been criticized for adding delay, attentional load, and complexity [16, 35], slowing down crucial medical procedures. As Verdaasdonk *et al.* [33] put it, "Time governs willingness and compliance in the use of checklists." It would therefore be desirable to improve the speed (and accuracy) with which aids can be used.

3.1 Comparing Two Checklist Formats

We compare two checklist designs. The first design is from the World Health Organization ("Standard") and is an example of current best practice [21]. The second is a dynamic format ("Dynamic") for which the current checklist step is enlarged and more distant steps shrunk or hidden [10]. For purposes of the illustration, we consider data only from five participants collected while they were searching the checklist to answer a single question: *What is the correct dose of atropine?* We used an eye tracker that is accurate to approximately 0.5 deg to 1 deg of arc.

To start, we compute the average time to answer the question with each checklist format. The result is that the Dynamic checklist format is 32% faster than the Standard format. But we would like more insight into why. We therefore analyze the eye movement data with the VERP Explorer. We load the image of the checklist and the eye movement data files into the VERP Explorer. At this point, the many controls of the VERP Explorer allow us to tailor an analysis to our interests.

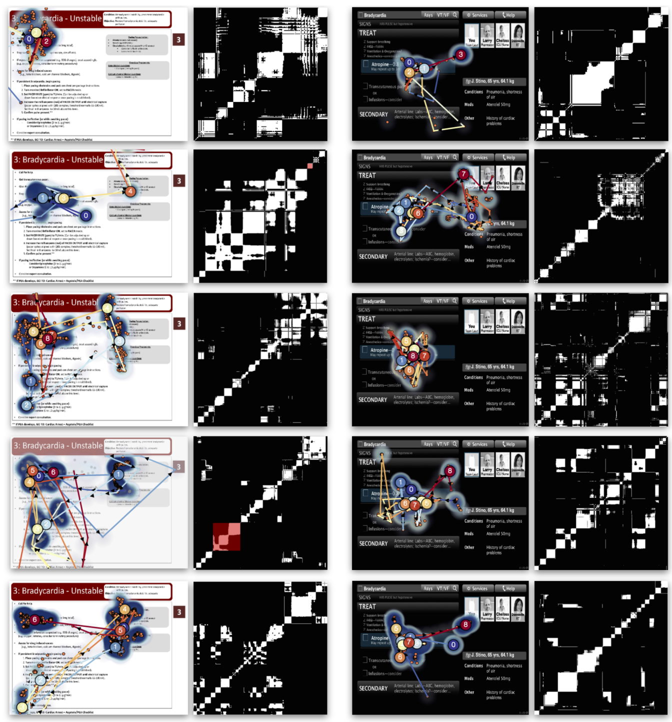
Figure 7 shows the screenshots from the VERP Explorer for the eye movements of the five doctors. They are arranged in order from the fastest trials to the slowest trials for each format.

Study Squares. The first thing to notice is that the eye movements for searching through text exhibit very different recurrence patterns than the semi-periodic function applications in Figure 2 investigated in the earlier literature. The recurrence plots of visual text search consist mainly of square patterns (*Study Squares*) comprised mainly of fixations, separated by subsequences of saccades on the diagonal.

To this basic patterns are added off-diagonal lines and squares representing regressive re-viewing of previously seen parts of the display (i.e., cycles). The Study Squares come about as in Figure 3 from a group of eye fixation points in close proximity, that is, exhibiting locality of reference. The more intensively some part of the scene is looked at, the larger the size of the square. Some squares have a checkerboard character, indicating that the doctor shifted her gaze to another part of the scene and then back. Searches taking more time often appear more scattered, reflecting the disorganization of the search. The brushing tools provided with VERP allow us to discover where square motifs on the recurrence plot are located in the scene.

Micro-Information Foraging. So far, we have been considering eye movements individually, but the square motif in our recurrence plots suggests that the eye movements for visual text search have a higher organization: a sequence of saccades to a position on the checklist followed by a set of fixations around that area (see Figure 7). This pattern is similar to the patterns found in information foraging theory [27]. We therefore call it Micro-Information Foraging, often shortened to just Micro-Foraging. The Study Squares form *information patches*. The design for the visualization of the Dynamic checklist has attempted to use the graphic setting of the checklist information so as to define boundaries for the patches. Inspecting Figure 7 we in fact find that the search patches are tighter. Furthermore, there should be fewer—ideally one—Study Square search patches to search. The VERP Explorer automatically identifies the Micro-Foraging search patches and numbers them from 1 (the starting point of the eye is labeled 0). It then draws an arrow between subsequent patches. This allows the VERP Explorer visualization of the search to be read as a kind of micro-narrative of what happened during the search. As a consequence, individual search sessions can be much more quickly analyzed and the results fed back into prototype design and evaluation.

Inadvertent Detractors. A visualization design may be basically sound, but inadvertently interact with some visual feature of the display in an unexpected way. For example, Figure 7 shows a search patch has formed near the pictures of doctors in the upper right. These pictures identify the staff performing the operation and give their names. This is because operating room staff often do not know each other and therefore can not give positive instructions naming who is responsible for their task, resulting in dropped tasks. But the high contrast blob around these pictures inadvertently attracts the eye during visual text search. There are many ways to fix this problem, but the point here is that this is the sort of problem that can remain invisible and decrease user performance despite a basically sound design. The VERP Explorer enabled us to find this problem easily.



Standard Dynamic

Fig. 7: Information Foraging analysis for ten cases. Left pair of columns shows eye movements and recurrence plots for Standard emergency checklist Right pair of columns shows Dynamic checklist. Both are arranged from fastest on top to slowest. Information patches are automatically detected and numbered. Generally there are more of them and they are less organized for slower trials.

4 Discussion and Conclusion

Eye-movement based analysis provides a unique opportunity for evaluating the effectiveness of the visual design of an interface. Eye movements are, however, lower-level manifestations of visual-cognitive interactions that need to be mapped to the behavior the designer usually needs.

To this end, we proposed a set of analytical methods to facilitate the eye movement based evaluation of the visual design of interfaces. We focused on visual search task and raised the level of behavioral characterization through visualization and interpretation of the recurrence plot of eye movements and the automatic visualization of the micro-foraging structure of the eye movements. We integrated these analysis techniques in an interactive tool, the VERP Explorer. The VERP Explorer is an open source web application and available at *https://www.github.com/uwdata/verp/*.

Finally, our work with pilot examples has led us to discoveries: the Study Square motif as a characteristic of visual text search, the Micro-Foraging model of visual text search, and a method for discovering idiosyncratic Inadvertent Detractors.

REFERENCES

[1] N. C. Anderson, W. Bischof, K. Laidlaw, E. Risko, and A. Kingstone. Recurrence quantification analysis of eye movements. *Behavior Research Methods*, 45(3):842–856, 2013.

[2] AngularJS. `http://angularjs.org/`.

[3] W. J. Arriaga AF, Bader AM and et al. A simulation-based trial of surgical-crisis checklists. *New England Journal of Medicine*, 368(15):1459–1460, apr 2013.

[4] T. Blascheck, K. Kurzhals, M. Raschke, M. Burch, D. Weiskopf, and T. Ertl. State-of-the-Art of Visualization for Eye Tracking Data. In *EuroVis - STARs*. The Eurographics Association, 2014.

[5] D. Boorman. Safety benefits of electronic checklists- an analysis of commercial transport accidents. In *In Proceedings of the 11th International Symposium on Aviation Psychology*, 2001.

[6] M. Bostock, V. Ogievetsky, and J. Heer. D^3: Data-driven documents. *IEEE Trans. Visualization & Comp. Graphics*, 17(12):2301–2309, 2011.

[7] M. Burch, A. Kull, and D. Weiskopf. Aoi rivers for visualizing dynamic eye gaze frequencies. *Computer Graphics Forum*, 32:281–290, 2013.

[8] M. Burch, H. Schmauder, M. Raschke, and D. Weiskopf. Saccade plots. In *Proceedings of the Symposium on Eye Tracking Research and Applications - ETRA'14*. ACM, 2014.

[9] B. K. Burian, I. Barshi, and K. Dismukes. The challenge of aviation emergency and abnormal situations. Technical report, NASA Ames Research Center, 2005.

[10] J. Cirimele, L. Wu, K. Leach, S. K. Card, T. K. Harrison, L. Chu, and S. Klemmer. RapidRead: Step-at-a-glance crisis checklists. In *Proceedings of the 8th International Conference on Pervasive Computing Technologies for Healthcare*, 2014.

[11] R. DALE, A. S. WARLAUMONT, and D. C. RICHARDSON. Nominal cross recurrence as a generalized lag sequential analysis for behavioral streams. *International Journal of Bifurcation and Chaos*, 21(04):1153–1161, 2011.

[12] A. Degani and E. L. Wiener. Human factors of flight-deck checklists: The normal checklist. Technical report, NASA Ames Research Center, 1990.

[13] Ç. Demiralp, M. Bernstein, and J. Heer. Learning perceptual kernels for visualization design. *IEEE Trans. Visualization & Comp. Graphics (Proc. InfoVis)*, 2014.

[14] J.-P. Eckmann, S. O. Kamphorst, and D. Ruelle. Recurrence plots of dynamical systems. *EPL (Europhysics Letters)*, 4(9):973, 1987.

[15] H. Edelsbrunner and E. P. Mcke. Three-dimensional alpha shapes. *ACM Trans. Graph.*, 13(1):43–72, 1994.

[16] A. Gawande. *The Checklist Manifesto: How to Get Things Right*. Metropolitan Books, 2009.

[17] T. K. Harrison, T. Manser, S. K. Howard, and D. M. Gaba. Use of cognitive aids in a simulated anesthetic crisis. *Anesthesia & Analgesia*, 103(3):551–556, 2006.

[18] M. Harrower and C. A. Brewer. ColorBrewer.org: An online tool for selecting colour schemes for maps. *The Cartographic Journal*, 40(1):27–37, jun 2003.

[19] S. Havre, B. Hetzler, and L. Nowell. ThemeRiver: visualizing theme changes over time. In *Proc. InfoVis'00*. IEEE, 2000.

[20] A. Haynes, T. Weiser, W. Berry, S. Lipsitz, A.-H. Breizat, E. Dellinger, T. Herbosa, S. Joseph, P. Kibatala, M. Lapitan, A. Merry, K. Moorthy, R. Reznick, B. Taylor, and A. Gawande. A surgical safety checklist to reduce morbidity and mortality in a global population. *New England Journal of Medicine*, 360:491–499, 2009.

[21] J. T. James. A new, evidence-based estimate of patient harms associated with hospital care. *Journal of Patient Safety*, 9(3):122–128, 2013.

[22] K. Kurzhals and D. Weiskopf. Space-time visual analytics of eye-tracking data for dynamic stimuli. *IEEE Transactions on Visualization and Computer Graphics*, 19(12):2129–2138, 2013.

[23] X. Li, A. Çöltekin, and M.-J. Kraak. Visual exploration of eye movement data using the space-time-cube. In S. Fabrikant, T. Reichenbacher, M. van Kreveld, and C. Schlieder, editors, *Geographic Information Science*, volume 6292 of *LNCS*, pages 295–309. Springer Berlin Heidelberg, 2010.

[24] M. A. Makary, C. G. Holzmueller, D. Thompson, L. Rowen, E. S. Heitmiller, W. R. Maley, J. H. Black, K. Stegner, J. A. Freischlag, J. A. Ulatowski, and P. J. Pronovost. Operating room briefings: working on the same page. *Joint Commission journal on quality and patient safety / Joint Commission Resources*, 32(6):351355, June 2006.

[25] N. Marwan. A historical review of recurrence plots. *Eur. Phys. J. Spec. Top.*, 164(1):3–12, oct 2008.

[26] N. Marwan, M. C. Romano, M. Thiel, and J. Kurths. Recurrence plots for the analysis of complex systems. *Physics Reports*, 438(56):237–329, 2007.

[27] P. Pirolli and S. K. Card. Information foraging. *Psychological Review*, 106(4):643–675, 1999.

[28] P. Pronovost, D. Needham, S. Berenholtz, D. Sinopoli, H. Chu, S. Cosgrove, B. Sexton, R. Hyzy, R. Welsh, G. Roth, J. Bander, J. Kepros, and C. Goeschel. An intervention to decrease catheter-related bloodstream infections in the ICU. *New England Journal of Medicine*, 355(26):2725–2732, dec 2006.

[29] M. Raschke, X. Chen, and T. Ertl. Parallel scan-path visualization. In *Proceedings of the Symposium on Eye Tracking Research and Applications - ETRA'12*. ACM, 2012.

[30] D. C. Richardson, R. Dale, and N. Z. Kirkham. The art of conversation is coordination: Common ground and the coupling of eye movements during dialogue. *Psychological Science*, 18(5):407–413, 2007.

[31] D. D. Salvucci and J. H. Goldberg. Identifying fixations and saccades in eye-tracking protocols. In *Proc. ETRA'00*. ACM, 2000.

[32] H. Y. Tsang, M. Tory, and C. Swindells. eseetrack–visualizing sequential fixation patterns. *IEEE Transactions on Visualization and Computer Graphics*, 16(6):953–962, nov 2010.

[33] E. G. G. Verdaasdonk, L. P. S. Stassen, P. P. Widhiasmara, and J. Dankelman. Requirements for the design and implementation of checklists for surgical processes. *Surg Endosc*, 23(4):715–726, jul 2008.

[34] M. Wattenberg and F. Viegas. The word tree, an interactive visual concordance. *IEEE Transactions on Visualization and Computer Graphics*, 14(6):1221–1228, nov 2008.

[35] B. D. Winters, A. P. Gurses, H. Lehmann, J. B. Sexton, C. Rampersad, and P. J. Pronovost. Clinical review: Checklists - translating evidence into practice. *Critical Care*, 13(6):210, 2009.

[36] D. W.-L. Wu, N. C. Anderson, W. F. Bischof, and A. Kingstone. Temporal dynamics of eye movements are related to differences in scene complexity and clutter. *Journal of Vision*, 14(9):8, 2014.

[37] J. E. Ziewacz, A. F. Arriaga, A. M. Bader, W. R. Berry, L. Edmondson, J. M. Wong, S. R. Lipsitz, D. L. Hepner, S. Peyre, S. Nelson, D. J. Boorman, D. S. Smink, S. W. Ashley, and A. A. Gawande. Crisis checklists for the operating room: Development and pilot testing. *Journal of the American College of Surgeons*, 213(2):212–217, 2011.