

EyeFIX: An Interactive Visual Analytics Interface for Eye Movement Analysis

Ayush Kumar**
Schepens Eye Research Institute,
Harvard Medical School MA
USA

Bharat Goel
Stony Brook University, NY
USA

Keshav Rajupet Premkumar
Stony Brook University, NY
USA

Michael Burch
University of Applied Sciences of the
Grisons, Chur
Switzerland

Klaus Mueller
Stony Brook University, NY
USA

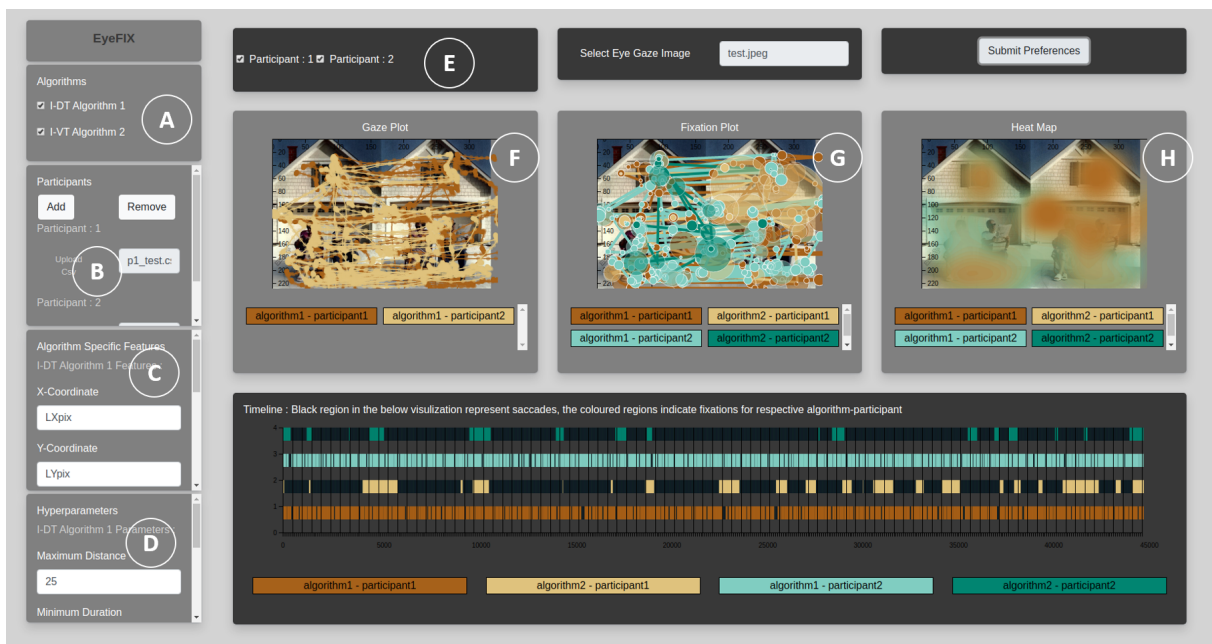


Figure 1: The EyeFIX interface with all major displays and functionalities.

ABSTRACT

Eye movements are closely related to the cognitive processes and often act as a window to the brain and mind. To facilitate a window to the brain using eye movements, we propose *EyeFIX*, an interactive visual analytics interface. Our interface currently focuses on processing gaze movements to generate the two most prominent events, fixations, and saccades which are used in a large part of

*Corresponding Author: ayush_kumar@meei.harvard.edu

Permission to make digital or hard copies of all or part of this work for personal or classroom use is granted without fee provided that copies are not made or distributed for profit or commercial advantage and that copies bear this notice and the full citation on the first page. Copyrights for components of this work owned by others than ACM must be honored. Abstracting with credit is permitted. To copy otherwise, or republish, to post on servers or to redistribute to lists, requires prior specific permission and/or a fee. Request permissions from permissions@acm.org.

VINCI '21, September 6–8, 2021, Potsdam, Germany

© 2021 Association for Computing Machinery.

ACM ISBN 978-1-4503-8647-0/21/09...\$15.00

<https://doi.org/10.1145/3481549.3481562>

the eye movement literature. Our interface has multiple interactive widgets that allow the users to choose the algorithm and tune its hyper parameters that control how fixations and saccades are generated. It has four major visualizations: (1) A Gaze Plot to showcase the gaze movement of each participant, (2) a Fixation Plot that helps to identify regions of the stimulus which are of interest to a particular participant and regions which the participant frequently visited, (3) a Heat Map to study the denser regions of fixation and regions which the participant frequently visited, and (4) a Timeline Visualization to assist in having a closer look at temporal regions of interest. We design a set of brushing and linking operators that allow users to interactively control all the visualizations to dig deeper in both, the spatial and temporal domains. We demonstrate the applicability of our interface with datasets obtained by human subjects viewing naturalistic stimuli while performing various viewing tasks, including visual exploration, visual search, and prolonged visual fixation.

CCS CONCEPTS

• **Human-centered computing** → **Visualization design and evaluation methods.**

KEYWORDS

Eye movements, Cognition, Visualization, Visual analytics, Fixation data

ACM Reference Format:

Ayush Kumar, Bharat Goel, Keshav Rajupet Premkumar, Michael Burch, and Klaus Mueller. 2021. EyeFIX: An Interactive Visual Analytics Interface for Eye Movement Analysis. In *The 14th International Symposium on Visual Information Communication and Interaction (VINCI '21), September 6–8, 2021, Potsdam, Germany*. ACM, New York, NY, USA, 5 pages. <https://doi.org/10.1145/3481549.3481562>

1 INTRODUCTION

The growing interest in the field of eye tracking by researchers from multiple domains such as human-computer interaction, linguistics, business, psychology, visualization [3–6], and so on [8, 10, 14] has resulted in it being more accessible and easy to use. Even the outreach of eye tracking devices has increased in a multitude of ways with the advancements in the hardware technology involving optical methods and computer vision [7]. However, the amount of data produced during the research has become challenging to analyze for the researchers from all of the involved domains [2, 12]. Eye movement data, being spatio-temporal in nature, further complicates the whole analytic pipeline which is the crucial component involved in collecting eye movement data using eye trackers [1, 11].

Eye movements build a crucial part of human behavior that systematically impact our cognitive and perceptual states which have become another aspect of psychological studies which have drawn much attention towards the algorithmic analyses of eye movement data and various metrics [12] associated with it. However, algorithmic findings sometimes do not reveal the correct reason or lead to the right conclusion alone. It is due to the lack of interactive control provided to the user which drives both, the algorithmic input as well as the conclusive output. A combination of algorithmic concepts, visualization approaches, interaction techniques, and the human users with their perceptual and visual strengths build powerful synergy effects to tackle much more complex problems in eye movement data analyses [2].

Analyzing raw eye movement data in the form of gaze data using gaze plots [9] does not benefit much to the users, resulting in visual clutter if carried out even for a few seconds [15]. Therefore, researchers, in general, analyze eye movements in the form of fixations (pauses over informative regions of interest) and saccades (rapid movements between fixations) [16]. Even though fixations and saccades are widely used as a window to the cognitive state and mind, there has not been enough work in this field, involving the interaction of eye movement parameters and its algorithmic dependencies on the cognitive state. These dependency results are typically generated from the raw eye movement data due to the powerful claims that can be made by looking into the recorded fixations and saccades, however, they cannot be used to model all of the truth about eye movements.

To facilitate the understanding of a cognitive state which is often used in decision making, we propose an interactive visual analytics interface to compare different algorithms and their output depending on the parametric perturbation being controlled by the user. This work-in-progress currently uses two well-known algorithms, *Velocity-Threshold Identification (I-VT)* and *Dispersion-Threshold Identification (I-DT)* to show the usefulness of our visual analytics interface. It enables the user to modify all of the parameters associated with both of the algorithms with the given widgets and to let us interact with the visualization produced using these algorithms. This can also be used to compare the cognitive state of multiple participants as our visual analytics interface lets the users upload the data for multiple participants. Brushing and linking operations allow users to interactively modify all the visualizations to explore both, the spatial and temporal domains in detail during analysis. We have used datasets [13] obtained by human subjects viewing naturalistic stimuli while performing various viewing tasks for demonstration purposes.

The limitations of using both, spatial and temporal components together, during the analysis by various interfaces/tools in the eye movement research community have motivated us to develop an interface that can let users

- (1) choose the desired algorithm to be used for generating fixations and saccades from raw data and controlling the parameters as well,
- (2) perform the analysis in a semi-automated way, using the brushing and linking in both, the spatial and temporal space.

2 DESIGN DECISIONS

Our motivation behind developing this interactive visual analytics interface is to support the domain experts in getting more efficient and explainable results after analysis.

Our interface is divided into two parts where the one to the left (Figure 1 (A-D)) lets users select and play with all the components related to the algorithm, whereas the one to the right (Figure 1 (E-I)) lets the user interact with the visualizations and interactive diagrams.

2.1 Eye Movement Data and Image Upload Followed by Parameter Tuning

The region to the left of the interface of the developed dashboard can be navigated and controlled by the user:

Firstly, we allow to upload the participants' eye movement data and the corresponding visual stimulus from the eye tracking study which is a static image in our case. Hence, if a user was to compare, for example, two participants, the user would upload two files, (.csv file format) corresponding to the eye movements and the single static image used by the two participants.

Secondly the user can tune the following parameters:

- (1) **Algorithm:** Allows the specification of the algorithm(s) that predicate how to model the eye movement data to record fixations and saccades. Our tool currently supports two algorithms: I-VT (Velocity-Threshold Identification) and IDT (Dispersion Threshold Algorithm).
- (2) **Participants:** Allows the specification of the number of participants the user would like to compare. However, the

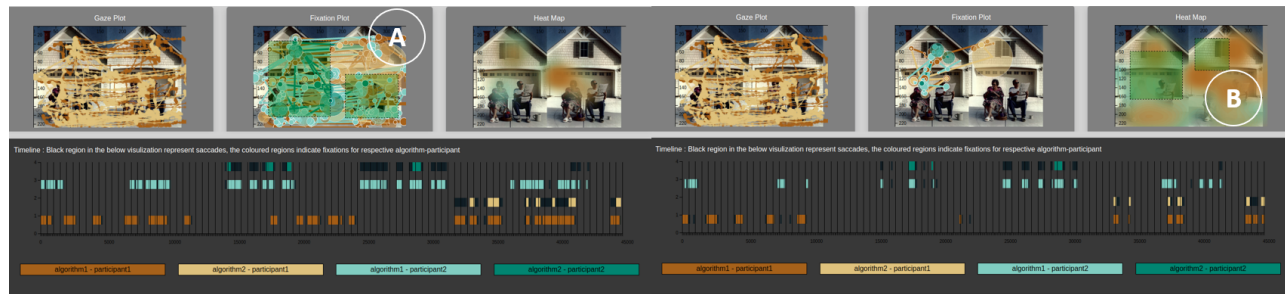


Figure 2: Multi-brushing/Brushing performed on a fixation plot. Results rendered on a heat map and a timeline plot.

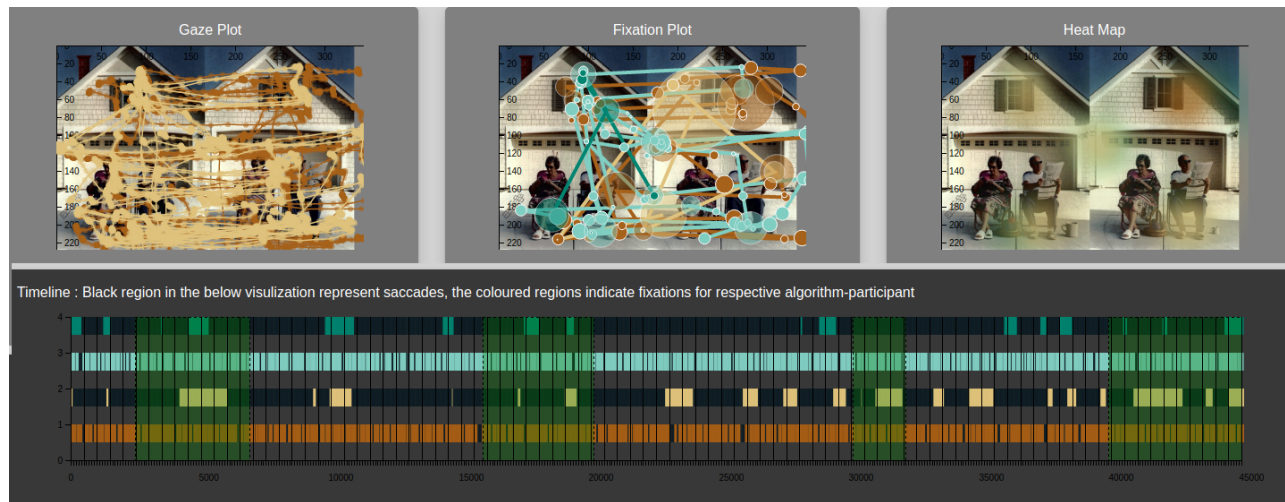


Figure 3: Multi-brushing/Brushing performed on a timeline plot. Results rendered on a fixation plot and a heat map.

more participants are involved the more processing power is required by the algorithms.

- (3) **Features:** Allows the specification of the column names corresponding to the eye movement data file (.csv file format). The file would need to contain three columns with data pertaining to the following: the X-coordinate (for left/right eye) in a float format and the Y-coordinate (for left/right eye) in a float format and the time in a time format.
- (4) **Algorithm-specific parameters:** Allows the specification of certain hyper parameters specific to the particular algorithms selected. These hyper parameters have an impact on how each algorithm decides how to classify each eye gaze record in any moment of time as a fixation or saccade considering the surrounding eye gaze data.
- (5) **Participant visualization toggle:** Once the data and image have been uploaded, parameters are specified, and the user has submitted (Submit preferences found on the top-right most corner of the dashboard). The participant toggle can be found to the right of the EyeFIX logo, these checkboxes can be used to hide and display participant traces on all major visualizations (Gaze, Fixation, Heat Map, and Timeline) which is elaborated in the following subsections.

2.2 Eye Gaze Visualization

The Eye Gaze Visualization (the first of three visualizations seen at the top of the dashboard) depicts the movement of one’s eyes from one place to the next based on the eye movement data uploaded. This “Eye Gaze” is then plotted on the uploaded image. Hence, one can use this visualization to study how different participant eye’s move for a specific study. The key illustrates which colored eye trace belongs to which participant. The color scheme in use is described in more detail in Table 1.

2.3 Eye Fixation Visualization

The Eye Fixation Visualization (the second of three visualizations seen at the top of the dashboard) gives an idea of how long a participant has been staring at a particular region of the image before moving on to the next one based on the eye movement data uploaded and parameters set by the user. This “Eye Fixation” is then plotted on the uploaded image. Hence, one can use this visualization to study on which regions of the image the different participants spend more time, focusing on the eye movement data from a certain specific study. The key illustrates which colored eye trace belongs to which participant-related algorithm. The color scheme used is described in Table 1.

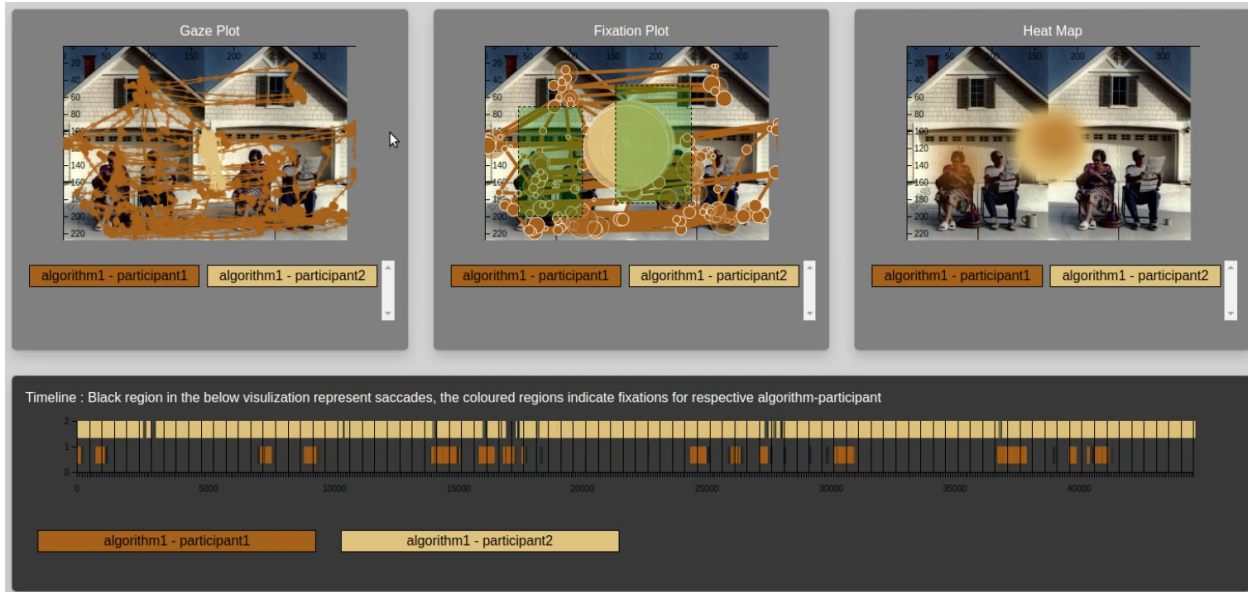


Figure 4: Multi-brushing/Brushing performed on heat map. Results rendered on fixation plot and timeline plot.

Index	Description	Color(s) Used
1.	Saccades	Black (#000000)
2.	Fixations in the Timeline Visualization and Eye Traces in the Gaze, Fixation, and Heat Map Visualizations. NOTE: Based on the number of participants and algorithm chosen these are assigned. A key is provided in EyeFIX below the Timeline Visualization for better assistance.	[Dark Brown (#a6611), Light Brown (#dfc27d), Aqua Blue (#80cdc1), Green (#018571)]

Table 1: Overview of color scheme used in the visualizations.

Multi-brushing/Brushing can also be performed by the user of this Eye Fixation Visualization which will result in highlighting only the brushed portion of the data in both the Eye Heat Map Visualization as well as the Timeline Visualization. This helps the user to understand the time range and time spent by the participant for a specific region.

2.3.1 Eye Heat Map Visualization. The Eye Heat Map Visualization (the third of three visualizations seen at the top of the dashboard) gives an idea of the most dense fixations among all fixation regions of each participant based on the eye movement data uploaded and parameters set by the user.

Multi-brushing/Brushing (see Figures 2 and 3) can also be performed by the user of this Eye Heat Map Visualization which will result in highlighting only the brushed portion of the data in both the Eye Fixation Visualization as well as the Timeline Visualization.

This helps the user to understand the time range and time spent by the participant for a specific region.

2.3.2 Timeline Visualization. The Timeline Visualization (the bottom most visualization) allows for Multi-brushing/Brushing (see Figure 4), meaning the user can select multiple regions for the participants. Each of these selections will correspond to a certain time range for which the user would like to know about the eye movement behavior of participants in that time frame. Upon Multi-brushing/Brushing the data associated with the selected region(s) is rendered by the Eye Heat Map Visualization and the Eye Fixation Visualization. The Eye Gaze Visualization remains the same to provide context of the entire eye movement data.

3 DISCUSSION AND FUTURE WORK

EyeFIX is a work-in-progress interactive visual analytics interface that currently supports I-VT and I-DT algorithms for fixation and saccade generation. To expedite the computations, we used pandas, Numpy python libraries for all computations, and have used the Flask and JSON frameworks on the server side, whereas D3.js is used for the visualization. We plan to extend to various other algorithms like I-HMM, I-MST, and I-AOI to compare the results. We also plan to evaluate our interface by letting domain experts interact with their own eye movement dataset. Our interface currently supports only eye movement data based on static stimuli. In the future, we might adapt it for dynamic stimuli and include head movements as well in the analysis. With the increased understanding due to various interactive and algorithmic parameter control, our interface will help to facilitate the use and analysis of eye tracking data for both, scientific research and the development of eye-based systems and applications.

REFERENCES

- [1] Gennady Andrienko, Natalia Andrienko, Michael Burch, and Daniel Weiskopf. 2012. Visual Analytics Methodology for Eye Movement Studies. *IEEE Transactions on Visualization and Computer Graphics* 18, 12 (2012), 2889–2898.
- [2] Tanja Blascheck, Michael Burch, Michael Raschke, and Daniel Weiskopf. 2015. Challenges and Perspectives in Big Eye-Movement Data Visual Analytics. In *Proceedings of the 1st International Symposium on Big Data Visual Analytics*. 17–24.
- [3] Michael Burch. 2017. Which Symbols, Features, and Regions Are Visually Attended in Metro Maps?. In *Proceedings of the 9th KES International Conference on Intelligent Decision Technologies (KES-IDT (Smart Innovation, Systems and Technologies, Vol. 73))*, Ireneusz Czarnowski, Robert J. Howlett, and Lakhmi C. Jain (Eds.). Springer, 237–246.
- [4] Michael Burch, Gennady L. Andrienko, Natalia V. Andrienko, Markus Höferlin, Michael Raschke, and Daniel Weiskopf. 2013. Visual task solution strategies in tree diagrams. In *Proceedings of IEEE Pacific Visualization Symposium, PacificVis*, Sheelagh Carpendale, Wei Chen, and Seok-Hee Hong (Eds.). IEEE Computer Society, 169–176.
- [5] Michael Burch, Andreas Kull, and Daniel Weiskopf. 2013. AOI Rivers for Visualizing Dynamic Eye Gaze Frequencies. *Computer Graphics Forum* 32, 3 (2013), 281–290.
- [6] Michael Burch, Kuno Kurzhals, Niklas Kleinhans, and Daniel Weiskopf. 2018. EyeMSA: exploring eye movement data with pairwise and multiple sequence alignment. In *Proceedings of the 2018 ACM Symposium on Eye Tracking Research & Applications, ETRA*. 1–5.
- [7] Christine Carl, Alper Açıık, Peter König, Andreas K Engel, and Joerg F Hipp. 2012. The saccadic spike artifact in MEG. *Neuroimage* 59, 2 (2012), 1657–1667.
- [8] Andrew T. Duchowski. 2003. *Eye Tracking Methodology - Theory and Practice*. Springer.
- [9] Joseph H. Goldberg and Jonathan I. Helfman. 2010. Visual scanpath representation. In *Proceedings of the Symposium on Eye-Tracking Research and Applications (ETRA)*. 203–210.
- [10] Kenneth Holmqvist, Marcus Nyström, Richard Andersson, Richard Dewhurst, Halszka Jarodzka, and Joost van de Weijer. 2011. *Eye Tracking: A Comprehensive Guide to Methods and Measures*. Oxford University Press.
- [11] Ayush Kumar, Michael Burch, and Klaus Mueller. 2019. Visually Comparing Eye Movements over Space and Time. In *Proceedings of the 11th ACM Symposium on Eye Tracking Research & Applications (Denver, Colorado) (ETRA '19)*. Association for Computing Machinery, New York, NY, USA, Article 81, 9 pages.
- [12] Ayush Kumar, Rudolf Netzel, Michael Burch, Daniel Weiskopf, and Klaus Mueller. 2018. Visual Multi-Metric Grouping of Eye-Tracking Data. *Journal of Eye Movement Research* 10, 5 (2018). <https://doi.org/10.16910/jemr.10.5.10>
- [13] Jorge Otero-Millan, Xoana G Troncoso, Stephen L Macknik, Ignacio Serrano-Pedraza, and Susana Martinez-Conde. 2008. Saccades and microsaccades during visual fixation, exploration, and search: foundations for a common saccadic generator. *Journal of vision* 8, 14 (2008), 21–21.
- [14] Michael Plöchl, José Pablo Ossandón, and Peter König. 2012. Combining EEG and eye tracking: identification, characterization, and correction of eye movement artifacts in electroencephalographic data. *Frontiers in human neuroscience* 6 (2012), 278.
- [15] Ruth Rosenholtz, Yuanzhen Li, Jonathan Mansfield, and Zhenlan Jin. 2005. Feature Congestion: A Measure of Display Clutter. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. ACM, 761–770.
- [16] Dario D Salvucci and Joseph H Goldberg. 2000. Identifying fixations and saccades in eye-tracking protocols. In *Proceedings of the 2000 symposium on Eye tracking research & applications*. 71–78.