

Visualizing Eye Movement Data of Web Maps: The ET2Spatial & ET2GIS & ET2QGIS Tools

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Abstract. This paper addresses the issue of costly analysis of eye-tracking data over dynamic interactive stimuli. The introduction offers a brief insight into the addressed issue. Afterwards, it describes the ET2Spatial tool that allows to capture and georeference eye movement data during user interaction with web maps. The main part describes 13 features of the ET2GIS tool that facilitate the visualization of dynamic data in ArcGIS Pro and QGIS environments. Both tools have the potential to be extended and can be used for usability studies of interactive cartographic stimuli as well as for the analysis of human interaction and cognition with web maps.

Keywords. Eye-tracking, Map Interactivity, Utility, Georeferencing, User-logging, GIS

1. Introduction

Cartographic eye movement research has evolved from static to dynamic map displays. Słomska's 2018 study highlighted that over a third of stimuli used in cartographic research are interactive, with a growing number of publications in cognitive cartography. Additionally, eye-tracking, used in almost one fifth of the GIS usability studies reviewed by Unrau and Kray (2019), is considered a significant method for such research. The cartographic community is working to improve eye-tracking data analysis. Notable tools include EyeMMV for analyzing eye-tracking data (Krassanakis et al. 2014), EyeMSA by Burch et al. (2018) for sequence alignment, and ScanGraph (Dolezalova & Popelka, 2016) for eye movement similarity comparison, useful in multiple domains including cartography and education. However, challenges persist. Eye-tracking with interactive stimuli is time-consuming and data-intensive. Traditional eye-tracking mechanisms strug-



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gle with interactive media, and creating dynamic areas of interest (AOIs) is labor-intensive. Tools like the one by Papenmeier and Huff (2010) aid in drawing dynamic AOIs, but rapid changes in interactive web media content make manual annotations impractical. Research into eye-tracking and interactive web maps has grown, focusing on understanding cognitive processes with dynamic maps. Innovative methods include a combination of eye-tracking and transforming gaze coordinates to geographic coordinates for more accurate analysis. Yet, current tools lack the ability to analyze gaze data from a spatio-temporal perspective despite its similarity to real-world geographic movement datasets. There's limited research on open-source eye-tracking solutions for dynamic maps. One tool, 3DgazeR (Herman et al. 2017), addresses eye-tracking in 3D environments by calculating 3D real-world coordinates for each gaze point. Ooms et al. (2015) presented a framework capturing the essence of challenges in this field, offering desktop-based user data logging solutions. FeatureEyeTrack from ETH Zurich (Göbel et al. 2019) is a tool aiming to simplify eye-tracking data analysis for dynamic online mediums, integrating eye-tracking with interactive web map functions.

2. Tools for eye movement data conversion to GIS

2.1. ET2Spatial

In 2022, a study introduced the ET2Spatial tool (Sultan et al. 2022) designed to capture and georeference eye movement data during web map interactions. This tool's primary purpose is to convert user gaze locations on the map into real-world coordinates. A significant motivation behind this research was the traditional eye-tracking software's limitation in consolidating data from multiple participants interacting with web maps into a unified file. The tool also allows for the visualization and comparison of multiple users' data simultaneously on a basemap, which was not possible with traditional eye-tracking software. The tool combines eye movement data with user action data, such as mouse clicks, user inputs, and displayed map extent and zoom level, which are recorded through logging. The tool uses Google Maps API v2, and the main program is written in Python. The ET2Spatial tool converts the points from screen coordinates to geographic coordinates, and the next step is file conversion and export. The tool generates a separate file for each participant, identified with the participant ID. The converted raw gaze points and fixation points files are provided as outputs for each participant. The main file formats considered for exports in the ET2Spatial tool are Geojson and Shapefile. The tool generates a CSV file as a byproduct for an alternative entry into GIS software. Geojson and Shapefile are popular file formats in the GIS community and are compatible

with most GIS software. Geojson can also be easily visualized with mapping libraries and APIs such as Leaflet, Mapbox, and Google Maps. The tool has expanded current knowledge by providing a new approach to inspecting eye-movement data as spatial features, subjecting them to traditional spatial operations and comparing them to standard techniques provided by eye-tracking software. The tool has also highlighted the need for more research in this domain and the development of tools to address the issue of analyzing eye-tracking data on interactive web maps.

2.2. ET2GIS

Following that, the ET2GIS toolbox was developed for Esri ArcGIS Pro 3.0+, which offers the creation of a toolbox using the ModelBuilder environment. The objective of the tool is to facilitate the import of output data from ET2Spatial into the ArcGIS Pro software and provide various methods of gaze data visualization. A Project template was designed for repeated work with the toolbox. This template includes the ET2GIS toolbox, both 2D and 3D maps with locked and unlocked zooming, as well as four basic base maps from Google Maps (Roadmap, Satellite, Terrain, and Hybrid). The tool ET2GIS includes 13 functions (Figure 1). Most of the tools were inspired by typical visualizations of eye-tracking programs (e.g. Heatmaps, Scanpaths, Areas of Interest, etc.). However, visualizations that are not commonly available in eye-tracking programs are also available (e.g., Space-time cube or Zoom Level Clustering). The output from ET2Spatial provides a separate file for each participant and task.

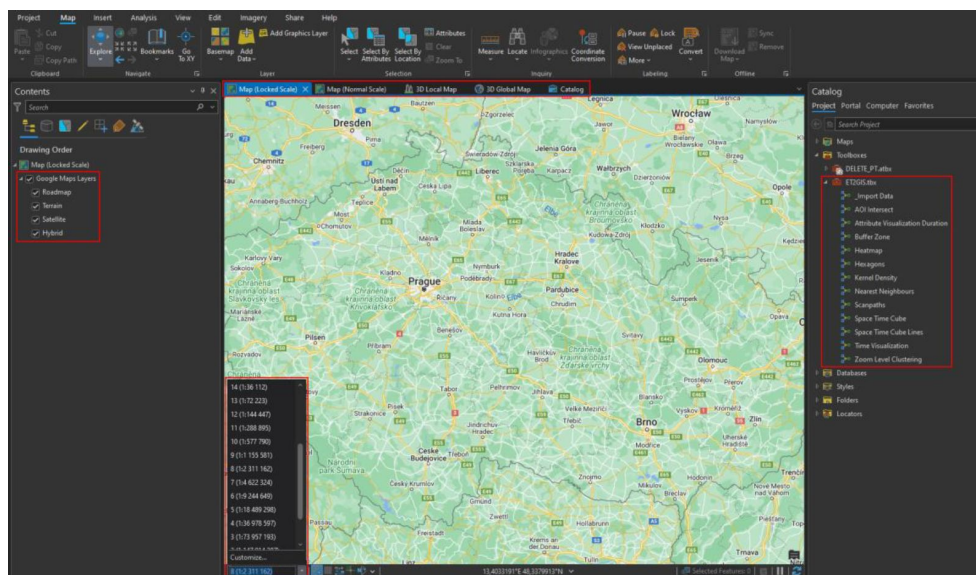


Figure 1. List of 13 functions in Project Template environment.

The next step involves **Import Data tool**, designed to consolidate data from multiple participants and tasks to streamline subsequent analyses and visualizations. The **AOI Intersect** tool allows to create areas of interest for the investigated stimulus, based on this, might be determined how many fixations belong to each area of interest. The **Attribute Visualization Duration** displays the fixation using Duration Time, which displays, using a graph, how long the respondent looked at a particular location. The **Buffer Zone** creates a circle around the defined point based on the distance parameter and displays the fixations that are inside the circle. The **Heat Map** visualizes the density of fixations using a continuous gradient. **Hexagons** offer visualization of the density of fixation points and raw points within hexagons, which can reveal a cluster of points overlaid that might otherwise be overlooked. **Kernel Density** is similar to the Heat map; however, while the Heat map only visualizes existing vector data, the Kernel Density tool works with a newly created raster layer, which can be further utilized, for instance, in a raster calculator. **Nearest Neighbours** displays the cluster of nearest fixations, determined by the average distance between the fixation and its closest neighbor. **Scanpaths** represent the order and duration of fixations for each respondent. The tool creates two new layers: the first shows the fixations in different colors for each participant to represent the fixation duration and its order, while the second layer links the line fixations based on their order. The **Space Time Cube** visualizes fixations in 3D space using the time feature. Similar to the Scanpaths tool, the **SpaceTime Cube lines** create lines using the Points To Line tool, but in 3D space, reflecting the time feature of the data. These lines are color-coded by a participant. **Time Visualization** allows users to view eye-tracking data over time via the Time tab, which allows visualization controls such as playback speed, rewinding, and more. The **Zoom Level Clustering** tool allows to visualize participant fixations according to the zoom level based on predefined map scales and the range of scales for which the data is displayed.

2.3. ET2QGIS

Besides ET2GIS, we are currently working on a similar tool written in Python that will enable us to perform spatial analyses of eye movement data in the environment of QGIS. The advantage of this approach is that QGIS is an open-source application and that all functionalities might be accessible through a single window. Since it is still a work in progress, only the possibility to import data and create AOIs is currently available.

3. Conclusion

This contribution presents the tool solving the problems of eye-tracking analysis on dynamic interactive web maps and their subsequent visualization. Traditional eye-tracking systems struggle to analyze dynamic content. The evaluation of static stimuli does not meet current needs for analysis using eye tracking in interactive environments such as web maps. There has been limited research on this topic, and even fewer free, open-source tools are available to address the issue. Therefore, the ET2Spatial was used to convert ET data collected in interactive maps, and both ET data analysis/visualization tools (ET2GIS and ET2QGIS) were developed.

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