Finding landmarks – An investigation of viewing behavior during spatial navigation in VR using a graph-theoretical analysis approach

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RTG Computational Cognition

DFG Deutsche Forschungsgemeinschaft

Universität Osnabrück

Background

Spatial navigation is increasingly investigated in complex virtual reality (VR) environments using eye tracking. However, classical analysis algorithms do not account for the changed conditions in VR, e.g. freedom of movement, thus, a new analysis method is needed.

Methods

Fig 1: Experimental setup

Eye tracking data of 22 participants was measured while they were freely exploring the virtual city Seahaven for 90 min using a head-mounted VR headset. The city Seahaven consists of 213 houses and was designed to resembled a small European town.

Pre-processing

Fig 2: Map of Seahaven

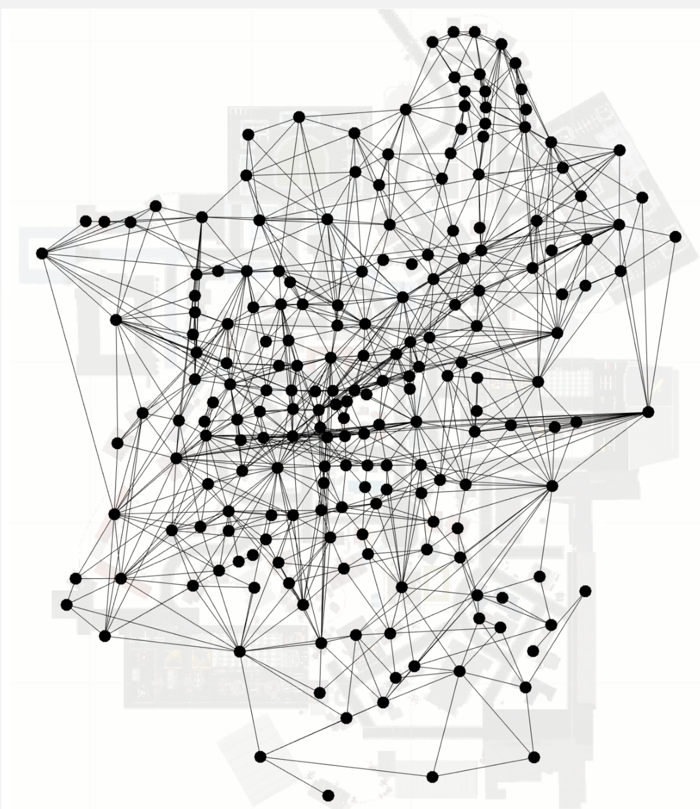

Fig 3: Gaze graph

1. Ray casting identifies the viewed objects
2. Cleaning: participants with more than 30% data loss are excluded
3. Interpolation of missing data samples
4. **Gaze events** are defined as data clusters on the same object of at least 266 ms duration
5. **Gaze graphs** created from gaze events (undirected & unweighted)
   - nodes = viewed houses
   - edges = visual connections

Results

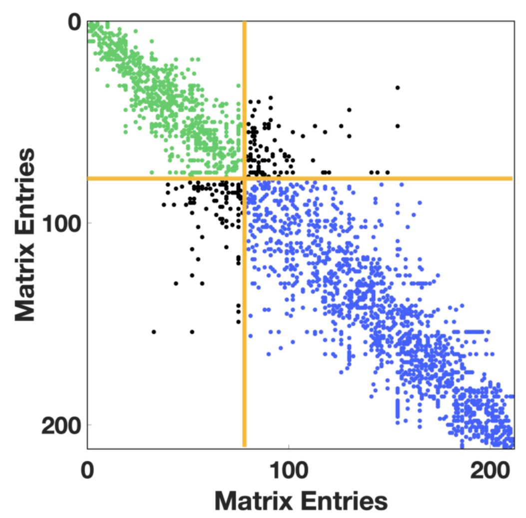

Fig. 4: The sparsity pattern of the graph's sorted adjacency matrix does not display clusters.

Do the graphs contain clusters?

We investigate whether the graphs contain clusters using the spectral graph partitioning approach. The results do not reveal any cluster patterns, so the city can be treated as one for the following analysis.

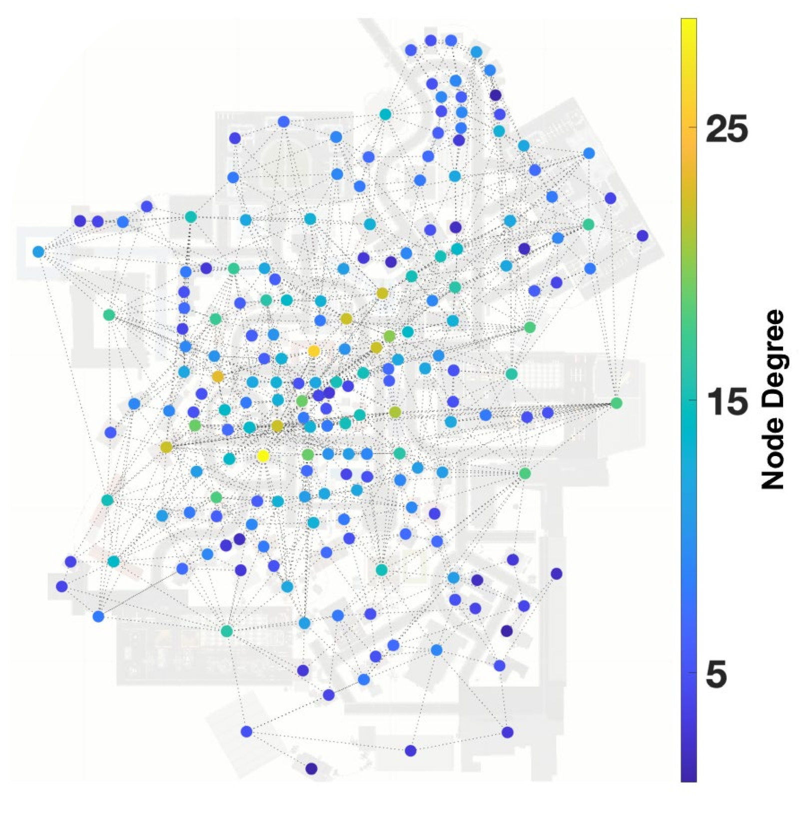

Fig. 5: Gaze graph with node color matching the node degree centrality values.

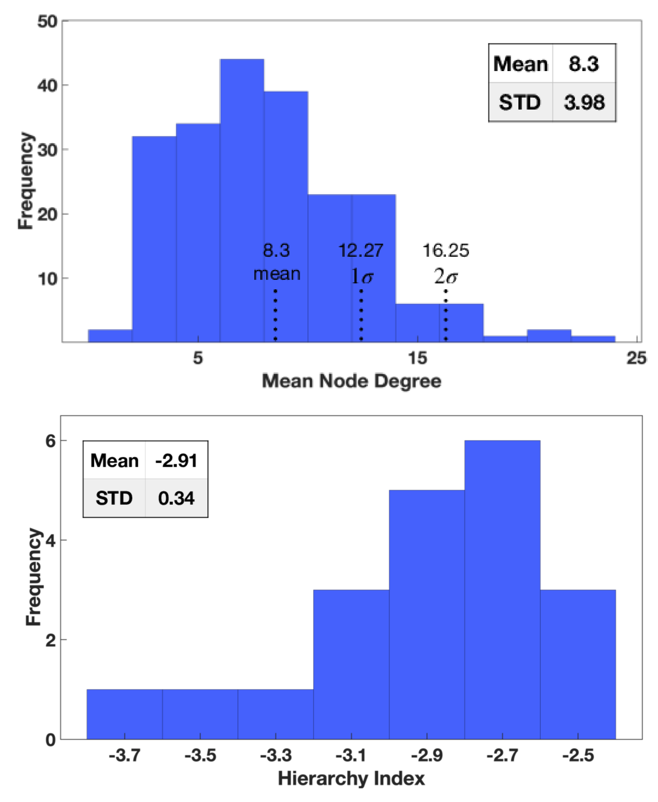

Fig. 6: Node degree distribution over all participants.
Fig. 7: Hierarchy index distribution over all participants

Some houses are outstanding in the analysis

The node degree centrality identifies important nodes in graphs. Our results reveal a small subset of 10 houses that have a high node degree consistently exceeding the two-sigma distance from the mean node degree of all other houses. The importance of these houses is supported by the hierarchy index, which shows a clear hierarchical structure of the gaze graphs.

Gaze-graph-defined landmarks

10 houses are outstanding in several graph theoretical measures and show several characteristics of landmarks. Therefore, we call them **gaze-graph defined landmarks.**

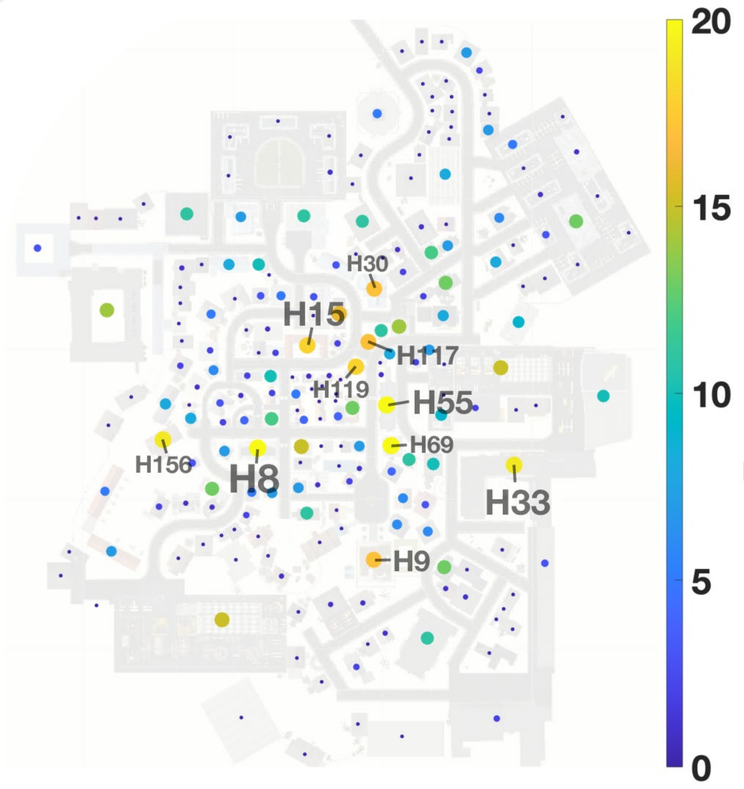

Fig. 7: Graph with houses color/size coded to match the frequency to occur in a rich club

A rich club of landmarks

The rich club coefficient shows, that the 10 high node degree houses appear most often in a rich club, thus, the gaze-graph-defined landmarks are preferentially connected to each other

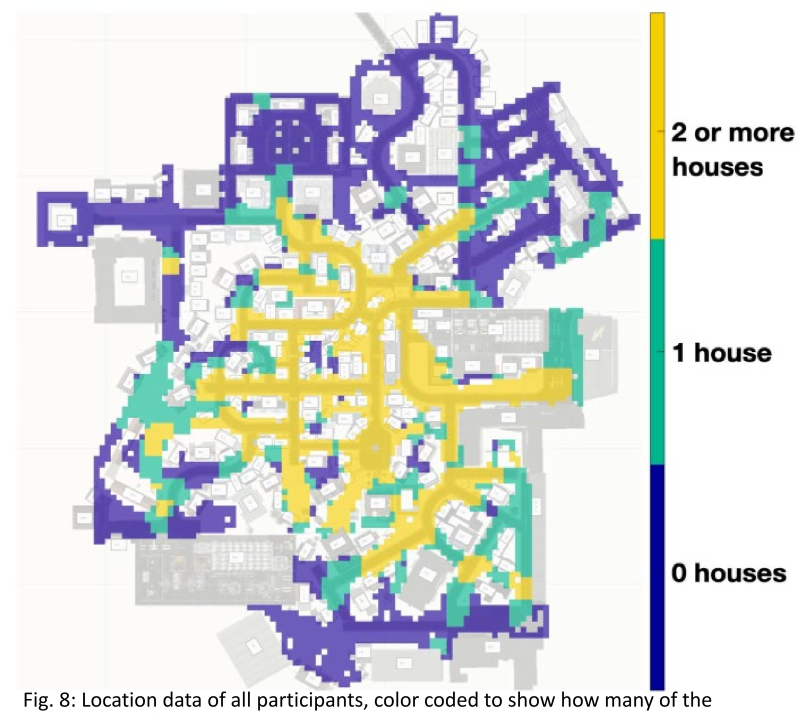

Fig. 8: Location data of all participants, color coded to show how many of the gaze-graph-defined landmarks were viewed by participants at each location.

Is there a theoretical basis for triangulation?

In a large part of the city, several gaze-graph-defined landmarks are visible. We do not know if participants performed triangulation, but in principle it would be possible in these areas

Summary

We propose new methodology to pre-process and analyze eye tracking data in complex VR environments using the data form gazes and a graph theoretical analysis approach. Our results identify a subset of 10 houses outstanding in several graph theoretical measures, which we call gaze-graph-defined landmarks. Overall, this method provides a new and unique insight into visual attention during spatial navigation.

Data availability

COS Open Science
GitHub

Data availability: https://osf.io/aurjk/, DOI 10.17605/OSF.IO/AURJK.
Code availability: https://github.com/JasminLWalter/FindingLandmarks_a_publication_repository

Pre-print link

bioRχiv THE PREPRINT SERVER FOR BIOLOGY

www.biorxiv.org/content/10.1101/2021.09.29.462279v2

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