VisWeek 2012

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Visual Analytics Methodology for Eye Movement Studies

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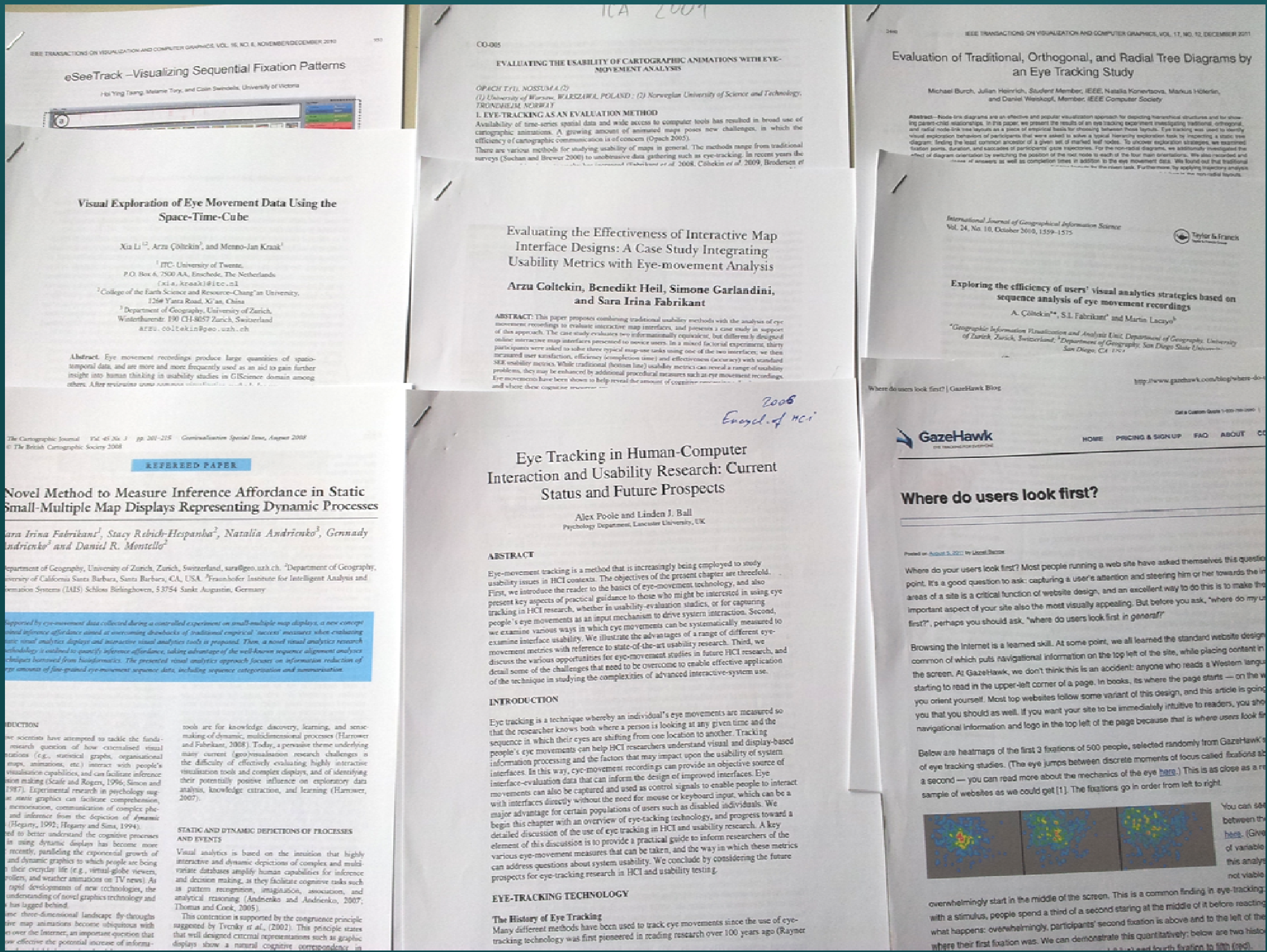
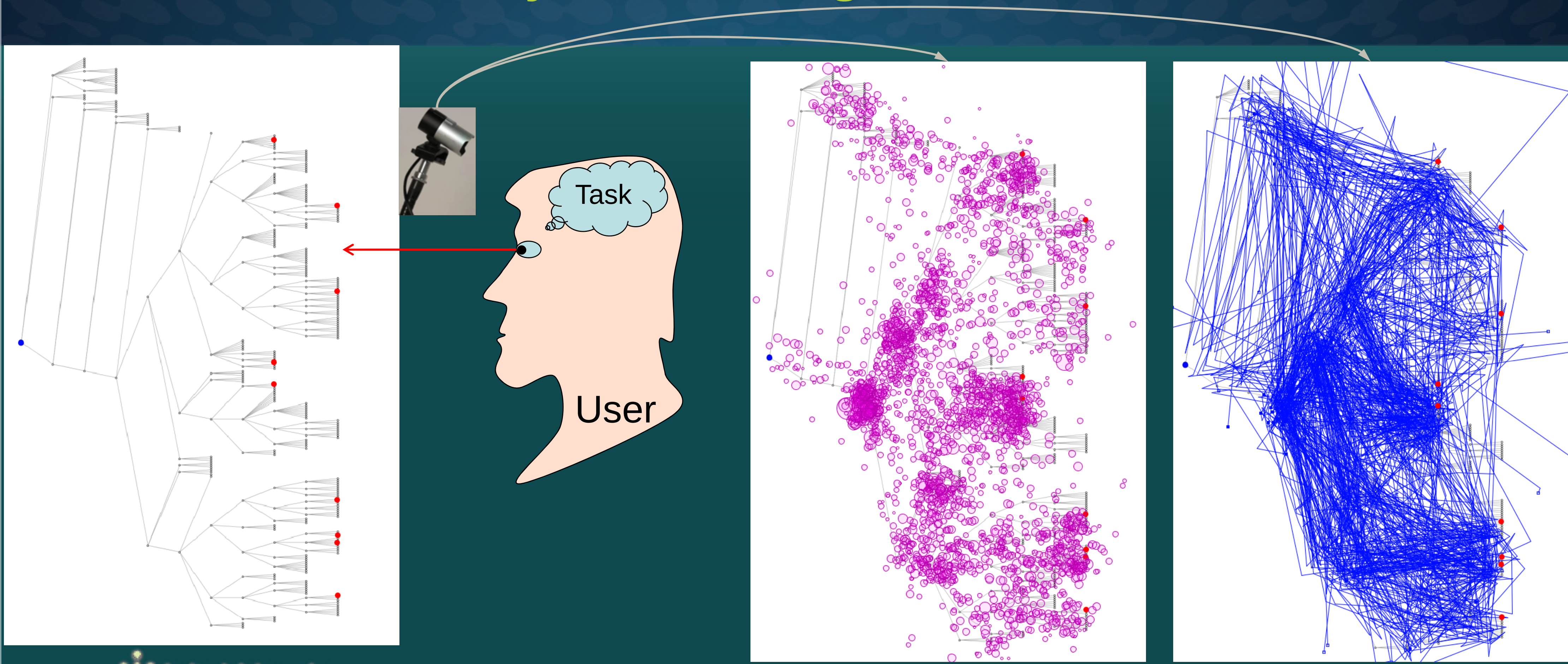
Michael Burch, Daniel Weiskopf

Introduction: eye tracking gains popularity



- Eye movement recordings are viewed as a window into internal cognitive processes (the “eye-mind” hypothesis)
- HCI and visualization researchers hope to understand user’s information processing and factors affecting the usability of the displays and interfaces

Introduction: eye tracking data



Eye fixations

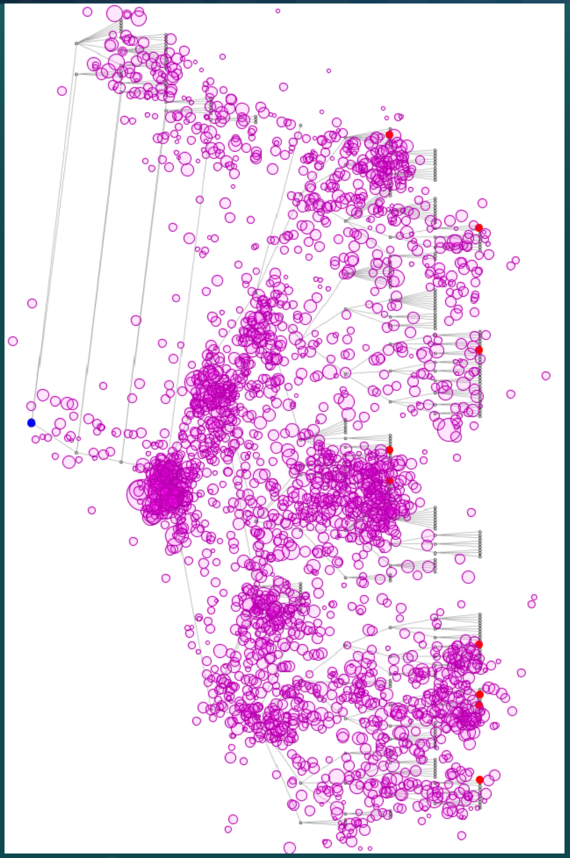
Eye movements

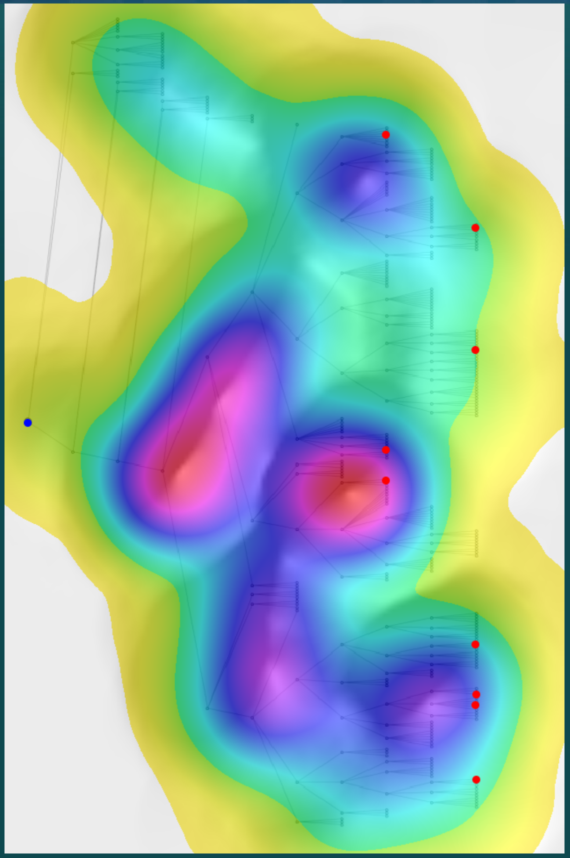
Introduction: tasks in eye movement analysis

- Attention distribution:
  - What areas attract user’s attention? How much attention?
  - Does the user find predefined Areas Of Interest (AOIs)? How easily?
  - How does the attention change over time?
  - What differences exist between users, displays, interfaces?

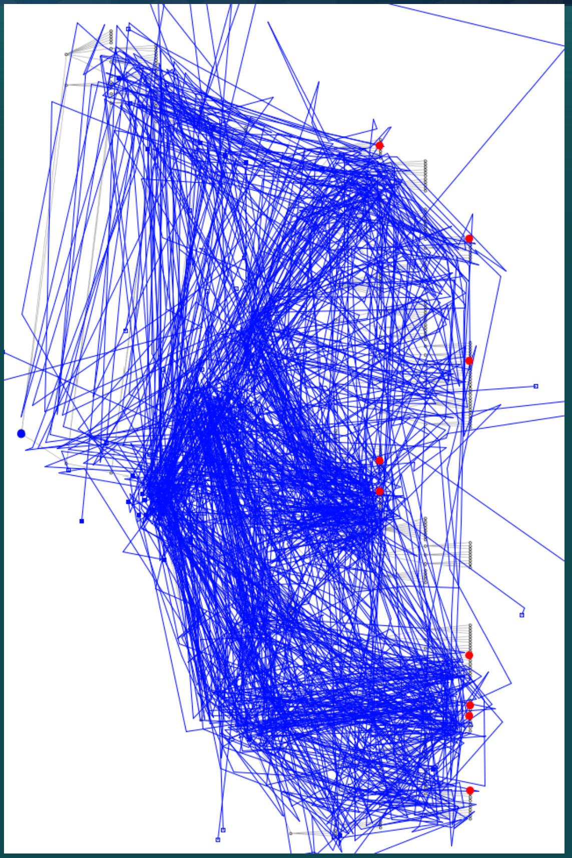
- Attention movement:
  - How much movement? How far? How complex is the path?
  - How is the path related to the display content? What is the sequence of attending the AOIs?
  - What is the search/ exploration/ problem-solving strategy?
  - Where are difficulties?
  - What differences exist between users, displays, interfaces?

Introduction: commonly used techniques





Attention distribution



Attention movement?

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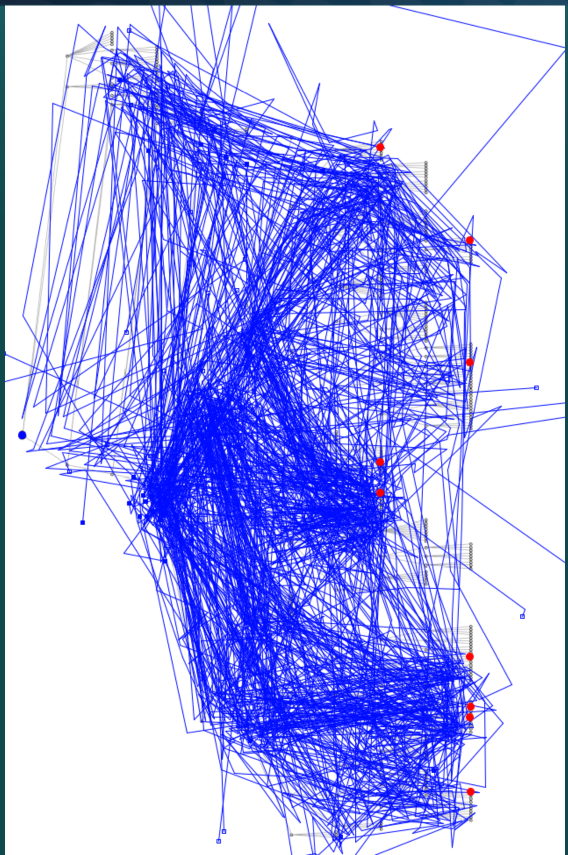
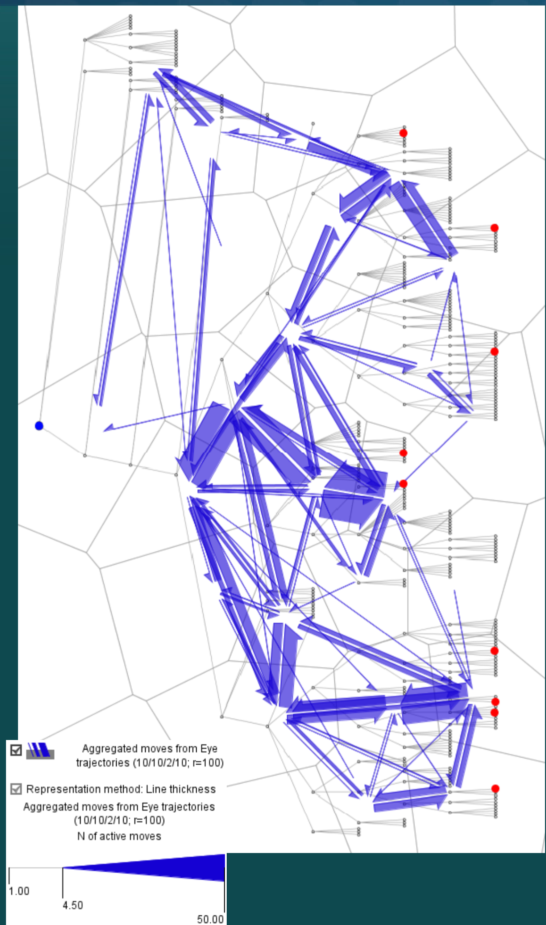
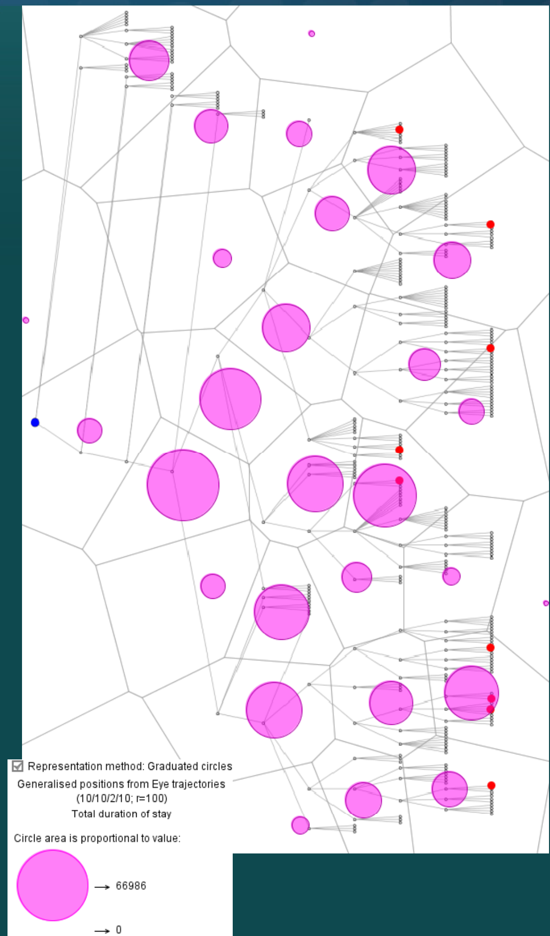
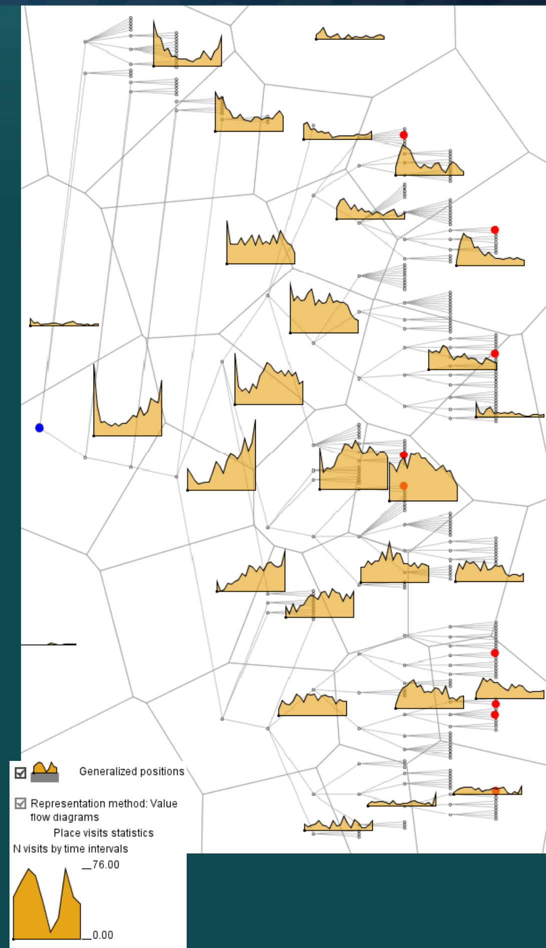
Geo-VA techniques can be helpful



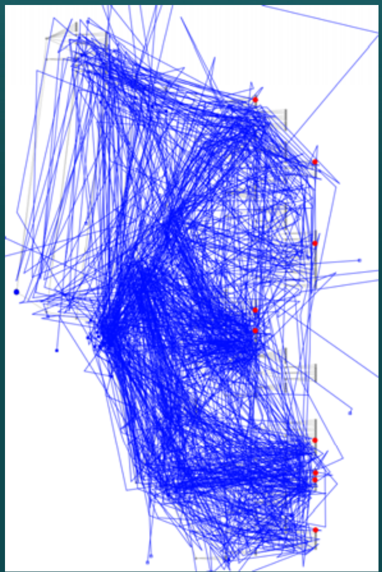


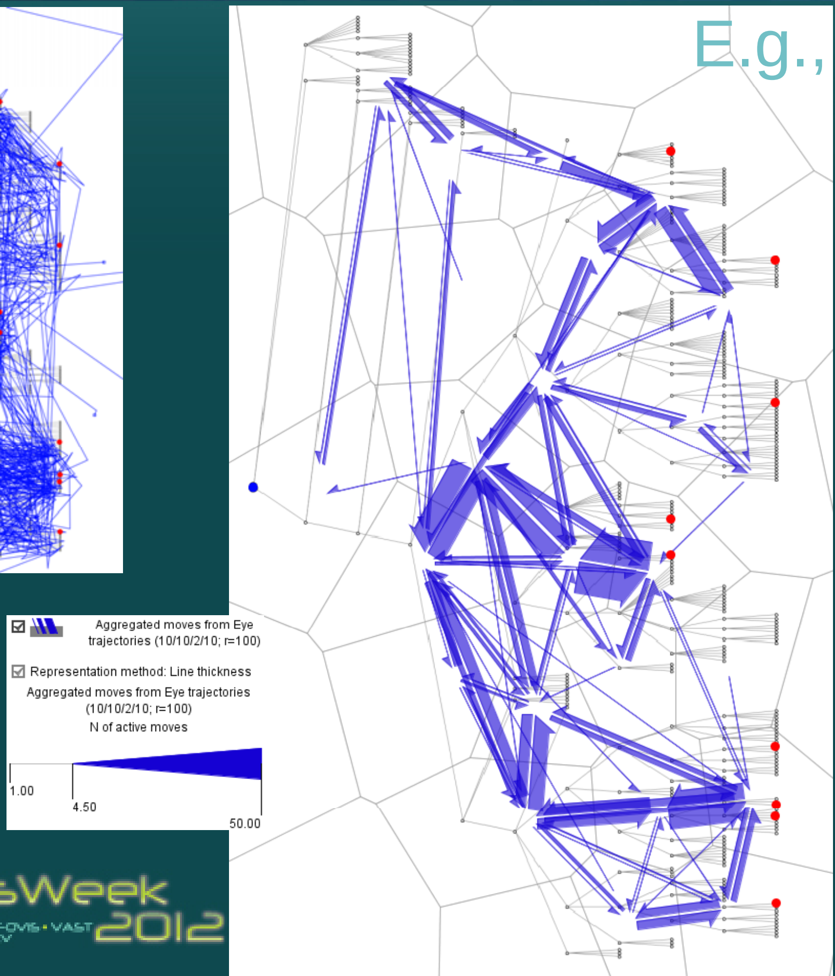


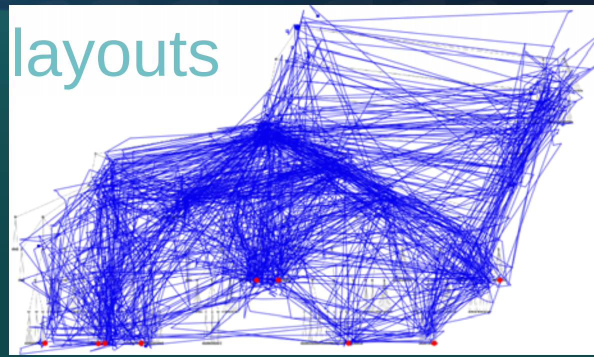


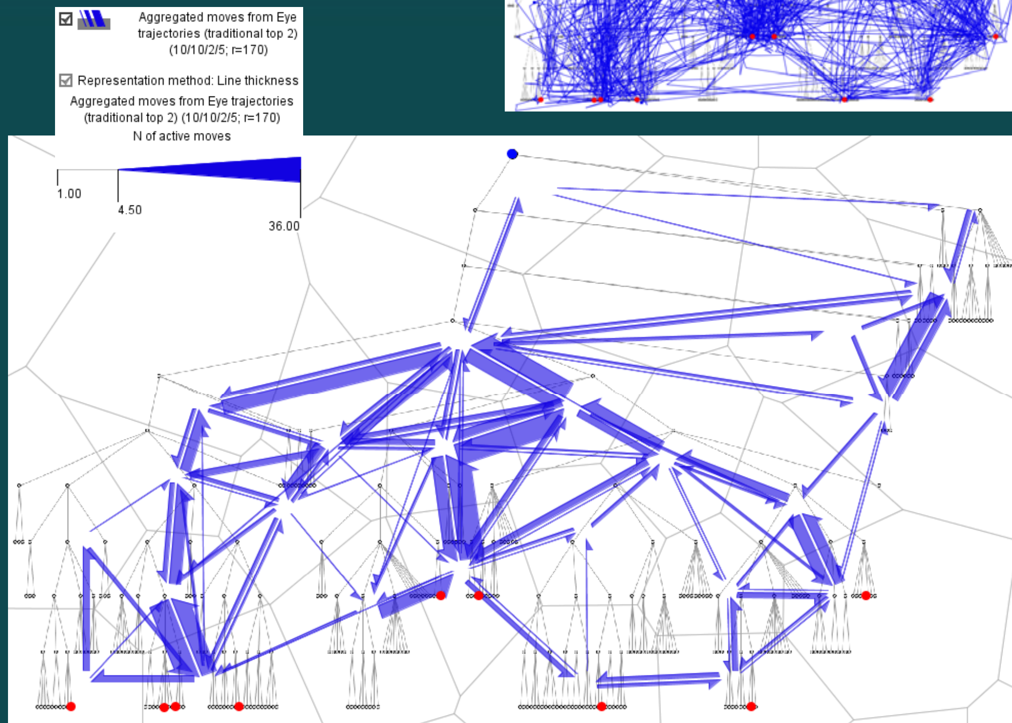
... also in comparative studies

E.g., 2 different graph layouts









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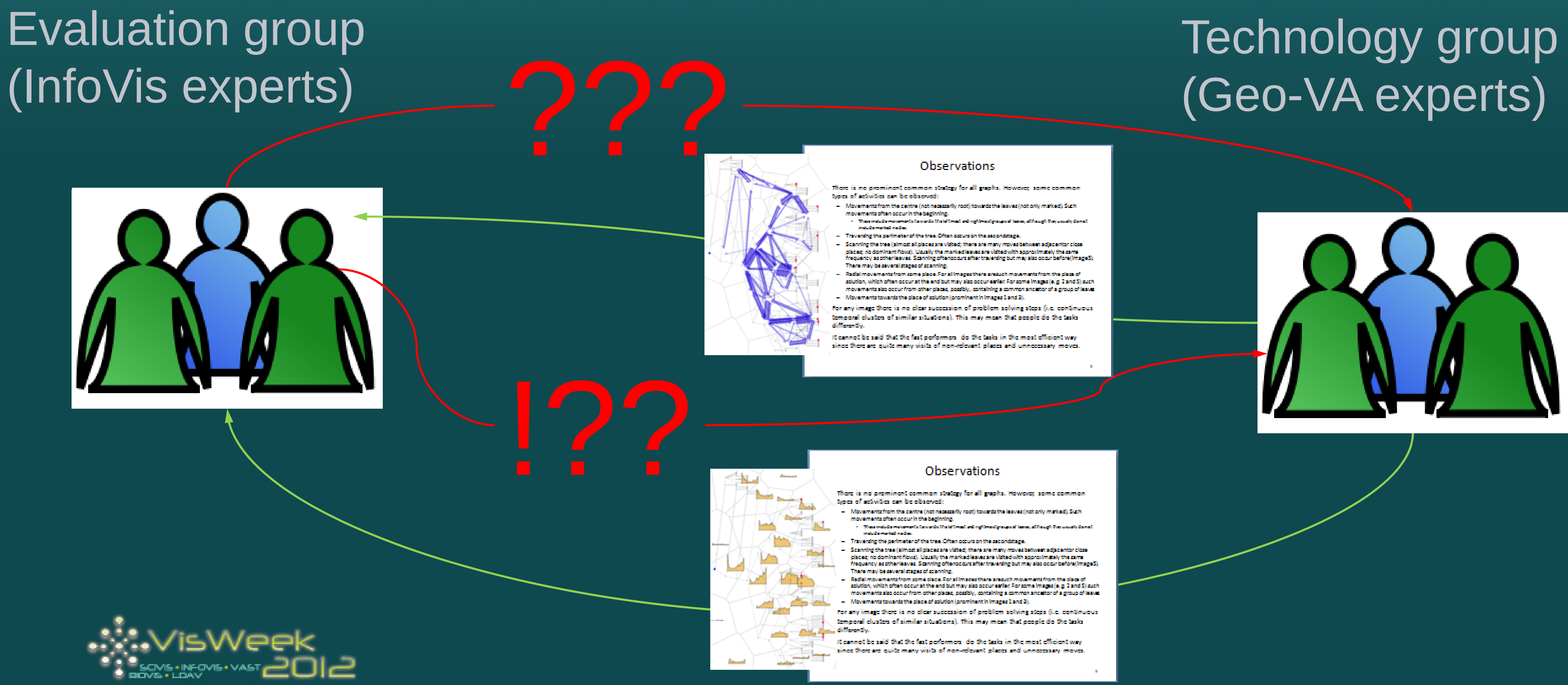
Empirical assessment of Geo-VA methods



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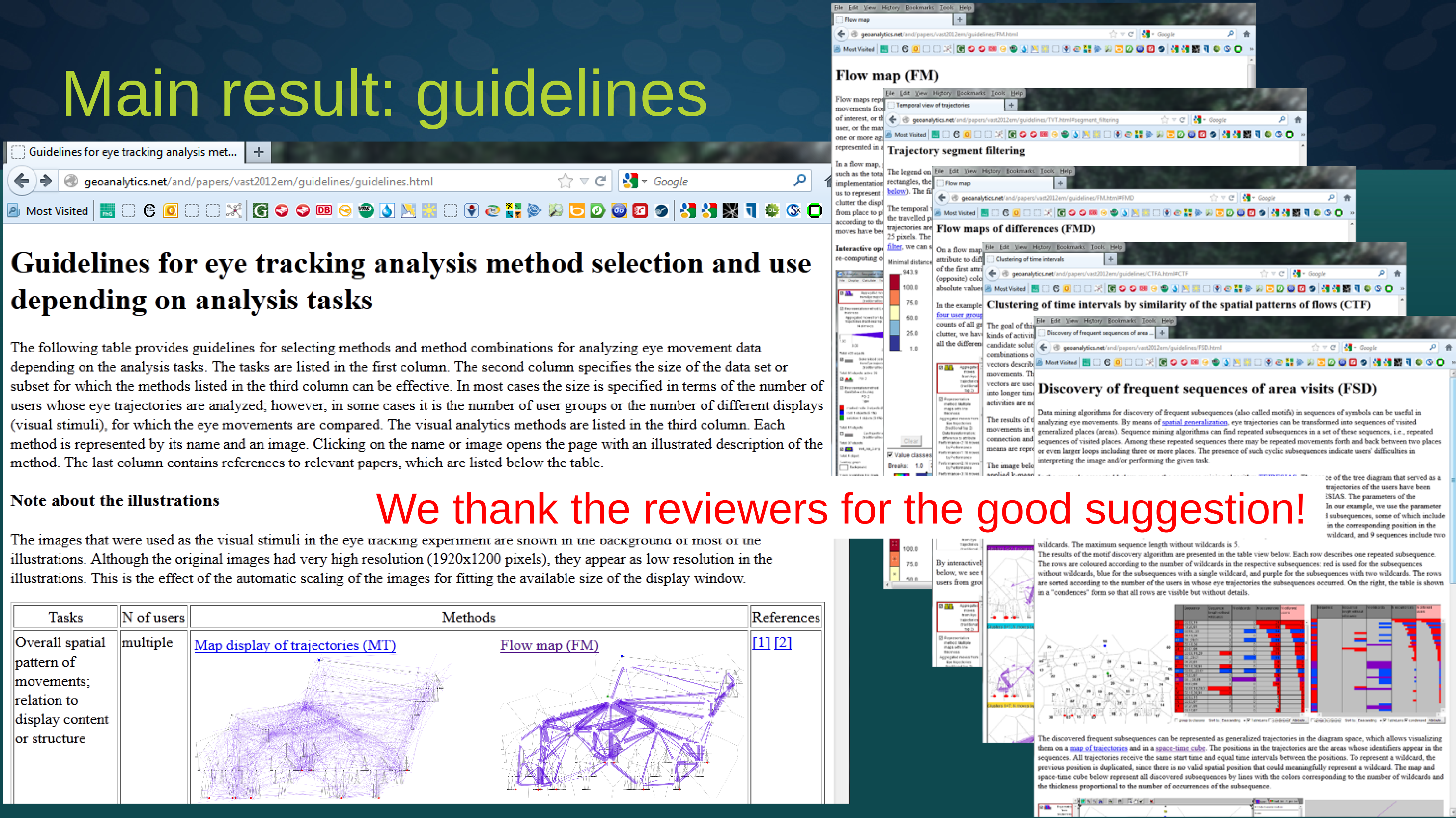
Eye tracking data used

- Visual stimuli: 54 tree diagrams
  - Layouts: traditional, orthogonal, radial
  - 4 orientations for traditional and orthogonal layouts: top ↔ bottom, left ↔ right
  - Different number of marked leaf nodes: 3 (×2), 6 (×2), 9 (×2)
- 37 participants
- Task: find the least common ancestor of the marked leaf nodes
- *See*: M. Burch, N. Konevtsova, J. Heinrich, M. Höferlin, D. Weiskopf. Evaluation of traditional, orthogonal, and radial tree diagrams by an eye tracking study. *IEEE Transactions on Visualization and Computer Graphics*, 17(12): 2440-2448, Dec. 2011

Main result: guidelines



Guidelines for eye tracking analysis met...

geoanalytics.net/and/papers/vast2012em/guidelines/guidelines.html

Guidelines for eye tracking analysis method selection and use depending on analysis tasks

The following table provides guidelines for selecting methods and method combinations for analyzing eye movement data depending on the analysis tasks. The tasks are listed in the first column. The second column specifies the size of the data set or subset for which the methods listed in the third column can be effective. In most cases the size is specified in terms of the number of users whose eye trajectories are analyzed; however, in some cases it is the number of user groups or the number of different displays (visual stimuli), for which the eye movements are compared. The visual analytics methods are listed in the third column. Each method is represented by its name and an image. Clicking on the name or image opens the page with an illustrated description of the method. The last column contains references to relevant papers, which are listed below the table.

Note about the illustrations

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Tasks	N of users	Methods		References
Overall spatial pattern of movements; relation to display content or structure	multiple	Map display of trajectories (MT)	Flow map (FM)	[1] [2]

Flow map (FM)

Trajectory segment filtering

Flow maps of differences (FMD)

Clustering of time intervals by similarity of the spatial patterns of flows (CTF)

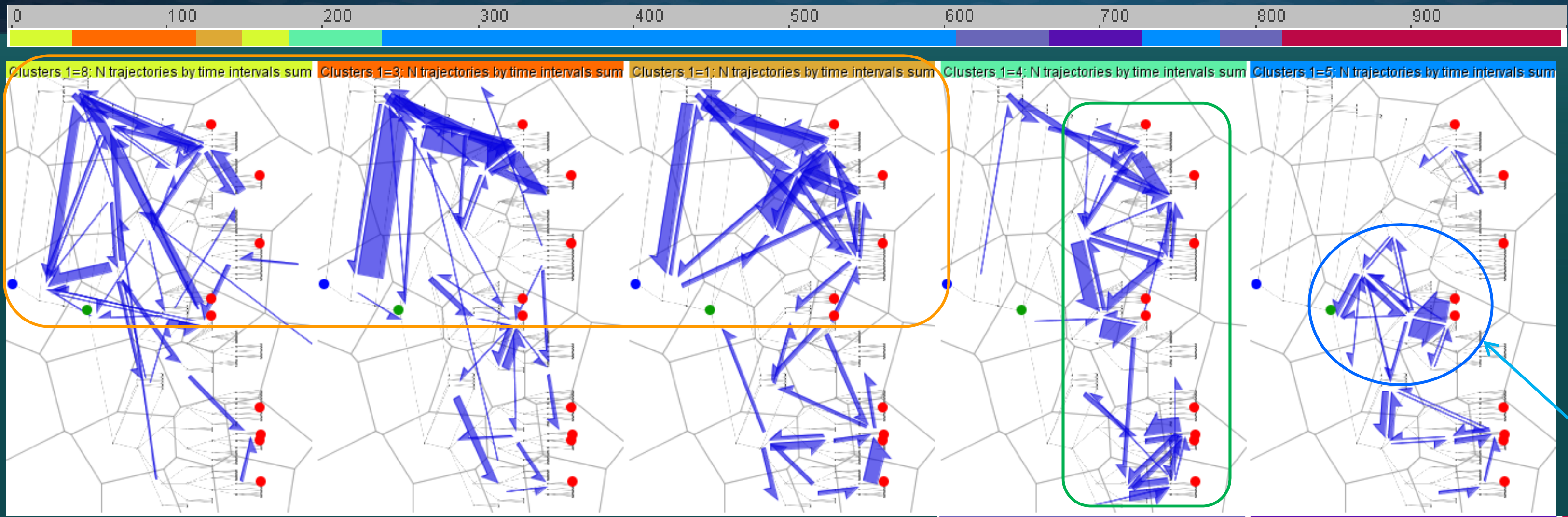
Discovery of frequent sequences of area visits (FSD)

Data mining algorithms for discovery of frequent subsequences (also called motifs) in sequences of symbols can be useful in analyzing eye movements. By means of spatial generalization, eye trajectories can be transformed into sequences of visited generalized places (areas). Sequence mining algorithms can find repeated subsequences in a set of these sequences, i.e., repeated sequences of visited places. Among these repeated sequences there may be repeated movements forth and back between two places or even larger loops including three or more places. The presence of such cyclic subsequences indicate users' difficulties in interpreting the image and/or performing the given task.

The discovered frequent subsequences can be represented as generalized trajectories in the diagram space, which allows visualizing them on a map of trajectories and in a space-time cube. The positions in the trajectories are the areas whose identifiers appear in the sequences. All trajectories receive the same start time and equal time intervals between the positions. To represent a wildcard, the previous position is duplicated, since there is no valid spatial position that could meaningfully represent a wildcard. The map and space-time cube below represent all discovered subsequences by lines with the colors corresponding to the number of wildcards and the thickness proportional to the number of occurrences of the subsequence.

We thank the reviewers for the good suggestion!

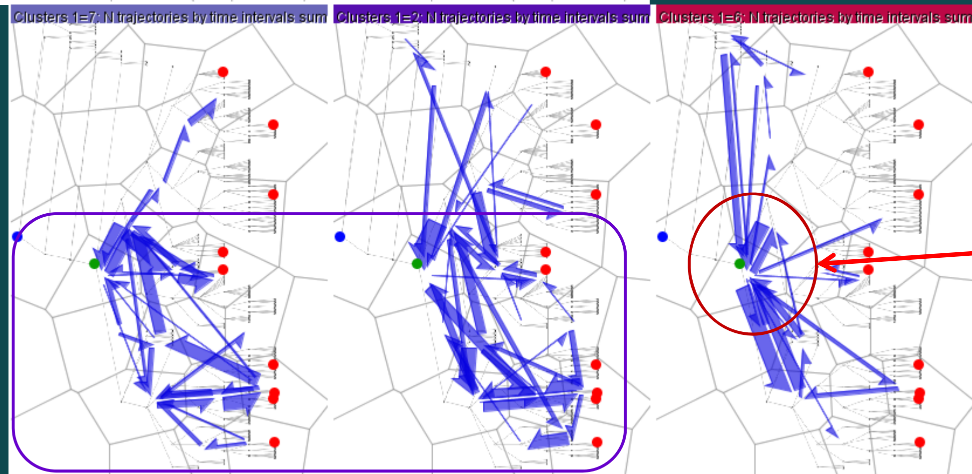
Example: eye movement patterns over time



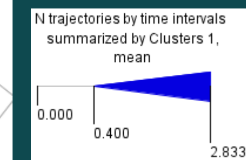
We can infer types of users' viewing activities

Loss of time!

Time intervals clustered according to similarity of the aggregate eye movements



Target!



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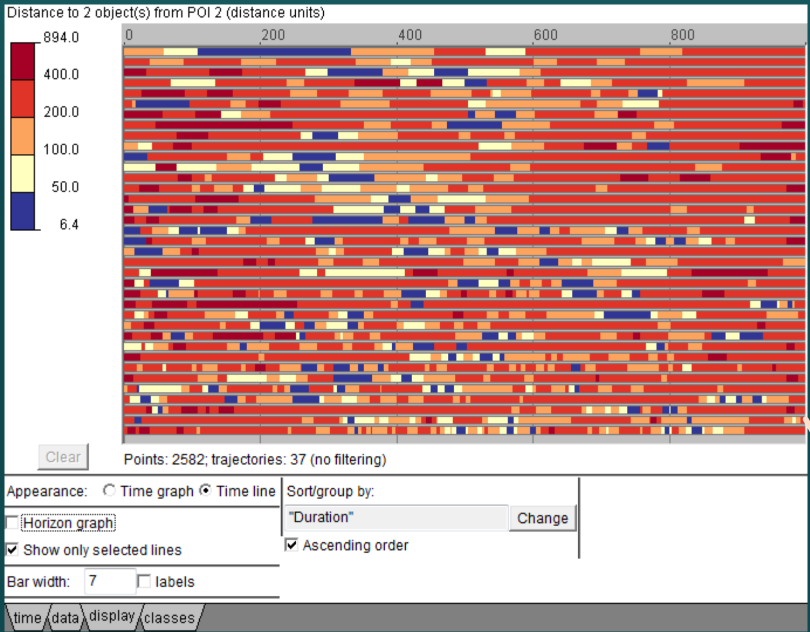
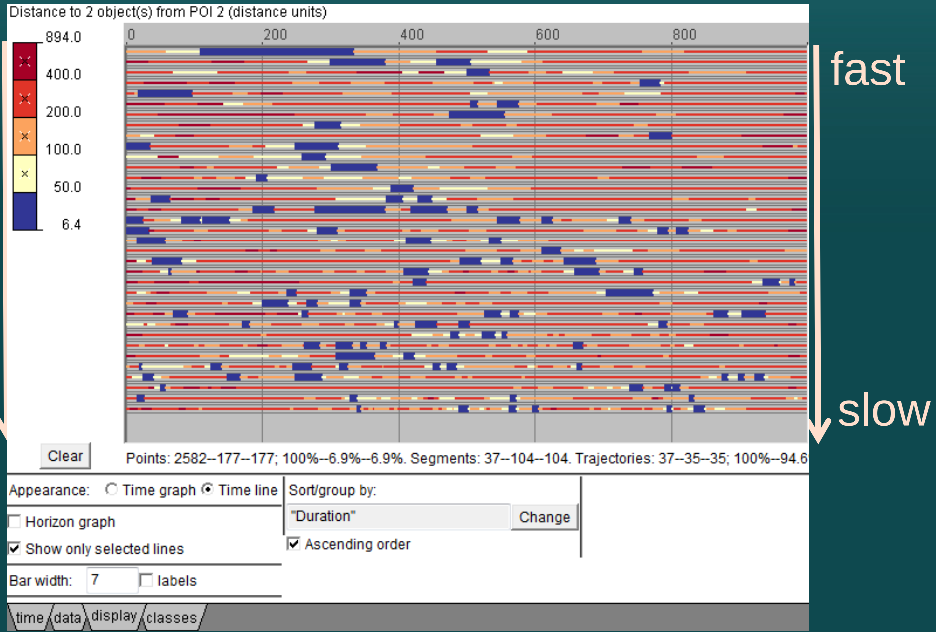
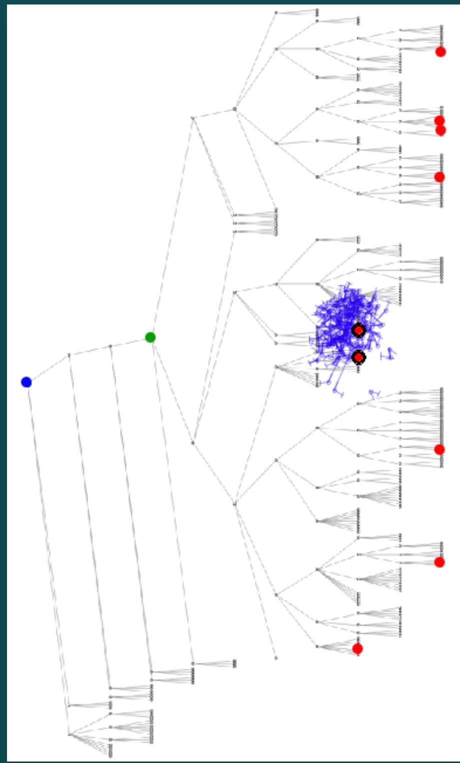
Who, when, and how often looked at the irrelevant nodes?







Trajectories are represented by segmented bars.
Horizontal dimension: (relative) time.
Segment colours: attribute values.
Segments can be interactively filtered.

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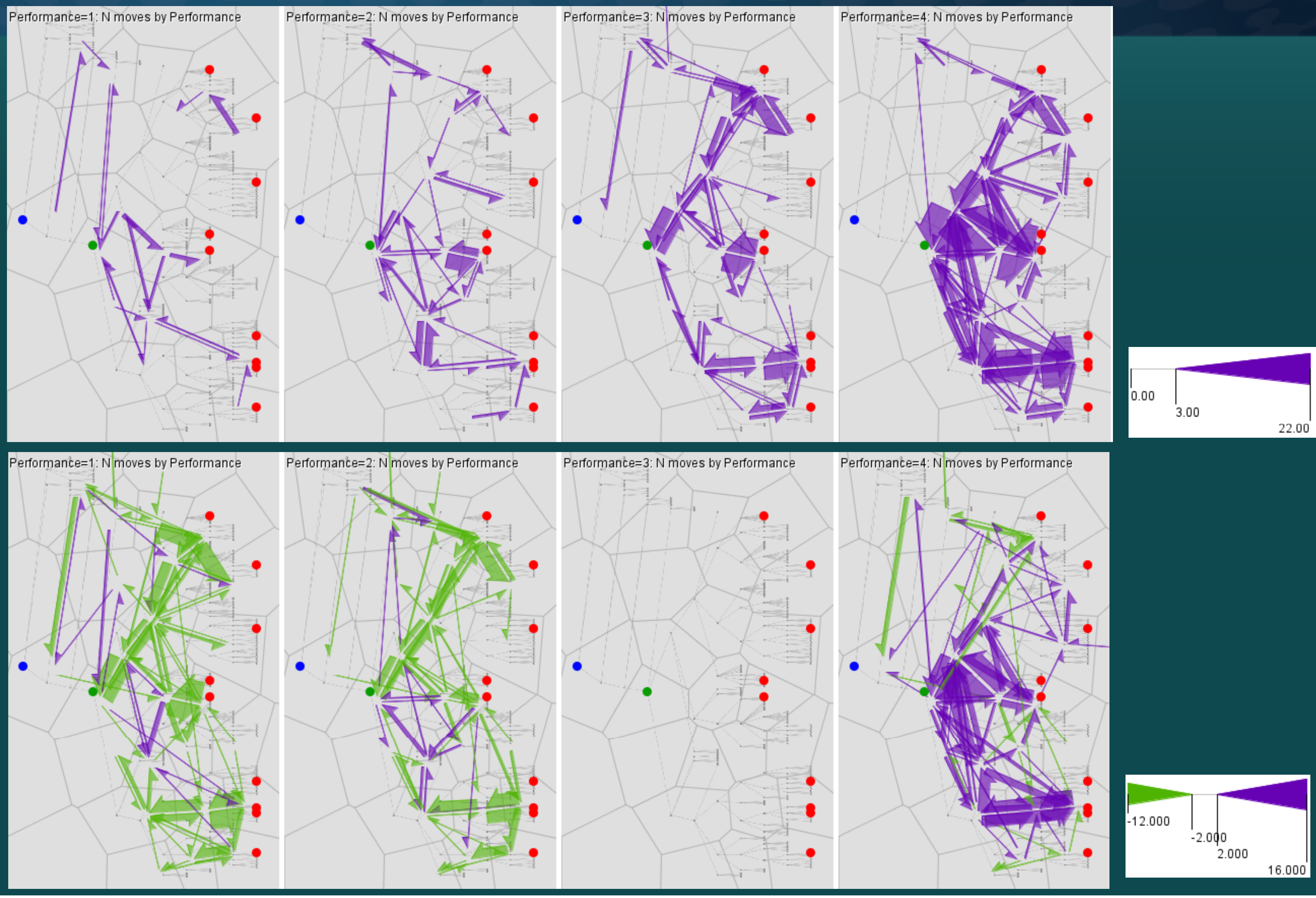
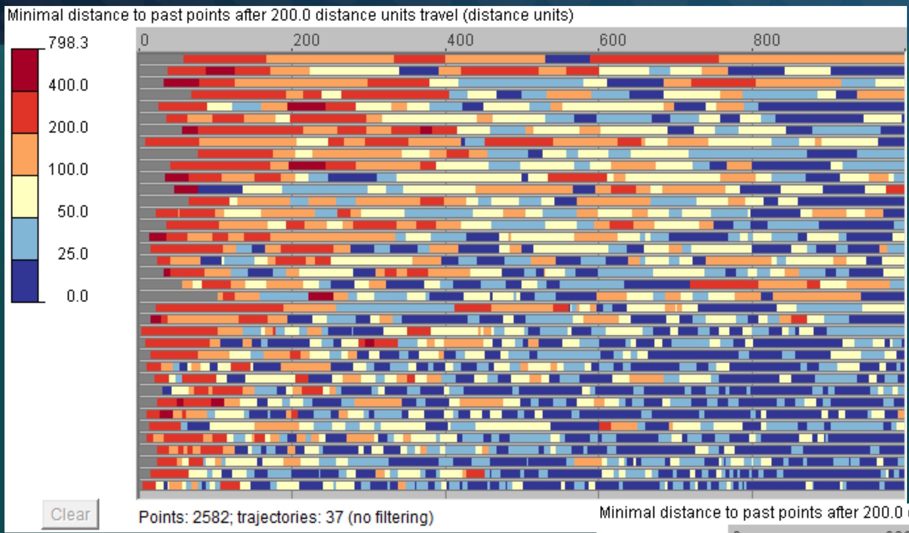
Comparison of fast and slow users

4 user groups according to task completion time (trajectory duration)

Differences to group 3

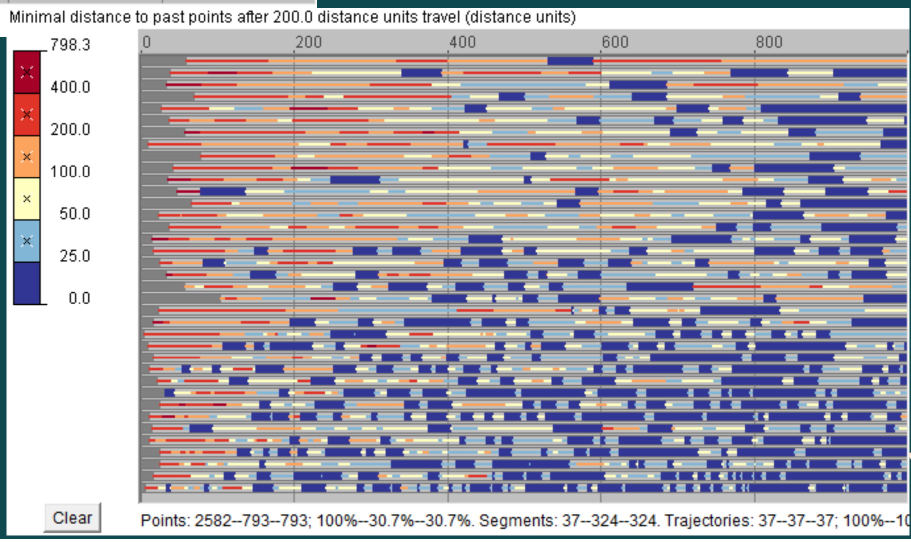


Performance and returns to previous points



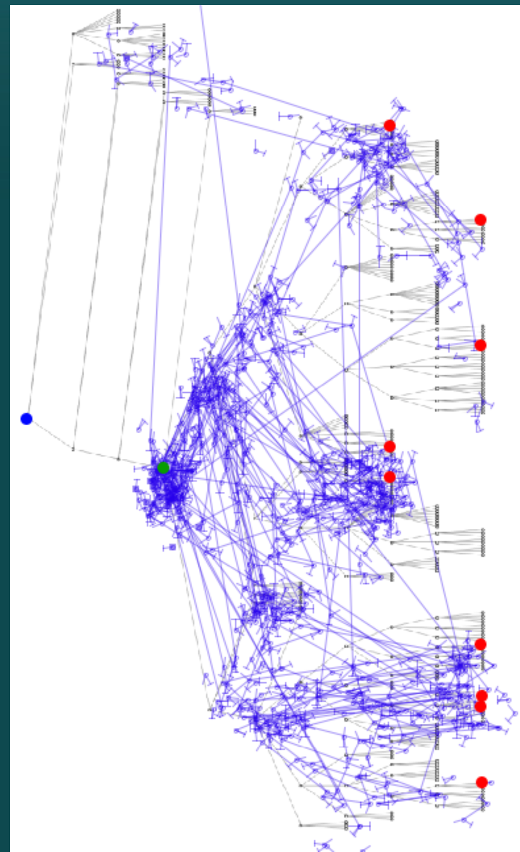
fast

slow



fast

slow



Frequent sequences

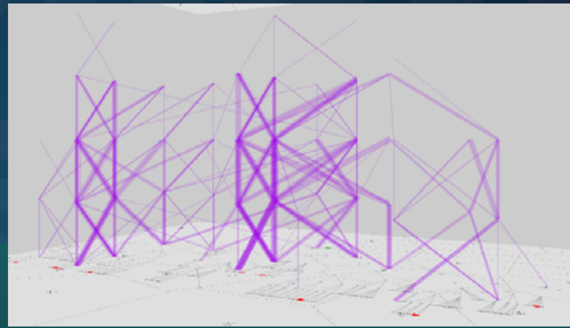
	Sequence	Sequence length	N wildcards	N occurrences	N different objects
28	12;02;12	3	0	22	16
9	13;07;06	3	0	15	14
46	02;12;02	3	0	14	14
32	07;13;07	3	0	13	6
88	02;12;.;03	4	1	11	11
47	02;12;03	3	0	11	9
40	06;07;13	3	0	11	10
105	12;.;12;02	4	1	10	9
72	12;02;.;03	4	1	10	8
58	03;12;02	3	0	10	7
56	01;03;01	3	0	10	9
45	02;12;14	3	0	10	7
104	12;.;12;03	4	1	9	4
94	14;.;02;12	4	1	9	9
70	12;02;.;02	4	1	9	8
63	13;07;.;07	4	1	9	6
43	17;05;11	3	0	9	9
38	12;03;12	3	0	9	4
19	12;02;03	3	0	9	8
15	13;07;13	3	0	9	4
100	06;.;13;07	4	1	8	7
98	07;.;07;13	4	1	8	3
95	14;.;12;02	4	1	8	7
86	07;13;.;06	4	1	8	6
81	02;12;.;12	4	1	8	6
73	03;12;.;12	4	1	8	3
69	17;05;.;14	4	1	8	7
55	14;11;05	3	0	8	7
52	14;12;02	3	0	8	8
50	20;02;12	3	0	8	8
36	07;06;04	3	0	8	7
101	06;.;06;04	4	1	7	6
91	13;.;13;07	4	1	7	5
90	03;.;02;12	4	1	7	4
85	07;13;.;13	4	1	7	3

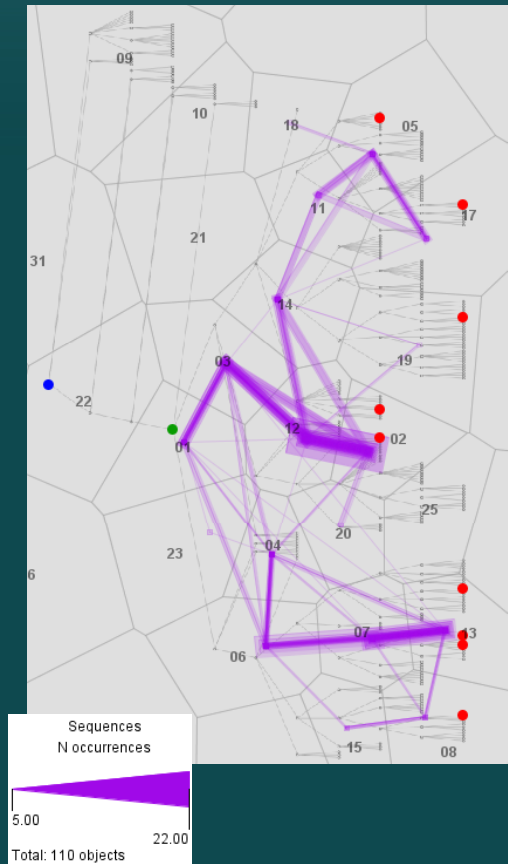
Sort by: N o Descending ☑ TableLens ☐ condensed Attribute...

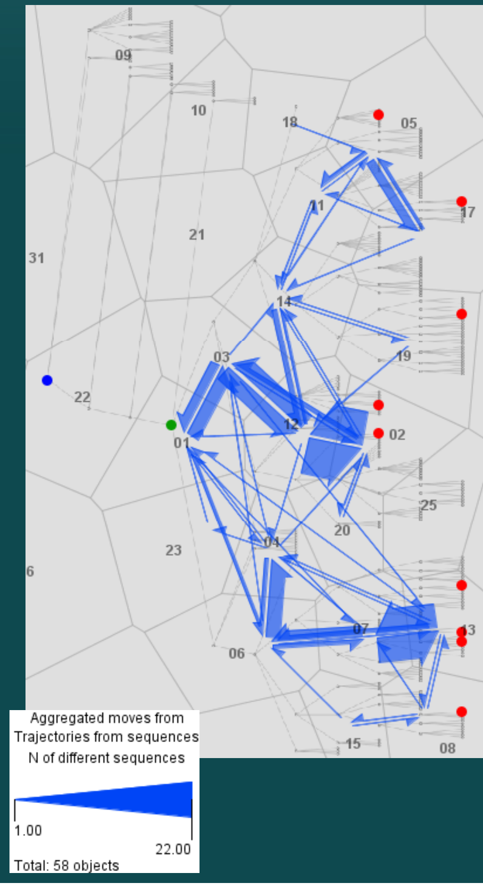
	Sequence	Sequence length	N occurrences	N different objects
28	12;02;12	3	22	16
9	13;07;06	3	15	14
46	02;12;02	3	14	14
32	07;13;07	3	13	6
47	02;12;03	3	11	9
40	06;07;13	3	11	10
58	03;12;02	3	10	7
56	01;03;01	3	10	9
45	02;12;14	3	10	7
43	17;05;11	3	9	9
38	12;03;12	3	9	4
19	12;02;03	3	9	8
15	13;07;13	3	9	4
55	14;11;05	3	8	7
52	14;12;02	3	8	8
50	20;02;12	3	8	8
36	07;06;04	3	8	7
61	03;01;03	3	7	6
57	03;12;03	3	7	5
53	04;03;01	3	7	6
33	07;13;04	3	7	6
11	05;11;14	3	7	7
6	05;17;11	3	7	6
3	06;01;03	3	7	7
54	13;08;15	3	6	5
48	01;03;12	3	6	4
44	18;05;17	3	6	5
42	15;08;13	3	6	6
30	06;07;13;07	4	6	5
25	12;02;12;03	4	6	4
24	12;02;12;02	4	6	6
20	03;12;02;12	4	6	3
14	13;07;13;07	4	6	4
13	07;13;07;13	4	6	2
10	05;17;05	3	6	6

Sort by: :ending ☑ TableLens ☐ condensed Attribute...

Without wildcards

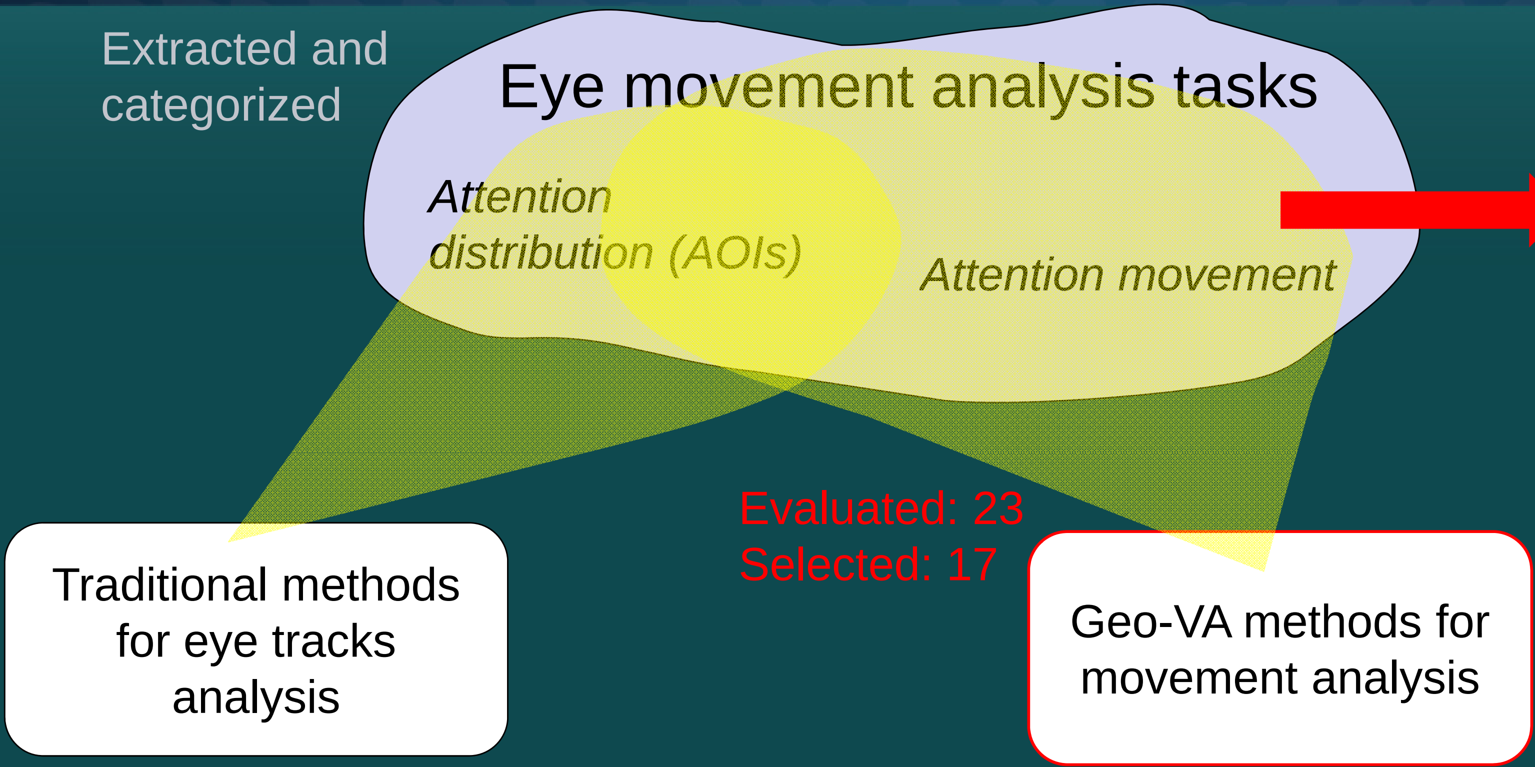






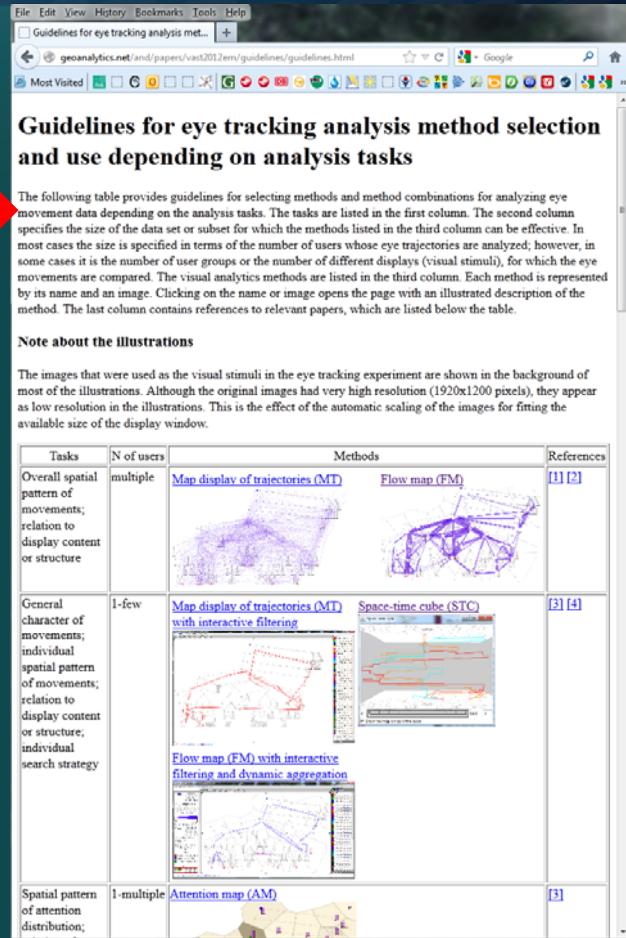
Conclusion

http://geoanalytics.net/and/papers/vast2012em/



Limitations analyzed

Suitability evaluated;
procedures defined



File Edit View History Bookmarks Tools Help

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geoanalytics.net/and/papers/vast2012em/guidelines/guidelines.html

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General character of movements; individual spatial pattern of movements; relation to display content or structure; individual search strategy	1-few	Map display of trajectories (MT) with interactive filtering; Space-time cube (STC); Flow map (FM) with interactive filtering and dynamic aggregation	[3] [4]
Spatial pattern of attention distribution;	1-multiple	Attention map (AM)	[3]