

Visual Analytics Methodology for Eye Movement Studies

Gennady Andrienko, Natalia Andrienko, Michael Burch, Daniel Weiskopf

Introduction: eye tracking gains popularity

EVALUATING THE USABILITY OF CAR (OGRAPHIC ANIMATIONS WITH EVE MOVEMENT ANALYSIS

Evaluating the Effectiveness of Interactive Map Interface Designs: A Case Study Integrating

Usability Metrics with Eye-movement Analysis

Arzu Coltekin, Benedikt Heil, Simone Garlandini, and Sara Irina Fabrikant

Bye Tracking in Human-Computer Interaction and Usability Research: Current Status and Future Prospects

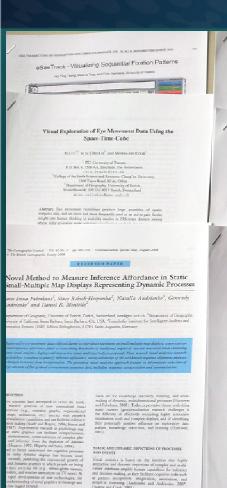
Alex Poole and Linden J. Ball

erfaces directly wastern popularious of usors such as disabled individuals. We divantage for certain popularious of usors such as disabled individuals. We as chapter with an overview of eye tacking rechnology, and progress town in chapter with an overview of eye tracking in HCI and usability research. A key life present of the use of eye tracking in HCI and usability research.

The History of Eye Tracking
Many different methods have been used to track eye movements since the use of eyemany different methods have been used to track eye movements since the use of eyemany different methods was first pieueened in reading research over 100 years ago (Rayne

mentions about system usability. We conclude by eye tracking research in HCL and usability testing

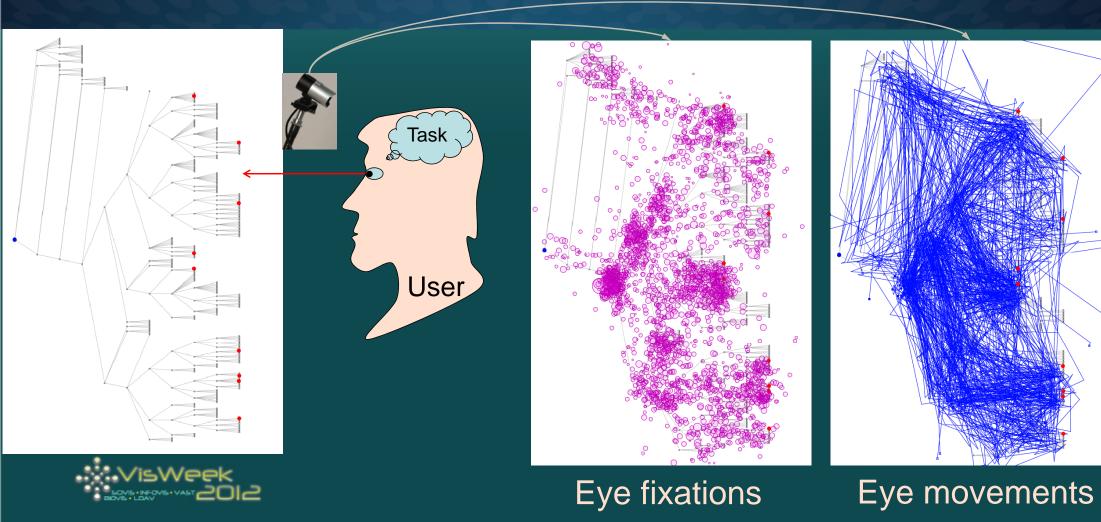
L EYE-TRACKING AS AN EVALUATION METHOD





- 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



Introduction: tasks in eye movement analysis

Attention distribution:

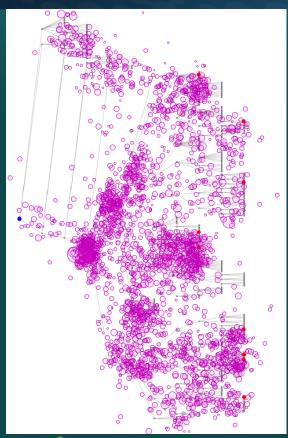
- What areas attract user's attention? How much attention?
- Does the user find predefined Areas Of Interest (AOIs)? How easily?
- How does the attention change over time?
- What differences exist between users, displays, interfaces?

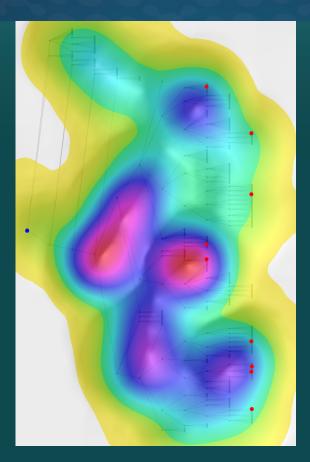
Attention movement:

- 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?



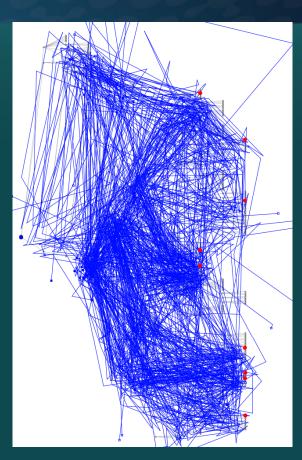
Introduction: commonly used techniques





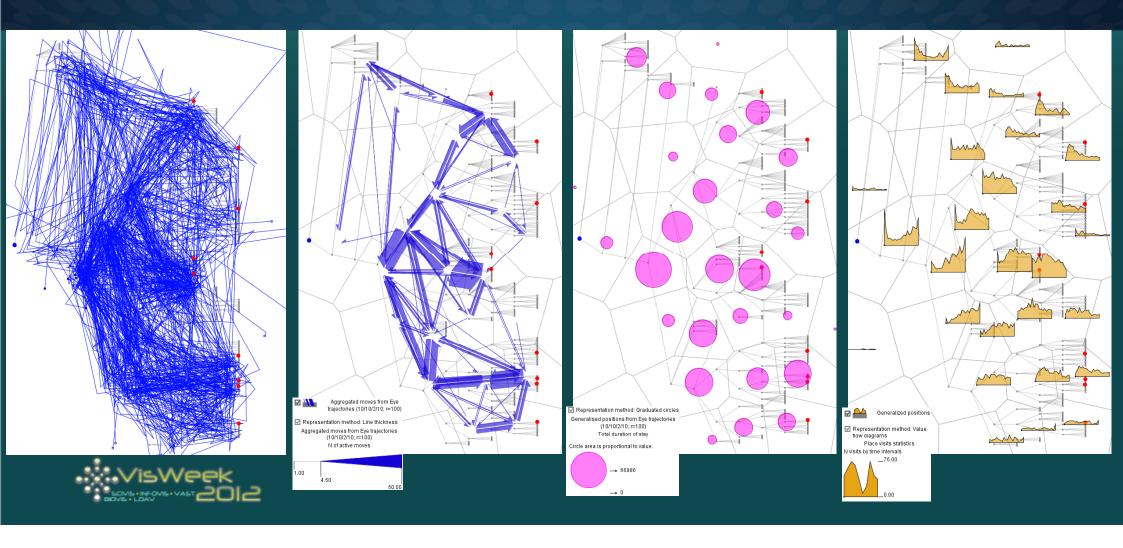


Attention distribution

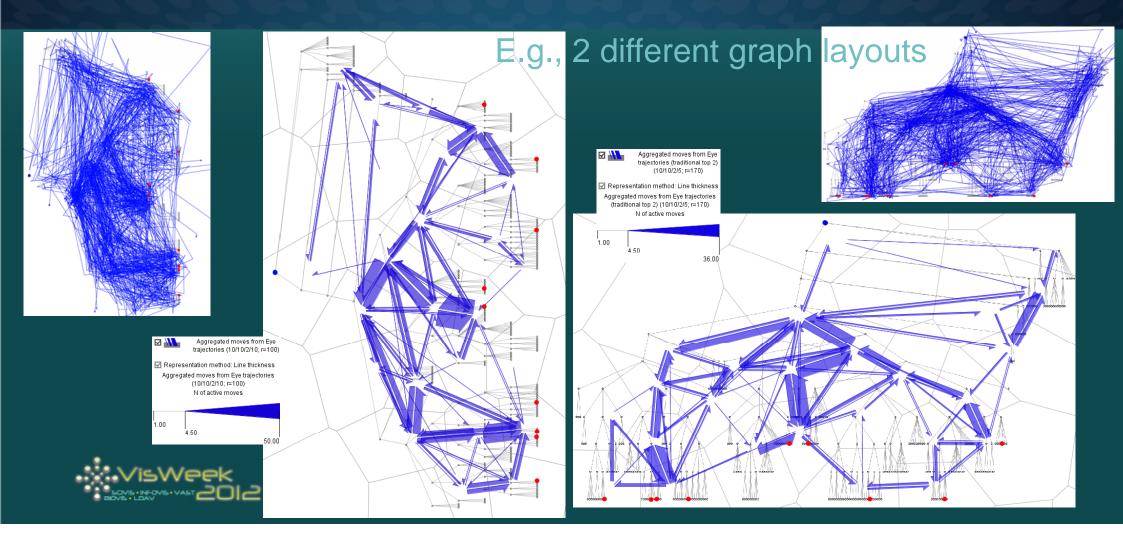


Attention movement?

Geo-VA techniques can be helpful



... also in comparative studies



Empirical assessment of Geo-VA methods

Evaluation group (InfoVis experts)



Technology group (Geo-VA experts)



Observations

There is no prominent common strategy for all graphs. However, some common types of activities can be observed:

 Movements from the centre (not necessarily root) towards the leaves (not only marked). Such movements often occur in the beginning.

Traversing the perimeter of the tree. Often occurs on the secondstage.

 Scanning the tree (almost all places are vithed; there are many moves between adjacentor close places; and definited flows). Usually the marked leavage are vited with appointments of the come frequency acother leavage. Scanning oftenoccurs after traversing but may also occur before[imaged]. There may be asswerableques of examine.

Badial movement from some place. For all images there areach movement from the place of
abution, which offers occur at the end but may also occur areafte. For some image(e.g. 2 and 3) out
movements also occur from other places, possibly, containing a common ancestor of a group of leave
Movement towards the place of solution (porminant in mages 1 and 3).

For any image there is no clear succession of problem solving steps (i.e. continuous temponal clusters of similar situations). This may mean that people do the tasks differently.

It cannot be said that the fast performers do the tasks in the most efficient way since there are quite many visits of non-relevant places and unnecessary moves.



!??

Observations

There is no prominent common strategy for all graphs. However, some common types of activities can be observed:

Movements from the centre (not necessarily root) towards the leaves (not only marked). Such
movements often occur in the beginning.
 These resides research to sevel their times and refidencing upon at leave, at faugh they causely denote

Traversing the perimeter of the tree. Often occurs on the secondstage.

Scanning the time (almost all places are violed; there are many moves between adjacentor close
places; no dominant flowe). Usually the marked leaves are violed with approximately the same
frequency as other leaves. Scanning oftenocours after travening but may also occur before [mage 5].
 There may be several close of canning.

frequency as other leaves. Examing offenceurs after travering but may also court before (impags). There may be assert integer of scoring or interest where several measurement from the piece of solution, with other occur of the end unmay also accord series. For some impage is gift and of just of movements also occur from other places, possibly, ontaining a sommon excessor of a group of leave. Movements counted the place of outloon (promitment in leage 2 and 2).

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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







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

We thank the reviewers for the good suggestion!

The images that were used as the visual stimuli in the eye macking experiment are snown in the background of most of the illustrations. Although the original images had very high resolution (1920x1200 pixels), they appear as low resolution in the illustrations. This is the effect of the automatic scaling of the images for fitting the available size of the display window.

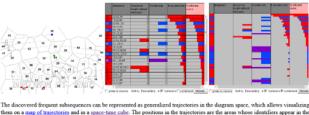
Tasks	N of users	Methods		
1	multiple	Map display of trajectories (MT)	Flow map (FM)	[1] [2]
pattern of movements;		10		
relation to				
display content or structure				
		1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1		

Flow map (FM) epresented in a Trajectory segment filtering such as the total implementation from place to pl ccording to the travelled p 25 pixels. Th Interactive ope filter, we can s 100.0 75.0 in the example Clustering of time intervals by similarity of the spatial patterns of flows (CTF) counts of all gr The goal of ti clutter, we have kinds of activiti vectors describi Discovery of frequent sequences of area visits (FSD) into longer time activities are no 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 movements in a 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 place means are repre or even larger loops including three or more places. The presence of such cyclic subsequences indicate users' difficulties in

wildcards. The maximum sequence length without wildcards is 5.

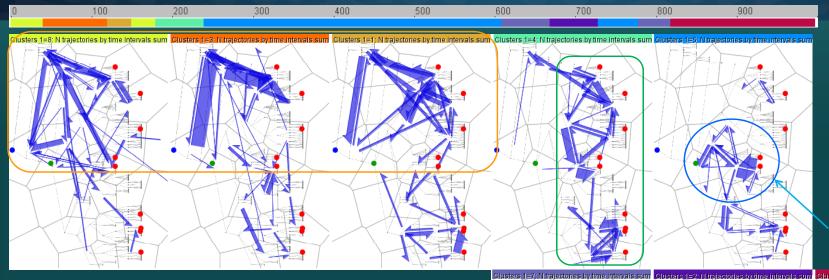
The results of the motif discovery algorithm are presented in the table view below. Each row describes one repeated subsequence. The rows are coloured according to the number of wildcards in the respective subsequences: red is used for the subsequences without wildcards, blue for the subsequences with a single wildcard, and purple for the subsequences with two wildcards. The rows are sorted according to the number of the users in whose eye trajectories the subsequences occurred. On the right, the table is show in a "condences" forms obtail all rows are visible but without details.

In our example, we use the parameter I subsequences, some of which include in the corresponding position in the



The discovered frequent subsequences can be represented as generalized trajectories in the diagram space, which allows visualizing them on a mage of traincistories and in a space-time cube. The positions in the trajectories are the areas whose identifiers appear in the requences. All trajectories receive the same start time and equal time intervals between the positions. To represent a wildcard, the reviews position is duplicated, since there is no valid spatial position that could meaningfully represent a wildcard. The map and papee-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.

Example: eye movement patterns over time

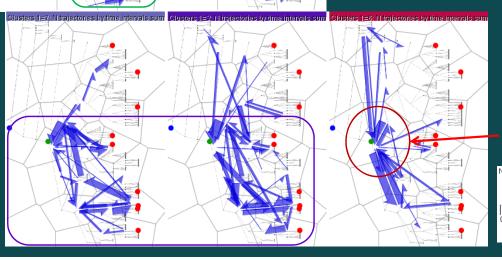


We can infer types of users' viewing activities

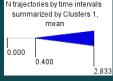
Loss of time!

Time intervals clustered according to similarity of the aggregate eye movements

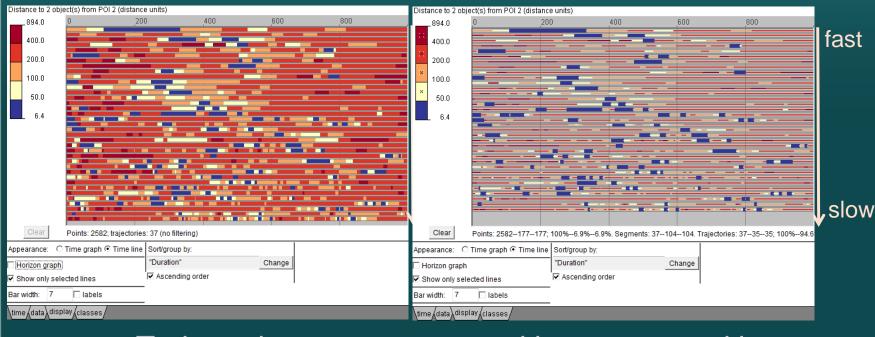




Target!



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

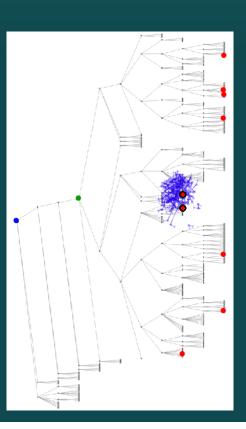


Trajectories are represented by segmented bars.

Horizontal dimension: (relative) time.

Segment colours: attribute values.

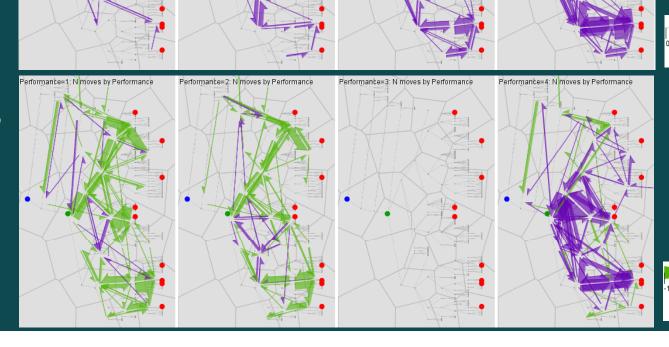
Segments can be interactively filtered.



Comparison of fast and slow users

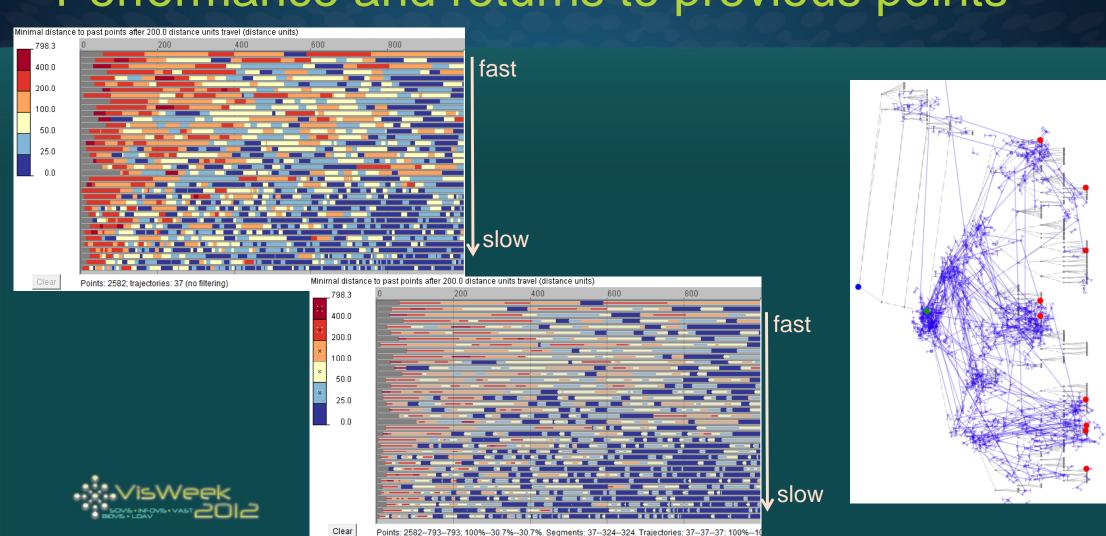
4 user groups according to task completion time (trajectory duration)

Differences to group 3





Performance and returns to previous points



Frequent sequences

	Sequence	Sequence	N wildcards	N	N different	
		length		occurrences	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		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	
	12:02:03	3	0	9	8	
15	13;07;13	3	0	9	4	
	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	Ŧ

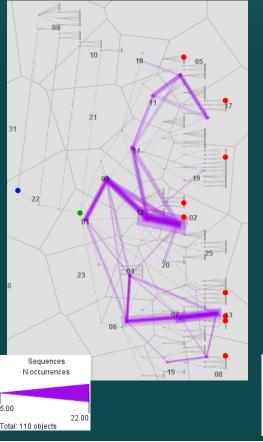
	Sequence	Sequence length	N occurrences	N different objects	
	40.00.40	_		-	_
_	12;02;12	3	22	16	1
9	13;07;06	3	15	14	
46	02;12;02		14	14	
32	07;13;07	3	13	6	
47	02;12;03	3	11	9	
		3	11	10	
	03;12;02	3	10	7	
	01;03;01	3	10	9	
	02;12;14	3	10	7	
		3	9	9	
	12;03;12	3	9	4	L
19	12;02;03	3	9	8	ı
15	13;07;13	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	L
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		4	6	4	
	12;02;12;02	4	6	6	
	03;12;02;12	4	6		
	13;07;13;07	4	6	3	
	07;13;07;13	4	6	2	
10	05;17;05	3	6	6	-
	4		, ,	,	-

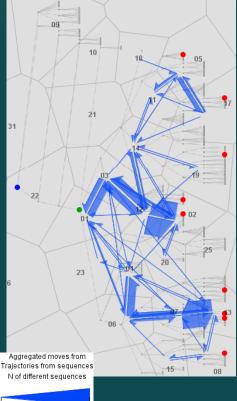


Sort by: N o → Descending → 🗹 TableLens 🗆 condensed Attribute...

Without wildcards







Conclusion

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

and use depending on analysis tasks

Extracted and categorized

Eye movement analysis tasks

Attention distribution (AOIs)

Attention movement

Traditional methods for eye tracks analysis

Limitations analyzed



Evaluated: 23

Geo-VA methods for movement analysis

Suitability evaluated; procedures defined



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