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Eye Tracking and Visual Analytics

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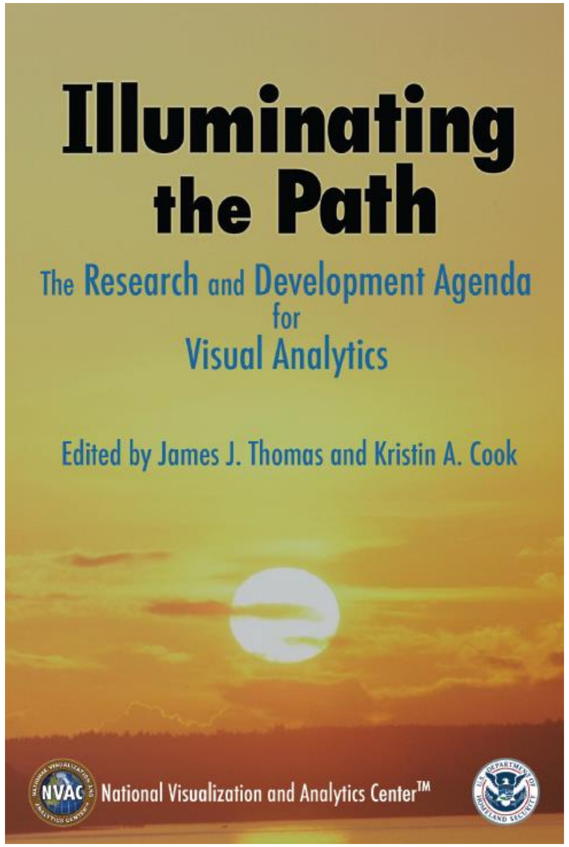
ETRA 2018 - Tutorial: Eye Tracking and Visual Analytics – Warsaw, Poland

Visual Analytics

- Why visual analytics?
  - Recent challenges related to data analysis
  - Complex data
  - Large-scale data
- Definition:
  “the science of analytical reasoning
  facilitated by interactive human-machine interfaces”

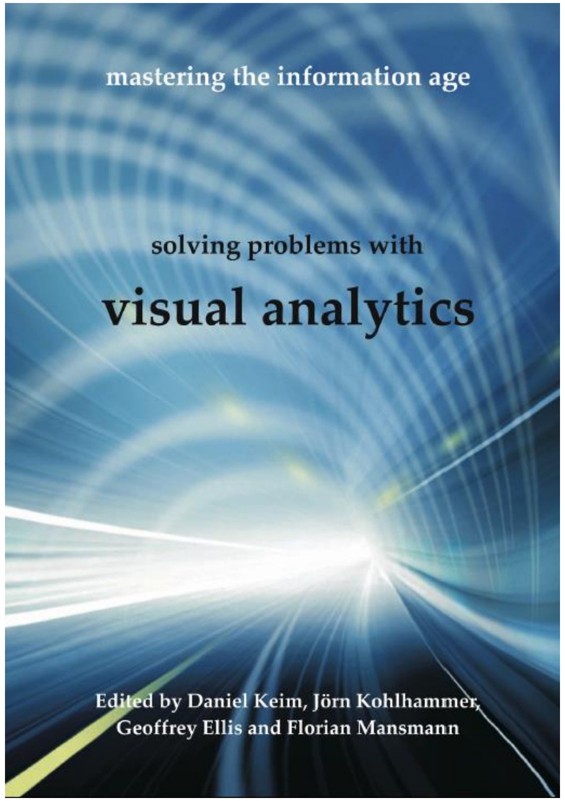
  [THOMAS J. J., COOK K. A. (Eds.): Illuminating the Path:
  The Research and Development Agenda for Visual Analytics. IEEE Press, 2005]



Refined Definition of Visual Analytics

"the creation of tools and techniques to enable people to:

- Synthesize information and derive insight from massive, dynamic, ambiguous, and often conflicting data.
- Detect the expected and discover the unexpected.
- Provide timely, defensible, and understandable assessments.
- Communicate these assessment[s] effectively for action."



[KEIM D. A., KOHLHAMMER J., ELLIS G. P., MANSMANN F. (Eds.):
Mastering The Information Age – Solving Problems with Visual Analytics. Eurographics, 2010]

Simplified Definition

Visual analytics =

interactive visualization + automatic data analysis

Multidisciplinary Research

- Analytical reasoning
  - How to maximize human capacity to perceive, understand, and reason about complex and dynamic data and situations?

Cognitive science
Knowledge management

- Visual representations and interaction techniques
  - How to augment cognitive reasoning with perceptual reasoning through visual representations and interaction?

Visualization
Human-computer interaction

- Data representations and transformations
  - How to transform data into a representation that is appropriate to the analytical task and effectively conveys the important content?

Data-mining
KDD
Statistical analysis

- Production, presentation, and dissemination
  - How to convey analytical results in meaningful ways to various audiences

Knowledge management
Communication sciences

[adopted from: Andrienko: Geospatial Visual Analytics Tutorial]

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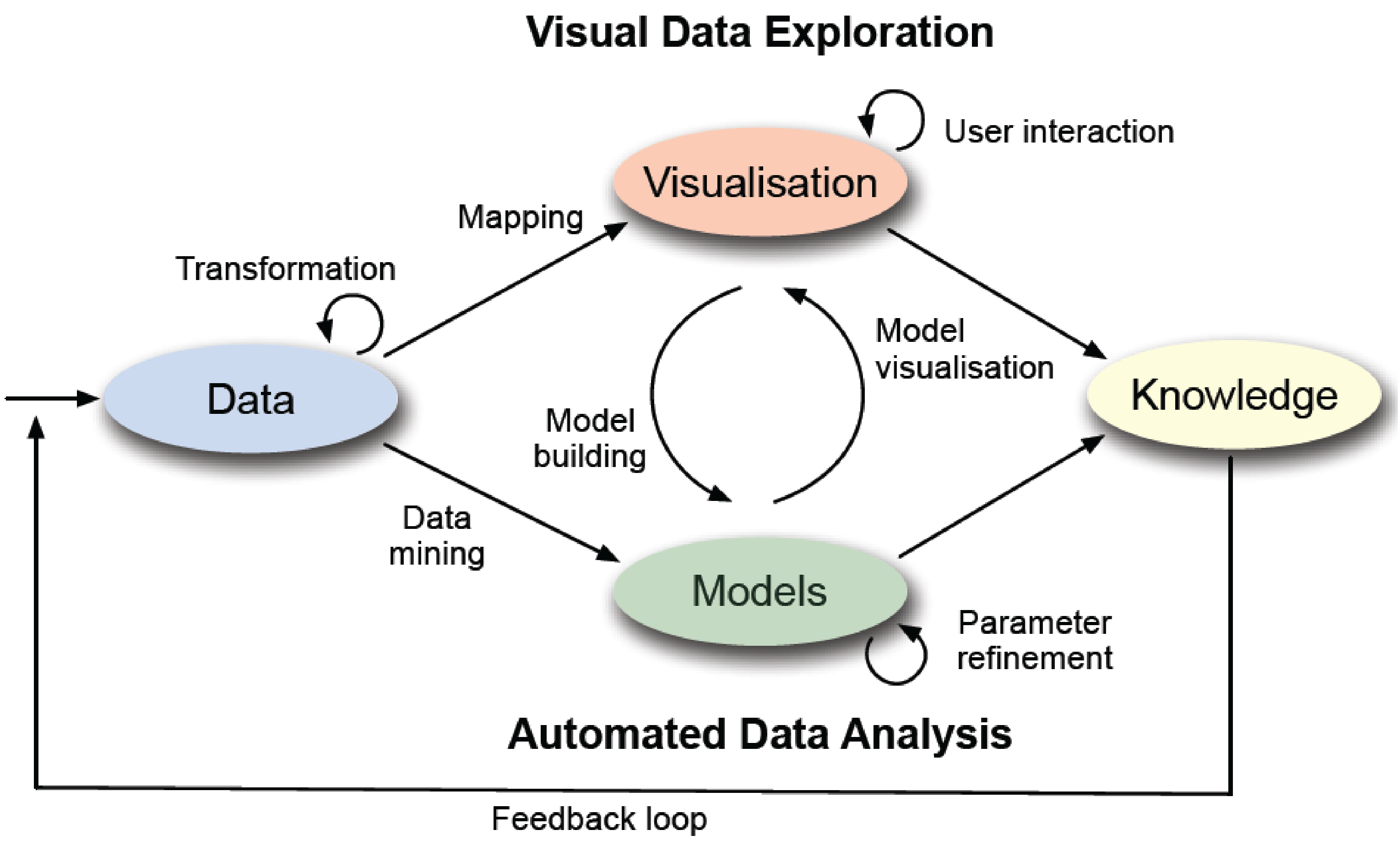
Visual Analytics Process



[KEIM D. A., KOHLHAMMER J., ELLIS G. P., MANSMANN F. (Eds.): Mastering The Information Age – Solving Problems with Visual Analytics. Eurographics, 2010]

Why Visual Analytics for Eye Tracking Data?

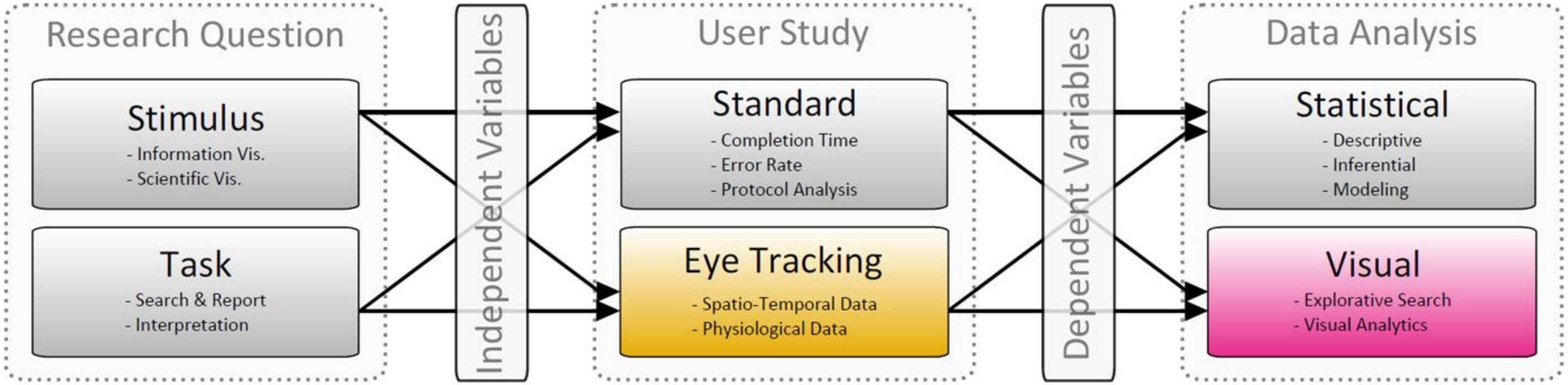
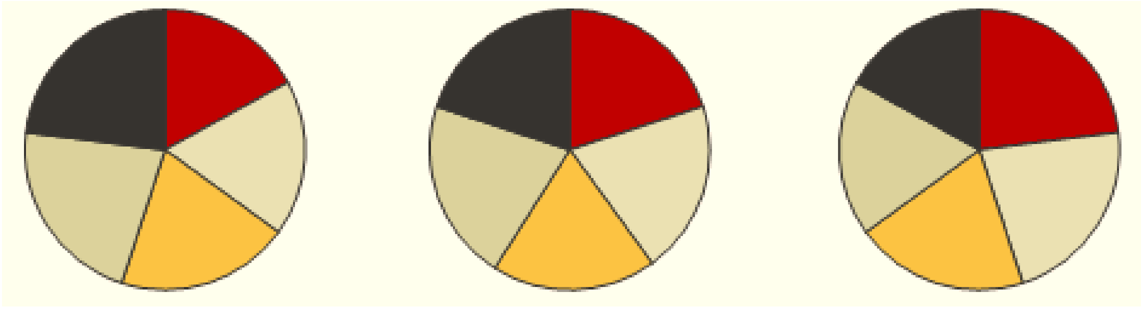
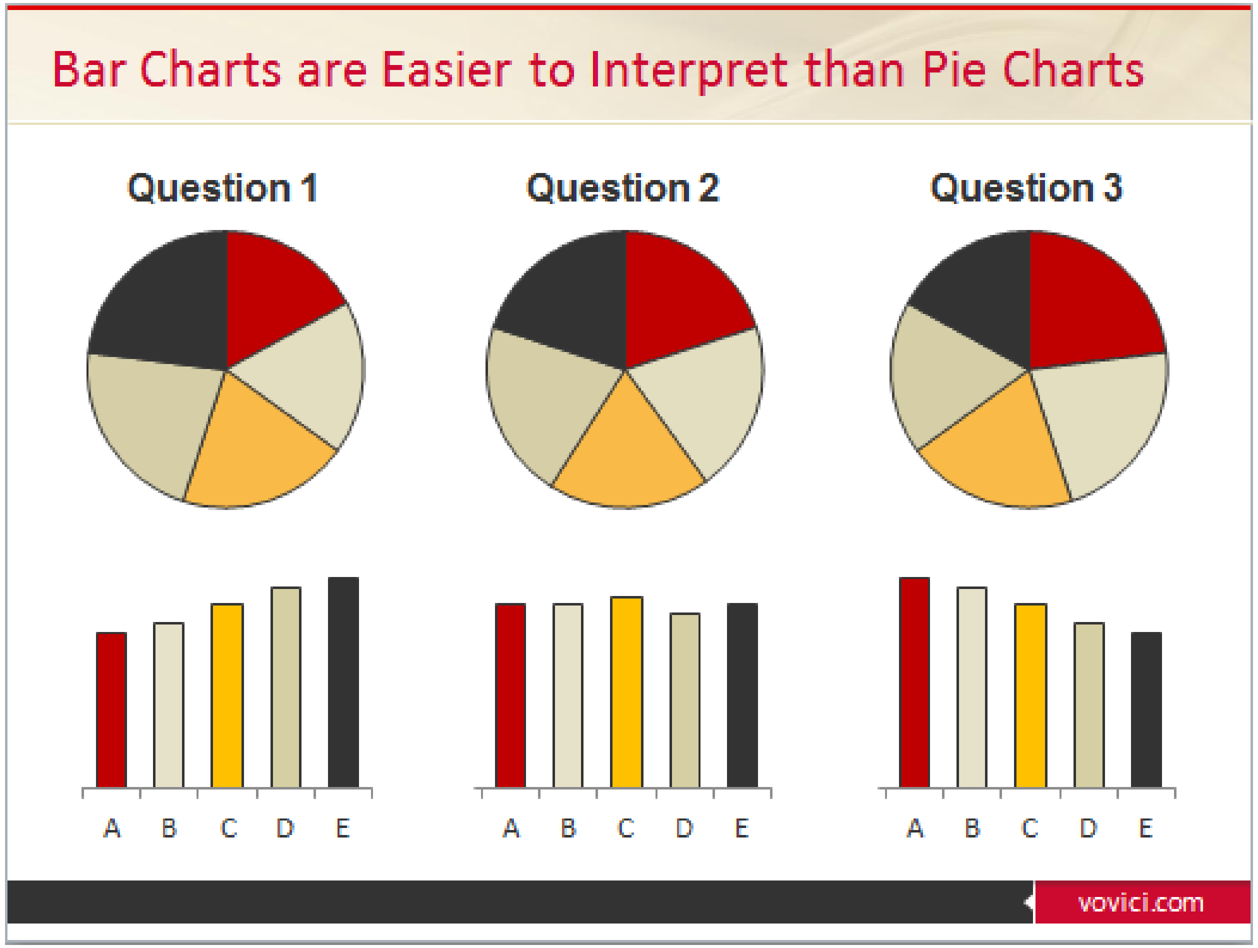


Figure 1: Pipeline of user-oriented evaluation. Stimulus and task represent the independent variables, measurements from a user study represent the dependent variables. The data analysis can then be performed with statistical methods, or in combination with a visual data analysis.

Traditional User Studies



Traditional User Studies



User Study Performance Measures

- Response times
- Error rates

➔ **Dependent variables of traditional user studies**

➔ **Typically statistically evaluated**
➔ **Hypotheses confirmed/rejected**

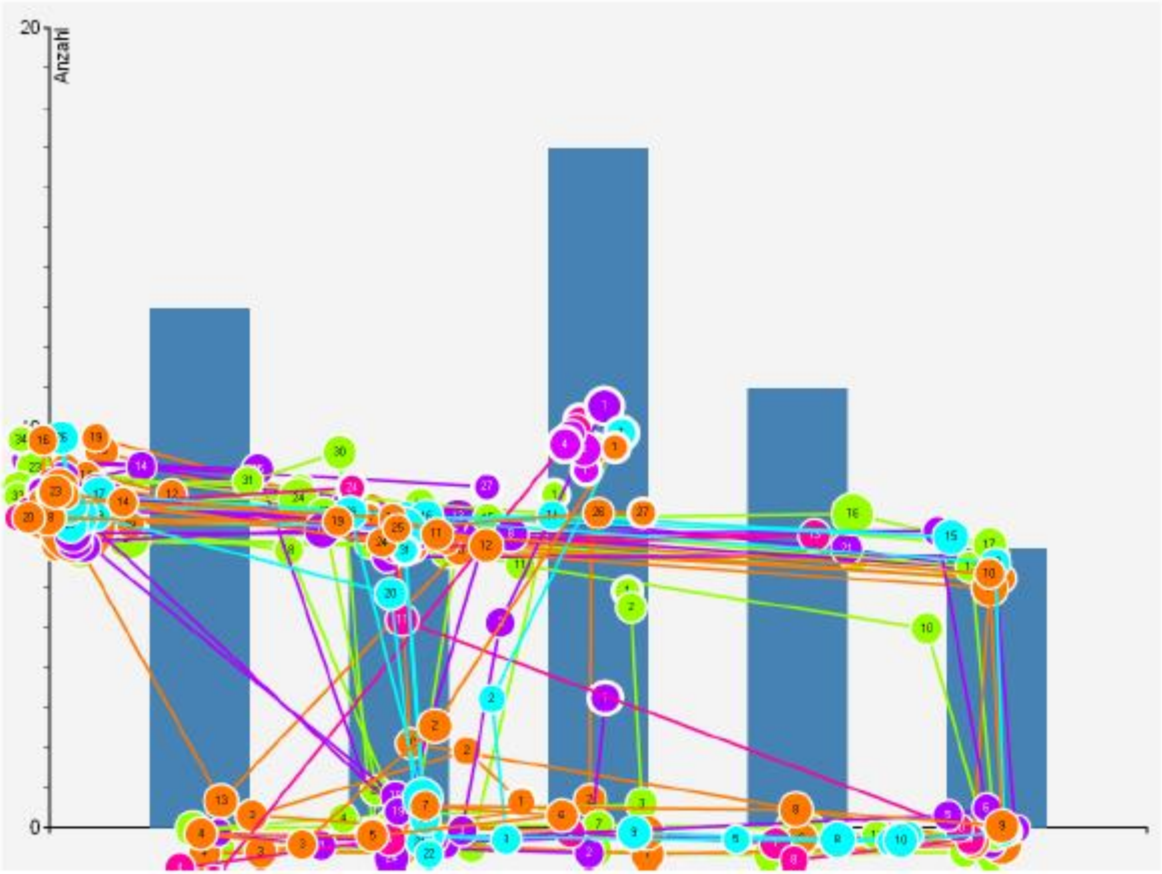
Eye Tracking in Information Visualization

- Additional dependent variable in form of eye movements
  - Spatio-temporal data

➔ **Challenge:**
Statistical evaluation of spatio-temporal eye movements with the goal to find common visual task solution strategies among the participants

➔ **Visual Analytics** (Algorithms, Visualization, Human User, Interaction, ...)

Eye Tracking in Information Visualization

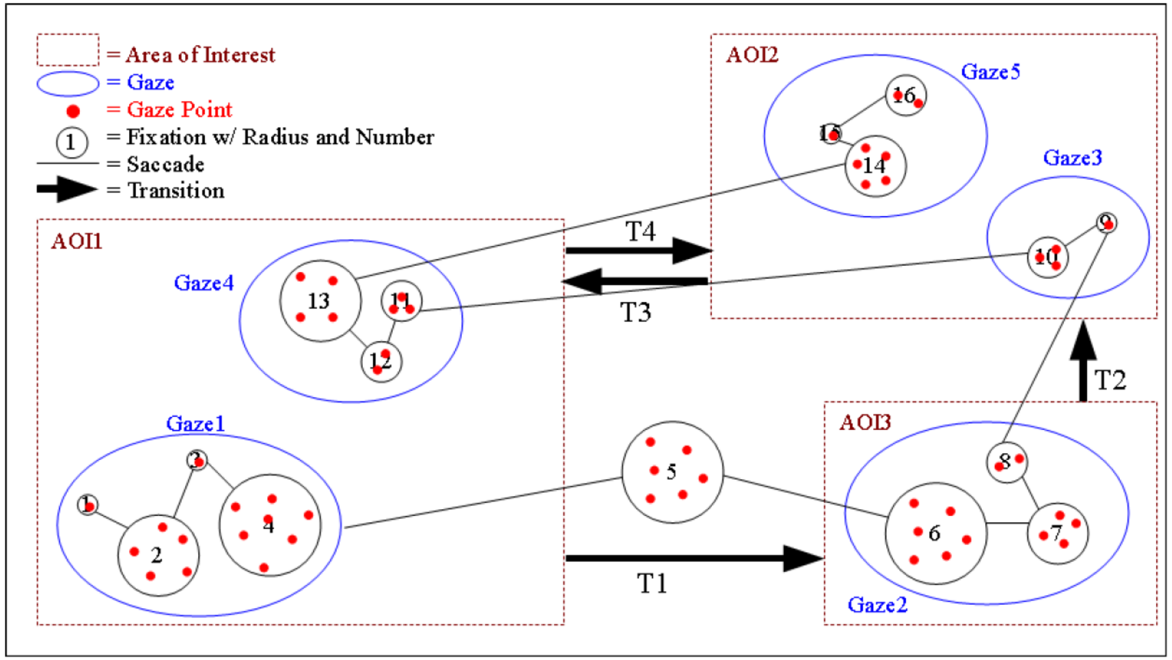


Eye Tracking Metrics

- Gaze points
- Fixations
- Gazes
- Areas of Interest

- Saccades
- Transitions

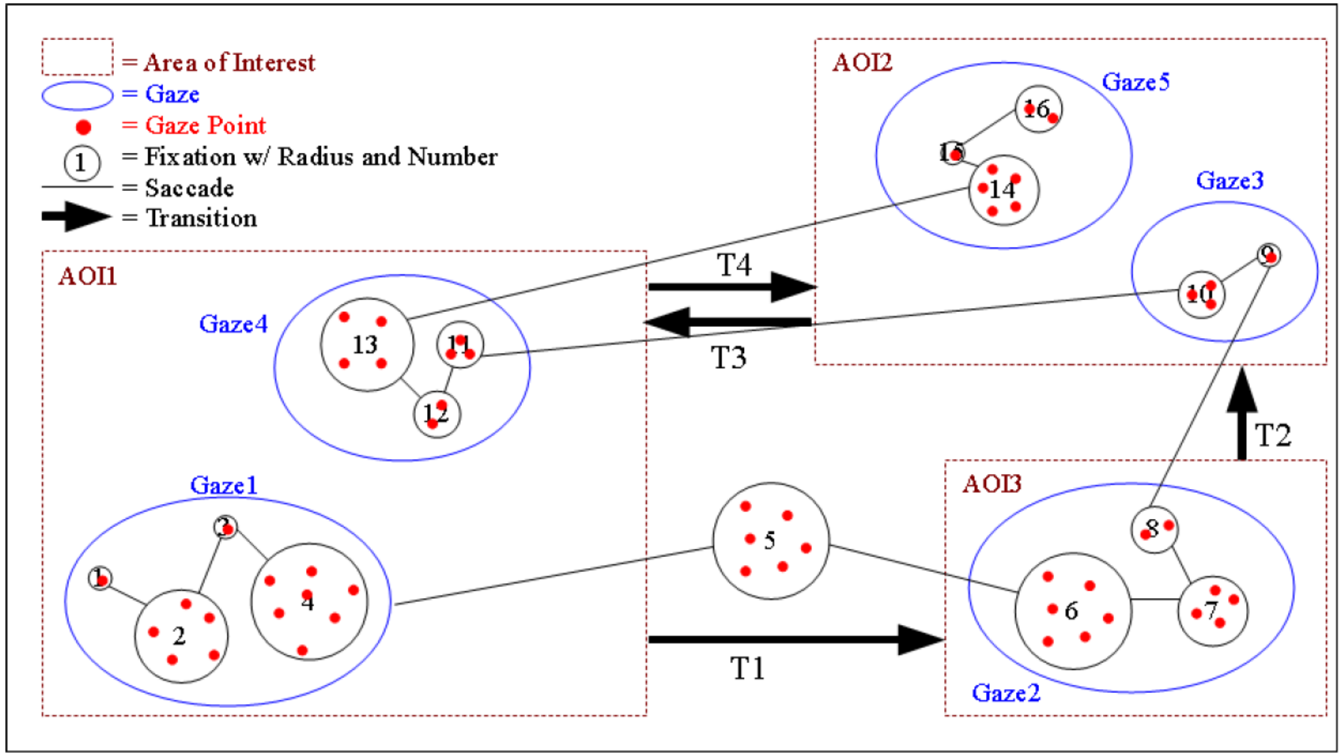
- Scanpaths



➔ **Inherent spatio-temporal nature**

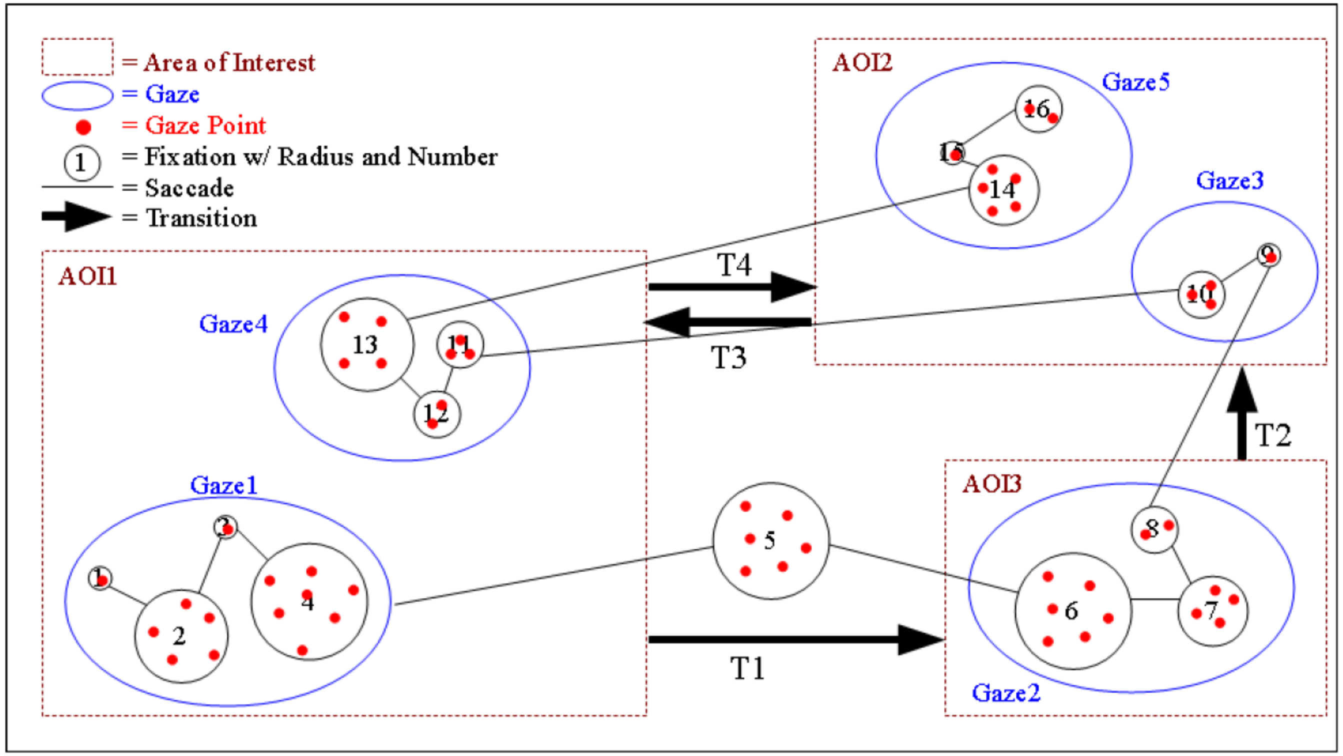
Eye Tracking Metrics

- Gaze points are spatially and temporally aggregated into fixations.



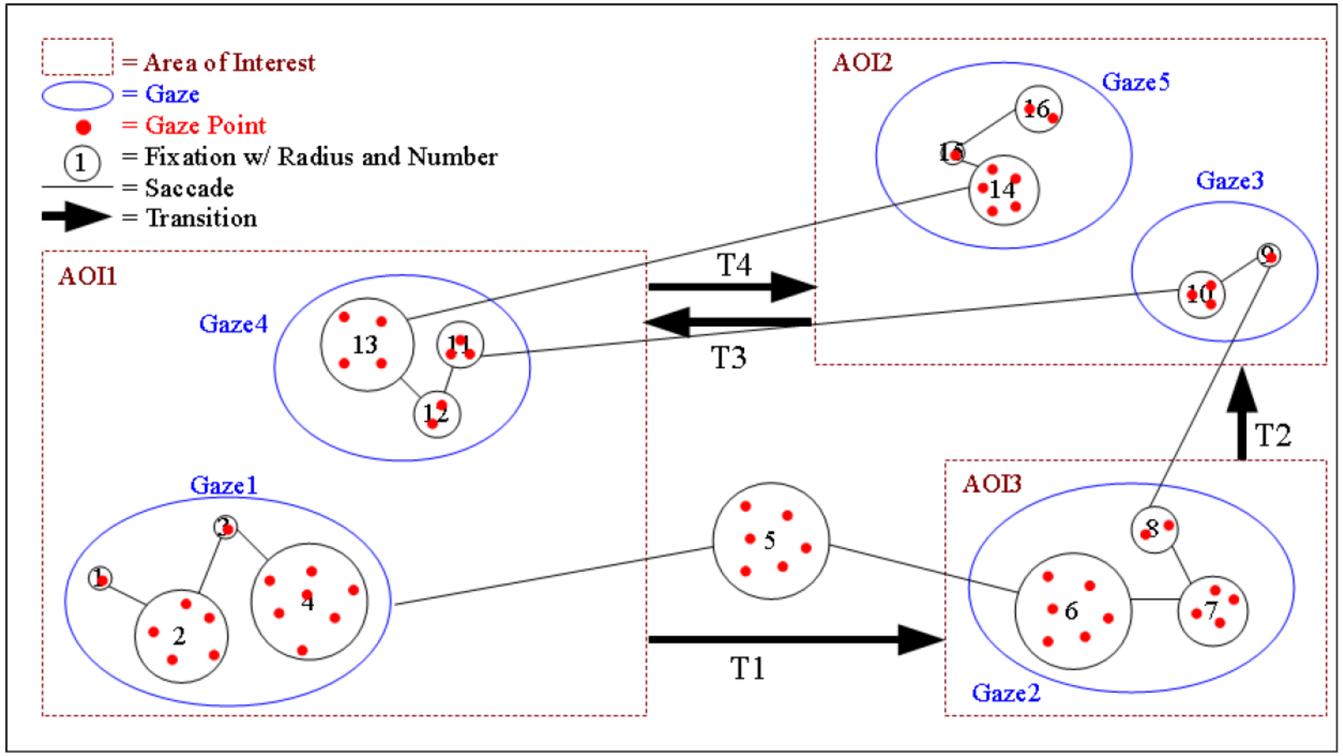
Eye Tracking Metrics

- Fixations are connected by saccades and have a certain duration represented by the radius.



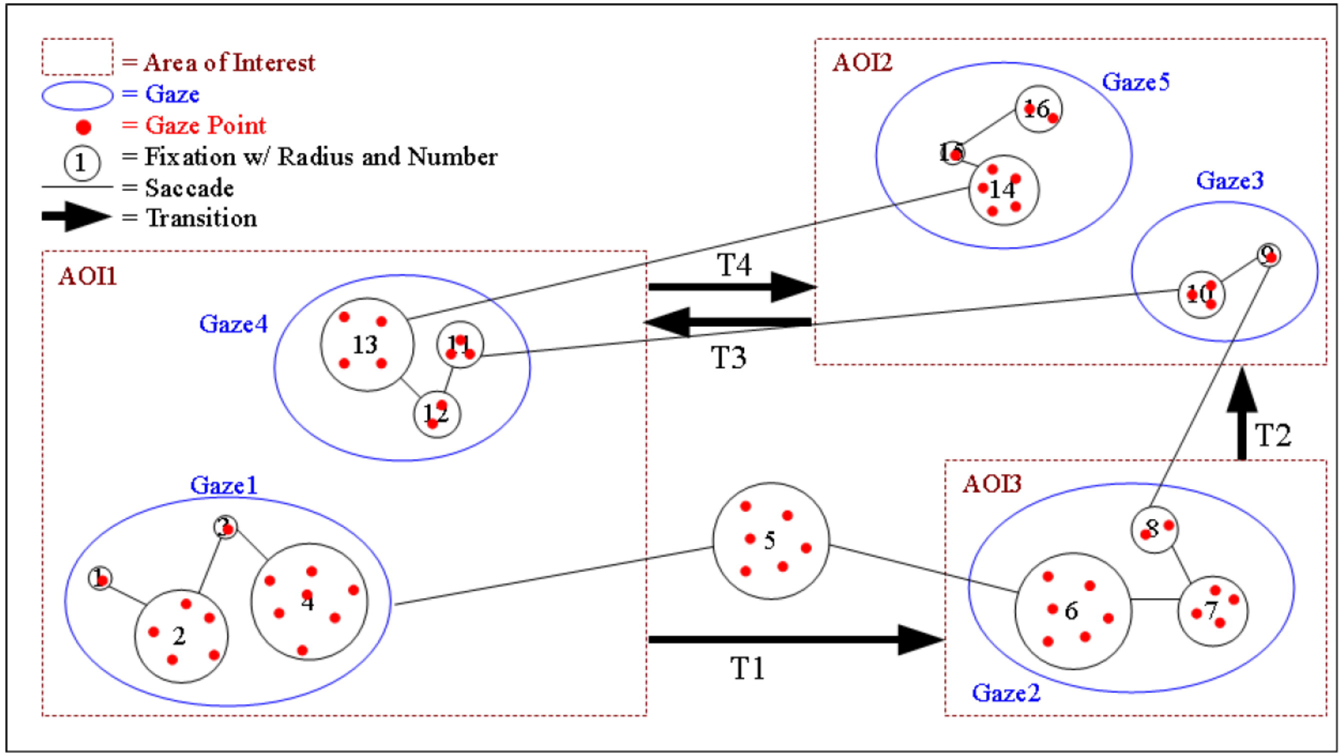
Eye Tracking Metrics

- A temporal order of fixations is a gaze, however, only if the fixations are within an AOI.



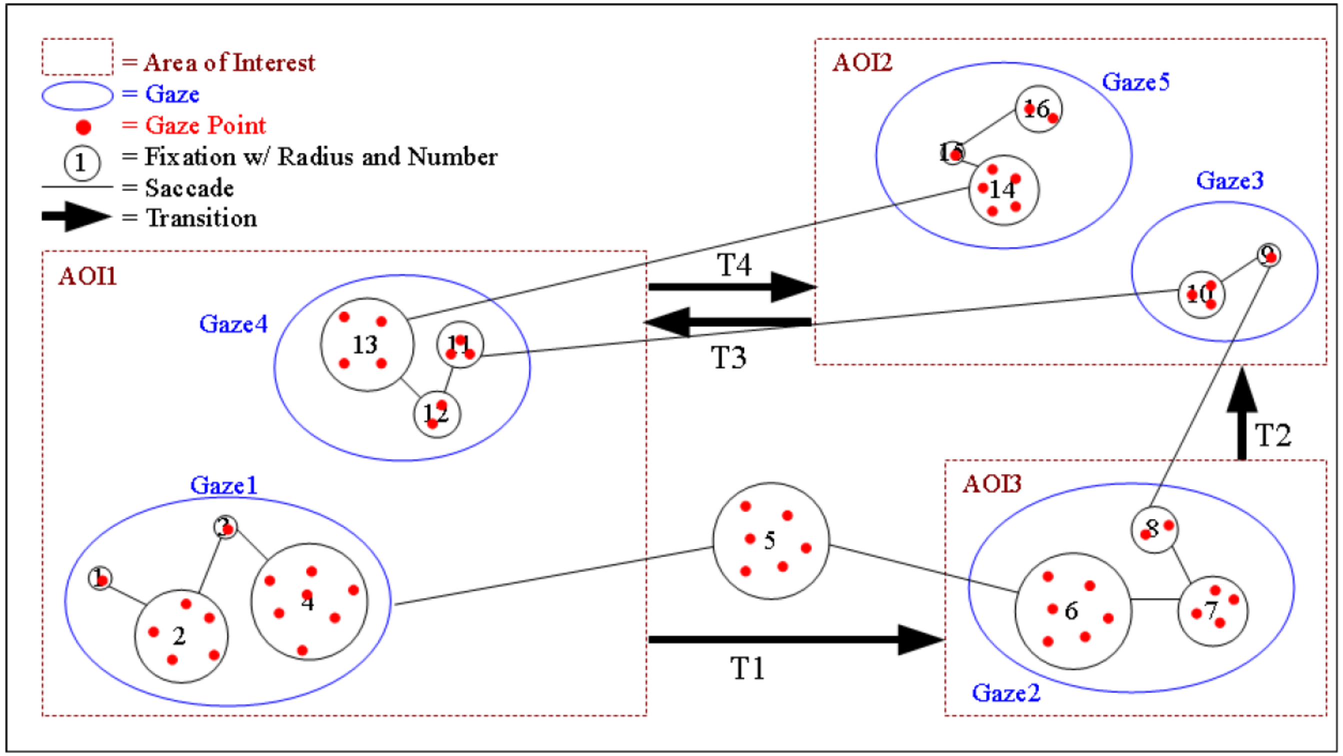
Eye Tracking Metrics

- An AOI is a region of specific interest on the stimulus.



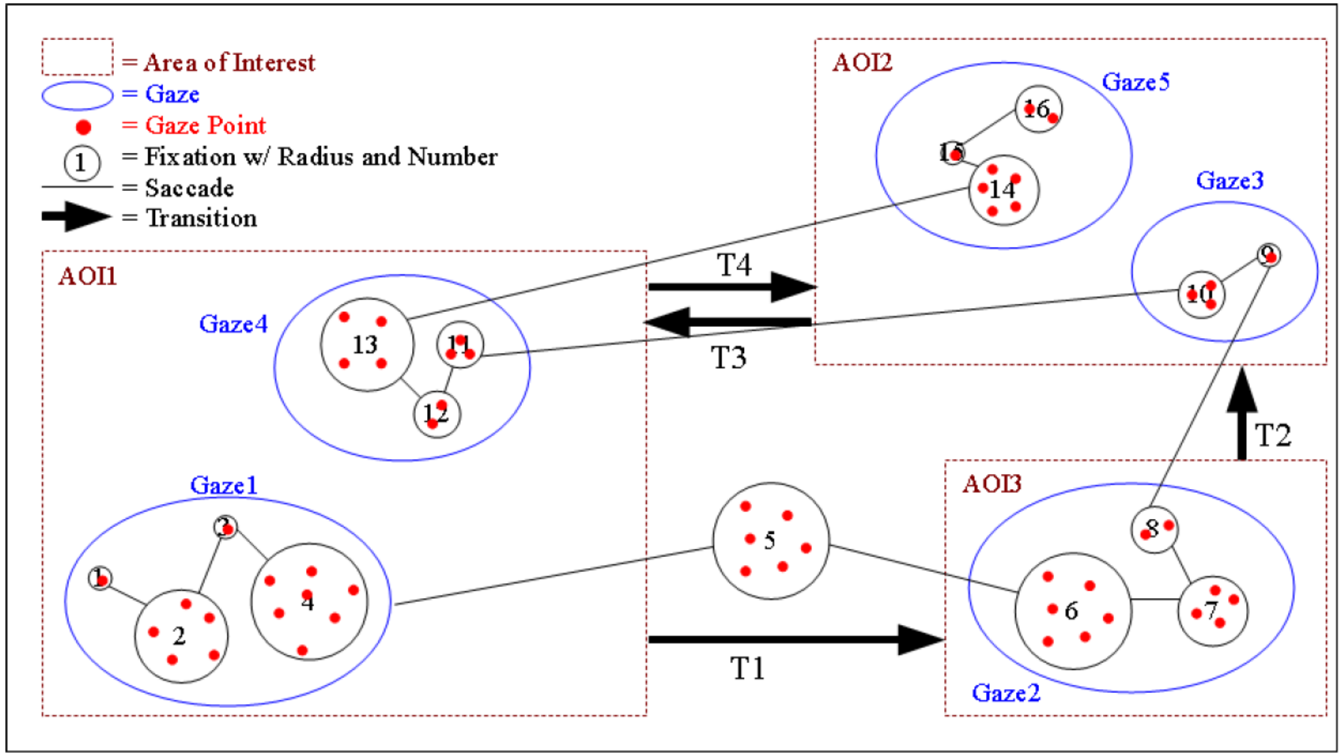
Eye Tracking Metrics

- A saccade from one AOI to the next is called a transition.



Eye Tracking Metrics

- A complete sequence of fixations and saccades is called a scanpath.



Eye Tracking Metrics

➔ Space and time dimensions make statistical evaluation of the data more complicated

Example Scenario: Metro Map Design

- Michael Burch, Kuno Kurzhals, and Daniel Weiskopf
  Visual Task Solution Strategies in Public Transport Maps
  Eye Tracking for Spatial Research 2014

Goal

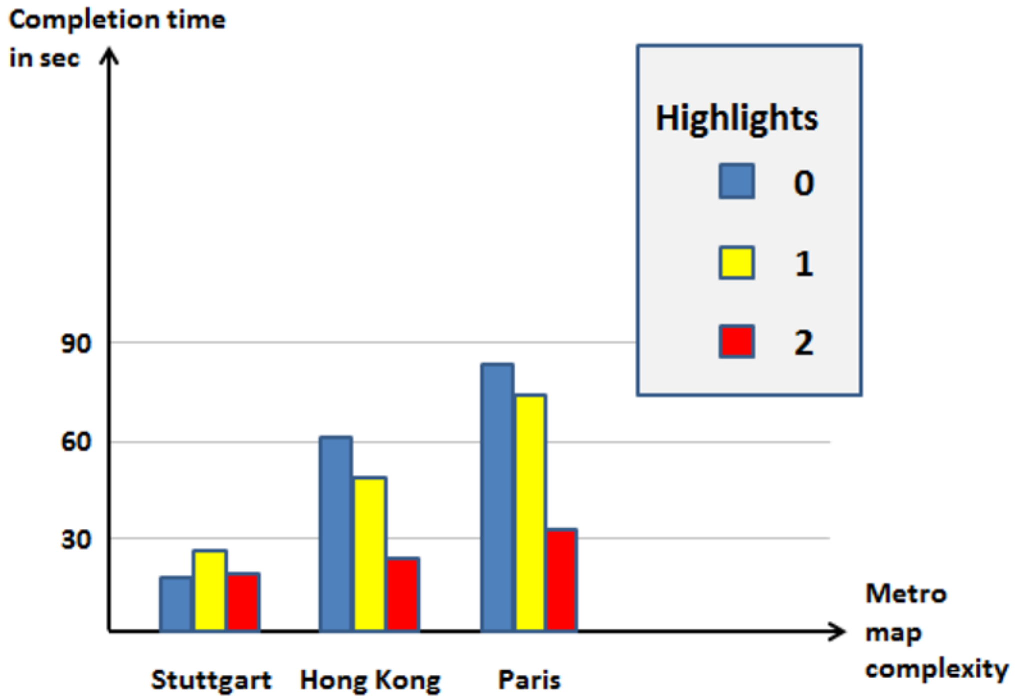
Understand how people read metro maps

Example Scenario: Metro Map Design

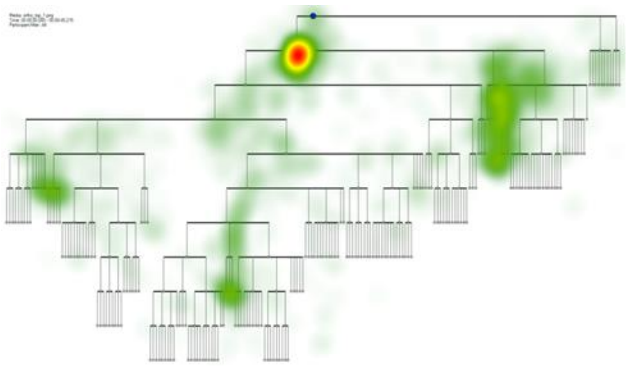
- Stimuli: Public transport maps/Metro maps
- Independent variables: Map complexities/station highlights
- Task: Find a route from a start to a destination station

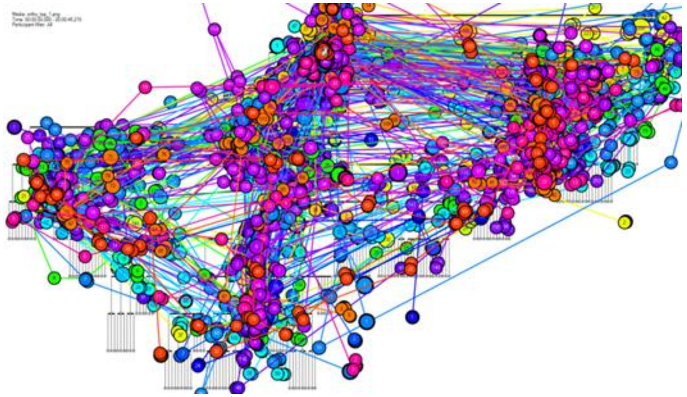
Example Scenario: Metro Map Design

- Results on completion times and error rates



Traditional Information Visualization Techniques

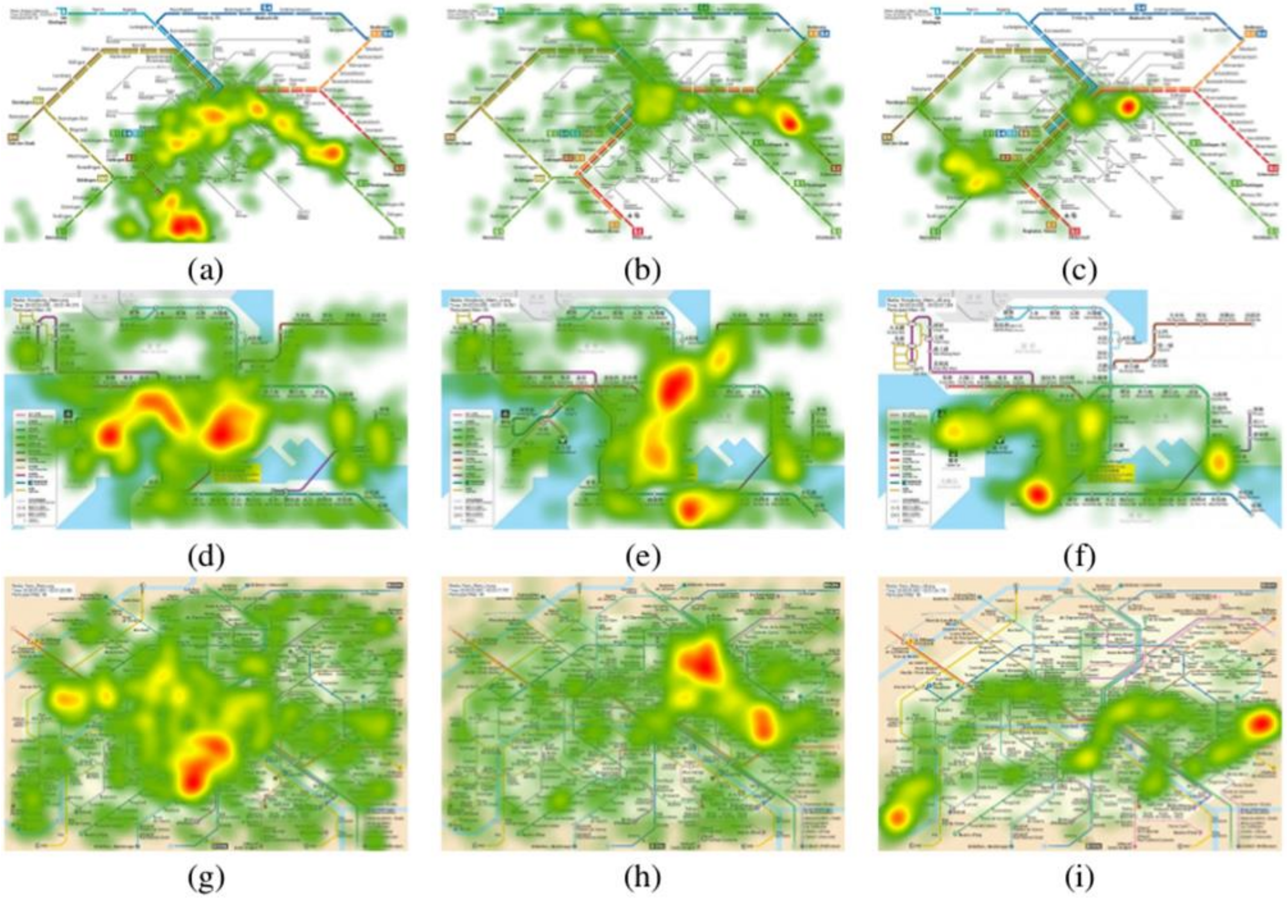




Heat map vs. Gaze plot

Example Scenario: Metro Map Design

- Results on reading strategies



Example Scenario: Metro Map Design

- Identified visual task solution strategy
  - 1.) Searching and locating start and destination stations
  - 2.) Finding a geodesic path between start and destination stations
  - 3.) Building a set of possible metro lines
  - 4.) Estimating possible interchange points
  - 5.) Partially solving the route finding task between interchange points
  - 6.) Cross checking the complete found route

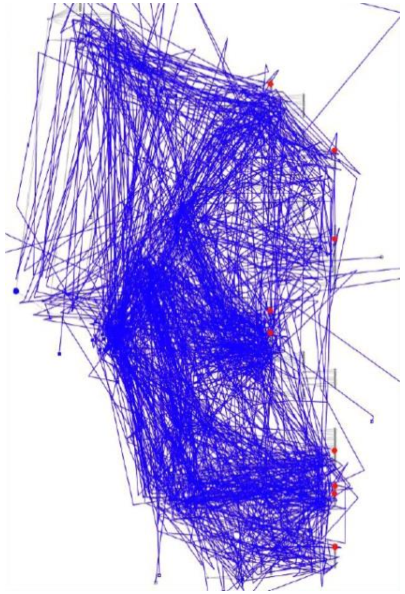
Mining Eye Movement Data

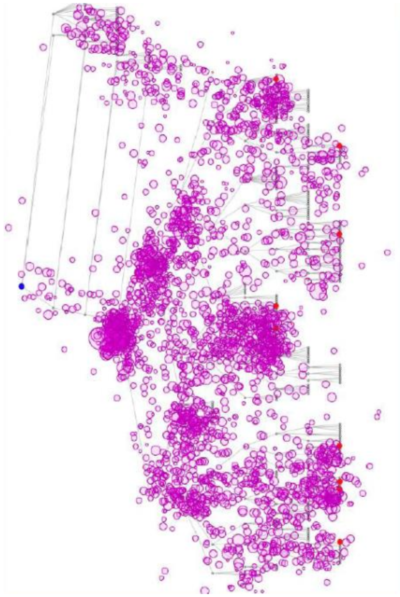
Why Visual Analytics for Eye Tracking Data?

- Complex and large data
  - Gaze information, fixations, saccades
  - Spatiotemporal data
  - Participant groups
  - AND: Stimulus data (spatiotemporal as well)

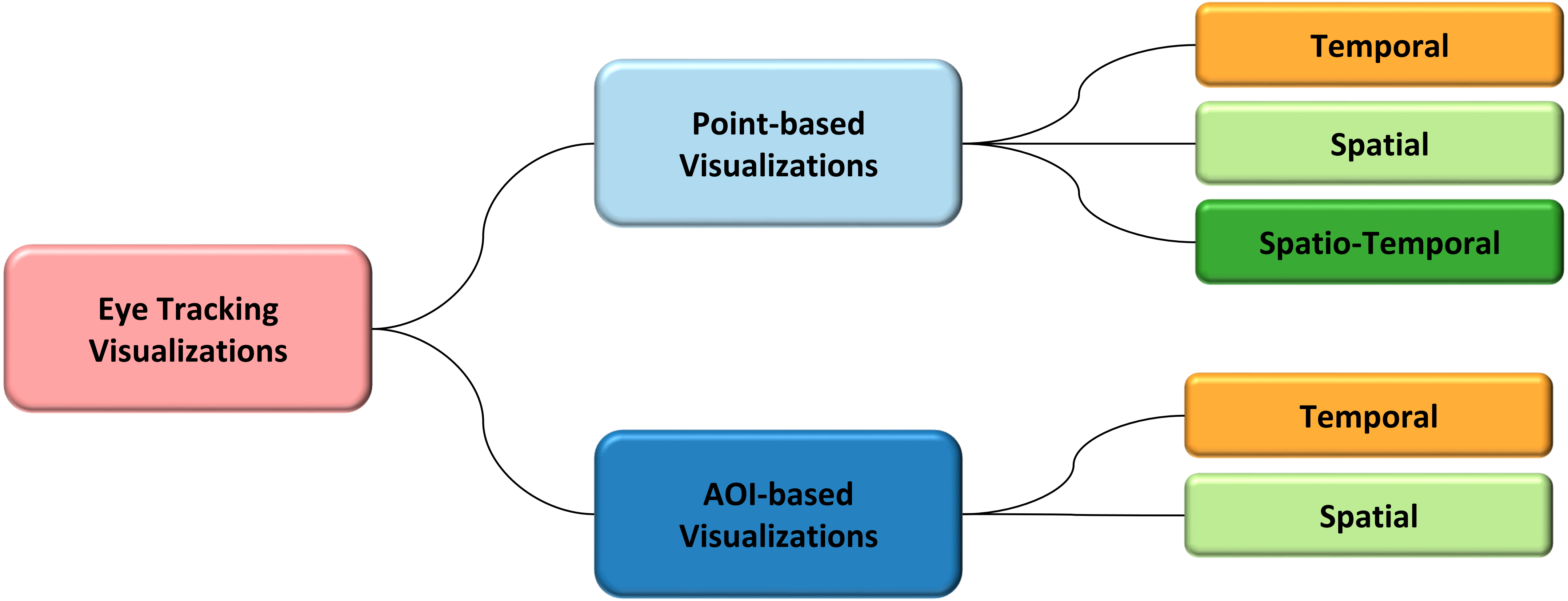
- Visualization alone may fail
- Automatic or statistical analysis less suited for data exploration and hypothesis building

➢ Combine best of both worlds!



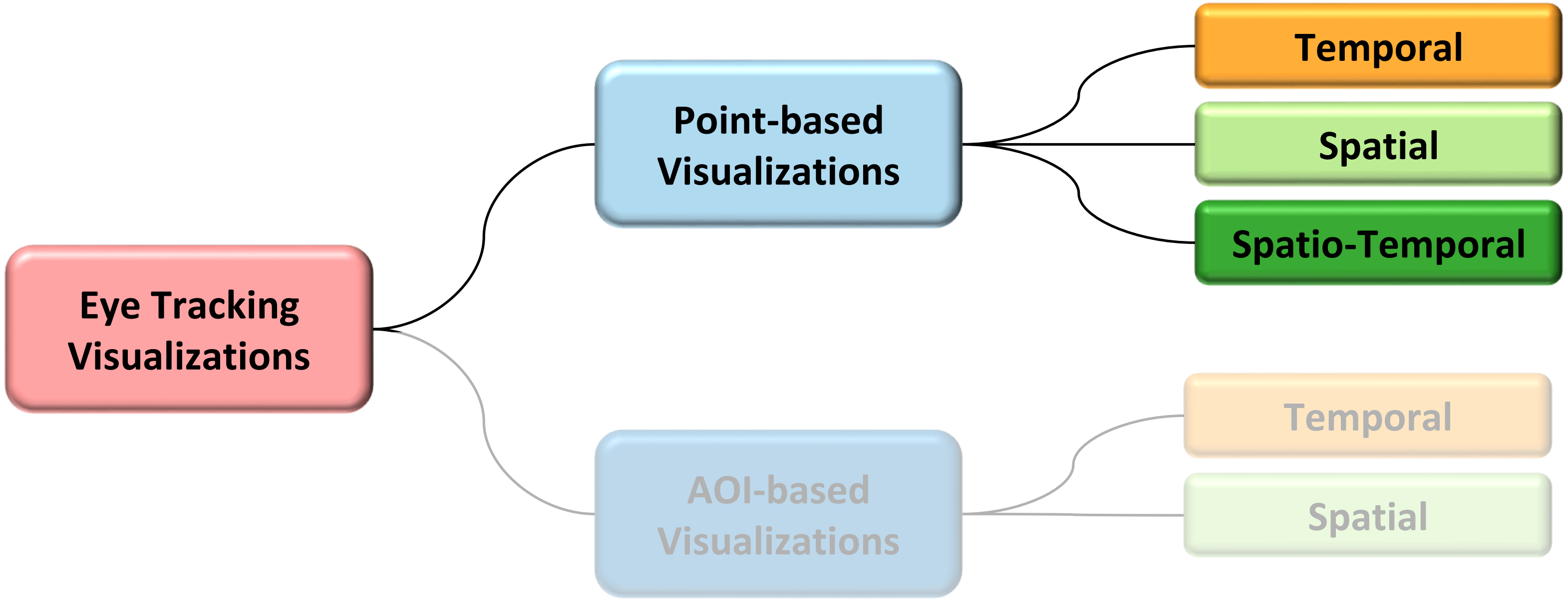


Revisiting: Classification of Eye Tracking Visualizations



Space-Time Visual Analytics

- Focus on point-based aspects
- Focus on spatio-temporal information
- Include (dynamic) stimulus



Space-Time Visual Analytics

- Static overview
- Data mining and computer vision
  - Shot detection
  - Gaze clustering
- Interaction
  - Density filter
  - Cluster size filter
- Multiple coordinated views

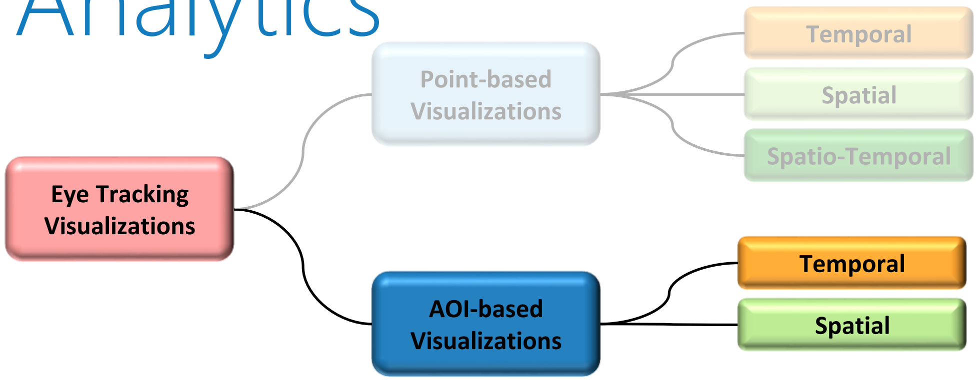
[Kurzhals and Weiskopf 13]

Space-Time Visual Analytics

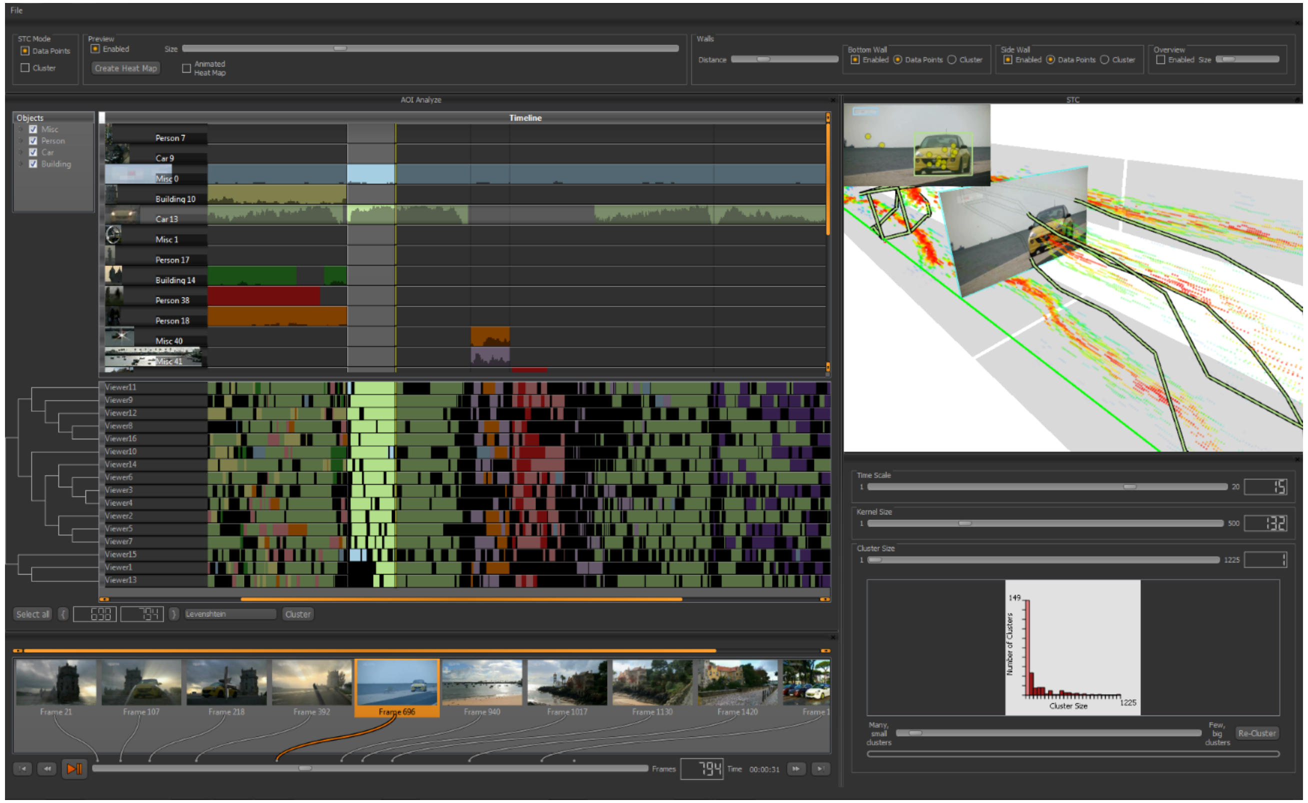
- Other components
  - Bee swarm
  - Heat maps
    - Static
    - Dynamic
    - Motion compensated
  - 3D scanpaths

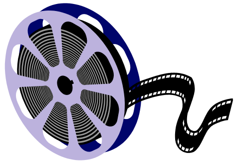
[Kurzhals and Weiskopf 13]

Complementary AOI-Based Visual Analytics



- AOI definition
- Hierarchical clustering of AOI scan paths
- Scarf plots

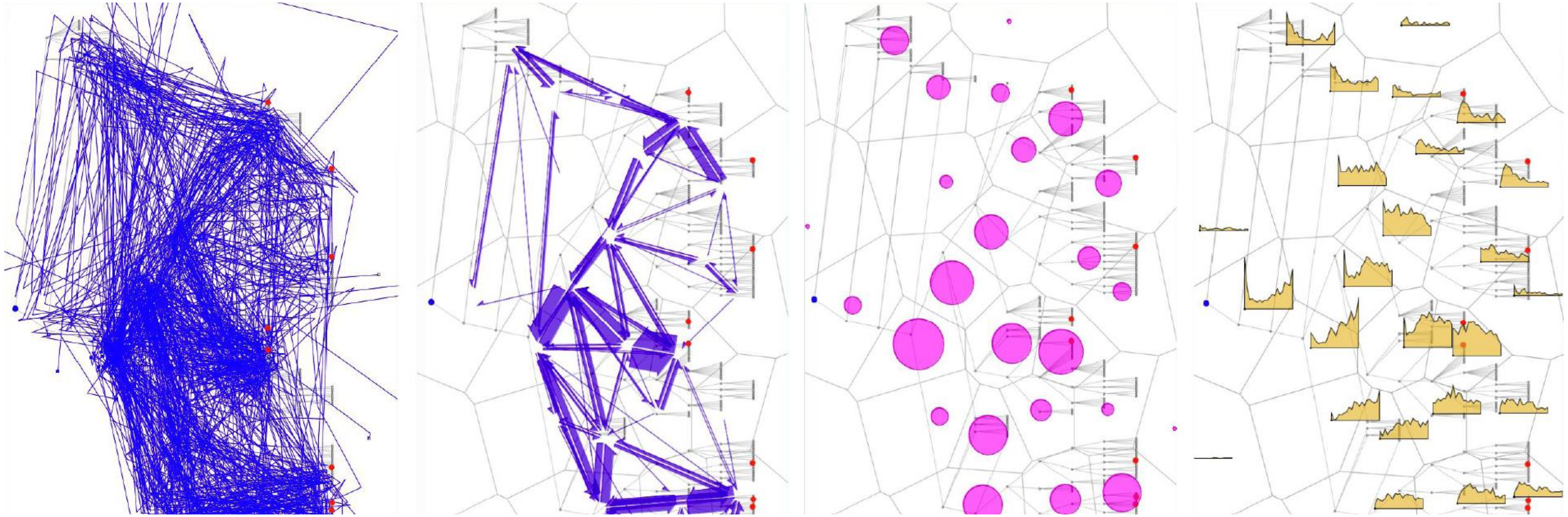




[Kurzhals et al. 14b]

Geospatial Visual Analytics for Eye Tracking

- Additional analytical techniques?
- Can we make use of existing visual analytics techniques from GIScience?



[Andrienko et al. 12]

Characteristics of Data and Analysis Tasks

- Commonalities between eye tracking and geospatial data:
  - Importance of 2D space and spatial relationships
  - Temporal evolution
  - Trajectories (movement) as highly relevant pieces of information
  - Groups of multiple moving objects / participants’ gaze
- Differences:
  - Instantaneous jumps (saccades) over relatively long distances
    - Intermediate points between the start and end positions less meaningful
    - No interpolation
  - Linking to underlying stimulus

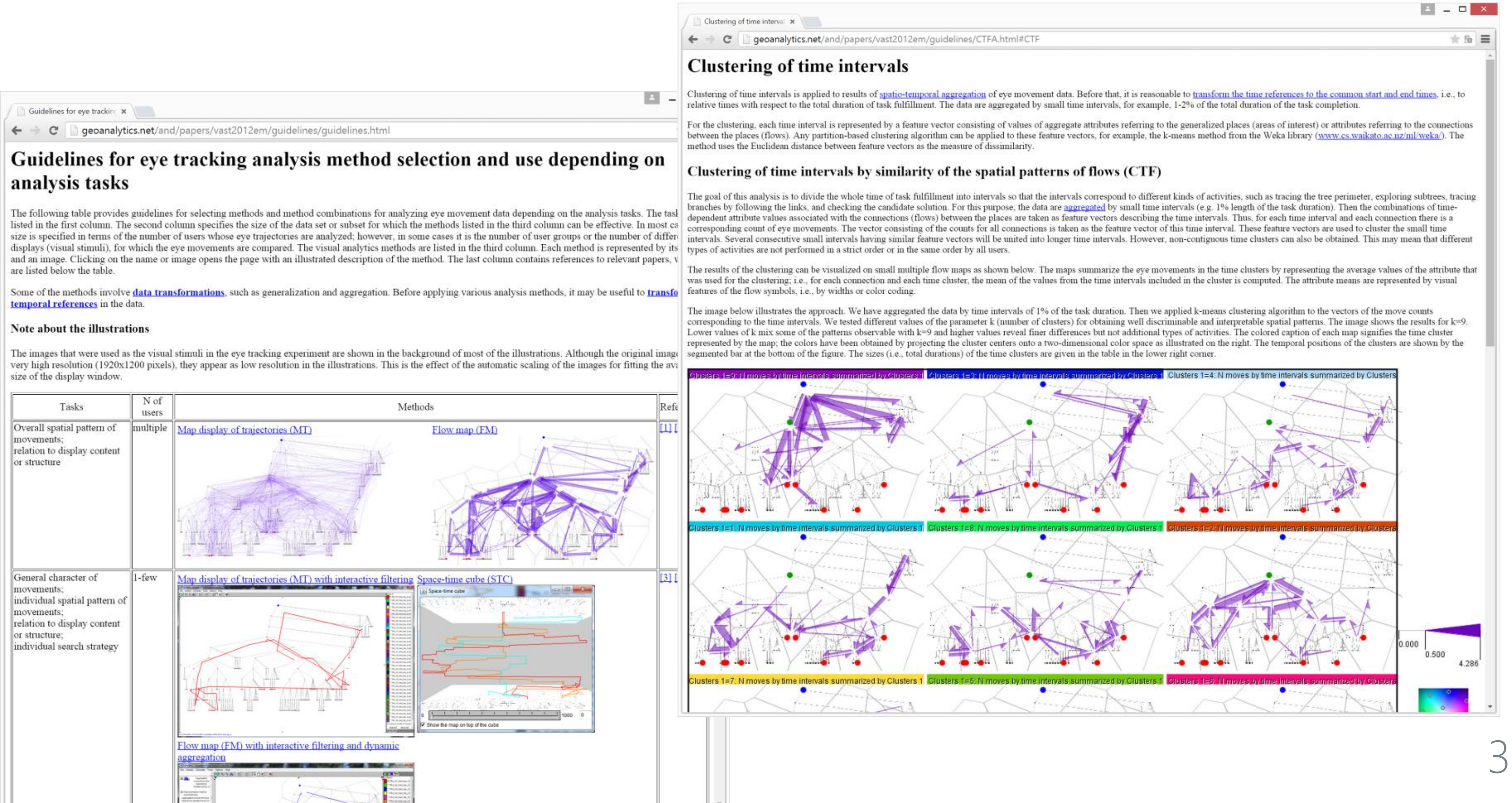
More Details on Tasks in Eye Movement Analysis

- Attention distribution:
  - What areas attract user's attention? How much attention?
  - Does the user find predefined 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?

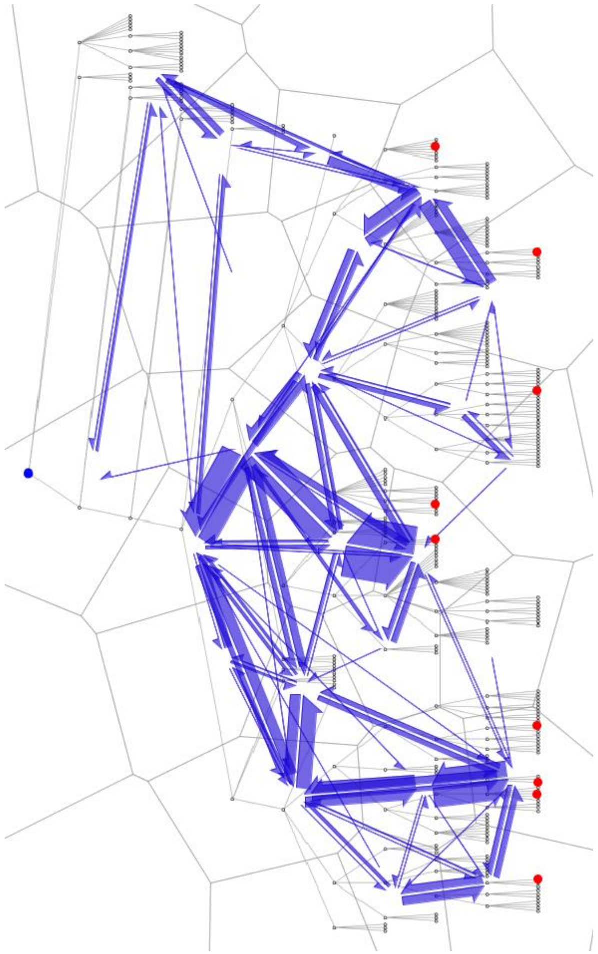
Guidelines

- Some geospatial visual analytics techniques carry over, others do not
- Guidelines: http://geoanalytics.net/and/papers/vast2012em/index.html [Andrienko et al. 12]



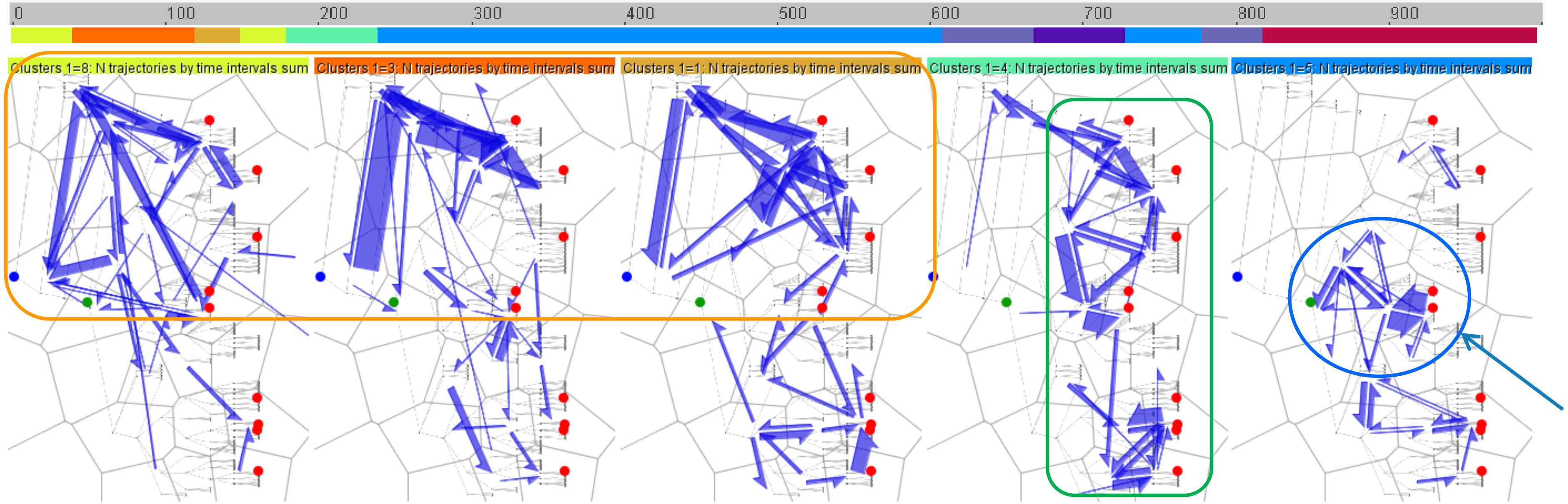
Example: Eye Tracking Study on Tree Visualization

- Study: readability of variants of node-link tree visualization [Burch et al. 11]
- Visual analysis of the gaze data [Andrienko et al. 12], [Burch et al. 13]



[Andrienko et al. 12]

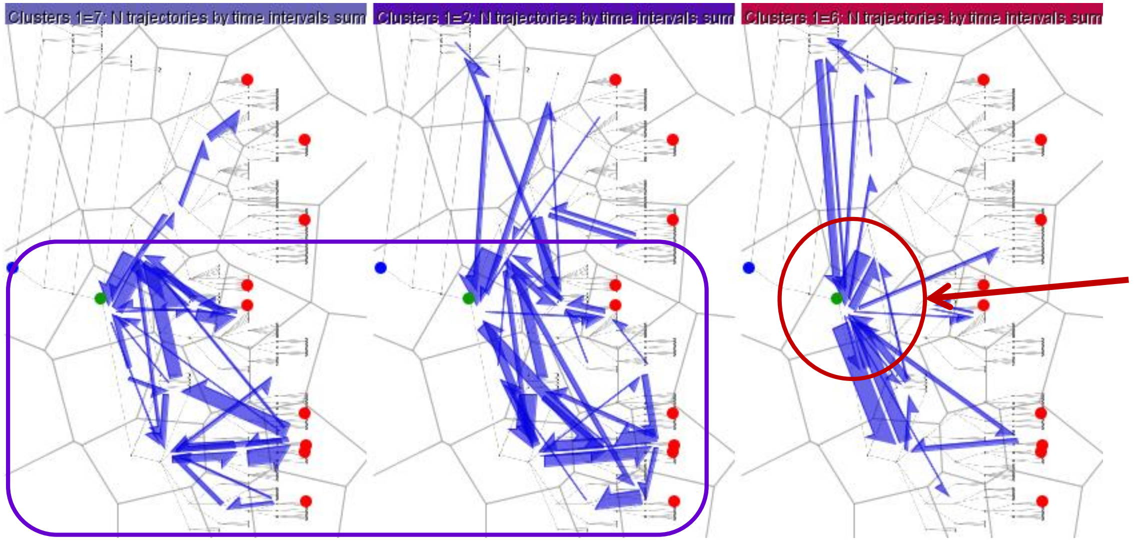
Eye Movement Patterns Over Time



We can infer types of users' viewing activities

Loss of time!

Time intervals clustered according to similarity of the aggregated eye movements

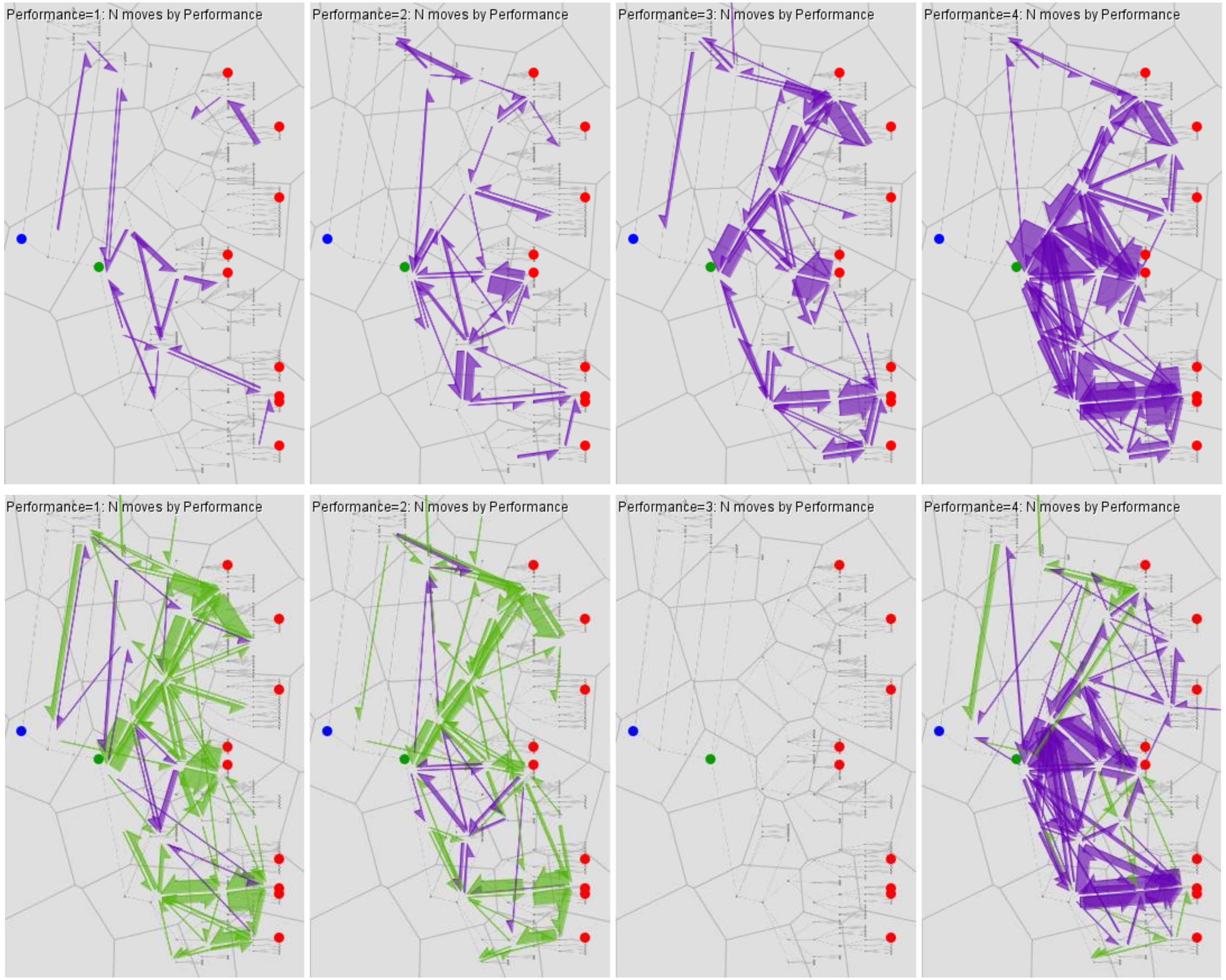


Target!

Comparison of Fast and Slow Users

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

Differences to group 3



From Laboratory to the Real World

- Properties of stimuli
  - Static 2D
    - Traditional InfoVis studies
  - Dynamic
    - videos, animations
  - Interactive
    - Web pages, GUIs, Visual Analytics systems
  - 3D scene, free exploration
    - Car driving, shopping, sports events

From Laboratory to the Real World

- Additional data sources
  - Electroencephalography (EEG)
  - Pupil dilation
  - Galvanic skin response (GSR)
  - Motion tracking
  - Functional magnetic resonance imaging (fMRI)
  - Verbal data
  - Mouse and keyboard interactions
  - Personal data from social networks
  - …

➔ Big Eye-Movement Data Visual Analytics

From Laboratory to the Real World

- 3 future scenarios
  - Car driving
  - Sports event
  - Shopping

Fig. 4. User wearing eye tracking glasses in a supermarket shopping task.

Future Challenges

THE PAST, PRESENT, AND FUTURE OF EYE TRACKING WITH RESPECT TO HARDWARE, COSTS, STIMULI, USERS, RECORDED DATA AND METRICS, AND EVALUATION METHODS.

	Past	**Present**	**Future**
Hardware & Costs	Stationary Eye Tracking Devices (Self made)	Professional Glasses (>\$30 000) Low-cost Remote Eye Trackers (\$99)	Smart Phones and Personal Eye Tracking Glasses
Stimuli	2D static stimuli (images)	2D/3D dynamic stimuli (virtual reality, video)	unconstrained real-world scenarios
Users	<10	10 to 500	>1,000,000
Recorded Data and Metrics	fixation and saccades	video, high-resolution gaze data (smooth pursuits)	numerous additional data sources
Evaluation Methods	Visual inspection	Statistics & Visualization	Big Data Visual Analytics

References

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