CO-213

A CONCEPTUAL FRAMEWORK TO REPRESENT MOVEMENT PATTERNS THROUGH VISUALIZATIONS OF NETWORK-CONSTRAINED MOVEMENTS

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ABSTRACT

In order to break down the complexity of visualizing network-constrained movements, this paper tries to systematically organize data, movement patterns derived from the change of data elements and visual representations through locational, attribute and temporal perspectives. A systematic structure, taking into account all the elements in networks and movements and the relationship among each other is provided. The proposed conceptual framework, which combines a visual problem-solving approach with an interactive visualization environment, outlines a road map to develop visual representations of network-constrained movements to support movement pattern analysis.

KEYWORDS

Movement; geographic network; movement pattern; visualization solution

1. INTRODUCTION

With the recent developments in positioning and tracking technologies, increasing amounts of data on movements are accumulated. Movement describes trajectories made by change in location of an moving object over time while the object maintains the same identity (Yuan & Hornsby, 2008), and moving objects are entities whose positions or geometric attributes change over time (Dodge et al., 2008). The top layer in Figure 1 gives an example of a moving object and its trajectory.

Movements occur in space, as free flow (e.g. hurricanes), or constrained by networks (e.g. trains). A network is a set of nodes interconnected by segments; networks can be categorized into two major groups: geographic and virtual networks. Geographic networks are spatial connectivity systems that carry flows of moving objects (Abler et al., 1972). These flows use either a fixed infrastructure such as roads (see the middle layer in Figure 1) or vague connections such as maritime routes. Virtual networks focus on the relationship and interactions between objects in non-geographic space, including communication networks and social networks. Geographic networks concentrate on the geographic structure of, and movement along, the network. This paper will discuss movement associated with geographic networks (further called network-constrained movements). The focus is on moving objects (i.e. vehicles, drivers, pedestrians) along road networks (see the lower layer in Figure 1).

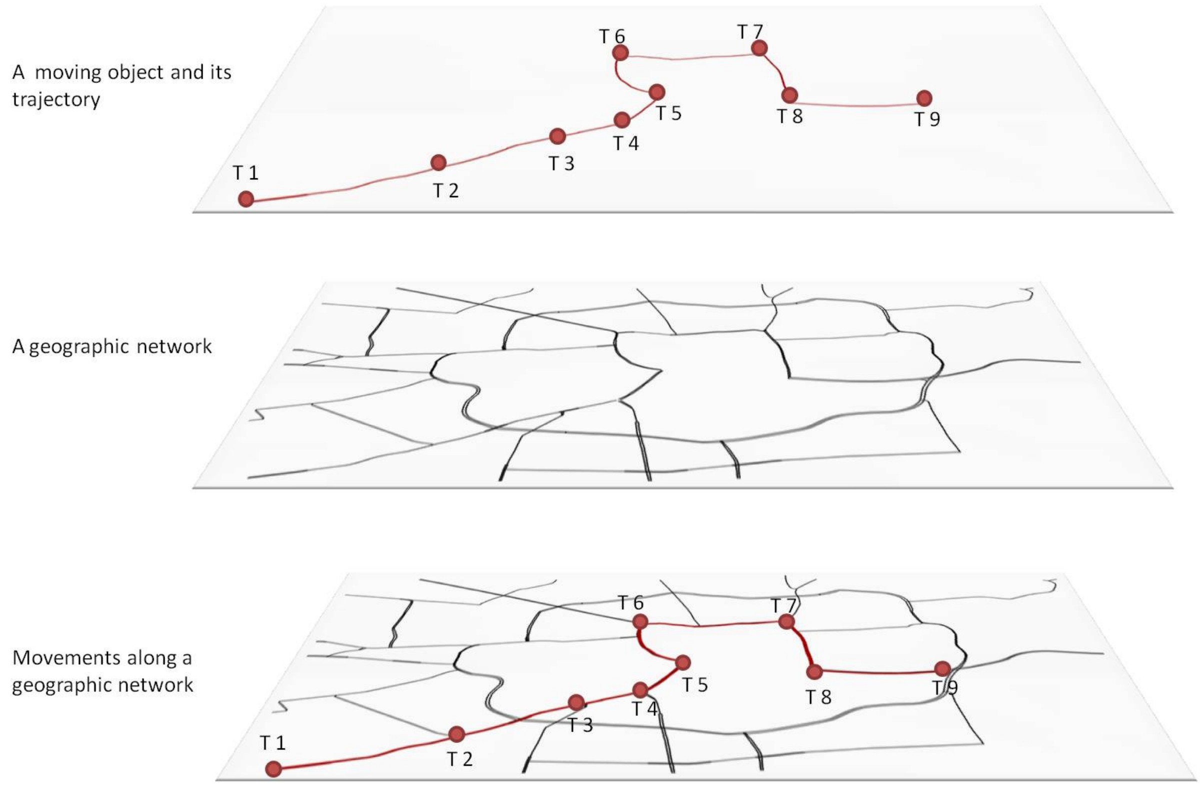


Figure 1 Movements and networks: The top layer shows a trajectory of a moving object; the middle layer shows a geographic network; the lower layer shows the combination of the trajectory and its associated geographic network

Movements along geographic networks result in various movement patterns. Generally, movement patterns include any identifiable spatial and temporal regularity or any interesting relationship between moving objects (Dodge et al., 2008). Correctly recognizing the movement patterns can help to understand the spatio-temporal behaviour of moving objects in different application domains, such as in crowd gathering (Janoos et al., 2007), animal migration (Grundy et al., 2009), or transport management (Jiang & Liu, 2009). A necessary prerequisite for observers/users to make sense of movement patterns is to be able to identify and distinguish between different types of movement patterns. Therefore, some researchers attempted to define classifications of movement patterns (Yattaw, 1999; Erwig, 2004; Andrienko et al., 2008; Dodge et al., 2008).

The high data volume, the interpretation of the data and recognition of patterns have stimulated researches to try to tackle the problem from different domains, like databases (Schneider, 2009), data mining (Giannotti & Pedreschi, 2008) and visual analytics (Andrienko & Andrienko, 2007). Throughout these approaches, visualization plays an important role because patterns in massive data on networks and movements are very difficult to understand without some form of visual representations. It may be argued that the detection of movement patterns should use methods like data mining instead of visualizations, however suitable visual representations could greatly enhance human’s perception and cognition. This paper postulates that the approaches are complementary, not exclusive. Visualizing data on movements or results of data mining can both help to understand the movement patterns. Therefore, many researches use visualization methods to facilitate identification of various types of patterns (e.g. Buliung & Kanaroglou, 2004; Andrienko et al., 2007).

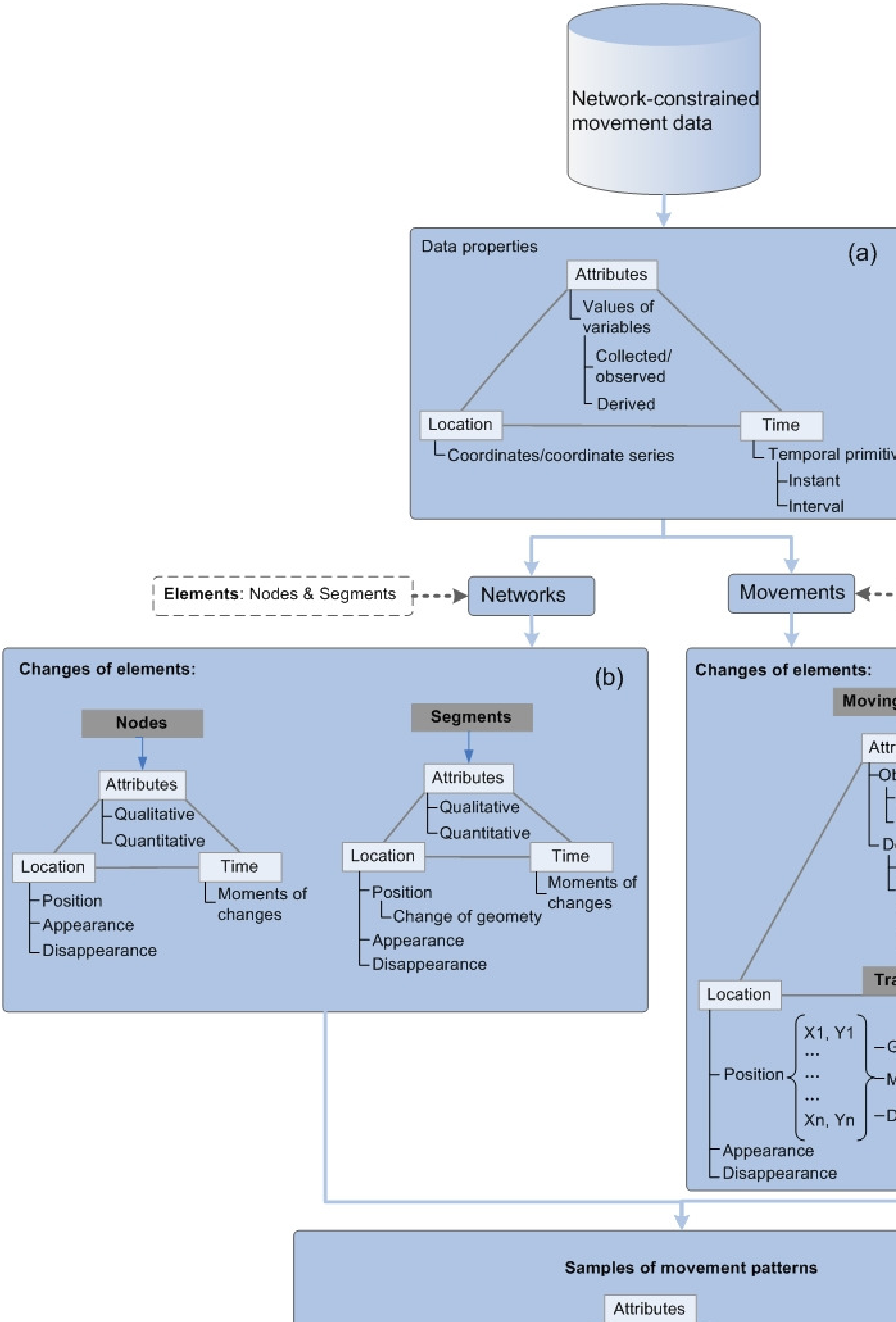
This paper proposes a conceptual framework to design visual representations in order to identify or compare different movement patterns and help users to visually solve their domain problems. Many visualizations of geographic networks, movements and movements associated with geographic networks exist. Many examples can be found at VisualComplexity.com (Woolman, 2005). But for a systematic design approach, questions have to be answered like: What are the characteristics of network-constrained movement data? What’s the relationship between data elements in networks and movement? What visualization methods could help to visually identify movement patterns? How to visualize movement data in order to identity and compare the different movement patterns? How to reduce complexity in visualizing network-constrained movement data?

This paper focuses on answering these questions. The remainder of the paper is organized as follow: It starts with an investigation of data properties, characteristics of network-constrained movements and movement patterns (section 2), followed by a proposed conceptual framework to help users tackle the problems using visual assistance in section 3. The aim is to break down the complexity of steps to be taken in selecting suitable cartographic representations. The framework includes a visual problem solving approach as well as a classification of network/movement visualizations according to the cartographic representation from a locational, attribute and temporal perspective. The paper ends with a conclusion and future plans (section 4).

2. NETWORK-CONTRAINED MOVEMENTS AND MOVEMENT PATTERNS

Network-constrained movement data are complex because multiple elements are involved: nodes and segments of networks and the moving objects. These data elements can be stored and visually represented as either points or lines. The data can be described from the locational, attribute, and temporal perspectives according to the pyramid model developed by Mennis et al. (2000). This structure will guide the discussion on data properties, changes of each data element and movement patterns from locational, attribute and temporal perspectives (Figure 2).

Data on networks and data on movements have properties in common (see Figure 2-a). These are the geographic coordinate(s) from the locational perspective, the collected/observed/derived data values from the attribute perspective, and temporal instants/intervals from the temporal perspective.



Network-constrained movement data
Data properties
(a)
Attributes
Values of variables
Collected/ observed
Derived
Location
Coordinates/coordinate series
Time
Temporal primitiv
Instant
Interval
Elements: Nodes & Segments
Networks
Movements
Changes of elements:
(b)
Nodes
Attributes
Qualitative
Quantitative
Location
Position
Appearance
Disappearance
Time
Moments of changes
Segments
Attributes
Qualitative
Quantitative
Location
Position
Change of geomety
Appearance
Disappearance
Time
Moments of changes
Changes of elements:
Moving
Location
Position
X1, Y1
Xn, Yn
Appearance
Disappearance
Samples of movement patterns
Attributes

Figure 2 Network-constrained movement data: (a) data properties; (b) changes of elements in networks; (c) changes of elements in movements; (d) samples of movement patterns could be produced by changes of networks and/or movements

Nodes and segments in networks can change over time (Figure 2-b). From the locational perspective, they both can appear and disappear. Their position and the geometry of segments can change as well. From the attribute perspective, the qualitative and/or quantitative values can change. And the moments of these changes are recorded from the temporal perspective. These changes of elements result in change of geometry and structure of the network, and therefore influence the trajectories of the objects that move along the network. For example, by temporally blocking some road segments, the vehicles that planned to pass through these segments have to change their paths as well.

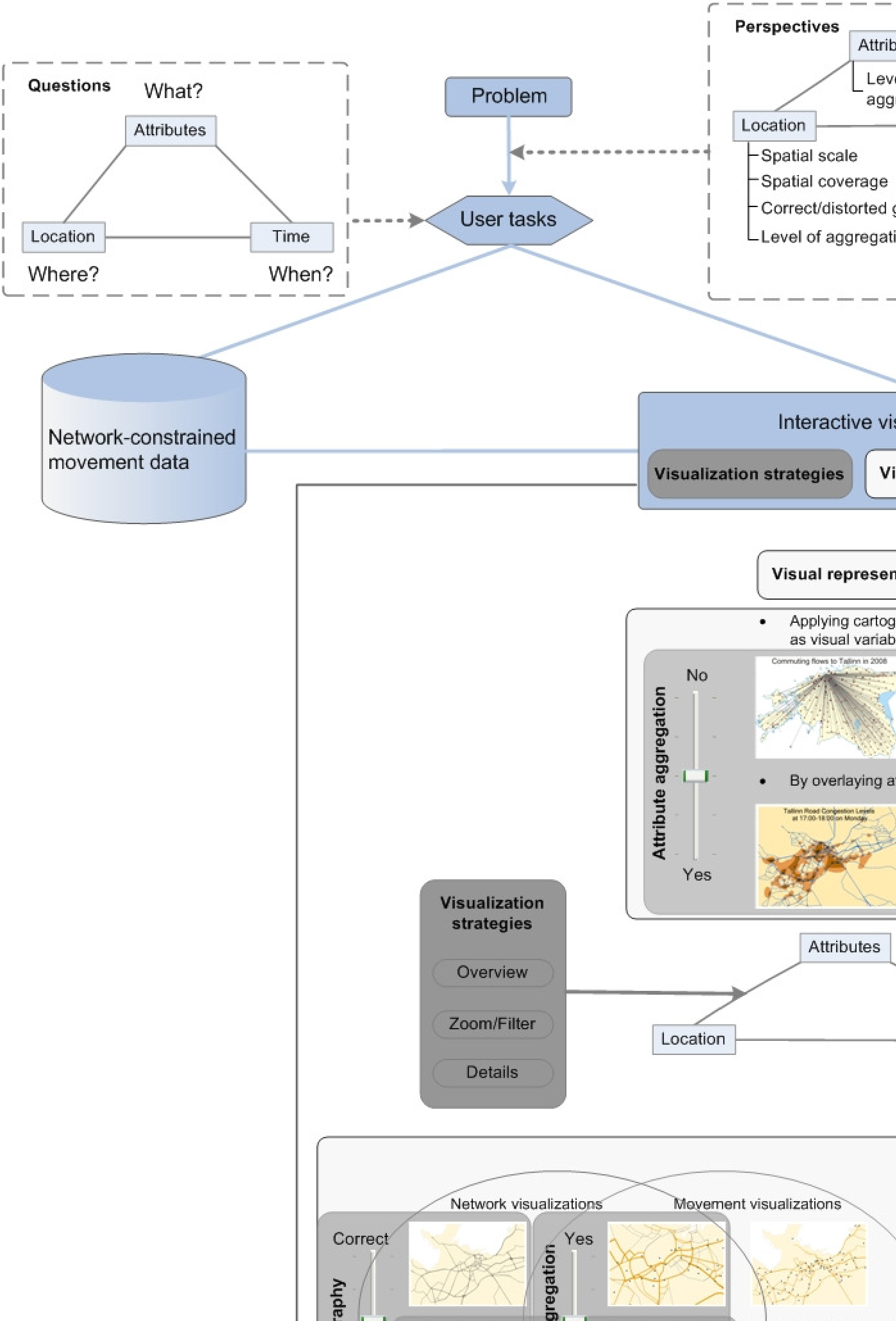
The locational, attribute and temporal changes of moving objects are more frequent than the changes of networks. As long as objects move along a network, data on movements change, even if the network does not change (Figure 2-c). When the geographic position of an object changes over time, a series of coordinates of the moving object can be recorded. These define a trajectory, with its geometric shape, movement distance and directions. In addition, the moving objects could appear/disappear. From the temporal perspective, whenever an object moves, the moments of change are observed at certain intervals and recorded as such. From the attribute perspective, the observed qualitative (characteristic of moving objects) and quantitative values can change and additional attributes can be derived. These include speed, velocity and acceleration of movements.

From the changes described above movement patterns can be derived. To facilitate the detection of movement patterns by appropriate visual presentations, one should be able to recognize different types of patterns. The classification of movement patterns has been studied by several researchers (Erwig, 2004; Laube & Purves, 2006; Andrienko et al., 2008; Dodge et al., 2008). Based on their work, several samples of movement patterns have been selected according to the relevance to our study of network-constrained movements. The definitions of these patterns is found in (Andrienko et al., 2008; Dodge et al., 2008). They are classified into spatial, attribute, temporal and spatio-temporal patterns (as shown in Figure 2-d). Since the proper instantiation of patterns depends on the application domain, some examples in the context of traffic are provided to help the reader get familiar with them.

When two vehicles pass the same location in space at different times, it belongs to the *co-location in space* (spatial patterns). These same locations could be attained in the same order (ordered), in different orders (order-irrelevant) or in the opposite orders (symmetrical). If they meet exactly at same place at same time, it then could be recognized as *co-incidence in space and time* (spatio-temporal patterns). *Opposition* means drivers drive in opposite directions. *Constancy* patterns can be found when traffic toward a place remains the same during a time interval. *Sequence* patterns happen when traffic patterns occur in a specific order, such as traffic increase - constant heavy traffic - decrease - constant low traffic and so on. When these sequences occur every weekday, it causes the *repetition* pattern. *Isolated object* refers to an individual moving vehicle on the road and it does not influence other vehicles. *Symmetry* patterns refer to, for instance, the traffic increase in the morning and decrease in the evening in industrial areas, while there is traffic decrease in the morning and increase in the evening in the shopping and restaurant areas. *Propagation* patterns could be caused by the traffic lights on the road. When the light changes to red, the vehicles in front have to decrease the speed and stop, the other vehicles that follow have to decrease their speed little by little as well. *Convergence* and *divergence* patterns happen when all vehicles drive to or disperse from the same crossroad. *Fluctuation* patterns are formed when an accident causes irregularly in flow of movements. A *trend* can be found in the situation where the traffic tends to gradually decrease after 10AM and increase after 3PM. For the temporal patterns, a *synchronisation* pattern records similar changes of moving vehicles occurring at the same time (full) or with some delay (lagged). And for the attribute patterns, the *attribute-cohort patterns* refer to situations where the attributes of moving objects influence the patterns. For example, similar age (age-cohort) or work of drivers could cause similar patterns.

3. A CONCEPTUAL FRAMEWORK TO REPRESENT NETWORK-CONTRAINED MOVEMENT DATA THROUGH VISUALIZATIONS

Maps and other graphics can provide insight in spatio-temporal patterns. They can support decision making and assist in problem solving. A common approach to visual problem solving is schematized in Figure 3 partly based on Li & Kraak (2010). In order to deal with a problem through visualization of data, the user will approach the problem from a specific perspective on location, attributes and time, and translate the problem into user tasks, taking characteristics of the data (figure 2) into account. This perspective defines the spatial scale and coverage, decisions on whether to use correct geography, the temporal coverage and resolution, as well as level of aggregation in space, time and attributes. The choice of the perspective will influence the formulation of user tasks. Basic user tasks include “identify”, “locate”, “compare” and “associate” (Knapp, 1995). Executing the user tasks mostly includes answering questions related to the where, what and when (Peuquet, 1994). For instance, transport managers, might be interested in questions such as: Where did traffic congestion occur at 8AM? What is the size of the traffic flows observed at 8AM in the city centre? When did a traffic accident happen in the city centre? Answering these questions could help them identify, locate, compare and associate different patterns derived from the network-constrained movements. With the tasks at hand, the user can ‘play’ with the data in an interactive visualization environment, which provides functions and tools that enable him/her to produce visual representations based on his/her requirements. In order to provide effective visualizations, a good visualization strategy and suitable visual representations should be provided in the interactive visualization environment.



Questions
What?
Attributes
Location
Time
Where?
When?
Problem
User tasks
Perspectives
Location
Spatial scale
Spatial coverage
Network-constrained movement data
Visualization strategies
No
Attribute aggregation
Yes
Commuting flows to Tallinn in 2008
Visualization strategies
Overview
Zoom/Filter
Details
Attributes
Location
Network visualizations
Movement visualizations
Correct
Yes

Figure 3 An conceptual framework. The upper part summarizes a scheme to support visual problem solving; the lower part presents a framework of an interactive visualization environment including visualization strategies, classification of visualization representations, and related functions.

A visualization strategy is an approach or workflow that supports the user in order to make sense of the large amounts of data. A classic way to visually exploring large amounts of data is by application of Shneiderman's (1996) Information Seeking Mantra ("Overview first, Zoom/Filter, Details on demand"). Overview provides a general picture of the whole data set. Zooming and filtering removes parts of data from the view to reduce the complexity of the data and to facilitate further data analysis. Details on demand provide insight in selected data, triggered by actions such as mouse-over. In the different steps of the Information Seeking Mantra, different movement patterns could be recognized. For example, the overview mode probably hides patterns which are only visible at a relative large spatial scale and only reveals small scale patterns. The strategy is an iterative process, and requires the necessary interactive functions to help the user go back and forward between different scales and dimensions.

Due to the complexity of the data (see section 2), visualizing them is not trivial. In order to break down the complexity, this paper attempts to develop a systematic classification of movement and network visualizations based on cartographic representations from a locational, attribute and temporal perspective (as shown in the lower part in Figure 3). The classification is based on a literature study on methods and applications in different domains that describe the characteristics and use environments of the visualizations.

The locational perspective considers the cartographic representations of the base map, i.e. network infrastructure with its nodes and segments, the structure of movement trajectories, which consist of segments, or distribution of moving objects. The visualizations can be categorized into two classes according to the representation of the geography: geographically correct or geographically distorted. The geographically correct visualizations represent the geographic location of both nodes and segments as accurate as possible within the scale limits. In the geographically distorted visualizations, the location of nodes could be represented correctly or distortedly, while the geography of segments is definitely distorted. The nature of the distortion is often a schematization to emphasize network/movement attributes or to improve the clarity of map content. Typical examples are schematic transportation visualizations, which are often used to produce underground maps. These maps distort the geographic locations of both nodes and segments, but preserve the topological patterns of networks. The London underground map is the most famous of those schematizations. Visualizations of movements along geographic networks can be created by overlaying movement visualizations and network visualizations. Several options should be provided to enable users to 'play' with the data based on his/her perspectives: options to change between geographically correct and distorted locations, to change spatial scale in a flexible way, and to change the level of spatial aggregation (for example, the trajectories created by different moving objects could be spatially aggregated as one trajectory if they share the same start and end positions).

From the attribute perspective, visualization needs to visually encode the attributes of movements and/or geographic networks. Two main approaches exist, the first one applies basic cartographic principles e.g. visual variables and their extensions (Bertin, 1974, 1983; MacEachren, 1992) to represent attributes. Examples are using different width of segments to represent quantitative values of movements or using different colours of segments to represent qualitative values. The second approach overlays an attribute surface on top of the base map. Examples are travel-time maps, which integrate time zones with geographic transport networks to indicate travel time between different places. Attribute aggregation functions (e.g. aggregating the value of each grid results in an aggregated attribute surface) should be provided to enable users to visualize the data from different attribute perspectives.

From the temporal perspective, the options to visualize time are: 1. Single static map in which time is considered as an attribute of the network/movements. The visual variables are used to express time. Alternatively the network/trajectories are distorted based on travel time, resulting in a time cartogram, or the third dimension is used to express time as in the space-time cube; 2. Displaying multiple static maps, where each map represents a separate moment in time; 3. Employing animated techniques. The temporal values can be aggregated at different temporal resolution, such as days, hours, and minutes. Therefore, functions related to selecting temporal resolution need to be provided from the temporal perspective.

Decisions based on a combination of the above perspectives result in a visual representation that can be adapted if the perspective changes, and for different steps in the visualization strategy. The visualization environment is meant to help users execute their tasks and visually solve their problems. A user could first determine what his/her perspective is (given the task) from a locational, attribute, and temporal perspective, and then select one or more suitable visualizations for each perspective. For example, assume that speeds of road segments are collected at a five minutes interval. When a traffic manager wants to observe and manage the congestion in the city, he/she needs to answer questions such as: Where does congestion occur? What causes congestion? When does the congestion occur? In order to get answers to these questions, he/she looks for traffic patterns such as co-incidence in space and time with low speed (congestion), constancy of low speed, propagation of decreased speeds and so on. In addition, by visualizing the cohort-related information of drivers, such as type of work, age etc. Results can summarize the main group of derivers who suffer from congestion at different location and different time periods. By visualizing correct geometry of the network, with aggregated speed attributes for each network segment, using series of maps or animation, the traffic manager could visually find the answers to his/her questions.

4. CONCLUSION AND FUTURE WORK

This paper has proposed a conceptual framework that leads to a combination of visualizations and functionalities, useful to discover patterns in network-constrained movement data. The framework systematically includes all the relevant elements, their location, attribute and time characteristics, and the relations between them. The authors argue that this framework could form a basis for the development of a comprehensive set of visual representations and interaction methods, to be implemented in a toolbox for network-constrained movement data analysis. The toolbox should enable flexible transitions, depending on (changes in) the location, attribute and time perspectives of users, and on the steps in the applied visualization strategy. The combination of functionalities is assumed to increase the power and suitability of the visualization results.

Future work includes validation and further adjustments to the framework, implementation, and carrying out a series of case studies to justify and improve the proposed solutions. The final goal of this research is to combine visualization methods and tools in a creative way that supports the detection of different movement patterns, and is suitable for very large network-constrained movement data sets.

5. REFERENCES

Abler, R., Adams, J. S., & Gould, P. (1972). Spatial Organization : The Geographer's View of the World. London etc.: Prentice-Hall.

Andrienko, G., Andrienko, N., & Wrobel, S. (2007). Visual Analytics Tools for Analysis of Movement Data. ACM SIGKDD Explorations, 9(2), 38-46.

Andrienko, G., Andrienko, N., Kopanakis, I., Ligtenberg, A., & Wrobel, S. (2008). Visual Analytics Methods for Movement Data. In F. Giannotti & D. Pedreschi (Eds.), Mobility, Data Mining and Privacy (pp. 375-410): Springer

Andrienko, N., & Andrienko, G. (2007). Designing Visual Analytics Methods for Massive Collections of Movement Data. Cartographica: The International Journal for Geographic Information and Geovisualization, 42(2), 117-138.

Bertin, J. (1974). Graphische Semiologie: Diagramme, Netze, Karten. Berlin: De Gruyter.

Bertin, J. (1983). Semiology of Graphics : Diagrams, Networks, Maps. Madison: The University of Wisconsin Press.

Buliung, R. N., & Kanaroglou, P. S. (2004). An Exploratory Spatial Data Analysis (Esda) Toolkit for the Analysis of Activity/Travel Data. In Lecture Notes in Computer Science (Vol. 3044, pp. 1016-1025).

Dodge, S., Weibel, R., & Lautenschütz, A.-K. (2008). Towards a Taxonomy of Movement Patterns. Information Visualization, 7(3-4), 240-252.

Erwig, M. (2004). Toward Spatiotemporal Patterns. In R. de Caluwe, G. de Tré & G. Bordogna (Eds.), Spatio-Temporal Databases – Flexible Querying and Reasoning (pp. 29-54): Springer.

Giannotti, F., & Pedreschi, D. (2008). Mobility, Data Mining and Privacy: Geographic Knowledge Discovery: Springer Publishing Company.

Grundy, E., Jones, M. W., Laramee, R. S., Wilson, R. P., & Shepard, E. L. C. (2009). Visualisation of Sensor Data from Animal Movement. Computer Graphics Forum, 28(3), 815-822.

Janoos, F., Singh, S., Irfanoglu, O., Machiraju, R., & Parent, R. (2007). Activity Analysis Using Spatio-Temporal Trajectory Volumes in Surveillance Applications. Paper presented at the IEEE Symposium on Visual Analytics Science and Technology, Sacramento, CA. 3-10.

Jiang, B., & Liu, C. (2009). Street-Based Topological Representations and Analyses for Predicting Traffic Flow in Gis. International Journal of Geographical Information Science, 23(9), 1119-1137.

Knapp, L. (1995). A Task Analysis Approach to the Visualization of Geographic Data. In T. L. Nyerges, D. M. Mark, R. Laurini & M. J. Egenhofer (Eds.), Cognitive Aspects of Human - Computer Interaction for Geographic Information Systems (pp. 355-371). Dordrecht: Kluwer Academic.

Laube, P., & Purves, R. S. (2006). An Approach to Evaluating Motion Pattern Detection Techniques in Spatio-Temporal Data. Computers, Environment and Urban Systems, 30(3), 347-374.

Li, X., & Kraak, M. J. (2010). A Temporal Visualization Concept : A New Theoretical Analytical Approach for the Visualization of Multivariabele Spatio - Temporal Data. Paper presented at the 18th International Conference on Geoinformatics 2010, 18-20 June Beijing, China

MacEachren, A. (1992). Visualizing Uncertain Information. Cartographic Perspective, 13(3), 10-19.

Mennis, J. L., Peuquet, D. J., & Qian, L. (2000). A Conceptual Framework for Incorporating Cognitive Principles into Geographical Database Representation. International Journal of Geographical Information Science, 14(6), 501-520.

Peuquet, D. J. (1994). It's About Time: A Conceptual Framework for the Representation of Temporal Dynamics in Geographic Information Systems. Annals of the Association of American Geographers, 84(3), 441-461.

Schneider, M. (2009). Moving Objects in Databases and Gis: State-of-the-Art and Open Problems. In G. Navratil (Ed.), Research Trends in Geographic Information Science (pp. 169-187). Berlin etc.: Springer.

Shneiderman, B. (1996). The Eyes Have It: A Task by Data Type Taxonomy for Information Visualization.In Proceedings IEEE Symposium on Visual Languages, Boulder, Colorado. 336-343.

Woolman, M. (2005). Visual Complexity. from http://www.visualcomplexity.com/vc/, Retrieved 10 Feb. 2011.

Yattaw, N. J. (1999). Conceptualizing Space and Time: A Classification of Geographic Movement. Cartography and Geographic Information Science, 26(2), 85-98.

Yuan, M., & Hornsby, K. S. (2008). Computation and Visualization for Understanding Dynamics in Geographic Domains : A Research Agenda. Boca Raton: CRC.