Results of the break-out group: Visualisation

Group discussion with Kevin Buchin, Urška Demšar, Aidan Slingsby and Erik Willems

In this group we decided to collect literature that we were familiar with that best illustrated how movement data in the form of trajectories can be visualised. Here we only list examples, while the slides of the presentation contain actual illustrations from listed papers.

One thing that all listed methods have in common, is to address the problem of how to display a large amount of tracks of moving objects. This is a challenging problem, because of high spatial density and visual cluttering, which can be addressed in many different ways. For example, data-processing approaches such as filtering and/or aggregation using kernel density, classification, clustering and other methods are common. Other approaches use various visual displays for this purpose, e.g. showing trajectories cartographically or non-cartographically or somewhere in between (cartograms). Yet another way is to use multiple interactively linked views to show different facets of data.

In this report we categorise methods based on what part of the data space is shown, i.e. geographical space, temporal space or attribute space, some combination thereof or an aggregation in one or more of the space components. Methods that use computational methods for pattern recognition in combination with visual methods form a separate category. However, these categories are only what we came up with during our short discussion and are therefore not fixed, nor are they mutually exclusive (i.e. there is certain overlap of methods) and should be extended/redefined as required in a more exhaustive literature review in the future.

1. Basic spatial visualisations

Many papers present trajectories simply as “spaghetti lines on the map”. This can be done either in:

- two dimensions (Brillinger et al. 2004; Bouten, Shamoun-Baranes, van Loon, 2010), sometimes with attribute filtering (Historical Hurricane Tracker 2010), sometimes combined with animation and temporal filtering (van den Spek 2010) or in
- three dimensions – this is the well-known space-time cube representation, sometimes also called space-time aquarium, which comes in many shapes and forms (Kraak 2003, Kwan 2004, Eccles et al. 2008), including cases where the space-time cube is presented using stereo vision (Kjellin et al. 2009).

2. Visual spatial/temporal/spatio-temporal aggregations

The standard spatial (spaghetti) displays quickly become very cluttered when a large number of trajectories is present. To solve this issue, various spatial, temporal and spatial aggregations exist that replace the actual trajectories with some other representation, which is visually clearer.

The most common aggregation is by using kernel density. This can be done in several ways:

- 2D kernel density of trajectory points (Dykes and Mountain 2003, Brillinger et al. 2004, van den Spek and Nijhuis 2010) or a selection of certain types of these points, e.g. stationary activity locations (Kwan, 2000)
- 2D kernel density of lines (Willems et al. 2009)
- 2D density using Brownian bridges as probability surfaces between each two recorded points (Horne et al. 2007)
- 3D kernel density of trajectories as polylines in space-time representation (Demšar and Virrantaus 2010).

Other aggregation methods include:

- various aggregations based on space/time/attribute space using new line objects (arrows, networks) and/or areal objects to represent clustering of trajectories (Andrienko & Andrienko 2008, 2009, 2010a, 2010b, Rinzivillo et al. 2008, Andrienko et al. 2010)
- unwinding a particular route onto a horizontal line and representation of the route with rows of coloured grid cells, either in a static version, where one row represents one trajectory (Dias 2007) or dynamic version, where one row represents the state of the same route at a particular moment in time (TrafficLink 2010).

3. Non-spatial visualisations

Non-spatial visualisations show two types of attributes: those that are physically related to movement (speed, acceleration, direction) and others (time budget, number of flows on a certain line segment, etc.). We found the following examples:

- Displaying speed and acceleration using various approaches (Brillinger et al. 2004, Dodge et al. 2009, Bouten, Shamoun-Baranes, van Loon, 2010)
- Visualising direction with a compass rose (Shamoun-Baranes, 2010) or colouring the unwound gridded route (as described above) according to motion azimuth (Laube et al. 2005).
- Displaying other attributes: time budget (Shamoun-Baranes, 2010) or a display of trajectory data using a weighted non-spatial mobility network with time spent at each location as vertex weights and flows between locations as edge weights (Song et al. 2010)
- Trajectory data can also be combined and visualised with contextual attributes at the same geographic location (Bouten, Shamoun-Baranes, van Loon, 2010).

4. Visualisations linked to data mining methods

In cases when trajectories themselves or the relevant context data form a difficult-to-display multivariate database, information is sometimes extracted prior to visualisation using computational data mining methods. This can also be done in a form of an interactive process between computational data mining and visualisation. Three examples of this type of visual exploration of movement data that we found all use a Self-Organising Map (SOM) for this purpose. The SOM (Kohonen 2001) is an unsupervised classification method based on a 2D neural network, which has the property that it finds an embedding from the n-dimensional original attribute space into the 2D SOM space, which preserves topology and patterns from the original space. I.e. data elements that are similar to each other in the original space will be located at similar positions in the 2D SOM space. The three examples that we found include:

- display of geographic trajectories in the SOM space, where the SOM clusters demographic areas based on census information (Skupin & Hagelman 2005, Skupin 2007)
- using a SOM to aggregate spatial units based on trajectory information (Andrienko et al. 2010) and
- using a SOM to cluster trajectories themselves, combined with other visual exploration methods, such as a Parallel Coordinates Plot and SOM component planes (Riveiro et al. 2008).

5. Conclusions

In this report we presented a brief overview of different methods for visualisation of trajectory data. In spite of the short time we had to prepare this at the Dagstuhl seminar, we have been able to find examples of many different visualisation methodologies. However this list is by no means exhaustive and the review should be completed by a thorough literature investigation in the future.

References:

Andrienko G and Andrienko N, 2008, Spatio-temporal Aggregation for Visual Analysis of Movements. *IEEE Symposium on Visual Analytics Science and Technology* October 21 - 23, Columbus, Ohio, USA.

Andrienko G, Andrienko N and Wrobel S, 2009, Visual Analytics Tools for Analysis of Movement Data. *SIGKDD Explorations*, 9(2):38-46.

Andrienko G and Andrienko N, 2010a, General Framework for Using Aggregation in Visual Exploration of Movement Data. *The Cartographic Journal*, 47(1):22-40.

Andrienko N and Andrienko G, 2010b, Spatial Generalization and Aggregation of Massive Movement Data. *IEEE Transactions on Visualization and Computer Graphics* (in press).

Andrienko Gennady, Andrienko, Natalia , Bak, Peter , Bremm, Sebastian , Keim, Daniel , von Landesberger, Tatiana , Pölitz, Christian and Schreck, Tobias, 2010, 'A framework for using self-organising maps to analyse spatio-temporal patterns, exemplified by analysis of mobile phone usage', *Journal of Location Based Services*, 4:3, 200-221.

Bouten, Shamoun-Baranes, van Loon, 2010, Explanation of bird movement data. Presentation at the *Dagstuhl seminar* on Representation, Analysis and Visualisation of Moving Objects. Dagstuhl Schloss, Dec 2010.

Brillinger DR, Preislerb HK, Agerc AA and Kiec JG, 2004, An exploratory data analysis (EDA) of the paths of moving animals. *Journal of Statistical Planning and Inference*, 122:43-63.

Demšar U and Virrantaus K, 2010. Space-time density of trajectories: exploring spatio-temporal patterns in movement data. *International Journal of Geographical Information Science*, 24(10):1527-1542.

Dias E, 2007, *The added value of contextual information in natural areas: Measuring impacts of mobile environmental information*. PhD thesis. Vrije Universiteit Amsterdam, the Netherlands.

Dodge S, Weibel R and Forootan E, 2009, Revealing the physics of movement: Comparing the similarity of movement characteristics of different types of moving objects. *Computers, Environment and Urban Systems* 33 (2009) 419-434.

Dykes JA and Mountain D, 2003, Seeking structure in records of spatio-temporal behaviour: visualization issues, efforts and applications. *Computational Statistics & Data Analysis* 43 (2003) 581 - 603.

Eccles R, Kapler T, Harper R and Wright W, 2008, Stories in GeoTime. *Information Visualization* (2008) 7, 3 – 17.

Historical Hurricane Tracker, 2010, http://www.msnbc.msn.com/id/30072578.

Horne JS, Garton EO, Krone SM and Lewis JS, 2007, Analyzing Animal Movements Using Brownian Bridges. *Ecology*, 88(9), 2354-2363.

Kjellin A, Pettersson LW, Seipel S and Lind M, 2009, Different levels of 3D: An evaluation of visualized discrete spatiotemporal data in space-time cubes. *Information Visualization* 2009:1–13.

Kohonen T, 2001, *Self-Organizing Maps*. 3rd edition. Springer Verlag: Berlin-Heidelberg.

Kraak M-J, 2003, Geovisualization illustrated. *ISPRS Journal of Photogrammetry & Remote Sensing* 57 (2003) 390– 399.

Kwan MP, 2000, Interactive geovisualization of activity-travel patterns using three-dimensional geographical information systems: a methodological exploration with a large data set. *Transportation Research Part C* 8 (2000) 185-203.

Kwan MP, 2004, GIS methods in time-geographic research: geocomputation and geovisualization of human activity patterns. *Geografiska Annaler 86 B* (2004), 267-280.

Laube P, Imfeld S and Weibel R, 2005, Discovering relative motion patterns in groups of moving point objects, *International Journal of Geographical Information Science*,19:6,639 — 668.

Rinzivillo S, Pedreschi D, Nanni M, Giannotti F, Andrienko N and Andrienko G, 2008, Visually driven analysis of movement data by progressive clustering. *Information Visualization* (2008) 7, 225-239.

Riveiro M, Falkman G and Ziemke T, 2008, Visual Analytics for the Detection of Anomalous Maritime Behavior. *IEEE 12th International conference on Information Visualization*.

Shamoun-Baranes J, 2010, Examples of time budget analysis using high resolution GPS tracking. Presentation by van Loon E. at the *Dagstuhl seminar* on Representation, Analysis and Visualisation of Moving Objects. Dagstuhl Schloss, Dec 2010.

Skupin A and Hagelman R, 2005, Visualizing Demographic Trajectories with Self-Organizing Maps. *GeoInformatica*, 9:2:159–179.

Skupin A, 2007, Where do you want to go today [in attribute space]?, In Miller H (ed), *Societes and Cities in the Age of Instant Access*. Springer, 2007, 133-149.

Song C, Qu Z, Blumm N and Barabási A-L, 2010, Limits of Predictability in Human Mobility. *Science*, 327:1018-1021.

Van den Spek S, 2010, Animated movies of moving pedestrians in the city of Delft. Presentation at the *Dagstuhl seminar* on Representation, Analysis and Visualisation of Moving Objects. Dagstuhl Schloss, Dec 2010.

Van den Spek S and Njihuis S, 2010, 3D-visualisation of Activity Patterns in Public Space.

TrafficLink, 2010, http://www.youtube.com/watch?v=Pb9OLBhMUjk.

Willems N, van de Wetering H and van Wijk JJ, 2009, Visualization of vessel movements. Eurographics/ *IEEE-VGTC Symposium on Visualization 2009. Volume* 28 (2009), Number 3.