JOSEF STROBL
Interfaculty Department of Informatics
University of Salzburg
School of Geography
Nanjing Normal University
Email: Josef.Strobl@sbg.ac.at

Josef Strobl is professor and head of the Interfaculty Department of Geoinformatics - Z_GIS at the University of Salzburg, Austria. He holds Geography degrees from the University of Vienna and has developed research initiatives in terrain analysis, spatial data infrastructures and spatial simulation. Based on international curriculum development experience he is leading graduate programs in Geoinformatics as well as the UNIGIS network of transnational distance education programs (www.unigis.net). He is a member of the EUROGI Executive Committee and serves on the boards of numerous other international associations. Josef Strobl has established the Research Studio "iSpace" within the Research Studios Austria Gmbh, and as a full member of the Austrian Academy of Sciences (ÖAW) chairs the ÖAW Commission for Geographic Information Science. As the founder of the annual AGIT / GI Forum Geoinformatics symposia he always looks forward to meet friends and colleagues at these and other events.

Movement Analysis: Extracting Information from Trajectories

"A *line is a dot that went for a walk*"—this phrase conveys a simplistic perspective on trajectories, and demonstrates that movement still is frequently recorded as traces, without fully taking into account the transient characteristic of trajectories in space-time, requiring a different approach to representation, analysis and visualization than polylines.

Trajectories not only include a temporal attribute at vertices, but at any particular time are realized as a point location only, therefore being a transient feature. Sampling along a trace creates a temporal instead of an ordinal sequence, allowing for spatiotemporal gradients and of course rates of change in any other metric attributes.

Analysis of trajectories has gained interest and relevance due to the ubiquitous positional recording devices and the resulting ease of data collection. Logistics, public transport, personal mobility, exercise like running and many other activities generate enormous amounts of data, clearly making the analysis of trajectories a big data analytics task based on adequate representational models.

Trajectories also can be considered 'the geometric dimension of relational geography' (which is dealing with measures from interaction, connections, flows, movement, transport, communication, etc. via link analysis), complementing a 'topological' approach where only origins and destinations are considered. Established O-D techniques answer some questions, e.g., in the domain of regionalization. O-D representations can be derived from trajectory data, but obviously not the other way around.

Contrary to static data, trajectory relationships only exist in time—two intersecting traces do not at all indicate that two moving features ever have met. Trajectories aggregated over time, though, might well point to a persistent relationship between origins and destinations. Similarly, temporal aggregation facilitates the identification of service areas or catchments through allocation techniques.

A range of operational questions need addressing through suitable methodological approaches, with several of these remaining open research tasks:

- Clustering (bundling) of trajectories
- Identification of closest, average or maximum distance between trajectories in time-space
- Gradients along trajectories, e.g., velocity
- Trajectory relations on surfaces, e.g., inter-visibility
- Impact of sampling intervals
- Prediction of trajectories

Trajectories come in different dimensionalities, like 1D (e.g., trains), 2D (e.g., ships) or 3D (e.g., airplanes). Depending on the given degrees of freedom, measurements need to be aligned with the respective reference frameworks. Similarly, linear referencing directly creates 1D movement datasets.

A specific type of trajectory data results not from recorded mobilities, but from models based on agents, or cost paths, or within networks. Whether used within a Monte Carlo context or a straightforward predictive approach, results from model scenarios and multiple runs require aggregation in order to generate actionable information from synthetic data.

Established aggregation methods frequently apply raster techniques exploring densities. While this approach provides some quick and easy insights, much of the structural information contained in trajectories is lost. Analytics therefore will have to retain the vector characteristics, much of this based on earlier work on 'moving objects databases'.

Analysis of recorded, current, intended or potential transport has enabled entirely new business approaches, including ride sharing, sharing of vehicles, logistics optimization and network capacity planning. Based on spatio-temporal pattern recognition and prediction, huge volumes of trajectory data have to be managed in a way to allow quick insights. This is facilitated by novel approaches to multidimensional indexing as part of a big data approach to movement records.

Early "time geography" research had focused on rather sparse sampled data, which by now has been replaced by a flood of observations resulting in serious big data environments. As opposed to traditional analyses of spatial data, near real time data streams play a key role. Instead of relying on recorded and well structured data like in established analysis methods, trajectory analysis demonstrates significant strengths as a “live” monitoring methodology of societies’ and economies’ dynamics.

In sum, a high degree of mobility of people, goods and data is a key characteristic of today’s society. Traditional spatial analysis does not fully account for the temporal characteristics of movement, too often representing these as simple tracks (polylines). Trajectory analysis poses a number of specific research challenges, ranging from big data management to pattern recognition, (movement) prediction and temporal enabling of established analytical operators. Obviously, this is a core foundation for planning multimodal transport, implementation of optimized sharing approaches and control of autonomous vehicles.