

# Visualization of Trajectory Attributes in Space–Time Cube and Trajectory Wall

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**Abstract** Space–time cube is often used as a visualization technique representing trajectories of moving objects in (geographic) space and time by three display dimensions (Hägerstrand 1970). Despite the recent advances allowing space–time cube visualization of clusters of trajectories, it is problematic to represent trajectory attributes. We propose a new time transformation—sequential ordering—that transforms the space–time cube into a new display, trajectory wall, which allows effective and efficient visualization of trajectory attributes for trajectories following similar routes. To enable temporal analysis regarding temporal cycles, we use a time lens technique for interactive visualization. We demonstrate the work of the method on a real data set with trajectories of cars in a big city.

**Keywords** Movement data · Trajectories · Space–time cube · Trajectory wall

## 1 Introduction

Interactive space–time cube (STC) has become a common technique for visualizing trajectories (Kraak 2003; Kapler and Wright 2005; Andrienko et al. 2003). STC can support comparison of spatial, temporal, and dynamic properties (e.g., speed variation) of several trajectories when they are close in time. However, exploration of a large number of trajectories distributed over a long time period is challenging. Recent papers (Andrienko and Andrienko 2010, 2011) propose to use space–time cube in combination with trajectory clustering by route similarity

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(Rinzivillo et al. 2008) and transformation of absolute time references to relative positions within a temporal cycle (daily, weekly, yearly, etc.) or within the individual lifelines of the trajectories (e.g., temporal distances from the start time).

In this chapter, we suggest another visualization technique that can be viewed as extending the space–time cube by applying a particular time transformation. The main idea is to represent a set of spatially similar trajectories as a stack of bands, which resembles a wall, giving the name to the technique: trajectory wall (Tominski et al. 2012). As in the STC, two display dimensions represent two spatial dimensions. The third display dimension is divided into bins so that each bin contains one band representing one trajectory. The bands are divided into segments, which are coloured according to values of thematic attributes related to trajectory positions, such as speed, acceleration, or distance to the nearest neighbour (henceforth called positional attributes). The trajectories can be ordered in the third dimension according to their temporal order. Hence, a trajectory wall can be viewed as a space–time cube where the absolute time is transformed to the temporal order of the trajectories.

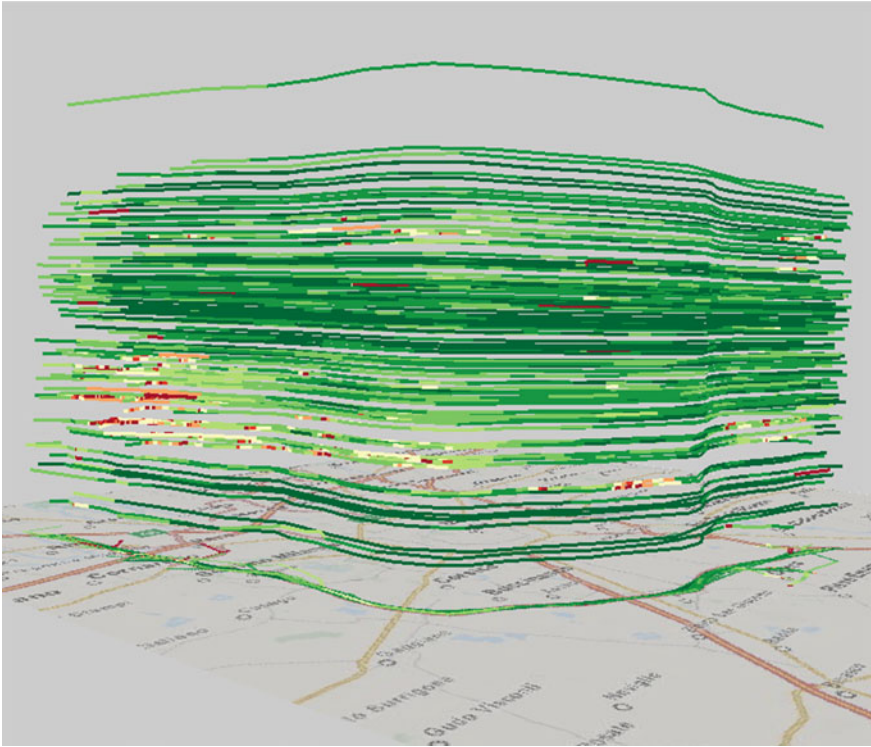
The trajectory wall technique is effective for spatially similar trajectories. Groups of spatially similar trajectories can be obtained by means of clustering (Andrienko et al. 2007; Rinzivillo et al. 2008; Schreck et al. 2008).

To represent values of a numeric positional attribute by colours of band segments, the attribute value range is divided into intervals, or classes. Several methods for defining classes are used in cartography (Slocum et al. 2009), including domain-specific class breaks, natural breaks, equal intervals, and equal class sizes. Andrienko and Andrienko (2006) proposed to use cumulative frequency curves for defining intervals interactively so as to obtain classes with similar cumulative measures computed by summing values of selected quantitative attributes. For trajectories, suitable cumulative measures are, for instance, total duration or total travelled distance.

## 2 Approach

For introducing our approach, we use a real data set of car traffic in Milan, Italy, during one day. We cluster the car trajectories according to route similarity and select one cluster consisting of 118 trajectories of the cars that travelled on the belt road counter-clockwise. The speed values for these trajectories are shown in a space–time cube in Fig. 1. The colours have been assigned to the class intervals <5 km/h, 5–10, 10–15, 15–30, 30–50, 50–75, 75–100, >100 km/h according to one of the Color Brewer colour scales (Harrower and Brewer 2003).

Figure 1 shows that the speeds within the given cluster are usually rather high, with some occasional exceptions during the day appearing as spots of yellow and red colours. It can be noticed that many trajectories had rather low speeds in the same area in close times. This indicates a traffic jam.

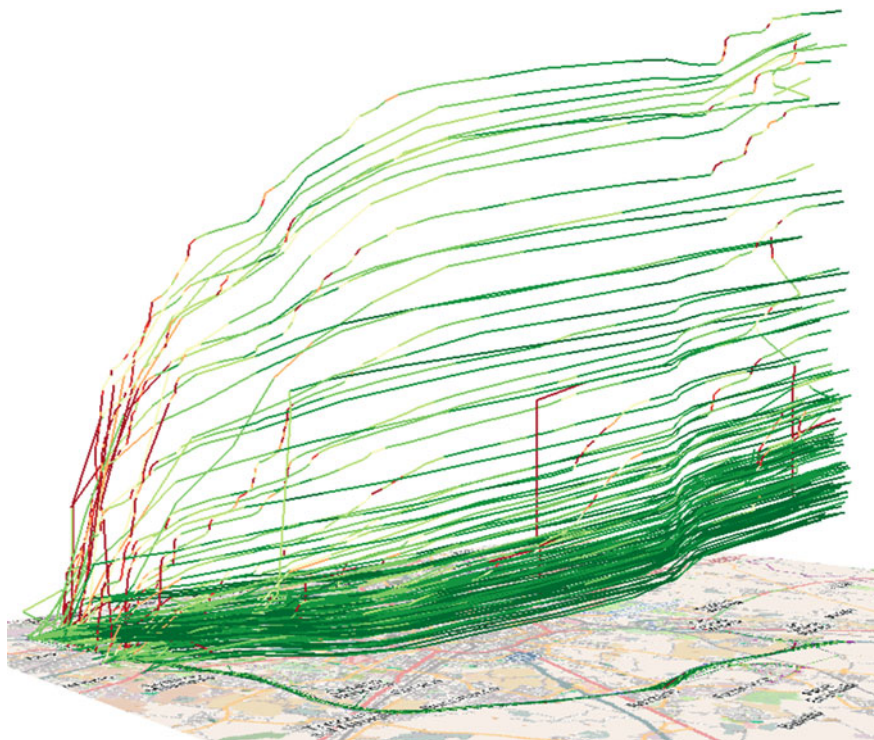


**Fig. 1** Space–time cube shows the speed dynamics for a cluster of trajectories passing the city along the belt road counter-clockwise (from *left to right*). The colour legend is provided in Fig. 3

The space–time cube representation has several disadvantages. First, the lines may overlap, and therefore it is impossible to quantify the amount of trajectories affected by the traffic jam. Second, the line may intersect (as cars have different speeds, see Fig. 2), therefore it is hard to trace the speeds along trajectories.

It appears logical to eliminate occlusions and intersections of lines in the space–time cube by using the stacking layout. For representing two-dimensional geographic space, we need two display dimensions. We can add one more display dimension and use it for stacking visual elements representing trajectories. These may be segmented bands such that their shapes and positions with respect to the two spatial dimensions of the display correspond to the spatial properties of the trajectories. Each trajectory receives its individual portion of the third display dimension. The bands representing different trajectories are stacked one upon another; hence, the bands of different trajectories do not overlap. An example is shown in Fig. 3.

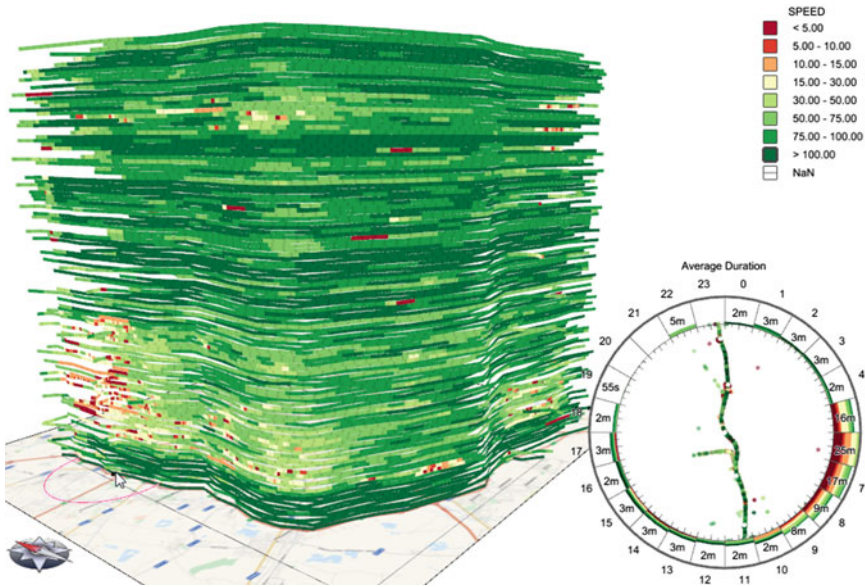
The display is oriented so that the northwest is on the left and the southeast on the right. The bands are ordered from bottom to top according to the start times of the respective trajectories. The colouring of the band segments encodes the values



**Fig. 2** The same trajectories as in Fig. 1 are shown with starting times aligned. A bunch of trajectories involved in traffic jam is easy to identify. The colour legend is provided in Fig. 3

of the positional attribute “speed”. High speed values are represented by shades of green and low values by orange and red; yellow corresponds to the speeds between 15 and 30 km/h. The bands where all or almost all segments have the same colour (green) represent trajectories with uniform high-speed movement. The intrusions of yellow, orange, and red colours indicate that the movement slowed down.

We have not only an elementary view of the speeds in each individual trajectory but also an overall view of the distribution of the speeds over the space and across the multiple trajectories. We see the places where many cars slowed down. Low speeds mostly occur in neighbouring trajectories in the stack. Since the trajectories are ordered according to their start times, the vertical dimension of the display partly conveys the temporal component of the data. Hence, closeness of segments representing low speed values in the display may mean that these values are clustered in both space and time. The big spot of reduced speeds in the lower left part of the display may signify a prolonged traffic jam in the morning. An optional information display overlaid on the trajectory wall can show detailed information about the trajectory and segment currently pointed with the mouse. The information includes the temporal references, which helps us to locate traffic jams in time. We find that, indeed, the congestion on the northwest happened in the morning from about 5:40



**Fig. 3** The same cluster of trajectories as in Figs. 1 and 2 is represented in a trajectory wall

till about 10:00. There was also a smaller congestion on the southeast from about 6:20 till about 7:20 in the morning. We also make a more general notice that in the morning the speeds were quite low on almost the whole length of the route. In the afternoon, a short period of obstructed traffic occurred from about 15:30 till about 17:00. This is also consistent with our previous observations (Fig. 1).

The mouse pointing gives us temporal information only on the elementary level of a single trajectory segment. To enable a higher level of temporal analysis, the display includes an element called time lens, which is visible in the lower right corner of Fig. 3. The time lens shows temporally aggregated information for an interactively defined spatial query area (a circle of a chosen radius around the mouse cursor position, visible in the lower left corner of Fig. 3). The interior of the time lens shows the relative spatial positions of the trajectory points within the selected area. The points are represented by dots coloured according to the attribute values. The ring of the time lens represents one of the temporal cycles: 4 quarters of a year, 12 months of a year, 7 days of a week, or 24 h of a day. In our example, the daily cycle is chosen. The ring is divided into bins corresponding to the units of the chosen cycle (hours in our case). The fill levels of the time bins visualize temporally aggregated information about the trajectories that intersect with the query area. The possible aggregates are the count of the trajectories, the total time spent in the query area (i.e., the sum of the times from all trajectories), and the average time (i.e., the total time divided by the count of the trajectories). In our example, the time lens shows the average times. The division of the bin contents into coloured segments shows the proportions of attribute values from different value intervals within the aggregates.



With the mouse, we have selected a query area in the place on the northwest where there are many trajectory segments with low speed values. The time lens shows us that such values mostly occurred in the hours from 5 till 9 in the morning (i.e., the intervals from 5–6 o'clock to 9–10 o'clock). Furthermore, we see great differences in the average times spent in the query area in different time intervals of the day. In the morning hours from 5 to 7, it took from 16 to 25 min on average for a car to move through the query area. In the next two hours, the average times decreased to 9 and 8 min, while during the rest of the day, the average times were 2–3 min. Hence, during the traffic congestion, the car drivers lost on average from 6 to 23 min of their time in comparison to normal driving.

### 3 Conclusion

In this extended abstract, we address an important and challenging problem of the visualization of positional attributes of trajectories in space and time. To overcome the problems caused by overlapping and intersecting trajectories, we propose to transform time into sequential order. This procedure transforms the space–time cube into a trajectory wall display.

We demonstrate by example that the proposed transformation enables effective and efficient visualization of positional attributes and facilitates interactive pattern detection. The technique can be applied to numeric attributes (with classification by given class intervals) and to qualitative variables. It works well with moderate-size data sets, up to several thousands of trajectories. To apply it to larger data, it is necessary to combine the trajectory wall displays with other interactive tools such as temporal animation, clustering, queries etc. (Andrienko and Andrienko 2013; Andrienko et al. 2013).

To enable detection of more complex patterns, it is essential to support flexible ordering of trajectories in the stack. Our current implementation allows ordering by different aspects of time (chronological order, hours of day, hours of week etc.) and by arbitrary attributes such as median or maximal speed. As a direction for improvement, we consider ordering trajectories by times of passing a selected geographical region.

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