Creating Maps of Artificial Spaces to Explore Trajectories

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ABSTRACT

We propose an approach to interactive visual exploration of trajectories of moving objects in which trajectories are mapped onto different coordinate systems enabling the analyst to look at different aspects of the movement. Geographic visualization techniques can be applied to these coordinate systems in the same way as in usual geographic map displays.

1 INTRODUCTION

Movement, i.e., changes of spatial positions of discrete objects, is a complex phenomenon comprising many aspects [1]. Maps showing the object tracks in space are essential for analysing movement in relation to the spatial context. However, maps alone are insufficient for representing various dynamic attributes of the movement, and they are usually combined with other types of visual displays [2]. The most commonly used display type is the time graph, i.e., a line chart with one dimension representing time and the other dimension used for encoding attribute values [3,4]. There are examples of similar displays where time is substituted by a relative distance along a path [5]. This idea can be generalized so that two display dimensions represent any two dynamic attributes, which is the basis of our approach.

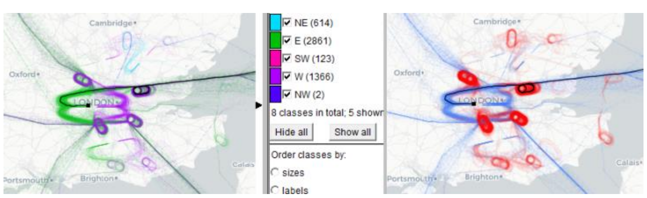

Figure 1: Trajectories of flights to London are represented by lines on a geographic map display. Left: The lines are coloured according to the landing direction. Right: Red colouring of line segments represents holding loops.

2 Approach

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2.1 Creation of new spaces

Data describing movements of discrete objects consist of records that include time stamps and spatial positions (coordinates) of the objects at the specified times. Such data are commonly called trajectories. Trajectory records may also include values of dynamic attributes characterizing the movement of the moving objects, such as speed or heart rate, and they can be extended with values of various attributes derivable from the positions and times [6]. Trajectories are typically represented in a map by lines connecting spatial positions of objects in the chronological order. Basically, this is analogous to representing trajectories in a line chart by connecting positions corresponding to attribute values at different times. Our idea is to treat such line charts as maps representing artificial spaces. This gives us an opportunity to use a uniform set of visualization and interaction techniques for map displays based on both physical and artificial spaces.

To create an artificial space and a corresponding map, the analyst selects two attributes that will form the space dimensions. The analyst may choose to build either a Cartesian or a polar coordinate system. Depending on the value ranges of the attributes, the analyst may set a scaling factor for one of the dimensions. The analyst may also create a map layer with labelled axes or grid lines corresponding to specified attribute values.

Examples of maps of artificial spaces are given in Fig. 2 and Fig. 3. They are based on a set of 5,045 trajectories of flights that arrived to the airports of London in the period December 1-4, 2016. Fig. 1 shows these trajectories in the geographic space. One selected trajectory is marked in black in all displays in Figs. 1-3.

2.2 Visualization of movement attributes

Fig. 1 demonstrates usual map displays, in which cartographic visualization techniques are used to represent attribute values associated with trajectories or their segments. On the left, the colouring of the lines encodes the landing directions, from which the eastern (green) and western (purple) ones notably prevail. On the right, colouring is applied to segments of the trajectories, so that red represents holding loops [7], when pilots wait for a permission to land. Figs. 2-3 demonstrate the use of the same visualization techniques in maps based on artificial spaces. In Fig. 2, the lines are coloured according to the landing directions, and we can see that the western landing direction was used till the morning of the second day and then gave way to the eastern direction. In Fig. 3, red and blue colours discriminate the holding loops from the remaining parts of the flights.

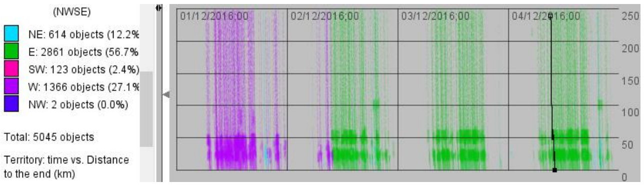

Figure 2: The trajectories are mapped onto a space with the dimensions representing time (horizontal) and distance to the end (vertical). The colouring encodes the landing direction; the thicker segments correspond to the holding loops.

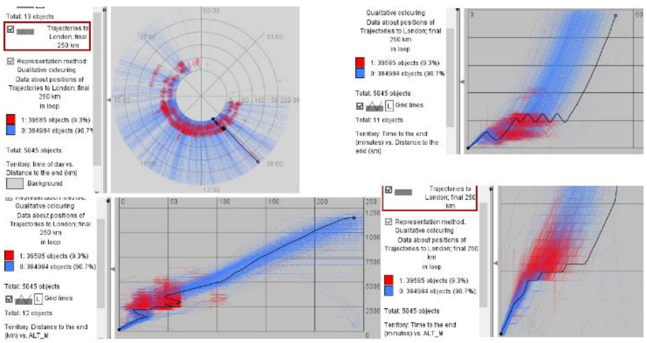

Figure 3: Maps of artificial spaces with polar (top left) and Cartesian coordinate systems. Top left: time of the day vs. distance to the end. Top right: time to the end vs. distance to the end. Bottom left: distance to the end vs. flight altitude. Bottom right: time to the end vs. flight altitude. The trajectories are represented in the same way as in Fig.1, right.

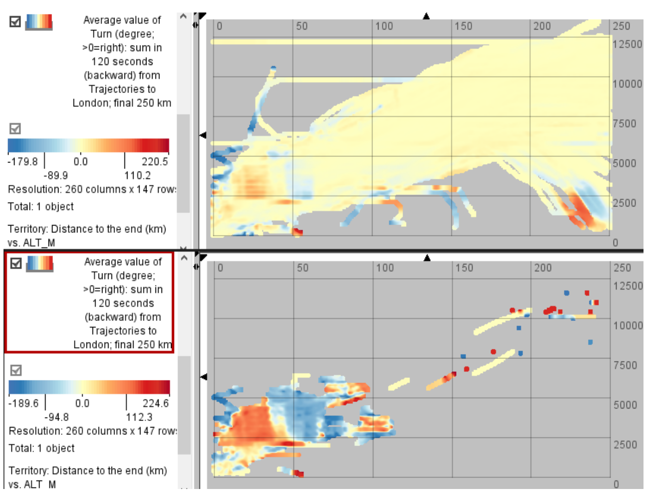

Figure 4: A raster constructed in the space of distance to the end vs. flight altitude represents the variation of the mean values of the attribute 'turn'. Top: the raster includes all data. Bottom: in response to interactive filtering, the raster includes only the turn values from the holding loops.

We see (top left) that the loops are especially frequent in the times from about 8 till about 17:30 o'clock, which corresponds to high frequency of arrivals in these times. We see (top right and bottom left) two major ranges of the distance to the destination in which the loops take place, and we see (bottom left and right) the range of altitudes at which the loops are made. These displays also show us that the airplanes descend stepwise, and the altitude decreases when they make loops.

In geographic maps, data can be represented not only using vector objects (points, lines, or polygons) but also by a raster, i.e., a spatially anchored matrix with cells containing attribute values, which are represented on a map by colour coding. A raster can be created from vector objects and their attributes. A point or line segment of a vector object contributes to the cell in which it fits spatially and to the neighbouring cells within a chosen radius; the contributions are weighted inversely to the distances from the cell centres. This operation can also be applied to artificial spaces, as demonstrated in Fig. 4. The raster containing the mean values of the attribute 'turn' has been created in the artificial space 'distance to the end vs. altitude' shown in Fig. 3, bottom left. The colour encoding represents right turns (positive) by shades of red and left turns (negative) by shades of blue. The raster reveals two ranges of distances to the destination with prevailing right and left turns, which mainly occur in the holding loops.

2.3 Interactive operations

Map displays based on artificial spaces allow the same interactive operations as usual map displays: zooming, panning, switching on and off the drawing of map layers, changing the appearances of objects in the layers (colour, line thickness, transparency, etc.), interactive selection of objects, which become marked in all currently existing displays (see an example in Figs. 1-3).

All maps are responsive to interactive filtering, which may involve various types of query conditions [1]: spatial, temporal, and thematic, i.e., based on attribute values. As an example, Fig. 4 demonstrates an effect of filtering, which extracted the loops from the trajectories, on a raster, which has been re-calculated using only the data satisfying the filter conditions. Moreover, a spatial filter can be interactively set directly in a map display, e.g., by drawing one or more "windows" selecting regions in space. The same can be done in maps based on artificial spaces. Such a filter selects objects based on the values of the attributes represented by the space dimensions. All kinds of filtering affect all currently existing displays, which are coordinated in this way.

3 CONCLUSION

Map displays employing cartographic visualization techniques for representing data can be based not only on a real space, such as the geographical space, but also on various artificial spaces. The latter can be created from attributes present in or derived from the data. Maps based on such spaces support exploration of various aspects of the data. We plan to demonstrate generation of artificial spaces from real-world aviation data using our prototype Java implementation.

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