Investigating Similarity of Trajectories through Physical Decomposition of Movement in a Space-Time Cube

Gavin McArdle and Urška Demšar

National Centre for Geocomputation
National University of Ireland Maynooth
{gavin.mcardle, urska.demsar}@nuim.ie

INTRODUCTION

Movement of entities and phenomena is one of the main processes in our physical environment. We are fundamentally dealing with how objects move through the basic framework of our physical world, defined by geographic space and time. Within this context, the ubiquity of tracking and positioning technology has led to large amounts of movement data being generated. This has created issues for analysing movement data, specifically for pattern recognition and path prediction (Orlando, 2007).

The paths of moving objects are usually represented as trajectories, i.e. a sequence of positions in the two-dimensional geographic environment with time stamps, i.e. $T = \{(x_1,y_1,t_1), \ldots, (x_n,y_n,t_n)\}$ for some n, such that (x_i,y_i) is the measured geographic location of the moving object at time t_i. Identifying similar trajectories is important in many disciplines, such as animal ecology (Horne et al., 2007).

Methods for identifying similar trajectories are commonly based on geometric similarity. Examples use Euclidian distance (Frentzos, 2007), the Hausdorff Metric (Zhang, 2006) and Fréchet Distance (Buchin, 2006). Other approaches incorporate temporal aspects of trajectories (Sakurai, 2005). Spatial transformations to realign trajectories for better comparison can also be used (Vlachos, 2002). In this paper we present an alternative approach by combining the physical description of motion in an inertial frame of reference and a space-time cube.

SPACE-TIME CUBE AND PHYSICAL DECOMPOSITION OF MOVEMENT

In a space-time cube, each trajectory is represented as a 1-dim mathematical piece-wise linear curve in three-dimensional space defined by two geographic coordinates and time which form a 3D polyline in a space-time cube. Space-time cubes are widely used for visual exploration of trajectories, particularly in time geography (Kraak, 2008). Usually aggregation (e.g. using kernel densities) and clustering are used to resolve overcrowding which occurs when large datasets are visualised (Demšar, 2010).

In this paper we extend the traditional space-time cube by decomposing the movement in the two coordinate directions of the underlying geographic space. This is done by projecting the three-dimensional curves onto the two perpendicular planes, x-t and y-t (fig.1). In each of these planes, the time of the projected curve can be considered as a function of one variable, i.e. $t=f_1(x)$ and $t=f_2(y)$ (Fig. 1).

Similarity of projected curves can be investigated in two ways, either by comparing projections visually on each plane, demonstrated in the next section of this paper, or by using a mathematical comparison between the projected curves (under development at the time of writing). In order to demonstrate TrajVis, the environment we developed for analysing trajectories, a dataset of hurricanes (http://www.nhc.noaa.gov) was used (see the screen captures in Figures 2-3).

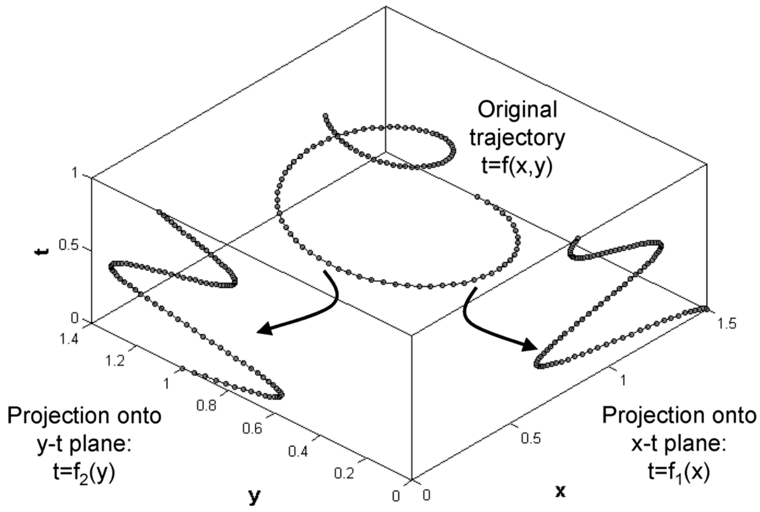

Figure 1: Trajectories in a space-time cube decomposed and projected on the x-time and y-time planes.

TrajVis – VISUAL EXPLORATION ENVIRONMENT FOR TRAJECTORY DATA

TrajVis consists of two interactive visualisation components; a space-time cube where a virtual globe represents the spatial aspect and a plot of trajectory paths decomposed into latitude and longitude.

Google Earth, embedded in a webpage is used as the spatial component in TrajVis. The third dimension is used to represent time by draping a space-time cube over the surface of the earth. The trajectories appear as bridge-like structures floating above the Earth's surface, seen in Figure 2. Colours distinguish each trajectory and users can fully interact with the interface.

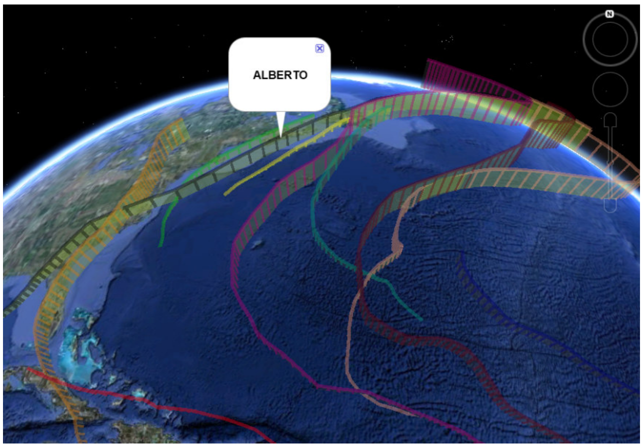

Figure 2: The virtual globe showing trajectories.

Each trajectory is also projected on latitude-time and longitude-time planes. These graphs, seen in Figure 3 are linked to the space-time cube through colour brushing. Spatial components appear on the x-axis and temporal ones on the y-axis. Longitude and latitude values are normalised to have the same starting position so they can be compared. For example, the black and turquoise trajectories (hurricanes Alberto and Isaac) are visually similar in the latitude-time plane, while their tracks in the longitude-time plane are very different.

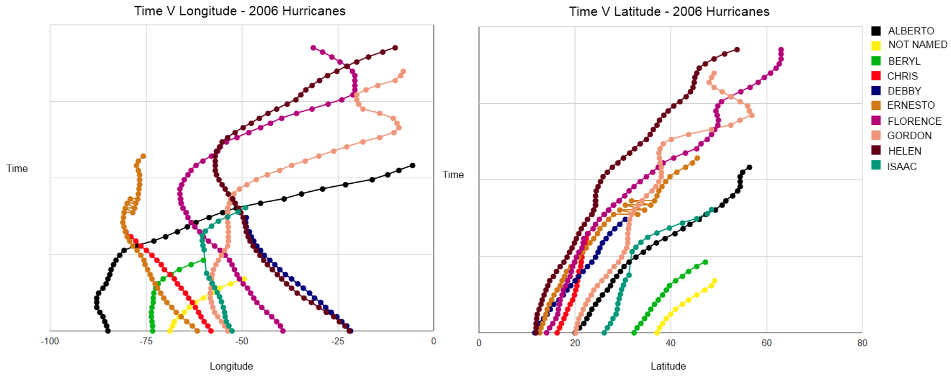

Figure 3: Graphs showing trajectories projected onto the planes: longitude-time and latitude-time.

CONCLUSIONS

Fundamentally, the paths of moving objects are represented as trajectories which contain time-specific location information. Identifying movement patterns in such datasets is important in many fields. Various techniques have been developed to visualise trajectories and compare their similarity. In this paper we propose a new approach by combining a physical description of movement in a space-time cube with an interactive visual analytics environment.

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