Visualising Data of Individual Animals Through an Adaptively Ordered Space-time Matrix

J.L. Rodda[1], A.B. Moore[1]

[1]School of Surveying, University of Otago, PO Box 56, Dunedin, NZ
Email: judy.rodda@otago.ac.nz ; tony.moore@otago.ac.nz

1. Introduction

The concept of visualizing space and time data in a framework that is both relevant and capable of handling complex data sets is not new. However, the problem of how to do it has not fully been realised (Andrienko et al., 2007; Andrienko and Andrienko, 2013; Kraak and MacEachren, 1994). For example, time geography elements such as lifelines, bundles, and prisms (Hägerstrand, 1970) have been frequently used for visualisation in a space-time cube (STC) context with a positive time vertical dimension added to two spatial (x,y) dimensions to create 3D space-time graphics (Kraak, 2003; Kraak and Koussoulakou, 2005). Geographic visualisation of data points in 3D with the STC offers the analyst an alternative way in which to observe interactions and patterns that may not be apparent in a traditional two-dimensional view (Kraak and Koussoulakou 2005). However, the STC becomes difficult for the analyst to differentiate the pathways and discern patterns as the number of pathways within the STC increases (Laube et al., 2006). Looking for trends within time series data lent itself to the evolution of research into the relative motion of objects through time (Laube et al., 2006, 2005; Laube and Imfeld, 2002; Zhao et al., 2008).

Adaptive Relative Motion (ARM) developed by Moore et al., (2013) aimed to optimally reorder the REMO matrix from an arbitrary object order that is kept through all time intervals. The solution was to, as much as possible, rearrange the order at each time interval so that geographically proximal objects are also close to each other as rows in the matrix (Moore and Rodda, 2015). A simulated annealing algorithm was applied to minimise the length of the path linking the average position of dolphins observed during any one time interval (i.e. a travelling salesman problem). The example ARM matrix featured here (Figure 1) is derived from located points of individual observations of a species endemic to New Zealand, Hector’s dolphin, in a bay on the South Island south coast (Te Wae Wae). Up to 8 seasons worth of data, from 2004-2006, was collected.

Analyses and geovisualisations of spatio-temporal aspects of movements of individual Hector's dolphin had not been attempted and therefore, the aim of this research was to examine the movement patterns of individuals across a combination of geographic and temporal dimensions, looking for patterns and relationships into how individual Hector's dolphin utilise the study area. Limited spatial analysis research with Hector's dolphin has shown that these dolphins alongshore home range is approximately 50 km (Bräger et al., 2002; Rayment et al., 2009), and distribution patterns moving from inshore to offshore are known to occur within seasonal time frames (Clement, 2005; Dawson and Slooten, 1988; Rayment, 2008; Slooten et al., 2006).

2. Analysis

2.1 Seasonal Dolphin Presence: Data Collection and Exploratory Analysis

Individual dolphins identified as having been observed in at least five seasons were extracted from the data set of eight total seasons. There were 58 individual dolphins seen in at least 5 seasons; only one dolphin seen in all eight seasons. Each instance that an individual dolphin was photographed, the photograph was recorded and counted as one observation. An individual may have been observed multiple times in any time period: day, week ~ month, season. For instance, the single dolphin recorded in all eight seasons had a composite record of 29 times observed over 16 days, in 14 weeks; while another dolphin in the database had been observed 58 times over 18 days in ten months, all observations occurring within 5 seasons. The 58 individual dolphin geo-spatial lifelines were binned into seasons.

An initial, exploratory analysis step was to map in Space-Time Cube (STC) 3D all of the encounter points representing the 58 individual Hector's dolphins, and thereafter, to link the points via lines. Visualising a separate colour for each dolphin would be both impractical and difficult to distinguish for the human eye; however, the data could be sorted according to the number of seasons each dolphin was observed. The geo-spatial lifelines represented in STC, for each individual dolphin were consolidated into a single average directional vector or bearing for each season.

The STC analysis (e.g. Figure 2c) highlighted that within the group of 58 individual dolphins some were observed only in the eastern portion of the study area (ten dolphins) or only in the western portion (eleven dolphin). This was an unexpectedly large portion of the total group of individual dolphins 36% (21 of 58) observed in constrained sections of the study area.

2.2 ARM analysis

With ARM, for each season, an ordering of dolphin positional vectors was optimised through a simulated annealing-based (Brownlee, 2012) travelling salesman algorithm (Applegate, 2006; Dantzig et al., 1954). Initial experiments with ARM produced results where the same object would encounter a large row separation from one time period to the next, reducing effectiveness and readability of the visualisation. Adjustments such as reversing the order (‘flipping’) and shifting rows (‘nudging’) only had a modest effect on this. Therefore the ‘distance’ (i.e. number of rows) between an object in one time interval and the next was factored into ARM calculation. The most readable ARM matrix visualisation to explore was predicted to be at the point where the overall cost between the geographic distance and the matrix distance was the least, the latter being subject to a scaling factor as its range is several orders of magnitude less than the geographic distance range. The overall cost (Equation 1) is a combination of the scaled geographic distance total plus the scaled matrix total for each iteration:

$$c = \frac{(g - g_{min})}{(g_{max} - g_{min})} + \frac{(m - m_{min})}{(m_{max} - m_{min})} \quad (1)$$

- c = overall cost; g = geographic cost; m = matrix cost;
- 'min' and 'max’ the minimum and maximum of geographic values and matrix values.

The result introduces a greater number of more interpretable horizontal paths (Figure 2a).

It was possible to use the twenty-one dolphins found exclusively in specific areas to assess ARM as a methodology to explore individual dolphin movement, to see if those constrained patterns of movement would also be visible within the ARM matrix (Figure 1). It was found that the optimised matrix visualisation does not compromise the effect of geographic distance, retaining visual instances of significant interaction between individual dolphins or even groups of individual dolphins.

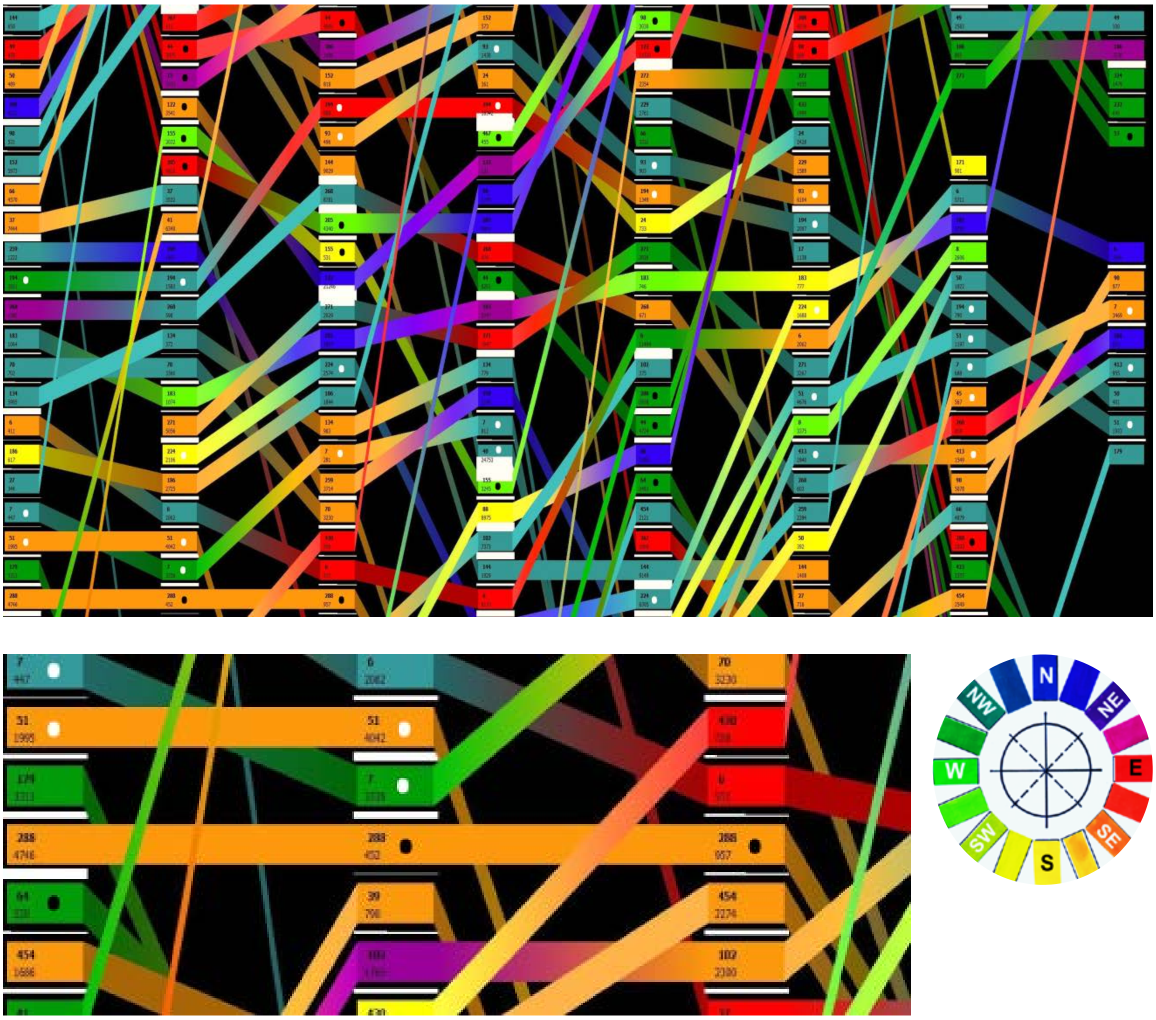

Figure 1. In this visualisation of a portion of the ARM matrix, each row in each column represents an individual dolphin that had been observed for a minimum of five seasons. Each column represents a season; season one summer through to season eight spring. Black dots mark dolphins observed only to the west, white dots represent dolphins observed only to the east. The geographic distance is depicted by the white bars in-between each row. Colours represent the directional vector (inset colour wheel) calculated from observation points collected each season.

'Storyboard' visualisations (Figure 2) depict a combination of 2D, STC, and ARM. This set of dolphins was chosen to be an example in this storyboard geovisualisation as neither dolphin was from the group of eastern or western dolphins.

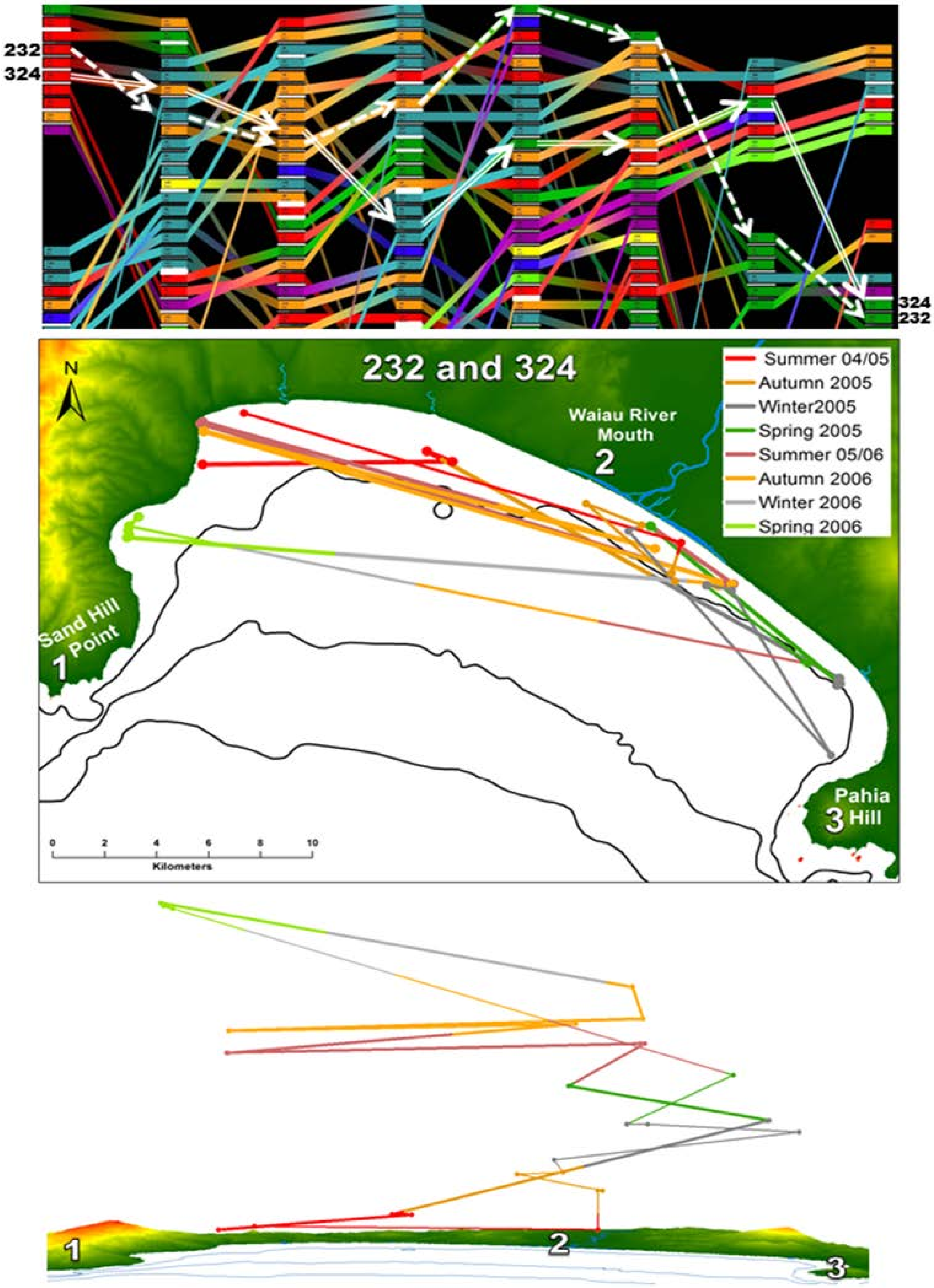

Figure 2. A storyboard example: ARM matrix (top), 2D centre map, and STC bottom map. Colours in the ARM visualisation are related to the directional vector (see Figure 1 inset). Colours of the points and lines in the 2D and STC maps are related to season (legend in the 2D map in the centre.)

3. Discussion

These results have illustrated that individual dolphin movement data collected at a coarse granularity can provide novel insights and aid in identifying clusters and activity patterns of individual dolphins. One of the most interesting insights was identifying movement patterns of individual dolphins that indicate some individuals were consistently observed during the study period in areas smaller than 100 km^2. At this time, it is not possible to say precisely why these individual dolphins have a consistent specific association with either the eastern or western ends of the study area. However, a reasonable hypothesis would be that they may be females, and that males or sexually immature dolphins swim back and forth across the length of the bay. Future research projects could take advantage of techniques to identify gender of groups of Hector's dolphins. Lacking detailed gender and behavioural information about each individual dolphin means caution is warranted with interpretation of the analyses presented here, not only because of the lack of specific details about each dolphin, but also because these data are episodic. In spite of these uncertainties, ARM matrix analysis was found to be both an efficient and effectual method to visualise individual dolphin movements from GPS linked photographs.

ARM proved to be a valuable tool for visualising and distinguishing groups of individual dolphins, often groups containing two or three dolphins moving in similar patterns illustrating that dolphins may move in synchronous patterns within the bay (seasons), yet they are not necessarily in the same geographical space. Further challenges will mean exposing ARM to larger datasets and also dissecting the effects of specific parts of the data, in a sensitivity analysis process.

There are exciting research avenues to be pursued in further developing ARM into a geovisual analytics tool. Here, multiple views (Moore & Rodda 2015) connected by brushing and linking (Monmonier, 1989), interactively querying data in one view to see results in that view and all other views (e.g. selecting a region in a choropleth map highlights a dot in a linked scatterplot that also represents that region). While the three frames in the Figure 2 storyboard are static, the proposed would propagate a brushing action on the ARM matrix to linked 2D map and STC displays, for example.

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