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Visualisation design for representing bird migration tracks in time and space

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Abstract

As increasing numbers of high quality data sets on bird migration become available, systematic means of designing ways of visualising them are needed. In a collaborative study of visualisation scientists and animal ecologists we specify a framework to describe design possibilities. We use this framework to generate visualisation designs that integrate time, space and context in a case study using white-fronted goose migration tracks. Developed visualisation designs were regarded as useful for migration ecology and work to improve them for easy usage in the future is ongoing.

Categories and Subject Descriptors (according to ACM CCS): H.5.2 [Information Interfaces and Presentation]: User interfaces—User-centered design

1. Introduction

Spatio-temporal processes such as animal movement are, by their very nature, complex to follow and understand. Several empirical and modelling studies try to unravel parts of the questions around where animals are when, and how and why they move in the ways they do [NGR*08]. Data sets for studying animal movement have increased in numbers and complexity in recent years, particularly with the introduction of remote tracking using ARGOS and GPS. Animal ecologists require new methods to be developed, applied and tested to look at these data sets, in order to challenge previous insights, generate new hypotheses and incorporate context in animal movement studies [SBvLP*12].

Animal migration is one of the most spectacular natural spatio-temporal processes, with animals covering large distances between breeding sites and wintering regions every year [New07]. Traditional studies of these processes by visual counts and ring recaptures, result in limited quantities of data on bird migration that are easily presentable in simple geographical maps. In contrast, high resolution GPS tracks provide possibilities for looking into the use of time and space during migration, answering questions and evaluating theories related to individual decisions, optimal migration timing, energetics and others.

In studies that use animal migration tracks to answer ecological and evolutionary questions, visual representations tend often to be map based, with little consideration of how suitable it is for the questions at hand. This topic is the specific focus of this short paper in which visualisation scientists and animal ecologists worked together to identify static visualisation possibilities in the context of viable research questions.

After reviewing visualisation techniques that have been used to show migration tracks in recent ecological publications, we specify a framework that describes the design space of visualisation possibilities. We map this space to ecological questions and apply our ideas to a data set of greater white-fronted geese (*Anser a. albifrons*) that migrate between central Europe and the Russian Arctic. With an emphasis on spatio-temporal generalities and variability, we explore different ecological questions and discuss how they can best be supported through visualisation.

2. Previous work

To get an overview of recent ways that animal migration tracks are presented in the ecological literature, we conducted a Web of Science search for ‘bird AND migration AND track’, between 2012 and 2013. There were 86 results, of which 71 were relevant ecological publications. Classifying the visualisation techniques used in data presentations in

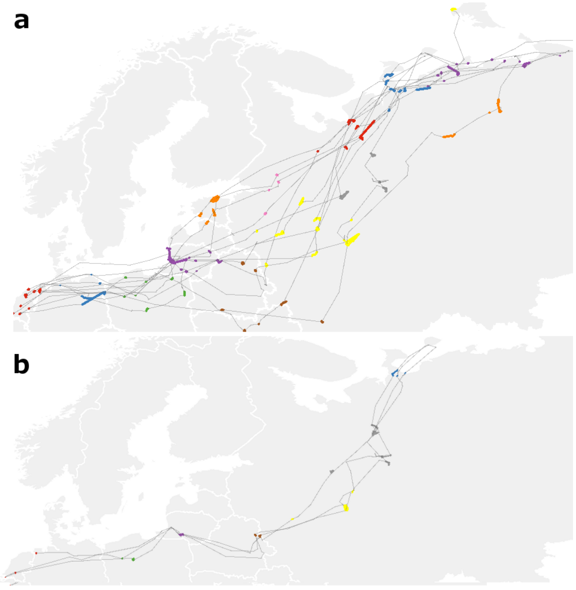

Figure 1: *Migration tracks of (a) 12 individual white-fronted geese and (b) one white-fronted goose during 3 successive years, from 1 March – 15 June. Colours differentiate between identified stopover regions.*

these publications revealed that maps with positions marked as points linked by lines or arrows, formed the majority of visual representations (57 out of the 62 cases with visual data representations). In 7 cases, time was indicated using text, colour or isoclines. Few studies integrated other aspects of the data addressing specific research questions, such as the relation of flight altitude and wind patterns [HBB*13].

3. Data

We use spring migration GPS tracks of 12 individual greater white-fronted geese between 2006 and 2008. Building on previous work [vWKK*12], we focus on this species' stopover use and the timing of spring migration in relation to food availability in space and time. A general map illustrating the data (Figure 1) shows GPS positions and stopover sites (combined into greater stopover regions) on their spring migration from central European wintering areas to their Arctic breeding sites. We also used three successive migration tracks of one individual goose (Figure 1b).

4. Design evaluation

To systematically establish suitable visualisation designs, we established a framework in which we map the visual channels of x position, y position and colour to aspects of the data, in such a way as to address the research questions under consideration.

The number of information carrying channels is limited, and some are easier to distinguish than others. The two spatial dimensions are widely considered as capable of holding information in a highly distinguishable way [BB67], whereas colour and other 'retinal' channels are more limited [CM84]. Therefore, information most crucial to the specific question should be shown on the spatial axes, whereas less important information should be encoded with visual channels with a lower information carrying capacity. In conventional maps the spatial dimensions are taken up by geographical coordinates, often with good reason. However, we challenge the widespread assumption in much of the literature that maps are always the most appropriate visual representation. We propose being more explicit why such design decisions are taken.

Our research questions are related to spring migration routes, timing and stopover use:

1. Along which routes do white-fronted geese migrate in spring, how do they time their migration and where do they stop for how long?
2. How much do individuals vary in stopover use and timing, are they interrelated?
3. Do white-fronted geese follow the so called 'green wave', i.e. does their arrival at stopover sites coincide with onset of spring?
4. By how much do timing and routes of the same individual differ between successive years?

Several parameters are necessary to address those questions. We acquired context information about onset of spring and extracted the following from the provided GPS tracks: *bird ID*, *time*, *longitude*, *latitude*, *distance from starting position*, *distance from intermediate track*, *stopover sites and regions* and *distance to other tracks at the same time of the year*. Each of the parameters has particular importance for each of the given questions (Table 1). Time and bird ID are most important for the posed questions. Thus, our design should focus on presenting those parameters through the channels that can reveal the largest amount of information, i.e. the two spatial axes.

Considering the simple map of the goose migration tracks (Figure 1), it becomes clear that it enables us to answer part of question 1, but none of the others. To address our questions about migration timing, we therefore consider alternatives to map visualisations.

In a first attempt to integrate time and space, we collapsed space into one dimension, i.e. distance from a starting location and compared it with time. As migration is usually a directed kind of movement, we only lose information about route variability away from the main migration vector. Plotting distance against time, integrating stopover region with a differential categorical colour scheme ([HB03]; Figure 2) showed that the geese were using stopovers frequently and often with long duration. However, some sites had a similar distance from the starting point and were not discernible

Question	1	2	3	4
x	1	-	(4)	(5)
y	2	-	(5)	(4)
Time	4	2	1	3
Bird ID	-	1	3	1 (year)
Context	Stopover region 3	Stopover region 3	Onset of spring 2	Dist to other tracks 2

Table 1: *Outline of visualisation design priorities. Numbers indicate the ranks of parameters of the migration tracks in terms of importance to answer the respective research question (see text). x (first spatial dimension) is related to longitude or distance from a starting position, y (second spatial dimension) is latitude or perpendicular distance to an intermediate migration track. The linear nature of our migration trajectories has an impact on our visualisation design.*

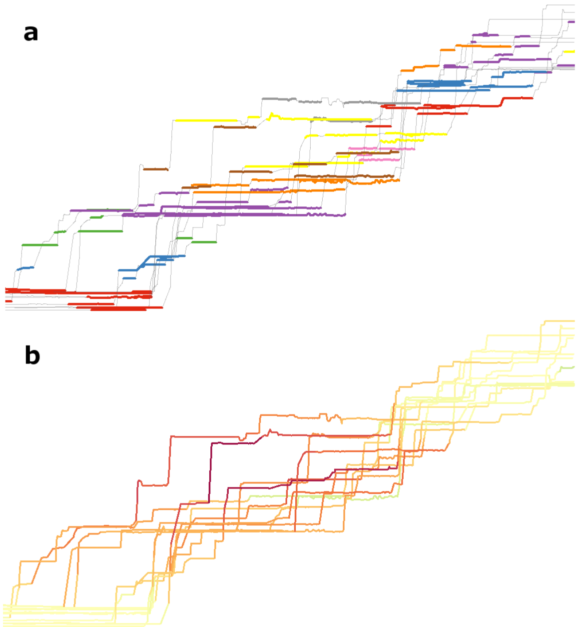

Figure 2: *Time (x, 1 March - 15 June) and shortest distance to a common starting point (y) for the 12 spring migration tracks. Colours indicate (a) stopover regions or (b) directional perpendicular distance to the intermediate migration track (red (south) - yellow - green (north)). Note the variability in timing and duration of stopovers which is clearly discernible here, but not in a map.*

by distance alone. Encoding perpendicular (directional) distance from an intermediate track through a diverging colour scheme ([HB03]; Figure 2b) solved that issue somewhat, additionally revealing at what times tracks were close to each other. Thus, this type of visualisation is able to address the timing aspect of question 1 (compare to Figure 1), at the cost of detail of space. In addition is provides insight into individual variation of (instantaneous) migration speed.

These patterns lead us to explore the variation of timing amongst individual animals. In Figure 3 we use the spatial dimensions to differentiate between individuals (y, ordered by geography) and show their temporal trajectory (x). Space is thus represented with a less broad information carrying channel: colour indicates distance from starting point (Figure 3a) or stopover region (Figure 3b). As we are using the y-axis to differentiate between just 12 individuals we can vary their temporal trajectories vertically to show additional spatial information. A vertical offset indicates distance from the intermediate track in Figure 3. Additional lines in Figure 3b use orientation to show whether arrival at any site preceded or followed the local onset of spring.

Using these types of visualisation revealed individual differences in migration speed and stopover behaviour. Arrival and duration at the different stopovers sites can intuitively be read off the time axis, and insight into mistiming can be gained by the tilted lines at stopover arrival (Figure 3b). These 'pop out' due to our visual propensity for interpreting angles [War12] indicating whether an individual bird arrived too early or too late to match the onset of spring. Thus, several aspects of questions 2 and 3 can be answered from visualisations of time vs. individual lines. The continuous vertical offset used in Figure 3 is not scalable to larger numbers of individuals, but a simple binary offset can be used for more tracks.

The fourth question differs from the others as it requires distances between individual tracks at all points in time. We consider three consecutive migration trajectories of the same bird. Time and year are the most important parameters; line width is used to carry the information about the number of years that tracks were close to any position of the bird in the respective focal year (Figure 4). Colours co-encode year to get a detailed understanding of which years are most similar. The graphic nicely reveals overlap in migration timing and space, thus addressing question 4, but does not hold any explicit notion about space or stopover use.

Most of the posed questions can be addressed through the graphics alread discussed. However, not one single visualisation can completely answer question 1. Additionally, we are aware that positions on a map hold more context information than plain distances and might thus be preferred by ecologists. So, we tried to integrate stopover timing in a map type of visualisation (Figure 5). By superimposing time line insets on each stopover region, timing of stopover use can be distinguished between individuals and regions. The use of colour for individuals makes it possible to follow tracks, even if the track line details are obscured by the stopover graphics. This visualisation is thus able to address space,

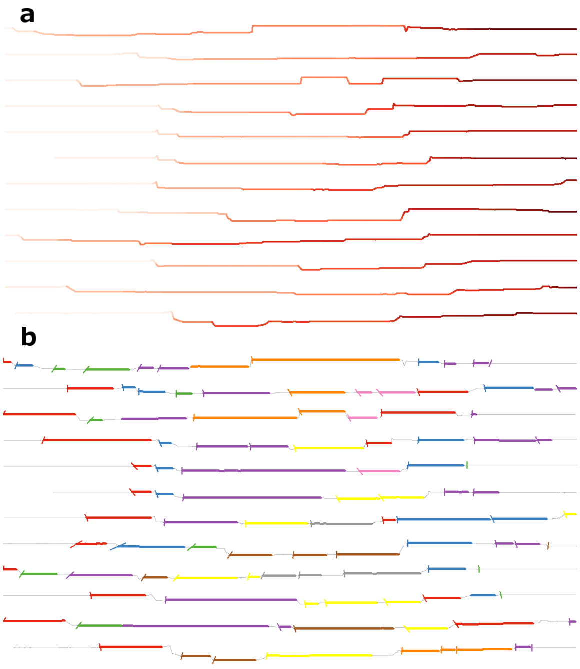

Figure 3: *Time (x, 1 March - 15 June) against individual bird (y) with an offset for perpendicular distance from the intermediate track. Colours represent (a) distance to starting point or (b) stopover region. Tilted lines indicate if stopover arrival was before (sloping right to left) or after (sloping left to right) onset of spring. The amount of mistiming is indicated by the degree of tilting. Birds are ordered according to their migration route (from North to South). Note that each stopover region (colour) can consist of more than one stopover site (line piece).*

Figure 4: *Time (x, 1 March - 15 June) against year of migration track (y and colour, 2006-2008) of one individual bird. Line width indicates the number of years that the bird's tracks were closer than 30 km in the respective time periods.*

time and individual variability of the migration tracks, but does not allow for additional context information (Table 1).

5. Discussion

Having evaluated the presented design approach on goose migration tracks, we tentatively conclude that it is useful to introduce the concept of systematic, question-oriented visualisation design (see also [AA06]) into migration ecology.

The framework is still very flexible, as some of our designs were well suited to address specific questions (e.g.

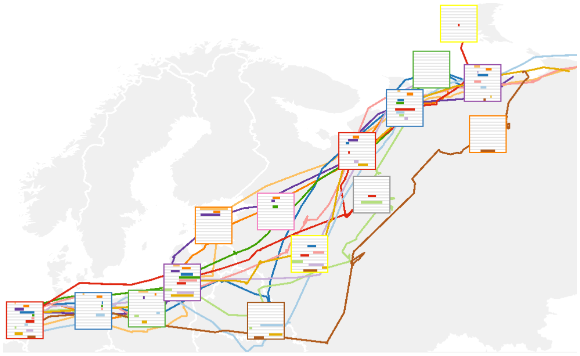

Figure 5: *Map of 12 migration tracks with colour indicating the individual bird. Insets are placed on the centre position of the corresponding stopover region. Small lines in the insets show stopover timing of each bird (time (x), ID (y)). Time scales in the insets are comparable in terms of time duration, but do not relate in absolute time.*

question 4 and Figure 4), whereas others could answer parts of more general questions, often implicitly providing additional information (question 2 and Figure 3a). Furthermore, question 1 could not be completely addressed in one single design, but interesting relations are shown in Figures 1, 2 and 5.

Informed visualisation designs as presented here cannot only illustrate ecological studies, but help to form new ideas and evaluate old hypotheses. For example, the detailed presentation of relations of timing of individual birds and onset of spring shows a good agreement with the green wave hypothesis [vWKK*12]. In addition, it revealed that stopover use varied consistently by year, which had not been considered previously. On the other hand, high levels of spatio-temporal consistency of tracks of the same individual between years were confirmed. The bird did not only use the same route, but very similar timing in the three years.

These points illustrate the effectiveness of our framework to control emphasis of time, space and context in visualization designs for bird migration tracks. We intend developing and evaluating the approach so that it can be used by the ecological community to analyse new tracking data in a more focussed manner.

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