

Visual Exploration of Migration Patterns in Gull Data

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1. Introduction

In recent years the computational analysis of ecological movement data has attracted an increasing attention, since ecologists collect more and more movement data. Gulls are an interesting and challenging bird species to analyze, since they use different and flexible flight modes. Also, for gulls, foraging and migration can take place at almost any habitat (Klaassen et al. 2011), and therefore feeding is possible almost anywhere along the migration route of the gulls.

It is generally believed in ecology that migrating birds minimize the time spent on the migration itself rather than the energy used to migrate. Klaassen et al. (2011) assume, though, that gulls optimize a different objective during migration, namely, minimizing the costs of migration, which is essentially the gull's energy that has been used during the migration. Gulls are very flexible in their movements, since they use a fly-and-forage migration by avoiding carrying loads to save energy and time, and switching frequently between flying and feeding. Therefore, it is assumed that the movement patterns during migration deviate for individual gulls.

However, little research has been conducted on migration studies of gulls (Klaassen et al. 2011). Here, we study the migration patterns including intermediate stops of gulls as groups and individuals. To enable an analyst to explore these episodes visually and interactively, we developed a prototype visual analytics framework.

Stienen et al. (2016) tracked 101 gulls with GPS devices with almost 2.5 million data points. We use this data set to evaluate our approach experimentally. Since we are interested in analyzing and visualizing migration flights, we have focused on the 75 Lesser Black-backed gulls of the data set in our study.

1.1 Related Work

To identify different homogenous movement episodes in trajectory data, trajectories are commonly *segmented*, i.e. cut into parts, according to characteristics of the movement. Segmentation together with classification or clustering of movement data helps to summarize and visualize large trajectory data sets interactively. Several approaches to these tasks have been developed recently, of which we describe the most related ones.

Segmentation algorithms have been successfully applied to geese trajectory data during migration (Alewijnsse et al. 2014, Buchin et al. 2013). These approaches segment individual trajectories into pieces of similar movements. Buchin et al. (2016) present algorithms to summarize segmentations of a larger number of trajectories in a flow diagram, which they apply to trajectories of football players to analyze spatial formations and plays.

Andrienko et al. (2011) propose a visual analytics approach for aggregating movement data by transforming trajectories into aggregate flows between spatial

regions. In their approach the user can control the overall level of abstraction of the visualization interactively. They evaluate their approach on deer and stork data and on trajectories in an urban context.

Density visualization is a powerful visualization technique for analyzing a large number of trajectories. One such example is the work by Willems et al. (2009), which present a multi-scale density visualization for trajectories, which they demonstrate on vessel trajectories.

1.2 Requirements for Analysis Tasks

We focus on analysis and visualization of migration trajectories, and identify a number of tasks that need to be supported by our approach.

T1: Identify spatial patterns. This task covers a comprehensive visualization of all trajectories, allowing the user to understand and compare spatial patterns in migration. A grouping of gulls with similar movements provides insights into different categories of migration behaviors. The behavior of individuals should be distinguishable from overall group patterns to investigate how the migration strategy of an individual deviates from the group movements.

T2: Identify temporal patterns. This task deals with analysis of temporal patterns across several scales, ranging from day/night patterns over days to seasonal patterns.

T3: Identify stopovers. This task covers a more aggregate view on the data to identify important or often used places where migrating gulls come together. Stopovers can also be considered at the level of an individual to visualize its migration strategy. A visualization should furthermore provide insight into the habitat of the stopover.

T4: Compare groups and individuals. This task concerns grouping individuals that show similar migration strategy, e.g. travel mostly along a coastline, over land, or over sea. The visualization should enable a visual linkage between these groups, but also the comparison of one or more individuals with a group.

2. Visual Analytics Approach

This section gives an overview on our visual analytics approach to explore migration patterns of gulls. First, we discuss the underlying algorithmic techniques that we have used to build our prototype implementation¹. After that, we link the analysis tasks to the visualization design.

2.1 Computational Methods

Our approach requires computing density maps efficiently and a structure that represents compactly a joint segmentation.

The density map should represent the relative cumulative time spent in an area. To achieve this, for each gull, we want them to contribute towards the density map based on where they have been, and for how long.

The provided data has irregular sample intervals. So we first interpolate the data for every gull using linear interpolation, so that we have a sample resolution of 15 minutes for each gull. Then, we construct bins which represent a grid over the possible locations of the gulls, and for each generated sample increment the value of the respective bin by one, representing fifteen minutes of time.

¹ version with cached heatmaps at <http://www.win.tue.nl/~kbuchin/proj/gullmigration/>, the complete sources with dynamic heatmaps: <http://www.win.tue.nl/~kbuchin/proj/gullmigration/src.zip>

Finally, we want to discretize the different values in the density map so it is visually easier to distinguish. The values per bin vary considerably, from one to over one hundred thousand. Therefore we discretized them to five ‘quintiles’ where a quintile cut is only made on a boundary between two different values.

We use a spatially-embedded flow diagram to represent the joint segmentation and stops. For segmentation we cannot readily apply stopover criteria used in existing algorithms (Buchin et al. 2013), since the stops of the gulls in the current data are more variable and frequent. We therefore use a criterion for stops that depends on multiple trajectories.

Specifically, we classify a data point as *idle* if the speed at this point with respect to the previous point in the trajectory is below a given threshold. A *stop* is now defined as a single-linkage cluster of idle points (for a given distance threshold). We represent a stop by the smallest disk containing all the corresponding idle points.

We may want to filter stops depending on importance, e.g., duration or number of individuals. In our approach, however, we maintain all stops and aggregate stops spatially based on the scale of the analysis. For this we perform a single-linkage agglomerative clustering, specifically, we use Kruskal’s algorithm on the Delaunay triangulation of the centers of the disks representing the stops. In the clustering computation, we take the distances between the corresponding disks as edge weights.

2.2 Visualization Techniques

Our approach is implemented in an interactive website, which is shown in Fig. 1. There are three panels: (A) a trajectory density map, (B) a visualization of stopovers and segmented trajectories, (C) a detail view with calendar.

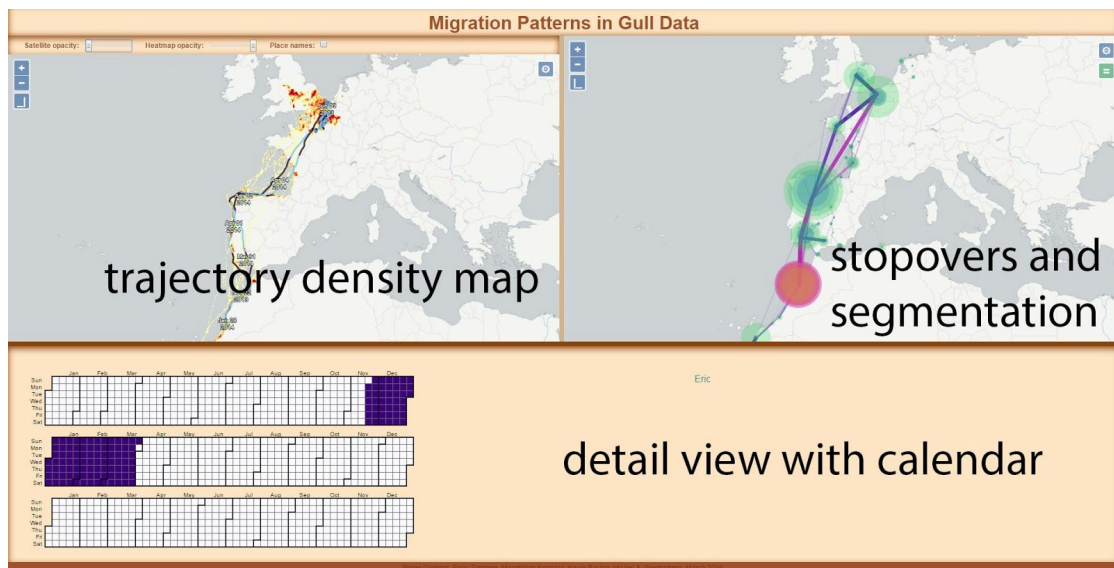


Figure 1. Interactive website. In this example one cluster of stops selected in the right panel. The trajectory density map shows the density for the gulls that visited this a stop in the cluster. One of these gulls was selected for which the trajectory is shown in the density map. The calendar shows the days on which this gull visited this stop.

The trajectory density map provides an overview of all trajectories (T1). The color map ranges from yellow to red, with red corresponding to the highest density. We

ensure that individual trajectories that deviate substantially from others are clearly visible by using an appropriate kernel size. This way, the trajectory density map also supports task T4.

The stopover visualization (T3) provides an overview of the segmented trajectories and the stopovers. Each stopover is represented as a disk, of which the radius encodes the number of trajectories of which this stopover is part. A slider allows the user to select the aggregation level (see previous section) to obtain coarse-grained or fine-grained aggregated spatial patterns of the trajectories (T1) and stopovers. The map type can be changed to a satellite view to investigate the habitat in the vicinity of the stopover (T3).

To provide insight into the temporal migration strategy of an individual, day, night and twilight are color coded in light blue, black and purple, respectively, when a trajectory is drawn (T2) on top of the trajectory density map. This allows a user to see if a gull travels long or short stretches on any particular day and also how many days the entire trip takes. The text labels on top of the trajectory show stopovers in the route and indicate the sequence and the direction of the movement.

The detail view shows an overview of the selected gulls. Males are in blue and females in red. As we select a stopover or an individual gull (T4), a calendar view is shown, which provides information on which gulls stopped at a specific location or stops of an individual gull distributed over days of the stops in the calendar (T2). The number of stops are visualized in a saturated scale of purple on a specific day. The darkest color indicates the day with highest number of stops.

3. Experimental Results and Discussion

In this section we summarize our findings in the dataset. We refer the reader to the video² for an overview of the visual exploration process of the data.

By selecting multiple clusters, we can for instance see that only three gulls have had stops in England and a wintering site in Africa at the coastline. The density map of the selection shows that the selected gulls moved along the coastline and did not stay in Europe in the winter.

Another interesting observation that can be made by selecting a cluster in the center of Spain is that those gulls stayed in Europe, as the density map shows (see Figure 2). The calendar view displays the temporal characteristics of stopovers for the gulls within the selected cluster.

² <http://www.win.tue.nl/~kbuchin/proj/gullmigration/gullmigration.mp4>

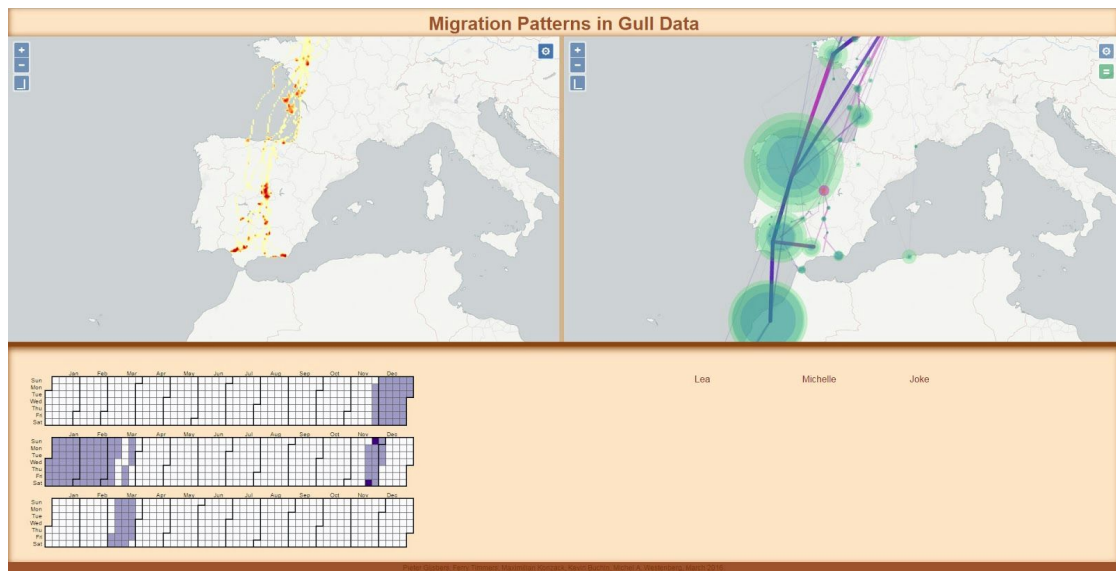


Figure 2. Selection of an inland cluster. In the right panel the cluster is highlighted and edge are colored purple depending on whether birds of the cluster use them. The density map shows that the birds of this cluster do not migrate to Africa. The detail panel shows the corresponding gulls and in the calendar when (and how many) these birds visited a stop of this cluster.

We also observe by inspecting the colorization of day/night movements that gulls fly frequently at night. This can be seen in Figure 3 for a gull that migrated to Africa. At the wintering location there is considerable more night movement than during daytime.

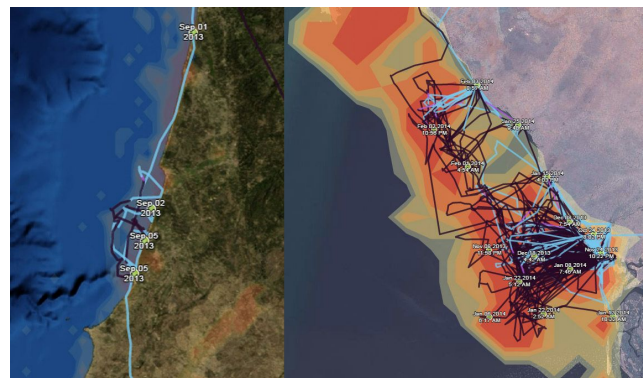


Figure 3. Activity at night. The coloring of the individual trajectories show considerable movement at night during the migration (left), but in particular at wintering locations in Africa (right).

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