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Meeting report

Analysis and visualization of animal movement

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The interdisciplinary workshop '*Analysis and Visualization of Moving Objects*' was held at the Lorentz Centre in Leiden, The Netherlands, from 27 June to 1 July 2011. It brought together international specialists from ecology, computer science and geographical information science actively involved in the exploration, visualization and analysis of moving objects, such as marine reptiles, mammals, birds, storms, ships, cars and pedestrians. The aim was to share expertise, methodologies, data and common questions between different fields, and to work towards making significant advances in movement research. A data challenge based on GPS tracking of lesser black-backed gulls (*Larus fuscus*) was used to stimulate initial discussions, cross-fertilization between research groups and to serve as an initial focus for activities during the workshop.

Keywords: GPS; movement ecology; segmentation; tracking; trajectories; visual analytics

1. INTRODUCTION

In ecology, the study of movement has gained great momentum in recent years [1,2]. As technology improves, more animal movement data are being collected at sea, on land and in the air, for a diverse range of taxa [3,4]. These data can be used to explore the intrinsic and external factors that may influence animal movement at different scales in space and time [5]. In turn, studying the movement of organisms can help understand the distribution and space use of species [6,7], foraging search strategies [8,9], animal navigation [10,11], spread of diseases [12] and facilitate applications, such as conservation biology [6].

Researchers studying moving objects, such as animals, ships, cars or pedestrians, face similar challenges in data analysis, interpretation and visualization. Typical technical challenges include identifying recurrent or abnormal spatio-temporal patterns of behaviour, identifying areas where objects converge in space and time and segmenting movement trajectories for further analysis. Unfortunately, the steps needed to go from data collection to gain new ecological insight, such as organization, exploration, visualization, quantification, inference and generalization of movement data, can be extremely demanding. Moreover, there are no established techniques to systematically apply these research steps, thus research on movement data is generally performed *ad hoc*.

The workshop brought together specialists from a wide range of disciplines with the aim of sharing expertise, research approaches, data and common questions between fields, and work together to advance movement research. To establish a common framework for discussions and interactive data exploration during the workshop, a data challenge was provided in advance and structured around an on-going tracking study of lesser black-backed gulls (*Larus fuscus*) [13]. The meeting included six plenary lectures from researchers involved in ecological and methodological research related to movement, group discussions and hands-on work sessions. Below, we summarize the topics covered during the workshop.

2. THE DATA CHALLENGE

Movement data were provided from a tracking study of lesser black-backed gulls breeding on Texel, The Netherlands, for four adult males and four adult females from 1 to 30 June 2010 (figure 1). Data were collected using the UvA Bird Tracking System [13]. Movement data included the individual ID of the bird, date and time, latitude, longitude, altitude above mean sea level, sensor temperature, GPS speed and distance from the nest. Participants were also provided with the nest location for each individual. For the first part of the challenge, participants quantified several aspects of movement, such as the number of trips per bird, trip duration, total distance travelled, distance from nest, flight speeds, amount of time spent in flight and aggregations of these values. The following criteria were provided to participants in order to filter and process the data: (i) a trip begins and ends when a bird moves 150 m away from the nest and returns within 150 m from the nest, respectively, (ii) any trip with a measurement gap of more than 60 min should be removed from further analysis, and (iii) only trips farther than 3 km from the nest were considered. A mean of 467 trips was identified with a mean trip duration of 5.3 h, the mean total distance per trip was 69.0 km and the mean maximum distance from the nest was 24.3 km. Interesting and unexpected variations in parameters which have significant ecological implications were identified, such as the number of trips and average speed. The data challenge was presented and discussed on the first day and used to help initiate and stimulate working group activities which are further described below.

3. UNCERTAINTY AND GRANULARITY

Uncertainties in animal movement data, owing to issues such as measurement spatial precision and accuracy and sampling frequency, may strongly influence interpretations of tracking data [14,15]. While an effect of sampling frequency on movement statistics such as total distance travelled, displacement speed

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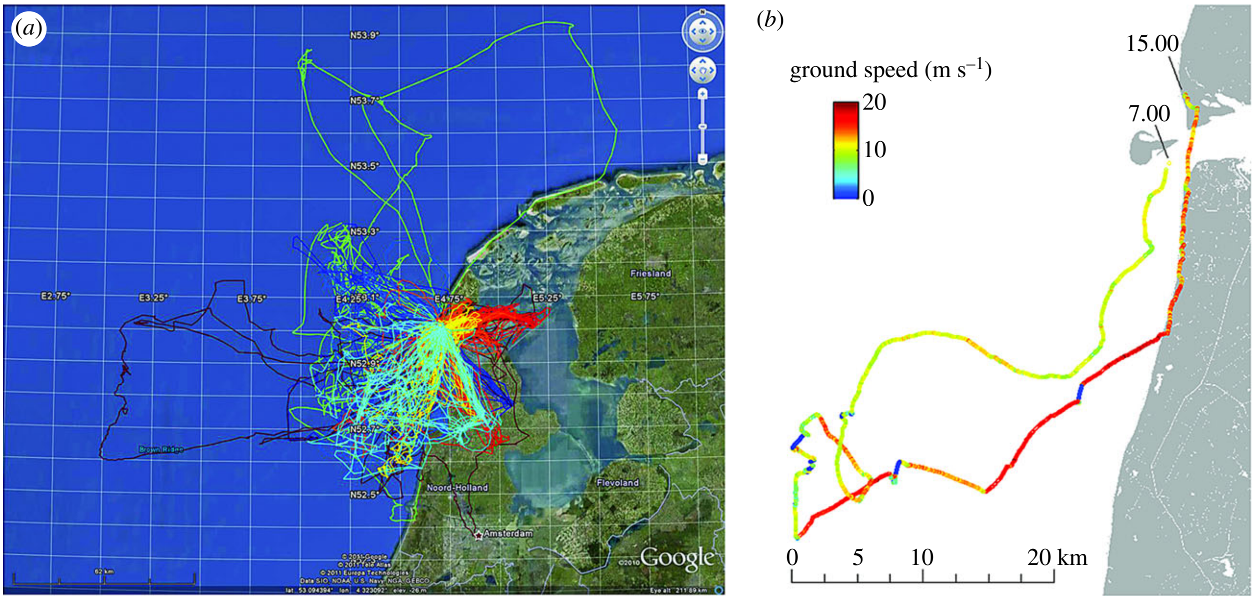

Figure 1. (*a*) Movements of eight adult lesser black-backed gulls used in the data challenge from 1 to 30 June 2010; different colours represent different individuals. (*b*) Trip of one individual (logger 320) from 07.00 to 15.00 24 June 2010, locations and instantaneous ground speed (ms^{-1}) were measured every 5 s; the grey areas represent land.

(ground speed calculated between two points) or turning angle is expected, it is not clear how, if at all, this effect can be corrected (figure 2). Furthermore, as sampling intervals increase, the uncertainty of the behaviour between fixes increases. The group explored ways to deal with these issues and extract extra information from instantaneous GPS measurements. For example, by combining instantaneous velocities measured by the GPS with displacement velocities it seems possible to measure homogeneity of behaviour within a given sampling interval, and thereby provide a statistic for segmenting trajectories into different behaviours (see §7).

4. INTEGRATING CONTEXT

When ecologists explore and interpret movement data, additional contextual information is implicitly and explicitly used in the process. For researchers developing methods, or ecologists who reanalyse data in the future, formal organization and storage of this information as some form of data annotation would be very useful. For gulls, this information may include attributes related to the individual such as sex, age and breeding status. Environmental information may also be very useful, such as habitat type (e.g. sea, coast, agricultural fields and urban areas), wind speed and direction, ocean current speed and direction. This also implies that an intermediate step is needed to collect and integrate diverse data sources which have different sampling scales in both space and time [6,16]. Context may improve data segmentation and classification (see §7) and be used in multi-dimensional visualization (see §5) and statistical analysis.

5. SCALE AND SCALABILITY

There is a need to explore data in multiple dimensions when trying to understand the movement of animals. Examples of variables which are sometimes available, beyond geographical space and time, are altitude (on land or in the air) or depth (under water), the speed of movement or information from additional sensors like acceleration or heart rate. The visual exploration of multi-dimensional data is inherently difficult, whereby scalability is a particularly important issue. Most tools can be applied to explore a small number of trajectories effectively (e.g. [10]), while the analysis of larger datasets is often required for generalization purposes. Workshop participants explored techniques from visual analytics [17] and geographical information science to deal with some of these issues. In particular, the group generated a prototype visualization for goose migration, focusing on key stopovers in space and time.

6. SPACE AND TIME

When considering resource use by animals on the basis of movement data, it is of interest to account for spatial and temporal auto-correlation of movement characteristics such as step length, speed and turning angle and to distinguish sites visited for a continuous period from sites revisited intermittently. This group discussed how to quantify and visualize space use when accounting simultaneously for time and explored the (combined) application of space–time cubes [18], Brownian bridges [19] and visual analytics. Another focus was the similarity of multiple trajectories over space and time, for example, when studying the interaction between individuals during flight [20]. Here, a combination of Brownian bridges to summarize trajectories via probability densities and the Earth Mover's Distance [21] to compare these densities was explored.

7. SEGMENTATION AND CLUSTERING

In movement analysis, data segmentation [22] and clustering can be used to reach higher levels of data aggregation, facilitating quantification, generalizations

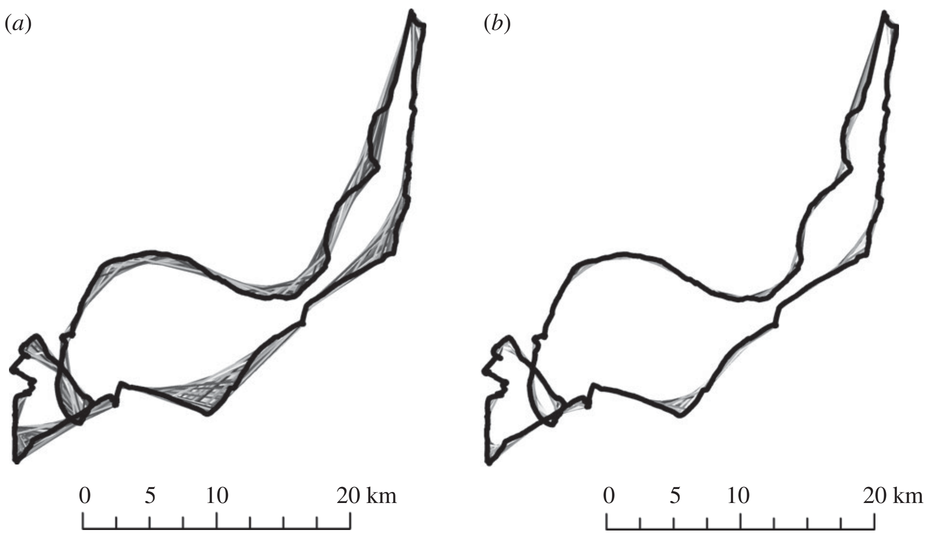

Figure 2. An example of the effect of sampling interval. Locations of one gull (logger 320, figure 1*b*) were measured every 5 s on 24 June 2011 and re-sampled 100 times at (*a*) 600 s and (*b*) 300 s intervals using a Monte Carlo simulation [14]. Fine scale movements are clearly lost at 600 s intervals, while slow and relatively straight movement segments such as long bouts of floating (more than 2 h) are retained at 600 s. Thick black line shows original trajectory for comparison.

and comparative analysis within and across individuals and taxa. The group discussed different approaches and set up plans to develop applications for data clustering and segmentation that could dynamically link to movement of web services where data are stored in standard formats and facilitate large user communities through initiatives such as Movebank [23,24] and Tagging of Pacific Predators [6].

8. CONCLUDING REMARKS

During the workshop, it was clear that, while there was some overlap between the heterogeneous research communities, there were also many differences in methods, aims, terminology or even criteria for successful collaboration, yet the workshop helped in bridging these gaps. Participants were enthusiastic about the inclusion of the data challenge and pre-workshop analysis using a common, clearly defined dataset and ecological case study. Beginning the workshop with presentations of the data challenge results provided researchers from diverse disciplines with a common basis for communication and interaction. One of the main conclusions of the meeting was that there was much to be gained by interdisciplinary research when studying movement. Two areas were identified where such collaborations might be especially successful, not only to help answer existing questions, but also to reveal unexpected patterns and generate new hypotheses: trajectory segmentation and developing tools (possibly for very specific tasks) to visually and interactively explore large datasets in space and time. Ecologists could benefit from tools being developed for very different applications while methodological researchers could benefit from working with people with specific domain-related research questions and a good understanding of their data. Furthermore, there was interest in sharing data and developing reference datasets to help develop, test and compare methodologies, for cross-taxa comparative analysis and for educational purposes. We look forward to further cross-fertilization between these diverse and complimentary disciplines.

Additional information about the workshop and plenary presentations are available online: http://www.lorentzcenter.nl/lc/web/2011/453/info.php3?wsid=453. We thank the participants for lively discussions, active participation and contributing to the data challenge and Ikram Cakir, Mieke Schutte and Pauline Vincenten for their organizational support. The workshop was funded by the Lorentz Centre and MOVE (COST Action IC0903). Tracking data were collected with the support of W. Bouten, the tracking research infrastructure is supported by LifeWatch and the BigGrid infrastructure for eScience (http://www.biggrid.nl).

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