A hybrid point-path approach for inferring dynamic interactions between pairs of moving objects

Jennifer A. Miller

The University of Texas at Austin. 1 University Station A3100 Austin, TX 78712 USA

Email: jennifer.miller@austin.utexas.edu

Abstract

'Interactions' between and among moving objects occur across widely varying spatial and temporal scales and are an important component for understanding spatial behaviours such as mating, predation, and territoriality as well as phenomena resulting from these behaviours such as disease spread. Behaviours and processes related to interactions are extremely important across many different objects, scales, and contexts, but they are generally difficult to quantify for reasons including semantic uncertainty (what is an 'interaction'?), analytical tractability (how should interactions be measured?), and issues related to interpretation and inference. While moving objects that interact can range from micro-scale (e.g., gas particles) to macro-scale (e.g., continental plates), the two most frequently studied types of objects are related to human and animal movement. 'Dynamic interactions' refer to interactions that are defined based on proximity in both space and time and while social network analysis can be applicable for studying interactions among human individuals as well as among animal individuals, a 'dyad' (comprised of two individuals) is more often used as the unit for studying interactions between animal individuals. The two main approaches of quantifying dynamic interactions between two individuals involve treating the locations as discrete **points** or examining the **paths** that are inferred as trajectories between subsequent points. In this research I present results that use a hybrid point-path approach of quantifying interactions and provide a new way to interpret them based on a null model approach. The hybrid point-path approach is applied to moving object data of wildlife animal species that represent different levels of difficulty with what is 'known' about their sociality.

Key words: movement pattern analysis, spatiotemporal, trajectories, null model, interaction

1 Introduction

'Interactions' between and among moving objects occur across widely varying spatial and temporal scales and are an important component to processes ranging from disease spread to information flow and technology diffusion. For example, close contact in space and time is often a prerequisite for the spread of diseases such as rabies, chronic wasting disease, and influenza while the spread of latent diseases such as anthrax require proximity in space with a temporal lag. Communication related to information flow can occur when two objects are spatially and temporally synchronous (e.g., face to face communication), temporally synchronous but spatially distant (e.g., telephone), spatially near but temporally distant (e.g., scent markings), and distant in both space and time (e.g., email message) (Miller 2005).

Interactions can also be negative, representing behaviours such as avoidance or repulsion. While behaviours and processes related to interactions are extremely important across many different objects, scales, and contexts, they are generally difficult to quantify for reasons including semantic uncertainty (what is an ‘interaction’?), analytical tractability (how should interactions be measured?), and issues related to interpretation and inference. ‘Dynamic interactions’ refer to interactions that are defined based on proximity in both space and time and while social network analysis can be applicable for studying interactions among human individuals as well as among animal individuals, a ‘dyad’ (comprised of two individuals) is more often used as the unit for studying interactions between animal individuals. The two main approaches of quantifying dynamic interactions between two individuals involve treating the locations as discrete **points** or examining the **paths** that are inferred as trajectories between subsequent points. In this research I present results that use a hybrid point-path approach of quantifying interactions and apply this method to dyads from different wildlife animal species with different levels of ‘sociality.’

Social network analysis has been employed to study interactions among several objects and the direction, magnitude and centrality of connections can be quantified, but this analysis framework is only appropriate for studying group dynamics for which sufficient spatio-temporal data are available. Dyads are a pair of objects (ex., humans, cheetahs, baboons) that represent a basic unit for studying interactions and sociality. Within GIScience research, human interactions have been studied more extensively than other types, and they are often based on detailed information such as ‘travel diaries’ from which activity spaces can be calculated and intersections of multiple activity spaces can be used to estimate potential social interaction and joint activity participation (Farber et al.,2013). Recent work has addressed the issues associated with measuring dynamic (human) interactions with hybrid, multi-temporal methods (Zhang et al. 2018).

In ecology, interactions have been defined as “actions directed towards, or affecting, the behaviour of another animal” (Whitehead, 2009:765) and while in rare cases they have been directly observed (Cooper et al., 2008; Ramos-Fernández et al., 2009; Haddadi et al., 2011), most of the time interactions are inferred by assuming spatial association to be equivalent to social association (the ‘gambit of the group’ (Whitehead and Dufault 1999).

Measuring interactions between animals is not straightforward, and depending on the objective of the study, what is considered an “interaction” can range from physical contact to sharing common resources, to basic awareness of each other. In spite of the importance of studying interactions, they have not been a main research focus in either computational movement analysis (GIScience) or movement ecology. Recent contributions using movement data to study interactions have focused primarily on technological advancements related to the ability to measure interactions rather than the ability to analyze or understand them. ‘Proximity loggers’ attached to individuals can record when a similarly outfitted animal comes within a specified distance and temporal threshold and can measure sustained interaction, but can only be used for relatively short distances (~100 meters) (see Drewe et al., 2010 for overview).

While these new advancements enable more and better quality data to be collected, and have resulted in an increasing number of studies on animal or human interaction, there have been few methodological advancements related to improving the ability to analyze and understand interactions.

Interactions are measured using data representing the locations of two individual along with a time stamp and the two main approaches involve treating the locations as discrete points or examining the paths that are inferred as movement between subsequent points. In this research I present results that use a hybrid point-path approach of quantifying interactions and provide a new way to interpret them based on a null model approach. The hybrid point-path approach is applied to dyads from different animal species that represent different levels of difficulty with what is known about their ‘sociality.’

1.1 Modeling interactions

Dyad interactions are measured based on either the point data or the paths or trajectories that are inferred as connecting subsequent points. When point data are used, interaction is defined either as a function of distance (e.g., the mean distance of all pairs or the number of times a pair is within a critical distance) or co-occurrence in some shared area (ex., the overlapping portion of their home range). While these point-based dynamic interaction metrics involve the concept of two individuals occurring “together”, path-based interaction metrics use movement trajectories as the basic unit of analysis and compare similarity in movement parameters such as speed, direction, and mean displacement (Calenge et al. 2009). These path-based metrics define interaction solely in terms of movement similarity and do not consider the distance between the two individuals or their location relative to designated spaces such as home range overlap. Since point-based metrics include explicit representations of proximity, they may be more appropriate for studying positive interactions such as direct contact related to mating or disease spread. Each of these approaches (point vs. path) has generally been considered separately when measuring interactions, although metrics that combine them are being introduced (Konzack et al. 2017, Zhang et al. 2018). The movement coherence quantified by path-based metrics may make them more appropriate for studying both positive and negative interactions related to, ex., predator-prey dynamics.

Both point- and path-based interaction metrics have limitations as well. Point-based interaction metrics typically require a subjective parameter such as home range delineation or a distance threshold. Distance thresholds can be based on previous research or observation while temporal thresholds are often a function of the data resolution. Path-based metrics involve fewer subjective decisions, but what they are measuring in terms of ‘interaction’ is really path similarity irrespective of spatial proximity and may not be appropriate for some applications.

In spite of the importance of measuring interactions, they have not been a main research focus in movement analysis. Few studies have tested different dynamic interaction metrics using the same data, and when they have been compared, the results have been quite incongruous (Long and Nelson 2013, Long et al. 2014; Miller, 2012; 2015). Most of the metrics that measure interactions range from -1 to 1 or 0 to 1 and either specify negative interaction or no interaction as the lowest value. However, it is unclear whether negative interaction can be measured using the same metrics as positive interaction. In fact, studies that have compared performance of these metrics using simulated data rarely find evidence of negative interaction (Long et al., 2015; Miller 2015). This research aims also to explore whether negative interaction can be identified with this hybrid point-path measure.

2 Methodology

The research presented here introduces a hybrid point-path approach to analyse interactions that harnesses the advantages of each approach. First, a point-based interaction is identified based on appropriate spatial and temporal thresholds. Then movement trajectory parameters including relative angle and step length are calculated for an appropriate number of 'steps' before the interaction, after the interaction, and compared to the movement parameters for the rest of the steps. The appropriate number of steps are dependent on the type of interaction of interest and the temporal resolution of the data. For example, when studying Brown Hyena interaction, one to three one hours steps before and after will be tested. Significant differences in these parameters (before- after-, and the rest of the steps) are used to identify potential movement behaviours such as attraction and avoidance.

3 Preliminary results

The new hybrid method introduced here uses GPS locations representing point-based dynamic interactions (two individuals within a spatial and temporal threshold) to compare path-based movement trajectories relative to the "interaction". Figure 1 shows the distribution of relative turning angles for two brown hyena individuals (Cyril and Honey) relative to when a spatio-temporal "interaction" occurred (locations within 500 meters and 1 hour of each other). The distribution of angles for the two steps that occurred right before an interaction are in blue; all other angles are in red. These preliminary results suggest that both individuals use more tortuous movement (relative angles between 150-210 degrees) right before they are close in space and time compared to all of their other movements.

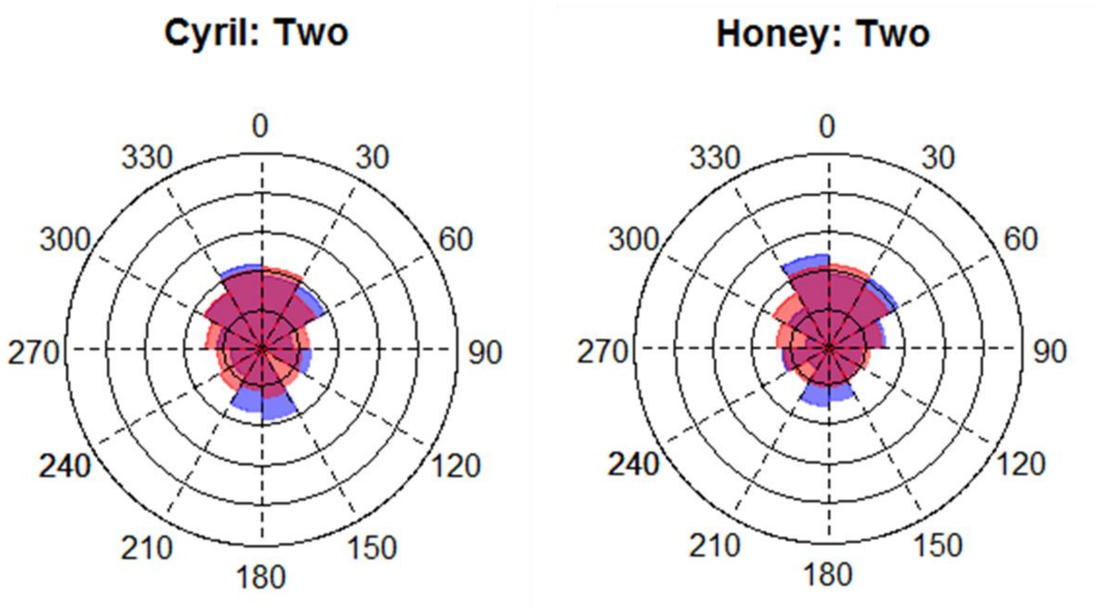

Figure 1: Distribution of relative turning angles for two hyenas (Cyril and Honey). Blue represents the angles **two steps** before an “interaction” occurred and red represents the angles for all other steps.

Acknowledgements

I gratefully acknowledge the assistance of Brendan Hoover and the support of National Science Foundation (#1424920).

References

Calenge, C., Dray, S., Royer-Carenzi, M., 2009. The concept of animals’ trajectories from a data analysis perspective. Ecological Informatics 4, 34–41.

Cooper, S.M., Perotto-Baldivieso, H.L., Owens, M.K., Meek, M.G., Figueroa-Pagán, M., 2008.Distribution and interaction of white-tailed deer and cattle in a semi-arid grazing system. Agriculture, Ecosystems & Environment 127, 85–92.

Drewe JA, Weber N, Carter SP, et al. (2012) Performance of Proximity Loggers in Recording Intra- and Inter-Species Interactions. *PLoS ONE*, 7(6), e39068.

Farber, S., Neutens, T., Miller, H.J., Li, X., 2013. The Social Interaction Potential of Metropolitan Regions: A Time-Geographic Measurement Approach Using Joint Accessibility. Annals of the Association of American Geographers 103, 483–504.

Haddadi, H., King, A.J., Wills, A.P., Fay, D., Lowe, J., Morton, A.J., Hailes, S., Wilson, A.M., 2011. Determining association networks in social animals: choosing spatial–temporal criteria and
sampling rates. Behav Ecol Sociobiol 65, 1659–1668.

Konzack, M., McKetterick, T., Ophelders, T., Buchin, M., Giuggioli, L., Long, J., Nelson, T., Westenberg, M.A. and Buchin, K., 2017. Visual analytics of delays and interaction in movement data. International Journal of Geographical Information Science, 31(2), pp.320-345.

Long, J.A. and Nelson, T.A., 2013. Measuring dynamic interaction in movement data. *Transactions in GIS*, *17*(1), pp.62-77.

Long JA, Nelson TA, Webb SL, et al. (2014) A critical examination of indices of dynamic interaction for wildlife telemetry studies. Börger L (ed.), *Journal of Animal Ecology*, 83(5), 1216–1233.

Miller, H.J., 2005. Necessary space—time conditions for human interaction. Environment and Planning B: Planning and Design, 32(3), pp.381-401.

Miller JA (2012) Using Spatially Explicit Simulated Data to Analyze Animal Interactions: A Case Study with Brown Hyenas in Northern Botswana. *Transactions in GIS*, 16(3), 271–291.

Miller, J.A., 2015. Towards a better understanding of dynamic interaction metrics for wildlife: a null model approach. *Transactions in GIS*, *19*(3), pp.342-361.

Nathan R, Getz WM, Revilla E, et al. (2008) A movement ecology paradigm for unifying organismal movement research. *Proceedings of the National Academy of Sciences*, 105(49), 19052–19059.

Ramos-Fernández, G., Boyer, D., Aureli, F., Vick, L.G., 2009. Association networks in spider monkeys (Ateles geoffroyi). Behav Ecol Sociobiol 63, 999–1013.

Whitehead, H., 2009. SOCPROG programs: analysing animal social structures. Behavioral Ecology and Sociobiology, 63(5), pp.765-778.

Whitehead H, Dufault S (1999) Techniques for analyzing vertebrate social structure using identified individuals: review and recommendations. Adv Study Behav 28:33–74.

Zhang, P., Beernaerts, J. and Van de Weghe, N., 2018. A Hybrid Approach Combining the Multi-Temporal Scale Spatio-Temporal Network with the Continuous Triangular Model for Exploring Dynamic Interactions in Movement Data: A Case Study of Football. ISPRS International Journal of Geo-Information, 7(1), p.31.