# Mapping Interactive Behaviour in Wildlife from GPS Tracking Data

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**Summary**

Wildlife researchers now routinely collect detailed data on animal movement using GPS tracking. Methods for studying interactive (e.g., social) behaviour in tracked animals remain limited. I propose three new methods for *mapping* interactive behaviour from GPS tracking data, drawing on fundamental geographical concepts, most notably Hägerstrand's time geography. I demonstrate each method on simulated data and will use examples from my research on white-tailed deer tracked with GPS collars to further exemplify each method. My analysis suggests that how interaction is represented in a GIS leads to different interpretations of wildlife behaviour, but also unique opportunities for further spatial analysis. Open-source software (in R) is provided for other researchers wishing to implement the proposed methods.

**KEYWORDS:** dynamic interaction, movement, time geography, wildlife telemetry, spatial-temporal analysis

## 1 Introduction

The study of wildlife movement ecology has been enhanced by the development of sophisticated tracking devices, most notably those utilizing GPS (Cagnacci et al., 2010; Tomkiewicz et al., 2010). Modern wildlife tracking studies now frequently collect data on multiple individuals being tracked simultaneously, with increasing spatial and temporal resolutions. These advances are facilitating new research questions relating to joint movement behaviour – often termed dynamic interaction (Kernohan et al., 2001). While many methods exist for studying complex spatial-temporal patterns in individual-level movement, methods for studying joint movement behaviour in animal tracking data remain limited in both scope and sophistication (Long et al., 2014).

Studying interactive behaviour is important to many areas of wildlife ecology (e.g., the spread of disease). Typically methods for studying interactive behaviour from wildlife tracking data have simply focused on testing whether or not interaction exists (Doncaster, 1990; Kenward et al., 1993). Moving beyond tests for the presence of interaction, researchers strive to associate interactive behaviour with underlying geographic variables. Thus, new methods for mapping where wildlife interactions

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occur across the landscape are essential to discovering relationships between interactive behaviour and spatially-heterogeneous geographic variables (e.g., landcover).

## 2 Methods

Here I propose three methods for mapping interactive behaviour from wildlife tracking data that result in three different GIS representations: point, path, or polygon.

### 2.1 Contact Points

Consider two tracking datasets $A$ and $B$ each comprising of GPS fixes recorded at discrete times. Two fixes ($a_i$ and $b_j$) are considered simultaneous if they are recorded at times within a pre-defined critical temporal threshold ($t_c$) of each other ($i - j < t_c$). Two fixes ($a_i$ and $b_j$) are considered proximal if they are located within a pre-defined spatial distance ($d_c$) of each other ($||a, b|| < d_c$). A contact is defined as occurring when two fixes are both temporally simultaneous and spatially proximal. To map the contact point, we first define the contact vector ($C$) connecting the two contact fixes and identify the mid-point of this vector, which we define as the *contact point* ($c_k$; Figure 1).

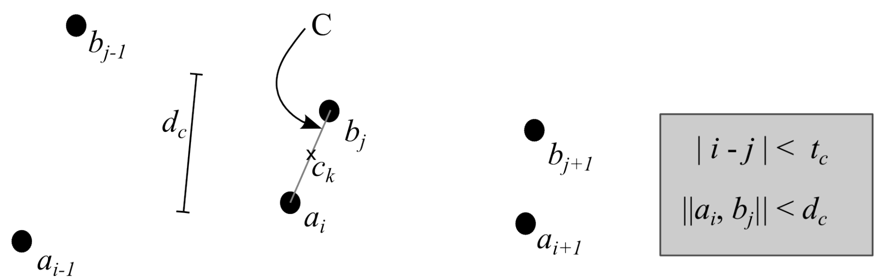


Figure 1: Contacts are defined when two fixes $a_i$ and $b_j$ are both temporally simultaneous ($i-j < t_c$) and spatially proximal ($||a, b|| < d_c$). A contact point ($c_k$) is then defined by the mid-point of a contact vector ($C$) and contact points can be mapped across the study area.

### 2.2 Interaction Paths

I extend the contact point method from 2.1 to continuous time in order to map *interaction paths*. For any time point $\tau$, $a_\tau$ ($b_\tau$) is an interpolated estimate of the location of animal $A$ (resp. $B$) along its movement path. From two location estimates, compute whether a contact point ($c_\tau$) occurs at time $\tau$ identically to the method from 2.1. If a contact point occurs at $\tau$, we add this point to the interpolation path, if it does not, we move to the next $\tau$ (Figure 2). Consecutive periods of interaction behaviour are stored as separate lines within the interaction path, representing different periods of interactive behaviour.

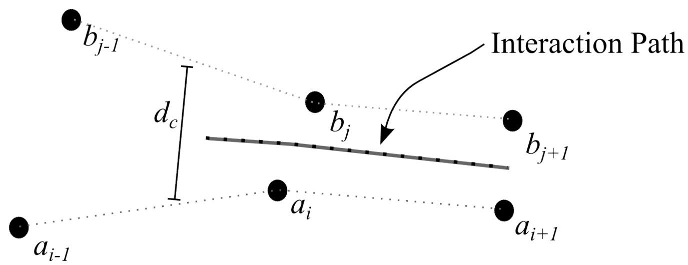


Figure 2: Interaction paths extend contact points to continuous time by interpolating animal locations along their trajectory. Interaction paths represent independent periods of interactive behaviour as separate paths (lines) on the map.

### 2.3 Social Interaction Spaces - Joint Potential Path Area (jPPA)

Drawing from existing movement theory from Hägerstrand's (1970) time geography, I use space-time prisms in order to delineate the social interaction space (Farber et al., 2013) of any two animals. *Social interaction spaces* are defined by the intersection of two (or more) individual space-time prisms (Figure 3), which delineate the movement opportunity space of an individual based on known movement locations (i.e., GPS tracking fixes) and an upper bound on mobility, termed $v_{max}$. Individual space-time prisms can be estimated from GPS tracking using the rigorous mathematical definitions from Miller (2005) and have been applied to wildlife previously in order to estimate home ranges (Long and Nelson, 2012). The social interaction space can be delineated simply by intersecting the space-time prisms from Long and Nelson (2012). Projecting the social interaction space onto the geographical plane results in a spatial measure of joint movement opportunity – the *joint potential path area* (jPPA; Figure 3b).

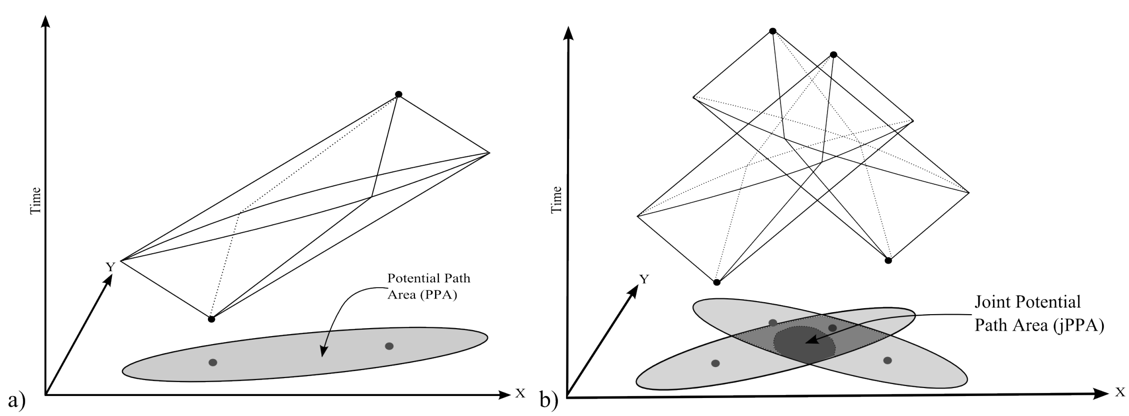


Figure 3: a) Space-time prism, between two known fixes, along with the potential path area (PPA) the projection of the space-time prism onto the geographical plane. b) Intersection of two space-time prisms representing the social interaction space. The projection of the social interaction space onto the geographical plane is a polygon termed the joint potential path area (jPPA).

## 3 Example: Simulated Data

To demonstrate each of the point, path, and polygon-based methods for mapping interactive behavior in wildlife tracking data I use simulated data consisting of two biased correlated random walks (Barton et al., 2009), where the bias in the second individual (Figure 4) is to the location of the first individual (following the procedure used in (Long et al., 2014)). The simulation approach was chosen as it allows for control of factors representing interaction strength and number of interaction episodes. In my presentation, I will also draw on examples from my research examining movement patterns in white-tailed deer tracked via GPS collars (Long et al., 2014).

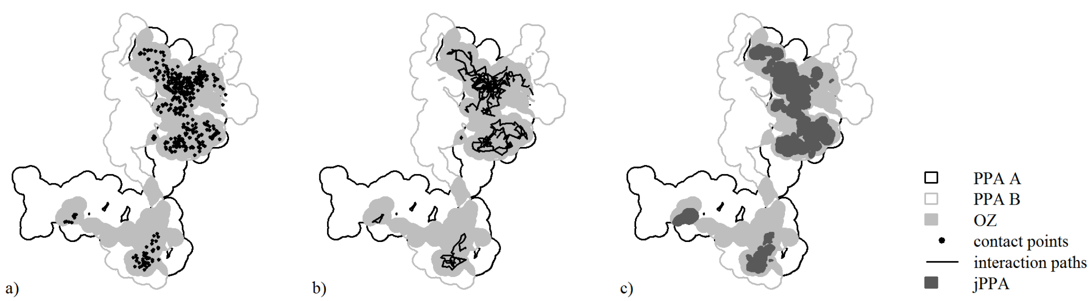


Figure 4: GIS mapping of contacts (using three different approaches) for a simulated dataset consisting of two biased correlated random walks. Mapped alongside the home ranges for each individual, and the home range overlap zone, are the a) contact points, b) interaction paths, c) joint potential path area (jPPA) polygons.

## 4 Discussion

The methods developed here focus explicitly on mapping where interactions occur within the landscape. In the past, methods have focused primarily on identifying only whether interactive behavior is present or absent (Doncaster, 1990; Kenward et al., 1993). Methods that are spatially explicit offer wildlife researchers the potential to explore spatial heterogeneity in interactive behavior across the landscape. Further spatial analysis of mapped contact points, interaction paths, or jPPA polygons will enable linkages between the patterns in interaction and wildlife behavior to be uncovered. For example, contact points can be analyzed as a spatial-temporal point pattern in order to examine spatial temporal clusters (i.e., hot spots) of interaction. Similarly, polygon shape metrics (e.g., number, area, shape complexity) applied to jPPA polygons can provide valuable insight into the behavioral processes generating observed interactions.

By mapping where interactions occur across the landscape researchers can begin to link interactive behavior to widely available datasets describing the landscape (e.g., from remotely sensed data). The spatial associations between mapped landscape variables (e.g., habitat types, topography) are likely to provide further insight into the environmental conditions associated with interactive behavior in wildlife. Further, point, path, and polygon-based measures of interaction can be compared directly to other discrete features existing on the landscape. For example, in many species it will be interesting to examine how interactive behavior is associated with linear features on the landscape (e.g., roads or cut-lines used for natural resource extraction activities, Latham et al., 2011).

The contact point method proposed can be easily extended. For example, attributes associated with the contact points (e.g., the $||a, b||$ distance) could be appended to contacts facilitating more sophisticated spatial analysis of contact point maps (e.g., as a marked point pattern). The interaction path method utilizes a simplistic linear interpolation algorithm from which to estimate the location of the animal along the movement path. While linear interpolation has been utilized widely, both for reasons of ease of implementation and effectiveness, more sophisticated algorithms for interpolating paths (e.g., curvi-linear, Tremblay et al., 2006) could enhance the analysis, especially with certain species (e.g., marine mammals). Finally, the jPPA method is limited in that it maps areas where interaction potentially could have occurred. Incorporating probabilistic models (e.g., Buchin et al., 2012) in order to estimate contact probabilities will further enhance jPPA analysis.

## 5 Conclusion

The growth of wildlife tracking, using GPS, has expanded substantially in recent years and wildlife ecologists are now equipped with incredibly rich data from which to study animal movement patterns (Cagnacci et al., 2010). Objective and quantitative methods for extracting useful movement patterns are required to better understand movement processes and relate these patterns to underlying-contextual information (Purves et al., 2014). Here I provide three straightforward approaches (point, path, and polygon) for mapping interactive behavior as applied to the study of wildlife tracking data. The contact point method provides easy to interpret point-maps of where contacts occur. The interaction-path method identifies areas where sustained interaction periods occur. Finally, the jPPA polygons identify areas of potential interaction that are easily integrated into home range analysis and can be straightforwardly linked to other spatial variables. Each method can be easily computed in a GIS, and I have implemented each as part of the R package `wildlifeDI` (Long et al., 2014) in an effort to facilitate wildlife interaction mapping by other researchers.

## 6 Biography

Jed Long is a Lecturer in GeoInformatics in the Department of Geography & Sustainable Development at the University of St Andrews. His research interests span quantitative geographical analysis and spatial ecology. Much of his work focuses on studying spatial patterns in wildlife movement through the use of GPS tracking data.

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