Cross-Scale Movement Trajectory Analysis

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1. Introduction

Individual movement can be characterised by descriptive movement parameters such as speed, sinuosity, or turning angle. Such movement parameters are normally derived from *trajectories*, that is two-dimensional time-stamped poly-lines. However, just as with the classic example of ‘slope’ derived from a terrain in geomorphometry, there is no *true* speed or sinuosity for a given time-stamp on a trajectory since any such attribute is defined as a function of sample point spacing, – or *scale* (Goodchild, 2001).

In this paper we aim to explore the sensitivity of a range of derived parameters to temporal scale, largely motivated by our access to a rather unique data set, featuring grazing cows whose position was recorded with very high temporal resolution. Such data allows cross-scale analysis of movement properties, enabling sampling at sub-second, minute, or even hourly scales. In this experiment we therefore address the specific research question – to what degree do movement parameters such as speed, sinuosity, or turning angle vary when derived at variable temporal scales?

We present a method where movement parameters are computed along trajectories, whilst the temporal analysis scale is systematically varied. The statistical properties of the resulting scale classes are visualised in box whisker plots, mapping speed, sinuosity, and turning angle as a function of temporal analysis scale. Initial experiments with two trajectories capturing the movement of cows in a paddock illustrate our method.

2. Background

In ecology, it is widely acknowledged that the key to the understanding of observed phenomena lies in the elucidation of the mechanisms intertwining pattern and scale (Levin, 1992). In GIScience, cross-scale methods investigating a geographic phenomenon at multiple scales have, for example, been exemplified for the measurement of the shape of the earth’s surface (Fisher *et al.*, 2004) and point clustering (Lu and Thill, 2008). Whereas the former reference stands for the crucial discussion on the scale-dependant definition of vague spatial features, the latter represents research identifying critical scales at which abrupt changes of patterns occur, or invariance across scales. Both examples illustrate that any selection of scale for modelling or analysing spatial phenomena may significantly influence what we see and hence how we understand the phenomenon under study.

When researching methods for cross-scale analysis for movement data, a side trip beyond GIScience and into behavioural ecology is rewarding. For decades, biologist have recorded and analysed the paths of animals of all sizes and across various scales. For example, Fryxell et al. (2008) summarise several studies investigating animal movement at three different scales (coarse-scale, intermediate-scale, fine-scale). However, most such cross-scale studies focus on biology and not methods, and furthermore rely on different data sources for different scales and hence hardly allow detailed methodological cross-scale studies.

Nams (2005), however, is an exception relevant to this experiment as he explicitly derives fractal dimension D (as a measure for sinuosity, or *tortuousity* as it is often termed in behavioural ecology) for the same trajectories at various scales. The hypothesis underlying his research states that animals express different movement behaviours (e.g., tortuous foraging at fine scales but directed advances at coarse scales) at different scale sections (so called 'domains'), which are identified through cross-scale analysis. In contrast to Nams' work focussing on space-only fractal dimension D, we suggest (a) the joint analysis of several movement parameters (speed, turning angle, *and* sinuosity), (b) the inclusion of inherently spatio-temporal movement parameters (e.g. speed), and (c) the explicit analysis of the measurement variance to be found at different analysis scales through box whisker plots.

3. Data and data preprocessing

The trajectories emerged from a smart farming project applying wireless sensor technology, carried out with CSIRO ICT Centre and CSIRO Livestock Industries, Rockhampton, Australia. Ten cows were tagged with GPS receivers and their trajectories were monitored whilst the cows were grazing on a paddock of 600m*200m at the CSIRO Rockhampton research site. The data cover roughly three days of continuous tracking at a sampling rate of four fixes per second. Out of the ten individuals two focus trajectories were selected for this experiment (#1008 and #1016), each featuring approximately one million fixes. For this experiment phases of extended resting were excluded by segmenting trajectories with resting phases (not moving beyond a threshold d = 0.6m for 10 minutes) serving as segment separators (45 segments for #1008, 26 for #1016).

4. Methods

In this paper we explore both *temporal sampling intervals* (the effects of the underling temporal resolution of our data) and the *temporal analysis scale* at which we measure a parameter (the measurement window over which we calculate a value). For the initial experiments presented in this abstract, the width of the moving measurement window was set to the same temporal analysis scale as the sampling interval (that is for sampling interval s = 10sec a window of width w = 10 sec). Hence, in the remainder of this paper the term 'scale' refers both to temporal sampling interval and temporal analysis scale. The sampling/analysis ratio, however, need not be constant but is a parameter of the presented method and its influence shall be investigated in further work.

The method investigates movement parameters for a series of temporal scales (0.5sec, 1sec, 10sec, 1min, 2min, 5min, 10min, 0.5h, 1h, 2h, 3h). At every given temporal scale, a moving window was shifted along the trajectory, systematically sampling the investigated movement parameter (Laube *et al.*, 2007). See Figure 1 for an illustration with three temporal scales s_1, s_2, and s_3 and three sampling windows w_1, w_2, and w_3. Note that sampling was only permitted within continuous segments between resting phases. All sampled values per scale were binned and each bin resulted in an item on the ordinate of the box whisker plots (see Figure 2).

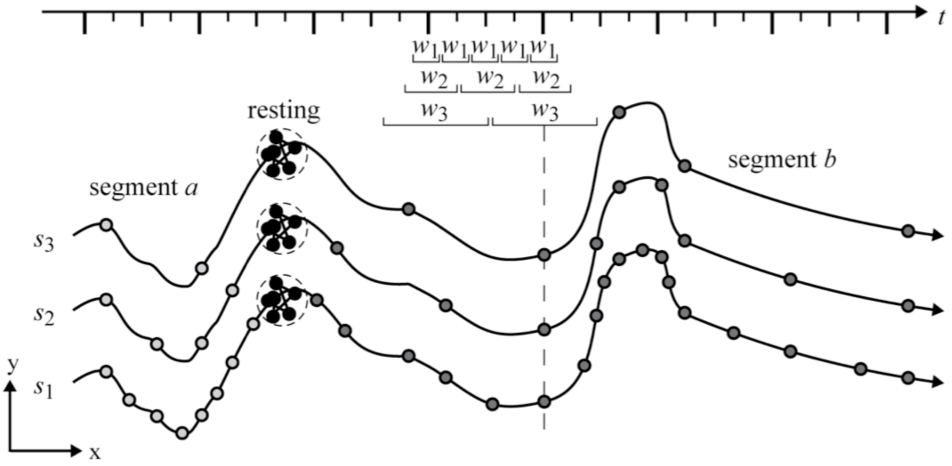

Figure 1. Deriving movement parameters at variable temporal scales.

Given a window *w*, *speed* and *turning angle* were computed for every *fix(t)* as the centered average for three fixes, sampled at $t_{-0.5w}$, *t*, and $t_{+0.5w}$. Although there exists a plethora of ways to term and compute 'wigglyness' of a poly-line (Claussen *et al.*, 1997), we chose *sinuosity* (Dutton, 1999), as the ratio between the actual track length and the line connecting the end points of the sampling window *w* (values of 1 representing straight trajectories, values > 1 indicating increasingly sinuous trajectories).

A Java application was coded for computing the trajectory parameters, and the R statistics environment was used for statistics and the box whisker plots. The box whisker plots show medians (horizontal bar), 25th and 75th percentiles enclosing the middle 50% of the data (boxes, also interquartile range, IQR), minimum and maximum values (whiskers), and outliers (data points more than 1.5 times the IQR from either end of the box).

5. Preliminary results

Figure 2 illustrates multi-scale box-whisker plots for speed, sinuosity, and turning angle for the two cows. Note that both speed and sinuosity plots do not show all values and that the sinuosity plot has a logarithmic y-axis. As a first observation both plot series are strikingly similar. This finding can be explained by the fact that both individuals move within a herd for most of the time, showing significant movement coordination.

Very short scale intervals measure the instantaneous magnitude of velocity, since sinuosity at these scales is ~1. As sinuosity increases with scale, speed typically decreases since the actual displacement resulting from a sinuous path is less than the path length. *Sinuosity* and its variance increase with scale, levelling out above a factor 10 at a scale of about two minutes. Perhaps surprisingly the two finest scales show very little variance, as we might expect considerable noise for narrow windows. However, these scales are very close to the raw data sampling of 4 fixes per second, and the signal to noise ratio is low after we filter resting cows, and explore movement parameters for moving cows. We speculate that the increase of sinuosity after 2h and 3h is probably due to the extent of the paddock. Grazing cows cross the paddock in around that time and are then pushed back by the fence, resulting in convoluted trajectories. Little variance is also found for *turning angle* at fine scales for the same reasons, though turning angles seems to contain little scale dependence in general.

A key result is that the joint analysis of speed and sinuosity reveals at which temporal scale speed is best measured. The low variance in sinuosity for the two finest scales suggests that cows diverge little from direct paths. That in turn implies that we can estimate the actual grazing speed of cows to be around $0.2 ms^{-1}$, which could then be used, for example, to estimate energy use over time.

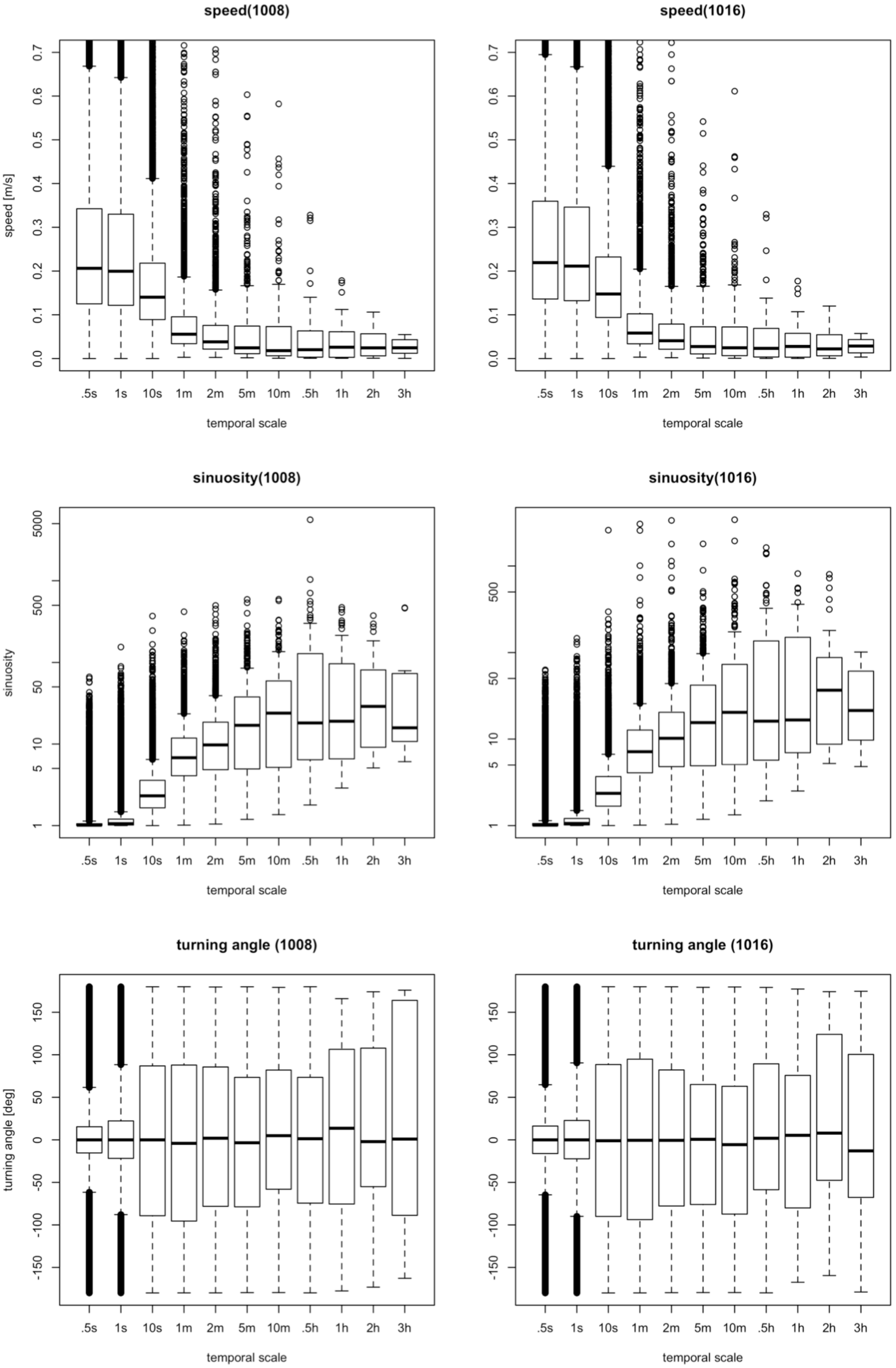

Figure 2. Cross-scale analysis of speed, sinuosity, and turning angle for two cows (#1008, #1016).

6. Acknowledgements

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References

Claussen D L, Finkler M S and Smith M M (1997) Thread trailing of turtles: methods for evaluating spatial movements and pathway structure *Can. J. Zool.-Rev. Can. Zool.* **75** pp2120-2128

Dutton G (1999) Scale, sinuosity and point selection in digital line generalisation *Cartography and Geographic Information Systems* **26** pp33-53

Fisher P, Wood J and Cheng T (2004) Where is Helvellyn? Fuzziness of multi-scale landscape morphometry *Transactions of the Institute of British Geographers* **29** pp106-128

Fryxell J M, Hazell M, Börger L, Dalziel B D, Haydon D T, Morales J M, McIntosh T and Rosatte R C (2008) Multiple movement modes by large herbivores at multiple spatiotemporal scales *Proceedings of the National Academy of Sciences* **105** pp19114-19119

Goodchild M F (2001) *Modelling Scale in Geographical Information Science*, ed N J Tate and P M Atkinson New York, NY: John Wiley and Sons pp 3-10

Laube P, Dennis T, Walker M and Forer P (2007) Movement Beyond the Snapshot - Dynamic Analysis of Geospatial Lifelines *Computers, Environment and Urban Systems* **31** pp481-501

Levin S A (1992) The Problem of Pattern and Scale in Ecology *Ecology* **73** pp1943-1967

Lu Y and Thill J-C (2008) Cross-scale analysis of cluster correspondence using different operational neighborhoods *Journal of Geographical Systems* **10** pp241-261

Nams V O (2005) Using animal movement paths to measure response to spatial scale *Oecologia* **143** pp179-188

Biographies

Patrick and Ross are both lecturers with the Department of Geography, University of Zurich. Patrick’s main research interests are movement analysis, spatio-temporal data mining, and most recently decentralised spatial computing for geosensor networks. Ross’ research interests include geographical information retrieval, geomorphometry, and uncertainty.