Scale Effects in Relating Movement to Geographic Context

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1. Introduction

Relating movement to context allows a better understanding of movement as traces of behavior, since movement is typically influenced by external factors such as the geographic context (Nathan et al. 2008). Within GIScience, movement analysis is mainly concerned with algorithmically detecting shape, arrangement, or interaction patterns on a geometric basis. Much less work has been done on relating movement to its embedding geographic context. Hence, this paper specifically addresses context-aware movement analysis, especially the little understood scale effects in quantifying the relation of movement to its context. Although there is previous scale-related movement research in GIScience (Laube and Purves 2011) as well as in behavioral ecology (Börger et al. 2006), most studies focus on one dimension of scale, be it spatial, temporal, or thematic scale, and do not consider interdependencies between the different scale dimensions.

To this end, we are specifically interested in revealing interdependencies between different dimensions of scales. So, we address the following research questions:

- How sensitive is the computation of a quantitative relation between movement and its embedding context to a systematic variation of the temporal, spatial and thematic analysis scales?
- When such scale sensitivity exists, can interdependencies between the different scale dimensions be identified and quantified?

An empirical study with movement data of chamois and terrain aspect as geographic context is carried out, in order to tackle these research questions.

2. Data and Methodology

In this study, GPS movement data of seven chamois (Table 1) from the Swiss National Park (in the South-East of Switzerland with an area of around 170 square kilometres) is related to the aspect of the terrain, in order to assess in what aspect classes the animals move, whilst the temporal scale of the movement data and the spatial and thematic scales of the aspect are systematically varied.

Table 1. Specifics for GPS movement data of chamois

Parameter	Chamois
Time span	12/2002 – 04/2010
Mean time span per animal	1.4 years
Temporal sampling rate	10min (every 2nd Wednesday) / 4h
No. of animals	7 (6 female, 1 male)
No. GPS points	29’571
Source	Swiss National Park

The experiments relating movement to aspect are carried out at three spatial scales (4, 20, and 100 meters raster resolution), three thematic scales of the context (5, 9, and 17 aspect classes), and three temporal scales of the movement (10min / 4h, 30min / 12h, and 1h / 1 day). Furthermore, movement is modelled in two different ways in order to discover scale effects depending on the chosen conceptual movement model. First, movement is represented as the mere GPS points. As a second movement model, the Brownian Bridge Movement Model (BBMM) is realized, which represents movement in form of a probability density surface as a raster (Horne et al. 2007). So, movement and the terrain aspect are related based on the GPS fixes and the BBMM within the 99% volume contours. The point-based movement model is related to the terrain parameter by considering the aspect values in the exact location of the GPS fixes. In the case of the BBMM, each cell of the BBMM-raster is related to the nearest neighbor in the raster representing the terrain parameter and the probability density value is used to weight the aspect. Relative distributions for different combinations of spatial, temporal and thematic scales are statistically analyzed by assessing the differences quantitatively using the coefficient of variation.

3. Results

We present our results in Figure 1 that show how the relative distribution of the context variable aspect varies with different temporal scales of the movement, different spatial and thematic scales of the context, and different movement-context relation-methods. The different rows in Figure 1 represent the variation of the thematic scale of the aspect (5, 9, and 17 categories). Moreover, this figure consists of four columns including different scales for ‘time’ and ‘space’, a ‘method’ and a ‘coefficient of variation’ column. The ‘time’ column illustrates the relative distribution of aspect for three temporal scales (10min/4h, 30min/12h, 1h/1d; t_1/t_2: temporal scale of t_1 every 2nd Wednesday, else temporal scale of t_2) when the spatial scale is kept constant at 4 meters (@4m). The ‘space’ column demonstrates the effects of systematically varied spatial scales (4m, 20m, 100m) on aspect at a fixed temporal scale of 10min/4h (@10min/4h). The ‘method’ column illustrates the relative distributions of aspect for the two different methods used to relate movement models to aspect (‘map pin’ vs. ‘BBMM-based’), using a point-based (GPS fixes) or a raster-based (BBMM) movement model. In the last column to the right, we present the ‘coefficient of variation’, where the bars reflect the within-class variation of the first three columns ‘time’, ‘space’ and ‘method’. In the colour version, the top orange bar references the variation of the ‘time’ column, the green bar the ‘space’ column and the blue bar the ‘method’ column. We illustrate this in the dashed box in Figure 1, where the ‘space’ and ‘method’ columns vary more than the bars in the ‘time’ column. This is mirrored in the corresponding coefficients of variation (for ‘space’ and ‘method’: around 0.2, for ‘time’: 0.004).

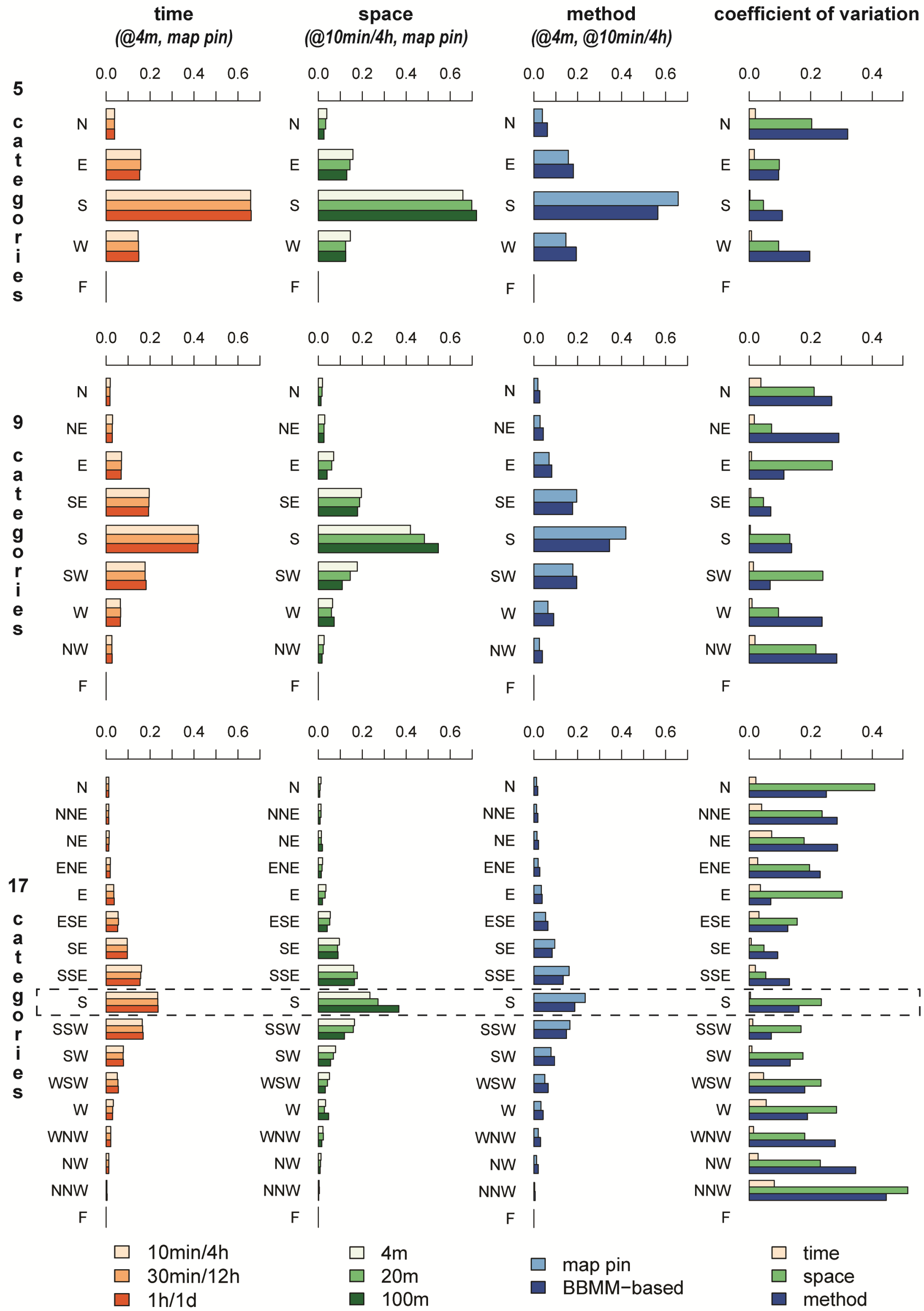

Figure 1. Relative distributions (0-1) of geographic context (terrain aspect) in relation to chamois' movement. Systematic variation of temporal scale of movement ('time' column), spatial and thematic scale of context ('space' column / y-axis), and relation-method ('method' column). 'coefficient of variation' (0-∞) column presents within-category variation.

3.1 Differences due to Scales and Methods

Considerable variations can be found within categories when varying scales and relation-methods. We sum up our most important findings in Figure 1 as follows:

- Variations due to spatial scale are larger (differences of up to 13%, coefficient of variation around 0.2) than variation due to temporal scale (differences negligible, coefficient of variation around 0.02).
- Coefficients of variation due to relation-methods are comparable to the ones caused by different spatial scales.
- With 17 categories of aspect, those categories with higher relative values of the distribution (e.g. South, dashed box), show in general smaller coefficients of variation than categories with a smaller share (e.g. North).

3.2 Interdependencies between Scales

Figure 2 shows coefficients of variation, which are computed in analogy to the procedure applied for the variation values in Figure 1 (‘coefficient of variation’ column). However, Figure 2a shows the coefficients of variation resulting from a systematic variation of the temporal scale (10min/4h, 30min/12h, 1h/1d, ‘temporal scale effects’) on *all* the spatial scales of the geographic context (4m, 20m and 100m). Similarly, Figure 2b shows variations caused by systematically varying spatial scale (4m, 20m, 100m, ‘spatial scale effects’) for *all* the temporal scales of the movement (10min/4h, 30min/12h and 1h/1d). For example, the smallest black bar in the dashed box in Figure 2a (17 categories, North) shows for a ‘4m’ spatial scale a coefficient of variation of 0.02 when varying the temporal scale (10min/4h, 30min/12h, 1h/1d). The first result in the following list confirms the expectations with respect to the number of categories. However, Figure 2 reveals interesting statements about interdependencies between different sorts of scales:

- As expected, the more categories of aspect are introduced, the smaller relative values per category get, and the higher grow potential coefficients of variation (law of large numbers).
- Differences due to temporal scale get more pronounced with coarser spatial scale (Figure 2a).
- Spatial scale effects are more stable with regard to different temporal scales (Figure 2b).

Scale effects that are discussed in this paper, similarly arise for the ‘map pin’ as well as for the ‘BBMM-based’ relation-method. So in this case study, the movement-context relation-method has no effect on the revealed scale effects.

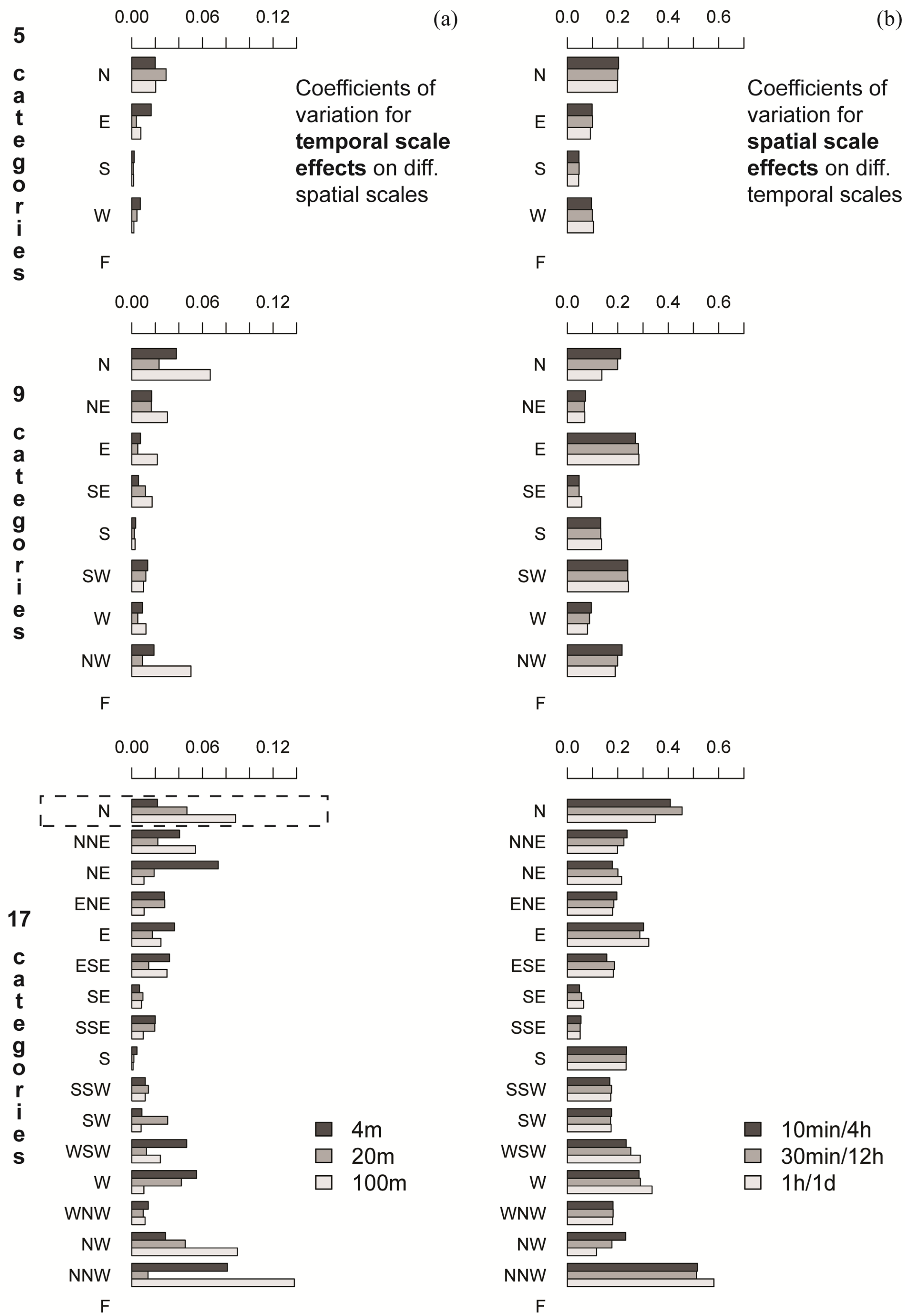

Figure 2. Coefficients of variation representing within-class variation due to variation of temporal (a) and spatial (b) scale across different thematic scales.

4. Discussion and Conclusions

In this paper, we illustrated with an empirical study the complex interplay between different types of analysis scales when relating movement to its embedding geographic context. In our study relating ungulate movement to terrain aspect the movement-context relation proved to be sensitive to some factors (spatial scale, thematic scale, relation-method), but not so much to others (temporal scale). Differences in preferences with regard to terrain's aspect might be more pronounced on a seasonal temporal scale for chamois. In terms of interdependencies between scales, our study suggests that the sensitivity of the results to the movement sampling rate depends on the spatial and thematic scale of the context. Similarly, the spatial granularity of the embedding context in turn matters more or less depending on the sampling rate of the movement. The key contribution of our work lies in providing quantitative evidence for the otherwise often overlooked complex interplay between the major scale dimensions in movement analysis.

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