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# Visual Characterisation of Temporal Occupancy for Movement Ecology

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**Abstract**

*Movement ecologists study aspects of animals' movement, behaviour, and the factors that might drive these. Temporal patterns of local occupancy often reveal the type of usage at a location. We present and apply temporal tile-maps that embed temporal visual encodings into cartographic representations, and do so in an interactive visual analysis context. This reveals spatial variation in temporal occupancy that allows places to be identified and distinguished according to their use by animals. We apply these to GPS data from tracking gulls and illustrate the application to movement ecology. The tool that implements this and data are available to download and use.*

Categories and Subject Descriptors (according to ACM CCS): I.3.8 [Computer Graphics]: Applications—

## 1. Introduction

Movement ecologists track animals and use the resulting data to answer ecological questions about how the environment affects animals' behaviour [Nat08, KCW*11]. In EuroVis last year [SvL16], we proposed visual encodings and interactive techniques – based on map and timeline linked view and interactive brushing – for initial stages of exploring of animal tracking data. This is implemented as BirdGpsExplorer, is demonstrated at https://vimeo.com/171595827, and is available from http://gicentre.org/birdGPS/.

Through visual exploration, we realised that *places* could be usefully characterised according to their *temporal patterns of occupancy*. By 'brushing' over the map view, interpreting temporal patterns in occupancy using a linked timeline, and considering these alongside aerial imagery, we could usefully characterise places of ecological significance. For example, places with night-time occupancy tend to correspond to roof tops and the middle of lakes which are likely safe sleeping places. Places that correspond to daytime activities tend to be grassy fields that provide food. These situations can be seen in Fig. 2. However, our techniques did not seem to adequately support this, as we could only consider one place at a time (through 'brushing'). Serendipity had too big a role here and we realised that a more *systematic* approach to characterise places according to their temporal occupancy was needed.

This led to the work that we present here. We extend our existing work – and the BirdGpsExplorer software – proposing new visual encodings and interactions to support characterising places based on their temporal occupancy. The "tile map" technique we present and illustrate in Fig. 3 discretises space into grid cells and uses this discretisation to embed temporal visual encodings into cartographic representations, doing so in an interactive visual analysis context. This allows differences in temporal occupancy to be compared geographically and at different geographical scales through interaction. We use a freely-available dataset of Black-Backed Gull and Herring Gull data [SDA*16] from http://bit.ly/2j7uPlm as an example of a GPS-tracked animal whose temporal pattern of occupancy implies behaviours of interest to bird movement ecologists. Some issues of interest may include: key foraging, sleeping and migration stop-over places; territories; social relationships between individuals based on co-occupancy; where we might need to do more fieldwork; and whether different individuals develop separate strategies from each other to cope with the environment.

## 2. Interactive brushing space-time views

Fig. 1 shows BirdGpsExplorer's [SvL16] coordinated linked space-time views with brushing, for interactively studying temporal occupancy by place. The map (Fig. 1, top) shows *geographical* aspects of the positional data and the timeline (Fig. 1, bottom) shows *temporal aspects* of the positional data. By interactively moving a *brush* (temporary selection) over the maps, only the corresponding points are shown in the timeline. This example confirms that these Lesser Black-Backed Gulls migrate southwards for the winter. Although it is easy to discover these migratory movement patterns, it can be extremely difficult to discover patterns with more spatiotemporal subtlety.

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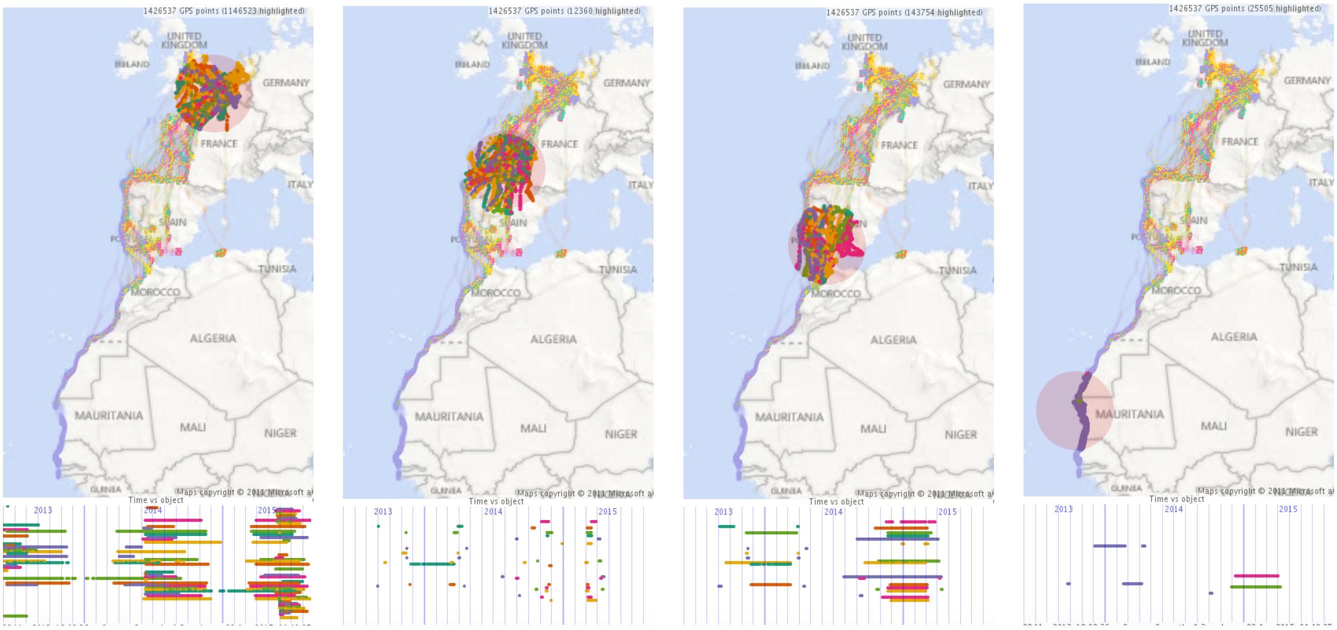


**Figure 1:** *Lesser Black-Backed Gulls. The interactively-linked space-time view shows the whereabouts of about 50 Lesser Black-Backed Gulls over a three-year period. The red circular area on the map interactively indicates the* times *at which they were there (from left to right in the timeline at the bottom) and* which individuals *(rows in the timeline). It indicates that the gulls migrate southwards for the winter (thicker vertical lines are the December-January boundaries). Maps from Microsoft Bing.*

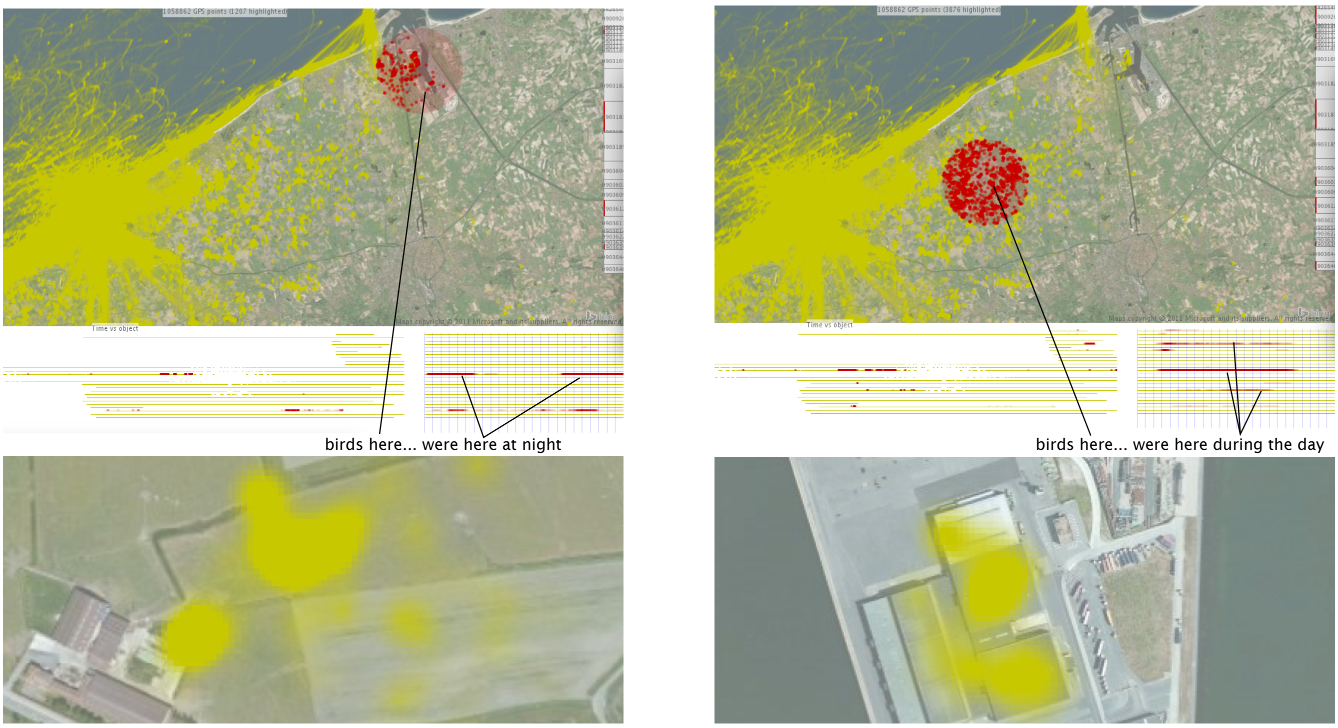


**Figure 2:** *Herring gulls. Left: brushed area has gulls in the daytime. Right: brushed area has birds at night. On each of the upper screenshots, the left (and wider) timeline as in Fig. 1, and the right (and narrower timeline) is over a day, running from midnight to midnight where vertical lines are hours. Below, zoomed-in aerial imagery shows a grassy field where some of the gulls feed during the day and a rooftop where some of the gulls spend the night. Aerial imagery from Microsoft Bing.*

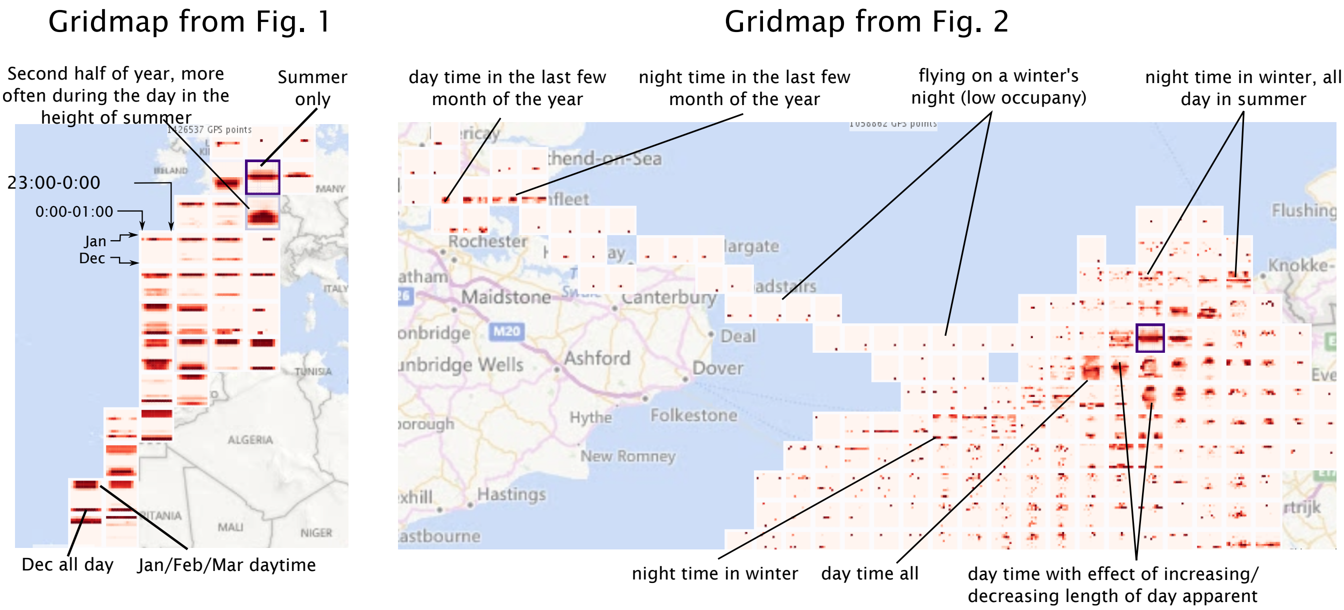


**Figure 3:** *Tile map where each tile summaries data for a grid-square. Each tile is a matrix where rows are* months *and columns are* hours*, coloured by occupancy (by time) relative to occupany in that grid square. Left: The Lesser Black-Backed Gulls from Fig. 1 where the seasonal shift is apparent this single static image, with the addition of diurnal patterns of occupancy. Right: Herring Gulls from Fig. 2. The glyph-like temporal signatures vary over space and are intuitive and recognisable.*

## 3. Tile maps that depict spatial variation in temporal signatures

We use temporal "tile maps" to characterise temporal occupancy in a more systematic way. Tile maps aggregate space into grid cells which we call 'tiles'. Into each tile, we place a visual representation of an hour- and month-based temporal signature of occupancy of all individuals across the area represented by the tile [AA10, SWD10].

Fig. 3 (left) shows a tile map for the situation in Fig. 1 that depicts the North-South seasonal occupancy shift. In order to embed the temporal signatures into the map, we have sacrificed spatial precision (see section 4.4 for more discussion about this tradeoff) by aggregating the spatial data into grid cells. Within these grid cells, we can embed a matrix of two temporal aspects – in this case, hour of day (columns) and month of year (rows), coloured by temporal occupancy [SvL16] – the amount of time spent there.

This is not particularly insightful for the migration example, but it becomes more powerful for more complex spatio-temporal patterns. Fig. 3 (right) shows a grid map for the Lesser Black-Backed Gulls from Fig. 2 and the temporal patterns of occupancy are varied and recognisable. As a static image, it provides the spatial distribution of temporal signatures of occupancy without requiring manual search with interactive brushings. We can distinguish between night-time occupancy, day-time occupancy and whether this changes through the year. In our implementation, the size of grid cells is defined in terms of screen size. Zooming and panning the map automatically reaggregates the data on-the-fly enabling temporal occupancy patterns to be explored at multiple spatial scales.

## 4. Grid map issues

### 4.1. Absolute vs relative occupancy

The occupancy matrix colour is scaled relative to each grid square, enabling relative occupancy signatures to be compared to each other. Overall, grid cells have different occupancy levels. In Fig. 4, the darkness of the grid outline is proportional to the occupancy compared to that in other grid cells. The more highly occupied grid cells are likely to be feeding or sleeping locations, whereas the gulls probably only travel through the surrounding grid-cells, leading to noisy-looking temporal signatures. Different approaches can be used for different glyphs. In Fig. 5, absolute occupancy is mapped to height and relative occupancy is mapped to width.

### 4.2. Interactivity, scale and MAUP

Since grid maps aggregate geographical space into grid cells, they may introduce a couple of problems.

Firstly, a static grid map presents occupancy patterns for places at a single spatial scale, yet places of ecological significance may be of different extents. We use interactive methods to help explore these scale effects. In our implementation, grid cells have an (adjustable) fixed on-screen size, so that interactive zooming of the map results in re-aggregation of the data allows multiple temporal occupancy to be explored at multiple scales and can help give a feel for the (in)stability of occupancy patterns at different scales. But some way of using domain knowledge to find places of certain extent limited would be useful.

Secondly, the arbitrary imposition of the grid can lead to the

Modifiable Areal Unit Problem (MAUP) [Ope84], the effect of which may make occupancy patterns highly sensitive to the grid discretisation. The grid discretisation depends on the state of the map's zoom level and pan offset. Distance-decay smoothing [EJ91] between grid-cells would help reduce the effect of this. Again, interactive methods can help – simple map panning results in on-the-fly reimposition of the grid, helping visually indicate the (in)stability of occupancy patterns with different grid offsets.

### 4.3. Potential for other glyphs inside tiles

The month-hour matrices we have been using are relevant for our application, but other aspects of time will be relevant for other use cases. For human-related activity, day of the week is relevant [SWD10, AAFJ16].

The tiles may hold any summary glyph that summarises characteristics of the space covered by each tile. These may be other temporal representations, such as line graphs (e.g. Fig. 3 of [SWD11]), rose diagrams or clock faces. For circular glyphs, a hexagonal rather than a square-based discretisation may be more appropriate. This can be generalised to non-temporal glyphs; multivariable glyphs that represent other aspects of data. For example, OD Maps depict flows by embedding destination maps for flows that originating from the space covered by the tile [WDS10] (e.g. Fig. 4 of [SWD11]). Fig. 5 demonstrates stacked barcharts that depict absolute and relative occupancy of the different individuals.

Where glyphs do not necessarily take up the whole tile – as in Fig. 5 – useful background context may help interpret the data. Where glyphs completely occlude the background imagery – as in Fig. 4 – this context is lost. Interactively-controlled partial transparency may help relate the background context to the tiled data.

### 4.4. Tradeoff between spatial and attribute precision

Increasing the screen-size of the tiles (regardless of zoom-level) has the effect of *reducing* spatial precision and *increasing* the space available to display each glyph. This *tradeoff* depend on:

- The *spatial resolution* at which spatial variation needs to be resolved to the use case.
- The *minimum resolution* required to visually interpret the glyph, depending on the glyph's type and complexity.

Each glyph in Fig. 2 contains $24 \times 12 = 288$ numerical summaries and needs to be a certain size for it to be visually resolvable. Choosing a compact design of glyph and further aggregating data within the glyphs (e.g. using 2-hour bins) are ways in which glyphs can be simplified such that the spatial resolution can be increased.

### 4.5. Data mining

There is potential to use data mining techniques to identify similar patterns of temporal occupancy. As well as identifying places that relate to foraging, sleeping and migration, taking into account the identity of the occupying individuals could also help identify territories, which individuals' territories overlap and whether some of these overlap spatially but not temporally. It might also help us understand to what extent species develop individual behaviours in response to the environment, by looking at which places are occupied by many individuals of the same species and which places are frequented by just a few individuals. Other datasets could also be taken into account – such as land cover – to derive more nuanced behaviours. Finally, data mining could also be used to identify different geographical scales of coherence temporal occupancies.

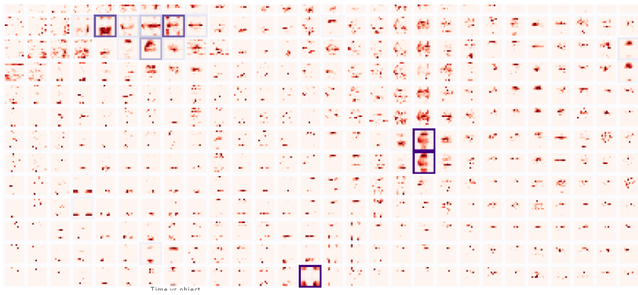

**Figure 4:** *The colour in the occupancy matrix is scaled relative for each grid square, whereas the darkness of the coloured outline coloured outline is directly proportional to the occupancy compared to that in other grid cells.*

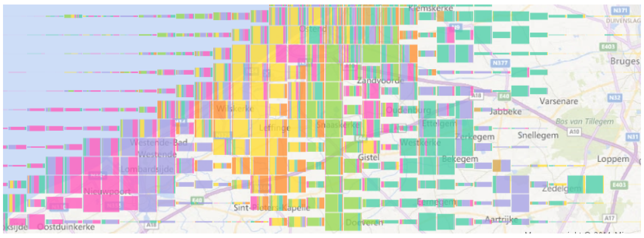


**Figure 5:** *A tile map, but rather than temporal signatures inside each grid, stacked barcharts of the relative occupancy (width) and absolute occupancy (height) are embedded, showing the spatial occupancy of individuals (hue).*

## 5. Conclusion

We show how temporal occupancy can help characterise and distinguish places and suggest a visual approach to help achieve this in an interactive exploratory context. For our gulls example, month-hour based temporal signatures of occupancy of places is helpful for inferring feeding, sleeping and migrating (to a lesser extent). Temporal tile maps such as Fig. 3 provide glyphs that enable one to pick out significant places for gulls and this appears to be useful.

Tilemaps introduce a number of issues that need to be investigated and addressed. We suggest some strands of work that relate to issues of scale, MAUP, noise where sample sizes are small, glyph design, and the tradeoff between attribute and spatial precision.

For further work, we wish to combine this with data-mining approaches so that we can identify temporal signatures of interest and automatically identify similar patterns of occupancy taking into account that fact that these may occur over different scales. Temporal signatures of occupancy can be used to infer semantics of places in a variety of contexts, including those that are human [AAFJ16].

## 6. Acknowledgements

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