Estimation of the Subjective Topological Structure of Action Spaces using Learning Agents

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1. Introduction

Interactions between individuals and urban infrastructure characterise many of the complex urban dynamics that today remain of significant interest to the GIScience research community. It is becoming increasingly clear that by more comprehensively understanding the nature of these relationships – between individuals and their environment – one can begin to more accurately predict the evolution of complex macroscopic phenomena. Developed in the 1960s and 1970s, the concept of action spaces provides a framework for capturing the nature of these subjective relationships between individuals and their environment (Horton and Reynolds 1971). This framework encapsulates an individual's spatial activities – the places they work, go to school, shop and spend their leisure time – influenced by a number of personal attributes. The nature of this space in turn influences an individual's spatial knowledge of an environment, thus further influencing and ingraining certain spatial behaviours.

Recent years have seen a growing recognition of the importance of understanding human activity zones, particularly within the domain of activity-based transportation modelling. However, existing approaches towards this challenge remain limited in a number of respects. Many employ ellipsoidal geometries in specifying the bounds of an activity zone (Rai et al. 2007, Schonfelder and Axhausen 2005), shapes that do not necessarily conform well with underlying urban structure and road network configuration. Furthermore, in assuming a geometric nature to the shape of activity space, existing approaches contradict conventional theories within behavioural geography and cognitive neuroscience with respect to the nature of spatial knowledge, where places (and relationships between places) are thought to be mentally encoded topologically rather than spatially.

This work introduces a method for estimating the subjective nature of action space through topological configuration. The approach builds on anchor point theory of cognitive maps, whereby spatial knowledge is hierarchical and defined by the topological relationships between salient points (Golledge 1978, Passini 1984, Winter et al. 2007). This approach is backed up by conventional research within cognitive neuroscience, where increases in hippocampal activity in the brain have been correlated with individual interactions with subjectively salient points (O'Keefe 1978, Macquire et al. 2006). In this model, action spaces are defined as hierarchical networks of interacting nodes, influenced by the subjective and experiential nature of individual activity.

This paper, representing early work in establishing a comprehensive method for action space generation, is outlined as follows. The next stage describes the methods employed in defining the subjective topological nature of action space. Following that, a case study and results will be presented for an individual, and comment offered as to the reliability of this assessment. Lastly, conclusions and plans for future work will be offered.

2. Methodology

The estimation of subjective action space across a population of citizens is achieved through agent-based simulation. For each agent three key factors are influential in shaping their action space. Of most importance is the individual's home location, influential upon defining the spatial extent of activity. Second, the individual is assigned an experience attribute, indicative of the length of time the individual has lived at their home location, and thus broadly indicative of that individual's complete knowledge of the nearby area. And third, the individual is assigned a set of activity zones with which they are expected to interact during the course of different activities.

The specification of this final element is achieved through spatial interaction modelling. Three types of activity are initially defined – convenience retail shopping, comparison retail shopping and leisure activity. The resulting spatial interaction model therefore takes the following form:

$$A_{ijk} = F_{jk}^{\alpha}\exp(-\beta d_{ij})$$

Where A_{ijk} is the attraction from location i to zone j for a given activity k, F_{jk} is the area of floorspace in zone j relating to activity k, and d_{ij} is the distance between location i and zone j, and α and β are parameters to be estimated. In all cases, travel is assumed to be carried out by car, and thus distance measures used here relate to angularity-constrained network distances. This score weights against both increased metric and angular distance along the road network, elsewhere defined as 'cognitive cost' (Raford et al. 2005).

Spatial behaviour associated with each activity is assumed to vary between activities, and thus impacts upon the definition of the spatial interaction coefficients α and β. Convenience retail refers to generally inexpensive goods, such as food and newspapers, and thus short network distances are strongly favoured. Conversely, comparison retail shopping relates to the purchase of more expensive goods, and so greater attraction to higher density concentrations of such zones is introduced, with less focus on network distance. With respect to leisure behaviours, two types of interaction are modelled, one that favours local leisure behaviours, and another favourable towards longer distance leisure activities. This distinction is made to again represent different types of leisure activity. Using these spatial interaction models, the strength of the relationship an individual holds with each nearby activity zone is established. Using these values a specified number of total trips are proportionately split between zones.

The topological representation of action space itself is established as agents traverse a hierarchical collection of nodes during the course of carrying out their given set of activities. Agents will proceed towards their target activity zone on a node-by-node basis, minimising angular deviation away from the target as they proceed. This is a principle of route selection identified elsewhere (Wiener et al. 2004, Manley et al. 2012). Direction estimation error (Hochmair and Frank 2000) is introduced through a uniform random error term added to the calculation of angular deviation, and thus introduces a degree of behavioural heterogeneity. Following each selection, the strength of node salience is incremented, providing an indication of the degree of activity across the topological representation.

As an individual's experience of a route towards a target improves, so does their propensity to identify new alternative routes. Individuals will initially route between high-level, widely-known nodes, however as experience increases new routes will be established from nodes in low levels of the hierarchy. With increased knowledge of an area, an individual will be potentially able to improve distance cost of their route.

3. Case Study and Results

This approach towards action zone definitions is implemented in London, United Kingdom, where a considerable wealth of data exists for the completion of this task.

3.1 Data

Activity zones are adapted from Greater London Authority (GLA) definitions of 182 retail zones across London. Spatial interaction models are computed using accompanying data relating to convenience retail, comparison retail and leisure floor space areas provided by Experian. The coefficients used in establishing spatial interaction were as follows:

	Activity Type			
Coefficient	**Convenience Retail**	**Comparison Retail**	**Local Leisure**	**Non-Local Leisure**
α	0.5	1.5	0.5	1.5
β	0.001	0.0005	0.001	0.0005

Table 1. Specification of spatial interaction coefficients

The node hierarchy used in establishing the topological representation of the action zone is adapted from a hierarchy of road network junctions. Four classes of junction are established, where junctions representing interactions between important, high volume roads are granted a high position (level 1) in the hierarchy, and local route junctions scored low in the hierarchy (level 4). Using this method, 816 level 1 junctions, 475 level 2 junctions, 110 level 3 junctions and 1687 level 4 junctions were generated. Junctions were selected for this purpose as an indication of potential decision points, where route selections are often made, and thus may maintain greater salience with the individual than other points on the network.

3.2 Results

For simplicity, the results presented here provide an indication of the action zones for a single individual living to the east of Hampstead Heath, north London, indicated in Figure 1. The spatial interaction models are executed given the location of the home individual, and trips split according to the results. For the purposes of this initial study, a total of 100 trips are generated for each activity type.

The resulting topological representation of this individual's action space is shown in Figure 1, along with the locations of nearby retail zones. As is clear, the action space extends considerably far from the home location, yet demonstrates greater local knowledge closer to the home location. Knowledge is clustered around and towards notable retail centres in the vicinity, notably Camden Town (with its large floor space of leisure and comparable goods) to the south and Archway (dominated more by convenience type goods) to the east. Some experience of central London zones, despite their distance from the home location, is also apparent.

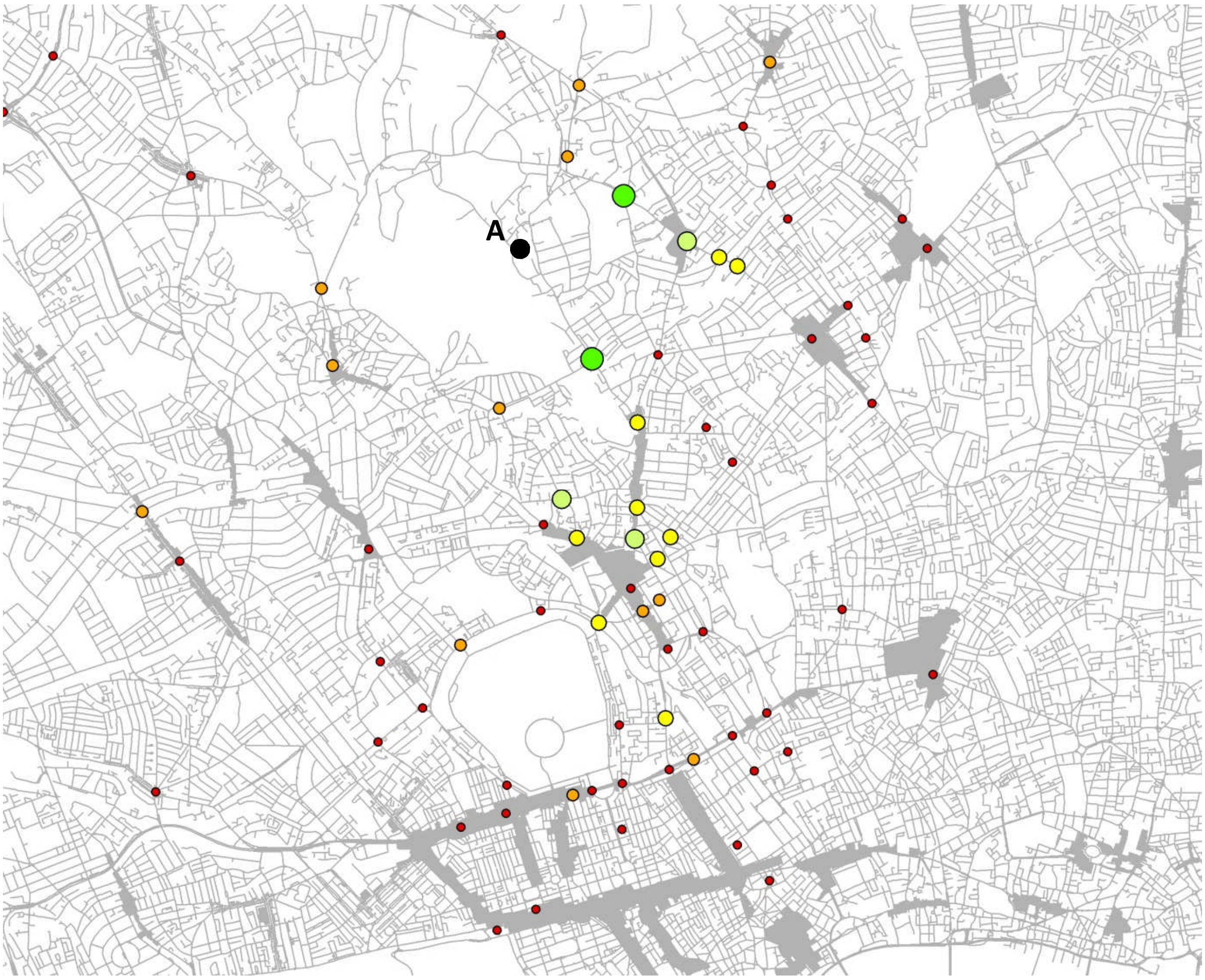

Figure 1. Topological configuration of action space for individual living at point A. Nodes are shaped and shaded (green to red) to indicate decreasing estimated salience to the individual.

4. Conclusions

The action space is a key driver of behaviour in the city. Interactions between individuals, influenced by their subjective comprehensions and usage of space, are central to shaping macroscopic urban phenomena. What has been offered in this work is a movement towards the estimation of subjective comprehension of space. This work seeks to incorporate a more realistic representation of space with respect to human comprehension than has been previously offered.

In line with the definitions described by Horton and Reynolds (1971), there remain a number of key challenges to address with respect to the progression of this work. Firstly, the model must be extended to incorporate the complete definition of action spaces, as originally defined. Such facets include a representation of socio-demographic variation, the influence of work locations, more accurate splits in activity volumes and factors of spatial structure and configuration. Furthermore, a greater number of travel options should be taken into account. In this work only road travel is considered, but further work should examine the influence of other forms of transport in shaping the extent of an individual's action space. In line with this, such a direction may necessitate the redefinition of the nodes that form the topological structure of the action space, incorporating additional elements relevant to distinct transport modes.

Yet of equal importance is the vital need for validation of this approach, something missing from this initial work. Exact specification of action space extents is clearly problematic, particularly where one seeks to quantify the knowledge or experience of a given individual. However, a longitudinal study of behaviours of individuals will enable the improved specification of parameters and validation of this approach. This is planned as a future step in this work.

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Biography

Ed Manley is a final year Engineering Doctorate student at University College London. His current research addresses the implementation of spatial cognition into transport simulation, yet his interests extends span across urban geography, cognitive science, complexity science and agent-based simulation.