Depicting urban boundaries from a mobility network of spatial interactions: A case study of Great Britain with geo-located Twitter data

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Existing urban boundaries are usually defined by government agencies for political and administrative purposes. However, it is not clear whether the boundaries truly reflect human interactions with urban space in intra- and inter-regional activities. Defining urban boundaries which consider socio-economic relationships and citizen commute patterns is important for many aspects of urban planning. In this study, we presented a method to redraw urban boundaries based upon human interactions with physical space. Specifically, we depicted the urban boundaries of Great Britain using a mobility network of Twitter user spatial interactions that was inferred from over 69 million geo-located Tweets. We redrew the non-administrative anthropographic boundaries in a hierarchical fashion based on different physical movement ranges of users inferred from the collective mobility patterns of Twitter users in Great Britain. The results of strongly connected urban regions in the form of communities in the network space yield geographically cohesive, non-overlapping urban areas, which provide a clear delineation of the non-administrative anthropographic urban boundaries of Great Britain. The method was applied to both national (Great Britain) and municipal scales (the London metropolis). While our results corresponded well with the administrative boundaries, many unexpected and interesting boundaries were identified. More importantly, as the depicted urban boundaries exhibited a strong instance of spatial proximity, we further employed a gravity model to connect human mobility research to understand and justify the distance decay effects in shaping the delineated urban boundaries. This well-fitted gravity model explains how geographical distances found in the mobility patterns affect the interaction strength among different non-administrative anthropographic urban areas, which provides new insights into the interactions between human activity and urban space.

Keywords: mobility pattern, urban boundary, spatial interaction, spatial network, community structure

# Introduction

Official urban boundaries are defined by government agencies for political and administrative purposes. Urban environments are conceptualized as spaces that are recreated and formed by human activities (Schliephake 2014). A fundamental question when using the administrative, “top-down”, approach to defining urban boundaries is whether the outcome respects the spatial interactions of humans. These interactions can take the form of trade, commerce, social connections, and political activity across borders. Urban boundaries that respect the human interaction space are important to city planning, traffic management and resource allocation (Gao et al. 2014, Jiang and Miao 2015, Liu et al. 2015, Long et al. 2015). Many studies adopt a “bottom-up” approach to urban boundary delineation, where the geographic space is partitioned into small units and each unit is represented as a node within a network structure. A suitable community detection algorithm is applied to partition the network and associated geographic space based on the strength of human interaction among the nodes (Lancichinetti and Fortunato 2009). Different social and spatial human interactions were considered to establish the edges of the network connecting the nodes. For example, a large set of telephone call records were used to represent the network of human interaction across space to delineate urban boundaries in Great Britain (Ratti et al. 2010). Extending the previous method to different countries (Sobolevsky et al. 2013), the authors argue that this method yields cohesive geographic divisions that follow the socio-economic boundaries. While other researchers use social ties of Twitter users to identify cohesive regions for different countries across the world (Kallus et al. 2015), they found evidence for dividing the urban space due to local conflicts and cross-country unifying trends that further support the “bottom-up” approach to mapping non-administrative anthropographic boundaries.

A common finding from the mentioned studies is that the strongly connected urban regions in the form of communities in the network space yield geographically cohesive areas, in spite of different community detection methods and various forms of social and physical human interactions were used. A general consensus is that those geographically cohesive areas are instances of the effects on spatial proximity, where the interaction strength between two urban regions decreases as the geographical distance between them increases (Fotheringham 1981). In particular, spatial proximity is closely related to Tobler's First Law of Geography: “everything is related to everything else, but near things are more related than distant things” (Miller 2004). While it is perhaps intuitively logical, few research efforts, which seek to quantitatively understand and explain how the spatial interactions shape the forms of connected geographical areas (i.e., urban boundaries), have been carried out. One of the major reasons is that geographical distance may affect the interaction strength, it is not an explicitly expressed constraint in the “virtual” human interactions, such as social ties or phone call initiation. In addition, there is a general lack of exploration regarding the linkages between the spatial proximity effects and the characteristics of the underlying spatial interactions.

In this study, we describe a novel approach to delineating non-administrative anthropographic urban boundaries from a mobility network of physical human spatial interactions. Specifically, the spatial interactions refer to the actual movements of Twitter users (i.e., the reallocation across the geographical space), which were extracted from more than 69 million Twitter messages from June 1st to December 31st, 2014. Geo-located Twitter data is proven to be a useful source for studying human mobility patterns at large spatial scales (e.g. the national level) (Hawelka et al. 2014, Jurdak et al. 2015). In addition, Twitter data are not as sensitive to user privacy issues and do not exhibit spatial granularity that is limited to the postal code level (Thiemann et al. 2010). We argue here that by investigating Twitter user mobility patterns, we can provide a different view of non-administrative units based on physical commutes rather than social ties or phone call initiation. A unique advantage is that non-administrative anthropographic urban boundaries can be delineated in a hierarchical fashion based upon different ranges of physical movement, which are inferred from the collective mobility patterns of Twitter users in Great Britain.

We delineated the geography of urban boundaries in Great Britain by imposing a virtual fishnet over the islands of Great Britain. Twitter user movements were used to establish the connections between the fishnet's cells to form a connectivity network, where each cell acts as a node within the network. We applied the map equation algorithm (De Domenico et al. 2015) to partition the network and associate geographic regions. The map equation algorithm was selected to avoid the inherent resolution problem (Fortunato and Barthlemy 2007) of the common modularity maximization method (Newman 2006). We found that the collective mobility patterns of Twitter users in Great Britain are divided into several distance ranges ranging from short, intra- to inter-city movements with clear distinction points. The identification of connected regions at each of these distance ranges yielded hierarchical boundaries of urban spaces in Great Britain. As the depicted urban boundaries exhibited a strong instance of spatial proximity, we further employed a gravity model to connect human mobility research to understand and justify the distance decay effects in shaping the delineated urban boundaries. The well-fitted gravity model explains how geographical distances found in the mobility patterns affect the interaction strength among different non-administrative anthropographic urban areas. Our study provides a first-step in connecting human mobility research with the delineation of non-administrative anthropographic urban boundaries based on Twitter user spatial interaction. This provides a new understanding of the interactions between human activities and urban space.

In real-world geography, urban regions are discrete components in a greater set of regions, with or without physical boundaries separating them (Jiang and Miao 2015). For political and administrative purposes, government agencies define various sets of boundaries to partition the geographical space into spatial units at different scales, for instance: states, counties, census tracts, and electoral districts. However, the spatial extents of these units often overlap and agglomerate depending how citizens perceive, organize their image of a city, and interact with the urban environments (Lynch 1960). As connections are made between these units via various human activities crossing boarders, such as social-economic relations and commute patterns of citizens, certain groups of units become more strongly connected than others. The boundaries of the agglomeration of these units are argued to reflect how people naturally interact with their geographical environment, which is important for city planning (Hollenstein and Purves 2010), urban growth evaluations (Jiang and Miao 2015, Long et al. 2015), and traffic management (Gao et al. 2014).

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