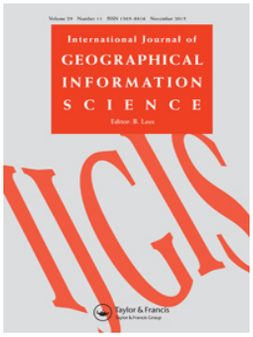

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INTRODUCTION

Geographies of mobility: applications of location-based data

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Geographies of mobilities

The increasing pervasiveness of mobile data – GPS tracking, mobile phones, and locative media worldwide – represents wide-scale changes in how individuals communicate and organize their movement through space. It also provides new opportunities for research and fresh challenges for society as we come to terms with these new technologies. For instance, the GPS and data trails inherent in the operation of mobile devices and user-created information such as geo-coded tweets and photos can provide new insights on population movement over space and time but also brings serious questions of privacy, particularly regarding how these data might be used by the state and businesses. Given this absolutely fundamental role of location-based data in today's society, this special issue of *IJGIS* joins the larger debates about techniques, applications, and theoretical framings associated with Miller and Goodchild (2014) term 'data-driven geography.'

These six articles emerged from the 2014 Mobile Tartu conference held in Tartu, Estonia, to discuss theoretical, methodological, and empirical aspects of research using mobile data – derived from mobile phone or crowd-sourced social media – and explore practical applications of these data in geography and planning. While the research in this issue represents a range of foci and case study locations, two interrelated topics run throughout the papers. First, are the continuing technical challenges associated with using these kind of data. The relative newness of these approaches and expanding geographies and data sources mean that researchers face the ongoing need to establish best practice for accuracy across a range of contexts. These issues, however, are balanced by the fact that successfully addressing these challenges results in the ability to conduct empirical research on questions and at scales previously not possible.

The second overall topic common to this special issue is the way mobile data are leveraged in practice via a range of applications for different end-user groups including smart cities and related technologies. Although we remain cautious in our expectations that the 'actually existing smart city' will match the rhetoric of technology companies' marketing (see Shelton *et al*. 2014), it is also evident that mobile data can provide new (and arguably better) ways for citizens and city officials to negotiate and manage everyday life as well as providing new ways of understanding and visualizing the city. This introduction highlights how articles correspond to these two meta-topics in order to highlight emerging debates within the field and suggest future research directions.

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Continuing technical challenges with location-based data

The technical challenges of using location-based data remain a fundamental issue and is a focus of all of the papers in this special issue, albeit in many cases a secondary topic is reviewed as part of the background framing for the primary research questions. The article that is most overtly focused on technical questions is by Toivo Vajakas, Jaan Vajakas, and Rauni Lillemets and titled 'Trajectory reconstruction from mobile positioning data using cell-to-cell travel time information' and outlines a technique used with passive mobile positioning data from mobile phones. In this paper, questions of locational accuracy are at the forefront. Although these kind of data can provide useful insight on the mobility of people across space, there remains a significant level of uncertainty within standard techniques for reconstructing movement trajectories. By incorporating the temporal dimension into the spatial process of cell handovers, Vajakas *et al*. are able to improve the accuracy of reconstructed trajectories (compared with actual traffic statistics measured by highway sensors) and compensate for irregular cell shapes and filter the 'ping-pong' effects associated with cell transitions. This approach provides better accuracy and as a result opens up new possibilities for using passive mobile positioning data in a range of spatial policy applications.

This technical challenge associated with accurately determining location is also a central theme taken up by Joaquín Torres-Sospedra, Raúl Montoliu, Mauri Benedito-Bordonau, Joan Avariento, Ana Sanchis, and Joaquín Huerta in their paper on 'Enhancing integrated indoor/outdoor mobility in a smart campus.' This applied research is also concerned with transitions, albeit not the handover of mobile communications between cells. Instead, this article focuses on user movement from outside locations to the indoors in the context of helping individuals navigate the space of a university. This shift from outdoors to indoors, however, comes with the challenge of creating systems that can seamlessly transition from one condition to another across a range of technologies and locational inputs. This research highlights the range of location-based data that is available for use, GPS, Wi-Fi, Bluetooth, each with its unique set of challenges, but also useful in cross-checking. This comparison to multiple data sources as a check to new location-based data echoes the approach of Vajakas *et al*. who compared traffic sensor–based counts with their improved reconstructed trajectory based on passive mobile phone data.

The remaining papers (introduced more fully in the following sections) are less focused on the technological challenges of location-based data, although clarity in methods is essential for Ahas *et al.'s* work with mobile phone data, Krisp *et al*.'s use of open street map data to measure complexity, and Grinberger and Shoval's work in identifying dynamic city centers. Finally, Kveladze and Kraak's paper reminds us that the challenges of working with these data is not limited simply to statistical formulas or technical algorithms but also depend upon the implementation of user interfaces that successfully work with human cognition in understanding the complexity of these data. In short, all papers acknowledge the necessity of addressing the methodological and technological challenges of location-based data in order to explore new research questions and practical applications over a range of scales from movement across highways or cities to walking across campus on down a hallway. The remaining part of this introduction reviews how papers take up this challenge and highlights the diversity of applications possible with the use of mobile data.

New research opportunities and applications within the context of smart cities

Although not an overt topic of research, the articles in this special issue share a common context of what one might refer to as a 'smart city' environment. The 'smart city' idea is a complex constellation of rhetoric, technologies, practices, and policies that is both widely promoted and critiqued. While it is beyond this introduction to review these debates (see Townsend (2013) and the March 2015 issue of the *Cambridge Journal of Regions, Economies and Society* for recent overviews and critiques), it is clear that the 'smart city' project's focus on information technologies and 'big data' sources to address a wide range of problems at the city level (Walravens 2015) resonates strongly with these articles. Numerous technology companies (see IBM 2012), city officials, and hacktivists have promoted these ideas and as such, we identify 'smart cities' as the key context from which this special issue emerged and an ongoing and dynamic project with which these articles engage and inform. For example, a common application of 'big location data' is transportation services, particularly the development of intelligent transportation systems which rely upon dynamic temporal datasets to structure services (Järv *et al*. 2014; Steenbruggen *et al*. 2015). Thus, regardless of the coherency of 'smart cities' policies, or the extent to which they have been successful, applications of location-based data – such as those explored here – are clearly tied to the evolving ways that cities are used, moved through, and represented.

As Torres-Sospedra *et al*. demonstrate via their university wayfinding application (SmartUKI), it is possible to leverage centralized databases for a range of complex services and uses and create map-based, augmented-reality interfaces for campus navigation. Various beta-testers of the system confirm that these kind of technologically enhanced directions are both feasible and useful to end-users in both outdoors and interior settings. While many wayfinding applications are primarily focused on the shortest or fastest routing, it is important to remember that there are any number of criteria one might choose to prioritize: a topic explored in Jukka M. Krisp, Andreas Keler, and Nicole Karais' article on 'Car navigation – computing routes that avoid complicated crossings.' In this approach, the researchers worked on developing a wayfinding application that addressed the desire to drive through a city and avoid complicated and challenging intersections, a routing of particular interest to new or nervous drivers. Using the topological characteristics of a road dataset, Krisp *et al*. automated the detection of 'nodes' (or the coming together of road segments) to weigh locations as less or more desirable based on their complexity, and created routings that prioritize avoid these locations rather than simply finding the shortest or fastest route. Of course, beyond the usability for 'inexperienced drivers' one might image any number of other possible applications such as scenic routing for tourism, hazard avoidance routing in the times of storms, or routings that ensure passage by certain kinds of restaurants at meal times; the latter is no doubt of considerable interest to any number of restaurant chains and retailers.

Both the SmartUJI and complicated crossing avoidance applications, however, do not directly address questions of the usability of the interface to location-based data, especially geotagged data that also includes a temporal dimension. In an effort to better understand these kinds of questions about spatial cognition, the paper by Irma Kveladze and Menno-Jan Kraak titled 'The Space–Time Cube as part of a GeoVisual Analytics environment to support the understanding of movement data' presents the result of an experiment testing the usability of Hägerstrand's Space–Time Cube in a GeoVisual Analytics environment. With the abundance of movement data, the Space–Time Cube has become a popular visualization to get insight, but its efficiency and effectiveness was

unknown. While it is not surprising that domain experts found the interface more effective and efficient than nondomain experts, this experiment also highlights the importance in properly assessing the incentives motivating users of any interface to locational data. Just as domain experts using the GeoVisual Analytics environment were more motivated to explore and understand the representations presented, so would other users, be they wayfinding through a campus with augmented reality applications or new drivers attempting to find the easiest way across a city, have greater incentive to use data and interfaces if they successfully addressed their pressing concerns. This is an important reminder of the centrality of understanding the needs and motivations of the end-user of a geovisualization or an application founded on location-based data.

In addition to possible 'smart city' applications, the articles in this special issue also highlight new research opportunities that have emerged alongside these data. In this vein, the paper by A. Yair Grinberger and Noam Shoval on 'A temporal-contextual analysis of urban dynamics using location-based data' explores the ability to use location-based data (in this case a detailed travel survey of over 30,000 individuals) to identify activity subcenters within an urban setting. Identification of key commercial nodes has long been an interest within the field of economic geography, and this article highlights our newly found ability to use detailed location-based data to identify multiple and dynamic centers of consumption rather than more static centers based on employment metrics. This represents a new approach to better understand the dynamism of cities and stands in contrast to the static understandings of earlier work in economic geography that was constrained by less-detailed datasets. The ability to look at temporal fluctuations (both within and between days) is especially important for a range of applications from transportation to crisis resilience.

This inclusion of the temporal dimension into spatial studies is particularly evident in the article by Rein Ahas, Anto Aasa, Yihong Yuan, Martin Raubal, Zbigniew Smoreda, Anto Aasa, Yu Liu, Cezary Ziemlicki, Matthew Zook, and Margus Tiru titled 'Everyday space–time geographies: Using mobile phone–based sensor data to monitor urban activity in Harbin, Paris, and Tallinn.' Leveraging the timestamp and spatial location of mobile phone activity, Ahas *et al*. analyze the differences in time use in three different national contexts by identifying emergent indicator points of activity. In addition to suggesting how best to identify key temporal points within cities, that is, daily low point, point of fastest accelerating activity, and overall activity time, this article also shows how larger cultural, societal, and institutional differences between countries are reflected in differences in the distribution of the temporal markets. The article also highlights how temporal differences can also be analyzed within cities to show how activity space varies across space and time. Finally, it brings out the important potential of mobile microdata to disaggregate city into spatial, temporal, and social layers (Yuan and Raubal 2014, Silm and Ahas 2014, Trasarti *et al*. 2015).

This effort by Ahas *et al*. to include the temporal aspect in addition to location information – also evident in Vajakas *et al*., Grinberger and Shoval, and Kveladze and Kraak – represents an increasingly common effort within GIS and urban studies to go 'beyond the geotag' (Crampton *et al*. 2013), and leverage as much of the ancillary and nonspatial data that have become part and parcel of location-based data. In short, a key outcome of the 2014 Mobile Tartu conference and this special issue of *IJGIS* is highlighting how other kinds of data and analysis (e.g., temporal, relational, contextual) beyond the spatial are increasing, available, and relevant to GIScience analysis.

Conclusion: smart research with location-based data

The six articles of this special issue underscore both the challenges and promises of data derived from mobile phone or crowd-sourced social media which we contend makes it one of the most exciting fields of research for GIScience. However, we also call on researchers to use this data wisely, not blindly. In short, more data does *not* necessarily make for a smart analysis or a smart city. Ironically, more location-based data means that we must work harder to do smart and relevant research.

Moreover, we also contend that these new sources of location-based data provide opportunities to revisit and test old questions in new ways (e.g., Grinberger and Shoval looking at the temporality of urban sub-centers and Kveladze and Kraak experimenting with novel interfaces to the Space–Time Cube) as well as extend the kinds of analysis we can do (e.g., Ahas *et al.*'s examination of emergent space–time patterns). We also see opportunity to explore new topics and questions, particularly ones that have not historically been a focus of GIScience. It is not a coincidence that the title of this special issue 'Geographies of Mobilities' echoes the title of a recent edited volume by geographers and social theorists Tim Cresswell and Peter Merriman who seek to engage with the 'new mobilities paradigm' that has emerged from other social science disciplines (see Sheller and Urry 2006). While rather orthogonal to the approach to mobilities outlined in this special issue and *IJGIS* more generally, we wish to highlight the useful complexity of this project. As Cresswell and Merriman (2011, p. 11) remark,

> This book is willfully wide-ranging in terms of the theoretical approaches taken and the types of mobility considered. Some chapters are historical, while others are contemporary. All, however, remain focused on the ways in which bodies and things move, the political, cultural and aesthetic implications and resonances of these movements, the meanings ascribed to these movements, and the embodied experiences of mobility.

Whether GIScience chooses to engage with these kinds of theories or moves more toward 'data-driven geography' as suggested by Miller and Goodchild (2014) or takes another path, our point is that the availability of mobile phone and crowd-sourced social media location-based data represents an exciting watershed movement. In short, as evidenced by this special issue, location-based data provide a means of understanding mobility and cities in new ways, but the theories and range of mobility that can be explored and research go well beyond the examples provided here. Perhaps even into areas in which GIScience does not necessarily feel comfortable or even interested, but as the availability of these data increases and the methods for dealing with them advance, new research horizons are appearing and it is our challenge to take advantage of them.

Disclosure statement

No potential conflict of interest was reported by the authors.

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