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Establishing the Integrated Science of Movement: bringing together concepts and methods from animal and human movement analysis

Supplementary information 3 – Overview of movement research across disciplines

In this document we provide a brief overview and history of each discipline's interest in movement:

- Movement ecology
- GIScience
- Geography
- Public health research
- Transportation science / transport geography
- Computer science
- Location-based services
- Physics

Movement ecology investigates animal movement, which is important for understanding how animals compete for resources and interact, both essential elements of the evolutionary processes (Nathan et al. 2008). Through the introduction of Very High Frequency (VHF) radio telemetry over 70 years ago, ecologists pioneered movement data analysis, which is a firmly established area in ecology (Holden 2006). Following the introduction of new tracking technologies (GPS trackers, biologgers), as well as a greater application of rigorous statistical and other analytical methodologies, movement ecology is currently undergoing a technological and data revolution (Cagnacci et al. 2010, Williams et al. 2020).

Geographic Information Science has a decades long tradition of analysing spatio-temporal data (Kwan and Neutens 2014). Movement analytics within GIScience can be traced back to pre-GIScience times, specifically, to time geography in 1970s through the introduction of concepts such as a space-time cube (Hägerstrand 1970) for representation of human movement. More recently, GIScience has played a fundamental role in establishing movement analytics as an interdisciplinary data science through networking initiatives such as COST Action "MOVE – Knowledge Discovery from Moving Objects" (Demšar et al. 2015b) and follow-up activities (Dodge et al. 2016, Long et al. 2018) which brought together methodological researchers in spatio-temporal analysis and visualisation with researchers from application disciplines, including movement ecology, human mobility, transportation and human-computer interaction.

Geography has a long-standing tradition in analysing human movement. During the "quantitative revolution" in the 1960s-70s, researchers pioneered mathematical methods for movement that were cutting-edge, for example methods for analysis of flows (Illeris and Pederson 1968, Goddard 1970). However, at the time such studies were limited by the computer power available and some of these movement methods have been temporarily forgotten, only to be re-discovered decades later in other disciplines (e.g. physics, O'Sullivan and Manson 2015). Others, such as spatial interaction modelling, which looks at how places are connected through movement (Roy and Thill 2005) have continued to this day in various analysis areas, from commuting (Niedzielski et al. 2015) to retail (Siła-Nowicka and Fotheringham 2019).

Within public health research there has been an increase in the use of movement data in the last ten years, utilizing frameworks from time geography and transportation research (Perchoux et al. 2014, Rainham et al. 2010). These studies typically use location-enabled technologies, often combined with accelerometers and/or mobility surveys, to quantify where people are undertaking health related activities, such as physical activity (Monroe et al. 2015, Smith et al. 2019). Movement data are also used in health research to measure environmental exposure, which can be linked to health behaviours and outcomes (Cerin et al. 2020, Sadler & Gilliland 2015). Human movement studies have further contributed to understanding the spread of infectious diseases (Balcan et al. 2009, Charu et al.2017).

Most recently, location and proximity data are being used for contact tracing during the on-going COVID-19 pandemic by a number of countries (Cho et al. 2020).

Transportation science and transport geography also have a long tradition in analysing movement, in particular movement of various types of transportation and human movement in urban environments (Ullman 1954, Batty 2013). Transport researchers are interested in modelling urban movement (Kerkman et al. 2017, Manley and Cheng 2018) and quantification of accessibility and equity of spaces (Farber et al. 2013, Neutens 2015). Until a decade ago, data collection data on human mobility consisted of cumbersome surveys that collected travel diaries. With the introduction of new widespread tracking technologies (such as GPS and other sensors in every smart phone) that enabled larger and faster GPS travel surveys, movement analysis has become popular to look at segregation patterns in cities (Palmer et al. 2013). Shen and Stopher (2014) provide a review of GPS travel surveys.

Computer science came to be interested in movement predominantly due to the increased availability of large human tracking data, such as GPS trajectories of vehicles or people. With the goal being algorithm and method development rather than creating insights into movement behaviour, their methods for movement can be largely divided into five main streams: computational geometry (Buchin et al. 2011a, Alewijnse et al. 2014); trajectory data mining (Nanni and Pedreschi 2006, Zheng 2015); creation and analysis of semantic trajectories (Alvares et al. 2007, Yan and Spaccapietra 2009, Parent et al. 2013); visualisation/visual analytics of movement (Rinzivillo et al. 2008, Andrienko and Andrienko 2013); and more recently machine learning / artificial intelligence for movement (Wang, Fu and Ye 2018).

A specific area at the intersection of computer science and GIScience are Location-Based Services, which combine geographic location with the general notion of services (e.g. emergency services, navigation systems, tourist tour planning, etc) (Schiller and Voisard, 2004). A substantial part of this field focuses on human navigation and wayfinding (Huang and Gartner 2009, Wiener et al. 2009) with a cross-over to spatial cognition (Kiefer et al. 2017), while other LBS researchers focus on analysis of human mobility and related activities (Huang et al. 2018).

Physics has a yet different motivation to explain (predominantly human) movement: it is interested in universal patterns that can be observed across all types of human mobility (Simini et al. 2012). Over the last 15 years, human mobility analysis in physics has featured complex networks, where physicists look for laws that govern the formulation and behaviour of flow networks, derived from mobile phone data (Gonzalez et al. 2008, Song et al. 2010b).

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