Absolute and Relative Movement Characterization: A Conceptual Movement Analysis Framework

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1. Introduction

In recent years, representation of inherently spatio-temporal movement data and its multi-disciplinary dedicated field of study, Computational Movement Analysis (CMA), has brought new insight into geographic dynamic processes (Gudmundsson et al. 2012). Despite the widespread application of movement data (see review by Long 2013, Demšar et al. 2015), conceptual frameworks in CMA are uncommon.

As an overview, Laube and Imfeld (2002) introduced REMO (RElative MOtion) to analyse relative movement activities among a group of moving point objects. They investigated the relations between the motions of individuals, based on three movement parameters: motion azimuth, speed, and change of speed. This was to identify their relative behavioural movements such as constance, concurrence or group turn. Dodge et al. (2008) categorized patterns of movement proposed by other researchers into 'generic' and 'behavioural' patterns. They conceptualized the movement itself and discussed the relationships between movement parameters and the patterns that can be extracted from observations. Laube (2009) categorized space representation models and discussed that each model has the capability to quantify movement descriptors, as well as exploring and explaining their relevant patterns. Dodge et al. (2016), categorized movement studies into understanding and modelling in a continuum in which process starts by quantifying movement, followed by contextualizing moving objects, and then CMA.

According to the literature, movement parameters are the building blocks of movement analysis (features or properties, either observed or constructed), which guide all pattern recognition and analysis processes. The impact of absolute and relative movement characterizations on the production of movement behaviour reasons has been also mentioned in the literature, which indicates more the need for building a framework rather than actual trials.

The lack of a comprehensive and widely accepted conceptual framework of movement is quite often recognized as a major hindrance for further development in CMA (Laube 2014). In this paper, basic definitions will be covered as a basis for communicating the conceptual model of movement analysis, with data structures accommodating both absolute and relative situations. Subsequently, the impact of different perspectives behind spatial, temporal, and spatiotemporal movement parameters will be discussed to investigate their potential for knowledge extraction, interpretation and modelling from movement data.

2. Space and Time Conceptualization in GIScience

Examination of dynamic geographic processes, relationships, and patterns are fundamental activities in GIScience (Mark 2003). The key to pursue the objectives of GIScience is the implementation of spatial observations and thereby relies on the representation of changes at observation- or model-level. Geographic dynamics refer to change in phenomena, whatever it might be, referenced to the earth's surface through passing time. Examples include changes in land cover after a wildfire or changes in land use during urban developments, to climate change as a result of global warming, to soil salinization, to spreading a disease or news, to movement data of animals' roaming or the human's daily commute (Goodchild and Glennon 2008).

Defining principal elements of geographic dynamics used to be crucial in 'data models' (Peuquet, 1984), on which representation of the real-world (geographic) processes was built. Perhaps the most applicable model was proposed by Sinton (1978), within which '*time*', '*location*' and '*theme*' were three basic components of statistical measurements (see also Berry 1964, Haggett et al. 1977, Dangermond 1983). He argued, to be able to represent these elements simultaneously, one should be fixed, while the second is controlled within a range of values, then the variation of the third one can be measured. Sinton's framework was challenged and failed later to fulfil the new data type requirements, although it is the theoretical foundation of vector and raster representation formats (Goodchild 2007). In the last couple of decades, advancements of data models have largely overcome these formal constraints as such in moving objects data modelling (see review by Pelekis. 2004). Understanding different concepts of space and time are still essential in movement descriptors, as one can see movement quantification is the reverse progress of abstracting geographic dynamic in observation. For CMA, there are a large number of reviews discussing definition of space and time in GIScience (Chrisman 1978, Nunes 1991, Langran 1992, Peuquet 2002, Goodchild 2007).

In short, the classical duality of space and time concepts stretching back to the philosophy of physics to fall upon the relative and absolute oppositions, where space is described as attributes of entities or entities are seen as attributes of space, respectively (Couclelis and Gale, 1986). Nunes (1991) states geography, like many other scientific fields, relies on geometry to represent, but not to define, geographic space. He discusses classical Euclidean geometry representing space as an empty container or framework within which things exist and move. In contrast, newer ideas in geometry see space as a set of objects and their relations. He also claims shifting the ultimate goal of geography, from the description of spatial arrangements into the production of rules about spatial processes has aroused critique about absolute geographic space. He believes the earlier explanatory objectives were yet to be established on the same concept of absolute space, as they were rather production of the laws of spatial distribution than the exp1anatory character of such laws.

From a cognitive science point of view, discrete-object and continuous-field distinctions are fundamental to how humans sense, store, analyse, and understand their environment (Couclelis 1996). These ontologies, resulting from relative and absolute dichotomies, are essential in queries on spatiotemporal observations. Peuquet (2002) in an compelling review draws the major lines in the evolution of space and time concepts in relevant disciplines. She tries to bridge between cognitive space and time with the modern computer-based learning, interaction, and knowledge representation.

To skip the recursive ontology trap, among all perspectives (e.g. linear and circular time, object- and location-based concepts, or vector or raster representation formats) a few perspectives focusing on absolute and relative have been mentioned as they are often referred in the literature as the base for space-time data representation context. Therefore, considering three basic components of observations and ultimate goals of representation, conceptually, nine (3x3) different space-time data structures (pairwise combinations of invariant, relative, absolute time vs. invariant, relative, and absolute space) in exploratory (analysis) and explanatory (models) operations are presented in a cube framework for integrated data, analysis and modelling in Figure 1.

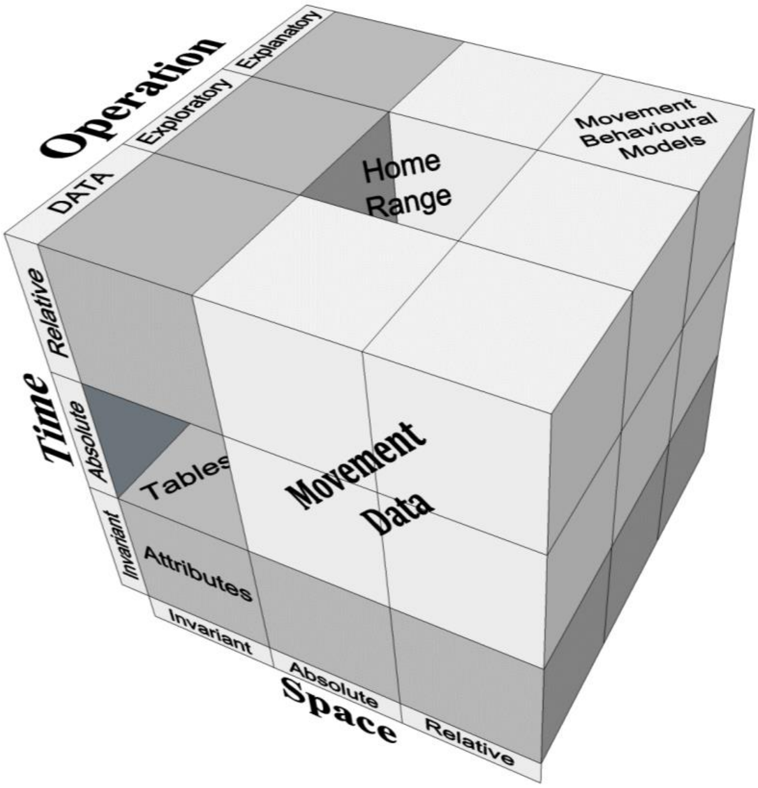

Figure 1. The space-time conceptual representation of data, analysis and modelling. In the sense of movement data and the agent's possible actions, one can start with invariant position or time (attributes only) before going up to absolute space and time parameters (coordinates and/or time instance/interval), then relative space (reflects the distance and angle, or topological relationship between moving objects, derived from absolute data) and/or relative time (in duration between acts). Extracting home range patterns are exploratory examples in movement analysis (possible from agent traversal into the second Operation layer), where foraging, fighting, and playing pattern are explanatory (3rd Operation layer) (Dodge et al. 2008 taxonomy).

2. Basics in the Framework

Movement and spatial distribution data are being collected in diverse forms for various purposes. These may relate to tracking individuals (e.g. animals, cars, and people), the main focus of CMA, or the distribution of phenomena (e.g. organisms, population, and ideas), mostly of interest in ***diffusion*** analysis (Hägerstrand 1953). This distinction adheres well to the process framework in figure 2, demonstrating the relationships among the concepts that will be discussed here.

Acknowledging the inherent complexity within movement data, as well as considering the degree of importance of the objects' position rather than their shape and size, physical moving ***objects*** can be simplified to a representation as point features (Laube 2001). Thus, a moving object can be simply represented as a tuple $(S, T, A)_i$ where S is a measured location at time T, and A is the measured attributes all indexed by the moving point identification i. Therefore, a spatio-temporal ***trajectory*** is an ascendant connected timestamp of relocations, generated by a moving object in order to achieve a goal, denoted as $tmo_i = \{f_0, f_1, \ldots, f_n\}$ where each f contains the spatial coordinates, if applicable, accompanied by other attributes during a given time in $0\ to\ n$ (Spaccapietra et al. 2008). This description keeps 'metaphoric trajectories' (any time-varying attribute, e.g. career trajectory) out of our framework as it doesn't include a spatial dimension. It still fits to the invariant space column in both absolute and relative time in Figure 1. The 'metaphoric trajectory' is such proof of Andrienko et al (2008) quote "time is an inseparable aspect of a trajectory", while space is not. For simplicity, while acknowledging 'symbolic', or 'Naïve geographical' trajectories (see Spaccapietra et al. 2008), we only provided an example of the geometric spatiotemporal trajectory to narrow the focus on numerical space-time analysis.

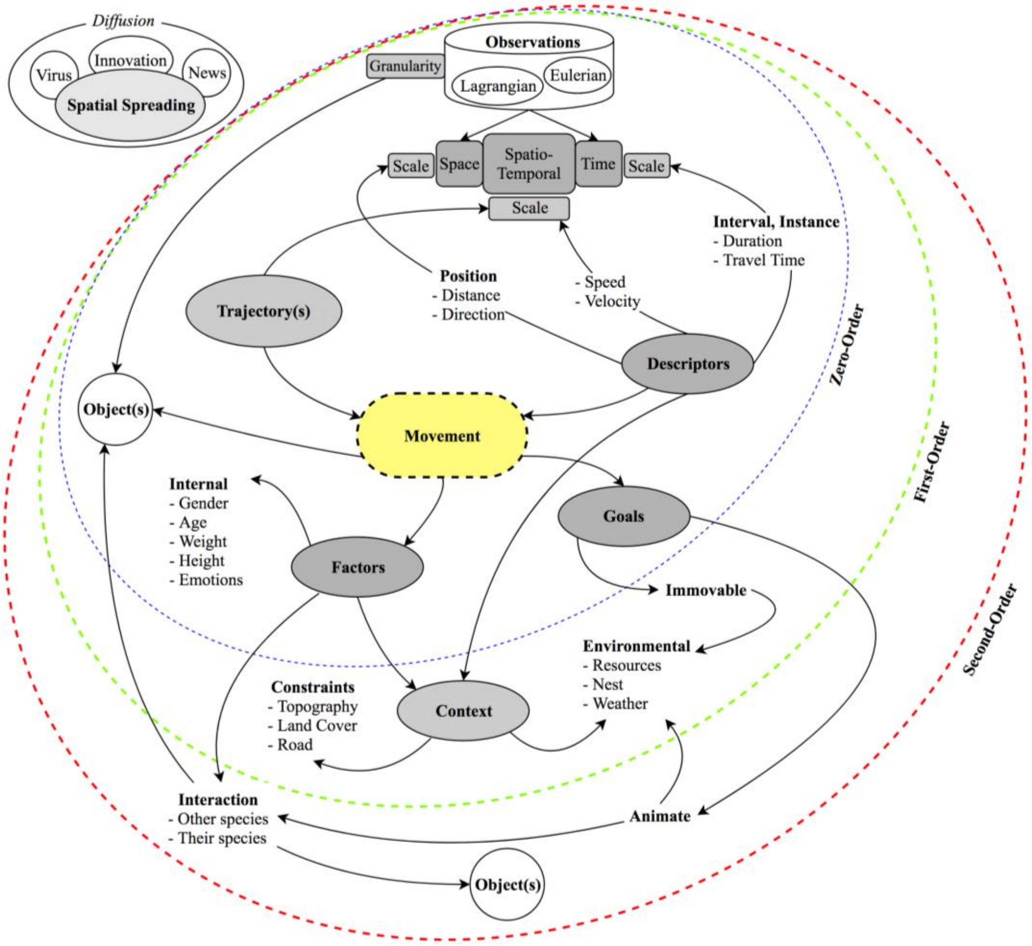

Figure 2. The conceptual framework of space-time agent processes. The direction of arrows shows the connections between the concepts, for example, it can be read as '*trajectories are spatiotemporal observations of objects' movement to achieve an animate or immovable goal that influenced by internal, contextual, and interactional factors'*. Another object has been introduced outside the zero- and first-order in order to illustrate second-order: moving objects in a movement dataset may have a different sense of the environmental constraints and internal attributes, but all concepts in the model apply to both objects. The arrow from the descriptors goes to the scale under the spatiotemporal, indicating the impact of temporal analysis scale on speed and velocity parameters (Laube 2014).

Movement paths can be the result of the objects' emotional (endogenous) or logical decisions, pursuing animate or immovable ***goals***. Movement decisions are influenced by diverse internal and external ***factors***, representing objects' reactions to the ***context***, in which movement happens (e.g. roads, land cover, and topography), and their internal states such as age, gender, and abilities. Many animal movement studies in ecological categories have the former group as the first-order influencing factors, but the intrinsic properties have been neglected or in the best situation considered as factors involve in random walk process (Edelhoff et al. 2016). We prefer to use zero-order factors for the intrinsic moving objects' properties, due to their possible unknown impact on movement decisions. Acknowledging that handling logical reasons within movement decisions is already difficult, here we prefer to take the moving objects' emotions as zero-order influencing factors. Even though some aspects of (say) animal movements can be mined by such zero- or first-order factors, and might be all that is needed for some objects, they will fail in extracting all features inside more complex movement data. Given a complex and high-resolution dataset, second-order influencing factors can reflect the interaction between moving objects' with other objects (Laube 2009).

Movement ***descriptors*** are spatial and temporal quantified parameters, describing the objects of interest's relocations over time. These, in fact, are such a representation of movement observations. Similar to the absolute and relative, as well as sampling granularity in the movement observations, absolute and relative perspectives alongside with space and time ***scale*** issue in movement characterization can accommodate different patterns and understanding. Dodge at al. (2008) pointed out three descriptor classes namely, 'primitive', 'primary derivatives', and secondary derivatives', based on the assumption that spatial and temporal position is initially measured to a universal reference. This does not completely fit with some positioning methods, where the distance between objects is often the only parameter of interest (e.g., signal strength difference based). Their primitive and secondary parameters though, conceptually, fit to the absolute and relative concepts.

3. Discussion

Regarding the absolute view in movement data structures, space and time are measured, referenced to some constant base implying a non-judgmental observation (Peuquet 2002). The constant base in a Euclidian space can be the zero point in the geographic coordinate system, a local zero point in the Cartesian coordinate system such as the center of a soccer pitch, or it can also be the element [1, 1] in a 2-dimensional grid space representation. The constant point in time can be the starting point of a calendar, either synchronized with a cycle or in a linear system, or a temporal event such as the moment that a system has been run and recorded. The majority of the data models record activities and attributes based on the absolute measurement as they are numeric values thus easy to represent. This is also because, in most cases, relative measurement can be drawn from absolute positions even though under the risk of neglecting spatial constraints.

The relative view involves measurement between events, objects, or locations. Relative representation can be either metric, such as distance and angle or non-metric as in the temporal relations (Allen 1983). Thus, in the Euclidean space, for example, the relative spatial attributes can be analytic geometry (e.g. angle and distance), or topological expression (e.g. next to) between two or more moving objects. The temporal position can also be in metric measurement (Δt), or just the expression (before, after).

In summary, the way movement is characterized often dictates what semantics can be derived from movement observations and governs how deep it can be understood. The absolute representation mostly leads to internal (zero-order) and contextual (first-order) understanding of movement, while relative characterization brings insights into the internal factors (mostly abilities), as well as interactions between moving objects (second-order). These absolute and relative perspectives are not isolated in movement studies, but their integration in a single framework is critical to do embedding and coupling analysis simultaneously. It is essential to understand all three influencing factor-orders in order to increase the semantic content of movement patterns and thus develop reliable prediction models.

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