Multi-scale Modeling of Movement

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Introduction

Our ability to study and model movement has profound implications in many areas of science and technology such as movement ecology, natural hazards, autonomous navigation, migration studies, and health. Although many commonalities exists, the ways in which movement has been modeled differs in various disciplines (Miller et al., 2019). For instance, movement ecologists are largely interested in quantifying micro movements of animals at local scales (i.e. fine spatial and temporal granularity) using for example step selection functions (Schick et al., 2008). These micro movements constitute the building blocks of the broader patterns forming migration paths, home-ranges of individuals, and ultimately dynamics of species population over space and time. On the other hand, geographers and human mobility scientists have traditionally been interested in studying origin-destination flows and movement patterns of individuals, mainly at population levels and macro scales (i.e. coarse spatial granularity) (Yuan, 2018; Miller et al., 2019). Accordingly, micro movement of individuals and local patterns of movement are less emphasized. This might have been due to the limited access to fine resolution tracking data of humans in the past. Today, high frequency and ubiquitous collection of tracking data at fine spatial and temporal resolutions provide an unprecedented opportunity to study and model movement across scale.

The interaction between different forms of scales in movement processes

Movement is a complex multidimensional process which operates in a space-time-context continuum across multiple scales (Dodge, 2019). Regardless of the context or entity type, movement happens through a series of embedded patterns at multiple frequencies in space and time (Ahearn and Dodge, 2018). When studying movement processes, we deal with all three forms of granularity (as in Kuhn (2012)): spatial (micro steps to macro flows), temporal (high frequency short-term events to low frequency long-term processes), and thematic (individual movement to collective dynamics).

Movement is manifested by a series of micro steps which are generated through local movement choices or progression of a moving phenomenon at each point in time. These steps are driven by the context within which the movement occurs (e.g. the entity's internal state and motion capacity, topography, transport mode, interactions with other entities, etc.) (Ahearn et al., 2017). Micro steps shape the trajectory of the moving entity at fine spatial and temporal granularity and are the building blocks of the broader patterns of movement. The broader movement patterns are mainly driven by the entity's behavior or the global objective of movement (e.g. commuting, shopping, hunting, patrolling home-range, migration, wildfire spread, etc.). However, the environment and interactions of the individuals can also influence how global movement patterns are formed over space and time. Compared with high frequency micro steps, these patterns often occur at lower frequencies and represent longer-term movement processes. 'Thematically' (Kuhn, 2012), movement patterns and interactions of individuals contribute to forming the collective behavior of a larger group of moving entities (e.g. fleet, flock, school). In turn, the collective dynamics of the group influences movement patterns of its individuals. Following are three example from different domains.

In human mobility, commuters make local movement choices based on their internal states (i.e. behavioral mode), available resources and immediate environmental conditions (e.g. local traffic information, available transportation, weather condition). Over the course of the commute, the local movement choices of a commuter form the global pattern of its trajectory between an origin and a destination. In aggregate, the movement trajectories of all commuters shape the daily or monthly commuting patterns of a city. In the spread of a disease, an infected agent can transmit the virus to the individuals within their spatial proximity along their trajectory.

The transmission of the virus at each step happens through interaction with vulnerable individuals. Over time, through movement of the infected individuals across larger spatial extents, the infection can spread to a bigger population at a broader geographic scale. In movement ecology, for example, patrolling of the home range is a global behavior of tigers (Ahearn et al., 2017). This global behavior is realized through local movement choices of the tiger at each step. The local choices are based on available resources, topography, or existence of other animals in her proximity. While patrolling (which could take a couple of weeks), the tiger makes several kills every few days. Therefore the movement of a tiger is realized though multiple embedded patterns at different spatial scales and temporal frequencies. Thus, to model movement more accurately in different domains, multiple scales of embedded patterns need to be incorporate.

Modeling movement across scale

In this position paper, we propose a multi-scale approach to modeling of movement. The aim is to build a generative to simulate movement processes in dynamic natural and social systems more accurately. The model generates micro movements in response to the internal state of the individuals and their immediate environment and geographic context. While these micro movements are driven by the characteristics of the immediate context encountered by the individual, they are at the same time guided by the entity's behavior and movement objectives at the global scale. There are methodological challenges for building such a model. For example, given a movement behavior, the question is how to properly identify its embedded movement patterns at different scales in a meaningful way? For this, we take an interdisciplinary and data-driven approach in which the model is parameterized using knowledge obtained from domain experts or inferred from the analysis of actual tracking data of the subject phenomenon (Dodge, 2019). Data can inform us about observed patterns and their frequencies. For instance, in Ahearn and Dodge (2018) we developed a recursive multi-frequency segmentation algorithm to decompose a long-term trajectory into its constituting patterns captured at different temporal frequencies. As an example, several months of tracking data of an albatross[1] was recursively decomposed into round trips between the Galapagos islands (where they nest) and coastal areas of Peru (where they forage). These trips were further decomposed to outbound flights to the coast, search and foraging movements along the coastline, return flights to the Galapagos, and search flights around the Galapagos. For this workshop, we are interested in discussing questions with respect to the relationships between spatial and temporal scales and how they relate to movement processes.

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[1]`https://videopress.com/v/d5iArmCv`