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A multidirectional model for studying mobility affordance of past landscapes

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ABSTRACT

This paper presents an approach to modeling human mobility across regional landscapes that considers all possible directions of travel in order to generate a continuous surface of movement probability. The approach improves upon models of human movement that rely on calculating travel costs between discrete points on the landscape by providing a way to examine how landscape features shape the potential for movement. I show how this method can be used to examine questions of mobility affordance, and the consequences for understanding how humans experienced past landscapes. To demonstrate the usefulness of this approach, I apply the methodology to examine the use of hilltop fortifications for controlling mobility during the Late Intermediate Period (1000–1450 CE) in the Colca Valley of the southern Peruvian highlands.

1. Introduction

Studying prehistoric movement poses particular challenges for researchers. In some cases, roads and major passes may be historically documented or still be visible on the landscape, but such formalized routes are rare and generally limited to long-term exchange routes or administrative road networks (e.g. Chacaltana et al., 2017; Ur, 2003). Most paths were never formalized and their ephemeral traces are rarely preserved in the archaeological record. Geospatial modeling has become an important strategy for studying mobility in contexts where paths are not preserved (e.g. Beaudry and Parno, 2013; Howey, 2007; Howey, 2011; Leary, 2014; Llobera et al., 2011; ten Bruggencate et al., 2016). Most approaches have focused on modeling optimal, or least-cost, paths between known points on the landscape (e.g. Contreras, 2011; Gustas and Supernant, 2017; Howey, 2007; White and Barber, 2012). However, movement is a dynamic process shaped not only by the specific origin and destination of travel, but also by changes in the physical and political landscape; factors which are not easily captured by least-cost paths (Howey, 2011; Howey and Brouwer Burg, 2017). Archaeologists often lack knowledge of the precise origins or destinations of travelers, or may need to consider many possible points of interest. Environmental conditions—such as rain, snow, or drought—may render even well-traveled paths unusable. Changes in political alliances, exchange partners, or conflict can also shape decisions about travel in unpredictable ways.

Even in the face of many unknown factors that influence the particular path an individual chooses to travel; all paths are never equally likely. Regardless of origin or destination, the landscape shapes possibilities for travel in important ways—open water, mountain slopes, marshes may provide barriers to travel, while open plains, mountain passes, and limited ground cover may facilitate it. Thus, we can conceive of the landscape as providing a range of mobility affordance or a diversity of material properties that, when encountered by an agent, provide opportunities for and limitations to travel that make certain paths more likely than others (Gillings, 2012; Llobera, 1996; Wernke et al., 2017). A focus on mobility affordance highlights the need to shift how we approach geospatial analysis of mobility; moving away from modeling travel between discrete points on the landscape, toward what Howey and Bouwer Burg have termed *total landscape geospatial modeling*, to better reflect the "potentialities for cultural processes inhering across the entirety of the landscape" (2017: 4).

This paper presents an approach to modeling mobility affordance using Circuitscape (McRae et al., 2008), a program that integrates circuit theory and graph-theory to model landscape connectedness. The approach outlined in this paper makes two significant contributions to the application of Circuitscape to modeling human mobility. First, I build on a method of omnidirectional circuit analysis developed by Anderson, Pelletier and colleagues (Anderson et al., 2014; Anderson et al., 2012; Pelletier et al., 2014) and advocated for by Howey and Brouwer Burg (2017) that eliminates the need for defining travel origin and destination. Second, I integrate the anisotropic costs of slope due to the direction of travel to develop a methodology applicable to the study of human mobility. The result is a regional raster representing the overall probability of travel (mobility affordance) regardless of direction of travel that has broad applicability to the study of mobility in the archaeological past.

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2. Resistance, current and mobility affordance

This paper uses *Circuitscape* (McRae et al., 2008), an open source toolbox containing a bundle of python scripts run through ESRI ArcMap 10.4. The program integrates circuit theory, network theory and graph theory to analyze regional landscape connectivity (McRae, 2006; McRae et al., 2008). The program was initially applied to landscape ecology and conservation, but has also been effective for modeling gene flow (McRae and Beier, 2007), disease transmission (Barton et al., 2010), and wildfire spread (Gray and Dickson, 2015). In archaeology, Howey (2011) uses Circuitscape to model travel between monuments in northern Michigan. In most applications, Circuitscape is used to model movement between known regions of interest, providing an alternative to least-cost path analysis. Here, I provide only a brief overview of how the program works before discussing the modified approach developed in this paper. For a thorough discussion of how Circuitscape compares to least-cost path analysis in studying human mobility, see Howey (2011).

2.1. Overview of Circuitscape

Circuitscape conceptualizes the landscape as a raster in which each cell represents the relative resistance (travel cost) to traverse the cell (McRae et al., 2008). As with other mobility analyses, a variety of costs can be used to generate the resistance raster, including slope, vegetation cover, and cultural features. Barriers can also be incorporated into the resistance raster to prevent travel through features such as open water or architecture. Origins and destinations of travel are represented as focal nodes, and electrical current is injected into the origin (source node) where it travels across the resistance raster to the destination (ground node). The resistance raster is transformed into a series of grid nodes connected by edges, and current travels from each grid node to all others as it moves from the source to the ground. The amount of current that passes through each grid node is determined by both the resistance of the node and the availability of other nodes.

The analysis produces a current raster, where the strength of the current of any given cell is interpreted as the likelihood that a traveler will traverse the cell on its way from the origin to the source. Areas of low resistance are more conductive, and thus have greater mobility potential. Similarly, areas of high resistance are less conductive and have lower mobility potential. Additionally, large areas of similar resistance have greater potential for alternate paths, and this is reflected in more diffuse current. By contrast, current is concentrated into more circumscribed corridors in areas where low resistance cells are adjacent to high resistance cells.

Circuitscape does not generate the globally-optimal path between two points (as produced by a least-cost path analysis); instead, it uses locally-optimal paths. Specifically, as the current flows through the raster, it continually seeks the path of least resistance based on the cost associated with each neighboring cell. In this way, the local landscape exerts greater influence on the possibilities of movement, which makes Circuitscape ideal for examining mobility in contexts where path optimization cannot be assumed—for example, in cases where individuals may be traversing unfamiliar landscapes. Additionally, the current raster encodes the relative potential for mobility across the entire raster, providing a means for conceptualizing the relative mobility affordance across the landscape.

2.2. Multidirectional circuit analysis

While most applications of circuit analysis have focused on connectivity between specific points of interest, here, the objective is to model overall mobility affordance without assuming origin, destination, or direction of travel. To do this, I build upon the "wall-to-wall" method developed by Anderson, Pelletier, and colleagues (Anderson et al., 2014; Anderson et al., 2012; Pelletier et al., 2014; see also Howey and Brouwer Burg, 2017). In this approach, focal nodes are placed along the edges of a square tile of the landscape. Current is injected into source nodes along one side, and flows across the tile to the opposite side following cardinal directions. The analysis is executed four times to model travel in each direction—North-South, South-North, East-West, and West-East. The results of the four runs are then processed and summed to produce a current raster reflecting the probability of movement from any direction, thus eliminating the need to specify origin and/or destination of travel.

One challenge to producing a generalized model of mobility is that the cost associated with terrain slope is dependent upon the direction of travel. For example, a slope with a northward aspect is experienced as an uphill slope by a traveler walking south, but a downhill slope by one traveling north. Furthermore, a person traveling east would transect the slope and experience very little effect from the slope. Slope rasters produced in GIS software assign slope value based on the maximum elevation change between the focal cell and each of its eight neighbors. The result is a maximum slope value with no accounting for the direction of travel.

The model described in this paper overcomes this challenge and makes a significant contribution to wall-to-wall modeling by parameterizing the travel costs of slope *in the direction of travel*. As explained below, the directional slope cost used to produce the resistance rasters is achieved by calculating the elevation change from each cell to its adjacent cell in the direction of travel to produce separate resistance rasters for each direction of travel. The appropriate directional resistance raster was used in the wall-to-wall method to produce an overall current raster for travel from any direction.

In this way, the model overcomes two important challenges of modeling human movement—the need to specify origins and destinations, and the different movement costs associated with slope in the direction of travel.

3. Methods

3.1. Analysis and focus regions

This simulation is subject to edge effects around the perimeter of the analysis region because the current is concentrated as it leaves the source and as it approaches the ground. To avoid these edge effects, the total analysis region used to produce the current raster needed to be at least four times the size of the research focus region (Anderson et al., 2014; Anderson et al., 2012; Koen et al., 2014; Pelletier et al., 2014). The focus region was delimited to encompass a roughly 25 km buffer from the fortifications identified during survey, resulting in a total area of 2346 × 2346 cells (~76 km^2, Fig. 1A). The total analysis region comprised 5428 × 5428 cells (~176 km^2, Fig. 1A). The results were later clipped to the focus region for interpreting the results of the analysis.

3.2. Resistance raster

The model requires four resistance rasters—each one representing the relative cost in traveling one cardinal direction. Ground cover in the case study region consists mainly of scrub and the region lies above the tree line. Additionally, given the mountainous terrain, slope is the primary cost for pedestrian travel. Therefore, only slope was modeled in this analysis. Other mobility analyses have incorporated additional variables (Gustas and Supernant, 2017; Howey, 2011), which should be considered for other contexts and applications. Elevation data was derived from SRTM DEM data with 1-arc *sec* (32.45 m resolution). The process for developing each resistance raster is elaborated for northward travel.

Slope cost was calculated for each direction of travel. For each raster cell, focal statistics were used to calculate the elevation of the cell immediately to the north. Slope was then calculated as a ratio of