Simulation of Spatial Disorientation in Human Walking Behavior: Optimizing Wandering Disutility Functions

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1. Background

Spatial orientation has been studied as one dimension of the abilities that humans use in the wayfinding processes (Golledge and Stimson 1997; Allen 1999). Rieser (1999) defines spatial orientation as "knowing where one is relative to objects in the surrounding environment." However, human wayfinding abilities are seriously degraded in people experiencing dementia. Efforts to model the underlying cognitive mechanisms that lead to spatial disorientation are scarce. Such models, especially in human walking behavior, would be helpful in the study of movement patterns, as well as prediction of disoriented behaviors.

2. Objective

This research focuses on modeling spatial disorientation. The main objective of this study is to develop an agent-based model that can be employed in simulating spatially disoriented walking behavior in humans. This model will be used to study movement patterns in a specific type of spatially disoriented walking behavior known as wandering, which is mostly observed in early stage Alzheimer's patients with cognitive impairment due to dementia.

3. Methods

To develop a method of modelling spatial disorientation, we reviewed the literature in search of a set of parameters that previous researchers have found to describe spatial disorientation in human walking. The criteria for choosing parameters were (1) the quantifiable nature and (2) whether the parameter could be modelled using stochastic variables. The parameters identified in this review are listed below and discussed in the following section.

1. Attention zone
   - Radius (r)
   - Arc length (s)
2. Frames of reference
   a. Viewer-centered
      - Distance from origin (d_o) or to destination (d_d)
      - Bearing to destination (b)

   b. Environment-centered

- Position of landmarks ($\boldsymbol{p}$)
- Number of turn decisions (n_t)

The first group of parameters is intended to model vision as a source of spatial information during wayfinding processes. The two parameters in this group determine the *attention zone*, which is a circular area ahead of the agent navigating in the environment (Torrens et al. 2012). Evidence in the literature support the assumption that disrupting the flow of information from the visual system contributes to spatial disorientation (Berthoz et al. 1999; Chown 1999). In the second group, viewer-centered parameters model spatial relations through distance and direction, while positions of landmarks provide absolute location-based spatial information. Finally, number of turn decisions or intersections on the network helps in modeling cumulative nature of errors in wayfinding and computational burden of the process along the route.

This research models spatially disoriented human walking behavior as a disutility function with three components, built upon the model presented by Nasir et al. (2014). In this proposed model, the first component (C_1) replicates normal walking on a network and represents the baseline model without introducing any additional noise that may impair wayfinding capabilities of the agents. This component generates a measure of total distance travelled based on position (x), walking velocity (ν), and time (t). The second component (C_2) introduces a systematic noise in wayfinding behavior modelled with stochastic errors designed to replicate cognitive impairment (Figure 1). Finally, random noise introduced by the third component (ε) models real world uncertainties from all other sources not considered in the second component.

The approach adopted in this research is based on optimally solving a routing problem in which agents move in predefined environments with controlled characteristics including positions of landmarks, network complexity, light, temperature, and sound. Equation 1 presents a general form of the objective function of this problem (J) that minimizes cumulative impedance in the routing problem.

$$J(x,\nu,t,e_l,e_b,\cdots,\varepsilon) = C_1(x,\nu,t) + C_2(e_l,e_b,\cdots,r,s) + \varepsilon \quad (1)$$

Two different types of agents (utilizing different routing problems) are defined in this experiment: healthy and cognitively impaired. Distinction between the two types is based on a measure of cognitive status, called MMSE (American Psychiatric Association 2013), which provides an overall index of cognitive impairment. MMSE values smaller than a certain threshold characterize cognitive impairment thus an increase in the probability of spatially disoriented movement (Algase et al. 2001; Algase et al. 2009). Such values will trigger a bias in the sampling of spatial disorientation parameters towards higher probabilities of committing wayfinding errors. Large population of agents will be instantiated and the assigned MMSE values will determine each agent’s membership to healthy or cognitively impaired type.

4. Expected Results

The developed model in this study is expected to demonstrate a correlation between travel patterns of spatially disoriented movement with the cognitive status values assigned to agents. Agents with status values indicating healthy cognitive functioning are expected to travel essentially minimum cost routes through designed networks. On the other hand, agents with status values indicating cognitive impairment are expected to be travelling much less efficient routes and may not even find their destination at all. A Monte Carlo experiment will be conducted in which large populations of each type of agents seek to optimally solve the routing problem within the set of predefined environmental settings.

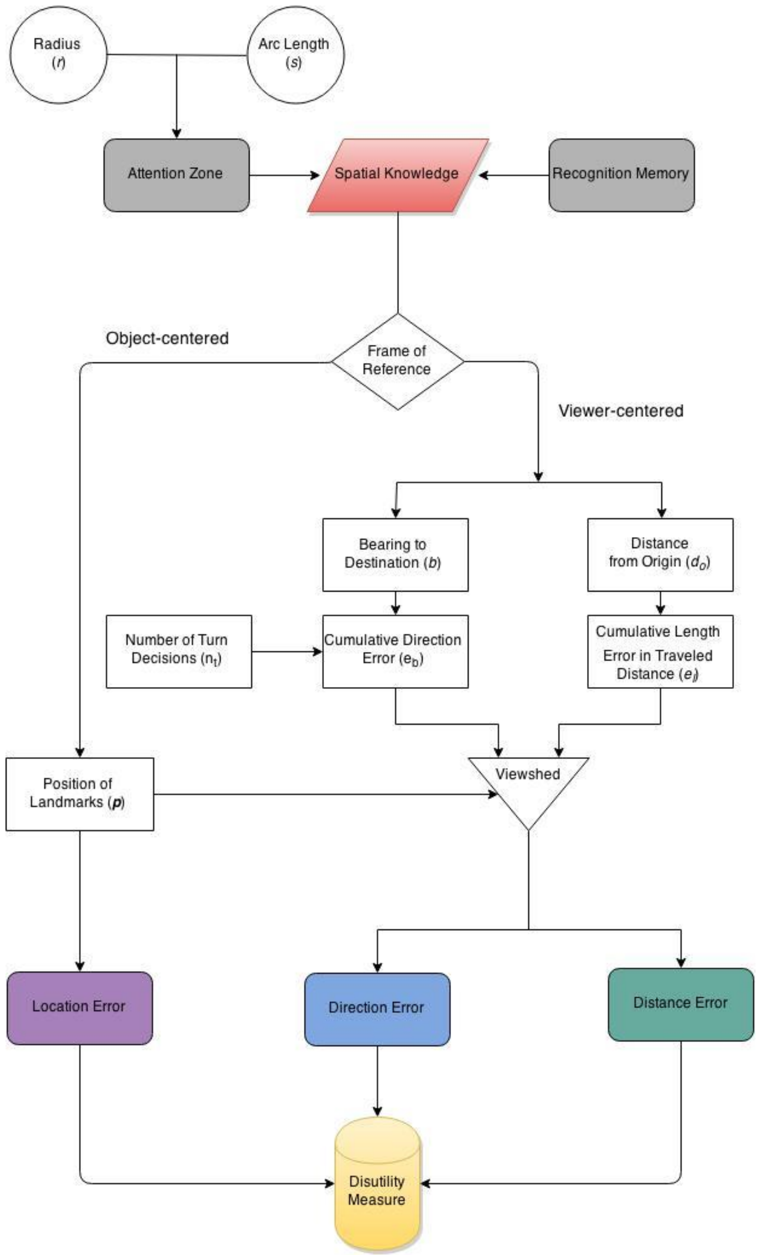

Figure 1. Data structure of the disutility measure.

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