Representation and modelling of the complexity of street intersections for navigation guidance

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Abstract. There is growing recognition that the complexity of road intersections within navigation environments is a critical factor of wayfinding. A complex intersection can increase the difficulty of spatial cognition and environment perception for pedestrians, leading to wrong decision-making and deviated navigation. Existing methods quantify the complexity of a decision point by simply outputting a single value, thus fail to match the perceived content under different passage strategies. Besides, most methods merely include the structural or visual features, and rarely contain a comprehensive integration of multi-dimensional characteristics. This study proposes a passage strategy-based computational method to assess the complexity of road intersections with their perceptual contents of street scenes. Specifically, we analyze several types of real-world perceived features when crossing intersections. Then, develop a combination of conceptual features regarding the visual, structural and semantic aspects based on different route strategies (i.e., whether pedestrians focus on a particular branch as an entrance or an exit), to depict the perceived complexity features of the road intersections. This study provides further implication that the innovative method can be integrated into route planning and communication, and navigation guidance services in complex scenarios.

Keywords. Decision-making; Intersection's complexity; Passage strategy; Navigation guidance

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1. Introduction

Road intersections are critical areas during wayfinding. They are the locations where decision-making and route-following errors occur. The complexity of navigation environments directly affects the guidance performance (O'Neill 1991) and raises the operation difficulty, involving the perception and understanding of environments, spatial cognition and mental representation (Richter 2009). Especially, in the context of road intersections, where the wayfinder needs to make turning decisions.

Current researches on road intersections' complexity ignore specific passage strategies. It outputs merely a single value, which leads to a mismatch between a single complexity result and the perceived scenes' content under **different passage strategies** (i.e., entrance branch and exit branch). The existing methods mainly construct complexity computation models for roads and intersections by extracting environmental features on structural or visual aspects. The former commonly detected the structural features of road networks (e.g., the length of road segments, the number of turnings, road intersections and their branches) (Sladewski et al. 2017, Zhou et al. 2019). The latter extracted basic image features (e.g., color, shape) to measure the visual complexity and cognitive elements (e.g., sky, building) to reflect wayfinder's psychological stress (Golledge 1999, Sanocki et al. 2015). Note that the above mentioned two fields address computational modelling of complexity somewhat separately, either in visual or structural aspects. Methods on combining both or more aspects are still under explored.

As a result, this study first considers the passage strategies when passing intersections (i.e., which branch the pedestrian concerns to be the entrance and which branch to be the exit) as a prerequisite, and proposes a model for evaluating the complexity of a wayfinding decision at road intersections. We argue that the calculation model, depending on the passage strategy and outputs multiple results, perform better than the model that only outputs a single value in describing the complexity of a wayfinding decision at a road intersection. From which an n-branches intersection will correspond to A_n^2 complexity values, respectively. This model incorporates the specific passage strategy as constraints and describes the intersection's visual, structural, and semantic characteristics. Eight features are extracted from easy-access geodata (i.e., street-view panoramas, road network, and POI data), to represent the intersection, and finally are integrated for decision-making complexity computation.

2. Research motivation

2.1. Overview

This study aims to represent the complexity of road intersections from navigation perspectives and develop a passage strategy-based computational method to quantify a single intersection more realistic and refined with multiple values of decision-making complexity. *Figure 1* demonstrates the framework of this 'working in progress' study.

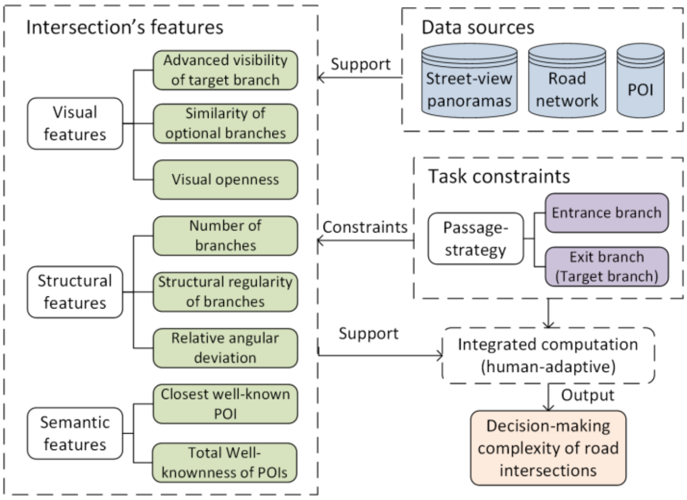

Figure 1. Framework of computational model.

2.2. Passage strategy-based features

Different passing routes provide diverse perceptual information to pedestrians, including perceived visual and semantic information, spatial attributes, and its mental representation of the road network. We believe that the computation of intersections' complexity needs to follow the specific traversal strategies. Therefore, we propose the following features to characterize the intersection visually, structurally, and semantically based on the passage strategy.

The **visual features** visually describe the global and local impressions of the real-world street scenes. Cognitive science research shows that human beings acquire external information mainly through vision, which is the main driver behind human perception (Brakus et al. 2009) and consequent experience). Previous studies extracted basic image features (e.g., color, shape, and size) and cognitive features (e.g., field of vision with sky and building areas) to measure the image/visual complexity of the scenes and wayfinder's psychology stress during the navigation process. Therefore, we investigate the visual attributes with the specific entrance and exit branch, and design the following visual features.

- ***Advanced visibility of target branch*** (to measure the visibility characteristics of the target branch as it approaches the intersection (Klippel and Winter, 2005)).
- ***Similarity of optional branches*** (to measure the visual similarity of the target branch versus its neighboring branches).
- ***Visual openness of the forward direction*** (to measure the openness of the field of vision on human perspectives at street level).

The **structural features** of the road network physically and spatially measure the fundamental properties of navigation environments. As Richter (2009) mentioned, intersections with regular branches are easier to understand and make correct decisions than irregular intersections. Intersections that offer multiple turns in the same conceptual direction are more complex, and intersections with oblique turns are more complex than those with prototypical turns. We focus on the specific routes and intersections' branches, and design the following structural features to answer the question of 'how many branches of this road intersection?', then come to 'how many branches in the same direction?', and further 'how the relative angular deviation of adjacent branches'.

- ***Number of branches***.
- ***Structural regularity of branches*** (to measure the structural regularity of the remaining branches).
- ***Relative angular deviation of adjacent branches*** (to quantify the spatial angular proximity of a target branch to its neighboring branches).

The **semantic features** represent the social-cultural attributes of environments. Generally, POIs work as adequate spatial references with their significant meanings and functions in real-world scenes and digital maps. Further, well-known POIs have prominent historical and cultural characteristics that always facilitate people's understanding of street scenes. Consequently, this study adopts the well-known POIs and their reviews data, and designs the following semantic features to capture all potential visible spatial reference objects on each route segment, and measures the semantically impacts on the complexity of decision-making at road intersections.

- ***Closest well-known POI*** (to quantify the semantically impact by the closest well-known POI locally).
- ***Total well-knownness of POIs*** (to quantify the global popularity properties of the target branch).

2.3. Modelling of the complexity of road intersections

This section incorporates the features mentioned above and designs an adaptive weighted-based computation method to integrate the above features. It can be summarized as $F(f_{vis}, f_{str}, f_{sem}) = F(f_{vis}) \oplus F(f_{str}) \oplus F(f_{sem})$, where f_{vis}, f_{str}, f_{sem} are resulting visual complexity, structural complexity, and semantic complexity separately, which can account for more or less complexity of the wayfinding decision.

3. Conclusion and future work

This paper develops an innovation framework for computing the decision-making complexity of road intersections based on the passage strategy. We further propose eight features based on visual, structural, and semantic aspects to characterize the road intersection of the real-world environments in terms of human perspectives. This study provides further insight into the multi-outcome results of decision-making complexity for specific road intersection. The results will provide solid support the user-friendly route planning services without complicated intersections and aid scene complexity evaluation to enhance signals for route communication and guidance.

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