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Spatial proximity is more than just a distance measure

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Abstract

In order to design **computer systems** that are intuitive to use, the way humans reason about their “real world” surroundings needs to be taken into consideration. Geographic Information Systems (GIS) focus on spatial reasoning. Over the last decades, many advances have been made in GIS interfaces and functionality; however the concept of proximity or nearness, which is essential in many forms of human reasoning, is still being addressed insufficiently.

This paper provides a thorough and comprehensive synthesis of the disparate literature that pertains to the subject of proximity. It offers insights into why existing methods for reasoning with proximity work, or do not work, and analyses their strengths and weaknesses. Finally, the paper provides the derivation of new proximity measures, and their evaluation, backed by experiments and reflections. New measures are formally described in a unifying and compelling framework. This framework acknowledges that while distance is one factor that influences proximity perception, proximity is much more than just a distance measure.

Highlights

- We show that proximity is context-dependent.
- Impact areas are superior to fixed distances to assess proximity.
- Impact Area Generation Model provides GIS applicability.
- Evaluation of proximity done in the context of touristic road travel.

Introduction

Human–computer interaction focuses, as the name already implies, on the interaction between user and computer. The aim is to provide systems that are intuitive to use. The employment of models of human reasoning that makes the human–computer interaction more “natural” is one way of approaching this goal. The concept of proximity or nearness in particular is essential in many forms of human reasoning. It plays a role in concept categorisation (Rosch et al., 1976, Rosch, 1978, Gärdenfors and Williams, 2001), case based reasoning (Sefion et al., 2003), and of course spatial reasoning, to name just a few. Areas such as Artificial Intelligence have employed notions of proximity in data-mining, machine learning and other search techniques. While various applications require diverse nearness or proximity measures, the most intuitive notion is that of *spatial nearness*: omnipresent in human cognition, it is in many ways the precursor for many of the more abstract notions. The aim of the work presented here is to propose a notion of spatial nearness that goes beyond the narrow topological interpretation, and is suitably general. This is not as trivial as might first appear. Surely, questions such as *How far is too far?* or *How close is too close?* seem easy to answer in most contexts. For instance, we know that if we need to get from *A* to *B* within 30 min and all we have to get there is a bicycle, then *B* is too far from *A* if we cannot make it within that time. Likewise, anything that can potentially hurt us is *too close* if we are within the impact area. So why then is it hard to find a general notion that encompasses all instances of spatial proximity? A key reason is that spatial proximity very much “is in the mind of the beholder”, but at the same time works at a subconscious level, as reflected for example in the “flight and fight” response. Finding a formalism that covers both basic perception and higher levels of cognitive evaluation of spatial proximity is the real challenge. We address it by proposing a new conceptual framework to qualitatively represent spatial proximity and enhance the capacity of spatial reasoning systems based on contextual information. Indeed, any model of spatial proximity should take context into account: for instance, one’s degree of proximity to an object depends on whether the object is meant to be seen or reached. Also a suitable model should incorporate conceptual and perceptual knowledge about objects, such as their functionality or their spatial extent. Within such a framework, distance is then one of the factors that determine proximity, but not the measure of proximity itself.

Geographic Information Systems (GIS) are a very relevant application area when it comes to spatial proximity, and are the focus of the work presented in this paper. Most GIS support a topological data model, and allow for an intuitive evaluation of topology—a set of spatial relationships. For example, one can search for objects that are contained in another object such as places within a country’s boundaries, or for objects that overlap such as a lake and a country’s boundaries. However, when it comes to proximity, it appears that from a conceptual point of view we are “stuck” with distance measures. For example, proximity tools such as buffering will generate a buffer of specified distance; other tools might generate distances between an object and other objects that are closest to it. But there is no tool that evaluates whether an object is near another one or not. The lack of such tools can be explained by the lack of workable models of spatial proximity.

Many formalisms of spatial reasoning do not account for proximity at all while others stipulate nearness as symbolic values, using natural language expressions such as *close to* or *near*. For example, Guesgen and Albrecht (2000) suggest associating spatial binary relations such as *far from* or *close to*, or unary predicates such as *downtown*, with fuzzy membership grades, which could be calculated for locations on a map using Euclidean distance. But as we have emphasised, distance is not the only factor that determines perception of nearness: Euclidean distance alone does not reflect factors such as relevant terrain characteristics, steep uphill climbs for instance, or simply the actual travel distance along road networks. While this additional information is usually available in GIS data, what to include in the evaluation of spatial proximity, and how to include it, is the bottleneck of a comprehensive abstraction. The question of a suitable notion of nearness remains.

Section snippets

Influence versus impact areas

Previous work suggests that a suitable notion of nearness should be defined from a more basic notion of influence area. We argue that this approach is flawed, and that nearness should rather be defined from a different basic notion: impact area. Let us first illustrate the difference between influence and impact areas, with an example involving water tanks and radio towers, depicted in Fig. 1.

Classically, the influence area of an object *o* is totally determined by *o*’s spatial boundaries, ...

A cognitively motivated data model of physical space

We need a simple model of physical space and spatial proximity that is cognitively motivated in an effort to incorporate to a larger extent human experience, in a way that is relevant to support the development of intuitive tools for users of geographic data processing applications. We start with the information that is relayed through our senses. The stimuli received from these senses are, so to speak, “raw material” that is meaningless to the human mind unless interpreted appropriately. ...

Factors that influence the perception of spatial proximity

It has often been argued (e.g., Frank, 1992) that distance is sufficient to describe proximity concepts denoted by linguistic expressions such as *near*, *close*, *far*. However, how can we explain that an ant which is 20 m away from a high rise building is considered to be far away from it, whereas another high rise building at that distance is considered to be close to it? Clearly, distance is by itself inadequate to account for such situations. Proximity seems more context dependent than location, ...

Influence areas and spatial proximity

As part of their model of generation of route descriptions expressed in natural language, Kettani and Moulin (1999) suggest to *grade* closeness in terms of influence areas. The term influence area was coined by several cognitive psychologists (e.g., Biederman, 1987) to describe an area mentally built around objects perceived in the environment. Kettani and Moulin formally define an influence area as a portion of space surrounding an object such that:

- the influence area has an interior and an ...

...

Ordinary Voronoi and power diagrams

Ordinary Voronoi diagrams partition a surface into regions that consist of all the points closer to the generating point of the region than to the generating point of any other region. This principle is often illustrated with the “post office problem”, with the post offices in a particular city used as generating points. The closest post office to a queried location is then the post office that is the generating point of the region where that location resides. For another example, take the ...

Summary of previous work

Proximity is a difficult notion that keeps resisting formal treatment due to its context dependency. Consequently, discussions on the actual nature of proximity have been the source of an ongoing debate in the scientific literature resulting in a diverse body of work. In the context of spatial reasoning, this is even more prevalent. While for other spatial notions such as topological and direction relations some unified views have formed within the research community, no such thing has happened ...

A spatial proximity framework

Let us now relate the previous considerations to spatial proximity queries on GIS data. Seeking a more intuitive way of letting users interact with the data, we would like to enable qualitative queries such as *Is place A near place B?* Considering that calculations will be needed to account for the quantitative measures that do impact on evaluation of nearness, how can such qualitative queries be instantiated? Our proposed solution is to cast the notions of impact area and generalised nearness ...

Impact areas and context

We assume that one particular object has been selected as *reference object*. In a given context, the impact area of this object is generated from the points that make it up. Context essentially represents information collated by an expert, who is expected to incorporate all relevant factors into the impact area. Of course, the question remains of how exactly the context should be defined. We suggest to address this by asking the following questions:

1. What is the purpose of the investigation? ...
2. What ...

...

Experiments

In the context of touristic road travel, expert knowledge can be extracted from tourist travel guides and expressed in the form of a specific mapping function, from which impact areas can be generated. Traditionally, GIS proximity analysis requires that fixed distance values be chosen as break values at the time of function definition. In our experiments, the break values are not fixed, but are generated dynamically for each query point. Moreover, the values can change whenever new domain ...

Conclusions and outlook

This paper examined spatial proximity with a focus on how it is perceived and reasoned about by humans. The goal was to find a representation that mimics this mental process, at least to some extent, and is implementable to support the development of more intuitive tools for spatial proximity analysis in spatial data processing. This goal was approached by developing a model of context-adaptive proximity. The derivation of new proximity measures and their evaluation, backed up by experiments ...

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