Place-Based Knowledge Systems: Human and Machine

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To tackle the problem of representing places we need to consider what people know and ask about them. This paper first suggests a list of potential queries of a 'platial' GIS, and it points out that half of them are not directly spatial but semantic, vaguely specified, and rooted in people's sensory–motor (SM) experiences of places. Recent research into human semantic cognition has indicated both explicit and separate storage of SM aspects of each stored concept or category, alongside other key features of how semantic memory appears to work. A very recent computational model taken from the semantic memory research area is briefly reviewed, which holds some potential to be applied to places. If found to effectively reflect human place cognition, this could eventually link a more humanly plausible semantic representation (probably informed by large-scale text sources) to spatial data in a GIS. Further necessary research is proposed.

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1 Introduction – Querying Places

Places are not merely spaces – this much we already know. What is less clear is exactly what we need from a 'platial' system that reflects human concerns about and interests in places.

Users of spatial information are often content to get results that are location-based – what I can do, eat, see, or buy 'near here'. So what kinds of queries would be truly place-based? The author initially became involved in place research because GI users appear to need to know things that relate to ordinary people's usage of place names to denote vaguely defined and often ambiguously denoted *regions* of space, when trying to give locational information such as the address of an emergency incident. However, realistic human-understood places (as opposed to artificial administrative ones) are of concern not only to emergency services but also to data analysts exploring the attitudes, preferences, and emotions of residents and potential consumers of goods and services; to urban and rural planners attempting to improve the local environment; and to researchers trying to model the socioeconomic effects of various phenomena. What kinds of queries might such users want to make of an augmented, place-based GI system? This is an important question because, up until now, we have often talked about the need for place modelling in GI science without specifying exactly what users would need or gain from it.

Based on the kinds of specialist GIS user and their place requirements that were highlighted in previous work (Davies et al., 2009), we can hypothesize at least 30 questions which people might want to ask about places, expressed for now as natural language queries to an imaginary system. These are by no means exhaustive – further analysis of online queries such as that by Hamzei et al. (2019) may well add more, although such users were querying the general web rather than a GIS. Still, a concrete

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list like the following can help us to ground discussion of what platial data needs to give us:

1. A caller said that an incident happened at the [object name or type] in [region toponym]. Which locations could they mean, and with what levels of confidence?
2. Which other locations could have been intended by [quoted name or partial address]?
3. To which place(s) is [address, location coordinates, or landmark name] most commonly said to belong?
4. How confident can we be about using [region toponym] for/at that location?
5. For whom is that toponym usage true at that point? (Any particular subpopulation? What's their frequency of visiting, and familiarity level?)
6. What's the toponym most likely to be applied at [new coordinates for a location]? (Interpolating at a point where no previous explicit data has been collected)
7. Where does [region toponym] extend to in general usage, with 90% confidence?
8. Does [any toponym] refer to more than one area, location, or object? (Disambiguation)
9. What other toponym names (local nicknames, overlapping places) are sometimes applied to [location address, coordinates, or landmark name]?
10. Show me all of the locations, objects or areas that are associated with [region toponym] with more than 80% confidence.
11. Show me only the areas and objects associated with [region toponym] by [specific subpopulation].
12. Show me a fuzzy map of (chosen area) – perhaps as understood and named by a specific subpopulation, or in a specific context of use.
13. How far do these two places [two neighbouring region toponyms] overlap?
14. How often is the same name used for both of these two [any toponyms]? By whom?
15. Where's the universally agreed core ('heart') of [region toponym]?
16. What are the main agreed characteristics of [region toponym]?
17. Which types of people feel positive, or negative, about [region toponym]?
18. How strongly do people feel about [region toponym]? (Or, show me the places where people seem to express the strongest emotions.)
19. Show me all of the places or locations where [characteristic] applies above [threshold value].
20. Show me a thematic map of [characteristic, e.g., household income] across [region toponym].
21. Show me all the places (areas and/or locations) in the city where people most often feel unsafe.
22. Show me the nearest beautiful, tranquil, lively, or busy place to [location].
23. How unsafe, busy, peaceful, or stressed do people feel in general in [region toponym], versus [another region toponym]]?
24. What types or proportions of people feel [some attitude or emotion] in [region toponym]?
25. How memorable or desirable is this [region toponym] likely to be, given its landmarks and general character (form and function)?
26. Show me a map of places that are memorable or desirable above [threshold value].
27. Which locations within [region toponym] particularly contribute to making it more memorable or desirable?

28. Tell me roughly how [region toponym]'s extents and character will appear to this type of person (someone living at specified address, someone with greater or less local familiarity).

29. Show me some places where [type of person] is likely to go.

30. Show me which places (not just specific locations within them) are generally more accessible to people with reduced mobility, or who have small children, or who have wheelchairs, buggies, or prams (strollers), or who are elderly, or who have a fear of crowds (or of open or enclosed spaces).

Note that where a toponym is included above, a place-based system needs somehow to give an answer which seems to best fit the user's context. This would ideally be based on knowledge about how toponym usage varies within a given area. In other words, disambiguation, vagueness, and context specificity are assumed to be built in and somehow 'solved' (or at least, tackled in some explicit way). Where a 'region toponym' is mentioned, this is intended to imply something like a neighbourhood or locality name at local environmental scales (Montello, 1993), but perhaps a region of a country or continent at geographic scale. Where the word 'place' is used above, it could most often be interpreted as implying a region toponym, but possibly not always. There is inherent ambiguity in what people mean when they say the word 'place', which a query system ideally would also cope with.

It will be seen that while the first fifteen queries above are spatial queries that relate mainly to places' vague, ambiguous, and overlapping extents, the second half of the list asks about various *qualities* of a region and its constituent locations. It is the latter type of question that would require more meaningful, semantic knowledge to be incorporated into a platial system.

To achieve this we may have to assume that even though each person's knowledge of a place is unique, people nevertheless will think and communicate with some degree of consensus about a place that extends across an area (i.e., subtend a region) and that many of them will recognize some of the same semantic, functional, and sensory (e.g., visible) features of a place with which they are familiar. That broad consensus knowledge will be more easily modelled in 'platial' data than the individuals' more personal and emotional associations with the place, although some level of adaptability to individual contexts is obviously also desirable in a platial information system. This paper assumes that we thus can move, carefully, from the humanistic qualitative and ontological notion of places (Cresswell, 2014; Davies, 2018) towards something that can be reconciled with GI science and systems.

Yet there is much more to this problem than merely capturing knowledge, whether commonly or individually experienced. We need to know how it is structured, and what effects this has on people's understanding and reasoning about places, so that what they 'mean' by a given toponym works in a similar way to what the system 'means' by it. Therefore, one way to bridge between humanistic and GI science understandings of places may well be the cognitive mechanisms that underpin people's platial concepts, which are at work when people reason and ask questions about them. Luckily, cognitive science has developed successively sounder, more evidence-based models of human semantic concepts and categories. Some particularly relevant recent work is outlined further below.

2 Places in Human Semantic Cognition

Places have semantic as well as spatial aspects – i.e., a place is to some extent a *concept* and, when it consists of a group of known locations within a region of any size, the place is also a *category* (of those locations). Therefore, useful learning for 'platial' modelling may emerge from current cognitive science understanding of human semantic memory and reasoning, which offers over half a century of research into our learning and processing of concepts and categories. Some initial implications of this research are explored below, and by Davies (2020).

To start with, an important aspect of learning about a new city or environment is the grouping and labelling of places. We are usually made aware quite quickly that the area has subregions within it that may be variously labelled as localities, districts, or neighbourhoods within cities, or as farms, hill ranges, conservation or wilderness areas outside them. Davies (2018, 2020) has argued that these ways of grouping locations provides cognitive efficiency, as with all categorical cognition: we can store, recall, name, reason, and communicate about multiple entities at once rather than handling each one individually.

Evidence also suggests that the way we think about region-shaped places such as urban localities follows the same tendencies and patterns as our thinking about semantic categories in general (Davies, 2020). There is *graded membership* – some members (individual locations, landmarks, or scenes) are not considered as 'obvious', 'typical', or 'good' a member as others. Furthermore, decisions about the membership of a given item (location) may vary with task context, expertise, and intent. This is the kind of finding familiar to researchers into cognition of semantic categories such as trees, birds, or household objects (Bailenson et al., 2002; Barsalou, 1985)

Theories of how we store and reason about such categories have changed and developed greatly since Rosch's famous prototype theory of the 1970s (Rosch et al., 1976). As well as hundreds of empirical experiments (for summaries see, e.g., Murphy, 2002), evidence has also been drawn from studying patients with conditions such as semantic dementia, who selectively lose their semantic knowledge while still having intact language and other skills (Patterson and Ralph, 2016; Ralph et al., 2017). This has led in recent years to an awareness that models based on simple similarity or typicality judgments and weightings amongs exemplars of a category, as might be simulated by a crude machine learning classifier, cannot explain all of the findings about how humans store semantic knowledge (Murphy, 2016).

Concepts and categories also appear to be stored in ways that take account of hierarchical membership (e.g., a robin is a bird is an animal; Raposo et al., 2012), although the hierarchy is apparently not always used when we make inferences (Murphy et al., 2012). This awareness of hierarchical structure is also found with place knowledge (Hirtle and Heidorn, 1993; Hirtle and Jonides, 1985). Human knowledge also seems to privilege a 'basic level' of a concept hierarchy: people respond more readily and use more frequently the concepts at one particular level of the hierarchy. Additionally, human categorization allows for defining crisp boundaries between categories on some occasions, for instance, where a fixed taxonomy is needed, but not in everyday casual usage. For a summary of this evidence, see Murphy (2002). There is some evidence that the basic level is also relevant in the people's understanding of the local landscape, although the study was not directly about named places (Edwardes and Purves, 2007).

Concepts are also learned from language. Indeed, for many concepts language is a primary or even the only source of information. This can also be true of places, especially ones we have not yet visited in person but have heard about verbally on repeated occasions. Thus *distributional* models of semantics, based on how names of concepts co-occur with particular sets of other words that provide explicit contexts, allow us to identify similarities between concepts whose co-occurrence patterns are similar, as judged by 'bag of words' statistical linguistic techniques such as latent semantic analysis (LSA). Such techniques tend to use huge corpora of text, rather than individual participant data, but do appear to reflect some common cognitive tendencies (Landauer, 2002).

Louwerse and Zwaan (2009) and Davies (2013) have demonstrated that where concepts are toponyms, the resulting similarity mappings closely resemble the real-world geographical layout of the places themselves, showing how even the spatial dimensions of places are implicitly represented within (large quantities of) language about them. This body of work using LSA showed that distortions in the 'map' seemed linked to people's grouping and categorizing of related places, causing them to be mentally clustered together. Some pilot human-participants work suggested that individuals' cognitive maps of their local area showed to some extent the same clustering and simplifying distortions as those derived from large-scale text corpora (Davies and Tenbrink, 2017). Thus some specific aspects of place cognition do appear to emerge from a distributional text-processing approach.

However, awareness has been increasing for 20–30 years of the 'grounding problem' in cognition: the need to link apparently abstract storage of knowledge back to our perceptual experiences of reality. 'Embodied cognition' has become a major research area over the past two decades, demonstrating that our processing even of abstract ideas often seems to involve our physical bodies (or more precisely, the areas of the brain which take inputs from our senses and which send messages to control our movements). Critiques of embodied cognition research have warned against overstating its conclusions, since 'neural reuse' (multiple purposes for each given brain area) is actually pervasive throughout the brain (Anderson, 2010). Still, it does seem true that some of our knowledge of most kinds of concept is stored in the brain areas that handle specific sensory modalities of sight, hearing, touch, smell, temperature, and taste (Ralph et al., 2017).

The 'hub and spoke' theory of semantic cognition, developed over the past 20 years, tries to account for its embodied nature (Patterson and Ralph, 2016). It argues that most concepts have an amodal

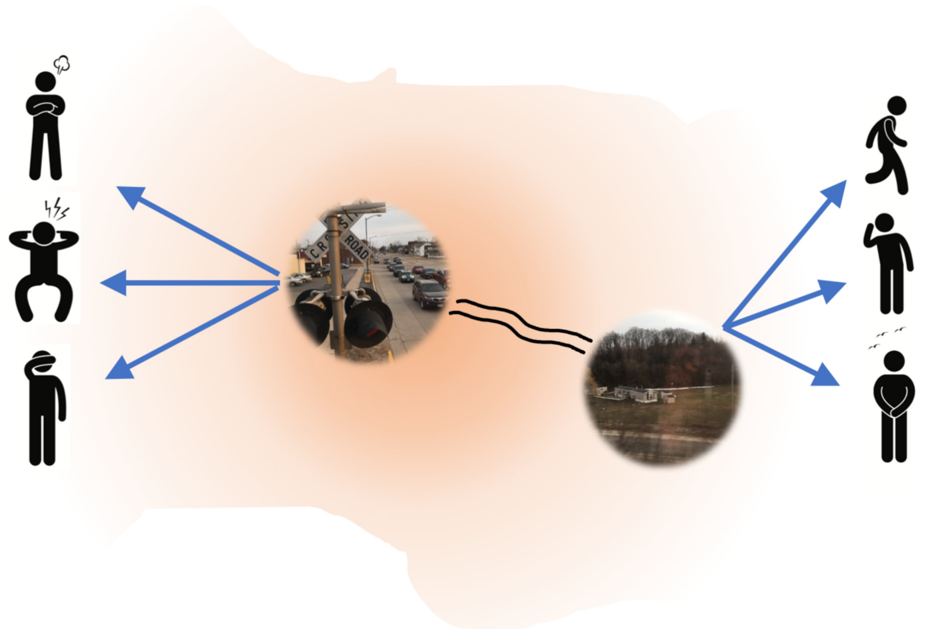

Figure 1: Applying the 'hub and spoke' theory of concepts to places. One exemplar location (scene) within a vaguely bounded locality or settlement (orange) is a railway crossing close to the centre, whose 'core' semantic knowledge is associated with certain sensory–motor properties. Being in the same town (i.e., being categorized in people's minds within that place which is named by the town's toponym) implies that to some extent, the location is linked spatially and semantically to another location on the edge of that town. But the second location may be associated with (in this case) more pleasant sensations and actions. Thus the diagram overlays the mental semantic space onto the physical geographic space, for the sake of illustration.

semantic 'core', stored in the anterior temporal cortex of the brain.[1] Importantly, that 'core' knowledge also links 'outwards' to modality-specific information about our perceptions of and motor responses to the concept, which are processed in the more specialist sensory–motor (SM) parts of the brain.

Of course, it is not of much consequence to platial information scientists that there is no single brain area where all semantic knowledge is stored. But more relevantly, the above also implies that if a place is represented mentally as a concept (and, for places beyond a single location in space, as a 'category' of contiguous locations) then it too will consist not only of a mass of similarity weightings as in the distributional models but also of separate 'embodied' knowledge of people's perceptual experiences of the place. As has already been acknowledged within the GI science literature, such knowledge should include affordances of what we can physically do at the place (Jordan et al., 1998; Kuhn, 2001) as well as sensory attributes concerning how the place looks, sounds, and feels (Mark and Freundschuh, 1995). Figure 1 attempts to apply these ideas to an imaginary person's knowledge of an example place, and of two locations (scenes) within it.

The richness of place representations will of course come as no surprise to the many qualitative researchers into 'sense of place', who have argued for the inclusion of such qualities for many years (e.g., Tuan, 1977). But it finally draws a clear three-way link between such research, more controlled empirical evidence, and potentially useful computational models of semantic cognition, the most relevant of which will be outlined briefly below. Thus these may finally start to be of direct use for 'place' modelling.

3 Modelling Meaningful Places Computationally

The semantic, but also sensory–motor experiential, nature of places implies that we will not fully capture people's knowledge of them simply by attributing locations within a GIS to one locality versus another – even if done using graded 'fuzzy' membership, so that locations at the margins have their ambiguous affiliation recognized (e.g., Brindley et al., 2018). Embodied cognition also implies that even adding known semantic attributes to such records of places within a GIS, perhaps via ontologies (Fonseca et al., 2002), even if those ontologies formally attempt to capture SM 'affordances' in terms of functions and activities that can be performed at the place (Kuhn, 2001), *still* may not adequately reflect the way that people consider them, or the structure of our knowledge about them. Can we use large-corpus data to extract place knowledge that reflects the structure of human semantic memory, while also adding a sensory–motor 'grounding' to our place data?

One possible way forward has been proposed, based on accumulated cognitive science evidence (Hoffman et al., 2018). Hoffman et al. constructed an interesting prototype connectionist computational model of semantic knowledge, based on the above 'hub and spoke' insight that we explicitly store sensory–motor attributes of concepts, plus separately abstracted 'core' knowledge. The model, like the long-established PDP (parallel distributed processing) model that preceded it, uses layers of hidden units to achieve representation of concepts according to their attributes (e.g., bird 'has wings' and 'can fly'). Unlike previous models, though, this one also learns from both distributional data (co-occurrence patterns of words with other words), and the temporal (sequential) context in which the words appear (since the proximity of a word or name to particular other words is also an important indicator of its semantics). The model also explicitly encodes the sensory–motor properties of some of the more concrete words in the input stream, so as to gradually learn to associate those properties with the names of related concepts. Thus in terms of modelling place, the inclusion of a park that was widely referenced as beautiful, or was heavily used for physical exercise, might cause those SM-related attributes to become associated with the overall neighbourhood. Since people speak and write of sensory–motor attributes of a place as well as more objective, measurable ones, it seems quite plausible to capture at least some of them from text sources.

Some of the goals of Hoffman et al.'s model were concerned specifically with the learning of concepts from language, and the inputs made to the system in its experimental version appear to have been artificially constructed rather than learning from naturally occurring discourse. As yet, it is also unclear whether the model replicates the various other facets of human semantic cognition mentioned earlier – the hierarchy with its preferred 'basic level', the fuzzy boundaries that are occasionally crisp, etc. – although its predecessor models did so and thus this may be tentatively assumed. Yet the inclusion of SM properties does start to give this kind of model the potential to model concepts that are cognitively realistic, with an explicit focus on what people physically experience and do.

It is also worth noting, of course, that locations and places are often also learned sequentially – not only from verbal information but also from travelling through and around them along linear paths through the space. Thus the sequentially sensitive aspect of the model is of interest for place learning from direct experience, as well as from verbal information.

Overall, this kind of hybrid approach seems to have the potential for such a model to effectively model places *as people understand them*, and to be linked to a GIS or other information system to allow for queries to be made about not only where places extend to and what data and language is associated with them, but also what they are like – beginning to model the 'sense' of place at last. Even so, of course, many questions remain to be answered about whether and how efficiently such models can be expanded for a real-world application rather than a small research demonstration, and also about how they can be linked to existing GIS. It is also as yet unclear whether such a model can replicate *all* of the aspects of category-based reasoning that may be relevant to places, since to date not all of those aspects have even been established empirically – an ongoing research project in itself. As suggested by one reviewer of this paper, it is also as yet unclear whether a system based upon the architecture that appears to underpin *individual* cognition can actually improve a model of (place) information that is inevitably collated across *populations*, in its aim to address multiple user needs.

4 Conclusion and Future Research

This paper has tried to outline some specific ways in which queries to a 'platial' GIS might go beyond the spatial and formally semantic. It then reviewed briefly some of the key findings in human semantic memory, and a recent model that seems to hold promise for modelling people's place knowledge computationally, such that a system could eventually result that truly reflected people's place understanding.

Obviously, a next stage should involve attempting to reproduce such a system, in which places in a specific local area would be the concepts it learned about from some large-scale text sources (probably web scraping). One would then test its outputs against human-participant experiments, and thence (if it appears to work) examine the important question of scaling up the system for more extensive geographies. These are not small challenges, but they may finally bring us closer to having genuinely ‘platial’ GIS.

Notes

1. Interestingly, this is quite close to the parahippocampal areas known to be involved in spatial processing of scenes and navigating large-scale spaces (Epstein, 2008), which may in fact be more generally involved in the processing of the semantic context associated with any stimulus according to Aminoff et al. (2013).

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