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RESEARCH ARTICLE

The semantics of place-related questions

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Abstract: The trend to equip information systems with question-answering capabilities raises the design problem of deciding which questions a system should be able to answer. Typical solutions build on mining human conversations or logs from similar systems for question patterns. For the case of questions about geographic places, we present a complementary approach, showing how to derive *possible* questions from an ontology of spatial information and a classification of place facets. We argue that such an approach reduces the inherent and substantial data bias of current solutions. At a more general level, we provide a novel understanding of spatial questions and their role in designing and using spatial information systems.

Keywords: question-answering systems, place-based information, core concepts of spatial information

1 Questions and information systems

Information can be defined as *answers to specific questions* [4]. From this perspective, designing an information system requires deciding what questions it should be able to answer, regardless of whether it has explicit question-answering capabilities or not. For example, a mobile app for bus passengers in a university town needs to answer questions like *What bus line goes to campus?* and *Can I get home from campus after 7pm?*

The explicit use of questions in information system design is still rare. A relatively recent form of it are so-called *competency questions* [9], serving to evaluate ontologies to which designers of a system commit. They define the kinds of information a system is competent to provide, i.e., what questions it can answer. For example, a competency question for a bus network ontology might be *How long does a bus ride between two given stops take?* Thus, competency questions represent a partial solution to our problem, i.e. they define *some* questions a system is expected to answer. However, they do not do this systematically or exhaustively, as they are typically derived from interviews with domain experts or prospective users. Designing the capabilities of an information system solely based on competency questions would therefore normally not be adequate. Conversely, while we have a more modest goal here, one could see our contribution as proposing a systematic approach to defining competency questions for spatial information systems.

Another system design paradigm anchored in questions is the *functional view* of knowledge representation. It goes back to the seminal work of Levesque, Brachman and others in the early 1980s [2], who argued for "a *functional* view of a knowledge base, characterized in terms of what it can be asked or told, not in terms of the particular structures it uses to represent knowledge". This idea offers an elegant and powerful view of the contents of knowledge bases as well as a design paradigm for query languages. We follow this paradigm, modelling user questions as first-order functions with well-defined result types. For example, the above competency question about bus rides corresponds to a function that returns an amount of time.

2 Deriving spatial questions from core concepts

We are now narrowing our focus from information systems in general to those providing spatial information, for example through location-based services (e.g., a bus network app) or spatial analyses (e.g., a GIS used to plan bus routes). We first show how to derive patterns of questions for such systems from the *core concepts of spatial information*, an ontology developed by the first author and collaborators over the past decade [15]. Table 1 provides an overview of the three *spatial concepts* among the core concepts and the questions they support. The core concepts also include three *information concepts*, structuring questions about the answers obtained. While such questions are relevant to place information, they are not themselves place-related, and thus lie beyond the scope of this article.

Concept	**Questions**	**Answers (example)**
Field	What *value* does this *attribute* take there and then?	The current temperature there is 25°C.
Object	What's the *state* of this individual at that time?	The restaurant was better when it was on Main Street.
Event	Why does this attribute *change* over time?	Today's storm will lower temperatures there by 10°C.

Table 1: Overview of the three core spatial concepts and the questions they enable.

The core concepts generalize concepts that are commonly used by scientists as well as lay people in application domains. As such, they are still meaningful to users, not just to designers. For the latter, they represent *choices* in the design of an information system. They determine how users should think about the system in order to use it productively. The designers of a bus tracking app, for example, may choose to see buses as moving objects or, alternatively, as attributes of positions on bus routes (taking values like "no bus" or "bus of line 13"). This choice reflects a duality of views commonly referred to as Lagrangian and Eulerian [1]. Similarly, an air quality monitoring system may be designed around *fields* of pollutant concentrations, or around regional *objects* of homogeneous concentration. While a particular conceptualization may sometimes appear more natural than others, the point is that conceptualizing a problem one way or another has direct consequences for the capacity, adequacy, and usability of an information system. Thus, users can ask about bus delays if buses are seen as moving objects, but not if they are attribute values of nodes and edges. Similarly, users can ask either for the exact location of the highest concentration of pollutants in town, or only for the area with maximal concentrations.

As shown in the table, each core concept comes with a *question pattern*, capturing the questions it enables. This makes the consequences of choosing a particular conceptualization explicit. The pattern can be formalized as a mathematical function. A powerful example is the field function, returning the value of an attribute z (e.g., the PM_{10} concentration) for any position x in a region $\mathbb{R}$ and at any time t in a period $\mathbb{T}$:

$$z = f(x,t) | \forall x \in \mathbb{R}, \forall t \in \mathbb{T} \tag{1}$$

This function expresses the question pattern on fields shown in the table. Furthermore, *any* field-related question (e.g., where and when the attribute reaches its maxima or minima) can be derived from it by using standard mathematical techniques, such as computing derivatives and inversion.

Objects differ from fields by having an identity as a whole, with properties and relations depending on the entire object, not on positions within it. The properties and relations of an object may include its location, shape, and any non-spatial attributes of interest. Following standardized practice [19], an object collection (such as a group of buildings) is itself considered an object with an identity and collective properties (including the location of the collection as a whole). An important sub-concept of an object collection is that of a *network*, where any two objects are either connected directly by a link, or indirectly by a path, or not connected at all. The links and paths may themselves be seen as objects, with their own properties, such as length or capacity.

The properties and relations of *events*, finally, also apply to their entirety, but events extend in time, rather than in space. For example, a storm may be characterized by the total amount of rain that accumulated at a location during the storm. Analogously to object properties being observed at a time t, event properties are observed at a location x. Events in themselves have no location, but get located through the fields or objects participating in them. For example, a road flooded during a storm locates the storm and can serve to locate the accumulated rain.

3 Deriving questions referring to geographic places

Places are a central notion in human geography (the *neighborhood* in which you grew up, *the convention center*), but remain weakly supported by information science and systems. Recently, the challenge of modeling places more adequately has gained both academic [22] and industry attention [24]. Question-answering systems provide a strong need and opportunity for improved computational models of places, as places occur in many questions that people ask.

Places may have imprecise boundaries (consider *downtown*) [7, 16], may be called or even located differently by different communities (consider *Macedonia*), and may have strong cultural or emotional significance (consider *Pearl Harbor*). Researchers have long argued that these characteristics mean that places are poorly represented by points, lines, and polygons, the geometric primitives commonly used for digital maps. We have recently shown [22] that a conceptualization of places as *objects*, in the sense of the core concepts of spatial information introduced above, addresses such concerns and provides a number of significant benefits. In this core concepts view of places, they

- … can be *identified* over the duration of their existence and beyond, allowing for the tracking of changes; for example, in their spatial extent (consider the growth of a forest, or the territorial changes of Poland over the last 500 years);
- … have a *location* in geographic space and time, which can be defined relatively or through spatial and temporal reference systems;
- … may have a *boundary*, which can be crisp or imprecise, or may only be *bounded* by the confines within which they are known to lie (consider the case of Matterhorn, on which you are probably not located now, though it seems impossible to define a boundary for it);
- … may have any number of *properties* and *relationships*, spatial or otherwise;
- … may have *parts* and *aggregates* (i.e., there are complex places);
- … may form *complex objects*, which themselves may be considered places (e.g., a city, consisting itself of a web of places);
- … may participate in *events*, such as storms, festivals, or epidemics;
- … may be understood as cut out from *fields*, as in the cases of climate zones or fear zones in a city.

This list of characteristics shows the modeling power of the core concepts in general, and the object concept in particular, when applied to geographic places. It illustrates the role of core concepts as design choices, providing an explicit account of the aspects of places that can be asked about and answered with an information system.

4 Refining place-related questions by place facets

Let us call the essential properties of places *facets*, using a term from facet theory [3] as one of multiple conceptual frameworks to describe aspects, properties, or characteristics of things—here of places. Based on a systematic literature review, Hamzei et al. [12] have collected more than one hundred place facets and categorized them in a hierarchy which could be considered an excerpt of a geographic domain ontology. While a literature review can never be exhaustive, it can at least reduce personal bias.

In the top level of the hierarchy, we find three kinds of place facets, (1) *primitive facets* that describe particular aspects of geographic places such as their physical properties, (2) *derived facets* that have mixed meanings and can be considered as combination of primitive facets, and (3) *linguistic facets* that captures properties of references to place such as place names or descriptions.

The derived facets depend on primitive facets, and questions seeking information about the derived facets can be rewritten as a series of questions aiming at finding primitive facets. For example, suggesting 'best places to visit' depends on many aspects from spatial and geographic facets to cultural and historic meaning of geographic places. Such question deconstruction is heavily context-dependent and lies beyond the scope of this paper. In the rest of this paper, we narrow down our investigation to primitive and linguistic categories.

The primitive facets are further divided in the four categories:

- *anthropocentric emotive facets*, such as place attachment, describe emotional bonding and feeling associated to places;
- *anthropocentric functional facets*, such as affordance, describe activities allowed and services provided at places;
- *geographic physical facets*, such as material form, describe physical and morphological properties of places and reflected on how places perceived through common senses; and
- *geographic spatial facets*, such as location and accessibility, describe the relationship between place and space.

Here, we demonstrate how these place facets, together with the spatial question patterns that have been introduced in the previous section, can be used to derive classes of place-related questions. The place facets allow for more specific question patterns, as they represent the kinds of answers that can be given to place-related questions.

With places conceptualized as objects, the primary question pattern for places is *What is the value of place facet p_i at time t?* A place facet can be any property of a place of interest. While emotive, functional and physical facets are attributed to individual places, facets may also characterize multiple places forming an object collection or a network. If a place network is viewed as an identifiable whole with properties, then it can again be conceptualized as an object—e.g., a public transportation network. Thus, emotive, functional and physical facets can be applied in the same way to describe the whole network. For example, people's satisfaction with public transportation in Melbourne can be considered an emotive facet of the public transportation network in that city.

Emotive and functional facets suggest patterns for questions about the relation between places and people. In both cases, these questions can be about the relations between a place and a person (e.g., a subjective experience or opinion), a community (e.g., cultural values and traditions), or an entire society or civilization (e.g., historical information). The emotive facets (attachment, sense of place, commitment, and salience and familiarity) provide questions that are often of interest to social scientists, policy makers, and planners. Yet, these questions also cover everyday questions of residents and tourists about the experiences and opinions of others. The functional facets capture a different aspect of people's exploration and experience of places, focusing on what a person can do or is allowed to do in a place.

Physical facets capture properties of the form, parts, and material of places. Their kinds vary across different types of places. For man-made places, architectural properties may be of interest; for natural places (such as mountains), geological and morphological characteristics play an important role. The question patterns using emotive, functional and physical facets are shown in Table 2 with examples.

Spatial facets capture spatial properties of an individual place and spatial relations among places. In the first subclass, *location*, *footprint* and *boundary* (if any) are the major properties that describe where a place can be found in space. Additional spatial properties such as *elevation*, *length*, and *area* are similarly describing spatial properties of a geographic place, and such properties can be inquired as well. Due to the importance of location and

Category	Subcategory	Pattern/Example
Emotive	Individual	*What is your feeling about place p?* How does it feel (What is your feeling) after visiting the orphanage?
Emotive	Social	*What are the social/cultural aspects of place p?* What is the cultural significance of Uluru?
Functional	Individual	*What can I do at place p?* What can I eat at this Subway restaurant?
Functional	Social	*What is (socially) allowed in place p?* What is allowed in this non-containment zone?
Physical	Material	*What are the material properties of place p?* What is the dominant soil type in East Texas?
Physical	Form	*What are the morphological properties of place p?* What is the architectural style of Fallingwater?
Physical	Parts	*What places are part of place p?* How many rooms does this mansion have?

Table 2: Question templates using emotive, functional and physical facets.

boundary of geographic places in question answering, these facets are individually investigated and their question templates are separately provided in Table 3.

The second subclass of spatial facets is related to the network sub-concept because it captures relationships among places. Two types of relationships lead to two types of networks: (1) spatial relationships between places in a configurational network and (2) accessibility relationships among places in a transportation network. Considering the question template of networks, the question can be rewritten for places as *what connects these two places at this time?* Table 3 shows the question templates and examples derived from spatial facets.

Questions can be posed about the linguistic facets to find referential information about places. Linguistic facets include specific, generic and indirect references to places [5]. In the simplest form, questions can be asked about the names assigned to places (toponyms). Place types are an example of generic references and thus can be asked for in place-related questions. The question templates using linguistic facets are listed in Table 4.

Place-related questions can also involve fields or events. Places as objects can be carved out of fields and emerge as participants in events. In the former case, places (e.g., the warm temperate zone) can emerge from bounded values of field attribute (e.g., a temperature interval). Similarly, a new place may emerge where an event has occurred (e.g., the Gettysburg Battlefield). These places can be the subjects in the aforementioned question patterns, but they can also be inquired based on their relation with the formative fields or events. Moreover, existing places can participate in events, and their properties can be changed through these events. Table 5 provides question templates for places in conjunction with events and fields.

Concept	Facet	Example
Object	Location/Footprint	*Where is (What is the location of) place p?* Where is Melbourne?
Object	Boundary	*What is the boundary of place p?* What is the boundary of international waters around Australia?
Object	Spatial properties	*What is the value of this spatial property of place p?* What is the surface area of Australia?
Network	Spatial relationships	*What is the spatial relationship between place p_1 and place p_2* What is the distance between Melbourne and Sydney?
Network	Accessibility	*How to get to place p_2 from place p_1?* How to get to Sydney from Melbourne by car? What is the driving direction from Melbourne to Sydney?

Table 3: Question templates using spatial facets.

Category	Subcategory	Template/Example
Linguistic	Specific	*What is this place p called?* What is the name of this mountain?
Linguistic	Generic	*What is the kind of this place p?* What is that silver thing?

Table 4: Question templates using linguistic facets.

The theory-driven classification of place-related questions presented in this paper captures *description questions* related to places [18]. Yet other classes of questions such as *comparison questions* (e.g., is the Black Sea bigger than the Baltic Sea?) can be constructed

Concept	Relation	Concept	Template/Example
Place	Emerge from	Event	*Where did the event take place?* Where did the battle of Gettysburg take place?
Event	Change	Place	*What is changed in place p during the event?* What is the impact of global warming on Lake Urmia, Iran?
Place	Emerge from	Field	*Where are places with a specific (range of) field attribute(s)?* Where are warm temperate zones located?

Table 5: Question templates for places in conjunction with events and fields.

similarly—i.e., designing the core question of objects based on the question class, and enriching the core question with place facets.

5 Related work

This article presented a top-down categorization of place-related questions, combining the core concepts of spatial information with the place facets, both previously established. To justify the proposed categorization, we now discuss other approaches to the categorization of similar types of questions—let us broadly call them geographic questions. For this purpose, we review primarily studies in geographic information retrieval (GIR) and geographic question answering, the main areas investigating the application of place-based question answering. First, we explore the data-driven (bottom-up) approaches to explain how data generation strategies lead to biases in the categorizations. Next, we investigate expert-driven question templates, and focus on their inherent bias brought in by the lack of theoretical grounding.

The early studies on GIR have documented how the web is commonly used for place-related search [14, 23]. These—by now dated—analyses of query logs show that places are searched for based on both specific and generic references. The importance of qualitative spatial relationships in geographic web queries for retrieving geographically relevant documents was further discussed in the literature [14]. This has led to the formulation of query templates describing the structure of frequently observed geographic web queries—e.g., `<theme, qualitative spatial relationship, toponym>` [21].

Henrich and Luedecke [13] developed a bottom-up approach to categorize geographic web queries into four main groups, *finding accommodation*, *searching for habitation*, *seeking information about places*, and *finding places that afford leisure time activities*. Due to biases in the web search dataset, this classification only captured spatial (localization) and functional properties of places and neglected emotive and physical properties.

Analyzing geographic question answering corpora led to different classifications of questions based on syntactic structure, word content and question intents [25]. Microsoft MAchine COmprehension (MS MARCO) [17], Geographic Questions (GeoQuestions201) [20], and GeoAnalytical Question (GeoAnQu) [25] datasets are examples of corpora that have been investigated in the literature. Hamzei et al. [11] classified questions in MS MARCO into a shallow hierarchy of (1) questions about non-geographical places, (2) questions about geographical places, including (2-1) spatial and (2-2) non-spatial questions. The non-geographical places category is out of the scope of this paper. The categorization of questions about geographical places only differentiates spatial and non-spatial properties of places.

Xu et al. [25] compared the three geographic question datasets based on their intents. The intents are classified as *toponym*, *type*, and *non-platial entity*. The linguistic facets (i.e., toponym and type) are differentiated from other facets in their study, but other facets (e.g., physical and functional facets) are captured in the entity category. Xu et al. [25] also found different intent patterns across the analysed datasets: they found that in geoanalytical questions, entity intents are frequently related to change, effect and trend while in search questions, general information such as population, zip codes and weather dominate. This only supports our claim that empirical, data-driven categorizations are always going to suffer from collection biases, and may not provide a true representation of the diversity and distribution of place questions of interest to people.

The top-down approach is also used in the literature for categorization of geographic questions. Ferres and Rodriguez [6] classified questions into where/what questions about location, area, height, length, flow, population, action and quality of places. Based on the facet classification presented here, Ferres and Rodriguez [6] focused on spatial facets and also captured functional facets of places, but neglected physical and emotive facets. Punjani et al. [20] categorized geographic questions into question templates based on location, type, and thematic features of places. The question templates only focused on specific and generic references to places, and other facets are captured as thematic properties.

In short, the *bottom-up approaches* are highly sensitive to biases in the data collection and thus only reflect question types represented in, or supported by the datasets. As a result, questions about spatial and functional facets are often overrepresented in these categorizations, while emotive and physical facets are marginalized. Except for the geoanalytical questions dataset studied by Xu et al. [25], the questions about places focusing on the event and field perspectives are entirely missing in other datasets. The categorization-based *expert-driven approaches* suffer from the same problem because they are designed to analyse and explain a specific question-answering scenario, e.g., web search. Moreover, the lack of theoretical grounding or a systematic approach is a salient problem of the expert-driven categorization. In contrast, our top-down approach is a generic, cross-disciplinary approach (since it is based on the spatial core concepts), and with lesser expert bias (since it is based on a systematic literature review and a broad categorization of facets).

6 Conclusions

For the case of place-related questions, we addressed the design problem of equipping information systems with question-answering capabilities, and specifically of deciding what questions a system needs to be able to answer. Our approach is intended to complement and guide data-driven design techniques and to contribute to the understanding of questions and their roles in information systems, as well as of spatial questions in general.

The main contributions are twofold. First, we propose a question pattern for each concept and refine these patterns to geographic places, using an object conceptualization of place, fields, and events. Second, we propose a detailed classification of place-related questions, derived from the question patterns for places and refined with categories of place facets.

This resulting classification includes *fourteen* classes of questions that cover geographic and anthropocentric information needs (see Tables 2-4). Three classes cover questions about places resulting from field and event aspects of places (see Table 5). We compared our classification of place-related questions with available data-driven and expert-driven classifications. We found that the theory-driven classification not only covers previously defined classes of questions, but refines them into a more detailed set of classes. Moreover, the theory-driven classification includes classes of questions which were not identified in the previous classifications, due to the inherent biases in those data sets.

The proposed classification also has limitations due to limitations in the underlying theories and in the scope of investigations. The categories of place facets have those limitations that influenced the study of them, including the lack of coverage for several disciplines such as public health and digital humanities in the systematic review. Consequently, some categories of place facets may not be covered in the review since that literature review was not (and could not have been) exhaustive.

The scope of our classification is limited to the questions seeking information about an instance of a concept (i.e., place) or its properties and relationships. Considering the upper-level taxonomy of questions [8], our study only covers five types of questions known as *short answer questions*—i.e., verification, disjunctive, concept completion, feature specification and quantification questions. While the remaining thirteen types of questions known as *long answer questions* [8] such as comparison, expectational, and judgemental questions were considered to be out of the scope of the present investigation, though potentially relevant to geographic places. For example, *How is Western Europe different from Eastern Europe?* is a long-answer comparison question that is not covered in our classification, and the answering process for such questions is challenging due to the need for a semantic similarity measure that covers different facets of places. Moreover, some categories of questions in the upper-level taxonomy belong to the conversational situation (e.g., assertion or request questions), and are not necessarily applicable to question-answering in general. In this paper, we focused on short-answer questions due to their generality and essential role in characterizing and evaluating question answering capabilities of information systems.

The results of our work can be used to design and assess the question-answering capabilities of place-based information systems. Moreover, the proposed classification can be used to characterise potentials and limitations of available question-answering and machine-comprehension datasets. Such characterisation requires proper methods and implementation for information extraction and text classification and can be investigated as another future direction of this research. Finally, the proposed classification can be used as a basis for the question classification task (the first task in question answering architecture [10]) that determines how and where the relevant information can be found or generated.

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