Spatial Function Representation and Retrieval

Abstract

This paper proposes a spatial functional representation intended to explicitly describe spatial meaning in our daily life and to utilize it for advanced location-based information services. The merit of our representation is threefold: (i) it considers a space as an artifact; a space is described from its function, property and structure. (ii) a space has different meanings to different persons; thus our representation conditions a spatial function by user type. (iii) not only physical function but also social function is considered; a space has a social meaning, and our representation describes spatial meaning both physically and socially. We detail the representation and show an application of an advanced navigation, what we call spatial function retrieval, by reasoning based on that representation.

Introduction

Spatial information has been received much attention recently. A ubiquitous computing environment (Weiser 1991; Nakashima 2003) enables us to monitor a user behavior and potentially provide tailored information services depending on the user situations such as location. Navigation (Butz *et al.* 2001) and city tours (Schmidt-Belz *et al.* 2002) are some of the major applications of GIS (Geographic Information Service) using location information.

Present GIS are built on two basic standard data structures: vector and raster (Frank 1992). Many studies have addressed GIS: for example, Coenen proposes a tesseral representation of space instead of a raster structure (Coenen *et al.* 1998). However the most studies emphasize an application aspect; the meaning of space is implicitly incorporated with so-called "landmarks," which refer to geographical objects important for assumed users. On the other hand, spatial representation has been considered in the context of spatial reasoning: for example, Forbus develops the MD/PV (Metric Diagram/Place Vocabulary) model to enable spatial reasoning (Forbus, Nielsen, & Faltings 1991). However, such research specifically addressed the mathematical aspect of a space. There remains a gap between the representation and the meaning of space.

We consider that space has a meaning. In other words, space has many implications. If one is in a certain space, that location and existence engender valuable influences, conditions and outcomes. For example, when one is in a lounge, that person may be able to drink something. She may be relaxing talking with someone else, or thinking alone while smoking. These actions are permitted socially in the lounge. A classroom contains necessary equipment for a lecture there. A student can have a lecture there, and a teacher can give a lecture. During the class, students are not permitted such actions as relaxing, eating, and talking. The classroom has different meaning to the teacher and the students.

In our daily lives, especially in a city, we are surrounded by many artifacts. We also consider space as an artifact. It is usually considerately designed by humans to have functionality. This paper is an attempt to capture the meaning of space by its functionality. For example, a lounge has functions such as "enable one to drink," "provide something to drink," and "enable one to be seated." A classroom has functions of "enable a student to hear a lecture," and "enable a teacher to give a lecture."

These functions are realized by the functions of objects that exist in that space: a coffee server offers the function of providing coffee. A chair enables one to be seated. A blackboard enables sharing information, thus contributing to a lecture. However, the function of space is sometimes more than the function of inner objects. For example, if there are chairs that are stacked in a corner of the room (as in a warehouse), the room does not provide a function to "enable one to be seated." Even if there are a blackboard, desks and chairs, they do not provide the function of enabling a teacher to give a lecture unless they are properly positioned. Moreover, even if they are properly positioned, if there is no wall, window or door, it is difficult for a teacher to teach. The property of a space being "confined" contributes to the function.

According to Sasajima, a function is defined as a result of interpretation of a behavior under an intended goal (Sasajima *et al.* 1995). However, a space usually does not have behavior[1]. Only persons can act. Therefore, we use

[1] A few exceptions might be: a vehicle where an inner space will also move and there is a movable partition, such as a curtain on a stage in a theater.

a term “property” instead of “behavior.” We define a spatial function as a result of interpretation of a property that is realized by a structure of a space under an intended goal.

Unlike divice functionality, spatial functionality involves human factors. For different types of users, a space offers different functions, e.g., a student and a teacher in a classroom, and a doctor and a patient in a hospital. Therefore, we claim that a spatial function should be conditional upon the type of user.

Moreover, there is a concrete distinction between what we call the *physical function* and the *social function* of a space. For example, if a room has chairs, a table, and an ash tray, smoking is physically possible. However, smoking might be socially prohibited in the room. On the other hand, smoking is physically and socially possible in a smoking room. In other words, there is a function to “enable smoking” (physically) and “permit smoking” (socially) in the room. Another example is: Can you enter your boss room without her permission? If the door is locked, one can not enter the room physically. But even if the door is open, we can not enter the room because to “enter the room” is not permitted socially without her permission or appointment. If there is a secretary desk of her, and the person can obtain permission to enter, the desk space is considered to have a social function to “provide permission.”

The importance of explicit conceptualization for reusability of knowledge has been widely recognized (Kitamura & Mizoguchi 1998). In this paper, we discuss a meaning of a space from the functional point of view and propose a knowledge representation of a space with high applicability and reusability. Developing a spatial representation is an essential issue in revealing how humans understand a space. Through construction of a spatial representation that concurs with our common sense, we can produce a more intelligent spatial information system. The latter half of this paper introduces a system called *spatial function retrieval* which searches spatial functions to satisfy a user’s need.

The rest of the paper is organized as follows: the next section discusses a space and its function. Then, methods to categorize and describe spatial functions are explained. After showing a sample description, we introduce spatial function retrieval as an application of our representation. We conclude this paper after discussion.

Consideration on Space

What is Space?

We define a space as an area that is empty and bounded by some boundary. A boundary might be a physical object such as a wall, door, and partition, or a conceptual line such as a territory borderline. Bittner distinguishes bona-fide and fiat boundaries (Bittner 2000); similarly we admit that boundaries can be physical and/or conceptual. In this paper, we consider a space as a 3D concatenated region.

In studies of GIS, the term “place” is sometimes used to represent landmarks, points, lines and regions. Although there are many different definitions and usages of place (Jordan, Raubal, & Gartrell 1998), we consider that a place is a space or a region that is assigned meanings ex-ante. On the contrary, a space is literally empty [2]: the meaning must be added to it[3].

Space has a hierarchical structure by its nature: A space contains subspaces within it. Because a space is a concatenated region, and therefore a set of points, it has subspace that is a subset of the set. Spaces are partially ordered by the set. Extremely, the greatest superset of a space is the whole universe, and the smallest subset of a space is a point.

Space also contains objects within itself. Because objects occupy a space, spaces and objects are also partially ordered. If we ignore objects that lie across two or more spaces, a space can be considered as a container that has subspaces and objects inside it.

Spatial Function

Usually, spaces such as rooms, exhibition halls and desk spaces are designed and used to provide functions that contribute to some objectives. Such functions are realized as special properties that are given by an appropriate structure. This is very similar to automobile artifacts: tires, handles, engines, shafts, and many other components comprise a car. Their appropriate structures give behaviors such as “generate power” and “contain humans and baggage,” and under some objective, those behaviors can be considered as functions “move fast” or “carry baggage.”

A space can also be considered as an artifact whose function is realized by the functions of inner subspaces, objects and their structures. For example, a library has a function such as “lend books to citizens” (for a librarian), “select books to lend,” and “investigate books” (for a user), where the objective of a library is to “manage and distribute books.” These functions are realized by its functionality of subspaces such as a circulation counter, bookshelf space, and desk space. A bookshelf space consists of bookshelves and books, and their structure: books are arranged in the bookshelves and the bookshelves are properly distributed with sufficient width for corridors.

Because a space is considered as an artifact, it is natural to employ a representation focusing on its functions. A theater, a library, a reading room, a waiting room, a consultation room, a dining room, a conference room, a toilet, and so on are all spaces that have functions as their objectives[4].

Unlike the functionality of devices, spatial functionality involves human factors. Spaces offer different functions for different types of users. A stairway enables a person to access other floor of a building. But it does not enable a person in a wheelchair to move. A security door can be entered by use of a key card, but not without the card. Therefore, we claim that a spatial function should be conditional upon the type of a user.

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[2] In Oxford Advanced Learner’s Dictionary in the second meaning, SPACE-: *an area or a place that is empty*.

[3] To avoid confusion, we will use the term “space” as far as we can. The term “place” is defined in the subsequent section.

[4] We must note that we can say that a function is achieved by certain functions of subspaces and the structure, but it is difficult to record all the necessary conditions for the function to emerge. There is always something out of our consideration, which is famously known as the frame problem.

Physical and Social Function, and Combination

A space function and a user type are considered both physically and socially. A space has a social function, such as "give a permission," "permit smoking," and so on. A user also has social attributes such as "position," "gender," and "permission."

Some might argue that "socially" is not appropriate: it should be "logically," "abstractly," or "cognitively." For example, a gender can be considered as a logical symbol. A room may be recognized cognitively as a relaxation space. However, in this study we want to describe a space by its use and how most users recognize it. We try to clarify socially consensual meaning about space. Therefore, we describe a space function physically and socially.

Of course, the usage of a space changes over time: a space is designed by an architect so that it has intended functions. Some functions are used and others are not during actual use. Moreover, the space may come to use differently. We must update the description of the space if the function of a space changes.

When space is recognized by the granularity level of GIS, landmarks such as hospitals, stores, and stations are considered as objects that have their own specialized functions. However, when considering the granularity level of an inner building space, functions of a space are more primitive and complex.

For example, a woman can go to buy a piece of bread at a kiosk space and go to a bench, take a seat and eat. A kiosk space provides a piece of bread, and a bench space enables him to be seated. In this case, two physical functions are used in combination. If a man gets a babies' nappy, he has to find a space for nursing. Different physical and/or social functions at different spaces are used in combination in our daily lives.

How to Describe Spatial Functionality

We propose to describe the meaning of a space by a triad:

(space region) (user type) (function type).

Namely, in a certain region, space has a certain type of function for a certain type of user. A function of space is conditioned mainly on the user type.[5]

A space region can be described using conventional notation. In this study, we use G-XML[6] (Arikawa & Kubota 2000), which is a protocol for encoding spatial data through extensions built upon XML. It supports a variety of spatial model such as a metrical and topological model including a vector and raster model. We will not address details of G-XML because it is not our focus.

For example, a space where a staff member can get a cup of coffee is described as Fig. 1. It is a form of XML. In the rectangle region, the "physically provide" function of coffee exists for a user type whose social attribute of "position" is staff. Below, we denote "<X>Y</X>" as "X:Y" for simplicity. The following are types of users and types of spatial functions that we propose.

```
<space>
 <Rectangle>
  <cordinates 200,120  340,180
 </Rectanble>
 <user>
  <aattr type="position">staff</aattr>
 </user>
 <pprov>coffee</pprov>
</space>
```

Figure 1: An simple example of spatial function.

Definition of User Type

The representation of a user is described by the user's physical and social attributes. Physical attributes concern things that the user possesses. Social attributes concern the abstract properties the user has.

The main reason to divide physical attributes and social attributes are two-fold. First, a physical attribute may be observed through some sensors, while social attributes are conceptual and are therefore invisible to sensors[7]. Second, physical attributes often condition physical functions, whereas social attributes often condition social functions.

Physical attributes and social attributes are interchanged in some spaces: Assume a situation in which we buy tickets to enter a museum. Buying a ticket means that the social attribute of "payment: yes" is changed to the physical attribute of "belongings: a ticket." In another situation, one may be required to present a student ID. This means that the physical attribute of "belongings: a student ID" is changed to the social attribute of "position: student."

pattr The `pattr` denotes a physical attribute. It includes two types.

- `belongings`: what a user has, such as money, a key, and so on.
- `devices`: what device a user has, such as PDA (Personal Digital Assistant), a cellular phone, and so on.

We distinguish these two because available devices might effect a way to send information to the user. For example, if a user has a PDA, then a system can send an image file to the user through the PDA.

aattr The `aattr` denotes social (or abstract) attribute. It includes the following types.

- `position`: e.g., students, professors, clerks, visitors or stockists (in universities); patients, doctors, nurses, guests, or salespersons (in a hospital); and so on. This attribute is domain-dependent and stable.
- `interest` and `knowledge`: these attributes affect mainly "provide information" function. These attributes are domain-dependent and changeable.

[5]We will extend this. A function of a space is also conditioned on the time, day and other external factors.

[6]Geographic information - XML encoding for geospatial data exchange. XML stands for eXtensible Markup Language.

[7]These attributes can be observed by sensors in a situation where an IC tag will tell a person's social attributes. It might be appropriate to categorize them as physical attributes if this situation becomes ordinary.

- gender, age, and so on: men or women, children, adults, or seniors. These attributes are domain-independent and stable.
- permission and appointment: yes or no. These attributes are domain-independent and changeable.
- ability: handicapped, visually impaired, and so on. To guide these people, this attribute is necessary. It is a domain-independent attribute concerning on availableness for many persons.
- payment: paid or unpaid. This is a necessary attribute where payment is done as at a shop, a restaurant, or a museum. This is a domain-independent attribute that is common in buisiness spaces.

Definition of function type

We categorize spatial functions as four types: that is, physically provide, socially provide, enable, and permit. "Provide" is a spatial function to provide something physically or socially, such as coffee or permission. It may change the user's physical or social attributes.

"Enable" is a spatial function to enable some action, and "permit" is a spacial function to permit some action. These are functions when we focus on the behavior of users in the space. If a user has an intention to do some action, the space provides the necessary condition.

pprov The pprov denotes a function of providing physical objects.

aprov The aprov denotes a function to provide an abstract object. An abstract object includes information, permission, appointment, and so on.

enable The enable is a physical function to enable a user to do some action. For example, a conference room enables a user to have a meeting. Such action is decomposed into partial actions: a meeting consists of sitting down, talking, taking memos, sharing information, and so on. There are many ways to decompose an action. For example, a meeting can be decomposed on a semantic level as e.g, giving agenda, solving problems, making decisions. However, we decompose action from a spatial point of view: if the action requires different subspaces, we distinguish these subspaces. A meeting can be decomposed as sitting down (which requires chairs), taking memos (which requires tables), and sharing information (which requires a projector). We consider "disable" as the negative of enable.

permit The permit is a social function that permit a user to do some action, that is prohibited in the superspace. We consider "prohibit" as negative permit. Sometimes, the permit function occurs along with an enable function: e.g., "permission: smoking" occurs sometimes with "enable: smoking" by ash trays. A fence disables someone to enter. It implies "prohibit: enter."

access The access is a function to go to other spaces, which is a part of enable functions[8]. But we distinguish access because this representation focuses on space, thus behavior related to space, i.e., movement, is important.

[8]We do not consider access as a part of permit function, because permit to enter is naturally described in a space to be entered, not in a space from which to enter. We do not discuss in detail because of the page limitation.

```
<?xml version="1.0" standalone="yes"?>
<spaces>
 <place type="restaurant" label="Udon">
  <space>
   <user>
    <aattr name="position">guest</aattr>
   </user>
   <permit id="func:permit:eat">eat</permit>
   <enable id="func:enable:eat">eat</enable>
   <service>restaurant
    <achievedby>
     <func ref="func:enable:eat"/>
     <func ref="func:permit:eat"/>
    </achievedby>
   </service>
   <user>
    <aattr name="position">staff</aattr>
   </user>
   <enable>cook</enable>
   </space>
 </place>
</spaces>
```

Figure 2: An example of spatial function representation.

In addition to the above functions, we define a service function. Service is a spatial function with human intervention, such as a guide service or a reservation service. A human judges the context of a user and provides appropriate functions to the user. In most cases, a service is designed to respond to a user's typical demand by utilizing the above spatial functions.

service The service is a spatial function that intends to respond to a user's demand. For that purpose, it comprises other spatial functions such as pprov, aprov, enable and permit.

There are some tags that are necessary to describe spatial functions. The reader can find a detailed specification and sample descriptions in (Matsuo 2004). The most important one among the remainder is the place tag.

place The place is a tag which binds up some functions. For example, a toilet is a place with many functions. By putting place tag, we can use the default knowledge about toilet, and we do not have to describe all the functions of a toilet for each. Actually, we think that to recognize a space as a place, i.e., a bundle of functions is humans's usual understanding for a space.

Figure 2 is a (simplified version of) spatial functions description of a restaurant space.

Controlled Vocabulary and Ontology

We need the following knowledge base to control the vocabulary:

- Object relation: to control the vocabulary of `pattr`, `pprov` and `aprov`. This can be done using thesauri and dictionaries.
- Action relation: to control the vocabulary of `enable`
- Social constraint relation: to control the vocabulary of `permit`
- Information relation: to control the vocabulary of `aattr`. This can be done through document processing technology, such as similarity measure, and so on.

Spatial Function Retrieval

The objective of our spatial function representation is to make a machine grasp the rough meaning of spaces. That enables a machine to make an inference that more closely resembles human reasoning about space than current systems.

For example, assume a user puts an input to a machine – "I am thirsty." If our system can interpret the input, it will search for a place where the user can drink. The current navigation system may have representation with the locations of cafes, so it can recommend the user to go to such places. However, there are other ways to satisfy the user's need: by showing the location of a vending machine, a convenience store, or a hot-water service room.

The system can also respond to the input "I am hungry": It searches for a place to get something to eat and a place where we can take a seat and eat. Then it can suggest "How about buying sandwiches at the store and going to the park to eat it?" This is a combination of multiple spatial functions.

We call our task *spatial function retrieval* (SFR). An SFR system consists of two parts: (i) interpret a user's demand, and obtain the functions to retrieve, and (ii) search for the functions from a spatial database.

The first part (i) is currently solved by looking up a predefined table, a part of which is shown in Table 1[9]. The following is a procedure for the search (ii). As the document retrieval system, it expands the query if our system fails to search.

1. **Direct search phase** Search for a place to respond to the user's need. If there is no appropriate place, go to Step 2.
2. **Decompose into functions and search** Decompose the user's need into necessary spatial functions, and retrieve. If there are no functions, go to Step 3.
3. **Query expansion and search** Expand the necessary functions using default knowledge about a place, or ontology of target objects.

Example of SFR

The overview of SFR system is shown as Fig. 3. For example, a query "I am thirsty" is input[10]. Then, the system will consult the table in Table 1, and search for "place: cafe" at

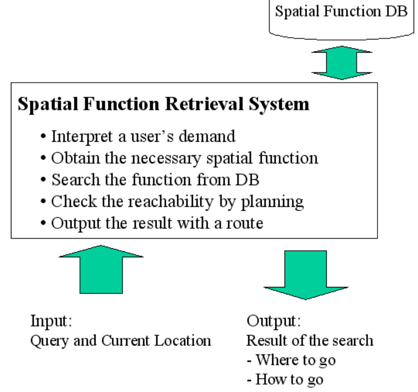

Figure 3: Spatial function retrieval system.

first. The system also examines whether there is a feasible path to go there by a planning algorithm. If the system fails, next it searches for "service: cafe" because there might be a cafe service in a restaurant, a food court, or a lounge. It also searches "pprov: drink & permit: eat." There may be a coffee server that the user can use and a space where the user can drink[11]. The result is provided to the user by the action sequence using natural language and a path on a map.

Discussion and Related works

There are many navigation systems these days. However, a user who uses a navigation system is a stranger to the area. He may not know well what kinds of facilities there are around him. For example, if an elderly man comes to Tokyo by himself, or if one visits a foreign country, he may not know where he should go if he is thirsty or tired. Our spatial function retrieval system can show spatial functions that might solve the user's demand. It is more advanced than the current navigation systems, in which a user must input a destination. Moreover, we can navigate a person without considering social functions in an emergency; we can escape through a president's office in case of fire if it is physically possible.

In our opinion, navigation is a task to search for an appropriate space for the user's demand and guide the user there. This is the same as document retrieval. Therefore it is fundamentally important how we deal with a user's ambiguous queries.

We can also apply user modeling based on our spatial function representation. A user's location history is changed into a history of functions that the user experiences. So far, no prominent results are obtained for user modeling research using a user's location information. The reason for this is the lack of consideration of semantics on spaces. This study may break through the current limitation of user modeling research for spatial information.

Keuneke classifies the concept of function into four types: *To Make*, *To Control*, *To Maintain*, and *To Prevent* (Keuneke 1991). Sasajima et al. proposed Function and Behavior Representation Language (FBRL), and categorized functions with a new type that is different from Keuneke's

[9] We already make more than 40 pairs of needs and spatial functions, which are categorized as nature's call, illness, weather, convenience, information, and trouble.

[10] Precisely, we assume that by natural processing techniques, we eventually categorize the user's utterance as an "I am thirsty" type.

[11] We have ontology that shows "eat includes drink" as described in the previous section.

Table 1: Relation between a user's need and spatial functions.

Need	1st phase	2nd phase
nature's call: I am hungry	place:restaurant	service:restaurant, {pprov:food, permit:eat}
I am thirsty	place:cafe	service:cafe, {pprov:drink, permit:eat}
I want to smoke	place:smoking room	{permit:smoke}, service:cafe
I want to go to the toilet	place:toilet	
I want to rest		{enable:sit, permit:sit}
breast-feeding, change a baby's diaper	place:nursing room	{enable: sit, prop:lockable}
illness: I feel sick	place:aid station	{enable:lie down, permit:lie down}, service:guide
convenience: I want to access the Internet	place:internet room	{enable:use LAN, pattr:belongings:PC}
I want to have a meeting	place:conference room	{enable:sit, property:lockable, ex-possession}

four types: *To Enable* (Sasajima *et al.* 1995). In our representation, spatial functions are categorized as two primitive types, provide and enable (or permit). Provide corresponds to *To Make*, that is, to set a parameter at a desirable value. Enable corresponds to *To Enable* and *To Prevent*, that is, to help (or prevent) the function work by satisfying necessary conditions. There is no function corresponds to *To Control* and *To Maintain* because we assume that the attributes of a person are stable.

Unlike such device function models, what demonstrates behavior in our spatial model is a person. A person can walk, work, dance, have a meeting, drink, and so on in a space. A space has a function to change the person's attributes. Therefore, it can be grabbed as an input-output relation. Also, a space contributes to a person's action. In this case, we focus on the behavior of a person rather than focusing on the person's (unobservable) attributes. In this way, we describe the function of space both from functional and behavioral roles by use of the provide and enable (permit) tags.

Conclusion

This paper proposes a spatial function representation to reveal the meaning of a space. The representation has the characteristic of having a user type as a condition. Not only physical functions, but also social functions are considered. To make a formal specification of spatial meaning is at the core of spatial and geographic data exchange and interoperability. Many other attempts are surveyed widely in (Frank & Raubal 2000). However there is no similar attempt to formalize the representation of spatial meaning as our approach.

A space has the intrinsic property of hierarchy. In our view, this property contributes highly to the availability of our representation. It is hard to describe the function easily if a function of a space effects a function of another space and the interrelationship consists a complicated network. However, a space has hierarchy and we recognize a space as an object. For those reasons, the description of spatial function is a relatively easy task compared to description of other artifacts.

Developing a spatial representation contributes advance information services such as spatial function retrieval. In addition, from the view point of artificial intelligence, it reveals how humans see and recognize a space. Children sometimes behave "out of place." That means, they do not yet understand social functions well. For producing an intelligent robot that behaves "in its place," our spatial function representation and successive studies will make a large contribution.

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