TRANSLATING THE WEB SEMANTICS OF GEOREFERENCES

Stephan Winter and Martin Tomko
Cooperative Research Centre for Spatial Information
Department of Geomatics, The University of Melbourne, Australia
winter@unimelb.edu.au, m.tomko@pgrad.unimelb.edu.au

1. INTRODUCTION

The Web consists of a large amount of predominantly weakly structured and organized resources, with only a few resources having an explicit and structured description of the content. We can think of the Web as an informal network of diverse heterogeneous data sources, including simple files as well as modern object-relational and semantic databases. Many, if not most of these resources provide some form of reference to geographic space. Georeferences link the features of physical or social reality described in the content of the resources to particular locations in geographic space.

The descriptions of features together with their georeferences can be seen as a map inherent in the Web. This map has some properties, particularly heterogeneity. The types of features described, the ways the features are described, and the ways the georeferences are made are diverse, and the links between features and georeferences are implicit and diverse as well. Without a specified semantics of features and their reference to geographic space, the Web-inherent map cannot be translated automatically into an explicit map of general or specific purpose. Vice versa, search engines have in general difficulties with geographic search when looking for keywords but not considering semantics of natural language structures.

In this chapter we will investigate georeferences in Web resources for a very specific purpose: exploiting the wealth of inherent geographic knowledge of Web resources for route directions. Choosing a specific purpose for (re-)constructing the inherent map in the Web allows identifying fundamental challenges for research by a single case-based study. A case-based approach limits the complexity of the reconstruction at least for the destination domain – the source domain, the Web, remains heterogeneous. Choosing wayfinding as the destination domain does not limit the generality of our findings; other destination domains have to address the same challenges.

In wayfinding, people generate travel routes from their mental maps, and communicate these routes by relating movement and orientation actions to landmarks at selected points along the route. In comparison, wayfinding services generate travel routes on metric travel networks, but cannot communicate these routes by referring to landmarks due to a lack of landmark knowledge. There is neither a clear understanding of what constitutes a landmark, nor is there a ready-made directory of landmarks available. In this situation, the map inherent in the Web is a rich pool of geospatial features, which potentially can be used by wayfinding services for searching for landmarks.

Our hypothesis is: Referencing to geographic space is fundamentally different for Web content providers and wayfinders; nevertheless, links can be established between what is represented in Web resources and what is looked for by wayfinding services. In this regard, the following question stands out: Can we generate orientation and wayfinding information out of ordinary Web resources? Or, more specifically:

- How can we identify features in Web resources spatially related to a location or route?

- How can we assess the (spatial) relevance of these features for orientation?
- How can we refer to selected features, or relate selected features to the wayfinder?

In order to approach the above research questions, the next section brings some definitions and a scenario to introduce the topic with more detail (Section 2). We then investigate georeferences in the destination domain, wayfinding (Section 3), and compare them with the current and emerging ways Web resources refer to geographic space (Section 4). We use a case study derived from the scenario in Section 2 to identify issues of translating the semantics of georeferences, and to direct to solutions (Section 5). For a street segment in Melbourne, Australia, we collect all available Web resources, identify and categorize their ways of georeferencing, and derive knowledge from these georeferences that is relevant for wayfinders along this segment. The procedure allows for the identification of research challenges for semantic translation of georeferences (Section 0). Finally we will summarize and discuss our findings in Section 6.

2. Background

2.1 Georeferences

We use the term *georeferencing* in a broad sense, extending here a recent definition by Hill (2004): Georeferencing is relating information (e.g., documents, datasets, maps, images, biographical information, artifacts, specimens, directions) to geographic locations through place names (i.e., toponyms), place descriptions (e.g., "the green building"), place relations (e.g., "the building opposite to the church"), place codes (e.g., postal codes), or through geocode (e.g., geographic coordinates).

For all these kinds of georeferences we can find examples in Web resources. Web resources can refer to geographic space either in the content or in tags. Georeferences in the content are made in natural language. They address the human reader, and require for proper understanding some semantic and world knowledge shared between content provider and reader. In principle, all the listed types of georeferences can occur in the content in some context. Familiar georeferences are of the type "contact us" with references to a telephone number or a post address; for an example see `http://www.geom.unimelb.edu.au/contact/index.html`. Details are discussed below (Section 4.1).Georeferences hidden in tags address automatic processing tools, and follow some externally defined and shared formal tag type definitions. For automated processing one would select only types of georeferences with a formal semantics, e.g., geocodes. Examples are discussed below (Section 4.1).

In contrast, georeferences made in route directions for wayfinders exist only in form of natural language, and hence, in all the variety and complexity of natural language (Weissensteiner & Winter, 2004). In route directions, the information is a direction to move or to orient, and this information is related to geographic locations through features along the route. Hence, georeferences are used to evoke some wayfinding behavior at specific locations along the route. The direction "at the church turn right" uses a place description by referring to a categorical term. It could use the place name as well ("at the Trinity Church turn right") if the route direction is given to a reader who is familiar with the place. Less common are place codes like postal addresses ("at 11 Main Street turn right"), but one can find references to street names ("at corner Collins St / Spring St turn right"). Uncommon are geocodes. Route directions are studied in more detail in Section 3.

2.2 Semantics and ontologies of georeferences

A wayfinder's semantic of georeferences is based on the capabilities of human perception and experience of space. To perform a wayfinding behavior at the place intended by the sender of the route direction, the reader – a wayfinder – has to recognize the place referred to from his or her perspective in an unambiguous manner. In contrast, the context of Web resource content suggests other meanings of georeferences. The context is not specified, but typically not wayfinding (although there are some Web resources giving route directions). More often, georeferences are given as identifier of individual or legal bodies, and serve to contact them by mail or to find them by street address. Perceptual aspects are irrelevant for that purpose.

So far, we deal with different information communities. An information community is a group of people sharing a semantics (Bishr, 1998). The information communities identified here are:

1. People seeking orientation or wayfinding information. The way this group refers to places is driven by their motor, visual, or other senses' experience. It is related to how people learn and memorize space, i.e., to landmark and route experiences, which is categorically different from postal address knowledge.
2. People seeking geographic information from Web resources. The most frequent georeferences in this community – but not the only ones – are postal addresses; however, the intended meaning of a postal address or any other georeference in a Web resource can be quite diverse.

From a formal perspective, each of the two information communities has its own ontology of georeferencing. An ontology in this sense is a specification of a conceptualization (Gruber, 1993). Conceptualizations represent ways in which an information community understands the world. A wayfinder for example uses concepts like *church*, *intersection*, et cetera, and a Web content provider uses concepts like *house number*, *street name*, or *post code*. A specification is some abstract description of those concepts, and includes at least a vocabulary of terms and some specification of their meaning (Bittner, Donnelly, & Winter, 2004).

With all the fuzziness in the definition of the information community of Web users, this paper explores the possibilities and challenges to use the georeferences in Web resources for helping wayfinders by route directions rich of perceivable and cognitively identifiable georeferences. In that respect, our final goal is a translation of terms using available ontologies, or by creating new ones.

2.3 Wayfinding

To illustrate the problem of georeferencing in wayfinding contexts imagine the following scenario, which will be referred to throughout this chapter. Hillary, a tourist in Melbourne, Australia, found a recommendation for the Indulgence Afternoon Tea at the Hotel Windsor in her travel guide, together with the address: 111 Spring Street. This information does not help her to find the place. So she asks at her hotel reception for the route:

> "To the Hotel Windsor?"

Note that Hillary does refer to the institution, Hotel Windsor, not to its address. Even locals might not know which building 111 Spring Street is, but they have an experience of the Hotel Windsor.

> "Ok, when you leave the Hyatt, turn right and walk down to the end of the street. At that intersection you can see to your left the Parliament, and opposite of the Parliament is the Hotel Windsor."

The direction giver refers to landmarks ("Hyatt", "Parliament") and to the structure of the street network ("end of street", "intersection"), remembering experiences he assumes to be shared by Hillary on location ("walk down", "you can see"). The reference to the Parliament in this context is an interesting one, since Hillary will have no idea what the Parliament in Melbourne is looking like. The direction giver seems to be convinced that she will recognize it instantly, which means that the Parliament building in Melbourne must have a prototypical appearance (Lakoff, 1987; Rosch, 1978). Hillary is now sure to find her way.

Now imagine that Hillary would have asked her mobile device for directions, instead of the receptionist. The user interface of her wayfinding service insists on a destination address; she has to go back to her travel guide entry to be reminded that this is 111 Spring Street. Then, the service starts: "From 123 Collins Street, walk ...". Trying to make sense of this she recalls that her actual location, the Hyatt, has the address 123 Collins Street. It turns out that this dialog demands some cognitive effort from Hillary.

Finally imagine Hillary, a tourist in some near future, declaring to her personal service *WebGuide*: "Guide me to the Hotel Windsor!" Can WebGuide, with its real-time access to all Web resources, provide better service than the current mobile device? Services like WebGuide will need to relate street address information – which is given by route planning services – to spatial features of physical or social reality that can be experienced by travelers. Furthermore, it needs to select from the pool of found features the ones that are of relevance for wayfinding and for the route.

3. GEOREFERENCING OF WAYFINDERS

In this section we review the relevant literature to identify the semantics of georeferences by wayfinders. This semantics will be contrasted later with the semantics of georeferences in Web resources. *Wayfinding* as a basic human activity is investigated in spatial cognition and related disciplines (Freksa, Brauer, & Habel, 2000; Freksa, Brauer, Habel, & Wender, 2003; Freksa, Habel, & Wender, 1998; Golledge, 1999; Golledge & Stimson, 1997; Jarvella & Klein, 1982; Kaplan & Kaplan, 1982). We are particularly interested in how people refer to geographic space in route directions, which is directly coupled with how people experience and memorize space.

3.1 Landmarks

People learn, memorize and communicate their environment by experiences (Golledge, Rivizzigno, & Spector, 1976; Golledge & Stimson, 1997; Siegel & White, 1975; Weissensteiner & Winter, 2004), an understanding that goes hand in hand with the embodied mind (Johnson, 1987) and the theory of affordance (Gibson, 1979). Wayfinding experience is acquired by motor, visual and other senses, which relate the activity to perceived environmental features that can become landmarks. Landmarks have a particular role in learning, memorizing and communicating routes (Cornell, Heth, & Broda, 1989; Habel, 1988; Michon & Denis, 2001). As Denis *et al.* (1999) have shown, people prefer to determine the place for re-orientation during wayfinding (decision points) by landmarks; they rarely use distances for that purpose. This observation is conform to the understanding that human landmark, route and survey knowledge (Siegel & White, 1975) is primarily of topological nature. In general, landmarks can be classified into landmarks at decision points, along route segments (route marks), and distant, off-route landmarks (Lovelace, Hegarty, & Montello, 1999; Presson & Montello, 1988). References to landmarks are made at preferred places along the route, at least at decision points (Denis, Pazzaglia, Cornoldi, & Bertolo, 1999; Habel, 1988; Klippel, 2003; Michon & Denis, 2001).

Already Lynch speaks of landmarks in his classic categorization of the structuring elements of a city (1960): he distinguishes landmarks, places, paths, barriers and regions. His concept of a landmark is a narrow one; from a cognitive point of view one can argue that the latter four structuring elements can form landmarks as well. But even his distinction is based on human experience of space.

The route direction Hillary got at the hotel reception referred to landmarks ("Hyatt", "intersection", "Parliament"). The Hyatt is a landmarks at the start point of the route, which is a distinguished decision point. The intersection with sight of the Parliament forms a structural landmark (Lynch would call it a place), and the Parliament is first a distant landmark (when standing at the street intersection), but later a landmark at another distinguished decision point, the destination.

3.2 Identification of landmarks

People refer to space in wayfinding situations preferably by landmarks. Next generation wayfinding services will be able to communicate routes by landmarks to lower the cognitive workload of a wayfinder. Since the notion of a landmark is subjective, bound to shared or sharable experience, services cannot identify landmarks. They can only implement generic methods to identify *salient features* in spatial data sets, as best matches.

A formal measure of salience is based on three qualities of landmarks: visual, semantic and structural ones (Sorrows & Hirtle, 1999). For each of these qualities some parameters can be defined as observables. Observing these parameters for all features, the features that have most distinct parameter values from others are called salient features, and will be considered for inclusion in route directions (Elias & Brenner, 2004; Nothegger, Winter, & Raubal, 2004; Raubal & Winter, 2002). Landmarks can be chosen dependent on route properties (Winter, 2003), and dependent on the context of the recipient (Winter, Raubal, & Nothegger, 2004).

Hillary's wayfinding service can only observe parameters of qualities of features. A service can for example identify that Hillary's current location, measured in geographic coordinates, is in the Hyatt. This conclusion can be done by reverse geocoding (deriving a postal address from geographic coordinates), and looking up directories. The business type *hotel* forms a semantic quality of the building, which distinguishes it from other buildings close-by, and hence, contributes to its salience.

3.3 Functions of landmarks in route directions

Landmarks are to be included in route directions on specific locations within the route description. The basic actions of a wayfinder are to change orientation or direction ("turn"), and to change location ("move"). Route directions can follow many grammars; Frank (2003), for example, distinguishes between "turn and move *n* segments", "turn and move distance", "turn and move until", and several others. If the grammar utilizes landmarks at decision points ("at *x* turn and move"), these landmarks function as anchors of an action.

Investigating the verbs or actions in route directions is a valuable task in itself. Results are action ontologies that define the degrees of freedom of a traveler in a particular mode of traveling (Kuhn, 2001; Timpf, 2002). By that way action ontologies co-determine the form and frequency of landmarks required in the route directions.

In our scenario, Hillary is a pedestrian tourist. The local expert at the hotel reception uses action verbs like “leave”, “turn right”, and “walk down”. Leaving is an action that refers to image schemata of a container and a path from inside the container to outside (Fauconnier & Turner, 2002; Johnson, 1987). A pedestrian in a building has clear categories of inside and outside, and will typically change between them through exits or doors. The next action is bound to the act of leaving: “when you leave the Hyatt, turn right”. We expect that outside is a street, and Hillary, when leaving through the hotel exit door, will find herself on a sidewalk that requires a decision whether to turn left or right. As a pedestrian, she has other choices as well (e.g., crossing the street), but they are not the prototypical ones.

3.4 Landmarks and the Web

From studying Web resources it becomes clear that they do not provide observations of visual, semantic or structural quality parameters of features of the environment in a first instance. They do not because their intention is different from providing route directions. Web resources intend to identify features (e.g., by a unique postal address), to find features (e.g., by route directions), or to establish trust in institutions (e.g., by naming an expensive location). General wayfinding and particularly measures of salience are not on this list. Nevertheless, georeferences in Web resources can be used to make conclusions on visual, semantic or structural qualities of features along routes, as we will show in Section 5.

4. GEOREFERENCING ON THE WEB

In the early stages of the development of the Internet, little attention was paid to the spatial location of both the infrastructure and the content. The reality proved the need for grounding the content in real world context. The Internet is closely coupled with its geography, and with the geography of the features described by the contents of the Web. This relation continues to deepen, as the Internet moves to its ubiquitous age. Mobile services increased the demand for context-aware applications, leading to a boom of location based and location aware services, and consecutively, to the spread of localised contents. Today, it is estimated that 20-35% of all the searches performed on the Web seek geographically related results (Young, 2004). Basic needs of geographical searches on location-based data retrieval are well summed-up and solutions are proposed in the project of the Alexandria Digital Library (Goodchild, 2004), with the focus on retrieving map files from a database. Requirements for geo-enhancement of the (Semantic) Web resources are described in Egenhofer (2002), including the description of basic query types.

Early georeferencing on the Web, still the prevalent method of georeferencing, mirrors approaches of more traditional media. It is restricted to text (e.g., addresses, postcodes, or telephone numbers) and images (e.g., photographs, sketches, maps). These methods are less suitable for automated processing and interpretation. Textual descriptions or images are forms of narratives, and their semantics is inferred in active reading processes. While automatic natural language understanding is an active field of research in Artificial Intelligence, in-depth understanding is still the challenge of the discipline (McCarthy, 1990). Address patterns are often integrated with parts of text containing natural language statements, often referring to relations between features of the environment (e.g., “close to”). Furthermore, these address patterns are often imprecise, inconsistent, or incomplete. For instance, our traveler Hillary would encounter problems when searching by keyword for “Hotels” and “Melbourne” on current search engines. Results point to places as distinct as Melbourne, Australia, and

Melbourne, Florida. Similarly she would experience problems with a search string "111 Spring Street" due to its incompleteness.

A step towards more formal forms of georeferences is represented by the various national address standards, providing some degree of unification of georeferencing, be it solely for mailing purposes. Only the Semantic Web (Berners-Lee, Hendler, & Lassila, 2001) brings the structure necessary to process Web resources automatically, by introducing formal language structures for annotating the content. These formal languages enable the creation of consistent models of all aspects of interest, called ontologies. These can be used to annotate the content and will enable machine aided reasoning and linking between various independent ontologies. In this way, the Web will change into a giant, intelligent knowledge base. However, we cannot expect that sudden massive conversion of current Web resources to match Semantic Web requirements will happen. Sophisticated algorithms parsing textual information on the Web are therefore required. Parsers seeking address structures and other georeferences have to be developed, as well as framework ontologies mapping and interconnecting these patterns. This section provides further details on existing georeferencing technologies on the Web and efforts to extract the location information from Web resources.

4.1 Informal georeferencing

The location of a host of a Web resource does not provide reliable clues about the location of the features described by the content of a Web resource. Therefore, we have to derive the location of the features described by the content by other means. Insufficient spread of semantically annotated resources forces Web users to extract the georeference information by parsing the text content. This task is not only affected by Web resource layout issues, but also by the problems of parsing natural language content affected by language and cultural differences. The only patterns with more structured content related to georeferencing are represented by postal addresses.

Parsing and understanding is complicated by the initial uncertainty of the reader at which level of detail the reference to geographical space is made. There is a difference between the level of detail provided by a general tourist guide describing Australia, and the same location described by regional, local, or community Web resources. A model for place name-based information retrieval was proposed in (Jones, Alani, & Tudhope, 2001). Similarily, a useful notion of localness was introduced by (Ma, Matsumoto, & Tanaka, 2003), describing the extent to which the site provides regional information, the level of detail of the resource (localness degree), and the ubiquity of the resource.

The successful extraction of location information from Web resources enables us to create a candidate set of potential features in the selected environment, and the localness analysis can contribute to filter only the most relevant features and assess their landmarkness and relevance to the specified location. Still, there is no certainty that the identified resources address an existent, permanent and salient feature that is useful for a wayfinder. Therefore, we propose to assess additionally the action ontologies associated with the georeferencing information.

4.1.1 Natural language statements

Natural language statements in Web resources are as flexible and various in their georeferences as people are in speech acts. Particularly private Web resources show narrative forms of georeferencing. These georeferences are frequently given in the context of wayfinding information, and hence, are a valuable source of data for intelligent analysis.

Such natural language statements communicate locations, frequently by subjective personal experience with the environment, and also spatial configurations. Different elements of the environment can be related through natural language statements describing their spatial relationships. These statements provide the wayfinder with information often accessible with less cognitive effort than when relying on formal georeferences. The reason probably lies in the aptitude of the narrator to communicate the elements relevant to the context of the assumed recipient. These personal sites are often designed for a specific audience, and are of specific value for this audience.

Humans often refer to features in the environment by providing their spatial context, in particular with regard to nearby landmarks. In natural language descriptions, one will find frequent usage of terms providing a description of a spatial relation between described features. Fuzzy expression as “close to”, “nearby”, “further down” are used as often as more exact terms as “next to”, “opposite”, “within a distance”, “after”. The context-dependent interpretation of fuzzy topological relations is beyond the focus of this chapter, but for a start see (Worboys, 2001).

The spatial relations between georeferenced features are also a valuable source of information to be interpreted by automated wayfinding services. Not only they enable to reconstruct a more adequate cognitive image of the environment and present it to the navigator , but they also provide this information in context, and select the reference points with the highest importance (and therefore saliency) in the specific situation.

4.1.2 Semantics of postal addresses

Compared to natural language statements, the semantics of postal addresses are relatively formal, although they appear in the Web content. Postal addresses are open to standardization at national levels; see for example the Australian and New Zealand standard on a Geocoded National Address File (ICSM, 2003). According to different land administration legislative in the world, a postal address refers to a polygon that not necessarily consists of a single cadastral parcel or a single land register property. A future Geospatial Semantic Web (Section 4.3) will provide ontologies for postal addresses. Several ontologies are required due to the different national systems of postal addressing.

Geocodes for postal addresses are currently becoming part of address files. They are geographic coordinates of a point representing an address. Note that geocodes have a semantics of their own: sometimes they are centroids of parcel polygons, sometimes center street front points, or arbitrary points inside of the polygons. Where no geocoded address files exist, geocoding can be calculated from street network datasets. Street segments contain typically two attributes representing the house number intervals for both sides of the segment. These attributes are linearly interpolated to calculate a geocode of a postal address. Note that in this case the geocode represents a point on the street network. Typically this point is used for dynamic segmentation of the street network for a route planning algorithm.

Address files provide exactly one geocode per postal address, and no finer distinction is made. Particularly in rural areas the position defined by the geocode and the position of a building on that ground might differ significantly, in Australia, for example, for some kilometers.

However, in our context limitations of addresses are manifold. Taking the perspective of a wayfinder, we are interested in features along a route. These features might have no postal address at all (e.g., monuments, or public land / crown land), or have another address (e.g., buildings at street intersections with an address of the crossroad, or rear sides of buildings). Vice versa, features with a specific street address might be located in backyards or galleries, and therefore be invisible from the street itself. Taking the perspective of Web resources, the problems are discussed above.

4.2 Formal georeferencing on the Web

4.2.1 Relating content to host location

The location of the host IP address – or the entity-based geographical context (McCurley, 2001) – is at best in indirect relation with the content served, and the localisation accuracy of IP addresses is unreliable. Depicting the spatial reference of a resource by assuming that it is mostly relevant to geographically close users provides only a low level of accuracy and reliability (Buyukkokten, Cho, Garcia-Molina, Gravano, & Shivakumar, 1999). The analysis of the location of users' IP addresses can help to locate a larger region of interest, but is not sufficient for wayfinding applications.

A different attempt, advocated by GIS specialists and building upon interoperability initiatives of the Open Geospatial Consortium (OGC) and the DigitalEarth initiative, was supposed to lead to the GeoWeb (Leclerc, Reddy, Iverson, & Eriksen, 2002). The attempt consisted of a new Internet top-level domain `.geo`, with special URLs containing the encoded georeferenced tile covering the queried area. In the proposed system, the URL `http://4e7s.14e3s.geo` would denote a Web resource containing information about a 1 by 1 degree area with the longitude 144 degrees east and 37 degrees south. This approach was meant to ease geographical queries on interoperable distributed OGC compliant datasources. Ideally, geographic 3D encoded content would be distributed over this Internet subnetwork. The project was abandoned after rejection of the `.geo` top level domain name.

4.2.2 Geospatial interoperability initiatives

The need for automated and interoperable processing of location information enabled to coordinate efforts among special professional interest groups, led by the Open Geospatial Consortium (OGC) and the International Standardisation Organisation (ISO) in cooperation. OGC's location specifications are strongly focused on expert spatial information data users and thus lack the support for general content providers' use. The standards developed focus on sharing specialised spatial data (rasters and vectors), metadata and on service interoperability. This focus influenced the design approach. The inherent complexity of spatial information is reflected by the standards, but makes them difficult to understand and implement. The complex structure of spatial data descriptions, namely the Geography Markup Language (GML) encoding (Cox, Daisey, Lake, Portele, & Whiteside, 2003) also virtually prevents wider adoption by general public for annotation of public Web resources. The spatial information community shares a more consistent view on spatial data semantics – representation, storage and handling – and understands details that might be irrelevant for general users. This is further underlined by GML being implemented as an Extensible Markup Language XML encoding (W3C, 2004a), with the structure formalised uniquely in XML schema (XSD) (W3C, 2004c). This technically disallows composition with other encodings.

Therefore, the resulting technology is not directly usable for semantically enhanced storage and publication of general Web resources, and a need for additional ontologies for spatial content categorization remains. The interoperability of these general usage ontologies should, however, have the possibility to be interoperable with future possible implementations of GML using the Resource Description Format (RDF) (W3C, 1999) or the Web Ontology

Language (OWL) (W3C, 2004b) encoding, to enhance the reusability of the content. In general, pure XML based approaches are suitable for fast deployment of interoperable, but strongly specialised services, while RDF encoded content is service agnostic and widely reusable, but often not designed with any particular service in mind. In our example (Figure 1), we show a point geometry referencing the GML namespace, integrated with a pure XML description of the Hotel Windsor, where our traveler Hillary wants to get. However, the tags used to annotate the content are only described in the `windsor.xsd` schema. The semantics of such a description are well interpretable by humans or specifically engineered systems, but there is no automated mean to transport these semantics to a different application. For instance, the tag `<stars>` has a meaning only to the designer of this specific system. In a global hotel database, this would probably be `<category>`. In Section 4.3, we will show how this can be done in RDF.

<fig>

Figure 1: Example of a XML description of Hotel Windsor with a GML part.

4.2.3 Geographic annotation

Geocoding the Web and more specifically the content of Web resources (geographic content-based context) is also possible through a wide spectrum of different tagging conventions, and is applied for example by photo annotation enthusiasts, some spatial location search engines, worldwide postcodes initiatives, and others. Some of them use a simple syntax and loose structure based on HTML, others are more sophisticated and support XML (and consecutively RDF) encoding, are strongly structured and partially approach the vision of the Semantic Web.

HTML tags are the simplest way to insert machine readable content in Web resources. Despite being well machine readable, they do not allow inclusion of structures and specific ontologies, or even simpler, unstructured vocabularies. As any XML based encoding, HTML allows the creation of custom made tags by content providers. As HTML parsers are made not to be vulnerable to these additions, it may be an appealing way to enhance the content of Web resources. On the other hand, the lack of structure and standardised tags limits their usability by general search engines. Usually inserted in the `<meta>` tags of the header of the Web page or around the annotated element, only two major sets of tags gained more widespread use, and both approaches are not maintained anymore. These were represented by `geotags.com` and `GeoURL.com`, both with associated search engines. Figure 2 shows the "Hotel Windsor" example in `GeoURL`. As long as a standardised set of markup tags is not adopted as a W3C specification and further implemented by major search engines, widespread use of geo-annotation through HTML tags will not be successful.

<fig>

Figure 2: `GeoURL` tag example.

4.3 Geospatial Semantic Web

Beyond simple georeferencing stands the Geospatial Semantic Web (Egenhofer, 2002), that will enable to avoid the problems of HTML/XML tags in many ways: no single annotation vocabulary needs to be standardised anymore. Knowledge sharing across different application domains is possible through interoperable, semantically enriched encoding in RDF-S or OWL. Formalised ontologies enable to use reasoners for querying asserted ontologies and enable to link independent knowledge bases. While many research groups are dealing with formalising geographical ontologies (Fonseca, Egenhofer, Agouris, & Camara, 2002; Fonseca, Egenhofer, Davis, & Borges, 2000; Grenon & Smith, 2004; Smith & Mark, 2001), only a few related the research to Semantic Web applications.

The majority of resources of the current Web are primarily focused to provide information related to what, when, where and how. The *where*, crucial in our context, is one of several categories of content, and frequently not the most important one. With the (Geospatial) Semantic Web, all these aspects of georeferencing become equally important. Ontologies of places are linked together through ontologies of relations and provide the georeference to resource specific content profiting of consistent action ontologies.

4.3.1 Georeferencing ontologies for the Geospatial Semantic Web

Ontologies focusing on formalizing place description were the first to be developed within the Geospatial Semantic Web area. One of the first attempts to encode location information in RDF is represented by the simple `RDFGeo` vocabulary of the W3C RDF Interest Group (W3C, 2003) enabling to annotate point geographies with latitude, longitude and altitude in RDF. This vocabulary even enables to tags resources that were not totally ported to RDF yet, by enabling the insertion of a subset of tags in XHTML. However, the limitation to point data makes `RDFGeo` hardly usable for more specialized applications. Figure 3 shows the “Hotel Windsor” example in `RDFGeo` annotation.

<fig>

Figure 3: Example of `RDFGeo` annotation of Hotel Windsor.

The proposal for a similar vocabulary encoded in RDF Site Summary (RSS) (Beged-Dov et al., 2001) can be found in the work of Singh (2004), focusing on the ease of annotating blog resources with coordinate attributes for community mapping applications. Current efforts led by the W3C Semantic Web Advanced Development for Europe project focus on the support for fuzzy geographical regions and resulting fuzzy relations between geographical objects (interpretation of terms such as “near”). It further focuses on ontologies for enabling the interoperability of different postal addressing standards (McCathieNevile, 2004). Other projects deal with the conversion of the OGC GML specification in RDF and OWL (Defne, Islam, & Piasecki, 2004). Goad (2004) has a critical view on GML translation to RDF and advocates simplicity over the complexity of the original OGC specification, which leads him to the proposal of `RDFGeom`, an alternative encoding, but with maintained support for a subset of the GML capabilities.

4.3.2 Spatial operations and spatial relation ontologies

Location semantics are closely coupled with spatial operations. These present the mean to query the Web for content based on query strings using references to relations between several features. In other cases, the system should describe the relations between features of the environment using spatial relation references as well. It needs to be simple enough for wide adoption among the general public. Implementation issues, reference system conversion, problems with different units and datums should be hidden to users (Neumann, 2003). Possibilities to query spatial data are still limited, as only a few ontologies for topology, distance and orientation exists (Hiramatsu & Reitsma, 2004), as well as spatial operators implemented in RQL are still not standardised (Corcoles & Gonzalez, 2003). The key is to enable the Geospatial Semantic Web to use fuzzy terms designing spatial relations in a manner consistent with human understanding of these statements. Imagine Hillary’s communication with *WebGuide: the system's replies needs to use terms such as opposite, close to and nearby consistently, but also coherently with Hillary;s understanding of the term.*

4.3.3 Georeferencing and action ontologies

Action ontologies provide the mean to link and assign human activities to static objects. IN the case of wayfinding, the most common use is to serialize the features used as navigation references along the path in a chronological manner and to provide specific directions to the navigator. The terms used change not only depending on the direction given, but also on the nature of the feature the direction is anchored to – a landmark, street segment, start or end of the path.

5. WAYFINDING GEOREFERENCES FROM WEB RESOURCES

In a case study we present an inventory and analysis of currently used georeferences in Web resources, and we demonstrate the possibilities of their use. The case study concerns a segment of Hillary's route from the Hyatt to the Hotel Windsor, namely 1-5 Collins Street, Melbourne, Australia. Figure 4 shows the environment.

Imagine the actions that Hillary's future WebGuide system would need to perform in order to provide her with user-friendly route directions. Hillary has a destination, and is looking for route directions. A route service can calculate a route, and this route has to be described to Hillary in a manner a human would communicate it. The route consists at this stage of street segments, i.e., address intervals. The addresses (or another formal method of georeferencing) serve as links to Web resources. WebGuide can therefore collect Web resources along the route, and from the content of these resources it can reconstruct the layout of the environment, identify visual, semantic and structural qualities of local features to determine their salience, and finally present a natural language description of the route, matched to the preferences of Hillary.

5.1 Experiment

A complete directory of Web resources referring to features, institutions, or events along a specific street segment can be so far collected only manually. Keyword based search delivers far too many results, for several reasons. On 06.10.2004, Google delivered for the query string **"2 Collins Street" "Melbourne"**, limited to Australian Web resources, 93400 links. Many of the found links refer in fact to other house numbers (non-perfect matches), others do not refer to a postal address at all (but describe, e.g., the tram lines in Collins Street), they refer to **Little Collins Street**, or to directory pages (e.g., a page "Bars in Melbourne"). However, many of the found Web resources refer to the correct address: **2 Collins Street** is one of the high-rising office buildings in this central business district area, with multiple Web resources describing the many businesses located here. The limitation to Australian Web resources is an IP address based filter, which excludes Web resources hosted elsewhere, but also excludes many false hits to any Collins Street in a Melbourne outside of Australia. Still, the query misses Web resources that contain the short form **"2 Collins St"**, or that, although being relevant, contain no street name at all.

For the case study, we collected by that way Web references for 1-5 Collins Street. We excluded any other type of georeference from consideration here, and also any Web resource that is not directly accessible via Google (e.g., searchable databases like the Yellow Pages). Resources with true addresses in the selected street segment were filtered out manually.

Figure 4 shows the addresses with some Web presence. In other work we assess the relevance of these resources for wayfinders (Tomko, 2004).

<fig>

Figure 4: Georeferenced Web resources along the whole segment of Collins Street, Melbourne, Australia.

5.2 Extraction of Georeferences from Web resources

Although georeferences are frequently found, they are not structured for general reuse. Web content providers include georeferences in form of postal addresses, maps, or place descriptions addressing a human reader. Additionally, their subjective categorizations of content describing the *where* let georeferences appear behind a variety of links from top-level Web resources: they may appear under “contact us”, “how to find us”, “next branch”, and so on.

Further, one may consider the technical insertion of the text within the page – tables, divisions, paragraphs and frames all split the content so, that it may not always be straightforward to retrieve the caption and its content. A simple search for address patterns on 1-5 Collins Street found 29 major ways of referencing to the location. This does not include all the descriptive references in natural language.

5.3 Action ontologies and georeferencing in the Web

To assess the variety of purposes, addressed by Web content providers through inserted georeferences, we have analysed the text in the immediate proximity of the reference (headers, sentences, captions) and categorised them in taxonomy. This was used to assert the action ontology of the resource creators, represented by task verbs related to the captions. These terms help us to understand the purpose of location references addressed by Web creators. Further, it enables us to isolate those that are most likely usable for wayfinding. Out of a set of 29 different captions and header types found in the set of Web references, we identified the limited amount of action verbs used (Table 1):

Table 1 Web designers' action ontology

Action	Verb	Category
Sending	to send	Mailing
Contacting	to contact somebody	
Being in / at	to occupy a position	Navigation
Finding	to find something	
Parking	to park	Parking (part of transport ontologies)
Selling	to sell	Identification
Winning	to win	

The first four terms constitute a substantial part of the samples examined. Resources describing actions referring to parking, selling and winning present a marginal part of the georeferenced resources and we can assume that resources dedicated to these actions are rare, or the importance of location information related to these activities is low.

In the case of e-commerce sites or even shop Web sites, selling is not a common action term. This changes if specialised resources are considered, specifically real estate databases. This is an exceptional situation where the location provided does not refer to the site owner or properties to sell (terms of the type “mailing” or “identification ” occur, such as “contact us” or simply “address”), but to the sold properties (usually using past tense – “sold”). In general, these are marginal means to refer to location. Unfortunately, the restricted diversity of actions relating to the georeferences makes the identification of features suitable for navigation difficult.

The primary purpose of postal addresses – mailing to persons or institutions – is still a common action term associated with georeferencing on Web resources. However, a missing term (associated to the action term “is” and the category of “existence/identification”) is even more common. It is obvious that Web authors do not distinguish between the different needs to wayfinders and mail addressing (even if one may argue that there is no difference, as the postman needs to find his way to the location).If we narrow the focus on the two categories of major relevance to wayfinding, namely to terms associated with identification and navigation, we can isolate a group of terms that constitute members of the content providers’ ontology and may be asserted in the ontology of wayfinders as well (Table 2):

Table 2 Terms used for georeferencing with navigation related usage

Terms	Type	Category
Organisation, branch, service name and address	Identification by feature usage	Existence, identification
Locations, buildings, members	Directory listing member entities of a certain type	
Where to buy, by location, region name	Directory organised by regions	
Where to find, is at…	Direct instructions for wayfinding	Navigation

The verb “be in / be at” is, not surprisingly, the most common action reference related to georeferences. According to Wordnet (Fellbaum, 1998), “be” can have the following main meanings: to have the quality, be identical to, occupy a position, exist, be equal, constitute, follow (work in a specific place, with a specific subject, or in a specific function), represent. As we can see, most of them are deeply rooted in references to location. In general, being is in general usage associated with the position (often in reference to the narrator or other elements).

The more the Web resources related to a specific term contain georeferences surrounded by terms belonging to a category of existence or related to navigation, the more probable it is that the resource as such actually describes the feature georeferenced in the content.

5.4 Reconstruction of the situation - bridging between georeferences

Translation between experiential characteristics of space and postal addresses and other descriptive georeferences needs explicit (or externally known) semantics and world knowledge.

The semantics of experiential characteristics of space is informal. For example, there is no accepted formal definition of a landmark. First steps towards a formalization are proposals for measures of salience (Elias & Brenner, 2004; Nothegger, Winter, & Raubal, 2004). Expanding and adapting these ideas, we can identify features in the perceivable space by methods from spatial analysis. The dominant visual sense of wayfinders leads to visibility analysis in the first instance (Batty, 2001; Turner, Doxa, O'Sullivan, & Penn, 2001).

Assessing the salience of a feature from its georeferenced Web resource follows different rules and is tangential to the previous research. Several approaches exist and are strongly depending on the application domain of the system – i.e. the target transportation mode, for instance. The salience of landmarks is a traveler's context dependent measure and needs to be assessed in accordance. Some suggestions may be found in (Ma, Matsumoto, & Tanaka, 2003; Tomko, 2004).

To reconstruct the image of the reality for a wayfinder, it is not sufficient to georeference the resources, and extract the ones that are potentially accessible, but one has to identify their relations with regard to space in order to create a natural language description of the environment. Only afterwards the contextual selection of a landmark can be done.

We have partially introduced the different ontologies related to concepts of georeferencing (location identification), showed how to isolate those that may be relevant for wayfinding (action ontologies), as well as mentioned the concepts of spatial relations and proximity that are found in natural language descriptions. This is an example how these complementary ontologies can be used to synthesize a somehow natural description of the reality, in specific of the situation at 1-5 Collins street:

- 1 Collins Street has a name: Rialto Tower.
- 1 Collins Street is at least 16 floors high.
- 1 Collins Street is an office building.
- 1 Collins Street is a landmark of Collins Street and has won an architecture prize.
- Opposite of 1 Collins Street is 4-6 Collins Street.
- 4-6 Collins Street has a name: ANZAC house.
- 4-6 Collins Street is within 150 meters of the Parliament train station.
- 2 Collins Street is adjacent to 4-6 Collins Street.
- 2 Collins Street has a name: Alcaston House.
- 2 Collins Street has at least 6 floors.
- 2 Collins Street has also a Spring Street entrance.
    - It is either a corner building, or it reaches across the block.
    - Spring Street is *close* to Collins Street.

It becomes obvious how these derived statements can be used by an intelligent service to enrich route directions with landmark references. The wealth of information provided through unorganized Web data provides a rich resource of descriptive information that enables to reconstruct a picture of the environment. Future research

The experiment in our case study was done completely manually. It envisions some future capabilities of a Geospatial Semantic Web, but it identifies also open problems for further research. Given the two information communities of Web content providers and wayfinders, we expect their formal ontologies of georeferences, and then we expect a knowledge base for mapping between the ontologies. We identify the following areas for further research:

- Ontologies of postal address systems. Ontologies of georeferencing are the promise of the Geospatial Semantic Web (Egenhofer, 2002). They will be used for semantically enriched encoding. Local search capabilities of the prominent search engines (e.g., Google, Yahoo, Sensis) require already some formalized understanding of postal address systems in heterogeneous resources. Hence, this research is under way.

- Knowledge base for relevance assessment. Given the richness and diversity of postal address georeferencing, what are the rules for ranking Web hits according to their relevance for wayfinders? Some preliminary rules follow from our case study with human wayfinding directions: preference has to be given to ground floor addresses, to some categories of businesses (both for their visibility), and to some global building characteristics (function, heritage). These rules need a formalization for automatic reasoning in the framework of above described ontologies. Other rules will categorize the meaning of an address in a Web resource, particularly in cases where several addresses appear. For instance, a Web resource can contain the address of a real estate object, and the address of the real estate agent. The functions of these addresses is quite different.
- Intelligent geocoding. It becomes clear that wayfinders perceive the physical features along a route from outside. But postal addresses in their primary meaning have a strong link to the wayfinders' perception: postal addresses are unique identifiers for (postal) delivery, which is the threshold point between **inside** (the private space) and **outside** (the public space). We hope that the image schemata of **container** and **path** (Frank & Raubal, 1998; Johnson, 1987) help to find a link between the two ways of georeferencing.
- Support for spatial relations. We need implementations of fuzzy spatial relations on postal addresses, like **near**, **next**, **opposite**, and so on. These implementations are required for two purposes: for understanding descriptive georeferences given in Web resources, and for generating natural language georeferences from addresses.

6. CONCLUSIONS

We have presented a literature review and a case study of ways of georeferencing in Web resources on one hand, and in route directions for wayfinders on the other hand. The main difference in the semantics of the two information communities is an identifier of features, institutions or persons in the Web, compared to an experiential view on the environment by wayfinders. With the goal of using Web resources for enriching route directions by landmarks, we focused on the translation of the semantics of georeferences in Web resources to meaningful georeferences in the context of route directions. For that purpose we made an experiment for a short street segment, and studied the available Web resources. We showed that an interpretation of georeferences in the content of Web resources allows to derive observable properties of features, and hence, can be used by a tool to select appropriate features as georeferences in route directions. Open questions for research are identified.

ACKNOWLEDGEMENTS

This work has been supported by the Cooperative Research Centre for Spatial Information, whose activities are funded by the Australian Commonwealth's Cooperative Research Centres Programme. Additional funding of the first author from an internal grant of the University of Melbourne is acknowledged.

REFERENCES

Batty, M. (2001). Exploring isovist fields: space and shape in architectural and urban morphology. *Environment and Planning B, 28*(1), 123-150.

Beged-Dov, G., Brickley, D., Dornfest, R., Davis, I., Dodds, L., Eisenzopf, J., et al. (2001). *RDF Site Summary (RSS) 1.0*.

Berners-Lee, T., Hendler, J., & Lassila, O. (2001). The Semantic Web. *Scientific American, 284*(5), 34-43.

Bishr, Y. (1998). Overcoming the semantic and other barriers to GIS interoperability. *International Journal of Geographical Information Science, 12*(4), 299-314.

Bittner, T., Donnelly, M., & Winter, S. (2004). Ontology and Semantic Interoperability. In D. Prosperi & S. Zlatanova (Eds.), *Large-Scale 3D Data Integration*. London: CRCPress.

Buyukkokten, O., Cho, J., Garcia-Molina, H., Gravano, L., & Shivakumar, N. (1999, June). *Exploiting Geographical Location Information of Web Pages.* Paper presented at the Proceedings of Workshop on Web Databases (WebDB'99).

Corcoles, J. E., & Gonzalez, P. (2003). *Querying Spatial Resources. An approach to the Semantic Geospatial Web.* Paper presented at the CAiSE'03 workshop "Web Services, e-Business, and the Semantic Web (WES): Foundations, Models, Architecture, Engineering and Applications".

Cornell, E. H., Heth, C. D., & Broda, L. S. (1989). Children's Wayfinding: Response to instructions to use environmental landmarks. *Developmental Psychology, 25*(5), 755-764.

Cox, S., Daisey, P., Lake, R., Portele, C., & Whiteside, A. (2003). *OpenGIS® Geography Markup Language (GML) Implementation Specification* (OpenGIS® Implementation Specification No. OpenGIS® project document OGC 02-023r4). Wayland: Open GIS Consortium, Inc.

Defne, Z., Islam, A. S., & Piasecki, M. (2004). Ontology for Geography Markup Language (GML3.0) of Open GIS Consortium (OGC). http://loki.cae.drexel.edu/~wbs/ontology/ogc-gml.htm.

Denis, M., Pazzaglia, F., Cornoldi, C., & Bertolo, L. (1999). Spatial Discourse and Navigation: An Analysis of Route Directions in the City of Venice. *Applied Cognitive Psychology, 13*, 145-174.

Egenhofer, M. (2002). *Toward the Semantic Geospatial Web.* Paper presented at the Tenth ACM International Symposium on Advances in Geographic Information Systems, McLean, Virginia.

Elias, B., & Brenner, C. (2004). Automatic Generation and Application of Landmarks in Navigation Data Sets. In P. Fisher (Ed.), *Advances in Spatial Data Handling II*. Heidelberg: Springer.

Fauconnier, G., & Turner, M. (2002). *The Way We Think*. New York, NY: Basic Books.

Fellbaum, C. (Ed.). (1998). *WordNet: An Electronic Lexical Database*. Cambridge, Massachusetts: The MIT Press.

Fonseca, F. T., Egenhofer, M. J., Agouris, P., & Camara, G. (2002). Using Ontologies for Integrated Geographic Information Systems. *Transactions in GIS, 6*(3), 231-257.

Fonseca, F. T., Egenhofer, M. J., Davis, C. A., & Borges, K. A. V. (2000). Ontologies and Knowledge Sharing in Urban GIS. *Computer, Environment and Urban Systems, 24*(3), 232-251.

Frank, A. U. (2003). Pragmatic Information Content - How to Measure the Information in a Route Description. In M. Duckham, M. F. Goodchild & M. Worboys (Eds.), *Foundations in Geographic Information Science* (pp. 47-68). London: Taylor & Francis.

Frank, A. U., & Raubal, M. (1998). *Specifications for Interoperability: Formalizing Image Schemata for Geographic Space.* Paper presented at the 8th International Symposium on Spatial Data Handling, Vancouver.

Freksa, C., Brauer, W., & Habel, C. (Eds.). (2000). *Spatial Cognition II* (Vol. 1849). Berlin: Springer.

Freksa, C., Brauer, W., Habel, C., & Wender, K. F. (Eds.). (2003). *Spatial Cognition III* (Vol. 2685). Berlin: Springer.

Freksa, C., Habel, C., & Wender, K. F. (Eds.). (1998). *Spatial Cognition* (Vol. 1404). Berlin: Springer.

Gibson, J. J. (1979). *The Ecological Approach to Visual Perception*. Boston: Houghton Mifflin Company.

Goad, C. (2004, September 2004). *RDF versus GML*. Retrieved 06 December, 2004, from http://www.mapbureau.com/gml/

Golledge, R. G. (Ed.). (1999). *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. Baltimore, MA: The Johns Hopkins University Press.

Golledge, R. G., Rivizzigno, V. L., & Spector, A. (1976). Learning about a City: Analysis by Multidimensional Scaling. In R. G. Golledge & G. Rushton (Eds.), *Spatial Choice and Spatial Behavior* (pp. 95-116). Columbus: Ohio State University Press.

Golledge, R. G., & Stimson, R. J. (1997). *Spatial Behavior: A Geographic Perspective*. New York: The Guildford Press.

Goodchild, M. (2004). The Alexandria Digital Library Project. *D-Lib Magazine, 10*.

Grenon, P., & Smith, B. (2004). SNAP and SPAN: Towards Dynamic Spatial Ontology. *Spatial Cognition and Computation, 4*(1), 69-104.

Gruber, T. R. (1993). *Toward Principles for the Design of Ontologies Used for Knowledge Sharing* (Technical Report KSL 93-04): Knowledge Systems Laboratory, Stanford University.

Habel, C. (1988). Prozedurale Aspekte der Wegplanung und Wegbeschreibung. In H. Schnelle & G. Rickheit (Eds.), *Sprache in Mensch und Computer* (pp. 107-133). Opladen: Westdeutscher Verlag.

Hill, L. L. (2004). Georeferencing in Digital Libraries. *D-Lib Magazine, 10*(5).

Hiramatsu, K., & Reitsma, F. (2004, 15th-16th April 2004). *GeoReferencing the Semantic Web: ontology based markup of geographically referenced information.* Paper presented at the Joint EuroSDR/EuroGeographics workshop on Ontologies and Schema Translation Services, Paris, France.

ICSM. (2003). *Rural and Urban Addressing Standard AS/NZS 4819:2003*. Retrieved 7.12.2004, from http://www.icsm.gov.au/icsm/street/index.html

Jarvella, R. J., & Klein, W. (Eds.). (1982). *Speech, Place, and Action*. Chichester, NY: John Wiley & Sons.

Johnson, M. (1987). *The Body in the Mind: The Bodily Basis of Meaning, Imagination, and Reason*. Chicago: The University of Chicago Press.

Jones, C. B., Alani, H., & Tudhope, D. (2001). *Geographical Information Retrieval with Ontologies of Place.* Paper presented at the COSIT 2001.

Kaplan, S., & Kaplan, R. (1982). *Cognition and Environment: Functioning in an Uncertain World*. New York: Praeger.

Klippel, A. (2003). Wayfinding Choremes. In W. Kuhn, M. F. Worboys & S. Timpf (Eds.), *Spatial Information Theory* (Vol. 2825, pp. 320-334). Berlin: Springer.

Kuhn, W. (2001). Ontologies in support of activities in geographical space. *International Journal of Geographical Information Science, 15*(7), 613-632.

Lakoff, G. (1987). *Women, Fire, and Dangerous Things - What Categories Reveal about the Mind*. Chicago: The University of Chicago Press.

Leclerc, Y. G., Reddy, M., Iverson, L., & Eriksen, M. (2002). Discovering, Modeling and Visualizing Global Grids over the Internet. In M. Goodchild & A. J. Kimerling (Eds.), *Discrete Global Grids*. Santa Barbara, CA, USA: National Center for Geographic Information & Analysis.

Lovelace, K. L., Hegarty, M., & Montello, D. R. (1999). Elements of Good Route Directions in Familiar and Unfamiliar Environments. In C. Freksa & D. M. Mark (Eds.), *Spatial Information Theory* (Vol. 1661, pp. 65-82). Berlin: Springer.

Lynch, K. (1960). *The Image of the City*. Cambridge: MIT Press.

Ma, Q., Matsumoto, C., & Tanaka, K. (2003). A Localness-Filter for Searched Web Pages. In X. Zhou, Y. Zhang & M. E. Orlowska (Eds.), *APWeb 2003* (Vol. 2642, pp. 525-536). Berlin: Springer-Verlag.

McCarthy, J. (1990). An Example for Natural Language Understanding and the AI Problems It Raises. In J. McCarthy (Ed.), *Formalizing Common Sense* (pp. 70-76). Norwood, NJ: Ablex.

McCathieNevile, C. (2004). *SWAD-Europe extra deliverable 3.20: Report on developer workshop 9 - Geospatial information on the Semantic Web.* (Workshop Report No. 9).
McCurley, K. S. (2001, May 1-5). *Geospatial Mapping and Navigation of the Web.* Paper presented at the he Tenth International World Wide Web Conference WWW10, Hong Kong.
Michon, P.-E., & Denis, M. (2001). When and Why are Visual Landmarks Used in Giving Directions? In D. R. Montello (Ed.), *Spatial Information Theory* (Vol. 2205, pp. 292-305). Berlin: Springer.
Neumann, M. (2003). *Spatially Navigating the Semantic Web for User Adapted Presentations of Cultural Heritage Information in Mobile Environments.* Paper presented at the SWDB'03. The First International Workshop on Semantic Web and Databases. co. VLDB, Berlin.
Nothegger, C., Winter, S., & Raubal, M. (2004). Selection of Salient Features for Route Directions. *Spatial Cognition and Computation, 4*(2), 113-136.
Presson, C. C., & Montello, D. R. (1988). Points of Reference in Spatial Cognition: Stalking the Elusive Landmark. *British Journal of Developmental Psychology, 6*, 378-381.
Raubal, M., & Winter, S. (2002). Enriching Wayfinding Instructions with Local Landmarks. In M. J. Egenhofer & D. M. Mark (Eds.), *Geographic Information Science* (Vol. 2478, pp. 243-259). Berlin: Springer.
Rosch, E. (1978). Principles of Categorization. In E. Rosch & B. B. Lloyd (Eds.), *Cognition and Categorization* (pp. 27-48). Hillsdale, NJ: Lawrence Erlbaum Associates.
Siegel, A. W., & White, S. H. (1975). The Development of Spatial Representations of Large-Scale Environments. In H. W. Reese (Ed.), *Advances in Child Development and Behavior* (Vol. 10, pp. 9-55). New York: Academic Press.
Singh, R. (2004, July). *GeoBlogging: collaborative, peer-to-peer geographic information sharing.* Paper presented at the URISA Public Participation in GIS 3rd Annual Conference.
Smith, B., & Mark, D. M. (2001). Geographic Categories: An Ontological Investigation. *International Journal of Geographical Information Science, 15*(7), 591-612.
Sorrows, M. E., & Hirtle, S. C. (1999). The Nature of Landmarks for Real and Electronic Spaces. In C. Freksa & D. M. Mark (Eds.), *Spatial Information Theory* (Vol. 1661, pp. 37-50). Berlin: Springer.
Timpf, S. (2002). Ontologies of wayfinding: a traveler's perspective. *Networks and Spatial Economics, 2*(1), 9-33.
Tomko, M. (2004). *Case Study -- Assessing Spatial Distribution of Web Resources for Navigation Services.* Paper presented at the 4th International Workshop on Web and Wireless Geographical Information Systems, Goyang, Korea.
Turner, A., Doxa, M., O'Sullivan, D., & Penn, A. (2001). From isovists to visibility graphs: a methodology for the analysis of architectural space. *Environment and Planning B, 28*(1), 103-121.
W3C. (1999). *Resource Description Framework (RDF)*. Retrieved December 15, 2004, from http://www.w3.org/RDF/
W3C. (2003). *RDFIG Geo vocab workspace*. Retrieved December 15, 2004, from http://www.w3.org/2003/01/geo/
W3C. (2004a, February 4). *Extensible Markup Language (XML) 1.1*. Retrieved December 15, 2004, from http://www.w3.org/TR/2004/REC-xml11-20040204/
W3C. (2004b, February 10). *OWL Web Ontology Language Reference*. Retrieved December 15, 2004, from http://www.w3.org/2004/OWL/
W3C. (2004c, October 28). *XML Schema Part 1: Structures*. Retrieved December 15, 2004, from http://www.w3.org/TR/xmlschema-1/
Weissensteiner, E., & Winter, S. (2004). Landmarks in the Communication of Route Instructions. In M. Egenhofer, C. Freksa & H. J. Miller (Eds.), *Geographic Information Science* (Vol. 3234, pp. 313-326). Berlin: Springer.
Winter, S. (2003). Route Adaptive Selection of Salient Features. In W. Kuhn, M. F. Worboys & S. Timpf (Eds.), *Spatial Information Theory* (Vol. 2825, pp. 320-334). Berlin: Springer.

Winter, S., Raubal, M., & Nothegger, C. (2004). Focalizing Measures of Salience for Wayfinding. In L. Meng, A. Zipf & T. Reichenbacher (Eds.), *Map-based Mobile Services - Theories, Methods and Implementations*. Berlin: Springer Geosciences.

Worboys, M. F. (2001). Nearness Relations in Environmental Space. *International Journal of Geographical Information Science, 15*(7), 633-652.

Young, R. (2004). *Google Local Search and the Impact on Natural Optimization*, from http://www.WebPronews.com