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A semantic geographical knowledge wiki system mashed up with Google Maps

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A wiki system is a typical Web 2.0 application that provides a bi-directional platform for users to collaborate and share much useful information online. Unfortunately, computers cannot well understand the wiki pages in plain text. The user-generated geographical content via wiki systems cannot be manipulated properly and efficiently unless the geographical semantics is explicitly represented. In this paper, a geographical semantic wiki system, Geo-Wiki, is introduced to solve this problem. Geo-Wiki is a semantic geographical knowledge-sharing web system based on geographical ontologies so that computers can parse and storage the multi-source geographical knowledge. Moreover, Geo-Wiki mashed up with map services enriches the representation and helps users to find spatial distribution patterns, and thus can serve geospatial decision-making by customizing the Google Maps APIs.

geo-ontology, semantic wiki, mashup, Google Maps

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1 Introduction

Web 2.0 applications, including blogs and wikis, provide a platform for users to collaborate and share information. Compared with blogs, wikis usually present knowledge more generally and objectively, especially when they have a large number of registered users. Among numerous wiki sites, Wikipedia (http://www.wikipedia.org) is a well-known successful example, where each user is able to contribute to a vast encyclopedia. In Wikipedia pages, lots of entries contain textually represented geographical knowledge. Goodchild used the concept of “volunteer geographical information sensors” to address that users can not only browse but also provide geographical knowledge in such environments [1]. In the implementation of Digital Earth and Digital China [2], the user-generated information is obviously an important component. However, such information without explicit geographical semantics can not be understood and manipulated efficiently by computers. Once a wiki system organizes the entries with geographical semantics and display localities, spatial analysis can be performed based on the user-generated information.

In this paper, a geographical semantic wiki system named Geo-Wiki is introduced to solve this problem. Geo-Wiki is a semantic knowledge-sharing web system based on geographical ontologies so that the user-created information is explicit and readable for machines [3]. In order to develop Geo-Wiki, the domain specific ontologies that take geographical knowledge into account should be built [4]. Assuming the objective of Geo-Wiki is to assist users to edit encyclopedia entries that focus on geographical knowledge, the entries with geographical semantics are investigated and a number of a domain specific terms are identified.

The remainder of this paper is organized as follows. In Section 2 a geographical domain specific vocabulary is mod-

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eled using the Web Ontology Language (OWL) and Protégé. This ontology model is managed by Geo-Wiki and provides conveniences to specify geographical semantics. In the Section 3, we design and implement Geo-Wiki based on the WampServer architecture (PHP+MySQL+Apache), which provides an extension that enables users to semantically annotate wiki pages. The contents with geographical semantics in Geo-Wiki are organized by a formal structure and can be browsed, retrieved and reused. Section 4 introduces a mashup that combines Geo-Wiki with Google Maps API (application programming interface) to support more applications.

2 Related research

2.1 Geo-ontology and geospatial semantic web

Geo-ontology and Geospatial Semantic Web (GSW) have become hot topics in geographical information science [4–8]. In information systems, an ontology refers to "a formal, explicit specification of a shared conceptualization" [9]. The major components of an ontology include axioms, classes, individuals, attributes, and relationships. In geographical domain, all geographical objects are parts of the Earth's surface [10]. Generally, geospatial class, geospatial label, and geospatial comparator are three essential components in geographical knowledge. Hence, the top-level geo-ontology includes object-field distinctions [11,12], geographical categories [10,13], distinctions between fiat and bona fide boundaries [14,15], and relationships, especially part-whole relationships [16], among objects [17,18]. Focusing on different topics, a number of ontologies have been documented, such as geospatial entities, coordinate reference systems, geographical features, feature types (http://www.ordnancesurvey.co.uk/ontology; http://www.alexandria.ucsb.edu/gazetteer/FeatureTypes/), place names (http://www.geonames.org/ontology/), and spatial relationships (http://www.ordnancesurvey.co.uk/ontology/SpatialRelations.owl). OWL is the standard description language, and has become part of the growing stack of W3C recommendations related to the Semantic Web. It is designed to meet the need to process the content of information by computer instead of just presenting it to users. GML (geography markup language) (http://www.opengeospatial.org/standards/ gml) provides standard geospatial terms and some corresponding definitions as a widely applied industrial standard. However, it does not consider much geographical knowledge, such as feature types and place names [19].

The Semantic Web "provides a common framework that allows data to be shared and reused across applications, enterprises, and community boundaries" [20]. Geospatial Semantic Web focuses on encoding geospatial semantics to process various queries. Ref. [5] identified three dimensions of information on the GSW: professional, naïve, and scientific. Four representations, including natural language with minimum markup, metadata, data models describing the structure of Web resources, and logical semantics, should be considered in GSW [4]. In the above introduction, we use the term "geospatial".

Generally, "geospatial" refers to geometrical entries and relationships, while "geographical" also considers geographical attributes [21]. In Geo-Wiki, since geographical events and geographical laws are taken into account in addition to geospatial entities and relationships, we tend to use "geo" to stand for "geographical". Moreover, the ontology in GSW is defined formally as the foundation to implement Geo-Wiki.

2.2 Mashups and Google Maps API

A mashup is a Web application that aggregates multiple services to achieve a new purpose. It is an important feature of Web 2.0 and can be used with software provided as a service (SaaS). With various mashup techniques, it is convenient for developers to obtain data from a variety of data sources on the web, and to integrate these data to build new applications. Generally, mashups have three objectives: data mediation, process mediation, and user interface customization [22]. Many applications belong to the first category. AlertMap (http://www.idemc.org) and Chicago Crime Map (http://chicago.everyblock.com/crime) are two typical examples. AlertMap combines data from over 200 sources related to severe weather conditions, biohazard threats and seismic information, and displays them on a map of the world, while Chicago Crime Map indicates the crime rates and crime locations in Chicago. The mashup based on Geo-Wiki presented in this paper falls into the category of "process mediation", which combines geographical semantics with analysis service and electronic map service together in web server processing.

Google Maps (http://maps.google.com) is an online mapping service that represents three types of geospatial data, i.e., remotely sensed images, symbolized vector maps, and terrain maps. Google Maps is implemented based on Ajax techniques, which makes interacting with the maps intuitive and easy. Google Maps API allows developers to embed Google Maps in their own web pages with JavaScript, PHP, or Flash. The API provides a number of utilities for manipulating maps and adding content to the map through services. Google Maps mashups combine existing Google Maps geospatial query/display engine with geospatial data provided by non-Google users [23]. A Google mashup consists of three layers: Google Maps, the mashup website, and the mapmaker's personalizations. When Google Maps is integrated with Geo-Wiki, the map maker's personalizations can be provided by the semantic wiki, and thus geographical analyses are supported in addition to locality visualization. Figure 1 demonstrates the conceptual architecture of the mashup combining Geo-Wiki and Google Maps.

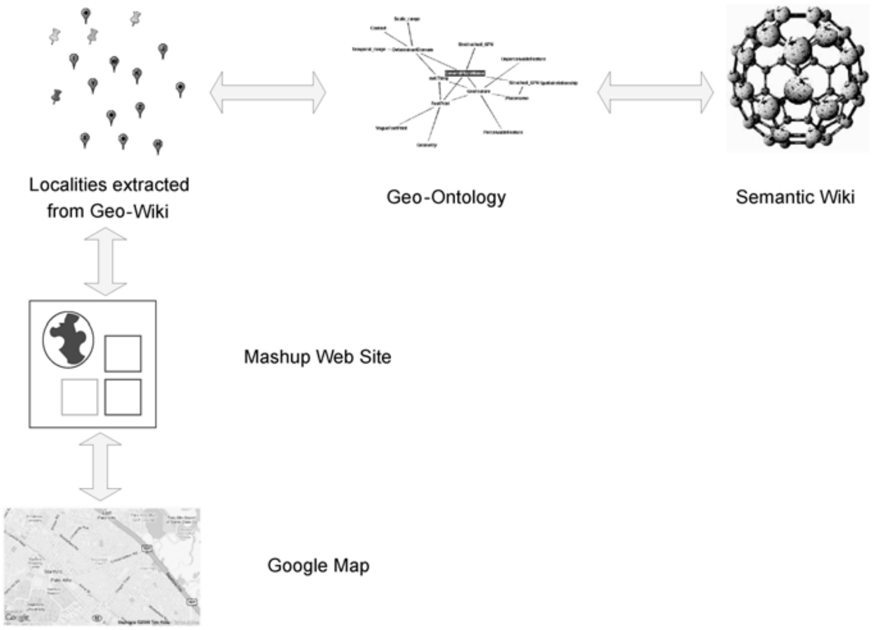

Figure 1 Conceptual architecture of the mashup combing Geo-Wiki and Google Maps.

3 Geographical entries and relationships in wiki systems

3.1 Geo-entries

An encyclopedia contains a great number of entries, such as persons, organizations, events, places, species, artifacts, and rules and laws. Generally, these entries can be divided into two categories: collection concepts (or classes) and individual concepts. An individual concept (e.g., A. Einstein) is an instance of a specific collection concept (e.g., Human), and it should be significant enough to be recorded in an encyclopedia. For example, there are numerous rivers in the world, while only a few, such as the Yangtze River, are described.

In Geo-Wiki, geographical knowledge refers to descriptions about geographical concepts, phenomena and events. Generally, an entry has geographical semantics when it is about a place or associated with at least one place. Examples of these two cases are China and the 29th Olympic Games, which is associated with Beijing. Hence, we can identify two types of geographical entries (geo-entries), i.e., tightly-coupled geo-entries and loosely-coupled geo-entries. The former directly describe geographical knowledge, and the latter are associated with geospatial distributions, especially places. Five types of tightly-coupled geo-entries can be summarized:

1) Geographical phenomena that pervade geographical space, such as terrain and temperature.

2) Geographical features are identifies form fields according to associated ontologies [24]. They are classified and thus collection concepts, such as river and mountain, come into being. These feature types can be organized in a tree structure. In Geo-Wiki, we use the feature type thesaurus (FTT) (http://www.alexandria.ucsb.edu/gazetteer) to manage geographical feature types.

3) Places and geographical features belong to individual concepts and occupy a major proportion of geo-entries. A named geographical feature can serve as a place, since it has a particular location, which is the footprint of the place. Hence, we introduce a property “has_footprint” to represent the location of a place or a feature [25].

4) Geographical events, such as hurricanes and earthquakes, have particular spatial distributions and relatively large spatial extents so that we can identify and name them.

5) Geographical laws may be not in agreement with empirical reality [26]. They are abstracted with assumptions by geographers or scientists in related areas. Typical examples include Christaller’s Central Place Theory, Davis’s Cycle of Erosion Theory, etc.

In addition to tightly-coupled geo-entries, many articles contain place names, that is, the described objects have geospatial distributions. We use the term loosely-coupled geo-entry for these articles. In Geo-Wiki, four types of loosely-coupled geo-entries are supported: ordinary events, persons, organizations, and species (Figure 2).

3.2 Relationships between geo-entries

In geographical knowledge, places are the fundamental components, while relationships among places construct a network structure. Most geographical knowledge can be represented by a proposition like “Beijing is the capital city of China”, where two place names and a binary relationship are involved. We thus use the term “place-based” [27] for such

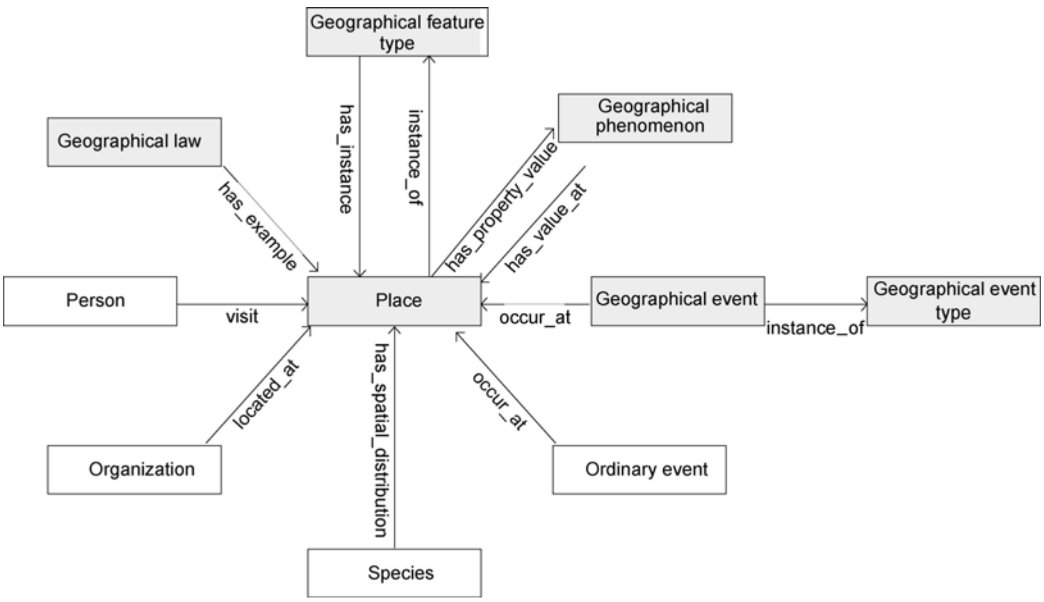

Figure 2 A conceptual diagram for place-based representation of geographical knowledge.

geographical knowledge. If we only consider geometrical characteristics, three types of binary spatial relationships among places, including topological, cardinal directional, and metric relationships, are emphasized. Several special relationships, such as between, parallel and along, which do not belong to the above three categories, are also used to represent geographical knowledge. Many geographical predicates imply ordinary spatial relationships with particular types of the involved places. For instance, "A is the capital city of B" means that A is a city, B is an administrative unit, and the topological relationship between A and B is inside. In Geo-Wiki, 31 relationships are summarized and managed (Table 1). In this list, three special relationships and two relationships with geographical semantics are identified, and more relationships can be appended to the system on a case by case basis.

Places are essential to geographical knowledge. Additionally, they also play an important role in ordinary knowledge. In addition to the relationships among places, we can introduce a number of relationships between places and other loosely-coupled geo-entries to organize propositional geographical knowledge, such as "the 29th Olympic Games were hold at Beijing in 2008". Figure 2 depicts a conceptual diagram for the structure of place-based geographical knowledge.

3.3 Design of geo-ontology

We use Protégé 3.4 (http://protege.stanford.edu) to build the OWL geographical ontology model and define geographical features, places, phenomena, loosely-coupled geographical concepts, and the relationships between them.

3.3.1 Geographical features and places

Geographical feature and place are two important concepts in geographical knowledge representation. Geographical features are perceivable and generally have distinct boundaries, while places refer to localities with vague boundaries [28]. A feature belongs to a particular type and has spatial extension. According to the above discussions, the ontology of geographical features is depicted in Figure 3, where "has_geometry" denotes the relationship between a feature and the associated geometry, and "rdfs:subClassOf" represents the hierarchical structure of geographical features. In practice, a place is generally represented by a feature, such as "Beijing", or a spatial assertion containing features and spatial relationships, such as "Beijing vicinity" [29]. The footprint of a place is often approximately represented using an MBR, a circle, or a convex hull. Figure 4 indicates the ontology of places.

```
<owl:Class rdf:ID="Feature"/>
<owl:ObjectProperty rdf:ID="#has_geometry">
    <rdfs:range rdf:resource="#Geometry"/>
     <rdfs:domain rdf:resource="#Feature"/>
</owl:ObjectProperty>
<owl:Class rdf:ID="#GeomorphologicalFeature">
    <rdfs:subClassOf>
    <owl:Class rdf:about="#Feature"/></rdfs:subClassOf>
</owl:Class>
```

Figure 3 Ontology of geographical features.

```
<owl:Class rdf:ID="Place"/>
<owl:ObjectProperty rdf:ID="has_footprint">
<rdfs:range rdf:resource="#Footprint"/>
<rdfs:domain rdf:resource="#Place"/>
</owl:ObjectProperty>
<owl:Class rdf:ID="Footprint">
<owl:equivalentClass><owl:Restriction>
        <owl:onProperty><owl:ObjectProperty
        rdf:ID="spatial_rel"/></owl:onProperty>
        <owl:someValuesFrom><owl:Class
        rdf:ID="Geometry"/></owl:someValuesFrom>
        </owl:Restriction></owl:equivalentClass>
</owl:Class>
```

Figure 4 Ontology of places.

Table 1 Classification of relationships among places

Categories	Relationships	Number
Topological relationships	Equals, Disjoint, Intersects, Touches, Crosses, Within, Contains, Overlaps	8
Cardinal directional relationships	North, Northeaset, Ease, Southeast, South, Southwest, West, Northwest	8
Internal cardinal directional relationships	I_N, I_NE, I_E, I_SE, I_S, I_SW, I_W, I_NW	8
Qualitative metric relationships	Close, Far	2
Special relationships	Between, Parallel, Along	3
Relationships with geographical semantics	Flows_into, is_capital_of	2

```
<owl:ObjectProperty rdf:about="#spatial_rel">
<rdfs:range rdf:resource="#Geometry"/>
<rdfs:domain><owl:Class>
        <owl:unionOf rdf:parseType="Collection">
        <owl:Class rdf:about="#Geometry"/> <owl:Class rdf:about="#Footprint"/>
        </owl:unionOf>
        </owl:Class></rdfs:domain>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:about="#directional_rel">
        <rdfs:subPropertyOf> <owl:ObjectProperty rdf:about="#spatial_rel"/></rdfs:subPropertyOf>
</owl:ObjectProperty>

<owl:ObjectProperty rdf:ID="east">
<rdfs:subPropertyOf><owl:ObjectProperty rdf:about="#directional_rel"/></rdfs:subPropertyOf>
</owl:ObjectProperty>
```

Figure 5 Ontology of spatial relationships: “east” as an example.

```
<owl:ObjectProperty rdf:ID="occur_at">
     <rdfs:range rdf:about="#Place"/><rdfs:domain rdf:resource="#Event"/>
</owl:ObjectProperty>
```

Figure 6 Ontology of aspatial relationships: “occur_at” as an example.

3.3.2 Relationships

Relationships are important components of ontologies. In Geo-Wiki, we focus on two types of relationships, namely, relationships among places (Table 1), and relationships between places and ordinary concepts (e.g., events). Figure 5 demonstrates the ontology of cardinal directional relationships using “east” as an example. Figure 6 depicts the “occur_at” relationship between places and events.

4 System design and implementation

4.1 Architecture and implementation

Geo-Wiki is a semantic wiki system that enables users to create textual description of geographical knowledge based on geo-ontology. Geo-Wiki intends to achieve the following objectives: 1) definition and management of a vocabulary of geographical knowledge; 2) allowing users to edit, browse and query the managed geographical semantic information; 3) creation and transform of geographical ontology models; and 4) maintaining links between geographical knowledge and map presentations.

The architecture of Geo-Wiki is shown in Figure 7. Browsing, editing, and modifying geographical knowledge are client-side tasks. Meanwhile, the entries representing geographical knowledge are managed at the server side by a popular wiki engine, MediaWiki (http://www.mediawiki.org/). This engine transforms the OWL geo-ontologies into a relational database to accomplish the extended geographical semantics.

In MediaWiki, the tasks of editing and storing geo-entries are accomplished by Web pages, which are distinguished by different namespaces according to their functions. A page’s namespace is signified by a specific prefix, such as “User”, “Help”, or “talk”. Page titles without a known namespace prefix simply belong to the main namespace.

The extensions for geographical knowledge in Geo-Wiki are based on the ontology model introduced in Section 3. Using the semantic annotation rules and the geo-ontology model with a vocabulary, we extend MediaWiki to support geographical knowledge. Additionally, Geo-Wiki uses Google Maps API to create mashups with Maps.

4.2 Semantic annotation rules

Geo-Wiki collects semantic data by letting users add annotations to Wiki texts via special markups. These markups are processed by the parsing and rendering components. For Geo-Wiki, the underlying ontological framework based on properties and types is the most important component for editor who could add new entries directly in wiki web pages. The main grammar rules of Geo-Wiki include the following syntaxes.

1) == Headline text ==

The character string in this annotation “==… ==” will be the headline of a wiki page.

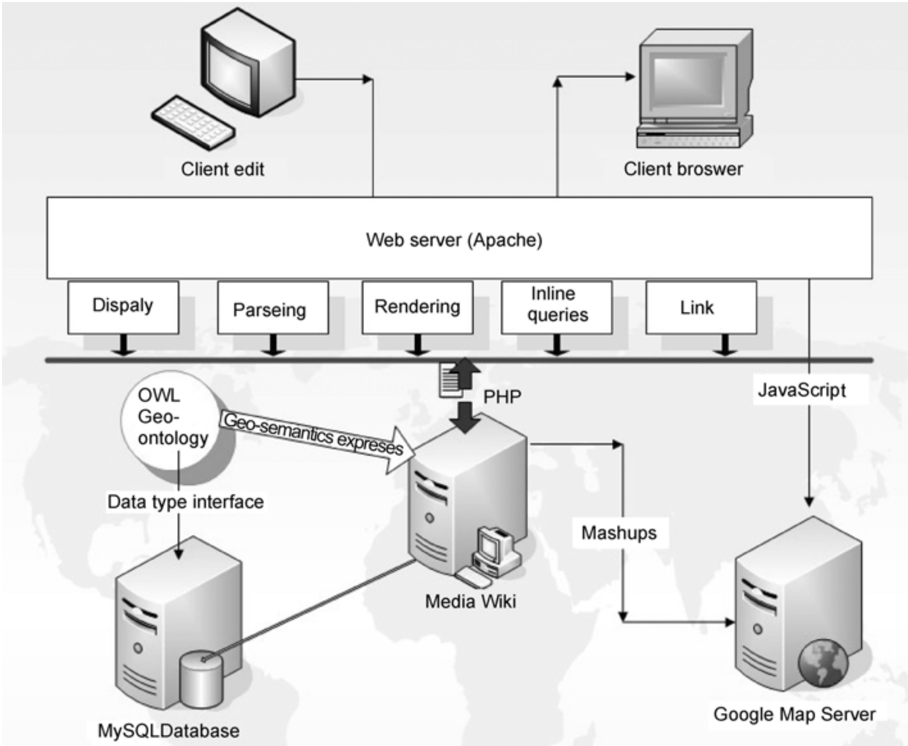

Figure 7 Software architecture of Geo-Wiki.

Beijing is a metropolis in northern [[I_N::China]] and the capital of [[is_capital_of::China]]. Beijing is China's second largest city after [[Shanghai]]. Beijing is recognized as the political, educational, and cultural center of China. The city hosted [[the 2008 Olympic Games]]
==Demographics==
The population of Beijing Municipality, defined as the total number of people who reside in Beijing for 6 months or more per year, was [[has_population:: 16,950,000]] at the end of 2008.
==Geography==
Beijing's geographical extent is [[has_footprint::(115.42E,39.42N)-(117.50E, 51.05N)]].
[[Category:City]]

Figure 8 Semantic wiki annotations of the entry "Beijing".

2) [[…]]

The text within square brackets [[…]] is transformed into links to the Wiki page with the name specified inside the brackets. However, the semantic relationships between them are not necessary.

3) [[A::B]]

In [[A::B]] annotations, "A" refers to a binary relationship defined earlier, such as "crosses" or "is_capital_of", and "B" represents the objects involved in the relationship or a numerical value attribute. For example, supposing the subject of a wiki page is Beijing, we can use the following annotations, such as [[has_population::16,950,000]], [[is_capital_of::China]], and [[northwest::Tianjin]], to represent three properties of the entry of Beijing.

4) [[Category:X]]

[[Category:X]] specifies the concept that a place or a concept subject belongs to. In Geo-Wiki, each page can be assigned to one or more categories, and each category is associated with a page in the "Category:" namespace. The category pages can be used to browse corresponding pages, and to organize entries hierarchically. Geo-Wiki provides a number of predefined categories, such as place, geographical feature, geographical event, and a set of geographical feature types, to help users to organize wiki pages.

As shown in Figure 8, the given links to [[Shanghai]] and [the 2008 Olympic Games]] do not carry any semantics yet. To state that Beijing is the capital city of China, the editor can simply extend the link to [[China]] by writing [[is_capital_of::China]]. This asserts that "Beijing" has a property called "is_capital_of" with the value "China". Moreover, the footprint (cf. "has_footprint") of Beijing is represented by the geographical coordinates and can be visualized on Google Maps (Figure 9).

As mentioned earlier, places and place-involved relationships are key components of geographical knowledge in Geo-Wiki. In user-generated wiki pages, these relationships are expressed by "has_property" or "has_subproperty", and corresponding links can be browsed according to their semantic content. For example, when searching the entry Beijing, a number of pages can be obtained based on the semantic relationships in addition to the ordinary hyperlinks (Figure 10).

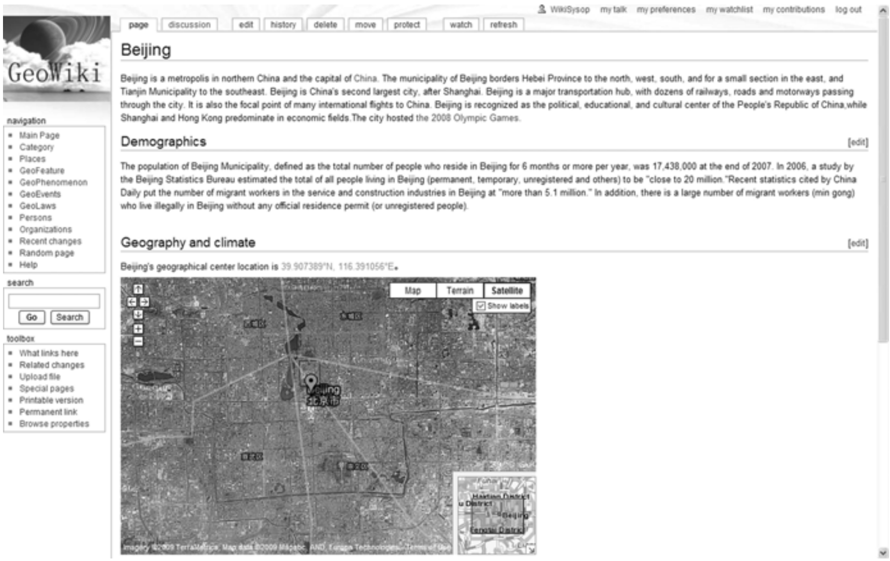

Figure 9 Beijing wiki page mashed up with Google Maps.

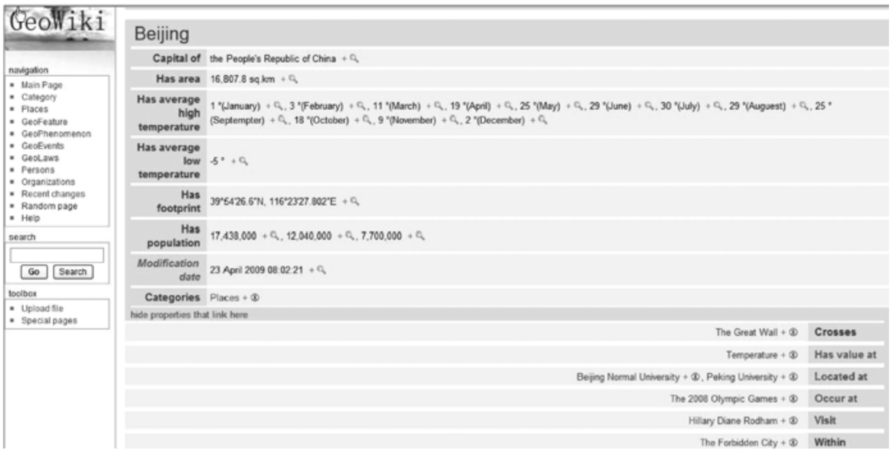

Figure 10 Relationship diagram associated with geo-entries.

Figure 11 Interaction between wiki pages and Google Maps.

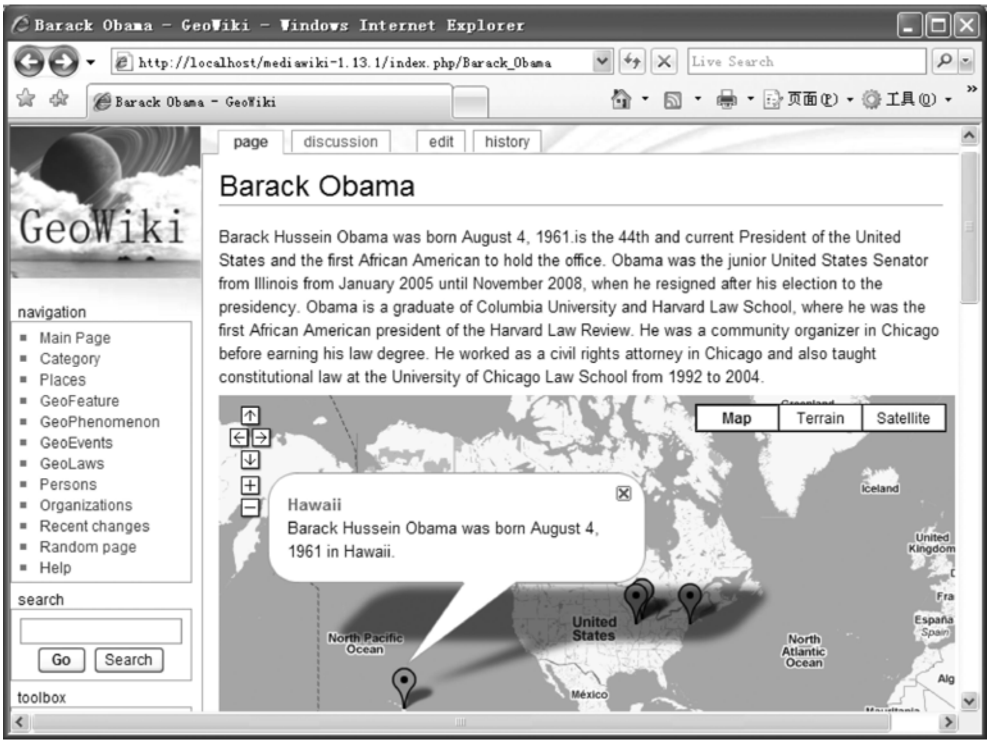

Figure 12 Identifying personal life trajectory according to user-generated content.

4.3 Applications

Geo-Wiki provides an extension that enables users to semantically annotate wiki pages representing geographical knowledge. The user-generated geographical knowledge is computer readable and mashed up with Google Maps, so that a number of applications can be implemented.

Geo-Wiki mashed up with Google Maps API can not only help users to view places locations in embed maps based on textual descriptions, but also inversely support links to related wiki pages based on Google Maps according to the footprint properties of places. As shown in Figure 11, the Forbidden City in Beijing is drawn on Google Map. If a user wants to know more information, he (or she) can simply click the link to the Forbidden City wiki page.

In addition to pages that directly describe geographical knowledge, places are involved in many loosely-coupled geo-entries, such as wiki pages on people. A person may visit many places in his (or her) life. Since the footprint of each place is explicitly represented, the life trajectory can be established according to one's wiki page. For example, Figure 12 demonstrates the life trajectory of Barack H. Obama, including a number of places, such as Hawaii, Columbia University, and Chicago. With the aid of Geo-Wiki, geographical analyses on user-generated knowledge can be easily performed.

5 Conclusions

This paper introduces the design and implementation of a geo-ontology-based semantic wiki system that supports users to edit and retrieve geographical knowledge. We first establish the domain specific ontologies that consist of a set of geospatial classes, labels, and comparators, as the foundation of Geo-Wiki. Geo-Wiki is implemented based on MediaWiki with pre-defined annotations derived from geo-ontology. Since geographical knowledge is explicitly represented in Geo-Wiki, spatial analysis provided by traditional geographical information systems can be performed to manipulate the user-inputted wiki-pages. In the era of Web 2.0, wiki systems like Geo-Wiki provide an approach for individuals to input various geographical data. This apparently widens the data source of geographical information applications. In the future, we plan to improve Geo-Wiki in the following aspects: 1) enhancing the ontology model to represent more constraints on relationships, especially on ternary relationships; 2) providing an intelligent reasoning mechanism to infer new knowledge based on user- generated information.

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