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SOCIAL NAVIGATION FOR SEMANTIC WEB APPLICATIONS USING SPACE MAPS

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Abstract. In this paper we deal with personalized navigation in an open information space. Our aim is to support effective orientation in increasing amount of information accessible through the Web. We present a method for personalized navigation based on social navigation where the information space is represented by an ontology. Navigational information is obtained by following user footsteps. It is attached to information fragment mapped to the user goal and to description of this goal using an ontology. This information is used later to show the way to similar goals. We use ontology representation of the information space that supports the effective navigation and the navigational ability to deal with frequent changes of information content in open environments. We demonstrate the proposed method in the context of developed software tool PENA for personalized navigation support in labor supply domain.

Keywords: Social navigation, personalized navigation, open information space, observation model, user model, space map, ontology

1 INTRODUCTION

Assisting a user in finding relevant information while navigating in a large information space through a web-based application is a key requirement for effective information processing today. One promising direction is personalized navigation [7].

The task of personalized navigation is to help the user find his/her way to the required information by directing him/her through the information space according to his/her goals, preferences and needs.

Techniques for personalized navigation were originally developed in the field of adaptive hypermedia and have been used successfully on closed information spaces. However, there are still problems with effective navigation that could be used in wide-open information space such as the Web. The issue is that in a closed information space an effective searching mechanism can be offered based on the knowledge of the structure and the content of this information space. In order to perform personalized navigation in open information spaces we should consider several additional aspects:

- *complex informational potential* – resource searching and selection in almost infinite amounts of information resources provided by the Web and obtaining relevant information from these resources;
- *acquiring navigation information* – acquiring meta-data on quality and propriety of information for a particular user;
- *frequent change of the information content* – storing and updating of information and meta-data;
- *orientation in the information space* – creating a structure on which the navigation is based.

One approach to facilitate these problems is to allow a software agent (machine) within a restricted scope to "understand" the information content without (or with minimal) human involvement. The problem of machine "understanding" and information processing of Web resources is the task which the *Semantic Web* initiative is aimed to solve by adding a semantic layer into the web information space to allow automatic information processing (`http://www.w3c.org/2001/sw/`).

This research builds on the Semantic Web initiative together with techniques for *adaptive navigation* that enable personalization [4], and *social navigation* that exploits the collective knowledge of large community of users [9, 10]. This combination is important in order to overcome problems related to navigation in open information spaces such as difficult orientation in the information space due to complex informational potential or frequent change of the information content.

One of the challenges for the Semantic Web is to develop methods for personalized navigation that would support navigation in a large and open information space. Navigation based on semantics assumes that resources in the open information space contain semantic annotation (created manually or discovered automatically by software tools). Personalized navigation is realized using meta-data description and employing Semantic Web technologies [11].

The aim of this paper is to present a method for personalized navigation support based on afore mentioned approaches. The method is intended for large information spaces with frequent changes of information content. It uses information about user group behavior and employs an ontology for representation of the domain, the user and observations.

Developing a method for personalized navigation is motivated by work on a research project aimed at support of acquisition, organization, maintenance and presentation of information on the Web [18]. The project outcome is a web-based information system for the online labor supply domain. The system itself consists of several cooperating software tools that realize a sequence of data acquisition and processing, thus operating on various levels of semantic understanding of individual sources. The sequence follows in successive steps from acquiring data containing job offers from the Web [19] through identifying documents in which job offers are present, offer extraction, organization [12] and their personalized presentation to the user [22]. This could be characterized as the transformation of a part of the Web to the Semantic Web, where existing documents are transformed to a representation, which augments the presented information by utilizing semantic concepts and their automated processing. Our method is included in the last activity in the chain, i.e. personalized presentation of job offers to the user.

The rest of the paper is structured as follows. Section 2 discusses related work. In Section 3 we give an overview of the proposed method for personalized navigation. Section 4 presents models for social navigation employing semantics, namely a domain model, user model and observation model. We describe the life cycle of models from their creation (Section 5) to the usage for adaptation (Section 6). The paper concludes with a summary and directions for future research.

2 RELATED WORK

There exist several techniques that provide effective support for navigation in a closed information space (such as educational book or digital library) [4]. Their success in navigating a user to his goals relies on the known structure and the content of the information space. However, navigation within an open space deals with complex informational potential and frequent changes of the content, which are not known in advance. Moreover, concepts in closed information spaces are tagged mostly manually by the authors, which becomes impossible for open spaces [13].

Existing approaches supporting navigation in open information spaces gain information from resources by an analysis of the content or by sharing knowledge within users with similar interests. Content-based approaches rely mostly on world-level document representation and user interests acquired by observing the user [21]. They usually employ machine-learning techniques.

Social navigation is based on an analysis of previous interactions of a group of users with the system providing personalized navigation support, thus providing collaborative navigation [9]. These interactions are recorded using various forms of feedback and used to create "collective knowledge". Within this approach groups of users with similar goals and preferences are created (automatically or manually). Social navigation is based primarily on collaborative filtering techniques as one of the most successful and widely used techniques in recommender systems [14, 15, 1].

Traditionally, collaborative filtering techniques are based on a comparison of a representation of a user's preferences (such as explicit ratings on items or implicit navigational patterns) with the historical records of past users to find the k most similar neighbors of the user. These historical records are used for recommendation. The bottleneck of this approach is the lack of scalability of the underlying memory-based k-nearest-neighbor approach which requires that the neighborhood formation phase be performed as an online process and the sparse nature of the underlying datasets which decreases the likelihood of a significant overlap of rated items among pairs of users [17]. Several optimization strategies have been proposed including similarity indexing to reduce real-time search costs, and dimensionality reduction methods based on latent semantic indexing to alleviate the data sparsity in the user-item mappings.

The precision of existing content-based and social navigation techniques is far from that achieved for closed information spaces when offering the most relevant information. Despite their ability to work with large information spaces, they do not provide sufficient power of navigation support for open information spaces at the same scale that was provided for closed information space oriented adaptive hypermedia systems.

Using explicit rating poses several problems such as user tendency in reading a lot more than providing any feedback or issue of stopping users regular process for providing explicit feedback [8]. In [5], collaborative approaches have been enhanced for social adaptive navigation support in open spaces. Rather than finding similar items in terms of structure and/or content, collaboration is based on observing clicking behavior and creating an index of presented concepts based on the number of visits of a group of users. The very idea is based on the simplest implicit feedback: group traffic [23].

On the other hand, navigation based on semantics (employing the Semantic Web technologies) provides more exact navigational results, while it deals with problems to obtain value and quality of presented information. Our approach to personalized navigation merges advantages of navigation based on semantics and social navigation based on the "footprint" approach as used in [5]. It is proposed for use in large information spaces with frequent changes of the information content. Frequent changes in such space cause the loss of navigational information obtained through tracking the user and group activity. Ontology representation of the information space provides structured description. This enables to attach the navigational information to the content and its characteristics, which are used later by navigating to similar goals. We use information about user group behavior for annotating (using different colors) interesting parts of the information space. Information related to user group behavior also includes time spent on individual concepts.

3 APPROACH OVERVIEW

The approach uses principles of social navigation – we gather knowledge for effective navigation support from monitoring behavior of groups of users. Social navigation is based on the well known social tendency to follow other users ("footprints"). We employ this information to navigate within an open information space in the place where expert knowledge on structure is used in a closed information space.

3.1 Information Space Map

An appropriate support technology for user navigation in an open information space that is generally large and complex is maps and landmarks [6]. Maps and landmarks show their usefulness in real world applications – they are considered as the best navigation tool for centuries. A distance between two objects is reflected by their position on a map. In our case, the position of two objects reflects their semantics similarity. The map links together similar information fragments by creating subspaces. Particular parts of the map are marked by suitable landmarks, thus the user can easily orient himself and follow landmarks to his goal – a piece of information s/he is looking for.

Crucial to proposed method of navigation are properties that describe information fragments and relations between them. Every property can represent a dimension in our visualization of the navigational map. The property values create a range of this dimension. As an example of dimension in the job offer domain we give the *type* dimension. The range for this dimension contains the values *part time*, *full time* and *contract*. The map shows the information space divided according to the selected dimensions by displaying a set information fragments for every value the dimension can take.

Figure 1 shows an example of the navigation map in job offer domain. The map is focused on job offers for IT professionals (see the largest set in the figure). Here two dimensions are visualized: *type* and *position*. In every such set all information fragments are visualized that have the property (represented by the dimension) with particular value characterizing the set.

Information space map also provides the navigation among multiple dimensions. Sets created on the basis of previously selected dimensions are displayed within sets from the most recently selected dimension as a kind of folder. The whole information space is divided into sets according to the most recently selected dimension. Every set on this level contains other sets of second most recently selected dimension, and so on. The structure of the map expands with every additional dimension selection and with it the possibility of more exact selection of the desired target information fragment. In our example of the navigation map (Figure 1) job offers are further divided according to the contract type (part time, full time or contract) in second level sets and according to the offered position in the smallest sets.

We strive to avoid overloading the user with too much detail in description of the information space parts. Therefore it is important to present the user only with

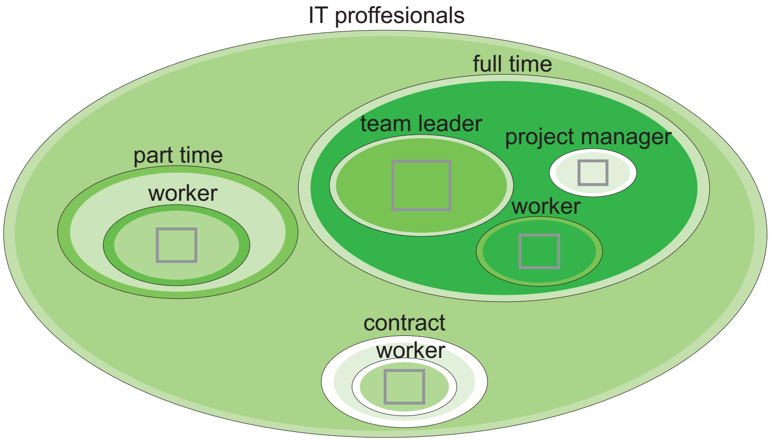

Fig. 1. Presentation of several dimensions

relevant dimensions. Navigation is realized primarily by annotations using colors and icons to express features such as user rating, group rating or subspace size.

By expanding the map structure the information space map becomes more complex and it can get difficult for a user to orientate him/herself in it. We enable the user to "focus" on a particular part of the map and change the map scale. The user can scale up the map by selecting one of the displayed sets on this map. In other words, we specify the value of some displayed dimensions. As a result all sets describing other values than the specified one will disappear from the information space map; and the map will contain only the selected set and its subsets. In job offer domain this can be done by displaying job offers concerning e.g. IT profession only as shown in Figure 1. If the user realizes that selected subspace does not contain the required information, s/he can select outside of the previously selected set and in such a way scale down the information space.

3.2 Method for Personalized Navigation

The basic principles of the proposed method are as follows:

- *it is based on semantic description in the form of ontology:* this enables to split an information fragment from its characteristics; thus we can bind personalized ratings not only to the particular information fragment, but also to its characteristics;
- *it uses social navigation:* navigation is realized using "footprints" of users with similar goals and preferences (group);
- *it uses techniques for effective navigation:* we use maps and landmarks to support user orientation in the information space; we also use techniques developed

for closed information spaces such as adaptive annotation, adaptive link generation and adaptive sorting.

Personalization consists of two processes: acquiring navigational information and using this information to navigate the user through the information space.

The process of acquiring navigational information consists of two steps:

1. *Record user accesses* – a new ontology object representing user access and describing the attributes of this access is created.
2. *Infer and update navigational information* (rating) for the user and for his group – ratings are maintained not only for the target information fragment but also for its properties and related information fragments according to the domain ontology definition. This way we bind the navigational information to the information fragment and also to its properties. Consequently, even when the target information fragment is no longer current we are still able to use the gained navigational information and apply it to related information fragments.

The process of using navigational information consists of the following steps:

1. *Find all the values of the selected dimension* and find the corresponding subspace for each of them.
2. *Get group ratings* of these subspaces.
3. *Get actual user ratings* of these subspaces.
4. *Display navigational map* containing the navigation results enriched with personalized ratings.

4 MODELS FOR SOCIAL NAVIGATION EMPLOYING SEMANTICS

Our method works with user, domain and observation models. Every model is represented by an ontology. Using ontology for models representation allows us to explore similarities between user goals and preferences to create groups, define an information fragment hierarchy in different dimensions and their relations, record navigational information (ratings) and use them for personalization.

The advantages of using ontology for modeling arise from the fundamentals of this formalism. Ontology provides a common understanding of a domain to facilitate reuse and harmonization of different terminologies [16]. It supports reasoning, which is considered an important contribution of ontology-based models. Once a model is represented as ontology, the ontology and its relations, conditions and restrictions provide the basis for inferring additional characteristics. For example, retrieval can be based on associations and not only on partial or exact term matching [20].

Domain model. The domain model contains information about both the structure and information fragments of the information space through which we provide navigation. Thus we are not able to describe its structure in general for any domain. Though we specify several restrictions to define the domain model:

- one ontology class is defined whose instances are targets for the navigation; when navigating through the space we always consider objects of this class as goals that the user wants to reach;
- target class properties and other classes that are related to the target class create the whole information space in which we provide the navigation.

The domain model is outlined in Figure 2. The *NavigationTarget* class is defined and its instances are targets for navigation.

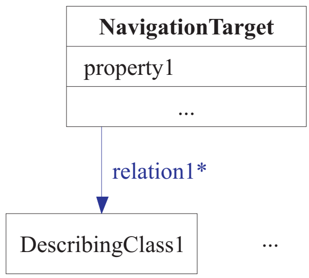

Fig. 2. Domain model structure outline

In our use case domain the navigation target is a job offer. This class is described by its properties and relations to other classes that can be considered as object properties. The domain model ontology developed for evaluation of proposed method represents an explicit conceptualization of job offers. Figure 3 shows a part job offer description structure.

The classes like contract type or salary specify a job offer and can represent dimensions. Description can be extended by other relations (salary is paid in certain currency) or by defining possible values (contract types).

In case there is a need for navigation to several rather different information fragments which we are not able to describe with the same properties and relations, it is sufficient for all properties in order to use our method to define the *NavigationTarget* class as the common super class. In this case the properties and the relations they differ in are defined in subclasses.

User model The user model contains information about a user and his/her preferences. Since we provide a method of social navigation, the user model also contains information about user groups and their preferences.

Our method does not require any specific features related to user modeling. By defining an ontology-based user model, we enable sharing user characteristics among a range of systems of the same domain (especially on the Web, where most ontologies are currently represented in OWL) [2]. Existing user models can be augmented by

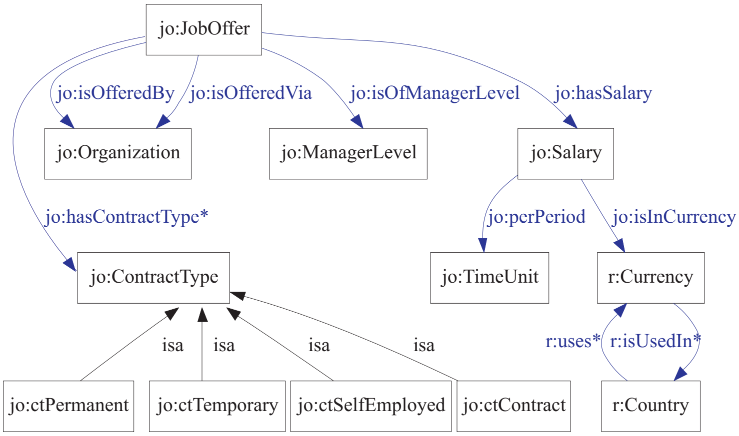

Fig. 3. Example of job offers domain model part

specific characteristics required by the method while keeping its domain dependent and domain independent representations from the original.

Observation model. While facilitating navigation we need navigational information in the form of recommendations or "footprints" in our case. We record information about user accesses (class *Access*) to objects of the information space. Recommendations are created based on access information and stored using instances of the *Rate* class. Figure 4 shows related classes from the user model (*User* and *Group* classes) and domain model (*NavigationTarget* and *DescribingClass* classes). According to the *Rates* we direct the user through the information space.

5 CREATING NAVIGATIONAL INFORMATION

The task of personalized navigation is to guide a user effectively to the particular information s/he is looking for. Thus we record user activities while navigating (e.g. space dimension, its property or the information fragment selection) and we use this information to create and update personalized navigation information (recommendations or rates).

User activity is recorded in an object of the *Access* class. We create the object, which contains the following access attributes:

- *accessDate*: date and exact access time,
- *accessObject*: selected object (property value or target fragment),
- *accessUser*: accessing user identification.

Despite the navigational information a user can get lost in the information space. In such case the user is typically looking for his/her way with several probes among

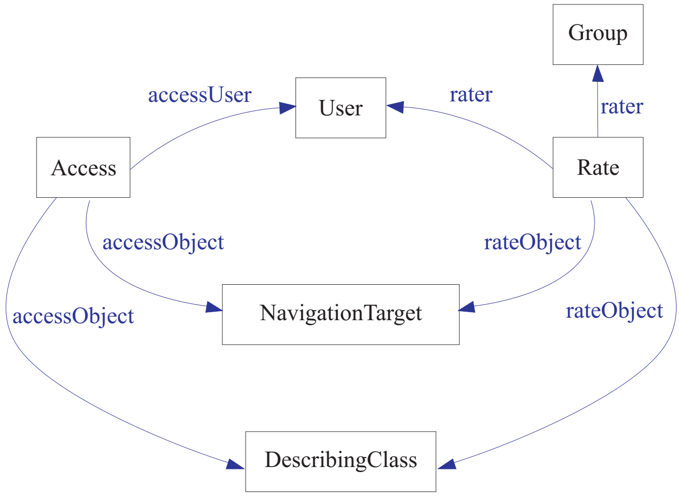

Fig. 4. Observation model structure

wrong subspaces. We do not consider the information about these "confused" accesses to create a recommendation. We perform the transformation of the access information into ratings only after a confidence that the user has really found the relevant information. We consider the user access to the target information fragment and his/her visit of it for a certain time as an estimation of user interest in particular information.

Then we use all previously recorded accesses to create recommendations (the *Rate* class instances). In this way we bind the recommendations not only to target information fragments but also to each of their properties and values that has been selected on the way to this target. This means the rating for the navigation target and all its property values are increased as described in the following calculation. Every property value describes certain part of information space according to certain point of view (dimension is represented by property). As a result these parts will be visualized with more intense color on the information space map.

When creating or updating rates we store the rate identification. We use access, user and his/her group attributes and previous values of rate attributes to express the final rate value.

The following attributes are defined:

- *userAccesses*: number of all accesses by users,
- *groupAccesses*: number of all accesses by users in particular group,
- *rateObject*: rated object,
- *rater*: user or group whose rating is being updated,

- *rateDuration*: access duration in seconds[1],
- *rateAccesses*: number of rater accesses to the *rateObject*,
- *rateAgeAverage*: average rate age in days,
- *rateLastModified*: date and time of the last update,
- *rateValue*: rate value, primary attribute for personalized navigation.

To update the *Rate* object we use its previous values (initially set to zero), information about the access (the *accessDate* attribute used for calculating the *accessAge*) and the *accessDuration* obtained when the user has visited a target information fragment. A rates update is realized in several steps:

1. *Update the rate object.*

   The *numDays* value is calculated as number of days passed from *rateLastModified*. If the rate is older than today ($numDays > 1$), recalculate the rate age average to current date:

$$rateAgeAverage := rateAgeAverage + numDays.$$

2. *Add new access to the age average.*

   Age average expresses the weighted average of all accesses to the particular object – weighted by *accessDurations*:

$$rateAgeAverage := \frac{\sum_{i=1}^{rateAccesses} accessDuration_i \times accessAge_i}{\sum_{i=1}^{rateAccesses} accessDuration_i}$$

   where index i refers to i-th *Access* values. For this calculation, the knowledge of all historical accesses to considered object would be necessary. The rate object stores the value of previous $rateAgeAverage$ and $rateDuration$, thus a modified expression where the $rateAgeAverage$ value is expresses based on the previous age average value and the new access information:

$$rateAgeAverage :=$$

$$\frac{rateAgeAverage \times rateDuration + accessDuration \times accessAge}{rateDuration + accessDuration}.$$

[1] Several authors found the time spent reading a page as one of the most important implicit indicator of interest [8]. In our method a limit for minimal and maximal access duration is defined. If the access lasts longer than maximal limit we take the maximal limit value. If the duration is shorter than minimum we do not use this access to update the rate. Similarly, long accesses can be also discarded, as these can result in interrupting the navigation.

3. *Compute age index value corresponding to the rate age average.*

   In order to cope effectively with frequent information content changes it is necessary to bind navigational information (ratings) not only to the target information fragments but also to their properties. Provided that the target information fragment is no longer up-to-date there is still the possibility of using gained rates. Like information fragments, rates can also get out of date. This fact is taken into consideration when computing the rate value by reflecting the age in *ageIndex* and using this to calculate the rate value.

   In our experimental study we used a function expressing slow ageing progress that accelerates after a certain time – thus the influence of the rate for navigation decreases significantly – but never disappears completely:

$$ageIndex = \frac{\frac{\pi}{2} - \arctan(rateAgeAverage - p)}{\pi}$$

   where parameter p signifies the number of days after which the rate started to loose its weight rapidly.

   In our case domain a job offer looses its relevance usually around 30 days after the exposition, thus p is adjusted to 30. Behavior of aging function for $p = 30$ is shown in Figure 5. However, the ageing function should be adjusted to characteristics of the modeled information space and its ageing process.

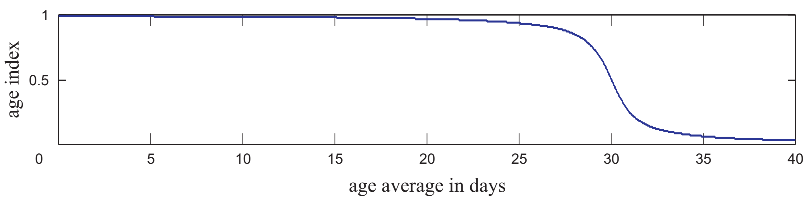

Fig. 5. Ageing function graph

   As the evaluation of this function after every access would be time consuming, we execute this operation in spare time after the session.

4. *Update information about the access.*

   Increase the number of rate accesses, user or group accesses to this object and accesses duration, and set last modification date to today:

   rateAccesses := rateAccesses + 1
   rateDuration := rateDuration + accessDuration
   rateLastModified := Today
   allAccesses := allAccesses + 1

   where by *allAccesses* we understand *groupAccesses* or *userAccesses* according to the rater value.

5. *Calculate rate value according to ageIndex*:

$$rateValue = \frac{ageIndex * \times rateAccesses}{allAccesses}$$

where the $RateValue$ range is interval $< 0, 1 >$.

6 USING NAVIGATIONAL INFORMATION

The crucial part of personalized navigation lies in a visualization of the navigational information to guide a user to his desired information fragments. Properties and relations that describe the target navigational class in the domain model are used to visualize navigation. Properties represent dimensions and their values represent the range of particular dimension visualized on the space map.

Classes describing the navigation target provide hierarchical structure (by their definition). They may have subclasses and may be described by other properties. The proposed method was tested in labor supply domain, where the navigation target is job offer and is described by its properties such as locality, offered position and type of job. A part of this domain ontology is shown in Figure 6.

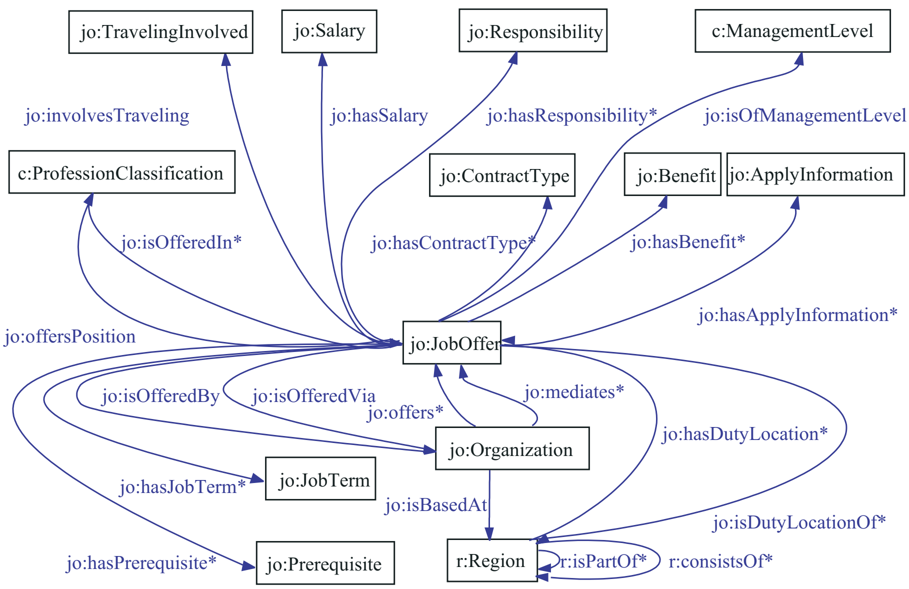

Fig. 6. Part of the used domain ontology

We consider a property line leading from the target class as the dimension extension. Thus sets depicted on the space map are not created directly from the target class property values; the range of the first property in the dimension extension is taken and sets are created from the property values. This step is repeated to navigate through the space map.

The map of the information space personalized for a particular user contains the following navigational information:

- *chosen dimensions*: list containing selected outlines of properties;
- *other dimensions*: hierarchical list of properties that can be chosen as a dimension or can extend selected dimension;
- *dimensions rates*: the $rateValue$ of the rate of every as yet unchosen dimension for current user and his group; graphical expression of these values (by color intensity) represents user's "footprints"and the "footprints" of his group;
- *information space map*: a map containing sets, their labels, rates and links to target information fragments;
- *multidimensional view*: the information space is structured into sets and subsets according to several dimensions. Every dimension corresponds to a set level. The information space is divided into sets according to the last selected dimension on the first level; these sets contain subsets according to second last selected dimension and so on;
- *mutual set position*: location of sets on the map expresses their mutual relation;
- *set size*: it reflects the number of items in the set (number of target information fragments) in comparison with other sets;
- *set label*: keywords to mach the set that show the common property values for all items in this set, thus the user can see from the first sight what s/he can find in a particular part of the information space at first glance;
- *set rates*: likewise by dimensions we display $rateValue$ of the rate of every set for the user and his group. Their graphical expression by color intensity represents the user's "footprints" (visualized by the outline color) and "footprints" of his/her group (visualized by the fill color).

Every set contains a link to reach target information fragments for which dimension values fulfil set characteristics. The target information fragments themselves are not displayed in the information space map, but a user can access them by following the link in the set. They are shown in a list enriched by user and group "footprints" with annotation similar to the dimension rate annotation.

Navigation through the information space is realized by several navigational components. Still, the user and group "footprints" from previous searching in the information space are the crucial elements of personalized navigation. The user's own traffic fulfils the task of directing the user by comparison with group traffic as the user sees the difference in exploration of particular information subspace between him/herself and his/her group.

We developed a software tool PENA (PErsonalized NAvigation) that supports navigation in the labor supply domain using the proposed method. Example from the GUI of PENA is shown in Figure 7. We used a domain ontology and user ontology developed within the scope of the project on acquisition, organization, maintenance and presentation of information on the Web [18, 2]. The information space of job offers is characterized by frequent information content changes and relatively short topicality of an information fragment – a job offer. Such an information space is challenging in the variability of its content. We therefore chose this to verify the proposed method.

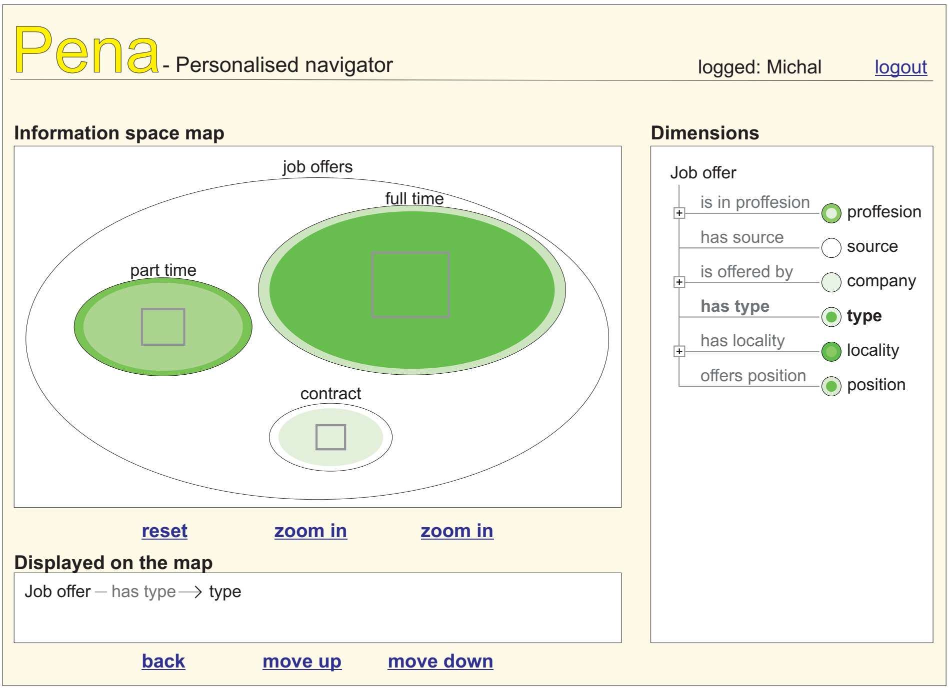

Fig. 7. PENA screen providing personalized navigation

The users in the labor supply information space are characterized by their desired job offers and they are coupled into groups according to the characteristics of the jobs they navigate (at the outset all user can constitute one group or the system can use explicitly given preferences by the users). The information space map displays the information space divided into job sets – every set represents all job offers that fulfill the set values in selected dimensions.

A user can adapt the information space map to his/her individual needs by selecting dimensions s/he considers as most relevant for him/her; s/he can explore different parts of the information space by selecting a particular set (or its outside) – s/he can change the map scale. S/he is guided by his/her own “footprints” represented by the intensity of the border color and by the “footprints” of his/her group (intensity of filling color).

The system provides navigation using object properties only; it does not deal with continuous property values. Another restriction is on the number of describing classes in certain level, e.g., 50 job offer types would not be readably displayed on the navigation space map in one time.

PENA was experimentally tested with two ontologies (represented by OWL-DL) describing job offer domain on different complexity levels. The more complex ontology [18] (see also Figure 6) itself is subdivided into several ontologies, which represent geographical and political regions, languages and currencies that are used in these regions, different hierarchical classifications (e.g., industrial sectors, professions, educational levels, qualifications) and generic offers, respectively. The ontology is fairly large and complex (a total of about 740 classes of which 670 belong to hierarchical classifications with a maximum depth of 6 levels). It contains several hundreds of job offer instances. To make the navigation fast within the information space of this size we process in real time the recording of user accesses; the inference is done in spare time or after the session.

7 CONCLUSIONS

In this paper we have presented a method for personalized navigation in open information spaces. The method is based on the use of social navigation and employing the semantics of the application domain represented by an ontology.

Comparing the method to existing approaches (navigating mostly in closed space) can withstand frequent information content changes and preserves gained navigational information despite these changes. We use "collective knowledge" to direct a user to a job offer set showing him/her, which set his/her group has considered "interesting" in comparison with his/her own preferences. The use of ontologies enabled us to split the information fragments and their characteristics and bind the acquired navigational information to both. Thus we preserve the navigational information even when the source information fragment is no longer available or current. It is still valid for fragment characteristics and we can use it to direct the user to information fragments with similar characteristics.

One of the most important parts of navigation is the visualization of navigational results. We use the ontology potential to structure the information space into subspaces (sets) to make the navigation more effective. This structure is visualized for the user on the information space map enriched by annotations with labels and colors. We experimented with the design method by creating a navigation support tool PENA based on this method and operating in labor supply domain.

There are still several open issues. Our further work focuses on more advanced uses of the ontology representation and its inference potential. We plan to include ontology constraints on navigation through various dimensions. There remains the problem of causing the user confusion when one dimension range contains too many values. We investigate the possibilities to avoid this confusion by additional space segmentation. Another important area related to effective usage of the proposed method is automated creation of user groups. We plan to use the results of analysis of monitoring user movement through the information space [3]. In this way it is possible to change a group for the user when his/her interests change.

Acknowledgement

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