Information Organization on the Internet based on Heterogeneous Social Networks

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ABSTRACT

The social Web has become an important trend during the last few years with a thriving number of social networking sites that currently address a variety of information needs. Following a first generation of human-centered social networks, the notion of object-centered sociality has been introduced to describe the fact that strong social relationships are built mainly when individuals are grouped together around a shared object. In this paper we attempt to further enhance the notion of the social object and present the concept of heterogeneous social network, where humans and social objects are uniformly treated as equal actors. The paper discusses how this notion can be exploited in different application domains and presents in more detail a particular example from the field of medical education.

Categories and Subject Descriptors

K.0 [**Computing Milieux – General**]. K.3.1 [**Computer Uses in Education**]. J.3.1 [**Life and Medical Sciences**]: Medical Information Systems

General Terms

Design, Experimentation, Theory.

Keywords

Social networking, Semantic technologies, Object-centered sociality, Linked Open Data, Actor network theory.

1. INTRODUCTION

The social Web, or Web 2.0 [1], has become an important trend during the last few years. Among the prominent social web tools, social networking websites focus on creating online communities of individuals who publish their content and activities while exploring others' content and activities, thus creating virtual on-line social groups and associations. This communication paradigm has been taken up by the community of researchers and academics and nowadays there is a thriving number of social networks dedicated to science and professional relations.

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At the same time, Semantic Web technologies [2] are specifically designed to address the challenge of data and knowledge management in a world with highly distributed resources. The semantic Web promises an infrastructure that comprises machine understandable content and, therefore, a worldwide Web made of semantically linked data instead of a mere collection of HTML documents.

In this work, these two paradigms of the social Web and the semantic Web are merged for modeling and implementation of heterogeneous social networks of human and nonhuman entities alike that aim to provide alternative ways for rich information organization in different application domains.

More specifically, we propose the use of the actor-network conceptual model [3] to derive working models and subsequently implementations for meaningful and relevant information organization in situations where humans, artifacts (real of digital), organizations and/or concepts interact. Such situations are quite common, and three indicative application areas that we are currently studying include the following: (a) educational content sharing; (b) personalized patient empowerment services; and (c) scientific knowledge management. In all these application domains, the principal idea is to view information organization and management as a heterogeneous social network of humans and various objects, all equal actors as perceived in the actor-network theory. The non-human entities involved are different for each application domain. The basic conceptual principles and the technological approaches for building such networks are presented, and a specific proof-of-concept example is also given.

2. BACKGROUND

As discussed extensively in the literature (see [4] for a thorough overview), in the broader sense 'social' means 'association', as the word derives from the Latin 'socius' meaning a companion or associate. When used in this way, the concept is left open to include anything that can be associated together. However, in the first days of deploying social internet applications, the term 'social' has been used in a way more akin to conventional social theory (e.g. [5],[6],[7]). In this narrower sense, the term is used to refer primarily to human aggregates among themselves. This view is in general indifferent to active nonhuman entities. Things, and for this matter information objects as well, are depicted as tokens and symbols, and they do not have the capacity to act in other ways.

A conventional social network approach concentrates on the network of humans, presumably based on some common social or professional interest – any implied artefacts or concepts are of no interest and are not represented or accounted for in the network

(Figure 1). Here the focus is to establish relationships and connections among humans. These are based on some commonly shared interest, object and/or concept; however this is only implied and not really accounted for in the network. Such an example from the domain of education is the Classroom2.0 social site (http://www.classroom20.com/) which creates a lively forum for discussions on web 2.0 tools and applications in education. Another example (of the many) in the field of healthcare is the CarePages (http://www.carepages.com/) a social network of people collaborating together to share the challenges, hopes and victories of anyone facing a life-altering health event. Finally, LinkedIn (http://www.linkedin.com/), one of the first professional networks connecting people together based on their job profile, is an example of a simple human-only network for scientists (as well as other professionals).

site can be a source of social connectivity, catalysing social networking in virtual spaces. This new approach to sociality has drawn attention, and current state-of-the-art research in the area involves various ways to exploit object-oriented sociality to the benefit of the community. An indicative example from the field of education is Edmodo (http://www.edmodo.com/) a social network for teachers and students who can interact in private virtual classrooms to share educational content and activities. In the healthcare domain, the PatientsLikeMe site (http://www.patientslikeme.com/) connects people based on their health issues and related shared experiences. Finally, an example from the scientific domain is the BioMedExperts (http://www.biomedexperts.com/), where connections between scientists are established based on common authorship of scientific publications.

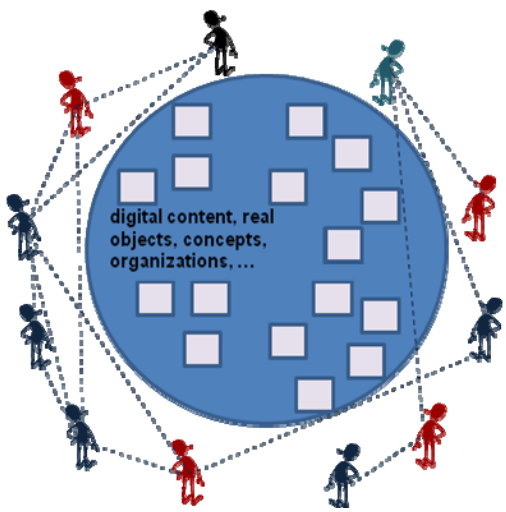

Figure 1. A conventional human-only social network, focusing on human interactions and in essence ignoring objects, concepts, artefacts, etc.

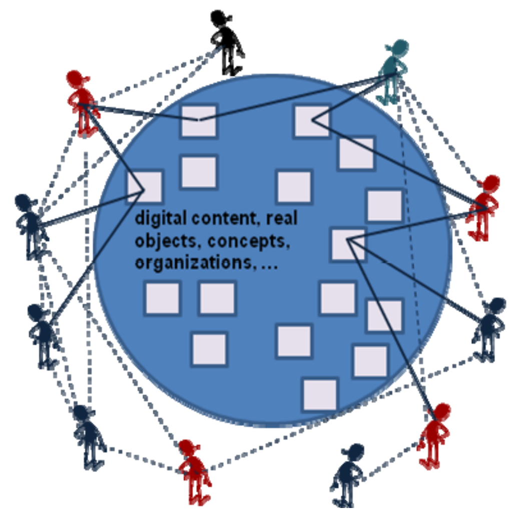

Figure 2. An object-centered network, where the focus is again on the human connections, however as they are formed based on commonly shared objects.

Social networking in this sense is good at realizing and representing links between people, but it doesn't explain what connects those particular people together and what connects those and not others [8]. One way to provide meaning to social networks is to establish relationships and promote self-organization into communities based on shared interests, and even more on specific items of interests. Recently the term 'object-centered sociality' was introduced [9] to describe the fact that strong social relationships are built mainly when individuals are grouped together around a shared object that mediates the ties between them. This can be achieved by organizing the network around the content people create together, comment on, link to, annotate similarly etc. [10]. Digital social objects are at the same time interaction triggers, context providers and communication anchors. Object-centered sociality constitutes today a specific and widespread kind of communication coexisting with others like micro-blogging, mail, forums, etc. An object-centered social network is a social structure formed by people interacting synchronously or asynchronously on a single common social object. In this case emphasis is placed on the connections between the humans and the objects and social interactions is basically established on the basis of commonly shared objects (Figure 2). Therefore, we can assume that each content item on a Web 2.0

In both cases, the focus is not on trying to establish connections based on performative aspects of radically heterogeneous networks, but rather to create associations based on human action, agency and perception. In our work, we attempt to further enhance the notion of the non-human digital object in an on-line social network by relying on the view and concepts of the actor-network theory (ANT). Actor-Network Theory is a sociological theory developed in the 1980's by Bruno Latour, Michel Callon and John Law (for a thorough introduction see [3]). The basis of actor-network theory is the concept of the heterogeneous network, that is, a network containing many dissimilar elements, including both social and technical parts. Moreover, the social and technical are treated as inseparable. This is the so-called principle of generalized symmetry, whereby human and non-human (e.g. artifacts, organization structures) should be integrated into the same conceptual framework and assigned equal amounts of agency. Actor-network theory claims that any actor, whether person, object (including computer software, hardware, and technical standards), or organization, is equally important to a social network. All participating entities can exert agency, i.e. they can have an effect via their interconnections. The outcome is being built unpredictably and collectively only via the interconnections.

3. HETEROGENEOUS SOCIAL NETWORKS

In this paper we present our view for truly heterogeneous social networks where humans and nonhuman entities of various types are integrated into the same conceptual framework and assigned equal amounts of agency. In this way, one gains a detailed description of the concrete mechanisms at work that hold the network together, while allowing an impartial treatment of the all acting entities. Based on the perspective of Actor-Network theory, we followed a 'symmetrical analysis', where the material and non-human elements of a network are not treated as mere social objects but they are rather treated analytically in the same way as the human elements. The focus is on linking and associations among all social entities, human and non-human alike, all represented as actors. This is graphically shown in Figure 3, where the social associations are among humans and among humans and non-human entities, but also among non-human entities themselves.

In implementing such a network, major challenges include a unified treatment and representation of all types of possible actors as well as the development of a social behavior for various nonhuman actors, and subsequently their own associations and networks. Both challenges can be addressed by concepts and technologies of the Semantic Web.

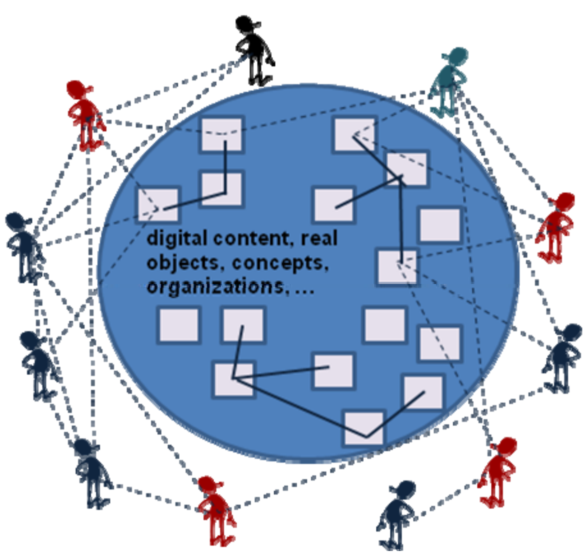

Figure 3. A heterogeneous social network where human and nonhuman entities are treated symmetrically as actors.

In the conventional Web, a resource can be described via an XHTML/XML document, where various tags are used to annotate the document, mainly regarding its presentation, not conveying any semantics about the resource itself. In order to describe a resource the W3C Resource Description Framework (RDF) [11] is commonly used to represent metadata about a resource in the form of triples: subject, predicate, object. Generally, the subject can be the resource itself while the predicate can be any relationship as defined in any XML namespace published on the Web. The object can be an explicit value but also a dereferencable URI. This way, an RDF triple can link the description of a resource with other sources of information on the Web, thus creating a worldwide graph-like linking of resources, what is currently termed Linked Open Data (LOD) cloud [12], [13], a community project of the World Wide Web Consortium's Semantic Web Education and Outreach Group (W3C SWEO).

The building blocks of the Semantic Web are considered to be ontologies, i.e. formal descriptions of parts of the world [14] that guide the specification and generation of the triple generation. There are numerous ontologies that are specific to domain, resource type and objective (also known as application ontologies), but there are only a few general ones (known in information science as upper or foundation ontologies) that are used frequently to build the former. For example FOAF [15] (Friend Of A Friend) is used to describe actors and their real world information, activities and relations, SIOC [16] (Semantically Interlinked Online Communities) to describe online communities and the interactions in them, SKOS [17] to describe terms of controlled vocabularies, OPO [18] (Online Presence project Ontology) to provide portability and visibility of an actor's profile between different social platforms etc.

3.1 Unified Description of Actors

One of the basic requirements is a unified and rich description of all actors to form as a basis for their social presence and their interactions within the social environment. This description includes two main aspects. The first aspect is a domain specific description of the profile for both humans and nonhuman entities. Such a social profile can be described with a variety of domain specific schemata or even ontologies.

For example, the profile of humans can be based on the FOAF (Friend Of A Friend) [15] ontology, mainly used to describe people, the links between them and the things they create and do. Actually, the first core class in FOAF is the 'agent' referring 'to things that do stuff' including persons, groups, software or physical artifacts. However, most often the sub-class 'person' is used to describe humans. Based on this basic description, one can also add more domain specific fields to provide the means for a rich description of a person. For example, in the case of education, one could also include fields such as "courses that I am teaching", "teaching interests/subjects" or "learning interests/subjects" [19].

Regarding the profile of a non-human actor, again a number of domain specific vocabularies and ontologies can be employed. For example, an educational content item can be described using the IEEE LOM (Learning Object Metadata) XML scheme seems the most prominent standard for describing learning objects [20]. Other, more elaborate and educational oriented schemata can also be used, for example the mEducator metadata scheme [21] developed to focus on medical education and stress educational aspects such as educational objectives, expected learning outcomes, etc. In the healthcare domain there is a plentitude of formal controlled vocabularies and ontologies, for example see the BioPortal [22] for an indicative list. Finally, in the scientific knowledge management field, there is also a thriving number of related ontologies, ranging from the comprehensive CERIF data model (the Common European Research Information Format) [23],[24], a formal model to setup Research Information Systems and to enable their interoperation, to the recently proposed VIVO ontology [25] which aims to integrate researcher information from disparate, largely authoritative, sources into a common format establishing interrelationships and to make it publically available.

On the other hand, one needs to describe information about the interactions between the various actors. Recently a new ontology based model has emerged targeting specifically the social networks that are object centered. OCSO [26] (Object Centered Sociality Ontology) is an ontology that describes the interactions between actors using FOAF (Friend Of A Friend), SIOC [16] (Semantically Interlinked Online Communities) and OPO [18] (Online Presence Project) properties. These actors are defined following the FOAF 'agent' core class, thus encompassing all types of entities.

3.2 Building the Social Profile of Actors

The second challenge in such a heterogeneous network where humans and non-human actors are equally treated is to provide the means for the non-human entities to somehow build their social profile and connections in an autonomous, independent and proactive way.

In general, the social aspect of non-human actors can be created in a variety of ways, including (a) the obvious connections via common tags that are used in their profile description; (b) connections based on collective usage and other related interaction of human users, i.e. what human users do with the nonhuman entities; (c) social connections based on some type of inheritance, i.e. non-human entities that are generated or are the product of other resources, in the sense of the genealogy tree; and (d) semantic connections and similarities that can be built based on the wealth of information available in the linked data cloud. These different ways of enriching the social profile of a non-human entity can be clarified with the following proof-of-concept example from the field of education.

4. AN EXAMPLE FROM THE DOMAIN OF EDUCATION

Continuous advances in medicine and life sciences lead to an ever expanding core knowledge relevant to the medical practice. Thus, medical academic institutions are increasingly required to invest in order to enrich their curricula by developing overspecialized courses and corresponding educational content. Educational content in medicine includes a broad range of learning object types that address both the theoretical as well as the clinical aspects of medical education. Its unique nature lies along with the fact that it is produced by both academics and clinical teachers, in a variety of places like hospital wards, healthcare practice units, laboratories, classrooms/lecture theaters, and recently the collaborative web and virtual reality spaces. In contemporary education, educational resources can be of a variety of different types. Considering the state-of-the-art nature, the complexity and, consecutively, the cost of state-of-the-art educational content, it is imperative that such content can be repurposed, enriched, and embedded effectively into respective curricula and continuing education, as well as public dissemination and awareness. This need for sharing, re-using and repurposing educational resources actually makes them a natural candidate for social objects in professional educational social networks.

This is addressed in the MetaMorphosis+ [19] semantic social network which aims to provide an environment for resource publishing, sharing and repurposing in medical education. The MetaMorphosis+ semantic social network is a heterogeneous network of persons (including authors, potential authors and final users of learning objects, e.g. students, teachers, educational managers, etc) and educational resources of any type. Educational resources in MetaMorphosis+ can be resources residing in a Learning Management System (LMS), in another educational repository, or merely available on the Web.

4.1 Building a Social Profile for Educational Resources

The most straightforward social dimension of an educational resource as a social object in a network can be realized in the conventional way of connections among profile tags. This requires a standardized metadata set to describe concisely an educational resource and thus create its social profile. Standardizing metadata for describing digital educational resources constitutes one of the main research topics in the e-learning community.

Educational resources in MetaMorphosis+ are primarily described by the mEducator RDF metadata scheme for describing medical educational resources [21],[27]. This includes a number of fields addressing different aspects of the educational resource: (a) general fields: resource title, unique identifier, URL, URN, intellectual property rights clearance/license, quality stamp (if any); (b) fields related to a general resource description: resource authors, creation date, citation (i.e. how the resource should be formally cited), keywords, content description, technical description (including any technical requirements to access and use the resource); (c) fields related to the educational aspect of the resource: educational context (for which the resource is intended), teaching/using instructions, educational objectives, expected learning outcomes, suggested assessment methods, educational prerequisites; (d) fields related to classification/taxonomy information: resource language, type, discipline, discipline subspecialty, educational level; and (e) fields addressing repurposing: resource parents, repurposing context, repurposing description. These user generated description metadata, when treated as social tags, create a complex and dynamic organization of educational resources in a similar fashion as in any conventional social network, thus realizing the resources' social network.

4.2 Resource Sociality based on Collective Usage Interaction

As it has been established, the basic function of a social network is to provide the environment for users to interact with each other promoting the communicator role. When social objects are introduced in these networks the interactions extend to include these objects which in this scenario are educational resources. These are accessed, used, shared, repurposed, and also rated, commented upon, and can be organized in a number of user specified ways in collections.

Capturing and sharing information about the attention that users spend on resources in specific contexts can provide a different aspect of sociality based on the personal views and mental models of the users. This way one can build the profile of a resource as it appears to the external user, as opposed to the profile of the resource according to the view of its creator, as depicted in the description metadata. The perspective and attention is normally captured via recording contextual attention metadata [28]. This includes data about the users' attention and activities that relate both to semantically rich actions on and interactions with educational content items as well as data on indirect interactions amongst content items. Additionally, basic interaction metadata can also be considered which includes all other basic user-system interactions that provide some kind of basic attention information (not necessarily semantically and contextually rich).

Apart from creating a better user experience in an individual environment, the motivation is that these interactions can give more information about the user's habits, likes, dislikes and interests that can be applied everywhere following the model of the Semantic Web. In order for these attention metadata to be able to be shared or aggregated in a meaningful way researchers have produced formats and uniform ways to represent them. For example the Attention Profiling Mark-up Language (APML) [29] has introduced a portable file format that describes user's interests and interactions in ranking order.

4.3 Resource Family Trees based on Repurposing History and Inheritance

The term 'repurposing' refers to changing a learning resource initially created and used for a specific educational purpose in a specific educational context in order to fit a different new educational purpose in the same or different educational context. Although not formally addressed as such, educational content repurposing is what any educator is routinely engaged in when preparing a new educational experience, including preparing the educational content itself. Customarily, when an educator sets the context and goals of a new educational experience, he/she will overview existing content and/or search for new relative content and then repurpose and re-organize content to fit the purpose of the new educational experience.

There can be a variety of situations where repurposing educational content is desired. These situations, referred to as "repurposing contexts", can be of a pedagogical nature, a technical nature or both, and include the following [30],[31]: re-purposing (1) in terms of the actual content; (2) to different languages; (3) to different cultures; (4) for different pedagogical approaches; (5) for different educational levels; (6) for different disciplines or professions; (7) to different content types; (8) for different content delivery media and/or technology; (9) to educational content from an initial content type that is not intended for education; and (10) for people with special needs.

In MetaMorphosis+ repurposing is addressed as a means to provide a different kind of sociality for the educational resources. Thus repurposing history and inheritance are used as basic social relationship among educational resources in order to cluster resources into families. Each repurposed resource declares its parent(s) resource(s). Following iteratively the 'parents' in a chain of repurposing ancestors, the entire 'family' tree of the particular resource can be compiled. A force-directed graph is used to depict the specific resource's family and inheritance patterns. Each node in the graph represents a resource, while the directed edges represent repurposing relationship, with the arrows pointing from the "source" objects to their "repurposed" descendants. The nodes also state the 'repurposing context', while they are active links to the resource profile where more information on the repurposing description can be obtained. For the entire resource collection, a circular directed graph representation is used which depicts all the resources with the various individual inheritance trees, usually not interconnected amongst them. A resource inheritance tree is a group of resources that have a relationship based on repurposing – this can also be viewed as resource 'family'.

4.4 Semantic Links between Resources by Harvesting the Linked Data Cloud

Finally, the social dimension of educational resources can be further expanded and enriched by harvesting semantically rich information available in the Linked Data cloud. The Linked Open Data (LOD) approach is simply about "using the Web to create typed links between data from different sources. These may be as diverse as databases maintained by two organisations in different geographical locations, or simply heterogeneous systems within one organisation that, historically, have not easily interoperated at the data level [12]. The goal of the Linking Open Data project is to extend the Web with a data commons by publishing various open data sets on the Web, and making links between data items from different data sources. Since its inception in June 2007, the size of the cloud has rapidly exploded and already includes a large variety of open data sets including several research and medical data sets. This wealth of information can be used to automatically enrich educational resources metadata with references to external vocabularies, and in particular domain specific vocabularies, thus creating a rich domain specific profile and extending the resource's social connections to other web objects.

The architectural framework for semantic data and service linking and federating of disparate educational resource pools that powers the social environment is described in detail elsewhere [32]. At the lower level of this semantic technology framework, a Web data and service layer employs distributed Web services that harvest educational resource metadata from heterogeneous data sources on the Web. In the upper layer, semantic data and service integration is achieved based on the Linked Services approach and on semantic technologies such as iServe [33] and SmartLink [34]. An RDF repository exposes harvested educational resource metadata as triples (http://ckan.net/package/meducator). Metadata as harvested by Web sources can also be enriched with existing LOD vocabularies).

This is of particular importance to extend rather unstructured metadata, such as keywords or free text subject and discipline descriptions with structured data based on well-known vocabularies. This is achieved by exploiting a variety of medical domain ontologies and the expanding LOD cloud to semantically annotate the existing RDF description of a resource and then expose its metadata back to the LOD cloud for further exploitation by third parties which make use of the web of LOD. Biomedical ontologies provide essential domain knowledge to drive data integration, information retrieval, data annotation, natural-language processing and decision support. BioPortal (http:// bioportal.bioontology.org) is an open repository of biomedical ontologies that provides access via Web services and Web browsers to ontologies developed in various formats including OWL, RDF, OBO format and Protégé frames [35].

In MetaMorphosis+ we have utilized the NCBO BioPortal's RESTful Web services programming interface to access and incorporated terms and concepts from the more than 260 ontologies provided to this day, corresponding to more than 4.5 million medical and life sciences terms. This way the MetaMorphosis+ user can annotate an educational resource with suggested standardized terms and concepts from a variety of ontologies, enriching the RDF output with dereferencable standardized terms as values for the various fields, e.g. keywords, discipline, specialty, etc. The ontologies used include, amongst others, prominent medical ontologies such as SNOMED-CT (Systematized Nomenclature of Medicine – Clinical Terms), ICD9/10 (International Statistical Classification Diseases and Related Health Problems), Body System (body system terms used in ICD11), MeSH (Medical Subject Headings), NCI (Meta)Thesaurus, Galen (the high level ontology for the medical domain), HL7 (the Normative RIM model v2), Biomedical Resource Ontology (BRO, a controlled terminology of resources to improve sensitivity and specificity of Web searches).

As an example, suppose a user intends to describe an educational resource by using the term/concept Telemedicine, in the list of 'Keywords' or in the 'Discipline' and 'Specialty' fields of the metadata description of the educational resource. Semantic annotation in MetaMorphosis can suggest a number of related standardized terms from the available ontologies.

5. DISCUSSION

The specific implementation of MetaMorphosis+ presented in the previous section is only an example of the various different ways one can combine object sociality and semantic annotation and linking to create powerful heterogeneous networks of humans and non-human entities.

5.1 Towards Patient Empowerment Services

Another interesting domain is that of the healthcare services environment. The first decades of applications of information technology in medicine had targeted the health care enterprise and services provided therein. Thus a major technological challenge has been the integration (control, data, presentation, and semantic integration) of various information systems and services to support the healthcare enterprise with emphasis on the tertiary level (e.g. hospitals). Towards this goal, a number of standards and standard communication protocols have been developed and implemented, with variable, albeit considerable, success [36].

Recently, patient empowerment has emerged as a new paradigm that can help improve medical outcomes while lowering costs of treatment by facilitating self-directed behavior change. The concept seems particularly promising in the management of chronic diseases [37],[38] and it is directly connected with personalized patient services and preventive measures. A recent review [39] shows that patient empowerment services mainly aim at educational programs patient reinforcement, with goals usually predefined by the health-care professional, thus in practice contradicting the very notion of empowerment [40].

At these early days of the citizen-centered paradigm, most of patient empowerment services and systems are offered as autonomous modules not directly integrated with each other or with healthcare enterprise information systems. Thus the challenge is to work towards integration efforts of patient centered services and especially semantic integration, which requires a basic agreement for the understanding and description of the respective environment. And, although a lot of work has been conducted towards a common understanding of the healthcare enterprise, even in the special case of the provision of home care, e.g. [41], an analysis and definition of the personal environment of the healthy citizen and the patient is still missing.

Following the line of thought presented in this paper, the health environment for the patient and/or the healthy citizen comprises of various coexisting and strongly interlinked entities: (a) individuals, including patients, healthy citizens and healthcare professionals; (b) organizations, including any institutional or organizational entity involved in any way in the healthcare process, e.g. healthcare providers, social services, health insurances, medical research institutions, research projects, pharmaceutical companies, well-being and fitness clubs, etc; (c) health conditions, i.e. any health or medical condition; and (d) health interventions, including diet, life-style, dialysis or other therapy, drugs, supporting devices, etc. All these can be viewed as actors within a heterogeneous social structure.

The co-existence of multiple networks of individuals, organizations and health conditions/interventions is exploited in order to create different views of the healthcare environment, thus creating variable impact. For example, an individual-centered linking visualization enhances integrated personal management of healthcare, collaboration and expert finding services. On the other hand, an organization-based linking visualization supports administrative, strategy and financial oriented goals, at an institutional, national and international level. Finally, resource oriented linking visualization/organization may serve a variety of goals. For example, visualization based on health conditions and interventions places focus on epidemiology and generation of new evidence on a large scale.

5.2 Towards Scientific Knowledge Management

Another area of application could be the management of scientific knowledge. In more details, conducting research implies the following steps: (1) after a research idea/proposal is generated, (2) in general, an enabling infrastructure may be used, (3) to carry out repeated and reproducible observations or to collect relevant data in authentic contexts, (4) that produce raw data, (5) which may then be processed and possibly transformed using appropriate processing tools (6) into research outcomes; (7) the entire process is briefly described against existing evidence (i.e. published works), and (8) this is subject to peer review and (9) finally published; (10) at a different level, such peer-reviewed work is then incorporated into scholar works and books, and in the formal (and public) educational process, while it may be linked with patents, and/or be commercially exploited.

This research process is usually supported by funding agencies and is carried out in various organizational research settings. Moreover, research is an open, collaborative process, based on communication and often collaboration at an international level. Many research projects are now collaborative endeavors spanning a number of research groups and organizations, even across nations. Well-known examples include the human genome and climate change, but there are many others, especially where expensive infrastructure is utilized such as particle physics or space science. Furthermore, knowledge of the research activity in one group or organization may influence the strategy towards research – including priorities and resources provided –in another group or organization.

Research information is used by researchers (to find partners, to track competitors, to form collaborations); research managers (to assess performance and research outputs and to find reviewers for research proposals); research strategists (to decide on priorities and resourcing compared with other countries); publication editors (to find reviewers and potential authors); intermediaries/brokers (to find research products and ideas that can be carried forward with knowledge/technology transfer to wealth creation); educators and learners (to take up state-of-the-art information and produce learning experiences and thus knowledge); the media (to communicate the results of R&D in a socio-economic context) and the general public (for interest). Thus, there is a need to share research information across organizations and countries, and between different funding agencies, and manage research information in a unified way. This becomes even more pressing if one considers the growing need/trend for multidisciplinary research. Such research process is typically more complex and 'painful' than research in a well defined discipline, while it usually plays a catalytic role in major science and technology breakthroughs.

Following the line of thought presented in this paper, the concept of a virtual scientific community can be explored by a heterogeneous social network where researchers (and non-researchers), research institutions (including research facilities and other stakeholders such as libraries and publishers), and research resources (ranging from raw data to published results to processing tools and beyond) are all participating as distinctive social entities. These diverse actors (humans, resources, organizations) are interlinked in a graph-like approach based on their relationships, which can be built by semantically linking data via a semantic data federation/linking layer. In this way, non-human entities may acquire a degree of 'personality' and 'intelligence' and turn into more realistic 'social entities'.

5.3 Epilogue

Following the approach of a heterogeneous network to organize information objects and humans alike and record their variable interactions one can further exploit notions and concepts of the actor-network theory to analyze the social structures and thus eventually gain more insights on the organization and communication of information.

Following the ANT perspective, actors in such an organization enter into networked associations, which in turn define them, name them, and provide them with substance, action, intention, and subjectivity. In other words, actors are considered foundationally indeterminate, with no a priori substance or essence, and it is via the networks in which they associate that they derive their nature. ANT is interested in the ways in which networks overcome resistance and strengthen internally, gaining coherence and consistence; how they organize and convert network elements; how they prevent actors from following their own inclinations; how they grant qualities and motivations to actors; how they become increasingly transportable and "useful"; and how they become functionally indispensable.

As such an ANT perspective into constructing and studying a heterogeneous semantic social network may give alternative insights for information organization and management on the web in a variety of different application domains.

6. ACKNOWLEDGMENTS

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