Genericity versus expressivity - an exercise in semantic interoperable research information systems for Web Science

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2013

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ABSTRACT
The web does not only enable new forms of science, it also creates new possibilities to study science and new digital scholarship. This paper brings together multiple perspectives: from individual researchers seeking the best options to display their activities and market their skills on the academic job market; to academic institutions, national funding agencies, and countries needing to monitor the science system and account for public money spending. We also address the research interests aimed at better understanding the self-organising and complex nature of the science system through researcher tracing, the identification of the emergence of new fields, and knowledge discovery using large-data mining and non-linear dynamics. In particular this paper draws attention to the need for standardisation and data interoperability in the area of research information as an indispensable precondition for any science modelling. We discuss which levels of complexity are needed to provide a globally, interoperable, and expressive data infrastructure for research information. With possible dynamic science model applications in mind, we introduce the need for a "middle-range" level of complexity for data representation and propose a conceptual model for research data based on a core international ontology with national and local extensions.

Author Keywords
Ontology; VIVO; NARCIS; CERIF; CRIS; Linked Data

ACM Classification Keywords
I.2.4 Knowledge Representation Formalisms and Methods

WebSci'12, May 2–4, 2013, Paris, France.

INTRODUCTION

The science of the 21^{st} century, to a large extent is team science [10], operating globally, often cross disciplinary, and fully entangled with the web. The study of science as a specific, complex, and social system has been addressed by many research disciplines for quite some time. The availability of digital traces of scholarly activities at unknown scale and variety, together with the urgent need to monitor and control this growing system, is at heart of knowledge economies and has brought the question how best to measure, model, and forecast science back on to the research agenda [32].

When reviewing the current models of science, it is clear there is no consistent framework of science models yet [7]. Existing models are often driven by the available data. For example, interdisciplinary bibliographic databases (such as the Web of Science or SCOPUS) use the principle of citation indexing [17] from the field of *scientometrics* to analyse the science system based on formal scholarly communication. Typical output indicators are counts of publications, citations, and patents. They form the heart of the current "measurement of science" and have been taken up as data by network science [5] and Web Science [23].

This specific kind of output is, however, only a tiny fraction of information on science dynamics. Traditionally, the measurement of science encompasses input indicators (human capital, expenditure), output indicators, and. where possible, process information [18]. Research Information Systems, around since WWII in Europe, are marking the shift to "big science" [29]. However, the input side to science dynamics, in particular researchers, has been underrepresented in quantitative science studies for quite some time. This is partly due to the lack of databases and the problem of author ambiguity in the existing database [33, 30]. Information on researchers has been mainly collected, documented, and curated locally at individual scientific institutions - and in nation-wide research information systems, at least in European countries.

The emergence of the web has transformed this situation completely. The web has become an important, if not the most important, information source for researchers and a platform for collaboration [6]. The extent and diversity of the traces scholars leave on the web has called for *alt metrics* [39]. It has also triggered the development of standards and ontologies capable of automatically harvesting this wealth of information, beyond existing traditional bibliographic reference.

The wealth of information provided on the web about researcher activities and their relations carries the potential for new insights into the global research landscape. But we are not yet at the point where this data can be both expressive enough to be useful and easy enough to consume.

To illustrate the current situation we display the conceptual space of communities dealing with research information in form of four mind maps (*c.f.* Figure 1). In the upper left corner we brought together concepts, which are relevant from the perspective of scientific career research and often conducted qualitatively, with rich factual evidence, which is hardly interoperable or scalable. For this mind node we drew on current discussions and first results [37] in a FP7 framework programme ACUMEN, Academic Careers understood by Measurements and Norms (see `http://research-acumen.eu/`), where sociologists and scientometricians work together. In the right lower corner we display the main classes of an ontology for research information (VIVO[1]) developed in the US. In the upper right corner, the main tables of a Dutch Research Information Database (NOD-NARCIS) are displayed, and in the lower left corner is a selection of information and concepts which can be retrieved using different fields in one of the leading cross-disciplinary bibliographic databases - the Web of Knowledge. Although, the mind map sketches are different in nature, from formal schemes to collection of aspects, this illustration shows their difference in size, granularity, scope, and expression or semantics.

In this work we argue for the need of a scalable, interoperable, and multi-layered data representation model for research information system (RIS). Science of science and modeling of science dynamics raise and fall with a consistent measurement system for the sciences. The contributions of this paper are as follows:

- A highlight of information loss happening when expressing data with generic ontologies;
- The introductions of the notion of levels of semantic agreement for expressing research data;
- A multi-layered ontology based on the above definition.

The remainder of the paper describes the landscape of research data publication before diving into the details of a specific Dutch case. We thereafter introduce our proposed multi-layer conceptual model for a research ontology and conclude in its potential for documenting research.

[1]`http://www.vivoweg.org`

CURRENT LANDSCAPE OF RIS

Publishing research data

In order to publish re-usable research data, one has to think in terms of standards and publication media. While the web imposes itself as the publication platform, the question of standards remains open and has been long investigated.

First efforts in standardisation have been undertaken from the traditional research information communities. One example is the "CERIF" standard developed by EuroCRIS[2]. This standard defines a set of generic classes and properties used to describe research data. The serialisation format used for the data is XML, although an RDF version is being considered[3]. The content management system (CMS) "METIS", popular in the Netherlands, uses this standard to store and expose research data. This standard has also been used for the Dutch portal "NARCIS"[4].

The Web of Linked Data is a way of combining the publication platform and the standards. More recent efforts have been made in this direction via a number of ontologies and publication platforms. The initiative LinkedUniversities[5] provides a reference towards these systems and highlights their practical use. VIVO a United States based open source semantic web application is another such a system. The application both describes and publishes data, using RDF to encode the data and OWL for the logical structure.In addition to its own classes and properties, the VIVO ontology incorpates other standard ontolgies thus increasing its interoperability [8]. However, the ontology relies heavly on the US academic model which limits its ability to accurately represent researchers in other systems.

VIVO and CERIF based CMS have been successfully put in use at many institutions. Still, the landscape of research information is very scattered and far from being connected. One of the reasons for this is a lack of agreement upon semantics for the data. Efforts have been made to align VIVO and CERIF [25] but the main problem remains that data publishers essentially have to choose between using a globally agreed upon representation, which is less expressive as a result of covering a vast amount of heterogeneous information (CERIF), or a very expressive and specialised ontology (VIVO), which is difficult to map to other ontologies of similar complexity.

The Dutch case

In the Netherlands, we find the following situation. All 13 universities (14 with the Open University) use a system called METIS to register and document their research information [14]. In practice, information is usually entered in METIS centrally by a person in the administration although, sometimes individual accounts to METIS are created. Aside from those unconnected local implementations of one system, higher education in the Netherlands embraced the Open Access Movement with a project called DARE. This lead to an

[2]`http://www.eurocris.org`

[3]`http://spi-fm.uca.es/neologism/cerif`

[4]`http://www.narcis.nl/`

[5]`http://linkeduniversities.org/lu/`

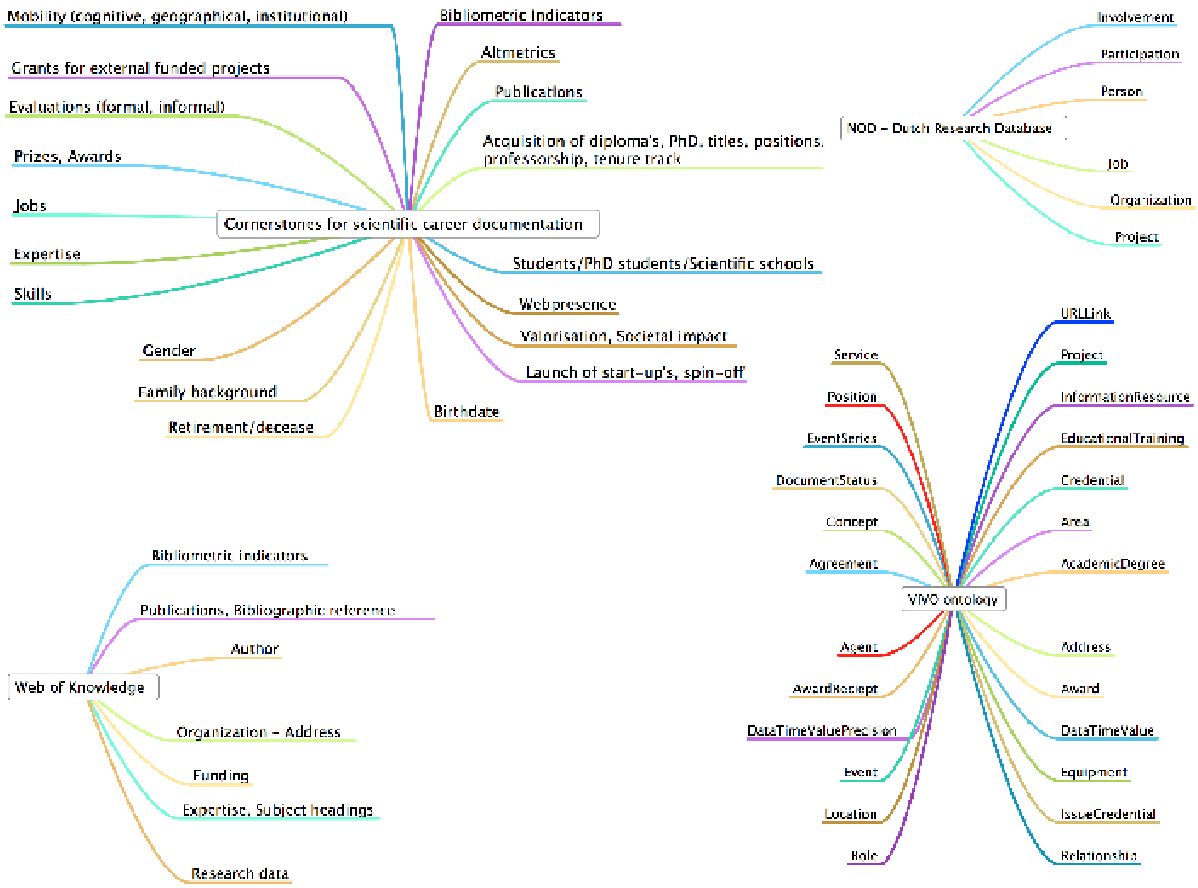


Figure 1: Conceptual space of four different communities dealing with research information. The variation among these mind maps illustrates the difference in size, granularity, scope, and expression of the different information systems with which they are associated.

open repository for scientific publications. Moreover, a web portal to Dutch research information exists - NARCIS - which harvests publications from open repositories, but also entails a very well curated (and still manually edited) research information database (NOD) with information about the scientific staff of about 400 university and outside university research institutions [13, 31].

As Oskam and other Dutch researchers already pointed out in 2006, "the researcher is key" [27]. Outside of institutional RIS this idea is prolific in Web 2.0. platforms such as Mendeley and Academia.edu. They have been designed around the needs of scholars. General social network sites such as LinkedIn - which is very popular for professionals in the Netherlands - and Facebook also profile themselves as outlets for individual researchers. This leads to a situation where user-content driven systems compete for the limited time and resources of an individual researcher and where, as a result, snippets of the oeuvre and academic journey of a researcher can be found at different places, recorded in different standards, and with different accuracy. The question raised in the 2006 paper: "How can we make the CRIS[6] a valuable and attractive (career) tool for the researcher?" [27, p. 168] is still waiting to be answered in a standardized way.

The purpose of documentation of science (and of careers of researchers) has grown far beyond the effective information exchange. Research evaluation relies heavily on indicators computed (semi) automatically from databases and the web. Currently, individual careers of researchers are very much influenced by indicators which are built on activities for which large amounts of standardised data are available. Prominent examples are journal impact factor or the H index. But, a researcher is not just a "paper publication machine". Grant acquisition is another important "currency" in the academic market - for individuals on the job market, as well as, for institutions competing for funding. Teaching is an area which is monitored locally and institutionally, but for which no cross-institutional databases exist. Moreover, researchers are no longer loyal to one institution, one country, or one discipline for their whole life. There is an increasing need for cross-discipline and cross-institutional mapping of whole careers.

Tracing scientific careers

Projects such as ACUMEN look into current practices of evaluation and peer review to empower the individual researcher and develop guidelines for how best to present your academic profile to the outside world. "ACUMEN" is the acronym for Academic Careers Understood through MEasurements and Norms. In this project, we analyse the use of a wide range of indicators - ranging from traditional bibliometrics to altmetrics and metrics based on Web 2.0 - for the evaluation of the work of individual academics. One of the author of the present work, Frank van der Most, also conducted interviews to investigate the impact or influence of evaluations on individual careers. For his work the following events are of interesting in tracking an academic career:

- Birth of the academic;
- Acquisition of diploma's and titles, in particular MA diplomas (and equivalents), PhD/Dr. diplomas, habilitiation, professorships of sorts and levels;
- Jobs, in universities and academic research institutes, but also in non-academic organisations. The latter is interesting because people move in, out, and sometimes back into academia;
- Particular functions within or as part of the job(s): director of studies (teaching), research-coordinator, head of department, dean, vice dean (for research, education, or other), vice-chancellor/rector, board member of faculty/school/university/institute;
- Launch of start-ups/spin-outs or people's own companies. It could simply be a form of employment, but start-ups or own companies may indicate economic or other societal value of academic work;
- Prizes;
- Retirement and decease.

For the study of the impact, or influence, of evaluations an overview of someone's career is necessary to "locate" influential evaluations. This "location" has multiple dimensions. One is the calendar time, *i.e.* on which date or in which year did an influential evaluation take place. Based on time, geographic, and institutional location the context of a particular evaluation event can be reconstructed. Scientific careers follow patterns which are influenced by current regimes of science dynamics (including evaluations).

Another important dimension concerns the location of an evaluation (or any event) within someone's career. If two academics apply for the same job, the location in time and place is the same, but if one is an early-career researcher and the other is halfway through his/her career, this clearly makes a large difference to how their applications are being evaluated and how the evaluation results are likely to impact their respective careers. A rejection may have a bigger impact on the early-career researcher than on the mid-career researcher.

Another ACUMEN sub-project investigates gender effects of evaluations and includes an analysis of performance indicators on research careers. This is planned to be a statistical analysis which would require some form of career descriptions.

One of ACUMEN's central aims is to identify and investigate bibliometric indicators that can be used in the evaluation of the work of individual researchers. A major point discussed in the ACUMEN workshops is the realisation that researchers have a career or a life-cycle which contextualises the values of bibliometric indicators.

Although the events listed above are interesting for ACUMEN, these events, or a sub-set or extension thereof, is likely to be interesting to many career studies. For example, productivity-studies would relate academic production of texts [11, 15, 24], courses taught, and other outputs to someone's career stage or career paths. An academic's epistemic

[6] CRIS stands for "Current Research Information System"

development (their research agenda) could be studied in relation to career stages [22] or mobility.

To be able to trace the co-evolution of individual career paths and the social process of science for larger part of science, one would need a different kind of information depending on the study being undertaken.

TOWARDS A CORE RESEARCH VOCABULARY

The challenge when designing a standard for sharing data is to make it generic enough so that aggregation makes sense, while being specific enough so institutions can express the data they need.

As it is highlighted by the two most popular search tools, consuming data exposed via VIVO from a number of external sources[7] at the international level, only the most general concepts such as "People" make sense. On the opposite, the search features offered by a national portal such as NARCIS proposes a number of refined search criteria. These two extremes of the data mash-up scale show that depending on the study being done, different levels of semantics agreement are likely to be put into use.

In contrary to XML schemas, Semantic Web technologies make it possible to express data using an highly specified model while also making it available using a more general model. The technology of particular importance here is "reasoning", that is the entailment of other factual valid information from the facts already contained in the knowledge base. For instance, if an RDF knowledge base contains a fact assessing that "A is a *researcher*" and another stating that "Every *researcher* is a *person*", the system will infer that "A is a *person*".

Leveraging this, it is possible to extend ontologies by refining the definition of classes and properties. The most refined versions of the concepts will inherit from their parents. We argue that for research information systems, three levels are necessary (see Figure 2). First, an international level containing a set of core concepts that can be used to build data mash-up on an international scale. Then, a national level extending the previous core level with concepts commonly agreed upon nation wide (*e.g.* positions). Last, an institutional level where every institution is free to further refine the previous level with its own concepts and properties that matter to its network.

As a feasibility assessment and to propose a first model, we hereafter introduce a core ontology and two national extensions. This proposal is based on related work, existing ontologies, and our personal experience but stands more as a first iteration of work in progress rather than a definitive model.

Conceptual models

Conceptual models allows for the representation of classes and properties of a knowledge base, along with their relations, in an abstracted way. The proposed conceptual models that

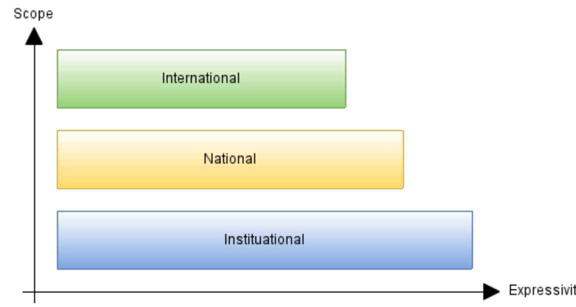


Figure 2: The proposed model of multi-layer ontology and its trade-off between scope and expressivity. At the lowest level, institutionaly defined semantics have the highest expressivity but the lowest scope.

we hereafter introduce are not dependent on the technical solution implementing them. There is however, as highlighted previously, an advantage in using Semantic Web technologies for this. This point is discussed in details in the following, after the introduction and the description of the three proposed conceptual models.

Core model

The model depicted in Figure 3 is a proposal for a core research ontology based on the work being done on CERIF, the VIVO ontology, the Core vocabularies [4], and the data needs of ACUMEN. As part of its goal to study the scientific career through the research data made available, ACUMEN needs a number of information related to individuals, such as but not limited to:

- Grants/project applications - both applied and granted. This in relation to persons (applicants of various sorts) and organisations (applying/receiving institutes, main and subcontractors, funding institutes);
- Skills. For instance, "Leadership" or "Artificial Intelligence". There is no limit to the definition and several thesaurus could be implied;
- Networks or network relations. Relation between persons and organisations, but also between persons and results are of particular importance;
- Memberships of scientific associations or academies;
- Conferences visited or organised.

The model contains classes to define individuals, projects, scientific output, positions and tasks. A generic "Relation" can be established between authors and papers, or teachers and courses taught. The exact meaning of the relation is to be defined either by sub-classes of it or by using the property "role".

National extensions

The second level of semantic agreement is that of national extensions. Based on the core concepts, these extensions allows for the modeling of concepts actually used in the country - using the language and terminology of that country. When building such an extension, the main assumption made is that

[7] See **http://nrn.cns.iu.edu/** and **http://beta.vivosearch.org/**

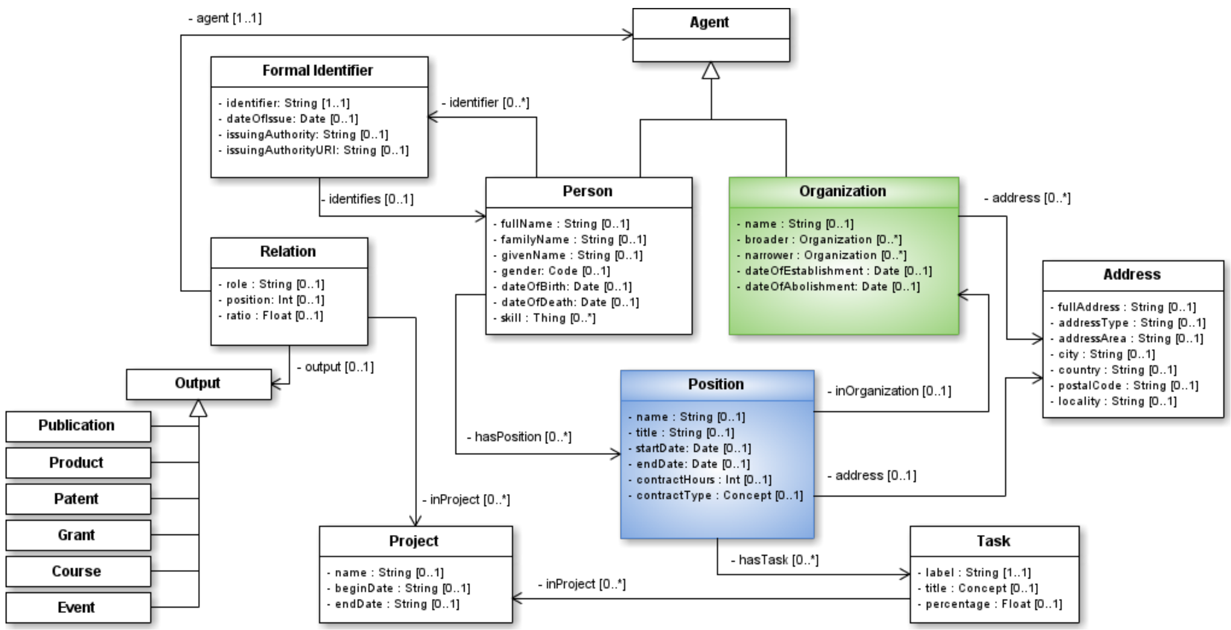


Figure 3: Conceptual model of the core ontology. This model describes the minimum set of classes, relationships, and properties needed to describe a natural person and trace his scientific career. These classes can be further extended by national and local ontologies to account for specificity. As an example, the coloured classes are extended in two national ontologies in Figure 4

there is a level of agreement that can be reached on a national basis.

An example of national extension is given in Figure 4. This extension extends the core "Position" and "Organization" classes to define the type of positions and organisation commonly found in the Netherlands (Figure 4a) and the US (Figure 4b). The classes depicted in the Dutch extension are those found in NARCIS, and as such represent the union set of all the specific classes used within the research institutions in the Netherlands[8].

It can be observed that the Dutch extensions shows a high level of variety, with some classes that could be replaced with other model mechanisms, such as the "part time Hoogleraar" class which is actually a "Hoogleraar" contracted with less hours.

We also note from Figure 4b that the national level has to be kept generic in the US because of the variation observed locally. In the US, many titles and/or positions are essentially at the discretion of the individual institutions (with some direction from the American Association of University Professors (AAUP)), thus a very detailed national ontology is not appropriate. However, for countries with a more centralised model and using title and positions officially described, more detail can be added at this level thus increasing semantic understanding. The national level allows for this grey area adaption instead of the current two level "very general" to "very specific" model.

[8]We must note here that this classes are not defined by an authority but are rather crowd-sourced. A more accurate, authoritative, list would have to be defined by an national entity.

Local extensions

Local extensions are the most specific level of specification we propose for this approach. These can be used to specify concepts and relations that are understood within a given sub community inside a country. For instance, in the Netherlands, the research institution KNAW defines an additional position "AkademieHoogleraar" for "Hoogleraar" which are appointed to universities but directly affiliated to KNAW. This additional position is only used by some institutions and for this academy - here, the "Akademie" in "AkademieHoogleraar" implicitly refers to KNAW.

Implementation

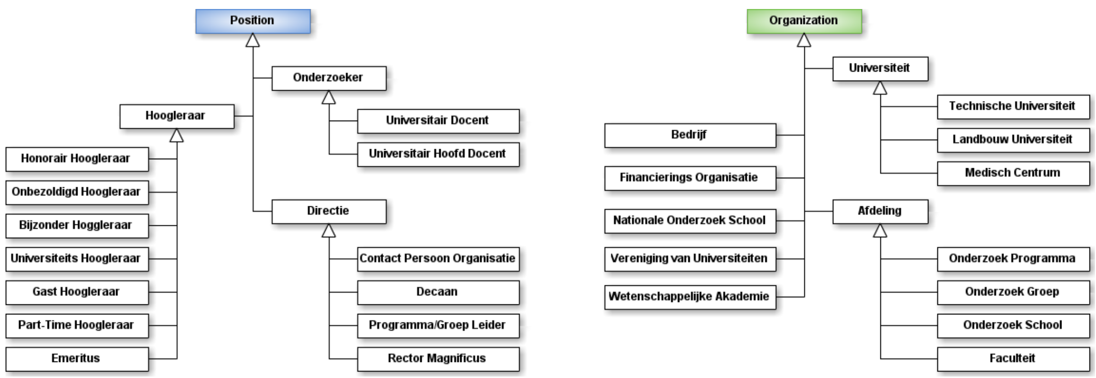
Prior to its concrete use, the proposed conceptual models have to be turned into an RDF based vocabulary. This vocabulary also has to be hosted under a domain name.

Vocabulary terms

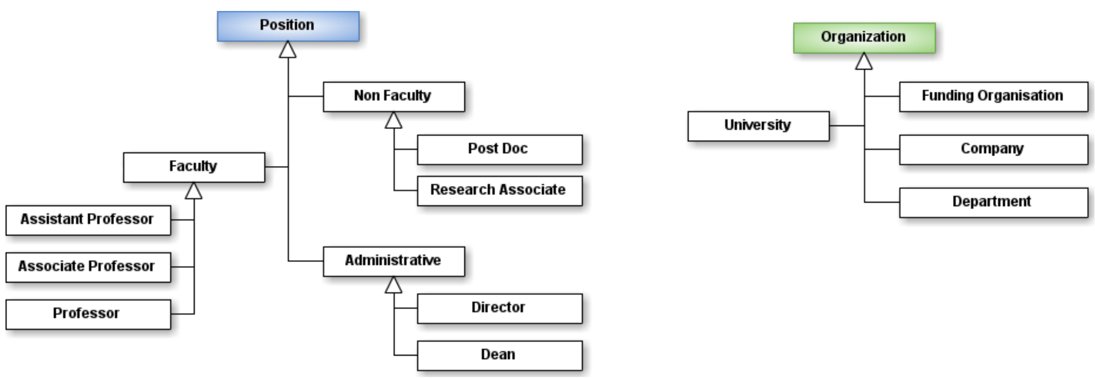
There are a large number of vocabularies published on the Web. The proposed models can effectively leverage most of their properties and classes from one of these existing sources of terms, having fewer new terms to introduce. In particular, the following vocabularies are to be considered:

- FOAF[9], for the description of the persons;
- BIBO[10], for the publications;
- LODE[11], for the description of events;

[9]`http://xmlns.com/foaf/spec/`
[10]`http://bibliontology.com/`
[11]`http://linkedevents.org/ontology/`



(a) Conceptual model of the extension for the Netherlands



(b) Conceptual model of the extension for the US

Figure 4: Example of two national extensions of the core model. These extensions allow for expressing the particularities found in the national system while grounding their semantic on the more generic concepts.

- SKOS[12], for the description of thesaurus terms such as those used to describe researchers' skills;
- PROV-O[13], to add additional provenance information to the data being served.

We also note that, by design, there is a significant overlap between the conceptual model of Figure 3 and that defined in the Core Vocabularies for Person, Location and registered Organisations in [4, page 10]. This allows for the proposed core vocabulary for research to be defined based on these other core vocabularies defined by JoinUp and formalised by the W3C in the context of the Working Group on Governmental Linked Data (GLD) [14].

Ontology hosting

The domain name at which an ontology is being served is, as for the data itself, often seen as indication of the person, or entity, in charge of supporting the ontology. To account for this, we envision the hosting of the core ontology and its extensions done at institutions matching the scope of the level of agreement. That is, an international organisation for the international layer, a national organisation for the national layer, and the institutions themselves for the local extensions. More concretely, such an hosting plan could be materialised as having: the core ontology being served by the W3C, the Dutch national ontology by the VSNU[15], and the local extension from the KNAW by the KNAW.

CONCLUSION

This paper operates at different levels. At the core it proposes a model to semantically describe data in Research Information Systems in a way which allows to aggregate but also to deconstruct if needed. It does so based on experiences with standards and data representation in the past and looking into very concrete practices - taking a VIVO implementation exercise in the Netherlands as point of reference and departure. A next shell of considerations around those specific mappings is added when we incorporate research outside of the traditional area of scientific information and documentation. Science and technology studies, science of science, and scientometrics have produced over decades of insights in the structure and dynamics of the science system. A wealth of information is available in this area, most of it case-based evidence. We include the aims and achievements of an on-going EU FP7 funded project (ACUMEN) which, in itself tries to combine bibliometric and indicator-based research with interviews, survey, and literature studies. The target subject of this project is the researcher. It is also the researcher which is targeted by Research Information Systems, and it is the researcher which is the innovative driver for science dynamics. Bibliometric indicators are heavily based on standards, part of them shared with RIS. What makes the ACUMEN project and the perspective of scientific career research so interesting for the design of future research information systems is the identification of factors relevant for career development which are not yet covered by current standards, databases, or ontologies. The last and most visionary shell in this paper is to design research information systems which can be used for science modeling. In the general framework developed by Borner et al. science models can be developed at different scales of the science system, from the individual research up to the global science system; they can differ in geographic coverage, as well as, in scales of time. In any case, the ideal would be having one data representation which can be scaled up and down along those different dimensions, and not singular data samples in incomparable measurement units not relatable for particular areas of the dynamics of science. Our main argument is to provide a data representation which is retraceable - if needed - towards its specific roots and at the same time can be aggregated. In such a "measurement system" we would find a middle layer of data granularity on which basis complex, non-linear models can be validated and implemented, to better monitor and understand the science system.

[12] **http://www.w3.org/2004/02/skos/**

[13] **http://www.w3.org/TR/prov-o/**

[14] **http://www.w3.org/2011/gld/wiki/Main_Page**

[15] the association in charge of the collective labour agreement for Dutch universities and other cross-institution regulations on salaries and positions

ACKNOWLEDGMENTS

This work has been supported by the ACUMEN project FP7 framework. We would like to think our colleagues Ying Ding, Katy Borner, and Chris Baars for their comments and support during this work.

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