On Interoperability of Ontologies for Web-based Educational Systems

Yannis Kalfoglou
Advanced Knowledge Technologies (AKT)
School of Electronics and Computer Science
University of Southampton, UK
y.kalfoglou@ecs.soton.ac.uk

Bo Hu
School of Electronics and Computer Science
University of Southampton, UK
bh@ecs.soton.ac.uk

Dave Reynolds
Hewlett Packard Laboratories, Bristol, UK,
dave.reynolds@hp.com

ABSTRACT

Interoperability between disparate systems in open, distributed environments has become the quest of many practitioners in a variety of fields. Web-based educational systems are not an exception, but provide some unique characteristics. In this perspectives paper we argue for the role of multiple ontologies in support of Web-based educational systems and speculate on the efforts involved in achieving interoperable systems. We draw our criticism from our involvement in interoperability tasks between ontologies for Semantic Web systems and elaborate on the role of communities of users in interoperability scenarios.

Categories and Subject Descriptors

H.3.5 [**Information Systems**]: -Online Information Systems -Web-based services;; D.2.12 [**Software**]: -Software Engineering-Interoperability;; I.2.m [**Artificial Intelligence**]: -Miscellaneous

Keywords

semantic interoperability, ontologies

1. INTRODUCTION

Interoperability has always been the Achilles heel when deploying large scale, independently developed systems. Interoperability is a pre-requisite for maximizing sharing of data, information, and ultimately knowledge between disparate systems. Homogeneous groups of engineers have been resolving this issue in familiar environments, like organisational intranets, using either manual or semi-automatic methods. However, the popularity of Web-based approaches and the advent of the ambitious Semantic Web changes the landscape for interoperable systems: interoperability needs to be achieved in an open, distributed environment, involving heterogeneous groups of engineers from distinct organisations following different design processes.

Nowadays, an Artificial Intelligence (AI) technology which emerged in the late eighties as a means for sharing knowledge between knowledge based systems, ontologies, is advocated as the preferable solution for enabling interoperability. Their applications vary across a wide range of fields, including Web-based Educational Systems (WBES). For instance, in the post-workshop report for a recent specialized event on the use of ontologies in WBES[1], the authors argue for using a "common vocabulary for domain knowledge representation" which enables WBES interoperability. These are also known as ontologies. Further, Simon and colleagues [20], summarize neatly the role of ontologies in WBES engineering with respect to achieving interoperability of educational artefacts:

> "Educational artefacts are understood as descriptions of educational service types (e.g., a course catalogue or an evaluation service) or instances of educational services and resources (e.g., a particular course, an assessment activity or an online text book). When an educational node forwards an educational artefact to another educational node for further processing, both nodes need to speak a common language. Hence, an ontology needs to be designed to provide a *lingua franca* common trade language for learning resources [. . .]."

In this paper, we advocate the use of ontologies – as our dedicated WBES colleagues – however, we will argue for the use of multiple ontologies to support a WBES, which is in line with the Semantic Web's *modus operandi*. This changes the focus for interoperability: first it has to be achieved at the underpinning ontologies level, which in turn will enable entire systems' interoperability.

Initially though, in section 2, we will review the arguments made for and against the use of a single, global ontology, to which all systems adhere to, and interoperability is based on. We will then argue for the role of communities in driving the ontology building and sharing exercise (section 3), before presenting some concise examples from our own experiences when dealing with real world deployments of ontology-based systems (section 4). We wrap up this short perspectives paper by pinpointing to potential research directions for the field of WBES with respect to interoperability in sections 5 and 6.

2. ON THE INEFFICIENCY OF A GLOBAL ONTOLOGY

WWW2005, May 10–14, 2005, Chiba, Japan.
.

[1]Accessible online from:
http://www.win.tue.nl/ laroyo/ICCE2002_Workshop/proc-Workshop-ICCE2002.pdf

Early ontology work suggested that they are suitable for achieving interoperability between disparate systems. In the mid nineties, the seminal article from Uschold and Gruninger provided supportive evidence of this claim [21]. This is best illustrated in a compelling figure of the authors which we redraw in figure 1.

As we can see from that figure, the presence of an ontology makes it possible for two disparate systems (in this example, a *method library* and a *procedure viewer*) to communicate, and ultimately share knowledge albeit they use different vocabularies.

This has been the dominant approach in the nineties. It has been applied to some of the long lasting knowledge sharing projects[2], as well as to a plethora of smaller knowledge sharing tasks. It is effective, once the ontology is up and running, and evidently has a knock-on effect on sharing and design costs [22]. However, it is not efficient: designing the "perfect" ontology that will accommodate all needs is not an easy task. There are irreconcilable arguments among engineers about how and what knowledge should be modelled when trying to build a comprehensive ontology for a given domain. Even when an overcommitted group finally resolves the disputed issues and releases the ontology, there are often inappropriate interpretations of its constructs by users or simply lack of appropriate tools to reason over it.

Furthermore, the emergence of the Semantic Web, made it possible to publish and access far more ontologies than knowledge engineers ever thought that it would be possible to build! Consequently, ontologies proliferated and made publicly available and accessible by large audiences. This brought forward a number of issues regarding scalability, authoring, deployment, and most importantly: interoperability of ontologies themselves. This is different from having a single, consensual ontology upon which interoperability will be based and engineers have to work out on how their systems will communicate with that ontology. There is a call for ontology to ontology interoperability, which includes the acknowledged problem of *ontology mapping*.

Ontology mapping though, is not an easy exercise. As it has been reported in a large survey of ontology mapping systems, [11], "[...] ontology mapping nowadays still faces some of the challenges we were facing ten years ago when the ontology field was at its infancy. We still don't understand completely the issues involved, however, the field evolves fast and attracts the attention of many practitioners among a variety of disciplines.". This resulted in a wide variety of potential solutions to the mapping problem, most of which though, are not fully integrated with the design phase of an ontology neither developed with a view to integration with other solutions. This ad-hoc manner of tackling the problem reveals a mundane need, as it was reported in a specialists' event for semantic interoperability and integration: "[...] it was stressed that domain ontologies need to be built and vetted by domain experts and scientists, as those built by computer scientists were usually rejected." [13].

In the next section, we elaborate on the role that communities can play to alleviate this tension between abundance of inappropriate domain ontologies delivered by engineers and the need for multiple user-certified domain ontologies.

[2]Like the 15 year effort to design, develop, deploy, and maintain CyC ontology – www.cyc.com)

3. EMPOWERING USER COMMUNITIES

In the context of a WBES, users can be seen as the "learners", so to speak, who are interested in accessing and using a wide variety of learning material. From a knowledge modelling point of view, this material is typically encoded as learning objects in some form of an ontology, in the ideal case. A typical *modus operandi* for deploying a WBES would then be for knowledge engineers to characterize, classify and offer learning objects to learners for immediate consumption. However, this ignores - to a certain degree - input from the learners. Although there would be a requirements specification phase where users (learners) can have their say, this is different from having learners engaged in the entire loop of an ontology lifecycle that supports a WBES. As it was concluded in the integration specialists' report: "[...] ontology generation should be done by community members rather than a handful of skilful engineers. That raised the question of how to increase human involvement in the process: it was argued that socially-inspired computing is different from social engineering, a norm in everyday practice at organisations." [13].

The quest is then to find appropriate mechanisms which will enable a targeted set of dedicated users, learners who use WBESs in our case, to modify and customize the WBESs underpinning model, an ontology. This in turn, will have immediate effects in the usage of the WBES, by maximizing user acceptance and usage; and eventually facilitate interoperability with other similar WBESs because learners themselves will highlight which parts of the WBESs are meant to be interoperable.

To the best of our knowledge, there is no working example of this idea of interoperable WBESs, however, there are notable examples of engaging vast communities of users in tasks which are typically seen as a "knowledge engineers job". For example, the work of FOAF network[3] begun as an amusement exercise for few, and nowadays involves a vast number of dedicated users who instantiate and optimize a large, common ontology for describing social network relationships. Another notable example in the Web realm, is the unprecedented success of Blogs which are already flooding the Web. Despite being loosely engineered and controlled, they are written and maintained by millions of users. Finally, there is a variety of (Semantic) Web machinery out there which could be used by large communities of users, like the RSS vocabulary.

Stepping back from technical details on how learners could be involved in ontology management, we look at appropriate theoretical frameworks that describe formally the engagement of users with ontologies. The most visible work in this front, is the Information Flow Framework (IFF) provided by Kent [14]. Kent argues that IFF represents the dynamism and stability of knowledge. The former refers to instance collections, their classification relations, and links between ontologies specified by ontological extension and synonymy (type equivalence). Stability refers to concept/relation symbols and to constraints specified within ontologies.

An ontology, Kent continues, has a classification relation between instances and concept/relation symbols, and also has a set of constraints modelling the ontology's semantics. In Kent's proposed framework, a community ontology is the basic unit of ontology sharing; community ontologies share

[3]www.foaf.org

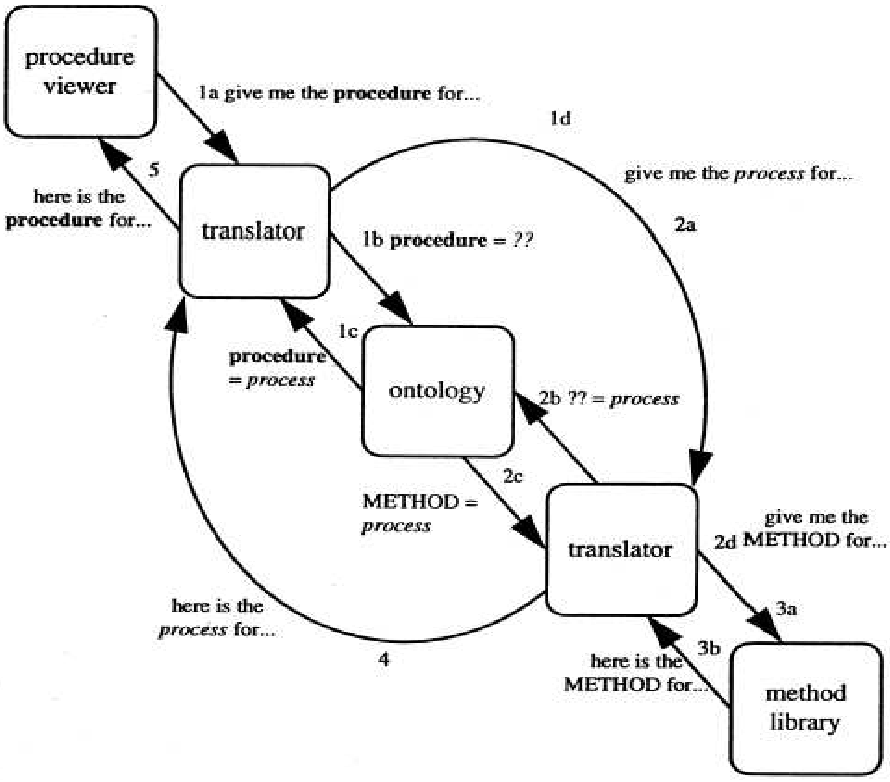

Figure 1: Using an ontology to achieve interoperability.

terminology and constraints through a common generic ontology that each extends, and these constraints are consensual agreements within those communities. Constraints in generic ontologies are also consensual agreements but across communities. Kent assumes two basic principles,

1. that a community with a well-defined ontology owns its collection of instances (it controls updates to the collection; it can enforce soundness; it controls access rights to the collection), and

2. that instances of separate communities are linked through the concepts of a *common generic ontology*,

and then goes on to describe a two-step process that determines the *core ontology of community connections* capturing the organisation of conceptual knowledge across communities (see figure 2). The process starts from the assumption that the *common generic ontology* is specified as a logical theory and that the several *participating community ontologies* extend the *common generic ontology* according to theory interpretations and consists of the following steps:

1. A *lifting step* from theories to logics that incorporates instances into the picture (proper instances for the community ontologies, and so called *formal instances* for the generic ontology).

2. A *fusion step* where the logics (theories + instances) of community ontologies are linked through a *core ontology of community connections*, which depends on how instances are linked through the concepts of the common generic ontology (see second principle above).

The applicability of Kent's framework in WBESs is evident from the fact that individuals and organisations involved in WBESs normally share a generic view of the domain and extend it according to their own special needs. Such a generic view offers the basis for a global *common generic ontology* (see Figure 2). Meanwhile, each participant of WBESs usually possesses a collection of data that can be partially projected onto the generic ontology. This collection of data – playing the role of *community instances* in IFF – provides the ground on which mapping between local, community, ontologies can be performed.

Kent's framework is purely theoretical and only parts of it have been engineered in certain, limited, contexts. However, it does highlight the role of communities in knowledge sharing by controlling instantiation of ontologies and providing extensions to commonly agreed ones. This way of using ontologies makes it possible to instantiate them with user-provided data, thus revealing the *operational* semantics (how instance data are to be used in accordance with a community's view) rather than the *intended* semantics (specified at design time by a knowledge engineer).

We already argued that there are no known examples of WBESs that employ the idea of empowering user communities for achieving interoperability, however, there is early work in applying this idea to certain instantiations of the interoperability problem which we review in the next section.

4. WORKING EXAMPLES

Four years ago the UK's Engineering and Physical Sci-

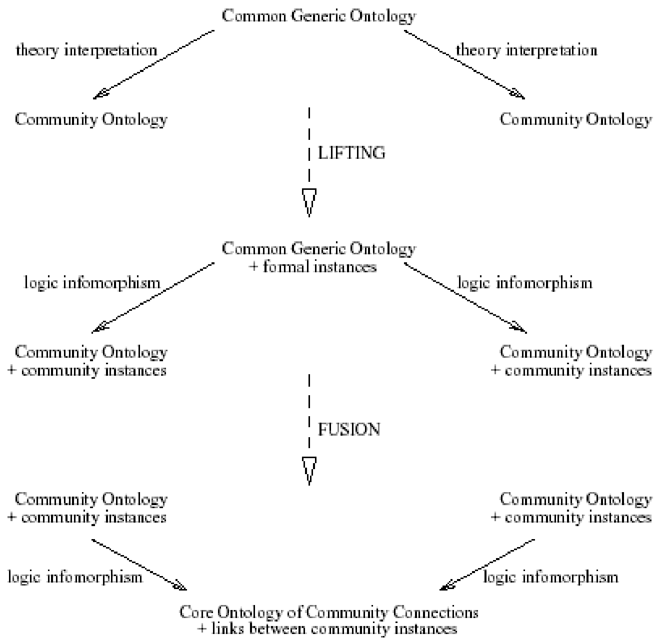

Figure 2: Kent's two-step process for conceptual knowledge organisation.

ences Research Council (EPSRC) funded an Interdisciplinary Research Collaboration (IRC) consortium of five leading British Universities to research Advanced Knowledge Technologies (AKT)[4]. AKT is focussing on the use of Knowledge Management (KM) technologies on the Semantic Web. One of our motto is to *practice what you preach*, so we were keen to experiment with a number of KM technologies in our own consortium setting. The aim was to help new workers familiarize themselves with AKT and the problem domain. A number of audio/visual digital technologies were used, ranging from video recording/playback to live Web-casts of our regular AKT workshops. This material was archived, processed, and made available to new members of the group as a learning material. In that sense, we deviate from the traditional view of using only course material (notes, exercises, references, etc.) as content for WBESs. We see a WBES as a tool for learning in an organisational setting that is not necessarily restricted to the University education domain, as is the norm.

Our preferable option for managing this material was to semantically annotate it using an underpinning ontology. As we envisaged that all content that will be characterized by this ontology should ultimately be shared by a variety of disparate systems, we opted for a single, global ontology. The resulting ontology, AKTive Portal and AKTive Support[5], represents one of the few well crafted, working examples of state-of-the-art Semantic Web technology [19], and supports award-winning applications like the 2003 Semantic Web Challenge winner. However, as we argued in section 2, the global ontology approach has its unbearable costs: it took us the best part of 3 years to finally settle with a version that was both commonly agreed by all stakeholders and most importantly, functional across a variety of systems that use it. Our conclusions were that this sort of global ontologies do have an effect in reducing reuse costs and help achieving interoperability but they are expensive to built and maintain.

We also had experiences with using small, domain ontologies, to support dedicated organisational learning systems. For example, *MyPlanet* is a Web-based personalized organisational learning system which we deployed in the early years of AKT to help learners browse and customize material related to organisational news [9]. The effort involved in building that system was considerably lower than the one in the AKTive Portal and Support ontologies case, however the impact on learners' experiences was limited due to the restricted scope of the underpinning domain ontology (describing only one kind of learning material - organisational news).

These two exemplar cases of using large, global ontologies and small, domain ontologies defined the two ends of the engineering effort spectrum in our experiments. As these efforts had no user involvement (with the notable exception of *MyPlanet*'s profiling mechanism that kept users engaged in the maintenance process), we experimented with technologies that allowed us to engage users in all phases of ontology management. In particular, Alani and colleagues describe a community-oriented approach for managing ontology-based Organisational Memories (OM) [1]. In our scenarios, OMs were used in a variety of settings, most of which address organisational learning and e-learning research. The approach we used is based on the *communities of practice* idea but we tuned it to manage an ontology. We were keen to engage

[4]More on www.aktors.org

[5]Accessible online from www.aktors.org/ontology

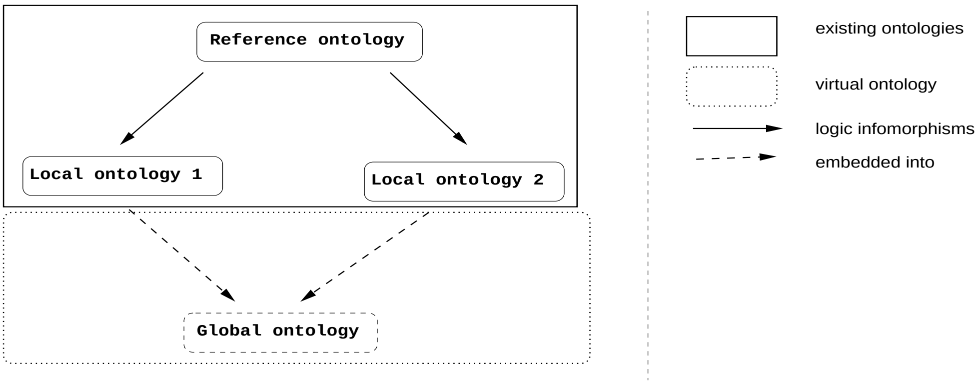

Figure 3: IF-Map scenario for ontology mapping.

users in the process, in particular, to have them instantiate the OM with ontology constructs of their interest. Thus, we set the experiment in our own organisation to have real world instances, like the University's underpinning ontology. Our conclusions with using this technology was that user involvement helped instantiate the OM with the appropriate ontology constructs, however, we do not have concrete conclusions about the impact of this approach to interoperability as there was only one underpinning ontology used. On the contrary, this sort of claim has been made by Schmitz and colleagues [18] when ontologies were deployed to support e-learning repositories (similar to our OM) in distributed environments and found that interoperability was achieved but in their case there was no user involvement in the process.

Our involvement with multiple ontologies also made us consider the ontology mapping problem, a key enabler for achieving interoperability, especially on the Semantic Web. We worked with Information Flow theory, proposed by Barwise-Seligman [2], and developed a system, *IF-Map*, that incorporates ideas from information flow between types (classes) and tokens (instances) of distributed systems. In Figure 3 we illustrate *IF-Map*'s underpinning framework for establishing mappings between ontologies.

The solid rectangular line surrounding `Reference ontology`, `Local ontology 1` and `Local ontology 2` denotes the existing ontologies. We assume that `Local ontology 1` and `Local ontology 2` are ontologies used by different communities and populated with their instances, while `Reference ontology` is an agreed understanding that favours the sharing of knowledge, and is not supposed to be populated. The dashed rectangular line surrounding `Global ontology` denotes an ontology that does not exist yet, but will be constructed 'on the fly' for the purpose of merging. The solid arrow lines linking `Reference ontology` with `Local ontology 1` and `Local ontology 2` denote information flowing between these ontologies and are formalised as *logic infomorphisms*. The dashed arrow lines denote the embedding from `Local ontology 1` and `Local ontology 2` into `Global ontology`.

In Figure 4 we illustrate the underlying workflow process of *IF-Map*[10]. It consists of four major steps: (a) ontology harvesting, (b) translation, (c) infomorphism generation, and (d) display of results. In the ontology harvesting step, ontology acquisition is performed. A variety of methods are applied in this step: use of existing ontologies, downloading them from ontology libraries (for example, from the Ontolingua [5] or WebOnto [4] servers), editing them in ontology editors (for example, in Protégé [7]), or harvesting them from the (Semantic) Web. This versatile ontology acquisition step results in a variety of ontology language formats, ranging from KIF [6] and Ontolingua to OCML [16], RDF [15],OWL, Prolog, and native Protégé knowledge bases. This introduces the second step, that of translation. The authors argue: "As we have declaratively specified the IF-Map method in Horn logic and execute it with the aim of a Prolog engine, we partially translate the above formats to Prolog clauses.". Although the translation step is automatic, the authors comment: "We found it practical to write our own translators. We did that to have a partial translation, customised for the purposes of ontology mapping. Furthermore, as it has been reported in a large-scale experiment with publicly available translators [3], the Prolog code produced is not elegant or even executable.". The next step is the main mapping mechanism – the *IF-Map* method. This step finds *logic infomorphisms*, if any, between the two ontologies under examination and displays them in RDF format. The authors provide a Java front-end to the Prolog-written *IF-Map* program so that it can be accessed from the Web, and a Java API to enable external calls to it from other systems. Finally, they also store the results in a knowledge base for future reference and maintenance reasons.

In this section we highlighted our experiences with using large or small, single or multiple ontologies, use of community-oriented systems and dedicated ontology mapping mechanisms. In the next section, we speculate on potential research routes for WBES interoperability, in particular, in multi-ontology environments like the Semantic Web.

5. GUIDELINES FOR FUTURE RESEARCH

The issues we highlight in this section are not restricted to specifically WBESs interoperability but address a wider range of issues with regard to WBESs: multi vs. single ontology support, Semantic Web enabled WBESs, semantic interoperability, community driven WBESs, versatile content for WBESs. All of them though, are glued together with a vision of how they can affect interoperability among WBESs. For each of these core themes, we pinpoint to potential routes for future research.

- **Multi vs. single ontology support:** one of the

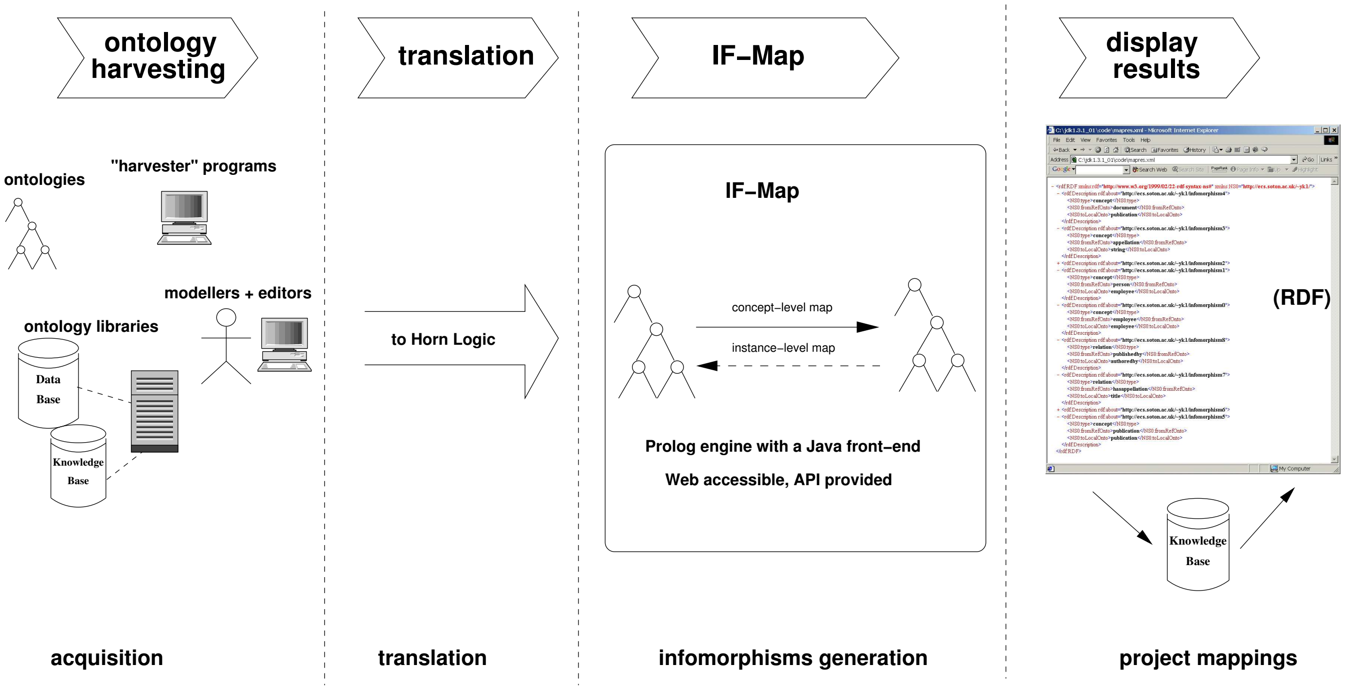

Figure 4: The IF-Map architecture.

trends we experience in developing ontology-supported systems is that we often have to underpin the system's functionality with more than one ontology. The advent of the Semantic Web made that easier to implement as more ontologies are available and accessible online than ever before. The arguments for and against using multiple ontologies are difficult to quantify as it depends on the quality and usage of the ontology in the system. For example, the use of a multiple ontologies structure in the award winning Computer Science AKTive Space application [19] made a difference when dealing with large, heterogeneous data sets extracted from a variety of online resources. These were only made possible to integrate by integrating multiple ontologies describing their semantics. The resulting integrated ontology, however, is a heavy solution (see section 4 for information about the effort involved) and it would have been inappropriate for a simple WBES that employs only a handful of data resources, originating from a single domain and addressing a single educational application (like a University online course). The issue of whether a single or multiple ontologies are better to support WBESs, needs to be viewed under the angle of well defined use cases where the ontological support requirements are clearly identifiable. To the best of our knowledge, such a requirements analysis for WBESs does not exist. Some intuitions though, with respect to scalability of large repositories supporting such systems are provided in [8].

- **Semantic Web enabled WBESs:** the advent and increasing popularity of the Semantic Web poses new challenges but also provides opportunities and solutions for WBESs interoperability. On the positive side we have an abundance of potentially supportive ontologies for a WBES easily accessible and immediately available. Further, Semantic Web initiatives for addressing interoperability issues are well under way and the first mechanisms for supporting this already exist, like specialized ontology mapping built-in constructs for OWL ontologies. On the negative side, the sheer volume of available ontologies and the distributed and loosely controlled structure of the (Semantic) Web sets new challenges for ontology usage in WBESs: authority and version control, trust and provenance, inconsistency and incompleteness, are among the most prominent issues to address before using Semantic Web ontologies in a WBES.

- **Semantic interoperability of WBESs:** a re-occurring theme from the past found new ground in the Semantic Web realm. Semantic interoperability aims at revealing and using semantics to achieve interoperable systems. On the contrary, the bulk of the work done in interoperability, in general, uses syntax only. The crux of the problem is that semantics are often not explicitly stated in artefacts but rather tacitly exist in a designers mind. Semantic interoperability is a knotty problem and as research suggests [12], we are far from having a universal, sound solution in the near future. It affects a variety of systems, including WBESs. We believe that WBESs do not pose any specific requirements for semantic interoperability, albeit an arguably uniform description of their underlying domain (educational artefacts), but they could benefit from semantic interoperability mechanisms especially when multiple, distinct ontologies are used to support them.

- **Community-driven WBESs:** this is one of the directions of WBESs research that could lead to fruitful results for interoperability in general. The unique characteristic of WBESs is that they appeal to large audiences. Hence, vast numbers of learners are immediately available for feedback. How these learners could be used to inform requirements for, or even tune, interoperability algorithms is still at an early research stage. However, user evaluation is a powerful feedback mechanism and WBESs provide a fertile ground for implementing large scale evaluation strategies. Our experiences with communities involvement in the design process of ontologies shows that it benefited and optimized the final artefact, but time and resource constraints should be accounted for.

- **Versatile content:** lastly, but not least, we see content issues as high in the agenda of future WBESs research. Traditional views of educational systems accommodate a rather limited domain of learning: that of University (or similar) online courses. The Web-based extension adds more resources to the traditional view and changes the mode of delivering those courses, but the perception remains the same: offering online courses, in the majority of cases. We advocate that nowadays, a wide variety of content is available online, not necessarily restricted to online courses material: story telling, experiences' reports, social networks, organisational newsletters to name only a few of the many different modes for engaging learners to learning tasks. These ways use versatile content which should be modelled and represented under the same roof, to make it processable by a WBES. Although an ontology will be the preferable choice for modelling this versatile content, interoperability needs arise at the very beginning of using it: distinct content resources will have to be glued together. Therefore, any mechanisms that address content aggregation and management issues should be consulted and possibly employed by interoperability practitioners. We point the interested reader to the work done in the context of the PROLEARN[17] initiative to provide an interoperability framework for learning objects repositories for a discussion on mechanisms to harvest learning content from a variety of resources[6].

6. CONCLUSIONS

In this paper we reviewed the role of single and multiple ontologies in support of WBESs. We argued for the role of communities in informing requirements for interoperable Web-based systems. We highlighted potential research directions for the WBESs community which could benefit Web-based systems communities in general. We would like to wrap-up this paper with a motto: there is a need for achieving interoperability of the means which are portrayed as an interoperability solution for WBESs in the first place: ontologies. And we believe that despite the long road ahead in resolving this knotty problem, WBESs have some unique characteristics which could help improving Web-based interoperability solutions.

[6]LorInteroperability initiative accessible from http://ariadne.cs.kuleuven.ac.be/vqwiki-2.5.5/jsp/Wiki?LorInteroperability

7. ACKNOWLEDGMENTS

This work is supported under the Capturing, Representing, and Operationalising Semantic Integration (CROSI) project which is sponsored by Hewlett Packard Laboratories at Bristol, UK. The first author is also supported by the Advanced Knowledge Technologies (AKT) Interdisciplinary Research Collaboration (IRC) project which is sponsored by the UK EPSRC under Grant number GR/N15764/01.

8. REFERENCES

[1] H. Alani, Y. Kalfoglou, K. O'Hara, and N. Shadbolt. Initiating Organizational Memories using Ontology-based Network Analysis as a bootstrapping tool. *BCS-SGAI Expert Update*, 5(3):43–46, Oct. 2002.

[2] J. Barwise and J. Seligman. *Information Flow: the Logic of distributed systems.* Cambridge Tracts in Theoretical Computer Science 44. Cambridge University Press, 1997. ISBN: 0-521-58386-1.

[3] F. Corrêa da Silva, W. Vasconcelos, D. Robertson, V. Brilhante, A. de Melo, M. Finger, and J. Agusti. On the Insufficiency of Ontologies: Problems in Knowledge Sharing and alternative solutions. *Knowledge Based Systems*, 15(3):147–167, 2002.

[4] J. Domingue. Tadzebao and WebOnto: Discussing, Browsing, and Editing Ontologies on the Web. In *Proceedings of the 11th Knowledge Acquisition, Modelling and Management Workshop, KAW'98, Banff, Canada*, Apr. 1998.

[5] A. Farquhar, R. Fikes, and J. Rice. The Ontolingua server: a tool for collaborative ontology construction. *International Journal of Human-Computer Studies*, 46(6):707–728, June 1997.

[6] R. Genesereth and R. Fikes. *Knowledge Interchange Format.* Computer Science Dept., Stanford University, 3.0 edition, 1992. Technical Report, Logic-92-1.

[7] W. Grosso, H. Eriksson, R. Fergerson, J. Gennari, S. Tu, and M. Musen. Knowledge Modelling at the Millennium - The design and evolution of Protege2000. In *proceedings of the 12th Knowledge Acquisition, Modelling, and Management(KAW'99), Banff, Canada*, Oct. 1999.

[8] S. Harris and N. Gibbins. 3store: Efficient bulk RDF storage. In *Proceedings of the ISWC'03 Practicle and Scalable Semantic Systems (PSSS-1), Sanibel Island, FL, USA*, Oct. 2003.

[9] Y. Kalfoglou, J. Domingue, E. Motta, M. Vargas-Vera, and S. Buckingham-Shum. MyPlanet: an ontology-driven Web-based personalised news service. In *Proceedings of the IJCAI'01 workshop on Ontologies and Information Sharing, Seattle, USA*, Aug. 2001.

[10] Y. Kalfoglou and M. Schorlemmer. IF-MAP: an ontology mapping method based on Information Flow theory. *Journal on Data Semantics*, 1:98–127, Oct. 2003. LNCS2800, Springer, ISBN: 3-540-20407-5.

[11] Y. Kalfoglou and M. Schorlemmer. Ontology mapping: the state of the art. *The Knowledge Engineering Review*, 18(1):1–31, 2003.

[12] Y. Kalfoglou and M. Schorlemmer. A channel theoretic foundation for ontology coordination. In *Proceedings of the Meaning, Negotiation and Coordination workshop (MCN'04) at the ISWC04, Hiroshima, Japan*, Nov. 2004.

[13] Y. Kalfoglou, M. Schorlemmer, M. Uschold, A. Sheth, and S. Staab. Semantic interoperability and integration. Seminar 04391 - executive summary, Schloss Dagstuhl - International Conference and Research Centre, Sept. 2004.

[14] R. Kent. The IFF foundation for ontological knowledge organization. *Knowledge Organization and Classification in International Information Retrieval, Cataloging and Classification Quarterly, The Haworth Press Inc.*, 2003.

[15] O. Lassila and R. Swick. Resource Description Framework(RDF) Model and Syntax Specification. W3c recommendation, W3C, feb 1999.

[16] E. Motta. *Reusable Components for Knowledge Models: Case Studies in Parametric Design Problem Solving*, volume 53 of *Frontiers in Artificial Intelligence and Applications*. IOS Press, 1999. ISBN: 1-58603-003-5.

[17] E. I. NoE. PROLEARN - technolgy enhanced professional learning. http://www.prolearn-project.net/articles/wp4/index.html.

[18] C. Schmitz, S. Staab, R. Studer, and J. Tane. Accessing distributed learning repositories through a courseware watchdog. In *Proceedings of the E-Learn 2002 world conference on e-learning in corporate, govervment, healthcare 4 higher education, Montreal, Canada*, Oct. 2002.

[19] N. Shadbolt, N. Gibbins, H. Glaser, S. Harris, and M. Schraefel. CS AKTive space or how we learned to stop worrying and love the Semantic Web. *IEEE Intelligent Systems*, 19(3):41–47, May 2004.

[20] B. Simon, P. Dolog, Z. Miklos, D. Olmedilla, and M. Sintek. Conceptualising smart spaces for learning. *Journal of Interactive Media in Education (JIME)*, (9), may 2004.

[21] M. Uschold and M. Gruninger. Ontologies: principles, methods and applications. *The Knowledge Engineering Review*, 11(2):93–136, Nov. 1996.

[22] M. Uschold, M. Healy, K. Williamson, P. Clark, and S. Woods. Ontology Reuse and Application. In N. Guarino, editor, *Proceedings of the 1st International Conference on Formal Ontology in Information Systems(FOIS'98), Trento, Italy*, pages 179–192. IOS Press, June 1998.