Semantic Interoperation to Support Context in Adaptive Applications

Alexander O'Connor, Vincent Wade
Knowledge & Data Engineering Group,
School of Computer Science and Statistics,
Trinity College, Dublin 2, Ireland
{oconnoat, Vincent.Wade}@cs.tcd.ie

***Abstract* – The challenge of supporting Ubiquitous Computing is to assist the user by helping their applications make better decisions with better information. Smart spaces and other information sources can provide this information, but it is unrealistic to expect all the information to be represented in the same way everywhere. This means that the goal of ubiquitous computing translates into a problem of information integration.**

This paper presents a new knowledge-driven approach to applying contextual information to user applications. The objective of the design is to use a semantic integration, represented in topic maps, to deliver knowledge found in available services to personalise and improve the functionality of an integrated application. A brief discussion of the different semantic technologies employed in the system is followed by a presentation of the architecture of the system and its novel combination of semantic technologies. Two Use Cases are discussed, one specifically related to Ubiquitous Environments. Finally, the work is related to other research in the areas of Semantic Mediation and Context Awareness.

I. Introduction

The drive towards the Semantic Web is a drive away from human-made, human-managed information exchange towards a more automated, customised method for supporting users in achieving their goals.

It can be argued that ubiquitous environments represent an excellent domain for this initiative: as the space which the user occupies becomes more intelligent, so it can respond better to the needs of its occupants. However, the process of integrating a wide variety of external, contextual information into applications useful to the user has proven to be a challenging area of research.

Similarly, there is considerable benefit to a semantic approach to Ubiquitous Computing. Semantic techniques allow application and service designers to structure complex information in a way that is detailed and explicit. This has the additional benefit of allowing information to be exchanged more easily.

In recent times, there has been a substantial trend in web technology towards a 'web of knowledge'. The web is no longer intended to deliver static, human-generated content to the reader but instead the focus is on the use of services and other machine-mediated functionality to achieve meaningful tasks [1].

Currently, the use of service-oriented architectures to permit users to create and exchange information on the web is based on the idea of hand-tailored orchestrations with output aimed at the human user. This type of usage is becoming increasingly popular, with many sites offering APIs with 'Mashup' creation in mind [2].

This paper outlines a new approach which involves integrating semantically-described services in order to provide a rich information gain to applications. The approach is based in Semantic Web [3] technologies and Topic Maps [4]. The objective is to provide a more expressive and flexible method for integrating information from a wide variety of sources. The system presented, the ACP (Adaptive Contextual Portal) employs a novel, semantic overlay technique to bridge information in separate services. This allows an application to integrate information from a ubiquitous environment in a knowledge-oriented way.

II. Context

It is possible to consider smart spaces and ubiquitous environments as being composed of a set of different services. There are several examples of different service composition methods used to achieve the goal of a smart space [5]. In considering these services, there is a clear delineation between the information which the application *must* have in order to operate correctly, and the information that the application *can*

978-1-4244-2067-4/08/$25.00 ©2008 IEEE.

benefit from to make improved decisions. The latter, beneficial information is context.

Typically, contextual information has been modelled explicitly, for example when modelling location [6]. This is a useful example of context as there are many ways to measure and express a person's location.

Location is a good example of how external information can be used to improve the functionality of an application, by making the behaviour of an application directly relevant to the user based on where they are.

Integrating context into applications is done with the hope that it will allow a better-informed application to make more decisions more effectively for the user. In each application, there is information that is critical to the function of the application, without which the application cannot perform at all. This information is not regarded as context, based on the definition in [7], context is the extra information that can be gained from a smart space that lets the application know more about why or how a task is being achieved, for example with the 5W1H model [8].

The type and content of contextual information depends on the application and the user, but in general it can be identified as information about the user or their task that can be added from sources which were not defined when the application was developed. This means that the specific form which context information takes can vary considerably. Different applications have different information needs, and applications can be used in different settings. One solution is to create a general model for ubiquitous environments, eg [9]. The other is to attempt to integrate different models based on interoperation techniques, as presented in this paper.

Semantic technologies such as ontologies provide a way to integrate a greater range of information, and to discover some of the relationships between different services and the application semi-automatically [10]. The system presented here depends on the richness of semantic descriptions in order to find knowledge that resides in external sources and give it to an application which could not otherwise acquire such knowledge.

III. Requirements

The objective of the design is to support adaptive applications with contextual information in ubiquitous environments. This objective defines the key requirements for the sort of architecture and the technology choices associated with solving the challenges presented.

The first challenge is to support the inherent variety in contextual information. It is likely that the sorts of information used for context will vary greatly, and will have values with potentially very large ranges. In light of this, it is necessary for the ubiquitous services that offer this information to describe their information in a detailed way. This is even more important when there is no explicit pre-determined model of context.

The second challenge is the application domain. Ubiquitous computing environments are rich environments, with many sources of potentially useful information. Each ubiquitous environment is unique, and presents a characteristic set of services and information. There is no guarantee that the model that represents one environment will have any relevance in another. This challenge reinforces the need for a model-agnostic[1] representation of context, but also points to the need for a query-oriented integration model. By starting out without an initial model for context, the integration process can be more general, but at the cost of increased difficulty in finding the integration.

The advantages of ontological and semantic approaches to context modelling have been shown before, eg in [11]. The use of a knowledge-based approach allows applications to discover new information within ontological representations through reasoning, and provides a framework that permits models to interact [12].

Ontologies provide a means for modelling complex information spaces, relating the entities to each other and recording their properties. An ontological reasoner can be used to take advantage of this structured information to make deductions about the described entities, knowledge which was not entered explicitly into the ontology at design.

In examining semantic approaches, one lesson that is apparent is that there is little agreement on the exact methods for describing and engineering ontologies. This arises because of the fact that these schemas are not only tailored to the information that they model, but often to the sort of use that they will be put to. In supporting an ontological approach to ubiquitous computing, there is considerable benefit for the

[1] A system that is model-agnostic is one that makes as few assumptions as possible about what information is going to be integrated. This means that there is no pre-determined set of entities which the context must adhere to. This means that there are no preconceptions in the system about what is, and is not, context.

application to be able to support a variety of semantic modelling approaches as well as syntactical variations.

The Semantic approach tends to suggest the use of services to provide information. A service oriented approach allows for the broader ubiquitous environment to be composed from a varied set of specific services, each of which is an expert at a particular small portion of the overall ubiquitous functionality. Multiple small services point to the need for the integration platform to be able to integrate multiple sources of information. A further advantage of this is to permit sourcing relevant information not only from the 'local' ubiquitous environment, but from any service that is relevant and which can be accessed.

It is intended that the system be designed to support adaptive applications. Adaptive applications are a rich area of research, but in general they can be described as applications which 'build a model of the goals, preferences and knowledge of the individual user' [13]. Adaptive applications maintain complex models of the user, and benefit from knowing more information about the user to whom they are adapting. This sort of application is a natural candidate for Context, as the model-driven architecture that these applications employ are open to new knowledge and users are likely to benefit from not having to go through an extended process for establishing their user model.

The engineering process necessary to create useful ontologies means that it is desirable to retain the full expressiveness of the rich semantic description. As ontologies often have a hand-crafted element, this points to the need to be able to retain this for use in structuring the information exchange.

The step that comes after linking information is *transferring* information. Perhaps the most important requirement for the information integration platform is that it reflect the full set of stages for transferring information. [14] defines three capabilities that an integration platform should have:

- Translating queries on one ontology as queries on a remote ontology.
- Altering instance data to agree with a target ontology's representation.
- Allowing an application to be driven by a different ontology than the one it was designed to use.

It can be argued that the third capability arises from a system that can perform the first two capabilities.

IV. Context-informed Architecture

Traditional context-aware applications generally can be recognised as having a component of their functionality which allows them to import data from sensors or other relatively low-level sources of information and integrate it into their operation[15].

This paper presents an alternative, knowledge-based approach to transferring context information. A knowledge-based approach moves the onus of integration from the application to a contextual mediator, called the ACP (Adaptive Contextual Portal). The Application that the user is employing (called the Target Application) is enriched in its knowledge with context sourced from external services (called the Sources of Context). These services are assumed to contain relevant contextual information, but in a form not readily accessible to the Target application due, for example, to differences in their representation.

In the context-informed model, the aware environment informs the application. The Target Application needs to present two things: an Ontology describing its knowledge, and instance data reflecting its current state. The Sources of Context are described by ontologies, which contain instance data representing their information.

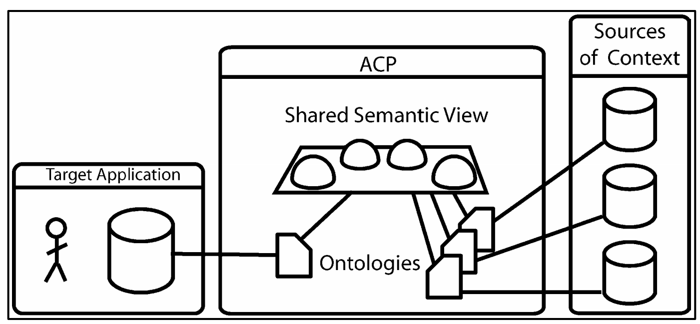

Figure 1: The Structure of the ACP. The Target Application, which is managed by the User is aware of the ACP, which provides enriched models based on information from the Sources of Context.

The principal advantage to the informed contextual model is that it frees the application developer from having to concern themselves with the potentially vast array of possible pathways for context. Instead, the objective of a context-informed design is to provide for functionality that calls for additional information to be included, and an information model that can accommodate the widest possible range of additions.

Context-informed applications are likely to exhibit adaptive behaviour, where their functionality can change considerably based on their information. Internally, adaptive applications often consist of sets of models with detailed metadata. The

Target Application receives new knowledge from the ACP in the form of a new version of its own instance data, as expressed by the ontology describing the application, with the new knowledge integrated by the ACP.

V. Information Model

The information architecture for the ACP (Adaptive Contextual Portal) is centred on the semantic network used to represent the holistic knowledge of the target application and the sources of context. This view of the links between knowledge of the different participants is called the *Shared Semantic View*.

Each participant in the ACP, the Sources of Context and the Target Application, is represented in the system by an ontology describing its knowledge. The ontological nature of these descriptions is particularly powerful, because ontologies allow for knowledge to be discovered: ontological reasoning can provide information not directly input by exploiting the structured relationships of entities in the ontology.

The Shared Semantic View is represented in the ACP as a Topic Map[4]. Topic Maps are a lightweight knowledge structure designed to provide a semantic index and express the relationship between 'topics'.

The structure of a Topic Map is designed to allow complex classification and management of concepts. Topic Maps are centred around Topics, which are representations of external concepts. Each Topic has a unique identifier, one or more names and a link to the resource that it represents. Topics can be linked to each other with Associations. Topics can be used to categorise other Topics as types, which allows the map to represent and categorise Topics by different characteristics.

VI. Constructing the Shared Semantic View

The Shared Semantic View, represented as a Topic Map, is used to construct a lightweight, semantic overlay network to bridge the knowledge from the services that can provide context to the application.

The Shared Semantic View is an abstract representation of the alignment between the Target Application's ontology and the ontologies describing the knowledge of the Source services. The SSV is designed to exploit the lightweight features of Topic Maps to associate the Classes and Properties of the different ontologies with each other, and classify them.

The ACP represents classes and properties as Topics in the Topic Map, but without needing to maintain the underlying relationships between the entities. This structural information is retained by the Schema Manager within the ACP, which is able to access the Ontologies in their native form. This is the mechanism by which the ACP 'overlays' the Topic Map on the Ontologies without losing information. Entities represented in the Topic Map retain their significance by using the Topic Occurrence to refer back to the Ontological description via a URN (Universal Resource Name). This allows the Topic Map representations of ontological entities to be reified directly.

Ontology alignment and matching is a very rich area of research of its own. There are numerous approaches to finding the links between different ontologies. The objective of these alignments is generally to find equivalent and similar classes, or classes that are related by containment, e.g. where one concept subsumes another.

Many of the alignment tools that exist today are off-line processes. The ACP has been designed to be able to import mappings expressed in the INRIA Align format [16], as used in the OAEI Ontology Alignment Initiative [17]. This format allows alignment applications to find, categorise and rate links between classes and properties in ontologies.

These mappings are represented, along with the metadata associated with them, as associations in the SSV's Topic Map. Associations in normal Topic Maps describe the association type and the roles of each topic, and this has been extended to employ an association topic, which itself can by typed and managed as a topic of its own. This association Topic can be used to create complex mappings and filtering of associations.

It is possible to import a number of mapping files from different matcher tools, including hand-coded alignments generated off-line.

Other operations can be performed on the map, for example to consolidate links or disregard low-confidence links.

VII. Transferring Knowledge

Once the Shared Semantic View has been established programmatically, it should ideally be reviewed by a *Semantic Integrator*, an expert familiar with the services being integrated, in order to verify that the automatic elements of the process have created a viable result.

One advantage of the structure of the system is that Topic Maps can be exchanged and combined. This allows an expert user, a Semantic Integrator, to provide a base Topic Map, which could then be customised by a user.

Knowledge Transfer depends on the categorised associations. Associations have a Topic representing them that can be typed with as many different types as is necessary. These types can represent metadata about the link, for example for being used to retrieve links representing a specific relationship, or links identified by a particular alignment tool.

There are three stages to transferring information. The first is to identify information need. This can range from the simple case of a blank space in the Target Application's instance data where a particular value is not known, and range up to complex inferences based on the quality of links.

The Second stage is the Semantic Translation of information. This can be case-specific and complex. In the simplest form, this is the process of moving information from slots as modelled in the Source ontologies into the slots provided by the Target Application's ontology. However, differences in modelling or in representation of the data might mean that there is considerably more work to be done in making the data comply with the requirements of the Target Application's ontology. The expressiveness and complexity of the Ontology Languages means that there is considerable scope for variation in the way similar concepts can be modelled. This is achieved in the ACP by the use of associations and their metadata, types can reflect operations needed to be performed on data in the Source Ontology instances in order to comply with the Target Model.

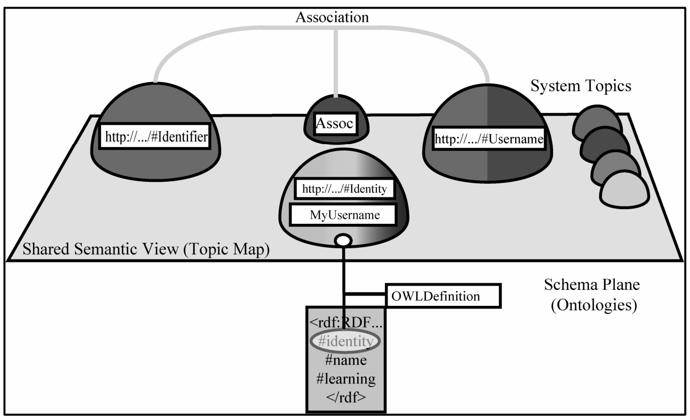

Figure 2: Diagram of the Shared Semantic View Topic Map. Two Topics are associated, and the topic describing the association is shown. In the foreground, a topic with two names and its occurrence link to the ontology describing it are shown. The topics are shaded with the colours of the Types, expressed as topics on the right side of the picture.

Finally, the Syntactic Transformation of the data can include such operations as the transformation of an ontological instance into a form understandable by the Target Application.

The methods for querying an application such as the ACP have been explored in previous work [5]. In summary, the application programmer is able to define points in the process of adaptation where semantic enrichment might occur. In this process, the relevant application model instances are sent to the context portal where the application is already registered and integrated. Knowledge integration is based on the idea that the ACP will return the enriched model in a format immediately understandable by the Target Appliction.

VIII. REASONERS

Importing ontologies, alignments and most other operations on the Topic Maps are achieved by the use of executable reasoners. Reasoners are able to act on the Topic Map, making changes or reading information. Additionally, a reasoner can access the Ontological descriptions in order to find links. Additionally, reasoners are used to manipulate and transfer instance data, for example from the Source Ontologies, in order to create an enriched model instance for the Target Application.

Reasoners are designed to be used in sequence, with smaller reasoners that perform specific operations being sequenced and managed by more complex reasoners.

Different categories of reasoners exist:

1) Reasoners can be created to represent specific operations such as importing Ontological concepts, or associating concepts based on alignments.

2) Reasoners can perform basic operations which can later be composed for more extensive tasks. A reasoner might be defined that is able to transport information between equivalent properties, but translate the way in which the data is expressed, e.g. by changing the weight of an object from lbs. to Kg. This could form part of a larger reasoner that sequences a variety of operations to create an enriched model with all the data in the correct units, expressed in the form needed by the Target Application.

3) Reasoners need not be directly related to import or transfer, they might be used to consolidate or structure the Topic Map. For example, a Reasoner might exist which can merge associations which agree in order to reinforce certain alignments.

Currently, reasoners are structured to directly interact with the frameworks that manage the ontologies, services and SSV. Reasoners currently are written in the core implementation language, and are tied to the structure of the system. In future, it is intended that these native reasoners be replaced or at least supplemented with reasoners written in the domain specific languages of the semantic structures used (for example, TOLOG for Topic Maps and SPARQL for ontologies).

IX. Implementation Considerations

The ACP is implemented in Java. Each component section of the system is written to be able to add new frameworks as required.

The Schema Manager currently supports the Jena Semantic Web Framework [18]. This framework supports a variety of Ontology Languages and dialects, such as RDF and the different flavours of OWL. In addition to loading and managing ontologies, Jena includes a number of ontological reasoners that allow clients to query knowledge from the ontologies, as well as manipulating instance data.

For managing the Topic Maps for the Shared Semantic View, the TM4J Java Topic Map Engine is employed [19]. This API includes an ISO compliant implementation of the Topic Maps Standard and has mechanisms for manipulating all the major Topic Map features. Additionally, TM4J can make use of the Hibernate Object-Relational Persistence Engine.

Reasoners are implemented in the form of Java Classes which conform to a tailored set of interfaces. Reasoners are loaded dynamically using the Java Dynamic Class Loader.

X. Experiment and Use Case

The first example scenario outlined comes from the use of the ontologies from the OAEI 2007 benchmark [17]. These can be described as bibliographical ontologies, describing different schemes representing publication databases. The advantage to these ontologies as a basis for examination is that they include a ‘gold standard’ mapping in the form of an INRIA alignment file[16].

The initial experiment to transfer data between these ontologies was concerned with the equivalence relationship. A partial record, consisting of an ontology instance with many of the details for a particular book blanked. The reasoners employed to perform this transfer include a reasoner to import the ontology classes and properties from each participant. A link is created from each topic to the URI (Universal Resource Indicator) in the ontology describing it. The Topic Map does not represent the relationships between classes or properties within the ontology, as the ACP retains the original ontology as the method for querying information of that sort.

A second reasoner was employed to locate the alignment links between the different classes and properties, as described by the alignment description file.

The third reasoner used scanned the instance information from the Target Ontology, and for each blank class, retrieved links from the Topic Map to find classes with suitable information. The alignments for the properties of the linked classes were then located, and used to query for the appropriate data from the instances in the sources of context.

This experiment evaluated the design of the ACP with independently developed ontologies. This permitted a more rigorous basis for disovering the types and complexity of the reasoners that need to be created to support linking the ontologies from the OAEI benchmark.

Another case study under investigation for the ACP is in the area of supporting ‘Extreme Collaboration’ [20]. Extreme Collaboration is the process of using unstructured discussion between expert individuals to create a high-volume communication environment. Individuals are responsible for specific parts of the project (for example, preparing a cost analysis for a NASA Mission, as in [20]).

Extreme Collaboration takes place in a ‘War Room’ environment, which has many of the properties of an immersive ubiquitous environment. The War Room includes various displays, a number of databases and visualisation tools as well as individual computers and communications equipment. Of particular interest is the software infrastructure in the room, which is based around a publish-subscribe method for distributing spreadsheets, based on an interest list that is managed by each user.

The first area under investigation for the ACP will be to see if it is possible to establish a set of ontologies to represent a similar war-room, but where services are used to record more semantic information. This information can be used to attempt to reflect the interest of the dynamic groups of users by retrieving appropriate documents and visualisations from an adaptive version of the databases outlined. For the initial experiments, the Dublin Core [21] ontology is being used to represent the descriptions of the available documents, while users’ knowledge is modelled with an ontology based on the Description of a Career Ontology [22]. User proximity and Interest list are based on custom ontologies.

The initial phase of this experiment is focussed on trying a set of automatic ontology matchers to find links between the ontological elements. The objective of this case is the transfer of the user's proximity, training and interests to an application that will select appropriate documents for them and the group they are in.

Once this initial phase has been evaluated, the second part of the case study will be to examine supporting the 'Team Leader' role. In [20], the Team Leader is described as setting the priorities and tasks that are most important and requiring of the most resources in the group. This job is complex, requiring the Team Leader to be aware of a large number of complex inter-relationships as they change dynamically, as well as the schedule and tasks associated with the overall project. There is a wide range of potential context in this area, including attempting to model the importance of preference and priority of scheduled tasks. This portion of the experiment is in the early modelling phase, where relevant ontologies are being chosen for potential integration.

The result of this experiment is intended to provide a methodology for developing and assembling reasoners. The 'War-Room' represents a richer combination of different types of information, taken from a variety of services, and further case studies will provide more input into how to engineer a robust set of low-level reasoners along with a process for assembling them to better manage context.

XI. Related work

Direct use of Topic Maps to represent heterogeneous context has been described before [23]. The objective of this work is to retain the ability to navigate the ontological definitions of the contextual information, and to apply a set of programs (reasoners) to construct a lightweight representation of the concepts and their inter-relationships in the Topic Map.

There is a rich community of research in the area of semantic alignment and ontology matching. Many of these, such as the Falcon Alignment Engine can be used on a variety of different schemas to find alignments. Many of the main candidates for automatic matching can be compared via the OAEI Workshop, which is run each year. The Benchmark ontologies used in workshop have formed part of the basis for checking coverage in the ACP implementation [17].

The field of ontology mapping has been surveyed by [24]. In this survey, the authors assert that "a single ontology is no longer enough to support the tasks envisaged by a distributed environment like the Semantic Web". The authors define six different terms for alignment, and show that a wide variety of approaches and technologies exist under the umbrella term of ontology and schema matching.

There are a number of other approaches to the problem of bridging representations in different ontologies. A number of proposals have been made to relate ontologies to a canonical upper ontology. There are two approaches to relating ontologies to higher level models. The first approach is to make use of an agreed upper ontology as the basis for engineering ontologies. In this case, new concepts related to the specific ontology domain are created with reference to the upper ontology's entities. For example, a new domain concept referring to a specific model of a car might be related to the more general automobile concept in the upper ontology. This has obvious advantages in the area of semantic interoperation, since it facilitates the process of finding close concepts by virtue of examining the references that entities make to their shared ontology. It is important to note that these relationships need not be limited to equivalence. Negative relationships (eg. disjointness) are one example of another relationship that can be defined. It is interesting to note that IEEE SUMO[25] in particular is, in effect, the result of an extensive process of semantic interoperation. The SUMO ontology is commonly used in conjunction with the mid-level MILO ontologies and other domain specific schemas. This demonstrates one reason that a different direction was chosen for the ACP project: it was not thought to be useful to restrict potential ontologies to those in use in the SUMO project. The second method involving upper ontologies relates to the process of engineering ontologies with direct reference to an upper ontology set.

The second method for finding mediation is to use logical rules to describe the mappings between a local and 'global' ontology. The OIS model describes using Description Logics (DLs) to represent the links between a local and global ontology in these logics. This facilitates the construction of queries to the linked ontologies, also expressed in a similar form.

Another approach to bridging ontologies is to extend the language directly. One example of this extension is the C-OWL initiative [26]. C-OWL defines a set of relations that can be used to create a 'Context' from ontologies. This allows the user to make a personalised schema from ontologies, expressed as a set of 4-tuples.

The ACP uses a Topic Map to express the links found in ontologies described in their native languages. The advantage of using a general, semantic structure such as a Topic Map is that it allows the Semantic Integrator to decide how alignments are described. The fact that the ACP retains the ontological definitions means that the transfer process can be based on the original descriptions of the information available, without the loss of expressiveness that might result from automatically translating the ontologies into another form. Finally, because topic maps represent the entities in the Target Application and Sources of Context, it is possible to create alignments between ontologies described in different formats, while reasoners can still access the original descriptions in order to create queries. In effect, the ACP attempts to provide a means to create and query custom upper ontologies, while placing the minimum pre-requisites on the Target Application or Sources of Context.

XII. Conclusions & Future Work

This paper has presented a system for providing context-informed enrichment of adaptive applications. The ACP, Adaptive Contextual Portal, is designed to establish a Shared Semantic View, which represents a semantic overlay over the detailed ontological definitions provided by services contributing to the System.

The Context-Informed approach means that the Target Application operates without any knowledge of the ubiquitous environment in which it is situated. It delegates the task of identifying, translating and integrating new contextual knowledge to the ACP. This has the advantage of reducing the need to support the numerous low-level concerns that context-awareness imposes on applications, but at the cost of needing to be able to accommodate an open, model driven exchange.

The ACP employs a knowledge-driven, semantic interoperation approach to locating and transferring information from the Sources of Context to the Target Application. In particular, this means that the ontological relationships are queried in order to gain structured information.

The current state of the system is that trials are being undertaken with a variety of scenarios (including those outlined in this paper) in order to determine the reasoners required for a basic reasoner toolset that can be used to construct new scenarios.

The next phase of development of the ACP will be concerned with moving towards increasing the amount of semantic reasoning undertaken both at the SSV and ontological level. This will involve the extension of the Topic Map model to assist in querying the structure of reasoned ontologies in more depth, in order to assist in exploiting the facility for gaining new knowledge from ontological reasoning.

There is a possible logical extension to this knowledge discovery wherein the Target Application's ontological model itself could be altered by the ACP. This might be employed to add completely new knowledge to the application. In practice, this will impose strict requirements on the adaptability of the Target Application, and may be possible only in a narrow set of scenarios.

One area which has not been discussed is service discovery, particularly with regard to Sources of Context. It is difficult for the Target Application to express its contextual need automatically, as it has no knowledge of the services that are present in the aware environment. The question of how to describe contextual offerings remains an open one for this project.

The ACP conforms to the requirements set out in advance for it. The advantage of translating links into topic map associations is that, in principle, it can represent links between numerous schemas of any form, so long as their entities can be related to the topics in the map.

The system is highly schema-agnostic. In the use cases described above, the INRIA alignment format[16] is employed, and this imposes a simple set of relationships between the topics. However, as the associations are themselves described by topics, it is possible to create reasoners that can translate different relationship types onto alignments, or otherwise merge or manipulate alignments based on their properties.

Currently, the process of querying the ontology underlying the topic map must be orchestrated within the reasoner. However, the future work described above is intended to allow for reasoners written in the query languages of the semantic structures to be used to call remote ontologies.

Acknowledgements

This work is funded by the Embark Initiative of the Irish Research Council for Science, Engineering and Technology: Funded by the National Development Plan.

The Authors would also like to thank Kal Ahmed for his advice on the implementation of Association Semantics.

References

[1] Shadbolt, N; Hall, W; Bernes-Lee, T.; *The Semantic Web Revisited*; IEEE Intelligent Systems, 21 (2) pp 96-101

[2] Ankolekar, A., Krötzsch, M., Tran, T., and Vrandecic, D. 2007. The two cultures: mashing up web 2.0 and the semantic web. In *Proceedings of the 16th international Conference on World Wide Web* (Banff, Alberta, Canada, May 08 - 12, 2007). WWW '07. ACM, New York, NY, 825-834

[3] Berners-Lee, T; Hendler, J; Lassila, O: *The Semantic Web*; Scientific American, May, 2001

[4] Pepper, S.*; The TAO of Topic Maps: Finding the Way in the Age of Infoglut;* XML Europe Conference, 2000

[5]Brønstead, J; Hansen, K.M.; Ingstrup, M; *A Survey of Service Composition Mechanisms in Ubiquitous Computing*; Second Workshop on Requirements and Solutions for Pervasive Software Infrastructures, UbiComp 2007 Workshops Proceedings, Innsbruck, Austria, 2007

[6] Strobbe, M et al.; *Design of CASP:* an Open Enabling Platform for Context Aware Office and City Services; Fourth international Workshop on Management of Ubiquitous Communications and Services, Munich, Germany, 2007

[7] O'Connor, A; *Mechanisms for Context-Informed Adaptive Hypermedia*; MSc. Thesis, available as TCD CS Technical Report; TCD-CS-2005-15; 2005

[8] Shimazu, K., Arisawa, T., and Saito, I. 2006. Interdisciplinary Contents Management Using 5W1H Interface for Metadata. In *Proceedings of the 2006 IEEE/WIC/ACM international Conference on Web intelligence* (December 18 - 22, 2006). Web Intelligence. IEEE Computer Society, Washington, 19, 909-912. DOI= http://dx.doi.org/10.1109/WI.2006.104

[9] Chen, H; Perich, F; Finin, T; Joshi, A; *SOUPA: Standard Ontology for Ubiquitous and Pervasive Applications*; proceedings of the International conference of Mobile and Ubiquitous Systems Networking and Services, Boston, USA, 2004

[10] Wang, X.H.; Zhang, D.Q.; Gu, T.; Pung, H.K., "Ontology based context modeling and reasoning using OWL," *Pervasive Computing and Communications Workshops, 2004. Proceedings of the Second IEEE Annual Conference on* , vol., no., pp. 18-22, 14-17 March 2004

[11] Gu, T; Wang, X; Pung, H; Zhang, D; *An Ontology-based Context Model in Intelligent Environments*, In Proceedings of Communication Networks and Distributed Systems Modeling and Simulation Conference, San Diego, California, USA, January 2004

[12] Yang-Seung Jeon, Eun-Ha Song, Minyi Guo, Kaurence T. Yang, Young-Sik Jeong, Sung-Kook Han, Sorrento, *Ontology-based composition of web services for ubiquitous computing;* Frontiers of High Performance Computing and Networking - ISPA Workshops,Italy, Dec. 1-4. 2006, LNCS 4331, pp.559-568.

[13] Brusilovsky, P; *Methods and techniques of adaptive hypermedia*; User Modelling and User Adapted Interaction, Special Issue on adaptive hypertext and hypermedia, vol 2, n 2-3, pp 87-129, 1996

[14] Noy, N.; *What do we need for ontology integration on the semantic web*, Proceedings of the Semantic Integration Workshop Collocated with the Second International Semantic Web Conference, Florida, USA, 2003

[15]Lonsdale, P., Baber, C., & Sharples, M. (2004). A Context Awareness Architecture for Facilitating Mobile Learning. In J. Attewell & C. Savill-Smith (Eds.), *Learning with Mobile Devices: Research and Development* (pp. 79-85). London: Learning and Skills Development Agency.

[16] Euzenat, J; *An API for ontology alignment*; http://alignapi.gforge.inria.fr

[17] Euzenat, J et al.;*Results of the Ontology Alignment Evaluation Initiative 2007*; Proceedings of Workshop 7: Ontology Matching; 6th International Semantic Web Conference & 2nd Asian Semantic Web Conference, Busan, Korea, 2007

[18]Jena Homepage; http://jena.sourceforge.net

[19] TM4J Homepage; http://tm4j.org

[20] Mark, G; *Extreme Collaboration*; Communications of the ACM, Vol 45, No. 6, pp89-93, June 2002

[21] Dublin Core Metadata Initiative; http://dublincore.org/schemas/rdfs/

[22] Parada, R.A.; *DOAC Vocabulary Specification*; http://ramonantonio.net/doac/0.1/

[23] O'Sullivan, D; Power, R.; *Bridging hetero-geneous, autonomous, dynamic knowledge at runtime*; 1st International Workshop on Managing Ubiquitous Communications and Services, Waterford, Ireland, 2003

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

[25] Niles, I., and Pease, A. Origins of the Standard Upper Merged Ontology: *A Proposal for the IEEE Standard Upper Ontology.* In Working Notes of the IJCAI-2001 Workshop on the IEEE Standard Upper Ontology, Seattle, Washington, August 2001

[26] Bouquet, P; Giunchiglia, F; van Harmelen, F; Serafini, L; Stuckenschmidt, H; *C-OWL: Contextualising Ontologies*; Proceedings of the 2nd International Semantic Web Conference, 2003