Ontology Based Policy Mobility for Pervasive Computing

Sven van der Meer
Brendan Jennings
Waterford Institute of Technology
Ireland
Email:
vdmeer@tssg.org
bjennings@tssg.org

Declan O'Sullivan,
David Lewis,
Trinity College Dublin
Ireland
(Declan.Osullivan
|Dave.Lewis }@cs.tcd.ie

Nazim Agoulmine
University of Evry Val d'Essonne
France
Email:
nazim.agoulmine@iup.univ-evry.fr

Abstract

The array of devices, networks and resources available in pervasive computing environments, or smart spaces, will require effective self-management systems controlled via user-level policies. However, the local nature of smart spaces means that they present a potentially huge increase in the number of and nature of management domains, e.g. representing individual homes, shops, businesses, schools, hospitals etc. However, differences in local domain models and local resource models means that policies relevant to one smart space will often use different semantics for subject and target objects compared to other pervasive computing domains. To allow users to capture personal preferences in terms of policies that can be consistently applied as they roam between smart spaces, the semantic interoperability problem resulting from different models for policy subjects and targets must be overcome. In this paper we present a framework where the use of ontology-based semantics for policy elements allows dynamic ontology mapping capabilities to support policy mobility. We demonstrate its operation with a case study showing policy mobility in a policy-driven smart space management system.

Keywords

Ontologies, policy-based management, pervasive computing.

1. Introduction

Pervasive computing describes situations where processors, sensors, actuators and displays are integrated into the physical fabric of everyday life, e.g. personal computing devices, household appliances, furniture, buildings, transportation, all linked though a ubiquitous mixture of wired and wireless networks [weiser]. Pervasive computing users represent a large market for service providers offering:

cellular services; access networks e.g. managed WLAN access; and application services such as 3G services or web services. However, a large proportion of the operational management for pervasive computing systems will fall on those responsible for particular pervasive computing environments. This typically will be those responsible for the operation of certain physical spaces, e.g. retail units, transport termini, universities, hospitals and private homes. We refer to a physical space equipped to operate pervasive computing as a smart space. Those responsible for the operation of a physical space, e.g. a university campus or airport, may treat sub-areas , e.g. an academic department building or a fast-food concession, as individual smart spaces and allocate some aspects of operational responsibility of the smart space to those who are more specifically responsible for running and using the space, e.g. technical support team in an academic department or the fast-food restaurant manager. We term each domain of operational responsibility as a managed zone. Thus managed zones can be nested and an authority operating a parent managed zone can delegate some operational responsibility to the authorities operating the child zones. However, there is also the opportunity for managed zones to overlap, for instance a fast-food restaurant chain may manage all the WLAN in its premises as a single distributed management domain, which it could thus view as a distributed managed zone. Where the restaurant are located in a concession, the managed zones of the restaurant chain and that of the concession giving body, e.g. the airport operator, will overlap, requiring mechanisms for resolving any resulting conflicts.

The operation of managed zones promises to be highly complex due to the range of types, the variable interconnectedness and adaptive, context-aware behaviour of the managed devices and services involved. Policy-based management offers the opportunity for easing the cognative load on human administrators by allowing them to specify policies related to organizational goals. However, pervasive computing systems, need to adapt to different contexts in different smart spaces, or changing context due to user or device mobility and resulting changes in network connectivity as well as varying device capabilities in terms of user inputs, displays, processing power, battery life, access link. Therefore, managed zones will have to exhibit characteristics of autonomic systems [kephart]. This is where smart spaces adapt autonomously to changes in context and specific user task requests but with policies providing instructions on the goals to be achieved by and constraints imposed upon this adaptive behaviour . The use of policy-based management for managed zones differs from its proposed use in autonomic management of computing or communication resources in that a broader range of policy-authors will be involved. Rather than policies being the remit of clearly identifiable administrators of server farms, storage arrays or communication networks, smart space resources must enforce management policies from different organisational groups and roles in particular, and most importantly by the individual user of the smart spaces. User policies can be used to specify user preferences for adaptive service behaviour, e.g. specifying the use of certain mail servers where possible or a preference for low cost over reliability for certain service types.

The source of the most serious challenges to implementing managed zones for autonomic management of smart spaces are not technological but structural. Embedding processors, sensors and actuators in everyday products implies an explosion in the number and type of organisations that need to be involved in achieving the seamless interoperability implied by the pervasive computing vision. Many of the network interoperability problems can be addressed by Internet protocols and XML data encoding. However, the potential for debilitating heterogeneity of semantics in application level interoperability remains. Consider the complexity involved in reaching agreements on and enforcing conformance to interoperability standards when the players involved expand from the likes of Microsoft, IBM and Cisco to all the potential organisations with applications embedded in their products, e.g. Kellogs, Nike, GAP, Yale, Ford, Pizza Hut, Pentel to name a few implied by pervasive computing scenarios. It is therefore clear that the pervasive computing vision implies a massive increase in scale of the application interoperability problem.

The work presented here is motivated by the belief that we cannot, therefore, rely on shared a priori knowledge, via common interoperability standards, to solve the application interoperability problems on the scale needed for pervasive computing. Instead, management software must somehow adapt at deployment time and at runtime to ensure that policies from disparate sources can be meaningfully applied to heterogeneous resources.

In this paper we examine the potential for using ontology-based semantics for supporting the run-time semantic interoperability required to allow user policies to be applied in different managed zones with different prevailing models of the managed resources. Automatic semantic interoperability between ontologies representing arbitary, separately developed models is currently beyond the abilites of current semantic reasoning techniques. However, we present a framework that guides the design and reuse of ontologies, and the mappings between them, in the development of managed systems towards a position where runtime semantic interoperation is feasible. This framework aims to minimise the human developer effort expended on ontology mapping while maximising the chances of successful automated semantic interoperability of the deployed managed system. We provide a case study showing how this framework could be used in the context of policy mobility between smart spaces with different management information models.

2. Semantic Interoperability for Policies

Interoperability problems can be classified as: *system*, i.e. related to hardware and operating systems; *syntactic*, related to representation languages and data formats; *structural*, related to model representation; and *semantic,* related to different meaning given to terms [sheth]. Ceri and Widom identify four categories of semantic conflicts [ceri]: naming conflicts (homonyms and synonyms); domain conflicts due to different reference systems, e.g. imperial vs. metric; structural conflict where differently structured data represents the same concept; and meta data conflicts, e.g.

where a entity is a class in one system and an instance in another. Ontologies can be used to describe the semantics of information sources and make the content explicit, and thus can be used to discover semantic equivalence between information concepts. A number of approaches to ontology-based semantic interoperability have been proposed [wache], mostly implemented as design-time assistance for human ontology mapping activities. However as ontologies represent formal semantics, then some semantic interoperability can be achieved by runtime comparison of and inference about ontological information. Though system and syntactic interoperability in management systems is increasingly supported through the use of XML [lewis01] and related translation techniques such as XSLT, structural and semantic interoperability (which together will be termed semantic interoperability in this paper) in information interchange between management systems of different parties continues to be a difficult problem. Design time solutions such as enforcement of standards conformance or hand crafted interoperability gateways are inappropriate for systems that want to exchange information in dynamic environments [cui], of which pervasive computing is one of the most extreme examples.

In network and system management domain, proposals have been already made for the use of ontologies in management information modelling. In [lavinal] and [shen], ontologies are used to capture management information specifically to support interaction between intelligent agent in management management systems. In [vergara] information models are mapped into ontologies to support the manual mapping between different information models. The approaches in [lavinal] and [vergara02] both use the DMTF’s Common Information Model, [dmtf] partly because of its current precieved usefulness and also because its meta-schema is similar in conceptual structure and data type capabilities to description logic based ontology languages such as OWL [owl]. It should be noted however that management information meta-model concepts that make these information models useful as management interface definitions, e.g. notifications, methods and bindings to management protocols, have no direct equivalent in ontology languages and need to be modeled explicitly. In policy-based management there has been some movement toward the use of ontologies in policy languages [tonti] with the aim of supporting more expressive and flexible policy definitions and using ontology-based reasoning to support policy authoring and conflict resolution. The relationship of ontology-based policy languages such as Rei and Kaos is discussed under related work.

3. Policy Management of Smart Spaces

The behavior of devices in pervasive computing environments is affected by a number of factors not directly related to the devices themselves, but rather determined by the use of the space in terms of task allocations and architectural morphology. Knowledge of the tasks undertaken within a space can be used to influence management decisions without anticipating what devices are likely to appear and their requirements. Equally, the way in which an architect designs a space or a set of spaces radically affects the movement potential, communication patterns and service behaviour that are possible within and across smart spaces and thus the capabilites of the managed zones via which they are operated. The real challenge is to enable mobile people and devices to roam across such spaces whilst maintaining communication and information services. In order to manage resource discovery and resource access the management strategies and rules should be mobile, requiring policy mobility.

We have realized a technical environment based on mobile and cellular IP [barratt] and integrated an hierarchical policy-based management (PBM) system [ghamri-doudane]. The integrated system and the enforcement of policies are shown in Figure 1.

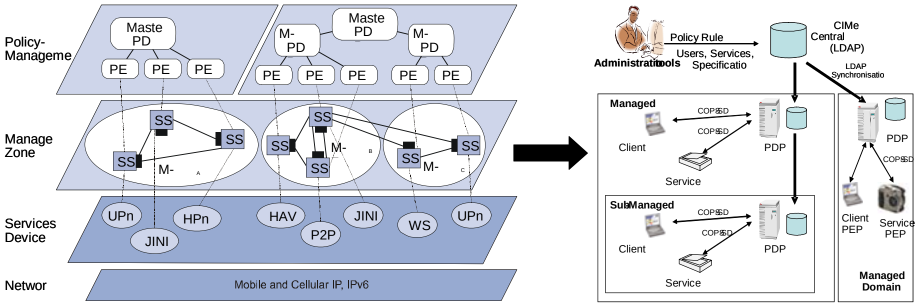

Figure 1. Policy Based Management and Smart Space Integrated System

We have developed a layered architecture to integrate hierarchical PBM with smart spaces. The lowest layer covers the network environment, here a combination of mobile and cellular IP with WiFi access points and an IPv6 backbone. On top of this, we use different state of the art technologies such as UPnP and Jini to locate, to access and to control devices. These devices are assembled within smart spaces and administrated within managed zones. The PBM system is used to support the managed zones in managing resource discovery and resource access. It uses master and local Policy Decision Points (PDP) and smart space specific Policy Enforcement Points (PEP). A PEP can access a resource via a control component that is mediating between the PBM and the employed technologies.

The right half of Figure 1 shows how policies are enforced. This mechanism follows the PBM architecture as defined by the IETF. An administrator defines the rules, conditions and actions that form a policy, using a pre-defined specification for Service Level Agreements (SLA), users and services. We have used DMTF-CIM as the basis for this information model because it is used as a reference model representing network and service information in the IT world. The administrator is supported with a set of tools for the definition of user and group profiles. CIM allows for the definition of the static view of the environment (user, network, service description) as well as the dynamic view (policy rules). Each profile defines a set of authorization and refrain policies concerning the use of resource in a specific smart space of a managed zone. The policy definitions are stored in a Policy Repository, which is queried by the PDPs. We used LDAP [openldap] for implementing the repository, which provides a shared space for storage, search and update of policy data. The PDP negotiates services via two different types of PEPs – provider PEP offering services and consumer PEP consuming these services. New customers need to identify themselves, the PDP determines access rights and sends the PEP a set of attributes that will allow it to interact with available authorized services. The PDP will notify all PEPs about newly available services. The PEP has to be installed on each customer terminal and any equipment in the smart space. Adaptors (proxies) may be used for equipment that cannot support this requirement. The communication between PEP and PDP is realized with COPS [boyle]. We have enhanced COPS with service discovery capabilities, termed COPS-SD [ghamri-doudane], to provide a simpler, more integrated managed zone infrastructure for both service discovery and policy-based management

This system can be used to dynamically apply resource access policies within a managed zone. For instance, we can specify that registered users get unlimited access to all printers, including expensive color printers, whereas guest users can only print on dedicated devices. When a guest user is registered by the administrator, he will automatically gain full access rights to all printers in the managed zone. We have implemented access to printers, scanners mail servers and web servers. These resource form the core of an office environment which was the main focus of the development work.

4. Policy mobility

The system described in the previous section enables the dynamic policy-based management of a single managed zone (intra managed zone). Considering multiple managed zones, where each is subject to autonomous procurement decisions and differing application-driven domain models, the semantic interoperability of policies can immediately be seen to arise in two situations. Firstly, where managed zones are nested hierarchically, a policy in a parent zone may need to be enforced in a child zone. Secondly, where a policy is related to the smart space behaviour preferences of a specific user, it must be enforced in different zones as the user roams. We focus here on the second scenario, as it clearly has more demanding requirements for runtime semantic interoperability. As stated earlier, the problem is structural. Our aim is the seamless roaming of a device or a user between managed zones (inter managed zones). Seamless means that the device or the user can instantly enjoy similar services with similar access rights and behavioural preferences, without manual re-configuration as a user’s personal policies are applied in differnet zones.. We focus here not on the differences in the concepts embedded in different policy languages, e.g. roles, domains, expression of deonic concepts and their delegation etc. Instead we focus on the semantics of the information models used to express the subjects and targets of policy rules and the actions that are performed between them. To outline this complexity in practise we use the following example. A smart space provider is managing different smart spaces for Small to Medium Size Enterpises (SMEs). Some of the SMEs require sophisticated managed zones using the CIM based PBM system introduced above, others are satisfied with a small and simple managed zone using the printer MIB [bergman] and standard PBM system. Mobile policies could be access control polcies if they related to resource that the user carries with them, e.g. access to a laptops GPRS Internet link. However, we expect mobile policies will more likely be obligation policies related to the users preference to using a resource (e.g. if document length is over 30 page set printer to 2up mode), or policies guideing the selection of services in the current smart space (e.g. always use the printer with the highest output capacity) However, the semantic interoperability of a mobile policy and the specified profiles for users and services remains a problem.

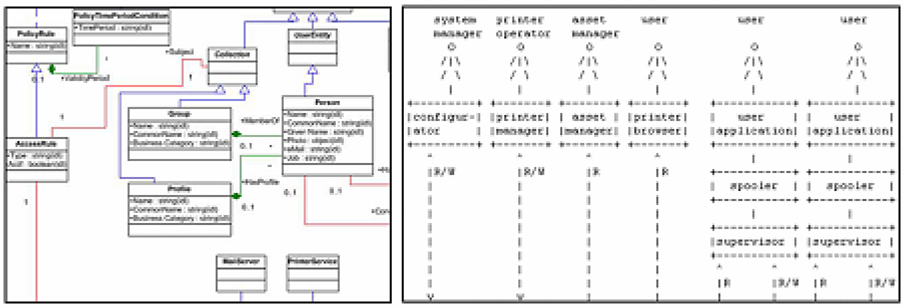

Figure 2: Fragments of CIM and Printer MIB

Figure 2 shows fragments of the CIM information model (left) and the printer's view of the network as the other information model [bergman]. In the CIM model, a user and a group are managed entities associated to access rules for services, in our example for a printer service. In the second model, users are categorized by means of system manger (configurator), printer operator (printer manager), asset manager, user (printer browser) and user (printing application). To move a policy from one domain to the other, these relationships have to be semantically translated and the pre-defined access rights have to be adapted to the given specifications. Thus, the CIM model can have any kind of configuration, including different natural languages, which are (semantically) not compatible to the second model.

5. Semantic Interoperability for Policies

In this context, we have been investigating ontology processing techniques to dynamically bridge between the terminology of two different pervasive computing environments which we assume have been developed using different ontologies. In [osullivan] we have shown how such dynamic bridges can be automatically generated given a set of ontology mappings.

The key challenge which has been our most recent focus is on how the mapping information between the ontologies can be derived. Automatically deriving ontology mapping information at runtime without the involvement of a human is generally considered impossible [klein] and so the challenge in our work has been to identify an integrated software and process framework which will minimise the amount of design time work involved and devolve as much work as possible to a runtime algorithm. Minimising design time work and devolving as much as possible to runtime processing is crucial for the uptake of this approach in pervasive computing environments. Equally important is maximising the applicability of human generated ontology mappings by ensuring it is sufficient to maximise chances of a successful runtime mapping between information conforming to concepts from the two ontologies concerned.

The resultant OISIN (**O**ntology **I**nteroperability for **S**emantic **IN**teroperability) framework is overviewed in Figure 3.Providing full details on the software and process elements of the OISIN framework would not be feasible in this paper but rather in this section we focus on how the OISIN framework has been applied to support policy interoperability.

In the first two phases the ontologies which are referenced by the policies from each party are characterised individually. In order to do this we had to first develop two ontologies representing the core concepts that would be used in authoring policies in the two SMEs, that is a CIM based ontology and a Printer MIB based ontology. Of course it is assumed in future that these ontologies would be preexisting.

The first phase of the framework transforms the ontology (whether in Ontology Web Language (OWL) format, relational database format etc.) into a common internal format. The software tools in the second phase characterise:

- the quality[1] of the ontology, so that poorly definined ontologies can be filtered out;
- the lexical patterns used in the ontology, to determine if it is suitable for the runtime algorithm;
- the dimension of the ontology, which will be used in determining the extent of partial mappings possible.

In the third phase class and property names of the ontologies are lexically compared (with support of WordNet and an encoded telecommunications domain specific thesauris) to identify potential matches (through exact or synonym matches) of ontology classes and their properties. This analysis is presented to the user in a graphical manner at the class level and a textual analysis at the property level once a class is selected. In Figure 4 for example the **M** identifies exact lexical matches (e.g

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[1] through referring to ranking services such as SWOOGLE and/or through interaction with peers

Printer) and the **P** identify partial matches on a lexical or synonym basis (e.g. Person partially matches on a partial synonym basis to Operator, Manager and User).

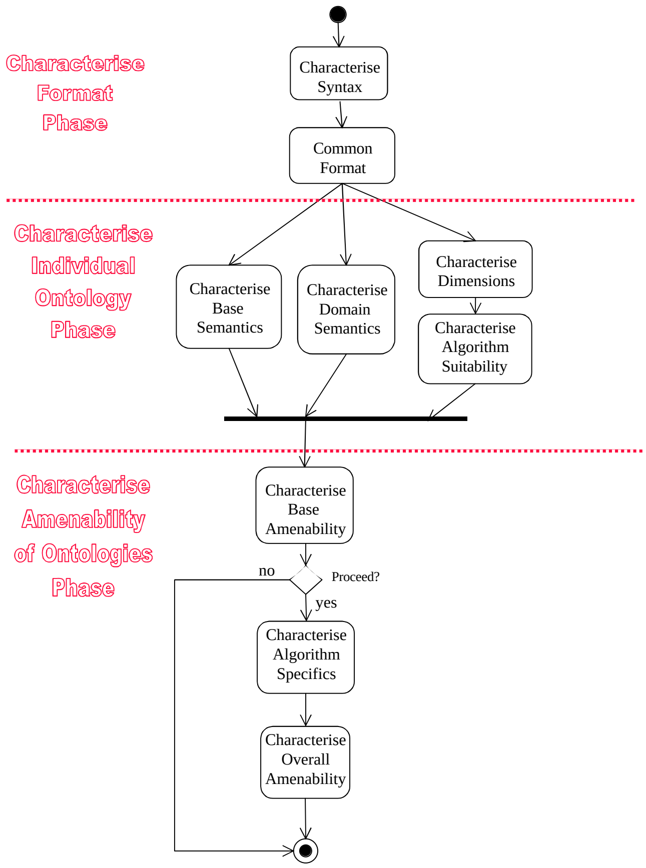
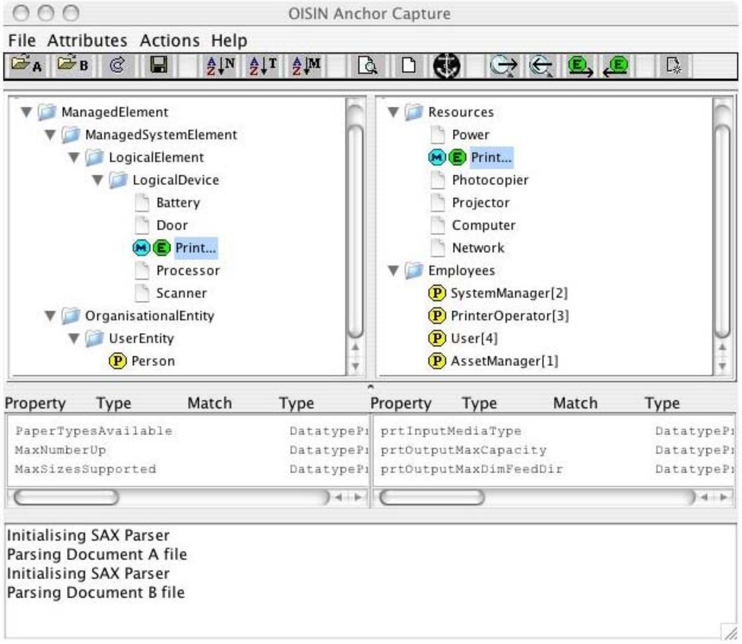


Figure 3: OISIN Process Overview

The user then identifies the “anchors” which correspond to key partial candidate mappings between the ontologies. This involves examining the two ontologies to try to identify equivalent concepts. During this examination typically the properties of the concepts are examined to identify equivalence as well. In our example the MaxNumberUp property property of the CIM Printer class can be seen to be equivalent to the prtOutputMaxCapacity property concept of the MIB Printer class. Once an anchor is chosen it is annotated with an **E** (e.g. Printer in the figure). In addition, transformation code can be associated with a mapping in order to provide the ability to translate from one value range to another.



Property	Type	Match	Type
PaperTypesAvailable			DatatypeP
MaxNumberUp			DatatypeP
MaxSizesSupported			DatatypeP

Property	Type	Match	Type
prtInputMediaType			DatatypeP
prtOutputMaxCapacity			DatatypeP
prtOutputMaxDimFeedDir			DatatypeP

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Initialising SAX Parser
Parsing Document A file
Initialising SAX Parser
Parsing Document B file
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Figure 4: Example of OISIN anchor capture process

During this process “anchor paths” are also identified. The concept of “anchor paths” was first introduced by [noy01]. The idea is that if two anchors are specified in the isa hierarchy of Ontology A the chances are that the classes which appear in the intervening path have a good chance of correspondence with those on the path of the corresponding anchors in Ontology B.

A key differentiation of our approach from others (e.g. PROMPT/Anchor tool [noy00]) is our belief that the determination of what is or is not considered an actual mapping can only be undertaken in the context of the applications involved in using the mappings and what they are trying to achieve. Thus our graphical tool helps the user identify candidate anchor and anchor path mappings. For this reason the original matching information as well as the partial mapping candidates provided by the user are made available to the application. Thus the output of this phase is a set of candidate anchor mappings (expressed using the owl:equivalentClass and owl:equivalentProperty XML elements), the lexical matching information for class and properties, the candidate anchor path information and the equivalence transformation information. This set of information is then used at runtime to transform terms used in a policy by party A into terms used in a policy by party B.

6. Related Work

This work is similar to that in [vergara03] and [vergara04] in that it proposes a methodology for mapping between management information models and implements tool to perform this mapping. Though their work also uses the concept of anchor points in ontology mapping [noy00], it is focussed on the main standardised information models, i.e. SMI, CIM, GDMO, and aims to develop a common ontological information model which a manager can use to manage agents conforming to the different standards via gateways which implement the mappings developed. Our approach aims to address the more open corpus of management information that can be expected in pervasive computing environments, with the aim of minimising manual model mapping and maximising automatic runtime mapping, which then have the potential to take into account the context of the mapping operation. The application to policy mobility is chosed specifically because it can only be achieved for pervasive computing by runtime mappings.

Our work is highly complementary to work on using ontology languages to express policies. The KaoS policy language [uszok] is expressed in DAML+OIL, a forerunner of OWL. Ontology-based reasoning is used in tools to support the policy engineering process, e.g. in developing and reusing policies and in resolving policy conflicts. The Rei policy language [kagal] has an RDF rendering and has been specifically applied to pervasive computing application, where the use of RDF allows policy subjects and targets to be defined through the properties they satisfy rather than specific indetification of group membership. Our work is complementary to these languages in that policy elements must be converted into OWL in order to be subject to the mapping process, so the use of Rei or KaoS would fit well, though we do not exclude mapping into and out of non-ontology based policy languages such as Ponder [damianou]. Though these language use ontologies to allow policy expression that include concepts from multiple different domain, neither of them directly address the policy mobility issue, i.e. that the semantics of the policy rules remains intact even when the domain concepts used in the element of the rule have changed.

7. Conclusion and Further Work

This work presents initial results into an ontology-based development framework that aims to support automatic runtime semantic interoperability between separately administered managed zones used for operating pervasive computing environments. The work focusses on meeting the requirements of policy mobility between such managed zones, though the framework can be equally applied to the selection and invocation of services [osullivan].

The framework aims to minimise the human involvement in mapping between two ontologies to that which is sufficient to guarantee the maximum chance on successful mapping being generated between concepts at runtime. In future work we also aim to show that such minimal human generated mapping allows automated mappings to be made that are most appropriate to the runtime context. This avoids the problem caused when human generated mappings are based on decisions that prejudge the problem domain in which the mapping is required. More broadly, we need to deepen our understanding of the role which ontologies can play in the modelling of management information, the maintenance of multiple models (including versioning), the binding to concrete management interfaces and software functionality and the use of mappings for guiding conceptual convergence between models.

Acknowledgements

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