A Semantic Approach for Description and Ranked Matching of Services in Pervasive Environments

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Abstract: With the recent developments in technology, new and diverse devices are being introduced into the pervasive world. This has raised new challenges for the discovery of devices and their services in dynamic environments. The existing approaches such as Jini [AOSJ99], UPnP [UPnP06], etc., describe services at a syntactic level and the matching mechanisms in these approaches are limited to syntactic comparisons based on attributes or interfaces. In order to overcome the limitations of these approaches, there has been an increasing interest in the use of Semantic Web technologies to support the description and matching of services. This paper proposes a semantic matching framework to facilitate effective discovery of device based services in pervasive environments. This offers a ranking mechanism that will order the available services in the order of their suitability; the evaluation of the experimental results have indicated that the results correlate well with human perception.

1 Introduction

The current trends in technology have introduced increasingly diverse devices and gadgets into the pervasive world. This has raised new challenges for the efficient discovery of devices and their services in a dynamically changing environment. The existing solutions for device discovery (such as UPnP [UPnP06], Jini [AOSJ99], etc.), characterise the services by using predefined service categories and fixed attribute value pairs and the matching mechanisms in these approaches are limited to string comparisons or key-word based searches. Such approaches are unable to identify a match between logically equivalent services that have different syntactic representations due to the fact that discovery is not supported by any form of inferencing.

With recent trends in the Semantic Web, there has been an increased interest in the use of ontologies to describe services and the use of logical reasoning mechanisms to support service matching. Recently, a number of semantic matching approaches have been developed (such as DReggie [CPAJ01], DAML-S matchmaker [PKP02], etc.) targeted at different domains, such as pervasive environments, grid, web services, etc., that try to come up with a pragmatic solution to meet the challenges in the service discovery arena. Due to space limitations we will not discuss these in detail, however [BPRL07] contains a discussion on the recent research efforts on semantic matching. In general, these approaches provide important directions in overcoming the limitations present in traditional syntactic approaches to service discovery. However, they still have limitations and overlooked issues that need to be addressed; particularly these approaches do not have an effective ranking criterion to facilitate the ordering of potential matches, according to their suitability to satisfy the request under concern.

In this paper we present a semantic matching approach, to facilitate the effective matching of requests and available services. This semantically compares the request against the available services and provides a ranked list of most suitable services. The rank will indicate the appropriateness of a service to satisfy a given request and thus provides a valuable decision support for the service seeker, in selecting the most suitable service. An OWL ontology is used to describe the services and a Description Logic reasoner is used to support the background reasoning tasks in the matching process. The remainder of this paper is organised as follows: Section 2 discusses the motivation behind the proposed framework for resource matching and identifies the requirements. Section 3 briefly describes the methodology behind the matchmaking framework. Section 4 discusses the prototype implementation of the service matching approach in a pervasive scenario. Section 5 contains the concluding remarks and future directions of this work.

2 Motivation and Requirements

In this section we discuss the desirable properties of a matching approach along with the motivating factors behind them.

Semantic Description and Matching Vs Syntactic Approaches: Semantic matching approaches supported by reasoning mechanisms allows logical inferencing over the service descriptions and therefore offers several benefits over the traditional syntactic approaches. It is often the case, that the service providers usually describe devices in terms of lower-level properties, and the service seekers or clients usually prefer to describe service requests using more abstract or higher level concepts. Semantic matching approaches supported by logical reasoning mechanisms will be able to identify a match between logically equivalent services that have syntactically different descriptions and therefore can offer flexibility in describing the service advertisements and requests.

Ranking of Potential Matches: Ranking is the ordering of the possible matching advertisements in the order of their suitability to satisfy the given request. In the absence of an exact match, a requester might be willing to consider other advertisements that are closer to the request and thus the ranking will be useful in gaining an understanding of the appropriateness of the advertisement. Most existing matchmaking solutions lack a pragmatic approach to rank available services. The proposed matching approach provides a ranking mechanism that will rank the advertisements on the basis of how well it satisfies the properties specified in the request.

Approximate Matching: One of the objectives of semantic matching is to offer flexible or approximate matching, i.e. service advertisements that deviate from the request in certain aspects should not be discarded but must be ranked or classified appropriately to indicate the suitability. In the current semantic matching approaches [LH03, PKP02], the degree of match or suitability of the advertisement have been determined using subsumption reasoning based on the taxonomic relation between the concepts. However we argue that subsumption reasoning alone is not sufficient in determining similarity for the purpose of resource matching. Depending on the concept involved, reasoning based on the taxonomy alone, will not accurately reflect the similarity between concepts. For example consider the concept *Processor*. Assume there is a request for a computer that has processor *Pentium4* and advertisements of computers with processors *Pentium3* and *Pentium1*. Both *Pentium3* and *Pentium1* will be disjoint from the originally requested concept of *Pentium4*, but a requester will consider *Pentium3* to be a better match than *Pentium2* and will be ranked higher. Thus the type of attribute involved in the individual requirement of a request will have to be considered in approximating and ranking of advertisements. The types of attributes and the approach taken in judging the similarity between them for the purpose of ranking will be described in Section 3.

3 Matching Framework

3.1 Description of Requests and Advertisements

To reap the benefits of semantic matching, the resources must be described in a language that facilitate the use of logical reasoning. In our framework, we consider resources that are described in OWL. A request will consist of several sub requirements to be satisfied. The description of an individual requirement will specify each resource characteristic the resource seekers expect in a resource, for the their needs to be satisfied; this will include the property or attribute they are interested in and the ideal value desired. The resource provider will specify all the relevant characteristics of the available resource in the resource advertisement. In general, the request and advertisement can take the form of: $R/A \equiv (r_1) \sqcap (r_2) \sqcap \ldots \sqcap (r_n)$; where r_i is either a named concept or an existential restriction of the form, $\exists p.C$ where p is a role and C is a named concept or a complex concept.

3.2 Matching Process

In the matching process, the available resources should be evaluated according to how well it satisfies each individual requirement specified in a request; i.e. the matching engine should quantify the extent to which each individual characteristic (r_i) is satisfied by the resource advertisement. For this, the matching engine will check how similar the advertisement is with respect to each r_i specified in the request; the similarity will be determined depending on the semantic deviation of the expected value in request and the available value in advertisement for the same requirement, and a score will be assigned accordingly ($Score_i$).

Each characteristic specified in the request (r_{iR}) can be a named concept(C_R) or an existential restriction ($\exists p.C_R$). If it is a named concept, similarity will be compared between the corresponding concepts in request and advertisement (*Similarity*(C_R, C_A)). If it is an existential restriction, the corresponding existential restriction(s) will be found in the advertisement ($\exists p.C_A$) and the similarity will be compared between the corresponding concepts in request and advertisement. If it is a composite concept the similarity will be judged recursively. The score($Score_i$) for each individual characteristic in the request will be assigned depending on this similarity.

The degree of similarity between concepts will be determined depending on the type of concept or attribute involved; determination of similarity between concepts will be discussed later in this section. A score($Score_i$) is assigned for each sub-requirement (r_i) specified in the request. The score for the advertisement (match score) will be determined by averaging these individual scores.

$MatchScore = \sum_{i=1}^{n} Score_i \div n$

The overall score for the advertisement provides an indication of how good the advertisement is in satisfying the given request. The score for an advertisement will in turn be used as the basis for ranking; the highest score will receive the highest rank and so on.

For the purpose of approximating and judging similarity within individual requirements, the attributes in a resource description are categorized into three types. Namely:

Type 1 Attributes: Attributes involving symbolic concepts for which judging similarity using the taxonomic relation is sufficient. In this case the matching engine will make use of a reasoner to judge the similarity by subsumption relation. Say the advertisement specifies that it has concept C_A as its value for a particular property or attribute and request specifies it has concept C_B. When a description logic reasoner is used to find the subsumption relation between these two concepts, it could fall under one of four types. These types, and the scores assigned are represented in Table 1. In the case where C_A is a super concept of C_B, the score assigned must be a value between 0 and 1; the appropriate value of t can be determined through a human user study. However, for the purpose of this implementation of the matching system we use a value of 0.6.

Subsumption Relation	**Score Assigned**
C_A and C_B refer to the same concept	1.0
C_A is a super concept of C_B	t (where $0 < t < 1$)
C_B is a super concept of C_A	1.0
C_A, C_B are not equivalent and do not have a subsumption relation	0.0

Table 1: Assignment of scores when Subsumption Relation is considered.

Type 2 Attributes: Attributes involving symbolic concepts for which judging similarity using the taxonomic relation is not sufficient. For example *Processor* and *Display Technology* concepts fall into this category. Hence in our work, if we wanted to find similarity between different Processor Types for example, the features/ properties of the Processors such as Clock Speed, Manufactured-By etc. will have to be used in measuring the similarity. However measuring similarity between concepts is out of the scope of the current work and we assume that the knowledge of similarities between such concepts is available to us (measured by using an available similarity measurement approach such as [Tve77], and available as domain knowledge in the ontology) and can be accessed by the matchmaking process.

Type 3 Attributes: When the attributes are numeric (integer or decimal) the degree of similarity between the requested and advertised attribute values must be determined depending on the level of deviation. We can either use the percentage deviation from the original requested value or we could use a fuzzy membership function to determine the level of deviation.

Due to space limitations, the matching process will not be discussed in more detail in this paper. However, [BPRL07] includes a more detailed explanation of the matching methodology along with examples.

4 Implementation

We have implemented the matching framework presented in the previous sections in a pervasive context for matching of device based services. The services involved are devices and the services offered by those devices. The service requesters are users seeking to utilise specific devices depending on their functionality. The Device Ontology presented in [BPRC04] (available at `http://www.ecs.soton.ac.uk/~hmab02r/DeviceOnt/DevOntology.owl`) is used for the description of requests and advertisements. The necessary ontologies were developed with the Protégé ontology editor. The matching engine was implemented in Java and the Pellet DL reasoner in combination with the Pellet-API is used to facilitate the necessary reasoning tasks during the matching process.

Once the matching system receives the OWL descriptions of the advertisements and request, it checks for the consistency of the descriptions. If they are consistent the matching process begins. Each advertisement is compared with the request using the matching mechanism presented before and depending on the suitability of the advertisement to satisfy the request a score is assigned to the advertisement. Once all the advertisements are compared and scored, the advertisements are ranked on the basis of the score they have received. Then the system returns the advertisements along with their rankings.

5 Conclusions & Future Work

In this paper we have presented a semantic matching framework which exploits the expressive power of OWL and the inferential capabilities of description logics in order to provide effective discovery and matching of services. The framework facilitates the ranking of potential matches in the order of their suitability to satisfy the request, which aids the users of the matching system to identify the order in which they should consider the returned matches. The ranking mechanism overcomes the limitations present in matchers which uses subsumption reasoning alone. The proposed framework has been implemented in a pervasive scenario and experimental results have been obtained. To evaluate the effectiveness of the matching system, a human study was conducted and the results indicate that the matcher results conforms well with human judgement. As part of our future work, we intend to facilitate the specification of priorities in the service request (when priorities or weights are associated with individual requirements in a request) and to incorporate priority handling in the matching system.

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