A Framework for Architecture-driven Service Discovery

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ABSTRACT
Service discovery has been recognised as an important aspect in the development of service centric systems, i.e. software systems that are constructed based on the composition of web services. In order to develop service centric systems it is necessary to identify web services that can be combined to fulfill the functionality and quality criteria of the system being developed. In this paper we present a framework to support architecture-driven service discovery – that is the discovery of services that can provide the functionalities and satisfy properties and constraints of systems as specified during the design phase of the development lifecycle. Our framework assumes an iterative design process and allows for the (re-)formulation of the design models of service-centric systems based on the discovered services. A prototype tool has been developed and includes two main components: a UML 2.0 integration module, which derives queries from behavioural and structural UML design models and integrates the results of the queries; and a query execution engine, which performs the queries against service registries. The execution of the query is a two-stage process based on a similarity analysis algorithm.

Categories and Subject Descriptors
D.2.2 [Software Engineering]: Design Tools and Technique – Computer-aided software engineering, modules and interfaces, object-oriented design methods, user interfaces.


Keywords: Service centric system, service discovery, profile, messages, queries, operations.

1. INTRODUCTION
The development of service centric systems (SCS), in which software systems are constructed based on the composition of autonomous web services, has been recognised as an important paradigm for software system development. Recently, software systems are being developed, deployed, and consumed in this way, shifting from traditional object-oriented approaches. This new paradigm focuses on the creation, discovery, and composition of autonomous services that can fulfill various functional and quality characteristics of the system.

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In the last few years, we have seen the emergence of important standards and technologies that enable the service centric vision. However, there is still the need to extend current software development practices with new processes, methods, and tools to assist the engineering of complex and dependable SCS.

An important aspect of service centric systems is the ability to support the discovery and composition of services at different stages of the development life cycle of a system. In this paper, we present a framework to support architecture-driven service discovery (ASD). By architecture-driven service discovery we mean the identification of services that can provide the functionality and satisfy quality properties and constraints of an SCS as specified by its design models.

Architecture-driven service discovery requires support to address some important challenges, including:

- The extraction of service discovery queries from SCS architecture and design models specifying the functionality and quality properties of such systems;
- The provision of a query language supporting both the expression of arbitrary logical combinations of prioritised functionalities and quality properties criteria for the required services, and similarity-based queries of the form "find a service that is similar to service X";
- The efficient matching of service discovery queries against service specifications and return of services that may have varying degrees of match with the queries;
- The assistance to system designers to select services for an SCS in cases where the discovery process identifies more than one candidate services satisfying a query;
- The integration of discovered services into an iterative design process in which SCS architecture and design models may be re-formulated following service discovery.

The above challenges have been identified by industrial partners in the areas of telecommunications, automotive, and software in an integrated European project focusing on service centric system engineering (SeCSE [16]). These challenges constitute the main driver underpinning the framework that we present in this paper.

Our framework adopts an iterative architecture-driven service discovery process in which the discovery activity relies on the ongoing development of the architecture of the SCS and, therefore, the available services identified during this process can be used to amend and re-formulate the design models of the system. The re-formulation of these models may trigger new service discovery iterations. The result of this process is a complete specification of the SCS architecture models.

The framework assumes the use of UML to specify structural and behavioural design models of the SCS. It includes a UML 2.0
integration module, which derives queries from UML design models and integrates back the results of the queries, and a query execution engine, which performs these queries against service registries. The execution of queries is based on a two-stage approach. In the first stage, services that satisfy certain functional and quality criteria are located. In the second stage, the similarity of these services against additional functional and quality discovery criteria is assessed based on a variant of a similarity analysis algorithm presented in [15].

The remainder of this paper is structured as follows. In Section 2, we describe the ASD process and framework with its main components, and introduce a scenario that we will use to illustrate our work. In Section 3, we discuss how queries are specified in our approach. In Section 4, we present the query execution engine. In Section 5, we discuss ASD results. In Section 6 we give an overview of implementation aspects. In Section 7 we present some related work. Finally, in Section 8, we summarise our approach and discuss future work.

2. ARCHITECTURE-DRIVEN SERVICE DISCOVERY FRAMEWORK

2.1 ASD Process

Our framework adopts an iterative architecture-driven service discovery process in which service discovery is seen as part of the design of service centric systems. In the ASD process, queries are derived from system design models and identify services that can subsequently be integrated into these models.

Figure 1 shows an overview of the ASD process. The process is iterative and starts from the construction of initial system structural (SySM) and behavioural (SyBM) models by the system designers. The SyBM model describes interactions between operations of an SCS that can be provided by web services, legacy systems or software components. The SySM model specifies the types of the parameters of the operations in SyBM, and constraints for these operations and their parameters (e.g., variants, pre- and post-conditions). These models are specified and visualised as UML sequence and class diagrams, respectively.

The interactions in SyBM and classes and interfaces in SySM are used to specify queries. The queries are used to identify candidate services and operations that can fulfil parts of (or all) the functionality of the system. Designers may select some of the discovered services and operations and bind them to the design models. This binding results in a reformulation of both the SyBM and the SySM models. The new versions of these models may be used to specify further queries to discover other services that can subsequently be integrated into these models.

It is also possible for the designers to realise that certain parts of the system cannot be fulfilled by available services. In this case, the designer may alter the design models so as to get the relevant parts of the system functionality from existing legacy systems and components, or by developing new software code. Designers may decide to terminate the ASD process at any moment, or when it is clear that further queries cannot discover services relevant to the design models.

Our approach assumes that SySB and SySM models are expressed in UML (as sequence and class diagrams, respectively). This is because UML is the de-facto standard for designing software systems and can effectively support the design of service-centric systems as it has been argued in [3][8]. Furthermore, UML has the expressive power to represent the design models that we use, and can provide a basis for specifying ASD queries (see Section 3).

2.2 ASD Process Overview

In order to support the above process we have developed an ASD framework that is composed of two main components: a UML 2.0 integration module and a query execution engine.

The UML 2.0 integration module is combined with a UML CASE tool (IBM Rational Software Modeler 6.0, in the current implementation) and is responsible for (a) extracting queries specifying the service functionality, properties, and constraints from the design models, based on the designer’s selections, and (b) integrating the discovered candidate services back into the design models.

The query engine executes the queries by searching for services in different service registries. The search is based on a graph-matching algorithm [15] that computes similarities between queries and service specifications. We assume that service specifications are composed of parts, called facets, which provide description of different aspects of services. The facets include information stored in service registries based on standard UDDI and ebXML technologies such as service interface specifications expressed in WSDL[17], behavioural service specifications expressed as BPEL4WS[2] or OMML [4], semantic service specifications expressed in OWL[12], WSMO[19], or WSML[18], and other information types (e.g., cost, quality, textual description) described in XML format.

2.3 ASD Scenario

In order to illustrate our work, in the rest of this paper, we will use an example of the design of a global positioning service centric system (GP_SCS) as a subsystem of a car-based Haptic device. The GP_SCS offers its users various functionalities including the identification of routes to get from one place to another, back-on-track re-routing, avoidance of specific areas, display of maps, and location of different points of interest in selected areas.

More specifically, our scenario focuses on the design of an interaction of GP_SCS that can locate the closest point of interest of a certain type (e.g. restaurants, car parks, cinemas) given an address. Based on requirements related to this functionality of the system, assume that a software designer has produced a behavioural model (SyBM) of the above interaction and a structural model (SySM) defining the data types used in the interaction, as shown in Figures 2 and 3, respectively. These models are specified and visualised as UML sequence and class diagrams, respectively. The scenario is taken from an “End-to-end travel” use case in which Traveller is the only actor. The sequence diagram in Figure 2 depicts the boundary of the system.
represented by component Haptical interacting with two broad external functionalities that the designer wishes to map to existing web services. The diagram contains three messages (FindAddress, Display Map, and FindPOI) with their respective arguments, and placeholders for web services that may be discovered, which are represented by the interfaces ILocationService and IMappingService. These interfaces, shown in Figure 3, contain operations corresponding to the messages in Figure 2. The operation FindAddress returns the location of an address in terms of its geographical co-ordinates; the operation Display Map returns the URL of the map of a given location; and the operation FindPOI identifies the position of a point of interest (POI) close to a specified location given the type of this point, its location, and a radius determining the acceptable distance.

3. Query Specification

An ASD query is specified by the system designer who selects an interaction I from SyBM, creates a copy of I called query interaction (I’), selects the messages in I’ that should be realised by operations of the services to be discovered, and specifies various constraints on these operations (e.g. restrictions on the number of parameters) or on the interaction as a whole (e.g. service provider).

An ASD query and its results are specified by using a UML 2.0 profile that we have developed (viz. ASD profile). The profile defines a set of stereotypes for different types of UML elements that may be found in (a) query interaction (e.g., messages), (b) results of query execution (e.g. messages, services), or (c) SySM model of a system that are referenced by elements of the query interaction (e.g., operations, classes that define the types of the arguments of interaction messages) or result parameters. The profile also contains metamodels of the facets that may be used for specifying services (e.g. cost, textual description).

Figure 4 presents the part of the ASD profile used for specifying an ASD query (see Section 5 for ASD results). In this case, a UML package is stereotyped as an <<asd_query_package>>.

The messages of the interaction may be stereotyped as: (i) query messages <<asd_query_message>> that indicate the service operations that should be discovered; (ii) context messages <<asd_context_message>> that imply additional constraints for the query messages (e.g. if a context message has a parameter p1 with the same name as a parameter p2 of a query message, then the type of p1 should be taken as the type of p2); and (iii) bound messages <<asd_bound_message>> that are bound to concrete operations that have been discovered by executing ASD queries in previous iterations. All the messages in a query interaction, which are not stereotyped by any of the above stereotypes, are treated as unrelated messages in I’. These messages should not restrict the services to be discovered in any way and do not play any role in the query execution apart from being copied back to the results of a query execution. The operations corresponding to the query messages are stereotyped as <<asd_query_operation>>.

The ASD Profile also defines stereotype properties, which are used to specify parameters and constraints for the elements to which the stereotypes containing these properties are applied. Both <<asd_query_package>> and <<asd_query_message>> stereotypes can specify query parameters. Some of these parameters are inherited from the abstract stereotype <<asd_query_element>>. The query parameters specified for asd_query_package are global (i.e., applied to the whole query).
The query parameters specified for asd_query_message are local (i.e., applied to specific messages of the query interaction). The global parameters are considered as default values in the query and can be overridden by local parameters.

Query parameters are used to limit the search space and the amount of information returned by the query execution engine (e.g., the number of services to be returned), and are specified as scalar values. Query constraints stereotyped as <<asd_constraint>> provide specific selection criteria for choosing services based on their various characteristics. These constraints can be applied for asd_query_package, asd_query_message, and asd_query_operation elements. The constraints may be formulated in terms of UML metamodel (e.g., number of parameters in a query operation) or facets metamodel (e.g. textual description, cost).

The constraints include (a) the type of the constraint (hard or soft), (b) the body of the constraint as an OCL [11] expression, and (c) an optional weight of the constraint if the constraint is soft (real value between 0.0 and 1.0). Hard constraints must be satisfied by all the discovered services and operations. Soft constraints influence the identification of the best services/operations but may not be satisfied by all the services/operations that are discovered. The use of OCL to specify constraints is motivated by the fact that OCL is the standard formal language for specifying constraints for UML models and therefore ASD queries which are based on them.

Following the specification of a query interaction, the tool generates an ASD query package that contains the context and query messages of the query, the classes that define the types of the parameters of these messages, as well as other classes that may be directly or indirectly referenced by these classes. The tool automatically executes the extraction of recursive data structures used in the parameters of the query messages. The resulting query package is represented in XMI 2.0 – the standard XML based format for representing UML 2.0 models.

Example. Consider the design of GP_SCS shown in Figures 2 and 3. Suppose that the designer wants to specify a query (Location Query 1) to identify services that can return the location of an address based on its geographical co-ordinates and services. Example format for representing UML 2.0 models.

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Figure 5 shows the specification of the query in our framework. Apart from the query name, all the other query parameters are optional. A default value is assumed for a query parameter that is not specified. After specifying the values for the query parameters, the framework generates a query interaction, which is stored in the query package.

As an example of specifying local query parameters, suppose that for message FindAddress the designer wants to restrict the number of candidate services returned to be not greater than 10 and the maximum number of services examined to be 100. The designer may also specify a local query constraint (in OCL) on message FindAddress such that the textual description of candidate services must contain the term “geocod”.

### 4. Query Execution Engine

The ASD query package is submitted to the query execution engine to be processed. The execution of queries is performed in a two-stage process. In the first stage, referred to as filtering, the query execution engine searches service registries in order to identify services with operations that satisfy the hard constraints of a query and retrieves the specifications of such services. In the second stage, referred to as best operation matching, the query execution engine searches through the services identified in the filtering phase, to find the operations that have the best match with the soft constraints of the query.

**Selection of best operation matching:** Detection of the best possible matching between the operations required by an ASD query and the candidate service operations identified in the filtering stage is formulated as an instance of the assignment problem as proposed in [15]. More specifically, given the set of operations required by an ASD query \( Q \), \( \text{Oper}(Q) \) and the set of service operations identified in the filtering stage, \( \text{Oper}_S(Q) \), an operation matching graph is constructed with two disjoint sets of vertices \( V^O \) and \( V^S \) defined as

\[
V^O = \text{Oper}(Q) \cup DV_k \quad \text{and} \quad V^S = \text{Oper}_S(Q),
\]

where \( DV_k \) is a set of \( k \) special vertices representing dummy operations (\( k = |\text{Oper}(Q)| - |\text{Oper}_S(Q)| \)). This formulation assumes, without loss of generality, that \( |\text{Oper}(Q)| > |\text{Oper}_S(Q)| \).

If this is not the case, \( k \) dummy vertices are added to \( V^O \) where \( k = |\text{Oper}_S(Q)| - |\text{Oper}(Q)| \).

The set of edges of the graph, \( E(V^O, V^S) \), includes all the possible edges between the required operations in \( V^O \) and the retrieved service operations in \( V^S \). These edges are weighted by a measure \( D(v^O_i, v^S_j) \) indicating the overall distance between \( v^O_i \) and \( v^S_j \) where \( v^O_i \in V^O \) and \( v^S_j \in V^S \). This measure is computed as the weighted sum of a set of partial distance measures \( d_f(v^O_i, v^S_j) \) quantifying the semantic differences between \( v^O_i \) and \( v^S_j \) with respect to each facet \( f \) in the descriptions of \( v^O_i \) and \( v^S_j \) according to the following distance function (the weights are assumed to be normalized):

\[
D(F, v^O_i, v^S_j) = \sum_{i=1}^{k} w_i \cdot d_f(v^O_i, v^S_j) \quad \text{if } v^O_i \in \text{Oper}(Q), \ v^S_j \in \text{Oper}_S(Q)
\]

\[
D(F, v^O_i, v^S_j) = 1 \quad \text{if } v^O_i \in DV_k
\]

\[
D(F, v^O_i, v^S_j) = \infty \quad \text{if } v^O_i \text{ should not be mapped onto } v^S_j
\]

where \( F \) is the set of facets in the descriptions of operations.
Function $D$ is defined to have a value in the range $[0,1]$ for all the pairs of operations drawn from $\text{Oper}(Q)$ and $\text{Oper}_{S}(Q)$. In the case of comparisons between an existing operation and a dummy operation $D_{S}$'s value is defined to be 1. This favours the possibility of mapping an existing operation onto a requested operation rather than leaving without a counterpart. Finally, $D$ is defined to take an infinitum value ($\infty$) in the case of operations which – by virtue of the constraints defined in $Q$ – should not be mapped onto each other. This precludes the matching of such operations when the optimal matching between $V_{Q}$ and $V_{S}$ is selected.

Following the computation of the $D$ distances for all the edges of the graph, the matching between the operations in $V_{Q}$ and $V_{S}$ is detected in two steps. In the first step, a subset $O(V_{Q}, V_{S})$ of $E(V_{Q}, V_{S})$ that is a total morphism between $V_{Q}$ and $V_{S}$ (or onto morphism if $|\text{Oper}(Q)| < |\text{Oper}_{S}(Q)|$) and minimises the function $\sum_{x \in V_{Q}, y \in V_{S}} D(F(x,y))$ is selected. $O(V_{Q}, V_{S})$ is selected using standard algorithms for the assignment problem [15]. In the second step, $O(V_{Q}, V_{S})$ is restricted to include only the edges whose distance $D(F(x,y))$ does not exceed a threshold value $D_{t}$.

**Partial distance functions.** For the facets corresponding to soft constraints defined as Boolean tests, the partial distances $d_{i}$ are defined as 1 if the test returns false or the facet is not available for a specific service, and 0, otherwise. The partial distance that is used to compare the facets specifying the signatures of two operations is defined as:

$$d_{f\text{-signature}}(v_{Q}, v_{S}) = w_{n} \cdot d_{l}(\text{name}(v_{Q}), \text{name}(v_{S})) + w_{p} \cdot d_{p}(\text{input}(v_{Q}), \text{input}(v_{S})) + w_{o} \cdot d_{o}(\text{output}(v_{Q}), \text{output}(v_{S}))$$

In this formula, $d_{l}$ is a linguistic distance built on top of WordNet lexicon [10] and $d_{p}$ is a function computing the distance between the sets of input or output parameters of two operations. For two sets of parameters $P_{1}$ and $P_{2}$, $d_{p}$ is computed by finding the best possible morphism $pm$ between the elements of these sets, defined as: $d_{p}(P_{1}, P_{2}) = \min_{pm} (\sum_{x \in P_{1}, y \in P_{2}} d_{p}(x,y))$, where $d_{p}(x,y)$ is a function that computes the distance between two specific parameters. This distance is computed by finding the best possible matching between the structures of the types of the given operation parameters using a variant of the class distance measures defined in [15].

Our operation matching framework has been designed to support modifications to the set of facets $F$ for service specifications. More specifically, when new facets are added to $F$, our framework could be extended to support them by incorporating partial distance functions enabling operation comparisons with respect to these facets.

5. ASD Results

The results of an ASD query identified by the query execution engine (i.e., best candidate services with smallest distances) is specified by using the ASD profile. Figure 6 presents the part of the ASD profile for ASD results. The ASD results are represented as a UML package stereotyped as $<<\text{asd\_results\_package>>}$.

The $\text{asd\_results\_package}$ contains a refinement of the query interaction used by the designer to create the query together with the structural model for the elements in the interaction, and a number of UML packages stereotyped as $<<\text{asd\_service\_package>>}$, one for each candidate service identified by the query execution engine. Each $\text{asd\_service\_package}$ contains elements representing a concrete discovered service together with the class diagram of all data types and their relationships used in the XSD schemas reverse engineered from the WSDL specification of this service. The structural model in the $\text{asd\_results\_package}$ contains copies of all data types from the $\text{asd\_query\_package}$ together with the mapping (stereotyped as $<<\text{asd\_mapping\_association>>}$) to the data types in the service packages. This data mapping is based on the data distances computed for each bound operation in the service against the query message associated to the service.

The operations in an $\text{asd\_service\_package}$ may be stereotyped as (i) bound operations $<<\text{asd\_bound\_operation>>}$ that denote the service operations with the best match to a query message or the one that the designer selects as the best candidate; (ii) candidate operations $<<\text{asd\_candidate\_operation>>}$ that reflect another possible result for the query message, but not necessarily the best match; and (iii) service operations $<<\text{asd\_service\_operation>>}$ that are all the remaining operations in the WSDL specification of the service. The above operations are grouped together in a UML component (contained in the $\text{asd\_service\_package}$) stereotyped as either $<<\text{asd\_bound\_service>>}$ or $<<\text{asd\_candidate\_services>>}$, depending on the existence of any bound operations.

![Figure 6: Part of the ASD Profile for ASD Results](image)

The interaction in the $\text{asd\_results\_package}$ refines the query interaction by replacing query messages by bound messages (stereotyped as $<<\text{asd\_bound\_message>>}$) corresponding to bound operations. When no operation is found, the query message is not modified.

The framework allows the designer to analyse the results of a query and select candidate operations to become bound operations. After the designer selects a particular service from the returned candidates, the structural model in the $\text{asd\_results\_package}$ is automatically updated with concrete data of the chosen service, and the interaction is modified to reflect the binding of the services and operations. The designer may use the $\text{asd\_results\_package}$ as a basis for a new iteration of the ASD process (see Subsection 2.1).

**Example.** Consider the execution of Location Query 1 against a service registry with 45 services. For this query, the query
execution engine selects four distinct services. Tables 1 and 2 show the selected services and their providers with the identified operations and the computed distance between these operations and the respective ASD query messages.

For this example, the best matching for ASD query message FindAddress is findAddresses() operation from service AddressManager (ArcWeb provider), and for query message FindPOI is getPoiList() operation from service FindNearbyPOIService (ViaMichelin provider). The above operations are stereotyped as <<asd_bound_message>> in the asd_results_package.

After analysing and accepting the results for messages FindAddress and FindPOI, consider the designer wants to create a new query (Location Query 2) for operation Display Map and start a new iteration of the ASD process.

For the discovery of a service that can return the URL of the map of a given location (Display Map), assume the designer wants the provider of this service to be ViaMichelin (the designer is now familiar with this provider from the results of the first query). In this case, the designer creates a new query, with a hard OCL constraint to restrict the discovery process to services provided by ViaMichelin.

Table 1: Results of query execution for FindAddress

<table>
<thead>
<tr>
<th>Provider</th>
<th>Service</th>
<th>Operation</th>
<th>Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArcWeb</td>
<td>AddressManager</td>
<td>findAddresses()</td>
<td>0.138</td>
</tr>
<tr>
<td>cdyne.com</td>
<td>AddressLookup</td>
<td>AdvancedCheckAddress()</td>
<td>0.145</td>
</tr>
<tr>
<td>cdyne.com</td>
<td>AddressLookup</td>
<td>CheckAddress()</td>
<td>0.150</td>
</tr>
<tr>
<td>cdyne.com</td>
<td>AddressLookup</td>
<td>CheckAddressW2lines()</td>
<td>0.152</td>
</tr>
</tbody>
</table>

Table 2: Results of query execution for FindPOI

For this query, the query execution engine identifies operation getMapDefinition() from service GetBestMapDefinitionService (ViaMichelin provider) as the best match. Figure 7 shows the complete sequence diagram with the bound services and operations for the two queries.

The framework also allows the designer to search for other results by using bound messages from previous iterations of the ASD process, as constraints for a query (context message).

As an example, consider again the query iteration for operation Display Map. Suppose that the designer wants to iterate the operations that can be discovered for query message Display Map, when this query message is constrained by the bound operation getPoiList() identified in Location Query 1. In this case, operation getPoiList() is stereotyped as context message <<asd_context_message>> in the query. For the bound operation getPoiList(), the framework has created data mapping associations between the data types used in query message FindPOI and those used in operation getPoiList(). For this particular case, data type GeoCoordinates in FindNearbyPOIService service, and data type Location is mapped to data type Location in the same service.

Since Display Map and FindPOI have originally the same parameter center of type Coordinates (Figure 2), and Coordinates is mapped to GeoCoordinates, the query will be constrained to find operations similar to data type GeoCoordinates. The results of the query will prefer services from the same provider as that of the context message, since the best matching algorithm considers the minimal distances between operation names, parameters, and (nested) data types.

The query execution engine identifies operation getMapDefinition() from service GetBestMapDefinitionService (ViaMichelin provider) as the best match, which is the same result as found for the previous case (i.e., when the service provider ViaMichelin was used as a hard constraint). However, if we consider another query for Display Map without any constraints on the provider or context message, the query execution engine returns getThematicGeographiesForExtent() from MapImage service as the best match for this query.

6. IMPLEMENTATION ASPECTS

The ASD framework has been implemented as an Eclipse plugin for IBM Rational Software Modeler/Architect 6.0 (RSM/RSA). This UML CASE tool has almost complete support for the UML 2.0 notation and XMI 2.0 model serialization, and is based on extensible and open Eclipse 3.0 IDE. The tool offers all the necessary requirements for extensibility and compliance to open standards. Only a small portion of the plugin uses the vendor-specific (IBM) API, but the majority of the UML model manipulation code uses the standard open source UML2 API provided by Eclipse, which greatly enhances the portability of our tool to other UML CASE tools based on Eclipse.

The ASD profile is also implemented as an Eclipse plugin, so that it is deployed in RSM and can be applied to UML models via RSM GUIs and programmatically. The specification of the stereotype properties is assisted by the use of Eclipse wizards and property editors. The definitions of OCL constraints are assisted by Intellisense live syntax checking and help. The query execution engine is currently a part of the plugin, but can be wrapped as a web service, which allows the execution of ASD queries independently of any particular CASE tool.

7. RELATED WORK

Some approaches have been proposed to support architecture-driven service discovery. In [6] the discovery of services is addressed as a problem of matching queries specified as a variant of Description Logic (DL) with service profiles specified in OWL-S [12]. Our framework is more general and supports the discovery of services specified in various specification formats (i.e. facets).

Hausmann et al. [5] propose the use of graph transformation rules for specifying both queries and services. The matching criteria in our work are more flexible and are based on distance measures quantifying similarities between the graphs. Another approach that uses graph-matching is [7] although details of the matching algorithm are not described.

The METEOR-S [1] system adopts a constraint driven service discovery approach in which the queries are integrated into the composition process of a SCS and are represented as a collection of tuples of features, weight, and constraints. In our approach, the queries contain information about features, weights, constraints, and parts of the design models of the SCS being developed.

The approach in [8] focuses on interface queries where operation signature checking is based on string matching and cannot account for changes in the order or names of the parameters.
In [4] the authors advocate the use of (abstract) behavioural models of service specifications in order to increase the precision of service discovery process. Similarly, in [14], the authors propose to use service behaviour signatures to improve service discovery. We plan to extend our work to use behavioural specifications, as proposed in [4].

Some specific query languages for web services have been proposed [13][20]. However, none of them can be integrated with UML-based system engineering design process.

Although the above approaches have contributed to the problem of service discovery, an approach that combines service discovery as part of the design process of SCS has not been proposed.

8. CONCLUSIONS

We presented a framework to support architecture-driven service discovery that is integrated with iterative UML-based system engineering design processes. Our framework addresses the five challenges described in the introduction, in particular allowing service discovery to be driven by architecture decisions taken during the development of SCS systems and fulfills the lack of processes and tools to assist the engineering of complex and dependable SCS. Together with industrial partners, we are conducting large-scale experimentation of our framework taking into consideration different types of service specifications ranging from structural, to semantic and behavioural aspects.

9. ACKNOWLEDGMENTS

The work reported in this paper has been funded by the European Commission under the Information Society Technologies Programme as part of the project SeCSE (contract IST-511680).

10. REFERENCES