CAD AND GIS INTEROPERABILITY THROUGH SEMANTIC WEB SERVICES

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***SUMMARY**: Computer-Aided Design (CAD) and Geographical Information System (GIS) are being used in tandem to support a variety of decisions throughout the life cycle of civil infrastructure systems. Existing CAD and GIS platforms have been developed independently with different purposes resulting in significant differences in terms of data formats they support, terminology they utilize, semantics of concepts they represent, and reasoning techniques on which they are based. For this reason, existing CAD and GIS platforms are currently not interoperable, resulting in wasted time and money due to limitations associated with exchange of data and knowledge. Within the context of this paper, we highlight a set of interoperability challenges associated with CAD and GIS platforms and describe a web-service based approach that will enable semantic interoperability between these two platforms. The paper specifically discusses research challenges associated with different components of such a proposed semantic web-based approach; namely task decomposition, ontology identification, web service discovery and matching, and service composition.*

***KEYWORDS**: semantic web services, CAD-GIS, interoperability, web service composition, automated planning, web service discovery*

1. INTRODUCTION

Civil engineering projects are multi-disciplinary in nature involving a large number of participants, such as designers, engineers, project managers, and construction managers. Since the advent of Computer-Aided Design (CAD) and Geographical Information System (GIS) tools, project participants have been increasingly leveraging these tools throughout the different phases of a civil infrastructure project. For instance, during construction of a facility in a densely populated area, a CAD system augmented with construction schedule information (also known as 4D CAD) would be employed to detect spatio-temporal conflicts between a crane and concurrent construction activities at a job-site, and a GIS would be used to plan an optimal route that minimizes traffic congestion for delivery of construction materials to the site.

Civil engineering tasks require that CAD and GIS platforms be interoperable as data or analyses results generated by one system (CAD or GIS) are often required by the other. For example, a set of spatio-temporal conflict results produced by a CAD system can be used by GIS to calculate possible time frames for delivery of construction materials to avoid further spatial conflicts. However, as existing CAD and GIS platforms have been developed independently with different purposes, there are significant differences in terms of data formats they support, terminology they utilize, semantics of concepts they represent, and reasoning techniques on which they are based.

Participants of civil infrastructure projects access both CAD and GIS during different stages of a project to perform different tasks. Often the completion of an engineering task requires translation of information created or maintained in one system (CAD or GIS) for use by the other system (Jones 2005). Existing solutions, commercial and non-commercial, to the interoperability problem have focused on developing data exchange formats between CAD and GIS platforms. For instance, major software CAD and GIS software packages provide data exchange between these platforms (e.g., see Autodesk 2007; ESRI 2007).

Realizing interoperability as being an important issue within their respective domains, a variety of Architecture, Engineering and Construction (AEC) and geospatial consortiums have focused on developing standards to enable seamless data transfer and interoperability among software systems within each domain. For example, International Alliance for Interoperability (IAI) is specifying data standards, such as Industry Foundation Classes (IFC), for the AEC community (IAI 2007), and Open Geospatial Consortium (OGC) has been carrying out similar standardization efforts, such as Geography Markup Language (GML), for the geospatial community (OGC, 2006). Recently, the interest in inter-domain interoperability between AEC and geospatial domains has spurred new standardization efforts such as IFC 2x3G specification (IAI 2007). While these efforts have focused on enabling data exchange between various CAD and GIS platforms, they have not addressed issues related to differences in semantics and reasoning capabilities between them. This is the reason why, to achieve full interoperability, there is a need for semantic interoperability solutions and reasoning techniques between CAD and GIS platforms. For example, some spatial analysis functionalities (e.g., buffer and spatial query) available in GIS are not available in CAD (Rasdorf et al. 2000). Similarly, CAD systems can perform operations (e.g., spatial conflict detection) at a finer level of details compared to GIS due to differences in the spatial scale of the objects represented. When CAD and GIS platforms are unable to resolve their semantics issues and to realize their reasoning capabilities, they would not be fully interoperable resulting in processing of many time-consuming tasks manually with a high level of ambiguity.

In this paper, we present a potential approach towards bridging the interoperability gap between CAD and GIS platforms. The premise of this approach are ontologies: to address semantic differences between the AEC and geospatial domains, and web services, and to allow dynamic composition of CAD and GIS operations needed to complete a specific task. We begin with a motivating scenario that is focused on the management of equipment space requirements to highlight the need for interoperability between the AEC and geospatial domains. We describe the components of the proposed semantic web service approach: task decomposition, ontology identification, web service discovery and matching, and service composition. We conclude by highlighting research challenges associated with implementation of some of these components.

2. EXAMPLE SCENARIO

Construction projects are becoming more complex as space on construction sites get tighter and more construction activities are scheduled concurrently. In such cases, space management required by various types of equipment becomes increasingly challenging (Akinci et al. 2003; Tantisevi and Akinci 2007). Ineffective space management results in conflicts, which can create work interruptions, productivity reductions, hazardous work conditions and damage to existing structures (Guo 2002; Varghese and O'Connor 1995). An example of an engineering task that involves space management is crane location analysis for construction sites. To ensure that a crane is safely located, all possible spatial interactions between a crane and existing structures on and around a job site need to be analyzed. These existing structures may include objects within a construction site, such as portions of facilities being built, existing equipment, material staging locations, and subsurface utilities. Similarly, possible spatial interferences between objects with close proximity to the job site, such as nearby buildings and power lines, should be analyzed. Finally, when a crane is located on an existing roadway, possible traffic impacts of lane closures due to crane operation must also be considered.

While some of these analyses, such as identification of possible spatial conflicts between a crane and facility that is under construction, can be performed by using data obtained from CAD and construction schedules, others, such as analysis of impacts of possible crane locations to subsurface utilities or nearby structures and power lines, need to be performed using data from both CAD and GIS. For the purpose of this paper, we will focus on the analysis related to identification of potential obstructions that are close-by to a possible location of crane, such as neighbouring buildings or surface utilities, as an example to highlight interoperability challenges associated with CAD and GIS integration. Determining a suitable location for a crane involves analyzing geometric constraints based on crane specifications and the dimensions of the building under construction, analyzing the load of the component to be lifted, and determining the feasible area to pick the load based on both geometric and load limits calculations. These analyses, however, will only ensure a safe operating area for a given crane with respect to the building under construction. In a real world job site, it is likely that there are multiple possible obstructions including neighbouring buildings and other objects, such as above-ground power lines (FIG 1).

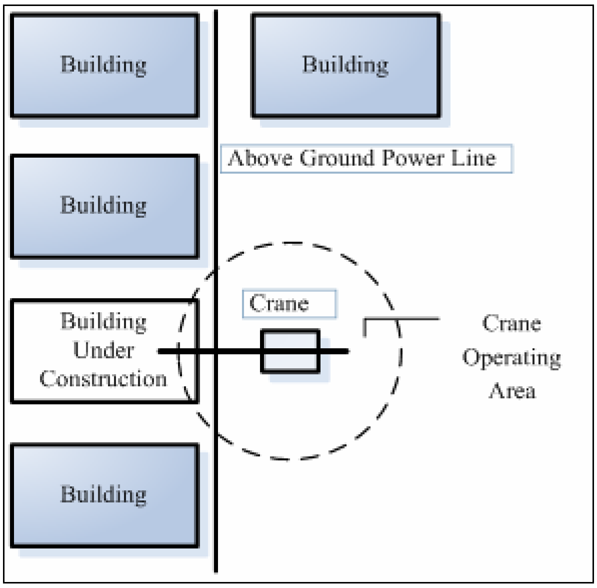

FIG 1: Potential obstructions for a crane based on its workspace

Detecting possible interferences between existing structures and the crane's workspace requires completion of a set of sub-tasks including: (1) identifying the "candidate" (i.e., potential) obstructions; (2) gathering, transforming, and assembling data needed for interference detection; (3) determining true obstructions from the candidates list; and (4) preparing the results for review. There are several approaches to accomplish the abovementioned sub-tasks. One approach is to create 2D drawings or sketches of a job site and overlaying the proposed position of the crane. This is a manual process and while it may be adequate, it may not include all potential obstructions or analyze possible interactions from a 3D or temporal point of view (Tantisevi and Akinci 2007). To overcome such shortcomings, the second approach is to model the job site, its surrounding and the crane in 3D and perform clash detection to identify possible spatial conflict. Both (2D and 3D) approaches leverage data and operations performed in CAD and GIS environments; albeit the nature of the data and the operations utilized are different based on whether a 2D or 3D analyses being performed. FIG 2 depicts these two approaches (note that there are other alternative approaches) to complete the task of identifying possible obstacles associated with a given crane location.

Both approaches (depicted in FIG 2) perform the required sub-tasks of identifying candidate obstructions, transforming and assembling data to identify possible spatial conflicts, performing conflict analysis and preparing and highlighting the resultant obstacles. However, each approach performs the required analyses using a different combination of CAD and GIS operations. For example, when analyzing potential obstructions, the 2D approach is more GIS-centric and uses a 2D spatial analysis operation (FIG 2(a)), while the 3D approach is more CAD-centric and performs a 3D collision detection analysis (FIG 2(b)). While similar categories of data are needed (e.g., neighbouring buildings, utilities, roads), the level of detail may differ based on the requirements of the selected operations. For instance, in 2D analysis, the heights of power lines and buildings are not available, while the height and detailed geometric information in 3D space are needed for 3D analysis. In addition, the direction of data transfer from one platform to another and corresponding data transformation are different in each of these approaches. For example, in the 2D approach, the local coordinate system (used by

CAD) must be manually matched to the global coordinate system used by the GIS; on the other hand, in the 3D approach, the global coordinate system of existing structures within the GIS need to be transformed into the local referencing system used within the CAD.

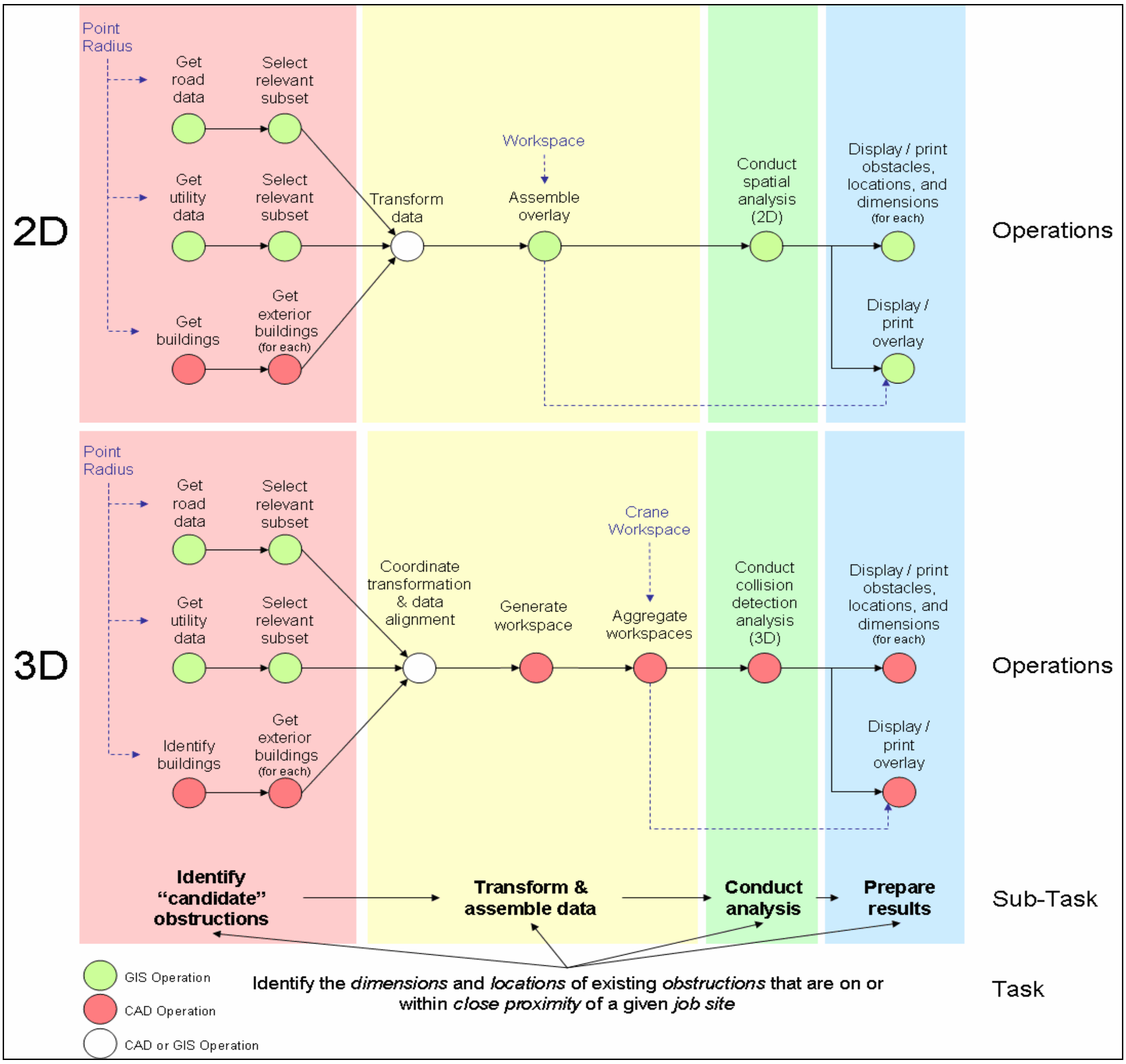

FIG 2: Alternative approaches 2D (FIG 2a) versus 3D (FIG 2b) for analyzing possible obstacles that might interfere with a crane operation during construction

Given the range of CAD and GIS operations needed to perform such analyses and the lack of interoperability between CAD and GIS, currently it is necessary for engineers to have both CAD and GIS skills to be able to perform engineering tasks that require data and operations between both platforms. In addition, currently both AEC and geospatial domains are faced with semantic ambiguities. For example, consider the term "obstruction". What constitutes an obstruction in the AEC domain may be markedly different from the same concept in the geospatial domain. A GIS expert may apply a definition inconsistent with the AEC domain and thereby fail to properly evaluate all potential obstructions. As we have seen with this scenario, while approaches described in FIG 2 can reduce the risk associated with the placement of a crane on a construction site, there are additional challenges that may make this analysis too difficult and/or too costly to perform. Within the context of this paper, we suggest a solution approach focused on semantic web services. Our vision for this approach will be discussed in the next section.

3. VISION: SEMANTIC CAD/GIS WEB SERVICES

The Semantic web offers a common framework that allows data to be shared and used across multiple applications and communities (W3C 2007). It is a collaborative effort initiated by the World Wide Web Consortium (W3C) with participation from a large number of researchers, academic institutions and industrial partners. The Semantic web leverages ontologies and standard languages, such as Resource Definition Languages (RDF) and Web Ontology Language (OWL) for recording machine-readable data and defining ontologies, respectively. In our proposed approach, we consider the Semantic web as a common framework for interoperating CAD/GIS operations. FIG 3 depicts the overview of our envisioned approach of using semantic web services for achieving interoperability between CAD and GIS. The approach consists of three modules: (a) task interpretation, (b) web-service matching, and (c) web-service composition.

The vision is task-oriented and begins with a user defining a specific geospatial analysis task (FIG 3). Using our scenario as an example, a task would be "*identify the dimensions and locations of existing obstructions that are on or within close proximity of a job site*". Additional information must be provided along with needed parameters and constraints depending on the context of the analysis that must be performed. For example, information on the model of the crane to be utilized, the building model for the building under construction, and site related data may be needed.

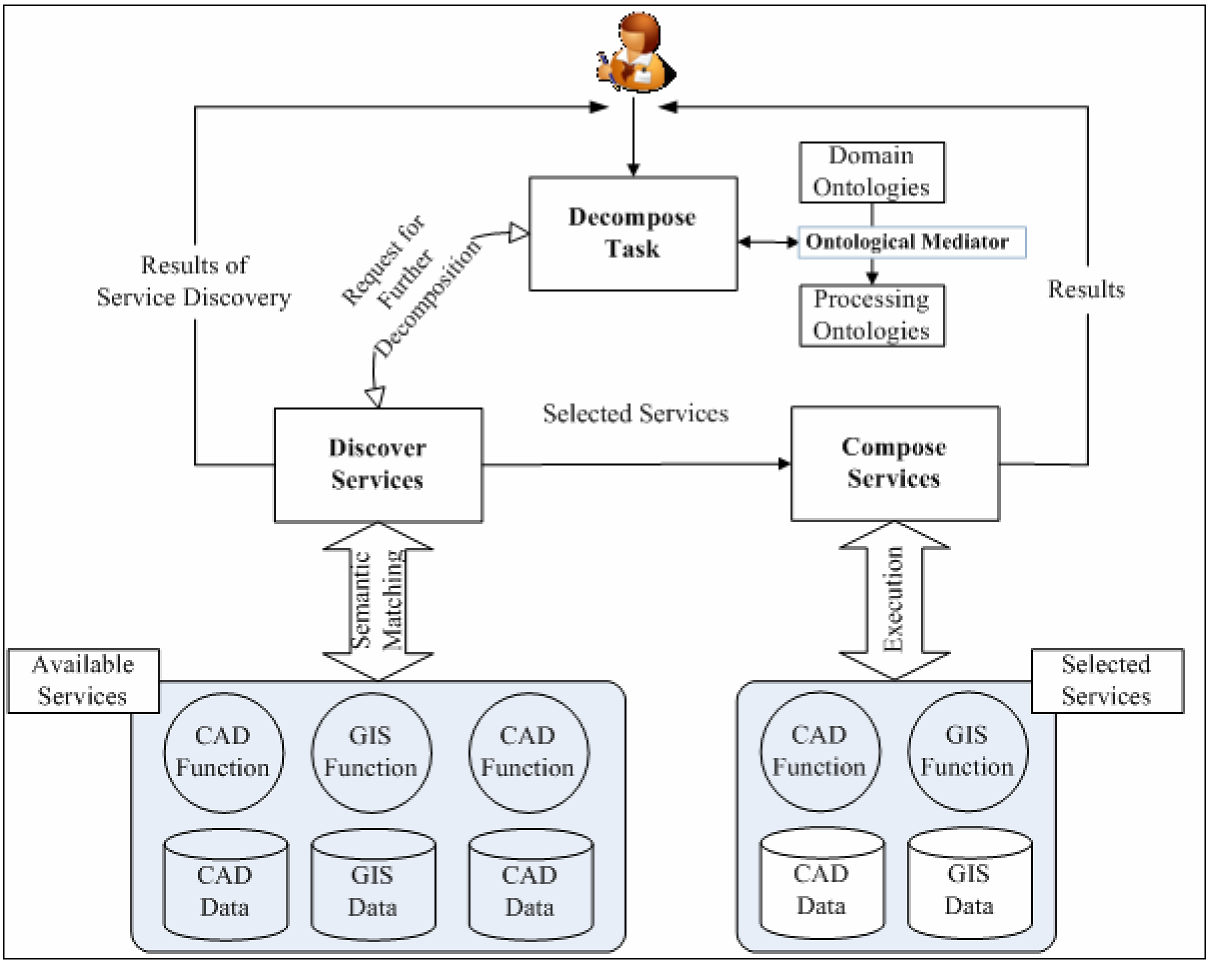

FIG 3: Semantic CAD/GIS web services vision

In this vision (FIG 3), AEC domain ontologies are proposed to be used to decompose a given task into a set of sub-tasks (using *Decompose Task* module), which in turn through the *Ontological Mediator* they are mapped to specific CAD or GIS operations (Peachavanish and Karimi 2007). The outcome will be a workflow of operations and data transfers that will be used to discover available CAD/GIS web services and to compose them in answering the given task. Using our scenario example, the workflow generated after the decomposition task would include operations to gather and transform data (e.g., from a CAD-based building information model to a vector-based GIS model), to assemble an overlay aligning the various elements under consideration (e.g., crane, building under construction, adjacent buildings, surface utilities) with the underlying geospatial coordinate reference system, and to conduct spatial analysis to identify obstructions.

Once the required operations are identified, the search for available services can begin with the help of *Discover Services* module. For each operation, a matching algorithm in *Discover Services* module evaluates existing services against the requested service (i.e., an operation). If a suitable service cannot be identified (i.e., no match is made), the operation will be further decomposed into lower level operations for which there may be match services. Further, in *Discover Services* module, each identified service will be evaluated based on Quality of Service (QoS) parameters. In the event that the available service for a specific operation does not meet the *QoS* parameters, feedback will be provided to the user and they will be given an opportunity to accept or reject the service. If no service can be located, the task cannot be completed and feedback will be provided to the user. If exceptions are encountered during execution (e.g., a service has become unavailable in the interim between identification and execution), feedback is provided to the user.

When matches between CAD/GIS web services for a given task are found, they need to be chained together (i.e. composed) and invoked in a specific order to provide the requested outcome. Service composition is done with the help of *Compose Services* module. In a highly dynamic environment, like web services, service composition is susceptible to multitude of sources of uncertainties including network latency, availability of services and quality of available services. A planning-based approach that can handle uncertainties to web service composition is the final module in our approach.

4. COMPONENTS OF THE SEMANTIC CAD/GIS WEB SERVICES APPROACH

To take full advantage of web services (allowing users to assemble operations based on the needs of each specific project), which are expected to be numerous for each domain, they need to be searched and matched semantically. To semantically search and match web services, ontologies, both those that define specific concepts within a domain and those general ontologies that define relevant concepts to the task at hand, are needed. Our proposed semantic web services approach for CAD/GIS integration requires that CAD/GIS ontologies be used to resolve potential semantics issues in deciding appropriate web services for CAD/GIS operations. The details of what these CAD/GIS ontologies should be, how they could be used for CAD/GIS problem solving, what CAD/GIS web services should be, and how they could be used for CAD/GIS integration are given in this section.

4.1 Ontologies

The key to our proposed approach is a set of ontologies, primarily domain ontologies, that upon submission of any given task help resolve semantic issues associated with CAD/GIS integration. Ontology is defined as an “explicit specification of a conceptualization” (Gruber 1993). Generally, it is represented as a set of concepts within a domain and the relationships between the concepts. The specification of an ontology comprises a vocabulary of terms where each term defines its meaning (Boury-Brisset 2003). Ontology has been used in various areas such as knowledge management (Fensel 2002), semantic web (Fensel et al. 2001), and data fusion (Boury-Brisset 2003).

Ontologies are becoming an increasingly important research area in the field of geospatial information science. Recent research in the area of geospatial ontology has been focused on the formal modeling of the geospatial world (Mark et al. 1999; Smith and Mark 2001), allowing for cross-system interoperability (Karimi et al. 2003; Peachavanish et al. 2006), geospatial data integration ((Cruz et al. 2004; Fonseca et al. 2003; Fonseca et al. 2002), and facilitation of geospatial information retrieval in heterogeneous networked environments (Klien et al. 2006).

AEC domain ontologies (e.g., IFC and Barbie) define concepts, activities, and objects and the relationships among elements defined within AEC/CAD domain. In 2006, OGC examined the feasibility of representing GML in OWL as part of a preliminary effort to extend existing services, encodings, and architectures with Semantic Web technologies (OGC 2007). Further, the Geospatial Incubator Group of the W3C has focused on addressing issues of location and geographic properties of the Web of today and tomorrow (W3C 2007). This group recognizes ontologies as a critical part of its scope and the development of recommendations for geospatial ontologies as a key short term objective.

Within the geospatial domain, multiple ontologies based on ISO, OGC, and Federal Geographic Data Committee (FGDC) standards have been developed and made available on the Internet. In the AEC domain, research efforts investigate the opportunities to leverage the current IFC model to derive ontologies and develop standard models of the knowledge within the construction domain (BARBi 2007; e-Cognos 2007; El-Diraby et al. 2005; El-Diraby and Kashif 2005). While both communities (geospatial and AEC) have been actively engaged in developing their own sets of standards to enable interoperability among different software systems within their respective domains, only recently has the aspect of interoperability among *inter*-domains been officially recognized.

4.1.1 Ontologies for CAD/GIS Problem Solving

As discussed in the scenario in Section 2, there may be multiple approaches to complete the needed analysis based on the characteristics of the task and the desired level of accuracy. The specific approach to conduct the analysis will drive a set of operations that need to be executed to provide the desired outcome of the given task. For example, for a site in a densely populated urban area, a more detailed 3D analysis may be needed than for a site located in a rural area, where a 2D spatial analysis may be sufficient.

In addition to utilizing ontologies for web service matching (discussed later in this paper), ontologies in CAD/GIS integration could be used to understand and interpret engineering tasks. This can be accomplished by decomposing a given task into its individual sub-tasks and identifying the required CAD and GIS operations that must be performed. Such a decomposition of a task requires ontologies in both AEC and geospatial domains. For example in our scenario, the task, "*identify the dimensions and locations of existing obstructions that are on or within close proximity of a job site*" could be decomposed into the following sub-tasks: *identify candidate obstructions*, *transform and assemble data*, *conduct analysis*, and *prepare results*. Clearly, performing these four sub-tasks requires both CAD and GIS operations from data transformation to spatial analysis to various computations to map generation.

Once a task is decomposed into a set of sub-tasks, each sub-task will be matched with a specific operation or a set of operations defined in CAD/GIS processing ontologies using the AEC-CAD/GIS Mediator that defines the relationship between domain level sub-tasks and processing operations. Each operation is defined in the processing ontologies with an identifier, one or more input parameters, and one or more output parameters. For example, the operation TRANSFORM takes a data file and a target format as input and produces a new data file in the new format as an output. The processing ontologies must support the definition of both basic operations, which cannot be broken down into simpler operations, and compound operations, which are operations made up of two or more basic (or other compound) operations. Once the operations are identified along with their parameters, a workflow will be constructed.

An alternative approach to identify the sub-tasks of a task and construct a workflow is to use Natural Language Processing (NLP) to interpret tasks. In this case, the task must be presented in a language with a specific structure common in the domain. NLP has been the subject of significant research to automate the creation of Conceptual Data Models (CDM) such as Entity Relationship Diagrams (ERD) from requirements specifications (Ambriola and Gervasi 2006; Chen 1997; Harmain and Gaizauskas 2000; Mich 1996).

4.1.2 Identification, Evaluation, and Selection of Ontologies

As the use of ontologies to establish formal semantic agreements gains popularity, it is unrealistic to expect that there will be agreement on a single ontology or even a small set of ontologies within each domain. It is more likely that a vast number of ontologies within and across domains will be developed. Given the vast number of ontologies within and across domains, identifying relevant ontologies and reconciling among different ontologies are critical and have resulted in approaches to map (i.e., establish links between ontologies) or merge (i.e., generate a unique ontology from a set of original ontologies) multiple ontologies (Kotis et al. 2006; Noy and Musen 2003). We believe that in order to achieve the vision of semantic CAD/GIS interoperability via web services and to realize the associated benefits, research in this area needs to go beyond merely merging and mapping ontologies. Techniques must be developed to identify, evaluate, and select the set of ontologies that adequately addresses the given task and to determine the best order of processing for the set of ontologies to ensure that the intended optimal solution for the task is achieved.

Once a task is decomposed into sub-tasks, a set of available processing ontologies must be identified and evaluated for each domain. The purpose of this evaluation is to select a set of appropriate ontologies that will provide the needed operations. An understanding of various ontologies and their relationship to one another within each domain is critical. FIG 4 depicts a possible set of ontologies covering a single domain. While some ontologies are independent of others (i.e., they represent concepts that are not represented by other ontologies within the domain and have no formal relationships), there are others that overlap (e.g., O^1, O^2, and O^3) or have a defined relationship (e.g., O^4, O^6, and O^8). For example, transferring a CAD file to a GIS file may involve multiple ontologies. The oval line on the left hand side of FIG 4 represents the set of available ontologies for a domain. However, for any given task only a subset of these ontologies may be needed, and it is possible that some of the needed ontologies will have similar or overlapping scopes that must be determined by mapping pairs of ontologies or by merging two or more ontologies into a single ontology. FIG 4 shows an example task where ontologies O^1, O^2, and O^3 are needed and while $O^1$and O^2 are distinct, both overlap with O^3.

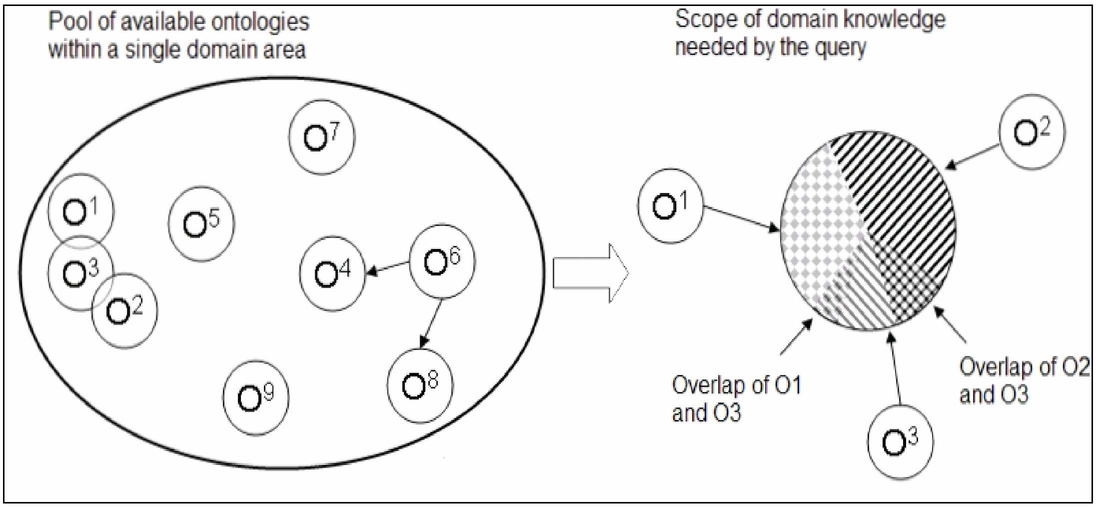

FIG 4: Selection of ontologies from available set of ontologies within a single domain

In our crane location scenario, one spatial analysis task involves determination of potential obstructions to the crane's movement (e.g., neighbouring buildings, surface/sub-surface utilities, roads, etc.). Completing this task requires a processing ontology that would capture and describe the specifics of the spatial analysis operations (i.e., inputs, outputs, parameters, etc.). If there are multiple ontologies that could provide such knowledge, then the one, ensuring the highest semantic confidence, should be selected. Semantic confidence in this context indicates a guarantee that the solution provided by the task is optimal and consistent within the context of the specific application and domain. In some cases, several ontologies may be needed to ensure semantic confidence. For example, addressing the task discussed in our scenario would require both CAD and GIS processing ontologies.

4.1.3 Optimal Ontology Processing

Once all the needed ontologies for a given task have been identified, evaluated, and selected, they must be processed in an optimal manner to provide semantic confidence. We model the problem of processing the required ontologies in a graph (see FIG 5) with the nodes representing individual ontologies and the links representing the relationship between the ontologies. Each link is assigned a weight ($pw_{x,y}$) which indicates the degree of overlap between pairs of ontologies.

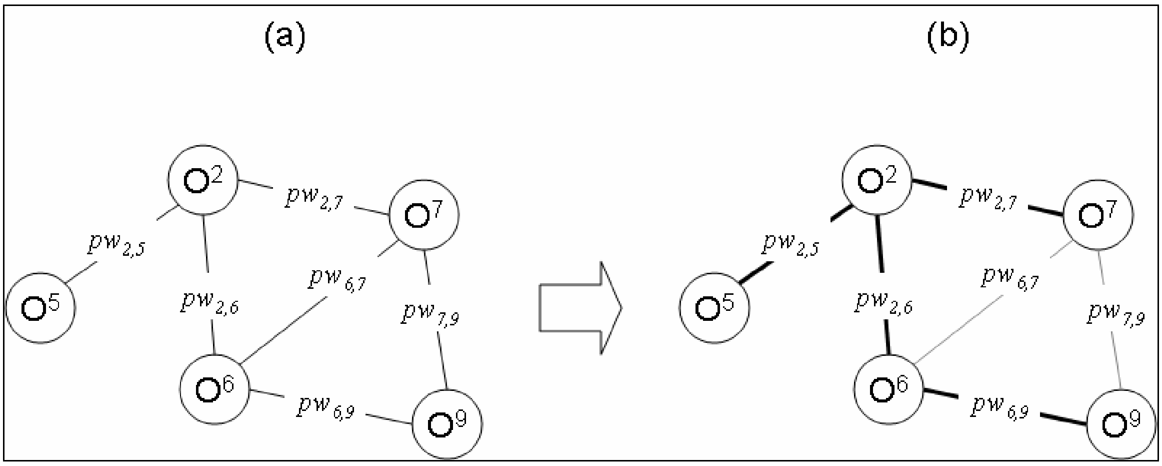

FIG 5: A graph representing ontologies and their relationships

Determining values for ($pw_{x,y}$) requires a technique that evaluates each pair of ontologies for overlapping concepts. The value for ($pw_{x,y}$) may range between 0 and 1 and will represent the amount of overlap between the two ontologies (*x*,*y*). A low value indicates a small overlap where a high value indicates a large overlap between the two ontologies. FIG 5 depicts those ontologies (O^2, O^5, O^6, O^7, and $O^{9)}$ that are selected out of the pool of available ontologies in FIG 4 and that are needed to address a specific task. The nodes of the graph in FIG 5 represent these selected ontologies and the links represent the relationship, with weights *pw*, between different ontologies.

With the problem represented as a graph, a solution to semantic confidence is the minimum spanning tree of the graph. In other words, the minimum spanning tree of the graph would guarantee the best solution (utilizing all the needed ontologies with the least amount of overlaps among them) to the task with the highest level of semantic confidence possible. The objective, i.e., determining the minimum spanning tree of the graph using the given weights, is shown in the equation below:

$$Minimize \sum_{\substack{i=1 \\ j=1}}^{n} (pw)_{ij} \tag{1}$$

where *pw* is the value assigned to the amount of overlap between the two linked ontologies (*i*,*j*). FIG 5b depicts a hypothetical minimal spanning tree for the graph in FIG 5a. Using this approach, the total amount of overlap is minimized while ensuring that all ontologies (representing the knowledge needed to resolve the entire task) are processed. The minimum spanning tree approach using an algorithm, such as Prim's or Kruskal's (Cormen et al. 2001), will result in an effective utilization of the required ontologies to ensure semantically correct outcomes (or semantics with the highest level of confidence).

4.2 Web Service Matching

Web services are an emerging technology for GIS and CAD applications. As the number of available CAD and GIS web services increases, finding the suitable ones that provide a solution to the tasks under consideration becomes more difficult. Therefore, effective service discovery is critical to the realization of our approach.

There are methodologies that facilitate service discovery from different perspectives, e.g., Business Process Execution Language for Web Services (BPEL4WS) from IBM and QoS parameters. Current techniques to discover services in distributed computing environments, such as Universal Description Discovery and Integration (UDDI), have several shortcomings. Examples of these shortcomings are failing to identify the best semantic similarity between service capabilities and user requests, and being unable to ensure that the capabilities of the identified service would meet the needs of the users—such needs are typically described in terms of desired accuracy, price, and response time, among others. For this, there is a need for a new service discovery technique that automatically selects a set of optimal CAD/GIS web services by satisfying both semantic and QoS criteria for a given task. In other words, such a technique must semantically match between concepts by optimizing QoSs preferred by users. For CAD/GIS integration, research in semantically rich service discovery requires development of algorithms that support publication of new services and service matching.

4.2.1 Service Discovery

Existing service matching algorithms usually perform a pair-wise comparison between a service request and all registered services (Li and Horrocks 2004; Paolucci et al. 2002). A match between a request and a service must involve semantic matching of the request concept(s) and the service concept(s). For discovery of CAD/GIS web services, a service matching algorithm and a QoS filtering algorithm are needed to: (a) evaluate semantic similarity between a user request and a registered service; (b) conduct comparisons between user's specific requirements and service(s)' capabilities in terms of QoSs; and (c) provide the user with a list of candidate services for further service composition (see FIG 6).

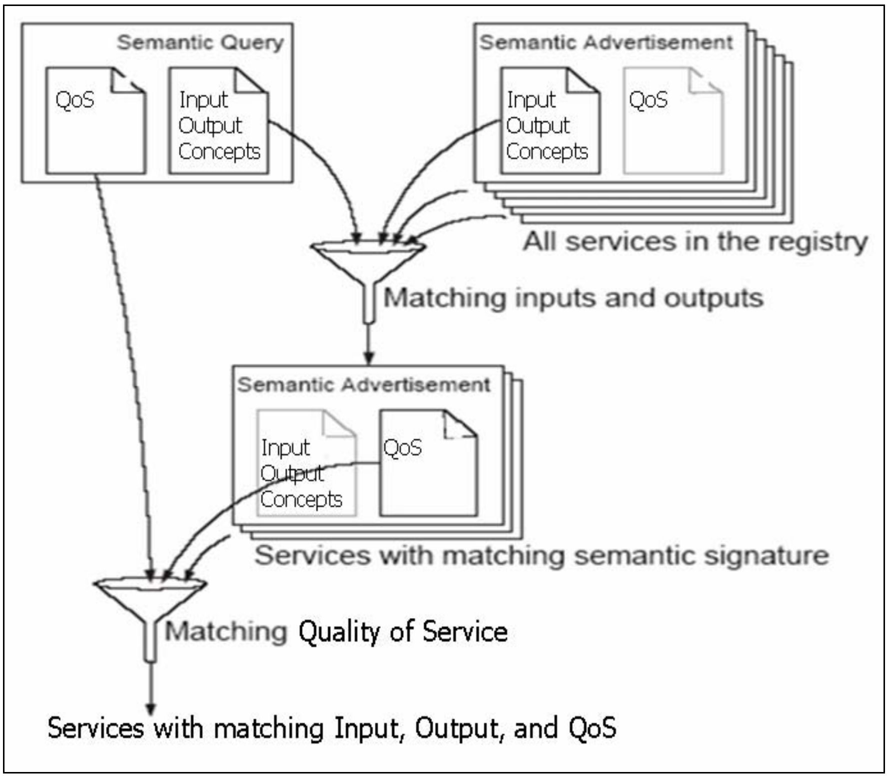

FIG 6: Matchmaking procedure

4.2.1.1 Service Matching Algorithm

Each sub-task of a given task should be matched to a set of one or more CAD/GIS operations using the AEC-CAD/GIS Mediator and a set of processing ontologies. Information on each operation in these processing ontologies forms the basis of the request for services. The main purpose of the Service Matching Algorithm is to compare the concepts derived from the processing ontology and requirements from the user with the concepts presented in form of published services. Once a new service profile is generated by the developer, its description is semantically interpreted and registered in an ontology.

The matching algorithm will search the relevant ontology to determine ontological relationship, if any, between the concepts. Such implicit relationships between service descriptions and requests can be derived through reasoning about the types of match between two output (or input and constraint) concepts as follows.

There are four types of similarity match between the output of a service (O^S) and the output of request (O^R), with each matching type assigned a score (Table 1):

Table 1: Types of similarity match between a request and a service

Type	*Description*
Exact	*If O^R and O^S are the same (highest similarity)*
Plug-in	*If O^R subsumes O^S, then O^S can be used instead of O^R*
Subsumption	*If O^S subsumes O^R, then the service may not completely satisfy the request*
Fail	*If O^R and O^S do not have either plug-in or subsumption relations, then the match fails*

These definitions of match types are based on previous studies on semantic matching (Li and Horrocks 2004; Paolucci et al. 2002), but utilize a different scoring matrix. Using these definitions of match types, the similarity between a service request and a service description can be reasoned and realized. For example, assuming *m* concepts in a service description and *m* corresponding concepts in a service request, the similarity or global match between the request *R* and the service *S* can be derived by summing up the match scores between the concepts pair based on the scoring matrix assigned from domain ontologies (see equations below).

$$match\ (C_i^R, C_i^S) = \begin{cases} Score\ 1 & if\ C_i^R = C_i^S \\ Score\ 2 & if\ C_i^R \subset C_i^S \\ Score\ 3 & if\ C_i^R \supset C_i^S \\ 0 & else \end{cases} \qquad (2)$$

$$similarity(R,S) = \sum_{i=1}^{m} match(C_i^R, C_i^S) \qquad (3)$$

An ontology is searched for finding the locations of the two concepts and for determining if they have any relationship using the scoring matrix defined in equations above. Upon completion of this search and assigning the scores, each concept will have a record of its sub-classes and super-classes, then either C_i^R or C_i^S needs to be searched, but not both. For example, FIG 87 shows a portion of an ontology, where concept C2 has a super-class C1 and a sub-class C4. Based on the list associated with C2, we can infer that C1 subsumes C2, C2 subsumes C4, and C2 has no relation with C3.

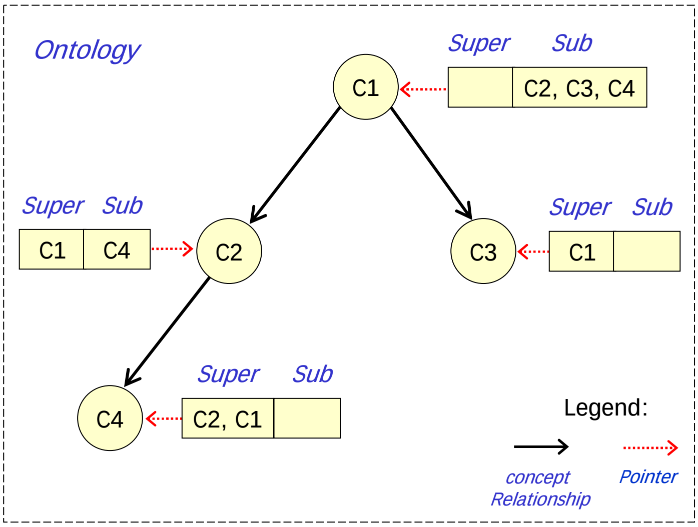

FIG 7: Matching concepts in an ontology

To determine if there is a match between a request O^R and a service O^S, the algorithm will search the ontology to find the location of O^R and determine the degree of match between the two concepts by checking to see if O^S appears in O^R's list of sub-classes and super-classes. The same process is followed to match between a service input and a request input.

FIG 8 shows the pseudo-code for the service matching algorithm. In this matching algorithm, a service request is matched against all the registered services. Whenever a match between the request and any of the registered services is found, the matched service will be assigned a matching score and the services with the highest similarity score will be recorded in the list of candidate services.

Main function match(request, All, G)	//G is an ontology, G = <V, E>
	//All is a list of all registered services
var service[ ]	// All.length = number of all services
int match = 0;	
for i = 1 to All.length **do**	//Find the final score by summing up the matching degree
match = serviceMatch(request, All[i]);	
if match != 0 **then**	
add All[i] to service;	//Add scored service to the list of candidate services
sort(service);	
return service;	

function serviceMatch(request, service)	//compare a request with a service
int m;	//number of concepts in request and service
parse request into concepts c1[m];	
parse service into concepts c2[m];	
for i = 1 to m **do**	
u_0 = the root vertex in G;	
score[i] = DFS'(u_0, c1[i], c2[i]);	//depth-first search of service concept
service.match += score[i];	//calculate match score
return service.match;	

function DFS'(u, x, y)	//x is request concept
	//y is corresponding service concept
if u = y **then**	
score = degreeOfMatch(y, x);	
return score;	
else	
status[u] = "traversed";	
for each neighbor v of u **do**	

```
        if status[v] != “traversed” then
            DFS’(v, x, y);
```

```
function degreeOfMatch(u, c)
int score = 0;
if c = u then
    score = “exact” or Score1;
if c is subclass of u then
    score = “plugin” or Score2;
if c is superclass of u then
    score = “subsumption” or Score3;
return score;
```

FIG 8: Pseudo code for Service Matching Algorithm

A match between a request and a service consists of the match of all the request concepts and the service concepts (function “serviceMatch” in FIG 8). Here the concepts include all input, output, and descriptions of request and service capabilities. A match is recognized if and only if for each request concept there is a service concept. To determine if there is a match, the algorithm first searches for the service concept in the ontology and then calls the scoring matrix (function “degreeOfMatch” in FIG 8) to calculate the degree of match (or matching score). The matching scores for all concepts are summed up as the global matching score (or similarity score) between the request and the service.

The last part of the algorithm is to sort the resulting matches. The sorting is based on the similarity scores for all matched services. Any sorting algorithm (e.g., insertion sort) can be applied here. After sorting, a list of all candidate services will be provided and will be input to the QoS filtering mechanism.

4.2.1.2 QoS Filtering Algorithm

The purpose of the semantic matching algorithm is to select optimal services. Optimal services not only semantically match a user’s request, but also best meet the user’s preferences (e.g., cost, response time, previous user satisfaction, level of encryption, and accuracy). For this, the QoS filtering algorithm will utilize those candidate services, each with a different QoS offerings (which consist of QoS parameters and values), selected by the service matching algorithm. QoS offerings by all candidate services will be checked against user-defined requirements and preferences and the most appropriate ones will be chosen. For the purpose of finding optimal services, a weighting scheme, based on weights for parameters, will be employed. One example would be the level of user satisfaction with candidate web services, measured on a scale from 1 to 10. Another example would be level of encryption, measured on a scale from 1 to 4.

4.2.1.3 Service Discovery Feedback

Once the discovery process is completed, a list of candidate services will be provided. Services with highest scores would match user’s request, with a high semantic confidence. Other identified services may be used as backups based on user flexibility. If an optimal service is not found, the process will search for the next best service.

It is reasonable to assume that users will not participate in the development of services, which means the search may result in no services or services that will not satisfy QoS parameters. In such cases, users will be notified and can modify their task or adjust the QoS parameters and re-discover services. When services that satisfy the request cannot be found, they will be marked for future searches to accelerate the service discovery process.

4.3 Web Service Composition

Once appropriate services for a given task are obtained, they need to be composed to provide the intended solution. Automated web service composition is defined as a computerized way of composing a set of available services to accomplish some user-defined task or goal (McIlraith and Son 2002). The concept of planning used in artificial intelligence domain can be considered as one of the promising techniques for automated web service composition (Pistore et al. 2004). A number of research efforts have perceived web service composition as a planning problem (Pistore et al. 2004; Sirin et al. 2004). For instance, Sirin, et al. (2004) leveraged the Hierarchical Task Network (HTN) planning technique along with OWL-S service descriptions (Sirin et al. 2004). Pistor, et al., (2004) viewed web service composition as a planning under uncertainty, where the planning domain is non-deterministic, partially observable and with extended goals (Pistore et al. 2004). A comprehensive description of the HTN planning technique and planning under uncertainty can be found in Ghallab et al. (2004). We also perceive web service composition as planning problem under uncertainty in accordance with Pistor et al. (2004) for the reason described below.

Classical planning techniques rely on such restrictive assumptions as determinism, full observability and reachability goals. These assumptions are not valid with planning under uncertainty. In a deterministic view, the execution path of each action is fully determined and can therefore be predicted. In a highly dynamic environment like web services, it is almost impossible to predict everything. This is due to a multitude of sources of uncertainties inherent in a dynamic environment. For example, network latency, availability of services and quality of available services contribute to uncertainties in web service composition. In addition to non-determinism, some states of web service composition may never be observable or observable only after some actions have been executed. For instance, in our example scenario, a planner that composes web services for transforming CAD data to GIS data cannot know the availability of transformation services until it searches all available CAD/GIS web services. Further, service composition constitutes a number of sub-goals and each sub-goal needs to specify requirements of different strengths to take into account non-determinism and possible (Ghallab et al. 2004). In the 3D transform and data assembly sub-goal, there may be either one single service or a set of multiple services (e.g., one individual service for co-ordinate transformation, workspace generation and workspace aggregation). Thus, from the non-determinism and possible failure point of view, it is safe to invoke one single service to achieve 3D transformation and data assembly sub-goal instead of invoking multiple services. Thus, web service composition has the characteristics of a problem involving planning under uncertainty

Planning under uncertainty has been extensively studied in the domain of robotics, manufacturing and logistics. Popular approaches for solving planning under uncertainty have been focused on leveraging the Markov Decision Processes (MDP), Partially Observable Markov Decision Processes (POMDP) and planning under model checking (Ghallab et al. 2004; Russell and Norvig 2003; Thrun 2002). With the MDP approach, the key idea is to formalize a planning problem as an optimization problem. Uncertainty related to action outcomes is modeled with some kind of probability distribution function (Ghallab et al. 2004). The goals are represented using utility functions, which are numeric functions giving preferences to actions to be executed. There are a number of viable plans and such plans as policies that specify the action to perform in each state. The objective of this approach is to search for a plan that maximizes the utility function. The difference between MDP and POMDP is that POMDP can handle partially observable states. An alternative to the MDP approach is a planning approach based on Model Checking. The main idea is to solve the problem model theoretically where sets of states and transitions are represented and manipulated symbolically (Ghallab et al. 2004). Such symbolic representation and manipulation often result in compact representation, thus saving computational time.

The aforementioned algorithms have been primarily tested on robotic applications (e.g., robot navigation), assembly and manufacturing. Limited research studies have been done on leveraging them for web service composition (Ghallab et al. 2004; Pistore et al. 2004). Current research studies have focused on the composition of a limited number of services (Pistore et al. 2004). Hence, it is still not clear whether the existing algorithms can scale well (in terms of computational time and resources) when the number of available services is vast (which is typical of web services). The MDP and POMDP algorithms seldom scale up when the number of states increases. The current success in web service composition using MDP/POMDP is based on a simple case scenario with a few services (Doshi et al. 2004). Therefore, it is necessary to understand the applicability and scalability of existing algorithms for the web service composition problem.

Further, MDP and POMDP leverage the concept of probabilities, utility functions and optimization to solve uncertainty-based planning problems. Such difficulties as calculation of utility function and probabilities have not been addressed yet. There is not enough statistical data to express state transitions (in MDP and POMDP) in terms of probabilities. In addition, defining a utility function in terms of QoS and assigning costs to these different QoSs have not been explored yet. Thus, there is a need to further exploration and formalization of the abovementioned problems.

5. CONCLUSION AND FUTURE RESEARCH

The lack of interoperability between CAD and GIS platforms results in inefficiency and increased costs. While current community and vendor efforts to address this issue have resulted in a low level of integration between existing platforms, significant benefits are still potential by enabling interoperability at the semantic level. We envision semantic CAD/GIS web services as a means for solving problems requiring both CAD and GIS data and operations and for insulating users from gaps in knowledge and ambiguity in semantics by allowing them to focus on addressing domain tasks. Such a semantic web service approach consists of task interpretation, web-service matching, and web-service composition. For task interpretation, there is a need for development of key algorithms and associated metrics to identify and evaluate ontologies needed to provide the required knowledge to solve cross-domain problems. In the area of web services, algorithms to support the publication of new services and perform service matching in support of CAD/GIS integration must be developed. Additionally, research is required to identify and quantify *QoS* parameters, and to develop a mechanism to provide feedback on the results of service discovery to the user in the event that the desired services cannot be identified. Finally, while web service composition can be characterized as a planning under uncertainty problem, the inherent differences between web service composition and existing planning under uncertainty problems, pose additional research questions with respect to the applicability and scalability of existing algorithms.

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