Development of a Logic Layer in the Semantic Web: Research Issues

Naeem Khalid Janjua, Farookh Khadeer Hussain

Digital Ecosystem and Business Intelligence Institute

Curtin University of Technology, Perth, WA

Naeem.janjua@postgrad.curtin.edu.au

Farookh.hussain@cbs.curtin.edu.au

Abstract— The ontology layer of the semantic web is now mature enough (i.e. standards like RDF, RDFs, OWL, OWL 2) and the next step is to work on a logic layer for the development of advanced reasoning capabilities for knowledge extraction and efficient decision making. Adding logic to the web means using rules to make inferences. Rules are a means of expressing business processes, policies, contracts etc but most of the studies have focused on the use of monotonic logics in layered development of the semantic web which provides no mechanism for representing or handling incomplete or contradictory information respectively. This paper discusses argumentation, semantic web and defeasible logic programming with their distinct features and identifies the different research issues that need to be addressed in order to realize defeasible argumentative reasoning in the semantic web applications.

I. ARGUMENTATION : AN INFORMAL REASONING

Any critical discussion of a certain topic involves differences of opinion among participants. In order to resolve these differences, discussion progresses through four distinct stages. The first stage is the confrontation stage where participants establish that they have differences of opinion. The second stage is the opening stage whereby participants are ready to listen and resolve their differences. The third stage is argumentation where participants exchange arguments which establish their position for or against, and the last stage is the conclusion in which they reach a consensus of opinion [1]. This characteristic of argumentation, that is, the resolution of conflicts, is a pivotal methodology used by human beings to reach a justifiable decision when information is incomplete and/or inconsistent. Argumentation is a rich interdisciplinary area of research spread across philosophy, communication studies, linguistics and psychology. In daily life, argumentation often has negative connotations, incorrectly suggesting quarrelsomeness and unpleasantness. It is the study of effective reasoning which is the fundamental way by which humans deals with conflicting information by taking into account arguments and counter arguments relevant to certain issues [2].

Reasoning is the process of inferring a conclusion from a given set of facts, propositions or arguments. It is one of the integral parts of human cognition for making day to day decision in a stochastic environment. The study of such reasoning started with Aristotle when he introduced the logic theory and started a scholarly discourse that was sustained by Islamic and Roman Catholic philosophers through the Middle Ages down to modern times [3]. It was dominant thinking that good reasoning needs to be deductively valid and a conclusion follows necessarily from premises. The following is an example of deductive reasoning:

Premise: All men are mortal

Premise: Suqrat is a man

Conclusion: Therefore Suqrat is mortal.

The systematic study of argumentation was also associated with formal logics and arguments were considered to be deductively valid. Such reasoning does not contain new information; it is analytical, requiring no reference to the external world, and it may be counterfactual. Therefore, deductive/formal reasoning does not add to our knowledge base; it merely rearranges it [2]. As a result, deductive reasoning was challenged in 1960 by the process of inductive reasoning where things are generalized from a restricted sample space to an unrestricted general conclusion. This is a common form of inference based on the idea that like things should be treated alike; it is also termed 'reasoning from analogy' For example, from observing that a number of mammals are warm blooded, biologists concluded that all mammals are warm-blooded. Most of the inductive generalizations are probabilistic in nature as they explain the relationship between specific facts and try to predict future knowledge, but without entailing it or ensuring its truth. For example, "This is an A and the probability of A being a B is high", leads to the inference that "This is a B" [4].

Reasoning is defeasible if a rule supporting a conclusion is challenged by new information. According to [5] "An inference is a defeasible if it can be blocked or defeated". According to [6] the salient difference between deductive and inductive logics is whether the conclusion is defeasible in principle, given the premises. In the case of deductive entailments, given the premises, the conclusion is not defeasible, in principle. In the case of inductive reasoning, it is. Deductive logic, that is predicate logic, comes under the umbrella of "Monotonic Logics" where adding new information to a given list of premises would not reduce the already existing amount of knowledge. This is the biggest problem with monotonic logics which requires a re-examination of the entire reasoning cycles when new information, especially information that contradicts existing knowledge [7], is being added to the knowledge database. Over period of time, it revealed that argumentation is the way

whereby a person takes up and defends particular standpoints. It is closely related to informal reasoning in contrast to logicians who tend to concentrate on the way in which conclusions are derived from premises [8].

Argumentation is formally defined as "a verbal and social activity of reason aimed at increasing (or decreasing) the acceptability of controversial standpoint for the listener or reader, by putting forward a constellation of propositions intended to justify (or refute) the standpoint before a rational judge" [9]. Numerous researchers across different domains of research are exploiting the power of argumentation to resolve decision-making problems.

II. Semantic Web : from ontology layer to logic layer

WWW is no longer just a pathway for digital data; rather it is a source for generating new information and knowledge for commercial activity, education, business and research. As a result, software and information services have become the real wealth of a knowledge-based society. However, it has become highly challenging to process this extremely large amount of data and extract new knowledge autonomously. Semantic web ontology layer development is an effort to address one aspect of this challenge by providing the means for publishing instance data using Resource Description format (RDF) with ontologies defined in Web Ontology Language (OWL) and RDF Schema (RDFS), to make it understandable by machines. Web Ontology Language (OWL), based on Description Logic, is a W3C proposed standard for representing knowledge on the semantic web and it provides constructs for cardinality restrictions, Boolean expressions and restriction on properties [10]. OWL has three variants, each having a different level of expressiveness for reasoning i.e. OWL Lite, OWL DL and OWL Full. The semantic web is seeking a universal medium for data exchange i.e. classifying, packaging and semantically enriching information for support of data automation, integration, and reuse across various applications [11, 12]. The OWL 2 Web Ontology Language, informally known as OWL 2, is an ontology language for the semantic web that became a W3C Recommendation on Oct 27 2009. OWL 2 is compatible with the OWL standard of 2004 which it supersedes. Similar to OWL 1, the main syntactic form of OWL 2 ontologies is based on an RDF serialization, although various alternative syntactic forms are also available. OWL 2 is also available in three variants: OWL 2 EL, OWL 2 QL and OWL 2 RL [13]. Similarly, efforts have been made to build semantic web services using service description standards based on ontologies, such as Web Ontology Language for Services (OWL S) , WSMO [14].

As the ontology layer of the semantic web is now sufficiently mature (i.e. standards like RDF, RDFs, OWL, OWL 2), the next step is to work on the logic layer for the development of advanced reasoning capabilities on the semantic enriched data for the extraction of new knowledge and for efficient decision making. Adding logic to the web involves using rules to make inferences. Rules are used to express computational or business logic, express policies or contracts in information systems which don't have explicit control flow, and are suitable for execution in dynamic situations for business collaboration. Rule-based systems have been extensively used in several applications and domains, such as databases, e-commerce, personalization, games, businesses (B2B, B2C) and academia. In e-business, they can be used to represent sellers' offerings of products and services, capabilities bits, and to represent buyers' requests, interests and bits for matchmaking [15].

There are two modeling paradigms for modeling the semantic web: classical logic paradigm and datalog paradigm. With the classical logic paradigm, OWL-based ontologies are handled by DL reasoning systems such as Pellet, RacePro, Fact++ etc that use existing DL algorithms for reasoning. DL reasoning engines have a good TBox (ontology schema) reasoning but they are inefficient in ABox (individual instance) reasoning. However, with the datalog paradigm, OWL semantics are transferred to rules that are used by a rule engine in order to infer implicit knowledge. However, in certain situations, given the open nature of the web, rules are insufficient for modeling [16].

Rules are classified according to three types: deductive rules, normative rules and reactive rules. Reactive rules are further classified as ECA rules and production rules. There are two ways in which rules can be used for knowledge acquisition on the semantic web. A one-way knowledge flow exists from an ontology module to a rule module, where an ontology module's instances are imported as basic facts and filtered with conditions in the rules. This passive knowledge query uses only deductive rules. Whereas, if a rule engine derives implicit new facts and updates those facts back to an ontology module, then this is reverse knowledge flow from a rule module to an ontology module. This reverse knowledge flow requires normative and reactive rules [17]. Keeping in view importance of rules in semantic web, Tim Berners-Lee has proposed N3Logic which allows rules to be expressed in a web environment. It extends RDF with syntax for nested graphs and quantified variables and with predicates for implication and accessing resources on the Web, and has functions which include cryptographic, string, and math. The main goal of N3Logic is to be a minimal extension of the RDF data model so that the same language can be used for both logic and data [18].

Web is a universal platform that can be used for sharing/interchanging rules for carrying out distributed processing. Development of Rule Markup Language (RuleML)[1] and Rule Interchange Format (RIF)[2], is a step forward to address challenges of rules sharing on web.

III. Defeasible Logic Programming and Semantic Web

In an updated version of a semantic web stack, rules are positioned next to the ontology layer because they can serve as an extension of, or alternative to, DL-based ontology languages and they can be used to develop a declarative system using ontological information. Combining DLs with

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[1] http://ruleml.org

[2] http://www.w3.org/2005/rules/wiki/RIF_Working_Group

rules will make possible the execution of expressive queries on instances since DL reasoning engines have low reasoning and querying performance. Rules can also be useful for defining integrity constraints over the ABox of the ontology e.g. axioms Person $\sqsubseteq$ hasSSN.SS and Person(george) are satisfiable in OWL even if we do not define an SSN for George [19]. Additionally, it is impossible to assert that persons who study and live in the same city are "home students" in DAML+OIL or OWL, while this can be done easily using rules: studies(X, Y), lives(X,Z), loc(Y,U), loc(Z,U) ---> homeStudent(X). Most of the studies have focused on the use of monotonic logics in the layered development of the semantic web which provide no mechanism for representing incomplete information and handling contradictory information. These limitations are inherited by description logic since this is a subset of predicate logic. Predicate logic and the inferences (deductive logic) we draw from it is an example of monotonic reasoning. In monotonic reasoning, if we enlarge the set of axioms, we cannot retract any existing assertions or axioms. Deductive/formal reasoning does not add to our knowledge base; it merely rearranges it [5].

The problems of knowledge representation and reasoning faced by semantic web today could be addressed by logic programming. Logic Programming is a predominant paradigm for expressing knowledge with rules, making inferences, and answering queries. It provides both a declarative reading (with well understood semantics) and an operational reading of rules (with implementations). Its semantics underlie in large part the four families of rule systems i.e. SQL relationship databases, OPS5 heritage production rules, Prolog, and Even-Condition-Action rules and its semantic are being used as proposal for rules in context of semantic web. There is currently much debate on the suitability of Logic Programming in the domain of semantic web. Many efforts have focused on the mapping, intersection or combination of DLs and LP in order to overcome the shortcomings that emerged during the practical applications of OWL [16]. In order to overcome the limitation of reasoning on OWL, [20] proposed Description Logic Programming which lies at the intersection of LP and DL instead of using Full FOL for addressing issues. FOL can express (positive) disjunctives which are inexpressible in LP although it does not provide support for expressing negation-as-failure and procedural attachments such as the association of action performing procedural invocation with the drawing of a conclusion about a particular predicate. On other hand, Logic Programming does provide these features to support non-monotonic behavior of the system [20]. Using Full FOL for knowledge representation is not practical because of certain limitations. For example, FOL has severe computational complexity; it is not understood at a basic research level in order to be used for non-monotonicity and procedural attachments; and, its inferencing techniques have severe practical limitations since it is unfamiliar to the great majority of software engineers, unlike rules (e.g., in the form of SQL-type queries, or Prolog) which are familiar conceptually to many of them.

The rules-based system described above indicates that good attempts have been made to harvest the benefits of logic programming for the semantic web. However, the rules defined in DLP are not capable of expressing non-monotonicity. Let us consider a simple example taken from [21]. Suppose that an online vendor wants to give a special discount if it is a customer's birthday. An easy way to represent this application with rules is as follows:

R1 : If birthday then special discount.
R2 : If not birthday then no special discount.

This solution works properly when the birthday is known. But there may be a customer who refuses to provide his date of birth due to privacy concerns. In such a case, none of the above rules can be applied, since their respective premises are not known. To capture this situation, we need to write something like:

R1 : If birthday then special discount.
R2$_0$: If birthday is not known then no special discount.

However, the premise of rule R2$_0$ is not within the expressive power of predicate logic. Thus, we need a new set of rules. We note that the solution with rules R1 and R2 works when we have complete information about the situation (for example, either birthday or not birthday). The new rule system can be applied to cases where the available information is incomplete. Predicate logic, and its special cases, is monotonic in the following sense: if a conclusion can be drawn, it remains valid even if new knowledge becomes available. But if rule R2$_0$ is applied to derive "no special discount", then this conclusion may become invalid if the customer's date of birth becomes available. This draws our attention to new kinds of rules known as *non-monotonic* rules or *defeasible* rules. Defeasible rules are weak rules and any claim which they support may be defeated by the addition of new information. Mostly, priorities are used to resolve conflicts among rules [22, 23] . DeLP [24] is a formalism that combines the result of logic programming and defeasible argumentation. Along with facts and strict rules representation, it also makes it possible to represent information in the form of weak rules in a declarative manner for introducing defeasibility into a system. DeLP has two main aspects: argument construction and the resolution of conflicting arguments. Argument construction is similar to that in other defeasible logic systems, in that an argument is of the form <h, A> where A is a set of rules, such that when considered in conjunction with a set of facts, A is a minimal set of consistent rules that provides a derivation for h. DeLP use argumentation formalism for treatment of contradictory information by identifying conflicting information in the knowledge base and applying a dialectical process for deciding which information prevails. Therefore, defeat should be result of global consideration of the corpus of available knowledge of the agent deriving the inference. This approach appears to be very attractive for semantic web applications because it is not possible to explicitly encode the common sense reasoning in the form of priorities in web applications.

IV. RESEARCH ISSUES

The semantic web is source of defeasible knowledge as it is open by nature and subject to inconsistencies deriving from multiple sources. Such inconsistent knowledge hinders the automated transactions on the semantic web, integration of business policies and applications etc. Currently the systems build on top of description logic for knowledge representation and reasoning in the semantic web applications are non-defeasible reasoning (monotonic) systems. Such systems are not capable of addressing the challenges described above. Artificial intelligence and philosophy are key disciplines which provide certain formalism like defeasible logic and argumentation respectively, to address the challenges of knowledge representation and reasoning faced by semantic web applications today. The attempts [22, 23] are way forward in addressing some of these challenges but they use priorities among rules to resolve conflicts whereas DeLP use argumentation semantics for identifying the accurate information among the pieces of contradicting knowledge and information. Therefore, in DeLP the decision making does not require the explicit encoding of reasoning in advance in the form priorities among conflicting rules and ultimate decision is supported by whole corpus of knowledge.

Based on the evaluation of the existing literature review, following research issues have been identified:

- The Semantic web development technologies follow monotonic logic which is incapable of representation and reasoning over incomplete and inconsistent information.
- Rules based engines have their own format for rule expression and not easy to share.
- Nonmonotonic techniques in logic programming e.g DeLP (Defeasible logic programming) has not yet explored for knowledge representation and reasoning in semantic web applications. Following would be critical research question in this regard:
  - Bringing semantic interoperability between defeasible logic programming (DeLP) and Semantic web ontology languages e.g OWL.
  - Implementation of data driven reasoning in DeLP reasoner.
  - Extending argumentative reasoning capability of DeLP reasoner by keeping in view factors important in semantic web for arguments profiling e.g Trust.
  - Graphical representation of reasoning chains generated during argumentation process and their traversing by users.

V. CONCLUSIONS

In this paper, we have discussed argumentation as a pivotal methodology for resolving conflicts among participants and its role in the reasoning process. The paper elaborates in detail on the current development of the semantic web along with its limitations in terms of knowledge representation and reasoning. Moreover, the benefits of defeasible logic programming on the semantic web are elaborated upon with an example. We concluded by establishing certain research challenges that need to be addressed in order to carry out argumentative defeasible reasoning in the semantic web applications.

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