Chapter 9
Recapitulation and Future Work

9.1 Introduction

In the existing literature, the approaches proposed for information representation and reasoning in Semantic Web applications do not provide any solution for Enterprise Information Integration (EII) and Enterprise Knowledge Integration (EKI) when the underlying information (both structured and unstructured) is potentially incomplete and/or contradictory and exists within the enterprise and/or in other enterprises. At the same time, defeasible reasoning-based implementations on the Semantic Web proposed in the literature have the capability to represent and reason over incomplete and/or contradictory information, only if it comes from an individual user/source with the help of predefined priorities between contradictory rules. However, such approaches fail to provide a solution in a group decision-making scenario where information may come from different sources/users and where priorities are not defined between contradictory rules in advance i.e. before reasoning.

In order to overcome this disadvantage and to provide monological argumentation support in Semantic Web applications by enabling them to represent, reason and integrate incomplete and/or contradictory information, five major research objectives have been identified (in Sect. 3.5) and addressed in this thesis. In Sect. 9.2, the different research issues that have been identified and addressed in this thesis are recapitulated. In Sect. 9.3, the contributions made by this thesis to the literature by successfully addressing the research issues are highlighted. In Sect. 9.4, areas for future work are identified and in Sect. 9.5 the chapter is concluded.

9.2 Recapitulation

The World Wide Web (WWW) is one of the major sources of information for software agents and Web applications to generate new knowledge and assist in the decision-making process. The extension of WWW i.e. the Semantic Web, provides a language stack (i.e. Semantic Web stack) that enables software agents and Web applications

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to represent and understand this information and process it autonomously. However, the current languages that lie at the logic layer of the Semantic Web are incapable of representing and reasoning over information that may be incomplete and/or contradictory. Although approaches have been proposed in the literature by different researchers to exploit defeasible reasoning in the area of the Semantic Web, none of them present an approach by which Semantic Web applications can represent, reason and integrate information (i.e. that may be incomplete and/or contradictory) when information comes from heterogenous sources. As a result, Semantic Web applications in an enterprise are not able to consider the information which exists within the enterprise and/or in other enterprises and fail to provide solutions for EII and EKI.

One way by which the above mentioned problem has been addressed in the area of AI is by using 'argumentation'. Argumentation formalisms are considered a pivotal methodology to reach a conclusion in the presence of incomplete and/or contradictory information coming from different sources/users. However, due to a lack of reusable components from AI, current argumentation-driven Semantic Web applications are dialogical in nature and provide no solution for monological argumentation on information which exists within the enterprise and/or in other enterprises to assist the decision maker in the decision-making process. So, in the course of the research documented in this thesis, the broad issue to be addressed i.e. *the design and development of a generic framework for monological argumentation in Semantic Web applications. Such a framework can be exploited for the development of different Semantic Web applications to represent, reason and integrate information exists within an enterprise and/or in other enterprises for enhanced business intelligence,* was identified. Several sub-problems were identified to solve the broad issue as follows:

1. Propose a methodology for incomplete and/or contradictory information representation in Semantic Web applications. Such information may be present within the enterprise and/or in other enterprises and may need to be considered during the intra-enterprise or inter-enterprise decision-making process.
2. Propose a methodology for monological argumentation performed by a hybrid reasoning engine to reason over incomplete and/or contradictory information. The proposed methodology needs to:
   (a) Extend the Rete network in order to compile rules that may represent incomplete and/or contradictory information.
   (b) Define syntax and semantics for data-driven reasoning over underlying information for arguments construction.
   (c) Define syntax and semantics for goal-driven reasoning to identify and resolve conflicts between arguments.
   (d) Propose a methodology for different argumentation-driven conflict resolution strategies to resolve conflicts between arguments and their counter-arguments during goal-driven reasoning.
3. Propose a mechanism to integrate the information being produced by different argumentation-driven hybrid reasoning engines and provide a graphical

representation for the decision maker for a better understanding of the reasoning process and its results.
4. Propose a mechanism to export the generated reasoning chains to other Semantic Web applications and vice versa. This will help to bring inter-operability between different information systems and pave the way for knowledge integration.
5. Propose a mechanism to query the knowledge base once the hybrid reasoning is complete in order to obtain an explanation of the reasoning results.
6. Propose a methodology to integrate the reasoning chains produced by different information systems into a coherent reasoning chain. Such knowledge integration will provide a complete picture about information spanning across different information systems.
7. Exploit the proposed GF@SWA in different Semantic Web applications to support intelligent decision making.
8. Validate the functionality and evaluate the features of the proposed GF@SWA.

9.3 Contributions of the Thesis

The major contribution of this thesis to the literature is that it proposes a defeasible logic programming-based framework for monological argumentation support in Semantic Web applications, which enables them to consider incomplete and/or contradictory which exists within the enterprise and/or in other enterprises to obtain better decision-making support in the intra-enterprise or inter-enterprise decision-making process. The contributions of this thesis are as follows:

1. Proposed a methodology for incomplete and/or contradictory information representation by extending Defeasible logic programming (DeLP) in order to represent incomplete and/or contradictory information in Semantic Web applications to assist group decision making. The methodology also proposed a translation mechanism to translate the information present in either RuleML or OWL/RDF format to DeLP format.
2. Proposed a methodology for monological argumentation performed by a hybrid reasoning engine. The hybrid reasoning engine performs data-driven reasoning for argument construction and goal-driven reasoning for conflict identification and resolution.
3. Proposed a methodology for different argumentation-driven conflict resolution strategies to resolve conflicts between arguments and their counter-arguments.
4. Proposed a methodology that can integrate the output of a hybrid reasoning engine in the form of a reasoning chain (called information integration). Such methodology links the facts to a conclusion and represents the reasoning chain in a graphical format.
5. Proposed a methodology for importing/exporting integrated information (i.e. reasoning chain) to different Semantic Web applications.

6. Proposed a methodology that involves the definition and application of an argumentation scheme over the reasoning chains followed by argumentative reasoning to integrate knowledge that comes from different hybrid reasoning engines into a single reasoning chain to facilitate enterprise-wide decision making.
7. Proposed a methodology for the hybrid reasoning engine to have a querying and answering capability backed by an explanation of conflict resolution and/or the conclusions drawn for the decision maker.
8. Demonstrated the application of GF@SWA in different Semantic Web applications to support intelligent decision making over incomplete and/or contradictory information which exists within the enterprise and/or in other enterprises.

In the following, a brief explanation of the contributions which this thesis has made to the existing literature is given.

9.3.1 Contribution 1: Methodology for Incomplete and/or Contradictory Information Representation

The first contribution of this thesis to the existing literature is that it proposes a methodology to represent information which exists within the enterprise and/or in other enterprises that may be incomplete and/or contradictory for consideration in the decision-making process. In the proposed methodology, first Defeasible logic programming (DeLP) is selected for information representation and the reasons behind the selection are discussed in Chap. 4. By using DeLP, the information presented in the different Semantic Web applications (each of which are discussed in Chaps. 5, 6 and 7) is captured in DeLP format either directly (with the help of Web-based forms) or indirectly (translation/transformation of existing information with the help of a translator). For transformation of existing structured information, two translators were developed i.e. RuleML translator and OWL/RDF translator, which are discussed in Chap. 5. To consider unstructured information in the decision-making process, a semantic annotation mechanism was proposed, as discussed in Chap. 7.

To the best of my knowledge, DeLP has been discussed in AI literature for information representation for software agents, critic and recommender systems etc., but it has been not used for information representation in Semantic Web applications for BI.

9.3.2 Contribution 2: Methodology for Monological Argumentation Performed by a Hybrid Reasoning Engine

The second contribution of this thesis to the existing literature is that it proposes a methodology for monological argumentation performed by hybrid reasoning to reason over information represented using DeLP language. The methodology was

discussed in Chap. 5. In the proposed methodology, the Rete network was extended to compile DeLP rules and make them ready for the hybrid reasoning engine. The hybrid reasoning engine performs two types of reasoning: firstly, data-driven reasoning for arguments construction; and secondly goal-driven reasoning for conflicts identification between arguments and their resolution. For knowledge integration, the working of hybrid reasoning was further extended with syntax and semantics, as discussed in Chap. 6.

To the best of my knowledge, there is no methodological approach proposed in literature where monological argumentation is performed by a hybrid reasoning engine that can reason over underlying information which may be incomplete and/or contradictory and use it in Semantic Web applications for BI.

9.3.3 Contribution 3: Methodology for Different Argumentation-Driven Conflict Resolution Strategies to Resolve Conflicts Between Arguments and Their Counter-Arguments

The third contribution of this thesis to the existing literature is that it proposes a methodology for the provision of different argumentation-driven conflict resolution strategies to resolve conflicts between arguments and their counter-arguments. Four different conflict resolution strategies were proposed: the Generalize conflict resolution, Dung's style based conflict resolution, fuzzy preferences and voting-based conflict resolution. The Generalize conflict resolution strategy was discussed in Chaps. 5 and 6, whereas the other strategies were discussed in Chap. 7. Each conflict resolution algorithm takes into account different conflict resolution criteria in order to address different contexts.

In the literature, the above mentioned conflict resolution strategies have been used but they have not been exploited in monological argumentation performed by a hybrid reasoning engine to resolve the conflicts among arguments in Semantic Web applications for BI.

9.3.4 Contribution 4: Methodology to Integrate the Output of a Hybrid Reasoning Engine in the Form of a Reasoning Chain and Generate its Graphical Representation

The fourth contribution of this thesis to the existing literature is that it proposes a methodology to integrate the output of a hybrid reasoning engine in the form of a reasoning chain and provides its graphical representation for decision makers to assist them in the decision-making process. The methodology was discussed in Chaps. 5 and 6 with the help of Semantic Web applications, and discussion was provided on

how arguments are linked to form a reasoning chain after conflict resolution and how its graphical representation assists the decision maker in different enterprise contexts for decision making. In Chap. 7, the proposed methodology was extended to provide more informative graphical representation of a reasoning chain such as a business process map extracted from the unstructured business policies of an enterprise.

Some argumentation tools have been proposed in the literature to manually draw and link arguments (i.e. dialogical argumentation) in the format of reasoning chains, however, there is no proposed approach by which the output of monological argumentation performed by a hybrid reasoning engine is integrated in the form a reasoning chain in Semantic Web applications for BI.

9.3.5 Contribution 5: Methodology for Importing/Exporting Integrated Information to Different Semantic Web Applications

The fifth contribution of this thesis to the existing literature is that it proposes a methodology to export the generated reasoning chains in a standard format so that they can be considered by other software systems and vice versa. This methodology was discussed in Chap. 6. By using this methodology, the Semantic Web application working within the enterprise and/or in other enterprises can share/exchange information in AIF format, paving the way for knowledge integration.

In the literature, different approaches have been proposed to import and export information in AIF format, however, none of them provide any mapping of DeLP-based reasoning chains to AIF format and vice versa, therefore they provide no solution for information and knowledge integration using Semantic Web applications for BI.

9.3.6 Contribution 6: Methodology for Knowledge Integration

The sixth contribution of this thesis to the existing literature is that it proposes a methodology to integrate the reasoning chains produced by different hybrid reasoning engines into a coherent reasoning chain i.e., knowledge integration, in order to provide a complete picture about a subject spanning across different Semantic Web applications. This methodology was discussed in Chap. 6. By using the proposed methodology, a decision maker can define an integration scheme in order to evaluate the reasoning chains followed by argumentative reasoning that results in the construction of an integrated recommendations space.

To the best of my knowledge, no approach or conceptual model has been proposed in the literature which provides a solution for knowledge integration in Semantic Web applications for BI when the underlying information is incomplete and/or contradictory.

9.3.7 Contribution 7: Methodology for the Hybrid Reasoning Engine to Have a Querying and Answering Capability

The seventh contribution of this thesis to the existing literature is that it proposes a mechanism to equip the hybrid reasoning engine with a querying and answering capability backed by an explanation of the results achieved through hybrid reasoning. This methodology was presented in Chap. 6. In Chap. 8, different Semantic Web applications were discussed that provide a Web-based interface to query the knowledge base and show the graphical representation of the results which are displayed back to the users.

In the current literature, DeLP query support has been provided to software agents in AI, however, this has not been exploited in Semantic Web applications for BI.

9.3.8 Contribution 8: Application of GF@SWA in Different Semantic Web Applications to Support Intelligent Decision Making

The eighth contribution of this thesis to the existing literature is that it demonstrates how the proposed generic framework i.e. GF@SWA, can be exploited by different Semantic Web applications to represent, reason and integrate information which exists within the enterprise and/or in other enterprises. The Web@IDSS, discussed in Chap. 5, exploits the functionalities of GF@SWA in order to provide a solution for EII when the underlying structured information is incomplete and/or contradictory. In Chap. 7, KR@PMD also exploits the functionalities of GF@SWA to provide a solution for EII when the underlying unstructured information is incomplete and/or contradictory. The Web@KIDSS, discussed in Chap. 6, exploits the functionalities of GF@SWA in order to provide a solution for EKI.

To the best of my knowledge, apart from this thesis, there is no proposed generic framework in the literature on top of which different Semantic Web applications for BI can be built in order to represent, reason and integrate information which exists within the enterprise and/or in other enterprises.

9.4 Future Work

In this thesis, a defeasible logic programming-based framework was designed and developed to support monological argumentation in Semantic Web applications. The generic nature of the proposed framework makes it flexible enough to be applied in different Semantic Web applications, as explained in Chaps. 5, 6 and 7, to provide better decision support to decision makers in the intra-enterprise or inter-enterprise decision-making process.

In this section, the future work that will be undertaken in order to strengthen the proposed framework to provide more intuitive results to support the decision-making process is discussed. The possible areas are as follows:

1. Automated production rules extraction from unstructured information.
2. Extension of the proposed framework to work with machine learning algorithms for better classification of information.
3. Extend the proposed framework with an actual/generic argument model for practical reasoning (GAAM).
4. A collaborative framework to reason over qualitative data to assist group decision making.

9.4.1 Automated Production Rules Extraction from Unstructured Information

As discussed in Chap. 7, the proposed framework provides a semantic annotation methodology to consider unstructured information in Semantic Web applications. In this methodology, a decision maker is provided with a Web-based form on which to load the process ontology and unstructured information e.g. a business policy document, after which the unstructured information is read and the process elements are extracted and annotated with a process ontology, and then the annotated predicates are utilized for the specification of production rules. This methodology may work well for the specification of a small number of rules, however, if the amount of information increases, this methodology does not provide an efficient solution.

This triggers the need for an extensible model for the extraction of production rules as strict and defeasible from unstructured information without human intervention and attaches a strength value to each defeasible production rule for further processing. The strength value may be assigned to a production rule on the basis of certain features, such as the amount of information it carries, how important the information is that it carries etc. The strength of individual production rules can then be used to compute the strength of a reasoning chain.

9.4.2 Extension of the Proposed Framework to Work with Machine Learning Algorithms

The goal of machine learning is to devise learning algorithms that do the learning automatically without human intervention or assistance. A fundamental problem of machine learning is dealing with large spaces of possible hypotheses. In the past decade or so, numerous machine learning methods have been used to automatically learn and recognize complex patterns and make intelligent decisions based on an enterprise data/information. One of the common attributes of these machine learning

methods is that their working and functionality is constrained by the amount and nature of the input data. In particular, existing machine learning either doesn't consider domain knowledge during classification, or if it does, then this knowledge holds for the whole domain. Such approaches ignore any specific information or situation that may apply to some small set of chosen learning examples.

In future work, it is intended to enhance the current generation of machine learning techniques with the argumentation formalisms described in this thesis. In such cases, the arguments (undefeated dialectical tree/s) pertinent to specific examples are considered during the mining of an enterprise data.[1] Such work will lay the foundations for performing large-scale analytics on Big data and Cloud computing applications.

9.4.3 *Extend the Proposed Framework as an Actual/Generic Argument Model for Practical Reasoning*

Yearwood and Stranieri (2006) proposed an argument structure called the Generic Actual Argument Model (GAAM) for capturing expert reasoning in the form of a certain domain, using a variant of a layout of arguments advanced by Toulmin (2003). In this model, arguments are captured at two levels of abstraction: the generic and actual level. The generic level argument's structure is sufficient to represent claims made by all members of the group and they use this structure to create their actual arguments. The GAAM model represents complex reasoning in such a manner that enables the convenient search and retrieval of relevant information. The argument trees represented using the GAAM framework can be readily converted into a format for rapid deployment and can be made available to other software applications.

In the proposed framework, as discussed in Chap. 6, the reasoning chains have been modelled with respect to the Toulmin model for argument structure i.e. backup evidence, warrant and conclusion. To provide a more practical argument structure, as proposed by GAAM, it is intended to extend the syntax and semantics of the proposed framework and exploit it for modeling the new product development strategy on top of the information present in customer relationship management systems for more practical reasoning.

9.4.4 *Collaborative Framework for Reasoning Qualitative Models Extracted from Quantitative Data to Assist a Group Decision-Making Process*

Traditionally, quantitative models over numeric data aim at producing precise numerical results as answers to users' questions about the problem domain. Such precise

[1] http://www.ailab.si/martin/abml/.

numerical answers are often overly elaborate, and contain much more information than is actually needed. In everyday life, humans use common sense to reason about problems qualitatively, without numbers.

The logic-based framework discussed in this thesis can be applied by multi-site collaborative teams who exploit information from 'Big data' to generate qualitative models (Suc and Bratko 2001) that can drive the reasoning process on an underlying rule-base that is specified by different knowledge experts. The outcome of the argumentative reasoning process will assist collaborative teams to discover non-trivial hidden insights in the Big data analytics and Cloud computing applications, explaining how, what and why information about an issue to the user.

9.4.5 Evaluation for Correctness of the Reasoning Chains Produced by GF@SWA

Section 8.5 elaborates the functionality validation and features evaluation of GF@SWA and the reasoning results are depicted in form of the reasoning chains. To evaluate the correctness of reasoning chains, in future work, it is intended to compare the reasoning chains depicted in Sect. 8.5 with the reasoning chains manually generated by a decision maker when he is provided with incomplete and/or contradictory information.

9.5 Conclusion

In this chapter, the work that has been undertaken and documented in this thesis has been recapitulated and the issues addressed in the literature which prompted the work done in this thesis have been highlighted. The different contributions to the literature as the result of outcome of work done in this thesis have also been highlighted. A brief description of the further work that is intended to be undertaken in order to extend the approaches developed in this thesis were then provided.

The work that was undertaken in this thesis has been published extensively as a part of the proceedings in peer-reviewed international journals and conferences. Selected publications are provided in Appendix B. A complete list of all the publications arising as a result of the work documented in this thesis is given at the beginning of the thesis.

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