


# Efficient Computation of Argumentation Semantics



Intelligent Systems Series



Beishui Liao



ZHEJIANG UNIVERSITY PRESS  
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Academic Press is an imprint of Elsevier



## 图书在版编目(CIP)数据

辩论推理系统的语义计算= Efficient Computation  
of Argumentation Semantics: 英文 / 廖备水著. —杭州:  
浙江大学出版社, 2015.3

ISBN 978-7-308-14325-7

I. ①辩... II. ①廖... III. ①辩论—推理—言语统计  
—研究—英文 IV. ①H019

中国版本图书馆 CIP 数据核字(2015)第 004935 号

Not for sale outside Mainland of China

此书仅限中国大陆地区销售

## 辩论推理系统的语义计算

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封面设计 林智广告

出版发行 浙江大学出版社

网址: <http://www.zjupress.com>

Elsevier 出版集团

网址: <http://www.elsevier.com>

印 刷 浙江印刷集团有限公司

开 本 787mm×1092mm 1/16

印 张 9.75

字 数 324 千

版 印 次 2015 年 3 月第 1 版 2015 年 3 月第 1 次印刷

书 号 ISBN 978-7-308-14325-7 (浙江大学出版社)

ISBN 978-0-12-410406-8 (Elsevier)

定 价 78.00 元

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浙江大学出版社发行部联系方式: (0571)88925591; <http://zjdxcb.tmall.com>

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# Preface

In artificial intelligence, argumentation is a mechanism for reasoning with incomplete and conflicting information, by means of constructing, comparing and evaluating arguments. In existing literature, many aspects of argumentation have been widely studied, including semantics, proof theories and algorithms, concrete argumentation systems, and various applications. One of the most important problems in this area is that under most of semantics, many natural questions regarding argument acceptability are computationally intractable.

To cope with this problem, some efforts have been made, such as identifying tractable classes of argumentation frameworks, and developing efficient algorithms. However, for a generic argumentation framework, how to efficiently compute its semantics and the changing of semantics in dynamic settings is still an open problem.

Inspired by the efficiency of local computation, in recent years, we have conducted a series of research on computing the semantics of a dynamic argumentation system, a static argumentation system, and a partial argumentation system. The corresponding results have been published in some journals such as *Artificial Intelligence*, *Journal of Logic and Computation* and *Annals of Mathematics and Artificial Intelligence*, etc. Based on the results we have obtained, the aim of this book is to systematically formulate the approaches and algorithms for efficient computation of argumentation semantics.

Since the computation of argumentation semantics is fundamental to the abstract argumentation theory, which is in turn the basis of concrete argument systems, I believe that the contents of this book could be useful for the readers who are in the areas of knowledge representation and reasoning, as well as some related application areas.

I thank Robert C Koons and Vladimir Lifschitz for their valuable discussions and comments, when I visited the University of Texas at Austin during July 2009 to July 2011. I thank Leon van der Torre, Richard Booth, Martin Caminada, and Tjitze Rienstra for the valuable discussions with them when I visited the University of Luxembourg in April 2012. And, I thank Pietro Baroni and

Massimiliano Giacomini for their insightful comments on a technical error in our previous works about the decomposability of ideal semantics, when I attended the Dagstuhl Seminar on Belief Change and Argumentation in Multi-Agent Scenarios in June 2013.

I acknowledge support from the National Social Science Foundation Major Project of China under grant No. 11&ZD088, the National Grand Fundamental Research 973 Program of China under grant No. 2012CB316400 and the National Natural Science Foundation of China under grant No. 61175058 and No. 60773177.

Hangzhou, China

*Beishui Liao*  
December 2014

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# Chapter 1

## Introduction

**Abstract:** In open and dynamic systems, information is often uncertain, incomplete and inconsistent. Comparing to some other non-monotonic formalisms, argumentation is more natural, and adaptable to handling such kind of information. After introducing the basic notion of argumentation, this chapter introduces the motivations of this book, as well as its structure.

**Key words:** artificial intelligence; uncertainty; incompleteness; inconsistency; non-monotonic formalisms; argumentation; computational complexity

### 1.1 Background

In the area of artificial intelligence, one of the most important topics is to handle the uncertainty, incompleteness, and inconsistency of information. There are a lot of applications related to this topic, such as belief revision, decision-making, inter-agent communication, medical reasoning, legal reasoning, semantic web reasoning, trust computing and normative systems, etc.

When an agent is situated in an open and dynamic environment, since the world can be other than it appears and the world changes [1], what the agent perceives is far from veridical and complete. As a result, the existing beliefs of an agent may conflict with some new information. So, belief revision is necessary for a rational agent to preserve the consistency of her knowledge. Related to belief revision, decision-making is a form of reasoning to determine actions. Given some available information about the current status of the world and the consequences of potential actions, there could be more than one alternatives [2]. Since the available information may be incomplete and uncertain and different alternatives could not be selected simultaneously, conflicts may arise in the process of decision-making. For instance, in medical reasoning, knowledge can be uncertain and inconsistent [3], and more than one explanation for a medical hypothesis could be possible based on different medical studies [4]; in

norm-governed systems, an agent may have several conflicting motivations, including internal desires and external obligations that are brought about by norms and policies [5].

In multi-agent systems, different agents interact each other to achieve certain goals. When agents have competing claims on scarce resources (such as commodities, services, time, money, etc.), not all of them can be simultaneously satisfied. First, for those agents who have conflicting interests and a desire to cooperate, negotiation is an important coordination mechanism [6]. Due to the conflicting interests and uncertain information from the environment, how to formulate the mechanisms of negotiation is still an open problem. Second, for those agents that have opposite goals, argumentation is a form of reasoning for each agent to pursue her own goals. Legal argumentation is a typical example. It is adversarial and dialectic in nature [7]. Since argumentation schemes (a kind of generalized rules of inference) need not concern strict, abstract, necessarily valid patterns of reasoning, but can be defeasible, concrete and contingently valid, the conclusions of different schemes could be conflicting and defeasible [8].

In addition, for some practical reasoning systems in open and dynamic environments, such as semantic web [9] and trust computing [10], inconsistencies of information are also very common. For instance, in semantic web, domain ontologies established by different parties may conflict. In trust computing, both the information and its sources are uncertain. The conflicts among them are inevitable.

In order to treat with the uncertainty, incompleteness, and inconsistency of information, a number of research efforts have been made in the area of non-monotonic reasoning. In 1980s, three non-monotonic formalisms (including default logic [11], circumscription [12] and autoepistemic logic [13]) were proposed. However, these formalisms are mainly suitable to epistemic reasoning. For practical reasoning and the reasoning in the process of multi-agent interaction, a more general non-monotonic formalism is needed. Meanwhile, from the perspective of implementation, the computational complexity problems of these formalisms are challenging. Furthermore, when considering the dynamics of systems (when new information is added to a system), the efficiency of computation is a great problem. This is because when a system is updated, any conclusions obtained previously could be overruled by some counter-arguments. So, for each modification, all existing conclusions should be recomputed. This is obviously inefficient.

## 1.2 The Notion of Argumentation

Due to the above-mentioned problems, in the past fifteen years, argumentation has been recognized as a non-monotonic formalism that is more general and natural than the traditional ones. In general, the study of argumentation may, informally, be considered as concerned with how assertions are proposed, discussed, and resolved in the context of disagreement [14].

The disagreement (inconsistency) may arise during the process of reasoning of an individual agent, or a set of agents interacting with each other. In different cases, the nature of inconsistency may vary. As mentioned above, in the process of epistemic reasoning (belief revision), the inconsistency of information is mainly due to the uncertainty and incompleteness of information. In the case of practical reasoning (decision-making, planning, etc.), an agent may have several motivations (desires, obligations, etc.). Due to the limitation of resources, the agent can not fulfill all of them, and the conflicts among different motivations arise. In means-end reasoning, there exist different options, which could be conflicting. In the case of inter-agent communication, such as negotiation and discussion, the interests, objectives, preferences or standpoints of different participants might be inconsistent.

Despite the fact that various arguments may have different internal structures and the nature of inconsistency between different kinds of arguments may vary, when evaluating the status of arguments, we may regard the attacks between arguments as abstract binary relations. Based on this idea, in 1995, Phan Ming Dung proposed an abstract argumentation theory, in which arguments are abstract entities, while the origins of attacks are also left unknown [15]. As a result, an argument system is simply represented as a directed graph (often called a defeat graph), represented as  $F = (A, R)$ , where  $A$  denotes a set of arguments and  $R \subseteq A \times A$  denotes a set of attacks.

Since the status of arguments is evaluated in an abstract argumentation framework, while the representation of underlying knowledge, the construction of arguments and the identification of attacks are comparatively independent, an argumentation system can be conceived of a two-level architecture (Fig. 1.1), and its working process is composed of three steps. First, according to a set of underlying knowledge, a set of arguments are constructed and the attacks between them are identified, forming an argumentation framework. Second, given an argumentation framework, the status of arguments is evaluated (in terms of certain criteria), producing sets of extensions of arguments (each extension could be understood as a set of arguments that are acceptable together). Third, for each extension of arguments, the associated set of conclusions is identified.

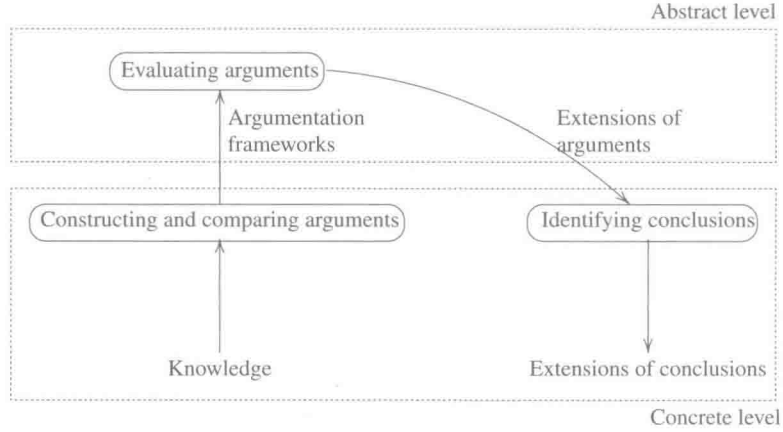
Let us consider the following example.

*Example 1.1.* The following is a story, called “Two Children Arguing about the Sun”.

When Confucius was traveling in the eastern part of the country, he came upon two children hot in argument, so he asked them to tell him what it was all about.

- “I think,” said one child, “that the Sun is near to us at daybreak and far away from us at noon.”
- The other contended that the Sun was far away at dawn and nearby at midday.
- “When the Sun first appears,” said one child, “it is as big as the canopy of a carriage, but at noon it is only the size of a plate or a bowl. Well, isn’t it true that objects far away seem smaller while those nearby seem bigger?”
- “When the Sun comes out,” pointed out the other, “it is very cool, but at midday it is as hot as putting your hand in boiling water. Well, isn’t it true that what is nearer to us is hotter and what is farther off is cooler?”

Confucius was unable to settle the matter for them. The two children laughed at him, “Who says you are a learned man?”



**Fig. 1.1** The working mechanism of an argumentation system

Now, let  $a$  denote the argument raised by one child, and  $b$  the argument raised by the other. Then, we get an argumentation framework  $F = (\{a, b\}, \{(a, b), (b, a)\})$ . For a skeptical agent, he accepts neither  $a$  nor  $b$ , i.e., the set (extension) of arguments is empty. Note that in this example, the underlying logic for representing the knowledge and the methods for constructing the arguments and identifying the attacks are independent of the evaluation of the arguments.

Since abstract argumentation is comparatively independent of the underlying argument construction and comparison, it shows great promise as a theoretically tool for handling the various reasoning problems under the context of inconsistency. It is not only suitable for the reasoning of individual agents, but also for the interactions of multiple agents. As a result, argumentation is now regarded as a non-monotonic formalism for logical deduction, induction, abduction and plausible reasoning, and is promising to be applied to various applications, such as semantic web, recommender systems, trust computing, normative systems, social choice theory, judgment aggregation, law and medical, etc.

### 1.3 Motivations of This Book

Given an argumentation framework  $F = (A, R)$ , a basic problem is to determine which arguments can be regarded as acceptable together. In order to resolve this problem, a lot of evaluating criteria (often called argumentation semantics) have been proposed. Some typical argumentation semantics include admissible, complete, preferred, grounded, stable, semi-stable, ideal and eager, etc. Each semantics stands for a set of criteria. For instance, a set of arguments  $B \subseteq A$  is regarded as *admissible*, if it is

*conflict-free* and it is able to *defend* each argument in it. Informally, we say that  $B$  is conflict-free, if there exist no arguments  $a, b \in A$  such that  $a$  attacks  $b$ ; an argument  $a$  is defended by  $B$ , if for every argument  $b \in A$  that attacks  $a$  then there exists an argument  $c \in B$  such that  $c$  attacks  $b$ . Definitions of some other semantics will be presented in the next chapter.

Under many semantics, determining the status of arguments is often not easy. It has been proved that many natural questions regarding argument acceptability are, in general, computationally intractable [16]. For this reason, in recent years, an increasing amount of work has been done on identifying tractable fragments of argumentation frameworks and developing more efficient algorithms [17, 18]. However, how to efficiently compute the semantics of a generic argumentation framework is still an open problem.

In order to efficiently compute the semantics of a generic argumentation framework, the following two lines of work have been undertaken. The first line of work is on developing efficient approaches by exploiting existing sophisticated problem solvers that have been developed for other purposes. According to existing literature, the approaches based on propositional logic [19, 20, 21, 22] and answer-set programming [23, 24, 25] respectively have been widely studied. They are also called *reduction-based approaches*, which reduce an abstract argumentation problem into an instance of a different problem (SAT or ASP), delegating the burden of computation to existing systems. Thanks to the efficiency of the solvers for SAT or ASP problems, the corresponding argumentation problems could be resolved more efficiently. The second line of work is on establishing efficient approaches dedicated to argumentation, including labelling-based approaches [26, 27, 28] and dialogue games [29, 26]. These approaches implement procedures for abstract argumentation from scratch, and therefore are called *direct approaches*. By adopting some specific techniques, the efficiency of direct approaches could be improved to some extent [27].

Although the above-mentioned two lines of work have made great efforts to improve the efficiency of computation, they all treat each argumentation framework as a monolithic entity, which may fundamentally restrict the improvement of efficiency. On the contrary, if we compute the status of arguments locally, then the computation may become easier. Let us consider the following three examples.

First, for most of argumentation systems, changing of arguments and their attack relation is an intrinsic property of them. When an argumentation system is modified, if we recompute the status of each argument afresh, it is obviously inefficient. As a matter of fact, for each modification to an argumentation system, it is very common that only a part of arguments in the system are affected. Hence, if it is feasible to evaluate the status of those affected arguments locally, then the remaining arguments are not necessary to be considered.

Second, according to [16], although for some argumentation frameworks with special structures (such as<sup>10</sup> acyclic, symmetric and bounded tree-width) there exist tractable algorithms, for a generic argumentation framework that might not belong to any tractable class, how to efficiently compute its

semantics still remains unresolved. A promising solution is to decompose a general argumentation framework into a set of sub-frameworks, such that the status of each argument in a sub-framework could be computed locally. Given that the status of each argument is computed in a sub-framework, which might belong to some tractable class and has smaller size than that of the original argumentation framework, the execution time for evaluating the status of arguments might decrease.

Third, when querying the status of some arguments in an argumentation framework, we may only take into consideration a subset of arguments in the argumentation framework that are relevant to these arguments. In other words, the computation of the status of some arguments is performed locally.

From the above three examples, we observe that local computation could be an effective means to decrease the computation time in many situations. This is due to the following two reasons. In the first place, comparing to the size of a whole argumentation framework, the size of a sub-framework is often smaller or much smaller. This idea has been adopted in divide-and-conquer algorithms, which have been recognized as an important algorithm design paradigm. In the second place, when an argumentation framework does not belong to any tractable class, some of its sub-frameworks might belong to some tractable classes.

Inspired by the above ideas, this book will introduce efficient approaches for computing the semantics of argumentation based on the theory of local computation.

## 1.4 The Structure of This Book

This book focuses on formulating efficient approaches for computing the semantics of abstract argumentation frameworks, and is divided into five parts. Besides Chapter 1 for introduction, the contents of other four parts are as follows.

In Chapters 2 and 3, some fundamental theories of argumentation as well as some existing approaches and algorithms for computing argumentation semantics are presented. For the readers who are familiar with the area of computational argumentation, this part may be skipped.

In Chapters 4 and 5, we introduce a theory of computation based on the idea of local computation. In Chapter 4, we first introduce the notion and the semantics of sub-frameworks. In Chapter 5, we formulate the relations between the semantics of an argumentation framework (global semantics) and that of a sub-framework (local semantics). This part lays a foundation for the subsequent part.

In Chapters 6, 7 and 8, we formulate three approaches for efficient computation of argumentation from different perspectives. Specifically, Chapter 6 deals with the computation of the status of arguments in a static argumentation framework, Chapter 7 studies the computation of semantics of a dynamic argumentation system, and Chapter 8 treats with the computation of a part of arguments in an argumentation framework.

In Chapter 9, we conclude the book and point out some future work.

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