

Present and Future of Formal Argumentation

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Abstract

Formal Argumentation is emerging as a key reasoning paradigm building bridges among knowledge representation and reasoning in artificial intelligence, informal argumentation in philosophy and linguistics, legal and ethical argumentation, mathematical and logical reasoning, and graph-theoretic reasoning. It aims to capture diverse kinds of reasoning and dialogue activities in the presence of uncertainty and conflicting information in a formal and intuitive way, with potential applications ranging from argumentation mining, via LegalTech and machine ethics, to therapy in clinical psychology. The turning point for the modern stage of formal argumentation theory, much similar to the introduction of possible worlds semantics for the theory of modality, is the framework and language of Dung's abstract argumentation theory introduced in 1995. This means that nothing could remain the same as before 1995—it should be a focal point of reference for any study of argumentation, even if it is critical about it. Now, in modal logic, the introduction of the possible worlds semantics has led to a complete paradigm shift, both in tools and new subjects of studies. This is still not fully true for what is going on in argumentation theory. The Dagstuhl workshop led to the first volume of a handbook series in formal argumentation, reflecting the new stage of the development of argumentation theory.

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Executive Summary

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Diverse kinds of reasoning and dialogue activities can be captured by argumentation models in a formal and still quite intuitive way, thus enabling the integration of different specific techniques and the development of applications humans can trust. Formal argumentation lays on the solid basis of extensively studied theoretical models at different levels of abstraction, efficient implementations of these models, as well as a variety of experimental studies in several application fields.

In order to be able to convert the opportunities of the present into actual results in the future, the formal argumentation research community is reflecting on the current assets and weaknesses of the field and is identifying suitable strategies to leverage the former and to tackle the latter. As an example, the definition of standard modeling languages and of reference sets of benchmark problems are still in their infancy, reference texts for newcomers are missing, the study of methodological guidelines for the use of theoretical models in actual applications is a largely open research issue.

From August 30 to September 4, 2015, twenty-two world leading experts in formal argumentation from 10 countries was gathered to develop an analysis of the current state of the research in this field and to draw accordingly some strategic lines to ensure its successful development in the future.

The program included first individual presentations on introductory overviews, logical problems and requirements for formal argumentation, specific formalisms and methodologies, relationship between various approaches and applications. Collective discussions on general issues then arose from individual presentations, mainly focusing on four topics, i.e. basic concepts and foundations, specific formalisms for argumentation, algorithms, and connections both inside the argumentation field and with outside research topics. In the end, discussion groups were aimed at identifying the most important open problems in argumentation. Many of them concerned foundational issues of the theory, e.g. how to formally represent various kinds of arguments and how to identify sets of postulates on the reasoning activity over arguments in specific contexts. However, the relationship between argumentation and other research fields (e.g. natural language processing, machine learning, human computer interaction, social choice) was seen to be of major importance, especially to develop more mature applications.

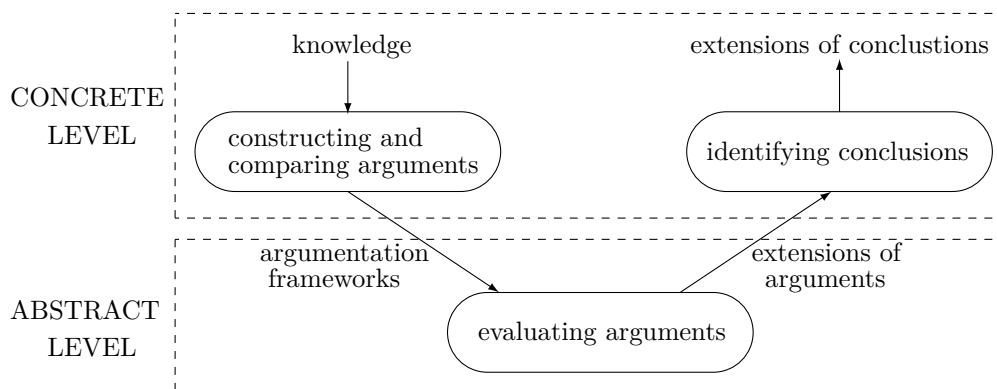
This document summarizes the discussions and results of the Dagstuhl Perspectives Workshop. We first present the many faces of formal argumentation, highlighting the role of formal argumentation in various disciplines. Then, we introduce the

- state-of-the-art of theories and algorithms of formal argumentation formulated in details in a Handbook of Formal Argumentation, including Dung's abstract argumentation and its extensions, structured argumentation systems (ASPIC⁺, DeLP, ABA and deductive argumentation), as well as a view on applications with special emphasis on the issue of mining arguments from natural language sources.
- Argumentation mining. Thereafter, we introduce the important roles that formal argumentation has played in the field of artificial intelligence. Finally, we discuss

- challenges and future developments. We identify challenging problems from some important perspectives, including theoretical foundations, and connections between formal argumentation and other areas. Moreover, we provide some methodological considerations for future development.

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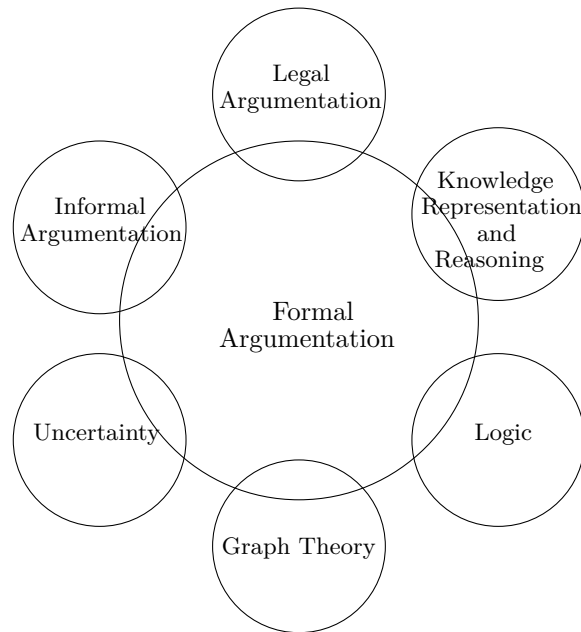
■ **Figure 1** The architecture of a Dung style abstract argumentation system.

1 Introduction to formal argumentation

The Dagstuhl Perspectives Workshop 15362 “Present and Future of Formal Argumentation” was held between August 30 to September 4, 2015, with 22 participants from 10 countries. The goal of this Dagstuhl Perspectives Workshop was to gather the world leading experts in formal argumentation in order to develop an analysis of the current state of the research in this field and to draw accordingly some strategic lines to ensure its successful development in the future. The attendees summarized the state-of-the-art, identified a set of challenging problems, and pointed out possible research directions, ranging from clarifying foundational issues of the theories developed in the literature to integrating argumentation with other research fields, especially in an application-oriented perspective. Following the workshop, the participants have contributed to the first volume of the handbook series of formal argumentation that appeared in 2018, and they are currently involved in the preparation of the second volume.

Formal argumentation is concerned with formalisms for capturing the reasoning in the context of disagreement. We briefly introduce some basic notions of formal argumentation. In general, the study of argumentation is concerned with how assertions are proposed, discussed, and resolved in the context of disagreement [4]. The disagreement or inconsistency may arise during the process of reasoning of an individual agent, or a set of agents interacting each other. In different cases, the nature of inconsistency may vary. In the process of epistemic reasoning and belief revision, the inconsistency of information is mainly due to the uncertainty and incompleteness of information. In the case of practical reasoning such as decision-making or planning, an agent may have several motivations like desires and obligations. Due to the limitation of resources, the agent cannot fulfil all of them, and the conflicts among different motivations arise. In means-end reasoning, there exist different options, which can be mutually exclusive. In the case of inter-agent communication, such as negotiation and discussion, the interests, objectives, preferences or standpoints of different participants might be inconsistent.

Traditional and informal argumentation is concerned with the evaluation of individual arguments. In contrast, Dung introduced his theory of abstract argumentation in which the evaluation of the status of arguments does not depend on the internal structure of the arguments at all, but only on the relation among the arguments with other arguments, and the



■ **Figure 2** Bridges from formal argumentation.

status of these related arguments. Consider his two-level architecture illustrated in Figure 1, taken from Liao [17]. In this architecture, the working process of an argumentation system is composed of three steps. First, on the basis of an underlying knowledge base (or from natural text), a set of arguments are constructed and the attacks between them are identified. They form a so-called argumentation framework, which is an abstract representation of arguments and their relationships. Second, given an argumentation framework, the status of arguments is evaluated in terms of a number of criteria, producing sets of extensions of arguments. Each extension may be understood as a set of arguments that are acceptable together. Third, for each extension of arguments the associated set of conclusions is identified, and the justification status for each conclusion is determined on the basis of these sets.

2 Interdisciplinary aspects of formal argumentation

Formal argumentation and formal logic play a central role in the foundations of various disciplines, and they are therefore often used as the methodology for interdisciplinary research projects. Before going into the details of the modern stage of formal argumentation, we highlight the role of formal argumentation in various disciplines, as illustrated in Figure 2. Note that in this figure, we only indicate the overlap between formal argumentation and other disciplines. Rather than giving a comprehensive review, we just provide some examples to show the possibilities and usefulness of bridging formal argumentation with various disciplines.

2.1 Informal argumentation in philosophy and linguistics

Maybe most obviously, formal argumentation can be considered as a candidate for the foundations or theory underlying informal argumentation in philosophy and linguistics. In 1965, Toulmin's much cited book "the uses of argument" led to a criticism on the use of classical logic for reasoning, and the rise of so-called informal logic [25]. Most of the criticism of Toulmin and colleagues has been addressed by non-monotonic logic and more recently, formal argumentation.

Whereas in informal argumentation the evaluation of single argument plays a central role, in formal argumentation the evaluation of argumentation frameworks is the focal point of discussion. Consequently, relations among arguments play a central role in formal argumentation, such as the notion of attack in Dung's theory. Modern formal argumentation offers a kind of interactive argumentation, where the evaluation of individual arguments is enriched with a theory where the evaluation of arguments depends on the evaluation of other arguments. The principle-based approach studies diversity by distinct acceptance semantics, and principles of these semantics [2].

A main challenge is to bridge informal and formal argumentation, in other words to build informal argumentation on top of the new foundations of formal argumentation. This is far from straightforward. From a methodological perspective, the insights of abstract argumentation are a guide, but Dung's theory should not be used as a straight jacket. Researchers in argumentation are free to generalise and adapt it as needed.

Maybe the most promising application in computational argumentation is argumentation mining [20], which is typically build of argumentation schemes developed in informal argumentation. The challenge is to use the foundations of formal argumentation also in this application.

2.2 Legal and ethical argumentation

Legal practice is build on legal argumentation, both in the two branches of roman and case law. It is combined with other kinds of reasoning such as normative and case-based reasoning. This is most explicit in the court room. Formal argumentation has developed in the artificial intelligence community around the ICAIL conference and the legal expert systems studied in JURIX.

Obviously, formal argumentation can be used to reason about legal rules and norms, to decide conflicts or to deal with uncertainty [8]. It is also well suited to deal with one of the main challenges in legal reasoning, called legal interpretation [18, 4]. Legal informatics and LegalTech receive a lot of attention recently, for example to automate regulatory compliance checking. Furthermore, ethical considerations play a role in law, so it may not be a surprise that formal argumentation can play a role in formal ethics as well, including machine ethics.

2.3 Knowledge representation and reasoning in artificial intelligence

Non-monotonic logic and logic programming were adopted in the early eighties as the main methodology in knowledge representation and reasoning, one of the main subareas of artificial intelligence. In the nineties their role was taken over by answer set programming and formal argumentation. Formal argumentation successfully established itself with a large number

of papers in the main journal in the area, called Artificial Intelligence journal, a dedicated journal called Argument & Computation, and a biannual conference called International Conference on Computational Models of Argument, or COMMA.

The modern stage of formal argumentation identifies in the diversity of argumentation and reasoning approaches a common core: Dung's theory of abstract argumentation. This paradigm shift in formal argumentation shows, roughly, how many forms of reasoning can be characterised at an abstract level as an instance of graph reasoning. As a consequence, formal argumentation has been used since the mid nineties as a general framework to classify reasoning methods, besides non-monotonic logic and logic programming also, for example, instances of game theory and social choice.

Algorithms and game-based decision procedures have been developed, together with a formal analysis based on a principle - approach, and complexity analysis. Moreover, various theories of structured argumentation extend Dung's theory with rules and priorities, and a search for a common theory of structured argumentation is currently the main challenge in the area of formal argumentation. There are many open questions in the foundations of formal argumentation, and we are convinced that insights from other formal areas can be used to further develop the theory.

2.4 Reasoning in mathematical logic and graph-theoretic reasoning

Dung's theory of abstract argumentation deals with binary attack relations, and his argumentation framework is a directed graph. As a consequence, abstract argumentation has a close relation to graph theory. However, the relation with graph-theoretic reasoning is relatively unexplored. Likewise the connection of argumentation with logic and liar paradox is yet to be studied in depth. We discuss them in the open problems sections.

2.5 Probabilistic and fuzzy reasoning

Formal argumentation, including Dung's model and its various extensions, can be viewed as a kind of qualitative approach. In recent years, enriching argumentation with uncertainty and fuzziness has attracted attention, since these two aspects are hardly absent in typical knowledge sources. For instance, when considering arguments in natural language texts, uncertainty and fuzziness pervade them both explicitly and implicitly [3]. The explicit presence of uncertainty and fuzziness is exemplified by statements like "I believe that tomorrow will probably be a bit colder than today", where the qualifier "probably" indicates (in a fuzzy way) that the subject's belief is accompanied by a certain degree of uncertainty, while the term "a bit colder" provides a fuzzy specification of tomorrow's expected temperature.

Given that uncertainty and fuzziness and argumentation live side by side, or even permeate each other, in daily discourse, one might expect that this close relationship has a formal counterpart in the models adopted in formal argumentation research, thus supporting the activities of identification and representation of arguments featuring uncertainty and fuzziness starting from natural language expressions.

Since uncertainty and vagueness can be interpreted in different ways by different measures such as probabilities, possibilities, and fuzziness, various kinds of uncertain and fuzzy argumentation have been proposed. Among them, probability-based approaches, including their concepts, formalisms and computational aspects, have been extensively studied.

Given an argumentation framework $F = (A, R)$, and a probability function p that assigns probabilities to arguments or sets of arguments, a basic question is how to interpret probability. There are mainly two approaches in existing literature. One is called constellations approach (external view). The external view is to think of $p(x)$ as the probability of the predicate “ $x \in A$ ”. That is, the probability that the argument x is present in A . It imposes probability externally expressing uncertainty on what the network graph is. Another is called epistemic approach (internal view). The internal probability is where the above numbers signify the value of the argument, such as its truth, its reliability, its probability of being effective, etc. [12]. In the epistemic approach, the topology of the graph is fixed but probabilistic assessments on the acceptance of arguments are evaluated with respect to the relations of the arguments in the graph. The core idea of the epistemic approach is that the more likely it is to believe in an argument, the less likely it is to believe in an argument attacking it [15]. The epistemic approach is useful for modeling the belief that an opponent might have in the arguments that could be presented, which is useful for example when deciding on the best arguments to present in order to persuade that opponent.

3 Foundations of formal argumentation

The first volume of the handbook is concerned with the foundations of formal argumentation. Dung’s framework and language constitute a turning point for the modern stage of the formal argumentation theory. This means that nothing could remain the same as before Dung—it should be a focal point of reference for any study of argumentation, even if it is critical about it. The handbook reflects the new stage of the development of the argumentation theory. The main content of the first volume of the handbook is as follows.

3.1 Overview

The first three chapters give a general overview of formal argumentation from different perspectives. In Chapter 1, Frans H. van Eemeren and Bart Verheij position formal argumentation in the scope of the larger research of (informal) argumentation. They point out that argumentation has been studied since Antiquity, and modern argumentation theory took inspiration from these classical roots, with Toulmin’s ‘The Uses of Argument’ [26] and Perelman and Olbrechts-Tyteca’s ‘The New Rhetoric’ [23] as representants of a neo-classical development. In the 1970s, a significant rise of the study of argumentation started, often in opposition to the logical formalisms of those days that lacked the tools to be of much relevance for the study of argumentation as it appears in the wild. In this period, argumentation theory, rhetoric, dialectics, informal logic, and critical thinking became the subject of productive academic study. Since the 1990s, innovations in artificial intelligence supported a formal and computational turn in argumentation theory, with ever stronger interaction with non-formal and non-computational scholars. In this chapter, the authors sketch argumentation and argumentation theory as it goes back to classical times, following the developments before and during the currently ongoing formal and computational turn.

In Chapter 2, Henry Prakken gives a historical overview of formal argumentation in terms of a distinction between argumentation-based inference and argumentation-based dialogue. Systems for argumentation-based inference are about which conclusions can be drawn from a given body of possibly incomplete, inconsistent or uncertain information. They ultimately

define a nonmonotonic notion of logical consequence, in terms of the intermediate notions of argument construction, argument attack and argument evaluation, where arguments are seen as constellations of premises, conclusions and inferences. Systems for argumentation-based dialogue model argumentation as a kind of verbal interaction aimed at resolving conflicts of opinion. They define argumentation protocols (the rules of the argumentation game) and address matters of strategy (how to play the game well). In this chapter, the author reviews the main formal and computational models for both aspects of argumentation, sketches their main historical influences, and discusses some main applications areas.

In Chapter 3, Thomas F. Gordon suggests applying software engineering requirements analysis methods to the development and evaluation of formal models of argumentation. Their aim and purpose is to help assure that formal argumentation models the full scope of argumentation as it is understood and studied in the humanities and social sciences, so as to provide a foundation for software tools supporting real argumentation tasks, in a wide variety of application domains.

3.2 Abstract argumentation

In this part, Pietro Baroni, Martin Caminada, Massimiliano Giacomin first present an overview on the state of the art of Dung's abstract argumentation frameworks and their semantics, covering both some of the most influential literature proposals and some general issues concerning semantics definition and evaluation. As to the former point the chapter reviews Dung's original notions of complete, grounded, preferred, and stable semantics, as well as a variety of notions subsequently proposed in the literature namely, naive, semi-stable, ideal, eager, stage, CF2, and stage2 semantics, considering both the extension-based and the labelling-based approaches with respect to their definitions [1]. As to the latter point the chapter analyzes the notions of argument justification and skepticism comparison and discusses semantics agreement.

Then, Gerhard Brewka, Stefan Ellmauthaler, Hannes Strass, Johannes P. Wallner, and Stefan Woltran describe abstract dialectical frameworks, or ADFs for short. ADFs are generalizations of the widely used Dung argumentation frameworks. Whereas the latter focus on a single relation among abstract arguments, namely attack, ADFs allow arbitrary relationships among arguments to be expressed. For instance, arguments may support each other, or a group of arguments may jointly attack another one while each single member of the group is not strong enough to do so. This additional expressiveness is achieved by handling acceptance conditions for each argument explicitly. The semantics of ADFs are inspired by approximation fixpoint theory (AFT), a general algebraic theory for approximation based semantics developed by Denecker, Marek and Truszczynski. After briefly introducing AFT and discussing its role in argumentation, the authors formally introduce ADFs and their semantics. In particular, they show how the most important Dung semantics can be generalized to ADFs. Furthermore, they illustrate the use of ADFs as semantical tool in various modelling scenarios, demonstrating how typical representations in argumentation can be equipped with precise semantics via translations to ADFs. They also present grappa, a related approach where the semantics of arbitrary labelled argument graphs can be directly defined in an ADF-like manner, circumventing the need for explicit translations. Finally, they address various computational aspects of ADFs, like complexity, expressiveness and realizability, and present several implemented systems.

3.3 Structured argumentation

There are four structured argumentation formalisms introduced in the handbook [5]. First, Sanjay Modgil and Henry Prakken reviews abstract rule-based approaches to argumentation, in particular the ASPIC+ framework [19]. In ASPIC+ and its predecessors, going back to the seminal work of John Pollock, arguments can be formed by combining strict and defeasible inference rules and conflicts between arguments can be resolved in terms of a preference relation on arguments. This results in abstract argumentation frameworks (a set of arguments with a binary relation of defeat), so that arguments can be evaluated with the theory of abstract argumentation. First the basic ASPIC+ framework is reviewed, possible ways to instantiate it are discussed and how these instantiations can satisfy closure and consistency properties. Then the relation between ASPIC+ and other work in formal argumentation and nonmonotonic logic is discussed, including a review of how other approaches can be reconstructed as instantiations of ASPIC+. Further developments and variants of the basic ASPIC+ framework are also reviewed, including developments with alternative or generalised notions of attack and defeat and variants with further constraints on arguments. Finally, implementations and applications of ASPIC+ are briefly reviewed and some open problems and avenues for further research are discussed.

Second, Kristijonas Cyras, Xiuyi Fan, Claudia Schulz, and Francesca Toni introduce disputes, explanations, and preferences in Assumption-Based Argumentation (ABA), a form of structured argumentation with roots in non-monotonic reasoning [9]. As in other forms of structured argumentation, notions of argument and attack are not primitive in ABA, but are instead defined in terms of other notions. In the case of ABA these other notions are those of rules in a deductive system, assumptions, and contraries. ABA is equipped with a range of computational tools, based on dispute trees and amounting to dispute derivations, and benefiting from equivalent views of the semantics of argumentation in ABA, in terms of sets of arguments and, equivalently, sets of assumptions. These computational tools can also provide the foundation for multi-agent argumentative dialogues and explanation of reasoning outputs, in various settings and senses. ABA is a flexible modelling formalism, despite its simplicity, allowing to support, in particular, various forms of non-monotonic reasoning, and reasoning with some forms of preferences and defeasible rules without requiring any additional machinery. ABA can also be naturally extended to accommodate further reasoning with preferences.

Third, Alejandro J. García and Guillermo R. Simari introduce argumentation based on logic programming. Among of the programming paradigms based on formal logic, Logic Programming has been a successful effort to create a declarative model of expressing computational processes producing significant theoretical and practical results; as such, the area has contributed computationally attractive systems with remarkable success in many applications. By blending concepts from the areas of Logic Programming and Argumentation, Defeasible Logic Programming (DeLP) proposes a computational reasoning system with an argumentation engine at its core capable of obtaining answers from a knowledge base which is represented with a language that uses logic programming constructs extended with defeasible rules [13]. The careful integration of foundational intuitions and concepts from both areas has formulated a framework that inherits from the logic programming field its expressivity and computational efficiency and receives from argumentation theory a human-like reasoning model facilitating its use in applications. In this chapter, after succinctly recalling the basic elements of logic programming the authors formally introduce the DeLP language and the warranting process that obtains the answers for queries. Then, they present DeLP-Servers, which give possibly distributed client agents running on remote hosts the ability to consult different reasoning services, as well as some extensions and applications of DeLP.

Fourth, Philippe Besnard and Anthony Hunter present a review of argumentation based on deductive arguments [6]. A deductive argument is a pair where the first item is a set of premises, the second item is a claim, and the premises entail the claim. This can be formalized by assuming a logical language for the premises and the claim, and logical entailment (or consequence relation) for showing that the claim follows from the premises. Examples of logics that can be used include classical logic, modal logic, description logic, temporal logic, and conditional logic.

3.4 Argumentation and dialogue

In this part, Martin Caminada first discusses argumentation semantics as formal discussion. He interprets a number of main-stream argumentation semantics by means of structured discussion. The idea is that an argument is justified according to a particular argumentation semantics if and only if it is possible to win a discussion of a particular type. Hence, different argumentation semantics correspond to different types of discussion. He provides an overview of what these discussions look like, and their formal correspondence to argumentation semantics.

Then, Fabrizio Macagno, Douglas Walton, Chris Reed discuss argumentation schemes. The purpose of this chapter is threefold: 1) to describe the schemes, showing how they evolved and how they have been classified in the traditional and the modern theories; 2) to propose a method for classifying them based on ancient and modern developments; and 3) to outline and show how schemes can be used to describe and analyze or produce real arguments. To this purpose, they build on the traditional distinctions for building a dichotomic classifications of schemes, and they advance a modular approach to argument analysis, in which different argumentation schemes are combined together in order to represent each step of reasoning on which a complex argument relies. Finally, they show how schemes are applied to formal systems, focusing on their applications to Artificial Intelligence, AI & Law, argument mining, and formal ontologies.

Finally, Katarzyna Budzynska and Serena Villata introduce approaches for processing natural language argumentation. Although natural language argumentation has attracted the attention of philosophers and rhetoricians since Greek antiquity, it is only very recently that the methods and techniques of computational linguistics and machine learning have become sufficiently mature to tackle this extremely challenging topic. Argument mining, the new and rapidly growing area of natural language processing and computational models of argument, aims at automatic recognition of argument structures in large resources of natural language texts. The goal of this chapter is to familiarise the reader focused on formal aspects of argumentation with this approach, and to show how argument structures, e.g. those studied in abstract argumentation frameworks, can be extracted, providing a bridge between mathematical models and natural language. To this end, they describe the typical argument mining pipeline and related tasks, and present in more detail a specific example of work in this area.

3.5 Computational aspects of formal argumentation

This part is about the computation aspects of formal argumentation. Wolfgang Dvorak and Paul E. Dunne first give an overview of the core computational problems arising in formal argumentation together with a complexity analysis highlighting different sources of

computational complexity. More specifically, they consider three of the previously discussed formalisms, that are Dung's abstract argumentation frameworks, assumption-based argumentation, and abstract dialectical frameworks, each of which allows to highlight different sources of computational complexity in formal argumentation. As most of these problems turn out to be of high complexity they also consider properties of instances, like being in a specific graph class, that reduce the complexity and thus allow for more efficient algorithms. Finally, they show how to apply techniques from parametrized complexity that allow for a more fine-grained complexity classification.

Then, Federico Cerutti, Sarah A. Gaggl, Matthias Thimm and Johannes P. Wallner introduce foundations of implementations of formal argumentation. They survey the current state of the art of general techniques, as well as specific software systems for solving tasks in abstract argumentation frameworks, structured argumentation frameworks, and approaches for visualizing and analysing argumentation. Furthermore, they discuss challenges and promising techniques such as parallel processing and approximation approaches. In addition, they address the issue of evaluating software systems empirically with links to the International Competition on Computational Models of Argumentation.

3.6 Principle-based analysis of formal argumentation

Choice problem: If there are many semantics, then how to choose one semantics from this set of alternatives in a particular application?

Search problem: How to guide the search for new and hopefully better argumentation semantics?

Whereas examining the behaviour of semantics on examples can certainly be insightful, a need for more systematic study and comparison of semantics has arisen. The principles used in a search problem are typically desirable, and desirable properties are sometimes called postulates. For the mathematical development of a principle-based theory, it obviously does not matter whether principles are desirable or not.

The formal analysis in the final five chapters of the first volume of the handbook is based on a principle-based evaluation of argumentation semantics, including dynamic principles and locality and modularity in abstract argumentation. At the structured level, rationality postulates and critical examples are presented. Meanwhile, the respective roles of logic and non-monotonic reasoning in argumentation are explored. Martin Caminada shows how to apply argumentation theory for non-monotonic reasoning using a kind of principles for structured argumentation called rationality postulates. The idea is that arguments are constructed using strict and defeasible inference rules, and that it is then examined how these arguments attack (or defeat) each other. Leendert van der Torre and Srdjan Vesic discuss the principle-based approach to abstract argumentation semantics, Ringo Baumann discusses existence and uniqueness, expressibility, and replaceability, and Pietro Baroni, Massimiliano Giacomin, and Beishui Liao discuss locality and modularity in abstract argumentation. The closing chapter of Alexander Bachman explores the respective roles of logic and nonmonotonic reasoning in argumentation. The notion of collective argumentation is introduced as a logical basis of argumentation frameworks, and provide it with a natural (four-valued) logical semantics. Bochman shows not only that argumentation and logic are important for non-monotonic reasoning, but also the other way round, namely that the main non-monotonic formalisms and argumentation systems constitute actually primary instantiations of Dung's abstract argumentation in appropriately extended logical languages.

4 Open problems and future development

Formal argumentation has developed as a branch of knowledge representation and reasoning within artificial intelligence. As a scientific community and research area, it can be positioned in between informal argumentation and mathematical logic, and it is inspired by applications in legal reasoning, linguistics, computer science, philosophy, and more. As may be expected from a research area in between informal argumentation and mathematical logic, there is a widespread use of different methodologies that are applied in formal argumentation. Moreover, the methodology may differ also on the application for which the formal argumentation models are developed. We consider open questions for the relation between informal and formal argumentation, then we consider questions related to the further development of formal argumentation itself, and finally we consider open questions concerning the relation between formal argumentation and mathematical logic, as well as other formal theories.

4.1 The bridge between informal and formal argumentation

Informal and natural language argumentation has attracted the attention of philosophers and rhetoricians since Greek antiquity. Informal argumentation studies evolving argumentation schemes, classifying them, and using them to describe and analyze or produce real arguments. Informal analysis highlights the role of critical questions and aims to reveal fallacies. Moreover, argument mining is an emerging area of natural language processing and computational models of argument, aiming at automatic recognition of argument structures in large resources of natural language texts. It is only very recently that the methods and techniques of computational linguistics and machine learning have become sufficiently mature to tackle this extremely challenging topic.

Compared to informal and natural language argumentation, the formalisms developed in formal argumentation are highly stylized, abstracting away many aspects characterizing argumentation in daily life. The few remaining concepts are then analyzed with formal rigor, also from a computational point of view. Moreover, an aim of formal argumentation is to develop formal models of argumentation which are useful as a foundation for developing software tools for supporting various argumentation tasks in practical applications. Tom Gordon emphasizes in his chapter that our aim should be to avoid developing a separate technical understanding of argument and argumentation with only a weak connection to how these concepts are understood in the humanities and related fields, both by scholars and practitioners.

The first fundamental distinction in formal argumentation, as highlighted in the historical overview of Prakken, is between argumentation as inference and argumentation as dialogue. Most research reported in the area is of the first kind, though a number of main-stream argumentation semantics can be interpreted by means of structured discussion, in the sense that an argument is justified according to a particular argumentation semantics iff it is possible to win a discussion of a particular type. Hence, different argumentation semantics correspond to different types of discussion.

The formal theory of argumentation as inference has highlighted the attack among arguments as its central concept. This reflects that argumentation is a process where different opinions may conflict, and these conflicts may be explicated and resolved. Consequently, many systematic introductions to argumentation start with Dung's theory of abstract argumentation frameworks, which takes the notions of argument and attack as primitive,

i.e., nothing is assumed about the structure of arguments or the nature of attack. However, as discussed by Prakken in his historical overview chapter, there had been quite some formal work on argumentation-based inference before Dung's landmark 1995 paper, and all this early work specified the structure of arguments and the nature of attack. According to Prakken, the seminal paper in this respect was Pollock's 1987 article, and many ideas developed in this early body of work are still important today.

The focus in early work on structured argumentation agrees with the usual approaches in informal argumentation, which do not have arguments as the primitive notion but concepts like claims, reasons and grounds. For example, Walton defines the term 'argument' as 'the giving of reasons to support or criticize a claim that is questionable, or open to doubt'.

Nevertheless, the notion of meaning in Dung's theory is radically different from many traditional theories. There are multiple semantics under consideration, and each semantics may present various alternatives. As we explain later, when we consider the relation between formal argumentation and mathematical logic, it means that the mainstream theories of formal argumentation discussed in this area are closer to para-consistent logic developed in philosophical logic, and non-monotonic logic developed in artificial intelligence.

Many relations between the various formalisms of structured argumentation have been discussed, but there is no consensus on a common core going beyond Dung's abstract theory, and there is no consensus on which system should be used in practice for which application. For example, a very expressive approach like ASPIC+ may be useful for a principle based analysis of structured argumentation, but a more restricted approach like ABA or DeLP may be more suited for implementation, or to prove certain formal properties.

The formal analysis discussed in the area is of two kinds. First, algorithms together with complexity results are presented for the defined formal systems. Second, a principle based approach is developed to analyze the formal systems. The principle-based or axiomatic approach is a methodology to choose an argumentation semantics for a particular application, and to guide the search for new argumentation semantics. The study of representation and (im)possibility results for abstract argumentation must be extended for a principle-based approach for extended argumentation such as bipolar frameworks, preference-based frameworks, abstract dialectical frameworks, weighted frameworks, and input/output frameworks.

Coming from informal and natural language argumentation, the theory of formal argumentation presents two challenges. The first challenge is whether the developed theories of formal argumentation can be used as a foundational theory of informal and natural language argumentation. For example, how can argument schemes be used to define arguments in the formal approaches, or how can the formal approaches support the natural language processing techniques and machine learning algorithms?

The second challenge is how the here developed theories of formal argumentation can be adapted or extended such that they cover a wider range of phenomena in informal argumentation. Ideally, these adaptations and extensions should still follow the mathematical elegance and simplicity of the presented theories. Moreover, these innovations should not affect the formal and computational properties of the theories, or at least they should not make large concessions.

4.2 Challenges for formal argumentation

In the past two decades, theories and algorithms of formal argumentation have been extensively developed. However, there are still some fundamental problems to be explored, including the problems related to time and dynamics, rationality postulates, models and semantics

of argumentation, preferences between arguments, and efficient algorithms. Some of the problems in this direction are identified as follows.

- **Validity or status of arguments with respect to time/dynamics.** Since argumentation is intrinsically dynamic, the status of arguments may change upon the changing of underlying knowledge. Since little attention has been devoted to explicitly consider the presence of time and its impact in an argumentation-based context, it would be interesting to further study the model of formal argumentation with respect to time/dynamics.
- **Qualitative postulates that should be satisfied in specific contexts.** Several rationality postulates have been proposed both for abstract and structured argumentation. However, further research should be devoted to study the sets of postulates that should be satisfied in specific application contexts. This may also require the identification of novel postulates.
- **Development of Dung’s theory.** Dung’s abstract argumentation plays an important role in the community of formal argumentation, and there are already a number of extensions of this theory. Further extensions might include the following.
 - Identifying an elegant formalism encompassing Dung’s model and capturing also different ways of evaluating arguments, e.g. balancing considerations.
 - Developing an alternative approach to model the cases where we are interested in only one argument, and focus mainly on explanation and justification.
 - Achieving a clarification on the “semantics of a semantics”, to make clear when to adopt a specific semantics instead of another. In this respect, a focus on specific argumentation contexts would be required.
- **Preference relation and defeat relation.** When considering the preference relation over underlying knowledge [14], an important question is how to lift the preference relation of the underlying knowledge to that of arguments. Meanwhile, preference order between arguments is dynamic and may depend on the labelling of arguments, thus a recursive process may be needed.
- **Efficient algorithms.** Since many natural questions regarding argument acceptability are computationally intractable, developing efficient algorithms for formal argumentation is important. According to the results of a recent competition on Computational Models of Argumentation¹, reduction-based systems (either SAT-based or ASP-based) are more efficient than non reduction-based. However, this may be due to the fact that research focusing on efficient algorithms is not sufficiently mature. Thus it would be interesting to study and develop algorithms for abstract argumentation not based on SAT problem, e.g., fixed-parameter tractable algorithms.
- **Negation of arguments.** It is not clear what is the negation of an argument. One possible way is to define operators, like negation of trust as distrust, negation of attack as support, negation of argument, etc.

4.3 Connection with other theories

Besides, formal argumentation can also be related to other formal theories like computational social choice theory, belief revision, neural networks, and Bayesian networks, etc.

- **Formal argumentation and logics.** The interplay between argumentation and logic has a long history. However, the relation between formal argumentation and various kinds

¹ ICCMA 2015: see <http://argumentationcompetition.org/2015/>

of logics are not clear. For instance, how to use argumentation to represent preference-based nonmonotonic reasoning, how to use argumentation to represent deontic reasoning, etc.

- **Formal argumentation and mathematics.** Given a directed graph, mathematicians and researchers in the community of argumentation may have different views. For instance, while the former pay their attention to the number of nodes, number of arrows, topological properties, connectivity, etc., and define the notion of a kernel of the graph, the latter concern more on arguments and look for complete extensions of the graph. It is worth to further study the mutual benefits of these two areas.
- **Formal argumentation and computational social choice.** There are some interesting research questions, e.g., to explore the relation between voting and the semantics of argumentation, or between the kind of democracy and the semantics of argumentation, etc.
- **Formal argumentation and belief revision.** Formal argumentation and belief revision are complementary. The former concerns how an agent changes her beliefs when new information arrives, while the latter deals with the the justification of new beliefs or the strategies to changes the beliefs of other agents. The connections between these two fields are promising and beneficial.
- **Bridge between uncertainty, fuzziness and argumentation.** As a combination of qualitative approach and quantitative approach, it is very promising to develop theories and applications by combining argumentation with uncertainty theory, including probability theory, possibility theory and fuzzy theory, etc.
- **Formal argumentation and other networks.** Abstract argumentation framework is a directed graph. It is natural to connect argumentation framework to other networks, such as neural networks, Bayesian Networks, etc.

We give some examples in the remainder of this section.

4.3.1 Connection with graph theory

Since the following sections discuss the connection with mathematical directed graph theory the style of writing needs to be more formal.

Abstract argumentation deals with binary relations R on a set S . The system (S, R) has sometimes the following properties when used by the argumentation community.

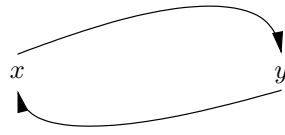
(*1) S is finite.

(*2) R is allowed to be reflexive and allowed to be symmetrical.

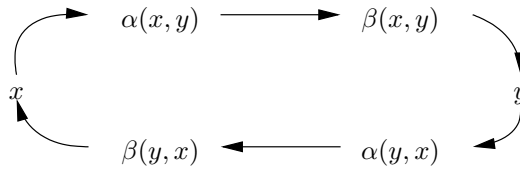
Also a lot of the mathematics studied in formal argumentation has to do with dealing with cycles arising because of these properties. In graph theory in comparison there is the notion of directed graphs (digraphs). The requirement is that R is irreflexive. There is also the notion of weak ordering where R is also required to be not symmetric $xRy \rightarrow \neg(yRx)$ [24]. Typically, there is no requirement that S be finite.

The abstract argumentation communities and the graph theory mathematicians ask slightly different questions about (S, R) . They also use different words/names for sometimes the same concept.

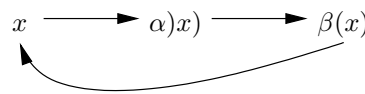
- If $x, y \in S$ and $\neg xRy \wedge \neg yRx$ in argumentation we say $\{x, y\}$ are conflict free. In graph theory we say they are independent.
- In argumentation they consider complete extensions, $E \subseteq S$. These are maximal subsets of conflict free points and researchers look at their existence. Among them are stable extensions. In graph theory such stable extension sets are called kernels and the mathematics of their existence is studied.



■ Figure 3



■ Figure 4



■ Figure 5

Stable extensions or kernels are subsets $E \subseteq S$ satisfying the following:

1. $\forall x, y \in E (\neg xRy \wedge \neg yRx)$
2. $(\forall z \in S - E)(\exists y \in E)(yRz)$.

In graph theory one studies also perfect kernels, namely kernels E such that also $S - E$ is a kernel. See papers of Walicki and Sjurdyrkolbotn.

Both communities realise that odd cycles in (S, R) cause problems and try to mathematically deal with them. The argumentation people are more algorithmic while the graph theory approach is more set-theoretical. Also in argumentation they deal with numerical graphs as well (papers by Gabbay-Rodrigues and others) while the graph community have less research about numerical annotation in the abstract math (there are many network communities such as flow networks, neural networks, etc., these are very numerical but they do not stress conflict freeness).

It is important to note that results and concepts in the argumentation community make the requirement of irreflexivity $(\neg xRx)$ and a -symmetry $xRy \rightarrow \neg yRx$ mathematically unimportant. In other words, any (S, R) can be rewritten as (S^*, R^*) , with $S \subseteq S^*$ and $R \subseteq R^*$ such that any kernel $E \subseteq S$ can be uniquely obtained and extended to a unique kernel $E^* \subseteq S^*$ by $E = E^* \cap S$. The idea is as follows, explained by example. Let $x \rightarrow y$ means xRy . Consider Figure 3. We may have $x = y$.

Figure 4 considers some new points. Let $\alpha(x, y)$ and $\beta(x, y)$ be $\alpha(y, x), \beta(y, x)$.

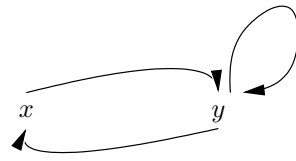
If $x = y$ we take only Figure 5.

Let (S^*, R^*) be extended as above for all pairs $\{x, y\}$ with $x \neq y$ and $xRy \wedge yRx$ and any z with zRz and $\alpha(z), \beta(z)$. So for example Figure 6 becomes Figure 7.

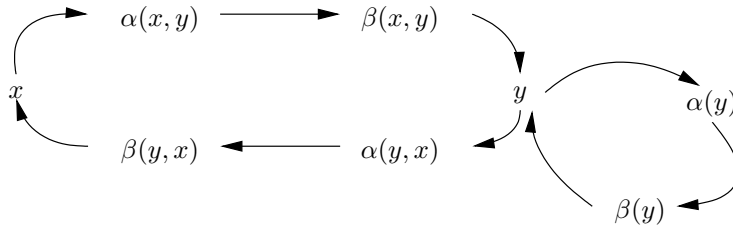
(S, R) of Figure 6 has one kernel/stable extension $E = \{x\}$. Figure 7 of (S^*, R^*) has the kernel E^* .

$$E^* = \{x, \beta(x, y), \alpha(y, x), \alpha(y)\}.$$

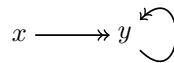
The above illustrates how mathematically formal argumentation can be connected with related mathematical directed graph theory. The formal similarities between the areas and the natural research instinct of the mathematicians involved will push cooperation between some of the individuals in each group.



■ **Figure 6** Showing (S, R)



■ **Figure 7** showing (S^*, R^*)



■ **Figure 8**

4.3.2 Connection with logic and liar paradox, Gaifman 1988

The basic meaning of xRy in argumentation is that if we accept x as “in” then we must reject y as “out”. This fits nicely with the liar paradox basic understanding that xRy means that x is a statement that y is false. In fact, Gaifman’s 1988 paper already introduced mathematically the graphs of argumentation networks of Dung’s 1995 paper. Gaifman’s evaluation, however, is different because of his different intended interpretation.

Consider Figure 8. According to Dung, the interpretation of $x \rightarrow y$ can be taken as ecological. x kills y . Thus since x is not attacked, x is “in” or is “alive”. Since x is alive and attacks y we have that y is “out” or “dead”. According to Gaifman and the liar paradox interpretation, x says that y is “false”. Since y says “I am lying” it cannot have a crisp value and so x cannot have a value. So we get $x = y = \text{no value} = \text{undecided} = \text{gap}$. (gap is the Gaifman terminology for the argumentation case of undecided.)

What about Figure 9? In argumentation $y = \text{und}$ and therefore $x = \text{und}$. According to the liar interpretation approach, y says I am lying and furthermore so is x . In comparison, x does not say anything about anyone else lying. We need to agree that if x says nothing about other statements then we let x be true.² This corresponds to Clause (C1) of the Caminada labelling. So following this agreement we get that $x = \top$. Let us now consider y . We have that that y is making two statements, namely y is saying “ y is false and x is false”. Thus since x is \top we get that the second statement of y is false. Thus we have:

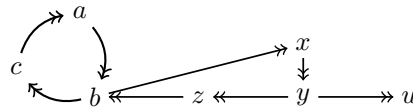
$$y = [(y \text{ is false}) \wedge x \text{ is false}] = \text{false}.$$

Note that Figure 9 is obtained from Figure 8 by reversing its arrows, and then Gaifman evaluation for Figure 9 gives the same result as Dung evaluation for Figure 8.

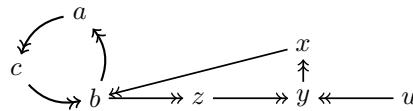
² Gaifman uses a classical model to evaluate x , so we can say in agreement with Gaifman that our classical model gives all such atoms value \top .



■ Figure 9



■ Figure 10



■ Figure 11

Let us do a more complex example. Consider the network of Figure 10.

If we calculate a Dung extension for this figure, we get that the only extension

$x = \text{in}$, $y = \text{out}$, $u = \text{in}$, $z = \text{in}$, $b = \text{out}$, $c = \text{in}$, $a = \text{out}$.

Let us calculate now the Gaifman extension for this same Figure 10:

$u = \top$ since u says nothing about anyone else

$y = \perp$ since y says u is lying and $u = \top$

$= \top$ since x says y is lying

$b = \perp$ since $x = \top$

$z = \top$ since $b = \perp$

$a = \top$ since $b = \perp$

$c = \perp$ since $a = \top$.

Now let us invert the arrows in Figure 10 and get Figure 11 and then compute according to Dung. $u = \text{in}$ (not attacked), $y = \text{out}$, $x = \text{in}$, $b = \text{out}$, $z = \text{in}$, $a = \text{in}$, $c = \text{out}$.

4.3.3 Connection with Saveliev 2017

Some formal "argumentation" work has already been done by mathematicians like Saveliev. This is a good sign for the future. Saveliev considered (S, T, U) with the following properties:

$T(x)$ means $x = \top$

xUy means x says that y is false

He required the following axioms

A1: $Tx \wedge Uy \rightarrow \neg Ty$

A2: $\neg Tx \wedge \exists y(xUy) \rightarrow \exists y(xUy \wedge Ty)$

Let us rewrite $xRy = \text{def.}yUx$. We get

$$\text{A1: } Tx \wedge yRx \rightarrow \neg Ty$$

$$\text{A2: } \exists y(yRx) \rightarrow [\neg Tx \rightarrow \exists y(yRx \wedge T(y))]$$

If we assume that (S, R) is such that every x is attacked (i.e. no start points $\forall x \exists y(yRx)$), then we get

$$\text{A1: } Ty \wedge yRx \rightarrow \neg Ty$$

$$\text{A2: } \neg Tx \rightarrow \exists y(yRx \wedge Ty).$$

Therefore we get

$$\text{A3: } Tx \text{ iff } \exists y(Ty \wedge yRx).$$

This is exactly the Caminada condition which mean that we are dealing with Dung networks where $\forall x \exists y(yRx)$ holds.

It is not a problem to make this condition true. For any x which is not attacked, add a new point $\gamma(x)$ and expand (S, R) to (S^*, R^*) with

$$S^* = S \cup \{\gamma(x) | x \text{ not attacked in } R\}$$

$$R^* = R \cup \{(\gamma(x), x), (x, \gamma(x)) | x \text{ not attacked in } R\}$$

The extensions E of (S, R) are obtained uniquely from those extensions of (S^*, R^*) where all $\gamma(x)$ are in. Let $\Gamma = \{\gamma(x)\}$. So $E \supseteq \Gamma$.

Saveliev proves theorems about his axioms, i.e. on models (S^*, R^*) . These can be translated to theorems on (S, R) , and vice versa.

5 Applications of formal argumentation

Applications of the theories and algorithms of formal argumentation have been proposed in several domains. This is mainly due to the ability of the theory to handle uncertain and possibly contradictory information, its capability of capturing diverse and heterogeneous reasoning mechanisms, as well as the fact that the basic concepts of the theory are akin to human intuition. In particular, a natural application domain is legal reasoning [4], since legal knowledge is inherently argumentative, while other obvious application domains are medical reasoning and e-democracy (see e.g. [16, 7]).

Whatever domain is considered, a core issue is the identification and/or acquisition of arguments. While these can be manually introduced by the user, a recent thread of research is devoted to automatically identify argumentative structures from textual sources, including arguments components (e.g. premises and conclusions), argumentation schemes related to arguments, and the relationships holding between arguments (such as subargument relations, attacks and support). This is a complex issue which requires (at least) the integration of Computational Linguistics research with the study of computational models of argumentation.

Regarding specifically the argumentation formalisms for argument mining, since structured argumentation systems are meant to capture more closely the actual construction of arguments in argumentation processes, they are more suitable candidate formalisms for this purpose. For instance, in the assumption-based model, argument analysis amounts to the identification, within a given text, of the argument claim, of its supporting assumptions and of the rules used for the claim deduction. Similar “component identification guidelines” could be drawn

for other structured systems. Two difficulties must be acknowledged, however, concerning the use of these formalisms for actual argument mining. First, some of these formalisms are still rather abstract, since, for the sake of generality, they leave unspecified some important aspects (e.g. the actual language adopted) hence they are not applicable without making some further specific choices at the implementation level. Second, and more important, they have typically been conceived to capture argumentation in already formalized settings (e.g. argument-based reasoning on possibly inconsistent knowledge bases) rather than at a natural language level. Indeed, due to the enthymematic nature of most natural arguments, some of the argument components encompassed by the above mentioned models, like the assumptions or the rules used, are left implicit in natural language expressions of arguments. Hence, one might argue that such structured formalisms are a suitable target for a “second level” analysis (and completion) of the natural arguments identified in a text, but, in a sense, can be too demanding as a first target formalism for the argument mining process itself. As a matter of fact, an analysis of the references in the papers presented at the First and Second International Workshop on Argumentation Mining shows that the structured argumentation formalisms are practically absent from current research on argumentation mining, while much more attention has been reserved to the use of semi-formal/diagrammatical schemes.

Semi-formal schemes, often lending themselves to a diagrammatical representation, provide models of argument structure and/or of inter-argument relationships which are typically focused on a few elements, regarded as crucial for the analysis and comprehension of some key aspects of the argumentation process. As such, these schemes do not provide a complete account nor a formal backing of the argumentation process as a whole, to be covered by other models, but rather can be regarded as shedding light on some central points, beneficial for the development of more complete and more formal models. Examples are the Toulmin model [25], subsequently developed by Freeman [10, 11], Wigmore diagrams [29] and Walton’s argumentation schemes [27, 28]. A discussion of the uses of this kind of models for argumentation mining is provided by [22], while an analysis of the papers presented at the First and Second International Workshop on Argumentation Mining and of some earlier influential work [21] shows in particular a prevalence in the use of Walton’s argumentation schemes.

Argumentation may be a natural way for human reasoning and communication. However, the gap between existing theories and algorithms of formal argumentation and real applications is still surprisingly big. Some research problems are as follows.

- **Natural language interfaces to arguments.** In order to facilitate the applications of theories and algorithms of formal argumentation to daily life reasoning and communication, it is vital to develop human-friendly interfaces.
- **Formal argumentation account of fallacies.** Fallacies are the most efficient way of human reasoning and persuasion in daily life. Formal models of fallacies are still missing.
- **Analyzing and modelling argumentation schemes** As a semi-formal model, argumentation schemes can play an important role to connect arguments in natural language and formal argumentation in AI. However, how to exploit argumentation schemes in formal argumentation is a problem not completely studied yet.
- **Argumentation mining.** Argumentation mining is a promising direction to apply theories and algorithms of formal argumentation. However, according to the state of the art, there are a lot of challenging problems in this direction, e.g., the identification and formalization of arguments and their components, the identification of various relations between arguments, the measurement and formalization of uncertainties of natural arguments, etc.

- **Software engineering methods for argumentation.** In order to connect the notions developed in argumentation theory with practical domains, the development of software engineering methods (e.g. for requirement analysis) would be useful to drive research in argumentation.

In addition, to study how theories of formal argumentation can be applied to practice, one may consider a more systematic research direction, called “argumentation analysis”, which is coined after the word “decision analysis”. The nutshell of decision analysis is the application of decision science to real-world problems through the use of systems analysis and operations research. It describes how people should logically make decisions in simple situations or complex situations. In the setting of formal argumentation, we need study procedures, methods, and tools for identifying, clearly representing, and formally assessing important aspects of argumentation from simple situations to very complex situations:

Reasoning problems Consider a simple reasoning problem, e.g. which people can together go to a party based e.g. on their (possibly temporal) constraints and individual preferences. Argumentation analysis may be considered as a prescriptive approach, especially concerned with dealing with uncertainties qualitatively and/or quantitatively. Prescriptive argumentation researches how optimal arguments could be accepted.

Agent interaction Consider a more complex problem of the argument of sex offenders in therapy. Every human being has reasoning distortion, but sex offenders have unusual and exceptional cognitive distortion. To model this distortion, we need to know how people actually make arguments, regardless of argument quality. Meanwhile, people also use logical fallacies, which are the most effective arguments in daily life. The prescriptive approach is found to be in fact rarely used in the reasoning of individuals. The hiatus between prescriptive argumentation and descriptive approaches is greater in high-stakes argumentation and negotiation, made under time pressure.

Institutions Consider the complex decisions of religious or legal systems over time. The institution builds up information and argumentation evolves into information processing. To model this kind of argument, we need to go beyond the above-mentioned prescriptive and descriptive approaches. An example in this direction is Talmudic logic. The Jewish Talmud is a body of arguments and discussions about all aspects of the human agents social, legal, ethical and religious life. It is a practical and coherent body of laws developed logically to address human behavior.

6 Conclusions

Some researchers seem to believe that the theory of formal argumentation may be more or less finished, and we can focus on computational aspects and the use of formal argumentation, since there is nothing important left to add to it. In our view, this is far from the truth. On the contrary, there is a large number of important open problems in the foundations in this field of research.

An important recommendation coming from this Dagstuhl workshop is that we need to evaluate the current argumentation formalisms. In particular, more investigation on how to apply the formalisms studied in formal computational argumentation to “real” reasoning contexts, including e.g. legal and ethical reasoning. An important issue to connect formal argumentation to real argumentation is to mine arguments from natural language text, which requires building novel applications for argument mining.

Moreover, from these argumentation applications a more systematic research direction may emerge, called “argumentation analysis.” In the setting of formal argumentation, we need study procedures, methods, and tools for identifying, clearly representing, and formally assessing important aspects of argumentation from simple situations to very complex situations.

Together, the applications and argumentation analysis may inform the further development of the formal machinery involved in argumentation theory. From a theoretical perspective, we call for more unified theoretical results rather than fragmentation into specific isolated studies. Moreover, the identification of some important applications that should be developed may contribute to this evolution of the community. In short, the research on this topic is active, vibrant, and rich, but the area is vast and diverse and needs to be connected together.

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