Dynamics in Formal Argumentation: A Survey with Emphasis on Structured Accounts

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Argumentation is an inherently dynamic process. In formal argumentation, an important knowledge-based approach to artificial intelligence, this dynamic aspect has been studied from a variety of perspectives. Historically, the research has mostly focused on the abstract approach to argumentation, in which the structure of arguments and the nature of the attacks between them are abstracted away. There are, however, both theoretical and practical reasons to study dynamics from the structured perspective. In this survey, we provide an overview of the various perspectives on dynamics in abstract argumentation. Then we go into more detail about the available literature on dynamics of structured approaches to argumentation. We show why it is beneficial to consider dynamics of structured accounts, review the existing literature and discuss how to continue this line of work.

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1 Introduction

We live in a dynamic world, where information is shared, dialogues take place and arguments evolve. Any application situated in this environment should be able to handle constant changes. Recent developments in AI, such as (by now well-known) ChatGPT and other LLMs, have made AI-based applications available to and known by the general public. Their wide applicability and popularity, as well as their ability to operate in dynamic settings, might suggest that all technological advancements for society's challenges can be achieved with learning-based approaches to AI. There is, however, still a need for knowledge-based approaches to AI, such as formal argumentation (Bex 2025; Castagna et al. 2024; Prakken 2024b). It is therefore essential to understand dynamics from a computational, knowledge-based perspective.

Formal argumentation is a well-established knowledge-based approach to artificial intelligence. Abstract argumentation frameworks, originally introduced by Dung (1995), model non-monotonic reasoning by means of abstract arguments and the attacks between them. This approach has been successful, with a large body of work and a lively community (Baroni, Gabbay, et al. 2018; Gabbay, Giacomin, et al. 2021; Gabbay, Kern-Isberner, et al. 2024) as well as various applications (Atkinson et al. 2017) to witness.

Argumentation is an inherently dynamic process, in which agents might need to incorporate new information into their knowledge base or they might want to achieve a certain goal by providing selected information. As such, dynamics is an important research direction in formal argumentation (Doutre and Mailly 2018; Gabbay, Giacomin, et al. 2021). In the abstract setting, in which the structure of arguments and the nature of the attacks between them have been abstracted away, dynamics has been studied from various perspectives (Doutre and Mailly 2018). For example, the types of change that can take place in an argumentation setting, such as the

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addition and removal of arguments and attacks, have extensively been considered, starting with work by Cayrol, Dupin de Saint-Cyr, et al. (2008). The modification of an argumentation setting to establish a certain goal, such as the acceptance of a desired set of arguments, was introduced as enforcement by Baumann and Brewka (2010). Moreover, incomplete and uncertain information has been explicitly modeled in various ways, for example as a special type of argumentation framework by Baumeister, Neugebauer, et al. (2018). Finally, the relation with belief revision (Alchourrón et al. 1985; Katsuno and Mendelzon 1991), another knowledge-based approach to AI, has been extensively researched and reviewed (Falappa, Kern-Isberner, et al. 2009).

Abstract argumentation, however, has certain drawbacks (Caminada and Wu 2011; Prakken 2018; Prakken and Winter 2018), that are especially concerning in dynamic settings. For example, it is often assumed that specific arguments or attacks can always be added or removed or that an argument can be attacked by any other argument. When we look at the content of the arguments, for example the knowledge base elements and the rules from which they are constructed, it becomes clear that these, often implicit, assumptions might not always be appropriate. In the argumentation literature there are several prominent structured approaches to argumentation: assumption-based argumentation (Bondarenko et al. 1997; Čyras et al. 2018), ASPIC$^+$ (Modgil and Prakken 2018; Prakken 2010), defeasible logic programming (García and G. R. Simari 2018, 2004) and deductive argumentation (Besnard and Hunter 2001, 2018), each with their own strengths (Besnard, García, et al. 2014). These make the structure of arguments explicit, as the arguments are constructed from a knowledge base and a set of rules, elements of which can be strict or defeasible. The attacks between the arguments are determined by the structure of the arguments and a chosen notion of conflict.

Noticing the problems that arise from the implicit assumptions made in abstract argumentation, dynamics of structured approaches to argumentation have gained interest recently (Abderrazik and Doder 2025; Berthold, Rapberger, et al. 2023; Borg and Bex 2021; Odekerken, Lehtonen, Wallner, et al. 2025; Prakken 2024a; Rapberger and Ulbricht 2023). While the investigated dynamic perspectives are similar to those studied in the abstract account, there are important differences. For example, in abstract argumentation a change to the framework was mostly limited to adding or removing arguments or attacks, in the structured account, the knowledge base or the set of rules can be modified. Conclusions are usually not formulated in terms of (sets of) arguments, but rather in terms of formulas, which could, for example, be knowledge base elements, assumptions or derived conclusions. Moreover, there is more flexibility in the changes to the argumentation setting, because elements of the knowledge base and the set of rules can individually be modified, where it is, for example, possible to distinguish between strict and defeasible elements. By modeling dynamics on the level of the elements from which the argumentation setting is constructed, the problems from the abstract account are resolved.

The aim of this survey is to provide an overview of the work on dynamics in formal argumentation and to show the potential for expanding the research on dynamics of structured approaches to argumentation. To this end we define the scope of this survey as works in which the main focus is on a theoretical understanding of changes to the argumentation setting, whether arguments and attacks, in abstract accounts, or knowledge base elements and rules, in structured accounts. It is not our goal to review all the technical details and results of the research within this scope. But, rather, to collect works on the different perspectives on dynamics, illustrating the richness of the available work and the potential of this line of research. Therefore, this survey makes three main contributions:

- We provide a high-level overview on the various perspectives on dynamics of abstract argumentation. Specifically, we consider works that study (a) how the argumentation setting can be changed in a dynamic environment; (b) how goals can be achieved by changing the argumentation setting; (c) incomplete or uncertain information in a dynamic setting; (d) the relation to belief revision; and (e) the inherent computational challenge of a dynamic setting. Given our focus on structured accounts, this part only provides an overview on the available perspectives, recent advances and the importance of the research, without going into detail.

- We go into more depth on works on dynamics of structured approaches to argumentation. We show how the various perspectives on dynamics in the abstract setting have been translated to the structured setting, where this is not possible and why and what further possibilities there are when the structure of the arguments is taken into account. It will become clear that, although dynamics of structured approaches might be less straightforward, this does not need to be a drawback. In contrast, each of the perspectives mentioned above can be considered in the structured setting, where existing problems are resolved, more questions can be answered, more flexibility is built-in and solutions to the increased computational complexity exist.
- An overview, based on the surveyed literature, of the problems of the abstract account is provided. Although the problems are numerous, solutions have been found through structured approaches to argumentation already. It shows the strength of such structured accounts, without having to choose one specific approach. Moreover, the variety of techniques, combined with these solutions shows the potential of this research direction, both theoretically and for applications.

Dynamic formal argumentation has been surveyed before. A general overview on the abstract account is presented by Doutre and Mailly (2018). More specific surveys have been published on enforcement (Baumann, Doutre, et al. 2021), the incremental approach to recomputation (Alfano, Greco, Parisi, G. I. Simari, et al. 2021b) and the relation with belief revision (Baroni, Fermé, et al. 2022; Falappa, Kern-Isberner, et al. 2009). To the best of our knowledge, this is the first survey with a focus on structured approaches to argumentation.

Some notions of dynamics are beyond the scope of this review. Specifically, we do not consider dialogues (Black, Maudet, et al. 2021) or discussions (Caminada 2018), unless the work provides theoretical notions for the study on dynamics, such as that by Odekerken, Bex, et al. (2022). Nor do we include work on dynamics in the sense of representation of argumentation and proof theories in logical methods (Arieli, Borg, Heyninck, and Straßer 2021), unless the representation is about dynamic settings rather than static ones, such as that by Coste-Marquis et al. (2014a,b).

Outline. We start in Section 2 with some technical preliminaries, needed to provide sufficient detail on the various approaches to dynamics. In Section 3 we provide an overview of the most important work on dynamics in abstract argumentation. This overview contains at least the introduction of the necessary notions for Section 4, which contains the main contribution of this survey: a review of the literature on dynamics of structured approaches to argumentation. We provide an extensive discussion, e.g., on the need to consider structured approaches when studying dynamics and possible lines for future work, in Section 5. An overview of the surveyed literature is provided in Table 1, at the end of the paper.

2 Preliminaries

In this section we will provide the technical preliminaries in order to discuss the literature on dynamics in formal argumentation in subsequent sections. In addition to recalling the most important definitions from abstract argumentation (Section 2.1) we will cover assumption-based argumentation (Section 2.2), ASPIC$^+$ (Section 2.3), defeasible logic programming (Section 2.4) and logic-based argumentation (Section 2.5), an introduction to these four approaches is given by Besnard, García, et al. (2014).

2.1 Abstract Argumentation

Central in formal argumentation is the argumentation framework, consisting of arguments and the attacks between them.

Definition 1 (Abstract argumentation frameworks (Dung 1995))**.** An *abstract argumentation framework* (AF) is a pair $\mathcal{AF} = \langle \mathsf{Args}, \mathsf{Att} \rangle$ where Args is the set of *arguments* and $\mathsf{Att} \subseteq \mathsf{Args} \times \mathsf{Args}$ is an *attack relation* on these arguments.

Intuitively, an AF can be interpreted as a graph, where nodes represent the arguments and attacks are the edges. Therefore, we will sometimes refer to the argumentation graph.

2.1.1 Semantics. Given an argumentation framework, semantics can be applied to it, in order to determine whether an argument is accepted or not, or to what extend it can be accepted. In the literature a variety of semantics have been proposed. In this section we only recall extension-based semantics and labeling-based semantics. Other types of semantics have been defined as well. For example, ranking-based semantics were introduced by Amgoud and Ben-Naim (2013) and Bonzon et al. (2016) and gradual semantics by Cayrol and Lagasquie-Schiex (2005a). Introducing these is beyond the scope of this survey.

Extension-based semantics. Extension-based semantics can be applied to an argumentation framework, to determine what combinations of arguments (called *extensions*) can collectively be accepted. We consider here the ones introduced by Dung (1995), see for a detailed discussion and additional extension-based semantics the survey by Baroni, Caminada, et al. (2018).

Definition 2. Let $\mathcal{AF} = \langle \mathsf{Args}, \mathsf{Att} \rangle$ be an argumentation framework, $\mathsf{S} \subseteq \mathsf{Args}$ a set of arguments and let $A \in \mathsf{Args}$. Then S *attacks* A if there is an $A' \in \mathsf{S}$ such that $(A', A) \in \mathsf{Att}$ and S *defends* A if S attacks every attacker of A. S is *conflict-free* if there are no $A_1, A_2 \in \mathsf{S}$ such that $(A_1, A_2) \in \mathsf{Att}$ and S is an *admissible extension* if it is conflict-free and it defends all of its elements.

An admissible extension that contains all the arguments that it defends is a *complete extension*. The *grounded extension* is the minimal (with respect to $\subseteq$) complete extension. A *preferred extension* is a maximal (with respect to $\subseteq$) complete extension. A *stable extension* is a complete extension that attacks every argument not in it. We denote by $\mathsf{Sem}(\mathcal{AF})$ the set of all extensions of $\mathcal{AF}$ under a given semantics.

Given an argumentation framework an acceptance strategy can be decided. In addition to a semantics, the user also has to decide on how to accept an argument: skeptical, when an argument is always accepted; or credulous, accepting arguments that are sometimes accepted.

Definition 3. Let $\mathcal{AF} = \langle \mathsf{Args}, \mathsf{Att} \rangle$ be an AF and let Sem be a semantics for it, such that $\mathsf{Sem}(\mathcal{AF}) \neq \emptyset$. Then $A \in \mathsf{Args}$ is: *skeptically accepted* if for each $\mathsf{S} \in \mathsf{Sem}(\mathcal{AF})$, $A \in \mathsf{S}$; *credulously accepted* if there is some $\mathsf{S} \in \mathsf{Sem}(\mathcal{AF})$ such that $A \in \mathsf{S}$; and *rejected* if there is no $\mathsf{S} \in \mathsf{Sem}(\mathcal{AF})$ such that $A \in \mathsf{S}$.

Labeling semantics. With labeling-based semantics, see e.g., the overview by Baroni, Caminada, et al. (2018), one of three labels is assigned to each argument, indicating that an argument is in an extension (`in`), attacked by an argument in an extension (`out`), or neither, meaning it is undecided (`undec`).

Definition 4. Let $\mathcal{AF} = \langle \mathsf{Args}, \mathsf{Att} \rangle$ be an AF and let $\mathcal{L}$ be a labeling, which assigns a label to each argument in Args. Then: an `in`-labeled argument is *legally* `in` iff all its attackers are labeled `out`; an `out`-labeled argument is *legally* `out` iff it has at least one attacker that is labeled `in`; and an `undec`-labeled argument is *legally* `undec` iff not all its attackers are labeled `out` and it does not have an attacker that is labeled `in`.

A *complete labeling* is such that every `in`-labeled argument is legally `in`, every `out`-labeled argument is legally `out` and every `undec`-labeled argument is legally `undec`. The *grounded labeling* is the complete labeling in which the set of `in`-labeled arguments is $\subseteq$-minimal. A *preferred labeling* is a complete labeling in which the set of `in`-labeled arguments is $\subseteq$-maximal. A *stable labeling* is a complete labeling in which no argument is labeled `undec`.

Given that a labeling assigns a label to each argument, labeling semantics is more general than extension-based semantics. There is, however, a correspondence with extension-based semantics: `in`-labeled arguments can be understood as part of an extension. Baroni, Caminada, et al. (2018) provide an extensive discussion on both extension and labeling semantics and how they relate.

2.1.2 Extensions of Abstract Argumentation. Dung's abstract argumentation frameworks have been extended and generalized in a variety of ways, many of which have also been considered in a dynamic setting. Since the focus of this survey is on structured approaches to argumentation, we do not provided details of all these variations, even if they have been applied. Instead, we mention a few here, together with references for the interested reader.

PAFs A preference relation among the arguments of an AF is added in preference-based argumentation frameworks (Amgoud and Cayrol 2002) and a variety of ways to handle attacks in view of preferences among the arguments have been considered, see e.g., the overview by Kaci et al. (2021).

BAFs In addition to the traditional attack relation, a support relation is added in bipolar argumentation frameworks (Cayrol and Lagasquie-Schiex 2005b).

HOAFs In higher-order argumentation frameworks, in addition to the traditional attack relation, attacks on other attacks and, in a bipolar setting, attacks on supports are allowed, see e.g., the overview by Cayrol, Cohen, et al. (2021).

SETAFs Collective attacks, where a set of arguments jointly attacks another argument, are added in SETAFs, see e.g., the overview by Bikakis, Cohen, et al. (2021).

ADFs Abstract dialectical frameworks allow for arbitrary relationships among arguments, including supports and collective attacks, see e.g., the overview by (Brewka et al. 2018).

For incomplete and control AFs we refer to Section 3.4. In the next sections we turn to structured approaches to formal argumentation. The formal definitions can be skipped on a first read, but it is recommended to read the intuitions of the various approaches.

2.2 Assumption-Based Argumentation

Assumption-based argumentation (ABA) is one of the main structured approaches to formal argumentation, introduced by Bondarenko et al. (1997), see also the surveys by Čyras et al. (2018) and Toni (2014). Most definitions in this section are based on the survey by Čyras et al. (2018).

An ABA framework is a tuple of a deductive system, a set of assumptions and a contrariness function over these assumptions. Arguments are deductions, that can be defined in several ways (Toni 2014). Following the work by Čyras et al. (2018), we consider here the tree-style definition (Dung et al. 2009). The set of assumptions is central in ABA: attacks are defined between sets of assumptions. Moreover, extension-based semantics are re-defined, in terms of sets of assumptions. Consequences are derived from such assumption-based extensions, by means of deductions.

Definition 5. An *ABA framework* is a tuple $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{} \rangle$ where:

- $\langle \mathcal{L}, \mathcal{R} \rangle$ is a *deductive system*, with $\mathcal{L}$ a language and $\mathcal{R}$ a set of rules;
- $\mathcal{A} \subseteq \mathcal{L}$ is a (non-empty) set of *assumptions*; and
- $\overline{}$ is the *contrary function*, a total mapping from $\mathcal{A}$ to $\mathcal{L}$.

An ABA framework is *flat* if there is no rule with an assumption as the head.

Arguments in ABA are deductions, derived by chaining rules in $\mathcal{R}$, often defined as trees (Dung et al. 2009).

Definition 6. A *deduction* for $\phi \in \mathcal{L}$ supported by $S \subseteq \mathcal{L}$ and $R \subseteq \mathcal{R}$, denoted by $S \vdash^R \phi$ is a (finite) tree such that:

- nodes are labeled by sentences in $\mathcal{L}$ or by $\top$;

- the root is labeled by ϕ;
- leaves are labeled by $\top$ or by members of S;
- non-leaves are labeled ψ with, as children, the elements of the body of some rule in R with head ψ and R the set of all such rules.

Attacks in ABA are between sets of assumptions.

Definition 7. A set of assumptions $A \subseteq \mathcal{A}$ *attacks* a set of assumptions $B \subseteq \mathcal{A}$ iff there are $A' \subseteq A$ and $b \in B$ such that $A' \vdash \overline{b}$.

Similarly, extensions are also defined in terms of assumptions.

Definition 8. A set of assumptions: is *conflict-free* iff it does not attack itself; is *closed* if $A = \{\phi \in \mathcal{A} \mid \exists A' \vdash^R \phi, A' \subseteq A \text{ and } R \subseteq \mathcal{R}\}$; and *defends* $a \in \mathcal{A}$ iff for every $B \subseteq \mathcal{A}$, if B is closed and attacks $\{a\}$, then A attacks B.

Then, $A \subseteq \mathcal{A}$ is: *admissible* iff it is closed, conflict-free and defends itself; *complete* iff it is admissible and contains all the assumptions it defends; *grounded* iff it is the intersection of all complete extensions; *preferred* iff it is maximally (w.r.t. $\subseteq$) admissible; and *stable* iff it is closed, conflict-free and, for every $a \in \mathcal{A} \setminus A$, A attacks $\{a\}$.

Conclusions from an ABA framework are drawn based on the deductions supported by an extension.

Definition 9. The *consequences* of an extension $A \subseteq \mathcal{A}$ is the set $\mathsf{Cn}(A) = \{\phi \in \mathcal{L} \mid \exists A' \vdash^R \phi, A' \subseteq A\}$.

2.3 ASPIC$^+$

ASPIC$^+$ has extensively been studied in the literature, see e.g., the surveys by Modgil and Prakken (2018, 2014). Most of the definitions in this section are based on the papers by Modgil and Prakken (2013) and Prakken (2010).

An ASPIC$^+$ setting starts from an argumentation system. Arguments are then constructed in an argumentation system from a knowledge base, which together form the argumentation theory. Based on the structure of the constructed arguments, the attack relation is determined. The arguments, together with the attacks between them and a preference relation over the arguments form structured argumentation frameworks. From this, via a Dung-style argumentation framework, conclusions can be drawn, both in terms of arguments and in terms of their conclusions.

Definition 10. An *argumentation system* is a tuple $\mathsf{AS} = \langle \mathcal{L}, \overline{}, \mathcal{R}, n \rangle$, where:

- $\mathcal{L}$ is a logical language;
- $\overline{}$ is a function that assigns to each formula in $\mathcal{L}$ a set of formulas such that, for $\phi, \psi \in \mathcal{L}$:
  - ϕ is a *contrary* of ψ if $\phi \in \overline{\psi}$ but $\psi \notin \overline{\phi}$;
  - ϕ is a *contradictory* of ψ if $\phi \in \overline{\psi}$ and $\psi \in \overline{\phi}$;
  - each $\phi \in \mathcal{L}$ is assumed to have at least one contradictory.
- $\mathcal{R} = \mathcal{R}_s \cup \mathcal{R}_d$ is a set of strict ($\mathcal{R}_s$) and defeasible ($\mathcal{R}_d$) inference rules of the form $\phi_1, \ldots, \phi_n \rightarrow \phi$ resp. $\phi_1, \ldots, \phi_n \Rightarrow \phi$, such that $\{\phi_1, \ldots, \phi_n, \phi\} \subseteq \mathcal{L}$ and $\mathcal{R}_s \cap \mathcal{R}_d = \emptyset$.
- $n : \mathcal{R}_d \rightarrow \mathcal{L}$ is a partial naming convention for defeasible rules, where $n(r)$ is a well-formed formula in $\mathcal{L}$ which says that $r \in \mathcal{R}_d$ is applicable.

A *knowledge base* in an argumentation system $\langle \mathcal{L}, \overline{}, \mathcal{R}, n \rangle$ is a set of formulas $\mathcal{K} \subseteq \mathcal{L}$ which contains two disjoint subsets: $\mathcal{K} = \mathcal{K}_p \cup \mathcal{K}_n$, the set of *axioms* $\mathcal{K}_n$ and the set of *ordinary premises* $\mathcal{K}_p$.

Arguments in ASPIC$^+$ are constructed in an argumentation system from a knowledge base.

Definition 11. An *argument* A on the basis of a knowledge base $\mathcal{K}$ in an argumentation system $\langle \mathcal{L}, \overline{}, \mathcal{R}, n \rangle$ is:

(1) ϕ if $\phi \in \mathcal{K}$. We denote by:
   - $\mathsf{Prem}(A) = \{\phi\}$, the set of *premises* of A;

- $\mathsf{Sub}(A) = \{\phi\}$, the set of *subarguments* of A;
- $\mathsf{Conc}(A) = \phi$, the *conclusion* of A; and
- $\mathsf{TopRule}(A)$ = undefined, the *top rule* (i.e., the last rule applied in the construction) of A.

(2) $A_1, \ldots, A_n \rightsquigarrow \psi$, where $\rightsquigarrow \in \{\rightarrow, \Rightarrow\}$, if $A_1, \ldots, A_n$ are arguments such that there exists a rule $\mathsf{Conc}(A_1), \ldots, \mathsf{Conc}(A_n) \rightsquigarrow \psi$ in $\mathcal{R}_s$ if $\rightsquigarrow = \rightarrow$ and in $\mathcal{R}_d$ if $\rightsquigarrow = \Rightarrow$. Where:
- $\mathsf{Prem}(A) = \mathsf{Prem}(A_1) \cup \ldots \cup \mathsf{Prem}(A_n)$;
- $\mathsf{Conc}(A) = \psi$;
- $\mathsf{Sub}(A) = \mathsf{Sub}(A_1) \cup \ldots \cup \mathsf{Sub}(A_n) \cup \{A\}$; and
- $\mathsf{TopRule}(A) = \mathsf{Conc}(A_1), \ldots, \mathsf{Conc}(A_n) \rightsquigarrow \psi$.

The above notation can be generalized to sets: for a set of arguments S: $\mathsf{Prem}(\mathrm{S}) = \bigcup\{\mathsf{Prem}(A) \mid A \in \mathrm{S}\}$, $\mathsf{Conc}(\mathrm{S}) = \{\mathsf{Conc}(A) \mid A \in \mathrm{S}\}$, $\mathsf{Sub}(\mathrm{S}) = \bigcup\{\mathsf{Sub}(A) \mid A \in \mathrm{S}\}$, and $\mathsf{TopRule}(\mathrm{S}) = \{\mathsf{TopRule}(A) \mid A \in \mathrm{S}\}$.

Attacks on an argument are based on the rules and premises applied in the construction of that argument.

Definition 12. Let A and B be two arguments. Then A *attacks* an argument B iff A *undercuts*, *rebuts* or *undermines* B, where:

- A *undercuts* B (on B') iff $\mathsf{Conc}(A) \in \overline{n(r)}$ for some $B' \in \mathsf{Sub}(B)$ such that B''s top rule r is defeasible;
- A *rebuts* B (on B') iff $\mathsf{Conc}(A) \in \overline{\phi}$ for some $B' \in \mathsf{Sub}(B)$ of the form $B_1'', \ldots, B_n'' \Rightarrow \phi$ and A *contrary-rebuts* B iff $\mathsf{Conc}(A)$ is a contrary of ϕ;
- A *undermines* B (on ϕ) iff $\mathsf{Conc}(A) \in \overline{\phi}$ for some $\phi \in \mathsf{Prem}(B) \setminus \mathcal{K}_n$ and A *contrary-undermines* B iff $\mathsf{Conc}(A)$ is a contrary of ϕ.

A structured argumentation framework (defined below in Definition 14) will come equipped with a preference ordering on the set of arguments, such that an argument A is considered weaker than an argument B when $A \preceq B$ and strictly weaker when $A \preceq B$ but $B \npreceq A$, which is denoted by $A \prec B$. Several ways of how such an ordering can be determined are discussed in the literature, see e.g., for details the work by Modgil and Prakken (2013). This ordering influences which attacks are successful (i.e., which attacks will become *defeats*).

Definition 13. Let A and B be two arguments, such that A attacks B in B' as defined in Definition 12. Then A *defeats* B in B' iff A undercuts, contrary-rebuts or contrary-undermines B in B' or if $A \nprec B'$. It is said that A *strictly defeats* B if A defeats B but B does not defeat A.

Argumentation theories and their corresponding structured and Dung-style argumentation frameworks can now be defined.

Definition 14. An *argumentation theory* is a pair $\mathrm{AT} = \langle \mathrm{AS}, \mathcal{K} \rangle$, where AS is an argumentation system and $\mathcal{K}$ is a knowledge base.

A *structured argumentation framework* (SAF) defined by an argumentation theory AT is a triple $\mathrm{SAF} = \langle \mathsf{Args}, \mathsf{Att}, \preceq \rangle$ where Args is the set of arguments that can be constructed from AT, $(A, B) \in \mathsf{Att}$ iff $A, B \in \mathsf{Args}$ and A attacks B as defined in Definition 12 and $\preceq$ is a preference ordering on Args.

From a structured argumentation framework $\mathrm{SAF} = \langle \mathsf{Args}, \mathsf{Att}', \preceq \rangle$ the corresponding Dung-style abstract argumentation framework can be derived: $\mathcal{AF}(\mathrm{SAF}) = \langle \mathsf{Args}, \mathsf{Att} \rangle$, where $(A, B) \in \mathsf{Att}$ iff $(A, B) \in \mathsf{Att}'$ and A defeats B according to Definition 13.

Extension-based semantics, as in Definition 2, can be applied in the same way as they are applied to abstract argumentation frameworks. Like for abstract argumentation it can be determined which arguments are skeptically or credulously accepted. In addition, acceptance and non-acceptance can be defined for formulas:

Definition 15. Let $\mathcal{AF}(\mathrm{SAF}) = \langle \mathsf{Args}, \mathsf{Att} \rangle$ be an argumentation framework, based on some argumentation theory AT, let Sem be a semantics and suppose that $\mathsf{Sem}(\mathcal{AF}(\mathrm{SAF})) \neq \emptyset$ and let $\phi \in \mathcal{L}$. Then ϕ is:

- *Credulous accepted*: iff $\phi \in \bigcup \text{Concs}(\text{Sem}(\mathcal{AF}(\text{SAF})))$, that is: there is some Sem-extension with an argument A such that $\text{Conc}(A) = \phi$;
- *Skeptical accepted*: iff $\phi \in \bigcap \text{Concs}(\text{Sem}(\mathcal{AF}(\text{SAF})))$, that is: in each Sem-extension there is an argument with conclusion ϕ.

When arbitrary or clear from the context, we will write that the formula is accepted.

2.4 Defeasible Logic Programming

Defeasible Logic Programming (DeLP) merges formal argumentation with logic programming (García and G. R. Simari 2004), see also the surveys by García and G. R. Simari (2018, 2014). Definitions in this section are based on the overview by García and G. R. Simari (2018).

In DeLP, reasoning starts from a DeLP-program, where defeasibility is added by distinguishing between strict information (both facts and rules) and defeasible information. In DeLP acceptability is about conclusions being warranted, based on marked dialectical trees, constructed from acceptable argumentation lines. Intuitively, an acceptable argumentation line is a chain of arguments, where each argument is a counterargument to the previous argument. Since an argument might have several counterarguments, a dialectical tree of such argumentation lines ensures that all possible counterarguments are accounted for. A literal is then warranted if there is a dialectical tree for an argument for it, such that the argument is defended in it.

Definition 16. A *defeasible logic program* (or *DeLP-program*) is a pair (Π, Δ) where:

- Π is a finite set of facts and strict rules, where a fact is a ground literal (i.e., a literal without variables) and a strict rule consists of a head and body: $L_0 \leftarrow L_1, \ldots, L_n$ ($n > 0$), such that $L_0, \ldots, L_n$ are literals;
- Δ is a finite set of defeasible rules $L_0 \prec L_1, \ldots, L_n$ ($n > 0$), such that $L_0, \ldots, L_n$ are literals.

Two literals are *contradictory* when one is the complement of the other w.r.t. strong (classical) negation. Since Π contains strict, non-defeasible, information, it is assumed to be internally coherent. This means that no pair of contradictory literals can be derived from Π. By chaining rules, defeasible derivations can be constructed.

Definition 17. Given a DeLP-program (Π, Δ), a *defeasible derivation* of a literal L, denoted $(\Pi, \Delta) \mid\!\sim L$, is a finite sequence of ground literals $L_1, L_2, \ldots, L_n = L$ such that:

- L_i is a fact in Π, or
- there is a rule R_i in (Π, Δ) with head L_i and body $B_1, \ldots, B_k$ and every literal in the body is an element L_j of the sequence appearing before L_i (i.e., $j < i$).

A defeasible derivation of L is a *strict derivation* if $(\Pi, \emptyset) \mid\!\sim L$.

Arguments for a literal are based on defeasible derivations from Π and (a subset of) Δ.

Definition 18. Let (Π, Δ) be a DeLP-program, L a ground literal and $\mathcal{A} \subseteq \Delta$. Then $\langle \mathcal{A}, L \rangle$ is an *argument* for L if:

- $(\Pi, \mathcal{A}) \mid\!\sim L$, i.e., there is a defeasible derivation for L from $\Pi \cup \mathcal{A}$;
- there is no defeasible derivation from $\Pi \cup \mathcal{A}$ of contradictory literals; and
- $\mathcal{A}$ is minimal (w.r.t. $\subseteq$).

Two important types of arguments are sub-arguments and counter-arguments.

Definition 19. Given an argument $\langle \mathcal{A}_2, L_2 \rangle$, an argument $\langle \mathcal{A}_1, L_1 \rangle$ is a:

- *sub-argument* of $\langle \mathcal{A}_2, L_2 \rangle$ if $\mathcal{A}_1 \subseteq \mathcal{A}_2$;
- a *counter-argument* of argument $\langle \mathcal{A}_2, L_2 \rangle$ for literal P if there is a sub-argument $\left\langle \mathcal{A}_2', P \right\rangle$ of $\langle \mathcal{A}_2, L_2 \rangle$ such that there are two contradictory literals with strict derivations from $\Pi \cup \{L_1, P\}$. Here P is called the *counter-argument point* and $\left\langle \mathcal{A}_2', P \right\rangle$ is the *disagreement sub-argument*.

Defeats between arguments are defined w.r.t. an argument comparison criterion (denoted by $\succ$). For the purpose of this section, it is not necessary to make this criterion explicit. In DeLP a distinction is made between two types of defeaters: proper defeaters and blocking defeaters:

Definition 20. Let $\langle \mathcal{A}_2, L_2 \rangle$ be a counterargument for $\langle \mathcal{A}_1, L_1 \rangle$ at point P and let $\left\langle \mathcal{A}'_2, P \right\rangle$ be the disagreement sub-argument. Moreover, let $\succ$ be a preference criterion. Then:

- if $\langle \mathcal{A}_2, L_2 \rangle \succ \left\langle \mathcal{A}'_2, P \right\rangle$ then $\langle \mathcal{A}_2, L_2 \rangle$ is a *proper defeater* for $\langle \mathcal{A}_1, L_1 \rangle$;
- if $\langle \mathcal{A}_2, L_2 \rangle$ is unrelated by the preference relation to $\left\langle \mathcal{A}'_2, P \right\rangle$, then $\langle \mathcal{A}_2, L_2 \rangle$ is a *blocking defeater* for $\langle \mathcal{A}_1, L_1 \rangle$.

It is said that $\langle \mathcal{A}_2, L_2 \rangle$ is a *defeater* for $\langle \mathcal{A}_1, L_1 \rangle$ if $\langle \mathcal{A}_2, L_2 \rangle$ is either a proper or a blocking defeater for $\langle \mathcal{A}_1, L_1 \rangle$.

In order to define when a literal is warranted (Definition 24 below) some further notions are needed. We start with an argumentation line, from which supporting and interfering arguments can be derived.

Definition 21. An *argumentation line* for $\langle \mathcal{A}_1, L_1 \rangle$ is a sequence of arguments, $\Lambda = [\langle \mathcal{A}_1, L_1 \rangle, \ldots, \langle \mathcal{A}_n, L_n \rangle]$, where each element of the sequence $\langle \mathcal{A}_i, L_i \rangle$, $1 < i \leq n$ is a defeater of its predecessor $\langle \mathcal{A}_{i-1}, L_{i-1} \rangle$.

The set of *supporting* (resp. *interfering*) arguments in an argumentation line $\Lambda = [\langle \mathcal{A}_1, L_1 \rangle, \ldots, \langle \mathcal{A}_n, L_n \rangle]$ are $\langle \mathcal{A}_1, L_1 \rangle$ (resp. $\langle \mathcal{A}_2, L_2 \rangle$) and the arguments $\langle \mathcal{A}_i, L_i \rangle$ for which i is odd (resp. even): $\Lambda_S = [\langle \mathcal{A}_1, L_1 \rangle, \langle \mathcal{A}_3, L_3 \rangle, \langle \mathcal{A}_5, L_5 \rangle, \ldots]$ (resp. $\Lambda_I = [\langle \mathcal{A}_2, L_2 \rangle, \langle \mathcal{A}_4, L_4 \rangle, \ldots]$). The set of arguments $\{\langle \mathcal{A}_i, L_i \rangle\}_{i=1}^n$ is *concordant* iff it is not possible to derive two contradictory literals from $\Pi \cup \bigcup_{i=1}^n \mathcal{A}_i$. These notions are needed to determine whether and argumentation line is acceptable:

Definition 22. An argumentation line $\Lambda = [\langle \mathcal{A}_1, L_1 \rangle, \ldots, \langle \mathcal{A}_n, L_n \rangle]$ is *acceptable* iff:

(1) Λ is a finite sequence;
(2) The set Λ_S of supporting (resp. Λ_I of interfering) arguments is concordant;
(3) No argument $\langle \mathcal{A}_k, L_k \rangle$ in Λ is a disagreement sub-argument of an argument $\langle \mathcal{A}_i, L_i \rangle$ appearing earlier in Λ ($i < k$);
(4) For all i such that $\langle \mathcal{A}_i, L_i \rangle$ is a blocking defeater for $\langle \mathcal{A}_{i-1}, L_{i-1} \rangle$ if $\langle \mathcal{A}_{i+1}, L_{i+1} \rangle$ exists, then $\langle \mathcal{A}_{i+1}, L_{i+1} \rangle$ is a proper defeater for $\langle \mathcal{A}_i, L_i \rangle$.

To determine whether an argument is defeated, one acceptable argumentation line might not be sufficient, for example because one argument might be defeated by several arguments. Therefore, dialectical trees are used:

Definition 23. Let $\langle \mathcal{A}_1, L_1 \rangle$ be an argument from a DeLP-program (Π, Δ), a *dialectical tree* for $\langle \mathcal{A}_1, L_1 \rangle$ is:

- The root of the tree is labeled with $\langle \mathcal{A}_1, L_1 \rangle$;
- Let N be a non-root node labeled $\langle \mathcal{A}_n, L_n \rangle$ and $[\langle \mathcal{A}_1, L_1 \rangle, \ldots, \langle \mathcal{A}_n, L_n \rangle]$ be the sequence of labels of the path from the root to N. Let $\{\langle \mathcal{B}_1, Q_1 \rangle, \ldots, \langle \mathcal{B}_k, Q_k \rangle\}$ be the set of all defeaters for $\langle \mathcal{A}_1, L_1 \rangle$. For each defeater $\langle \mathcal{B}_i, Q_i \rangle$ $(1 \leq i \leq k)$, such that the argumentation line $\Lambda' = [\langle \mathcal{A}_1, L_1 \rangle, \ldots, \langle \mathcal{A}_n, L_n \rangle, \langle \mathcal{B}_i, Q_i \rangle]$ is acceptable, the node N has a child N_i labeled $\langle \mathcal{B}_i, Q_i \rangle$. If there is no defeater for $\langle \mathcal{A}_n, L_n \rangle$ or there is no $\langle \mathcal{B}_i, Q_i \rangle$ such that Λ' is acceptable, then N is a leaf.

Given an dialectical tree $\mathcal{T}$ a *marked dialectical tree* $\mathcal{T}^\star$ is obtained by marking every node in $\mathcal{T}$:

- each leaf of $\mathcal{T}$ is marked as U;
- an inner node N of $\mathcal{T}$ is marked as D iff N has at least a child marked as U, otherwise it is marked as U.

Finally, the notion of a warranted literal can be defined:

Definition 24. Let (Π, Δ) be a DeLP-program, L a ground literal and $\langle \mathcal{A}, L \rangle$ an argument from (Π, Δ) and $\mathcal{T}^\star$ a marked dialectical tree for $\langle \mathcal{A}, L \rangle$. Literal L is warranted from (Π, Δ) iff the root of $\mathcal{T}^\star$ is marked U.

2.5 Logic-Based Argumentation

Logic-based or deductive argumentation was introduced by Besnard and Hunter (2001, 2008), see also the surveys by Besnard and Hunter (2018, 2014).

Starting from a base logic, arguments are constructed based on the available formulas and the consequence relation of the logic. The base logic can be classical logic, another logic, or a set of general constraints a logic should satisfy, such as transitivity and monotonicity. Attacks between arguments are defined if the conclusion of one argument conflicts with parts of the other argument. From arguments and their counterarguments argumentation frameworks can be constructed (recall Definition 1), from which conclusions are drawn. Like in the abstract setting, such conclusion can be drawn with extension-based semantics. Now, however, these conclusions can also be formulated in terms of formulas.

Definition 25. A *logic* is a pair $\mathsf{L} = \langle \mathcal{L}, \vdash \rangle$ where $\mathcal{L}$ is a language and $\vdash$ is its consequence relation.

A common choice for a logic is classical logic, but other logics can also be chosen. Moreover, often there are only some minimal assumptions placed on the logic, for example that the consequence relation is Tarskian (i.e., it is reflexive, transitive and monotonic) (Tarski 1956). From a logic arguments are derived:

Definition 26. Given a logic $\mathsf{L} = \langle \mathcal{L}, \vdash \rangle$, a *deductive argument* is a pair $\langle \Phi, \phi \rangle$ such that $\Phi \vdash \phi$. It is said that $\Phi \subseteq \mathcal{L}$ is the support of the argument and $\phi \in \mathcal{L}$ its conclusion.

An argument $\langle \Phi, \phi \rangle$ can be assumed to be consistent (i.e., $\Phi \nvdash \bot$) or minimal (i.e., there is no $\Phi' \subset \Phi$ such that $\Phi' \vdash \phi$), but this is not always necessary. Conflicts between arguments are determined based on contradictions between the conclusion of one argument and the support or conclusion of another argument. For example, in classical logic:

Definition 27. Let $\mathsf{CL} = \langle \mathcal{L}, \vdash_{\mathsf{CL}} \rangle$ be classical logic and $A = \langle \Phi, \phi \rangle$ and $B = \langle \Psi, \psi \rangle$ two arguments. Then A *attacks* B if, for example:

- A is a *classical defeater* of B: $\phi \vdash_{\mathsf{CL}} \neg \bigwedge \Psi$;
- A is a *classical undercut* of B: if there is some $\Psi' \subseteq \Psi$ such that $\phi \equiv_{\mathsf{CL}} \neg \bigwedge \Psi'$;
- A is a *classical rebuttal* of B: if $\phi \equiv_{\mathsf{CL}} \neg\psi$.

Abstract argumentation frameworks (Definition 1) can be drawn from deductive arguments and the attacks between them. Note that these frameworks can be infinite.

Definition 28. Let $\mathsf{L} = \langle \mathcal{L}, \vdash \rangle$ be a logic and let $\Delta \subseteq \mathcal{L}$ be a knowledge base. Then an *exhaustive graph* is a pair $\mathcal{AF}(\Delta) = \langle \mathsf{Args}(\Delta), \mathsf{Att}(\Delta) \rangle$ where:

- $\mathsf{Args}(\Delta) = \{\langle \Phi, \phi \rangle \mid \Phi \subseteq \Delta \text{ and } \langle \Phi, \phi \rangle \text{ is an argument}\}$; and
- $\mathsf{Att}(\Delta) = \{(A, B) \mid A, B \in \mathsf{Args}(\Delta) \text{ and } A \text{ attacks } B\}$.

Argumentative reasoning can now be done as in the abstract case. Note that semantics, for example those from Definition 2, can be applied, from which conclusions can be drawn. These conclusions can be about arguments that are accepted (recall Definition 3), or about formulas:

Definition 29. Let $\mathsf{L} = \langle \mathcal{L}, \vdash \rangle$ be a logic, $\Delta \subseteq \mathcal{L}$ and let $\phi \in \mathcal{L}$ be a formula. Then ϕ is:

- *skeptically accepted* if for each $\mathsf{S} \in \mathsf{Sem}(\mathcal{AF}(\Delta))$, there is some $A \in \mathsf{S}$ such that ϕ is the conclusion of A;
- *credulously accepted* if for some $\mathsf{S} \in \mathsf{Sem}(\mathcal{AF}(\Delta))$, there is some $A \in \mathsf{S}$ such that ϕ is the conclusion of A.

In what follows, we will refer to the above four approaches as well as their variants as *structured approaches to argumentation*. Moreover, we will sometimes write about the *elements from which an argumentation setting is constructed*. By this we mean, for example, the ABA framework, the argumentation theory in ASPIC$^+$, a DeLP-program and the knowledge base and choice of attack relation in logic-based argumentation.

3 Dynamics in Abstract Argumentation

As argumentation is an inherent dynamic process, it is not surprising that dynamics in formal argumentation has been studied for quite some time. A variety of ways in which argumentation might be dynamic has been considered, ranging from updating the different components of an argumentation framework and reaching a certain goal to reasoning with incomplete information and the relation to belief revision.

Given that the focus of this survey is on the structured account of argumentation, it is not our goal to be exhaustive in this section. Rather, we introduce the various notions of dynamics of abstract argumentation and the questions that are investigated, including pointers to the literature for the interested reader. First, we look at changes to the argumentation setting (Section 3.1), with which the research area started. Then we will overview some solutions to the inherent computational complexity of dynamics (Section 3.2). We discuss goal-based changes, such as enforcement and forgetting, in Section 3.3 and reasoning with incomplete and uncertain information in Section 3.4. Work on the intersection of belief revision and abstract argumentation is covered in Section 3.5. A more detailed overview is provided by Doutre and Mailly (2018).

Note that it is hard to make a proper distinction between categories. For example, when does a change become goal-oriented or when is the work more on belief revision operators than on enforcement? In such cases, we have placed the work in the section where it best fitted, also based on other works discussed in that section.

3.1 Changes to the Argumentation Setting

The study of dynamics of argumentation started in the abstract setting, asking questions such as: what happens to an argument, an extension or the whole argumentation framework, when an argument or an attack is added or removed? We start this section with work on this general question, then we consider *equivalence* and the notion of *expansions*.

Adding and removing arguments and attacks. Much of the work on dynamic argumentation, especially on the addition and removal of an argument or attack, can be traced back to Cayrol, Dupin de Saint-Cyr, et al. (2008), which was later extended to the addition (Cayrol, Dupin de Saint-Cyr, et al. 2010) and removal (Bisquert, Cayrol, Dupin de Saint-Cyr, and Lagasquie-Schiex 2011) of an argument and the combined study (Bisquert, Cayrol, Dupin de Saint-Cyr, and Lagasquie-Schiex 2013a, 2012). Moreover, change in bipolar argumentation frameworks has been studied (Cayrol and Lagasquie-Schiex 2015).

The work by Bisquert, Cayrol, Dupin de Saint-Cyr, and Lagasquie-Schiex (2011) and Cayrol, Dupin de Saint-Cyr, et al. (2010) was further extended to argument-based decision systems by Amgoud and Vesic (2010). Change to AFs is related to abduction by Booth, Gabbay, et al. (2014), where abductive AFs are introduced to change a framework into one in which a desired set of arguments is supported (i.e., one of the arguments in that set is accepted).

Rather than studying a specific argument or the effects of an update on the whole argumentation framework, updating an argumentation framework without changing the set of accepted arguments is investigated for the removal of an attack or argument by Boella, Kaci, et al. (2009b) and the addition of an argument by Boella, Kaci, et al. (2009a). This idea can be further explored in terms of robustness. For example, the question of how many changes an AF can handle before the extensions of a framework change is studied by Bistarelli, Santini, et al. (2018) and a tool to visualize this is provided by Bistarelli, Faloci, et al. (2018). A principle-based approach to robustness is taken by Rienstra et al. (2020), where robustness of both labelings and extensions under various semantics is defined as that the labeling/acceptability of two arguments does not change after an attack is added or removed between those arguments.

Recently, attack removal monotonicity for several extension-based semantics was explored (Amgoud and Vesic 2020). Moreover, the addition and removal of arguments for both admissibility-based and naivity-based[1] semantics were studied (Baumann and Ulbricht 2021). One of their main goals is to understand the influence of attackers and supporters on the acceptability of (sets of) arguments.

Equivalence. In knowledge representation and reasoning the notion of equivalence is an important one. In, for example, classical logic, equivalence between formulas can be decided if nothing changes when a subformula is replaced by an equivalent one. Unfortunately, in non-monotonic reasoning this is less straightforward (Baumann and Strass 2022). Yet, in our argumentation setting, equivalence can help to understand the dynamic process when receiving new information. To this end strong equivalence was introduced for abstract argumentation frameworks (Oikarinen and Woltran 2011). Let $\mathcal{AF} = \langle \mathsf{Args}, \mathsf{Att} \rangle$ and $\mathcal{AF}' = \langle \mathsf{Args}', \mathsf{Att}' \rangle$ be two argumentation frameworks, then $\mathcal{AF} \cup \mathcal{AF}' = \langle \mathsf{Args} \cup \mathsf{Args}', \mathsf{Att} \cup \mathsf{Att}' \rangle$.

Definition 30 (Strong Equivalence (Oikarinen and Woltran 2011))**.** Two AFs $\mathcal{AF}_1$ and $\mathcal{AF}_2$ are *strongly equivalent* to each other w.r.t. a semantics Sem iff for each AF $\mathcal{AF}_3$ $\mathsf{Sem}(\mathcal{AF}_1 \cup \mathcal{AF}_3) = \mathsf{Sem}(\mathcal{AF}_2 \cup \mathcal{AF}_3)$ holds.

Strong equivalence has subsequently been studied for labeling semantics (Baumann 2016), argumentation frameworks with collective attacks (Dvorák, Rapberger, et al. 2020) and for claim-augmented argumentation frameworks (Baumann, Rapberger, et al. 2023) and ABA (Rapberger and Ulbricht 2023) (see Section 4.1.1). The notion has been further generalized by Baumann, Dvorák, et al. (2019). Moreover, equivalence of expansions introduced by Baumann and Brewka (2010) has been considered.

Definition 31 (Expansions (Baumann and Brewka 2010))**.** Let $\mathcal{AF} = \langle \mathsf{Args}, \mathsf{Att} \rangle$ be an AF, an AF $\mathcal{AF}^\star$ is an *expansion* of $\mathcal{AF}$ iff $\mathcal{AF}^\star = \left\langle \mathsf{Args} \cup \mathsf{Args}^\star, \mathsf{Att} \cup \mathsf{Att}^\star \right\rangle$, such that $\mathsf{Args}^\star \neq \emptyset$ and $\mathsf{Args} \cap \mathsf{Args}^\star = \emptyset$. An expansion is:

- *normal* if there are no new attacks between existing arguments (i.e., for all arguments $A, B \in \mathsf{Args} \cup \mathsf{Args}^\star$, if $(A, B) \in \mathsf{Att}^\star$ then $A \in \mathsf{Args}^\star$ or $B \in \mathsf{Args}^\star$);
- *strong* if it is normal and new arguments are not attacked by existing arguments (i.e., for all arguments $A, B \in \mathsf{Args} \cup \mathsf{Args}^\star$, if $(A, B) \in \mathsf{Att}^\star$ then it is not the case that $A \in \mathsf{Args}$ and $B \in \mathsf{Args}^\star$);
- *weak* if it is normal and existing arguments are not attacked by new arguments (i.e., for all arguments $A, B \in \mathsf{Args} \cup \mathsf{Args}^\star$, if $(A, B) \in \mathsf{Att}^\star$ then it is not the case that $A \in \mathsf{Args}^\star$ and $B \in \mathsf{Args}$).

The first study on equivalence of expansions was done by Baumann (2012b), which has been further extended (Baumann 2012a). Baumann (2014) studies the equivalence of updates and deletions, related to expansions.

Thus, in a dynamic environment it is essential to understand how (the relation among) elements of a setting and changes to these elements influence the conclusions that can be drawn. Only when understanding this can we aim to create efficient ways to handle dynamics and achieve goals.

3.2 Computational Complexity

When a setting is changed conclusions usually have to be recalculated. This can become computationally expensive very quickly. It is therefore important to ask: how difficult is it to compute the results of a change to the argumentation setting? When a change takes place, should all the calculations be done again or can we: limit the recalculations to just a part of the argumentation setting; or can we rely on previous calculations? These questions are considered by a variety of approaches that improve the recalculation effort in a dynamic setting.

[1]Under naïve semantics, an extension is a $\subseteq$-maximal conflict-free set.

Computational complexity. The parameterized complexity of three reasoning tasks in dynamic abstract argumentation are studied by Kim et al. (2013): Sem-Repair (can a set of arguments become an extension, in at most k elementary changes?); Sem-Adjust (can an extension be modified such that it contains a desired argument, in at most k elementary changes?); and Sem-Center (given two Sem-extensions, with distance k, is there a Sem-extension that has at most $k-1$ distance to both extensions?).

A computational study of the first two of these problems is provided by Lehtonen, Niskanen, et al. (2018), in which both an iterative SAT-based approach as well as a more direct approach via a MaxSAT solver are explored. Extensive empirical evaluation shows that generally speaking, the MaxSAT approach is more effective, though there are cases when the iterative SAT-based approach performs well.

In general, reasoning tasks in abstract argumentation can be computationally hard, see also the overview by Dvorák and Dunne (2018). Therefore, recomputing the acceptability status of each argument and/or the extensions for a given semantics with each change might not be feasible, especially if the size of the AF increases. To this end several proposals have been made to efficiently recompute a status in a dynamic setting.

Division-based method. A division-based method is proposed by Liao et al. (2011) and then generalized by Baroni, Giacomin, and Liao (2014). The idea is to divide an abstract argumentation framework into three components after an addition/removal: a set of affected arguments; a set of unaffected arguments; and a subset of the unaffected arguments that conditions the affected arguments. The complexity of recomputing extensions after modification can be simplified if the chosen semantics satisfies some topology-related properties, i.e., directionality (Baroni and Giacomin 2007) and, in the generalization (Baroni, Giacomin, and Liao 2014), SCC-recursiveness (Baroni, Giacomin, and Guida 2005).

Splitting. A method to split an argumentation framework, related to weak expansions (Definition 31), and calculate the extensions of that framework is presented by Baumann (2011). Calculating the extensions of an AF can then be split between the two frameworks, again relying on the directionality property (Baroni and Giacomin 2007).

Incremental computation. The idea of an incremental approach to recompute extensions in a dynamic argumentation setting was introduced by Greco and Parisi (2016a,b, 2017) for single extension semantics. This was then generalized to multiple extension semantics (Alfano, Greco, and Parisi 2017), skeptical preferred acceptance (Alfano and Greco 2021; Alfano, Greco, and Parisi 2019), extended argumentation frameworks (Alfano, Greco, and Parisi 2018b) and a structured approach to argumentation (Alfano, Greco, Parisi, G. I. Simari, et al. 2018). See also the overview by Alfano, Greco, Parisi, G. I. Simari, et al. (2021b).

Consider the case of calculating a single extension after an update (i.e., adding or removing an attack). Given an AF $\mathcal{AF}_0$, a Sem-extension $\mathcal{E}$ and an update u. First, the influenced set of $\mathcal{AF}_0$ is determined. Intuitively, this set contains the arguments whose status might have changed after the update. If this set is empty, then the update is irrelevant and $\mathcal{E}$ is also an extension of the updated AF. Second, based on the influenced set, the reduced argumentation framework is calculated. This reduced AF contains the framework induced by the influenced set as well as other nodes and edges. Third, an extension of the reduced framework can be obtained by calling a solver for the static case. Fourth, based on the extension of the reduced framework, an extension for the updated AF can be calculated.

Experimental results show that this approach significantly improves approaches where the most efficient algorithms for static AFs are applied after each update (Alfano, Greco, and Parisi 2018a, 2019, 2017). Moreover, it can be modified to apply to structured approaches to argumentation as well, see Section 4.2.

Another incremental approach for reasoning tasks in dynamic AFs, this time SAT-based, is introduced by Niskanen and Järvisalo (2020a). For a dynamic setting in which a sequence of modifications to the attack relation is applied and complete, preferred, stable and grounded semantics, four reasoning tasks are implemented: credulous and skeptical acceptance, computation of a single extension and enumeration of all extensions.

Thus, the computational complexity of reasoning tasks in formal argumentation is a challenge, especially in a dynamic setting. By only selectively recomputing the conclusions of the argumentation setting, significant improvements can be obtained and dynamic argumentation becomes feasible for real-world applications.

The importance of efficient recomputation in a dynamic setting is also recognized by the International Competition on Computational Models of Argumentation,[2] where recent editions have had a dedicated dynamic track.

3.3 Goal-Based Changes

The addition or removal of information or arguments does not have to be arbitrary, but can be tailored toward a certain goal. Questions of interest are then: can an argumentation framework be modified to ensure that a desired set of arguments becomes an extension? Is it possible to forget about a certain argument or set of arguments and if so, how? Can an argumentation framework with no conclusions be repaired to derive something meaningful? These are the types of questions related to *enforcement*, *forgetting* and *repairing* in argumentation.

Enforcement. The notion of *enforcement* was introduced by Baumann and Brewka (2010) for extensions and three types of expansions of abstract argumentation frameworks were introduced (recall Definition 31).

Definition 32 (Enforcement (Baumann and Brewka 2010))**.** Let $\mathcal{AF} = \langle \mathsf{Args}, \mathsf{Att} \rangle$ be an AF, Sem a semantics and let $\mathsf{S} \subseteq \mathsf{Args}$ be a set of arguments such that $\mathsf{S} \notin \mathsf{Sem}(\mathcal{AF})$. An $(\mathcal{AF}, \mathit{Sem})$-*enforcement* of S is a pair $(\mathcal{AF}^*, \mathsf{Sem}^*)$ such that (i) $\mathcal{AF}^* = \mathcal{AF}$ or $\mathcal{AF}^*$ is a normal expansion of $\mathcal{AF}$ and (ii) $\mathsf{S} \in \mathsf{Sem}^*(\mathcal{AF}^*)$.

This notion has subsequently been studied extensively, see also the recent overview by Baumann, Doutre, et al. (2021). Baumann (2012b) studies the effort needed to enforce a set of arguments in terms of minimal change, related to belief revision. Local updates, i.e., argument-fixed enforcement, where the set of arguments remains the same and the attack relation is modified, is studied by Coste-Marquis et al. (2015). Kontarinis et al. (2013) modify the set of attacks as well, in order to reach a certain goal in a debate, by determining sets of successful moves. The work on minimal change is extended by Doutre and Mailly (2017), in which a unified framework for studying the modification of AFs is provided and the effects of changing the semantics are studied. In addition to a set of arguments that should be accepted (i.e., positively enforced), a set of arguments that should not be accepted (i.e., negatively enforced) is added to the enforcement problem (Niskanen, Wallner, et al. 2016), the computational complexity is determined and algorithms are provided.

Rather than restricting the enforcement setting, constraints can be defined to specify, e.g., the allowed modifications. For example, Doutre and Perrussel (2013) study three types of constraints, see also the overview by Doutre and Mailly (2018). Moreover, families of structural constraints on ADFs are introduced by Wallner (2020) and these are applied to adapt an enforcement operator to ADFs as well as a structured approach to argumentation (see Section 4.3).

Recently, preference-based extension enforcement was introduced (Hung and Huynh 2025), where preferences are used to determine what attacks can be removed in order to enforce a set of arguments. Rather than PAFs, revealed preference argumentation (Hung and Huynh 2023, 2021) is applied, as this makes the results instantiation-proof. Moreover, an extensive investigation on the necessary and sufficient conditions of enforcement for a variety of settings has been done (H. Zhang and S. Zhang 2025).

The computational complexity of (extension) enforcement has been studied and a variety of approaches to efficient algorithms have been considered. For example, Coste-Marquis et al. (2015) consider minimal enforcement by

[2] https://argumentationcompetition.org.

local updates via pseudo Boolean optimization, this work is extended by Wallner et al. (2017) in which algorithms are provided for enforcement problems in different complexity classes and Niskanen, Wallner, et al. (2018) propose three types of algorithms for enforcement under grounded semantics, a semantics not considered by Wallner et al. (2017). Further improvements for the more complex problems, i.e., those exceeding NP-completeness, are achieved via SAT-based counterexample-guided abstraction refinement algorithms by Niskanen and Järvisalo (2020c).

Forgetting. With enforcement there is a set of arguments that should be accepted; the opposite operation has also been studied. First, removing an extension was studied by Baumann and Brewka (2019). Related to AGM contraction (see also Section 3.5), extension removal is about (minimally) adjusting the AF to ensure that the extension no longer occurs.

Forgetting, that is, removing some information to reach a desired result, is a well-known concept in knowledge representation and reasoning (Eiter and Kern-Isberner 2019; Gonçalves et al. 2016) and related to AGM contraction (Alchourrón et al. 1985; Rodrigues et al. 2011). In abstract argumentation, forgetting is studied by Baumann and Berthold (2022), Baumann, Berthold, et al. (2025), and Baumann, Gabbay, et al. (2020). Forgetting in argumentation can be:

- *syntactical*, where the arguments are removed from the argumentation framework;
- *semantical*, where the acceptance of the arguments is considered, often resulting in constraints on the acceptability of arguments that are not forgotten;

or mixed. This is reflected by the various types of desiderata, 25 in total, that are proposed (Baumann, Berthold, et al. 2025).

Repairing. Although argumentation is designed to reason with conflicting or incomplete information, sometimes no conclusion can be drawn at all. For example, because no extension exists (e.g., stable semantics) or only the empty extension is available (e.g., grounded and preferred semantics). This semantical collapse has been studied in knowledge representation and reasoning since at least the work by Reiter (1987). Intuitively, two questions are asked: given an inconsistent setting

- *diagnosis*: what parts of the setting cause (and therefore explain) the inconsistency?
- *repair*: how to adjust the setting to make it consistent?

These are the questions studied by Baumann and Ulbricht (2018) and Ulbricht and Baumann (2019) for abstract argumentation, both credulous and skeptical reasoning and various extension-based semantics. Especially the existence of and finding a (minimal) diagnosis is investigated. Such a diagnosis can be argument-based or attack-based, where removing the identified arguments (respectively, attacks) results in a consistent setting. Repairs under grounded semantics are especially of interest, since these are computationally less hard to compute and these can be used to construct repairs for other semantics.

Niskanen and Järvisalo (2020b) investigate the computational complexity of smallest diagnoses and, by showing a correspondence with minimal correction sets (Marques-Silva et al. 2013), efficient SAT-based algorithms are provided. Specifically for stable semantics, it is shown how adding an argument can repair an AF (Takahashi and Miwa 2023). Moreover, three types of optimal repairs are proposed for inconsistent prioritized knowledge bases by Bienvenu and Bourgaux (2020), it is then shown how these are related to (preference-based or set-based) argumentation frameworks.

Thus, research on goal-based changes, in particular enforcement, has been especially fruitful. This is not surprising, as reaching a goal, e.g., persuading another agent, can be a central objective in argumentation-based applications. These works therefore strengthen formal argumentation as a suitable approach for real-world applications.

3.4 Incomplete or Uncertain Information

Whether in a static or dynamic setting, not all information is always complete or entirely certain. In a dynamic setting questions related to this uncertainty are: what information can we include in the argumentation setting and what information is uncertain? What information might become available or might be discarded in the future? How can a goal be reached by manipulating information that an agent has control over? These questions are studied in *incomplete argumentation frameworks*, with notions of *stability* and *relevance*, and in *control argumentation frameworks*. In this section we also consider *resolutions* and *probabilistic argumentation*.

Incompleteness and uncertainty play an important role in argumentation and formal argumentation research (Hunter, Polberg, et al. 2021; Mailly 2022). Not every interpretation, however, is related to dynamics. In this section, as well as in Section 4.4, we focus on the dynamic interpretations of uncertain information.

Incomplete Argumentation Frameworks. Initially introduced as partial argumentation frameworks (Cayrol, Devred, et al. 2007), in incomplete argumentation frameworks (Baumeister, Järvisalo, et al. 2021; Baumeister, Neugebauer, et al. 2018) there are two disjoint sets of arguments and two disjoint sets of attacks: a definite part and an uncertain part. Intuitively, the definite part is an abstract framework as in Definition 1, while it is not known what elements of the uncertain part are part of the argumentation setting, if any.

Definition 33 (Incomplete argumentation frameworks (Baumeister, Järvisalo, et al. 2021; Baumeister, Neugebauer, et al. 2018))**.** An *incomplete argumentation framework* (IAF) is a quadruple $\mathcal{IAF} = \langle \mathsf{Args}, \mathsf{Args}^?, \mathsf{Att}, \mathsf{Att}^? \rangle$, where:

- Args is the set of definite arguments and $\mathsf{Args}^?$ is the set of uncertain arguments such that $\mathsf{Args} \cap \mathsf{Args}^? = \emptyset$; and
- Att is the set of conditionally definite attacks and $\mathsf{Att}^?$ is the set of uncertain attacks such that $\mathsf{Att} \cap \mathsf{Att}^? = \emptyset$.

Note that an attack in Att is only definite if both the attacking and the attacked argument are definite. Elements can be moved from the uncertain part to the definite part or they can be removed entirely by means of a *completion* (Baumeister, Järvisalo, et al. 2021; Baumeister, Neugebauer, et al. 2018) or *partial completion* (Odekerken, Borg, et al. 2024, 2022). A completion is an AF derived from an IAF by resolving all uncertainties (i.e., $\mathsf{Args}^? = \mathsf{Att}^? = \emptyset$). A partial completion is an IAF derived from an IAF by resolving some uncertainties, while others remain.

Incomplete argumentation frameworks do not inherently model dynamics. For example, they can represent one agents' model about the knowledge/beliefs of another agent (Mailly 2022), relating this work to persuasion and strategic argumentation (Thimm 2014). A dynamic interpretation is that by, e.g., Odekerken, Borg, et al. (2024), where the uncertain parts represent information that can be added in the future. Under this interpretation stability and relevance are of interest, see below.

IAFs were generalized to bipolar settings (Fazzinga et al. 2023; Lagasquie-Schiex et al. 2024), higher-order settings (Doutre, Lagasquie-Schiex, et al. 2025) and IAFs with set attack (Lewin and Skiba 2025). Their semantics and computational complexity were extensively studied (Alfano, Greco, Parisi, and Trubitsyna 2022; Mailly 2024a, 2023, 2024b) and notions of explanations (Alfano, Calautti, et al. 2023) and plausibility (Mailly 2025) have been introduced.

Stability and relevance. Interestingly, unlike many other notions of dynamics, the notion of stability was first introduced in a structured setting (see Section 4.4). Stability was introduced for IAFs by Mailly and Rossit (2020) and further studied by Odekerken, Borg, et al. (2024, 2022). The notion of relevance extends this line of work and was directly introduced for IAFs (Odekerken, Borg, et al. 2022). Intuitively, given an $\mathcal{IAF} = \langle \mathsf{Args}, \mathsf{Args}^?, \mathsf{Att}, \mathsf{Att}^? \rangle$:

- $A \in \mathsf{Args}$ is *stable* in $\mathcal{IAF}$ if the acceptability status of A does not change anymore for any partial completion;

- $U \in \mathsf{Args}^? \cup \mathsf{Att}^?$ is *relevant* for $A \in \mathsf{Args}$ if there is some partial completion in which U is added to the definite part or removed from $\mathcal{IAF}$ altogether, such that A becomes stable.

ASP-based algorithms for finding relevant updates were proposed by Odekerken (2024). Moreover, the notions were generalized to extensions and sets of arguments (Xiong, H. Zhang, et al. 2024; Xiong and S. Zhang 2025b) and the interdependence of possible relevant elements was studied by Xiong and S. Zhang (2025a).

Control Argumentation Frameworks. Closely related to IAFs are control argumentation frameworks (CAFs), introduced by Dimopoulos et al. (2018). Such a framework consists of three parts: a fixed part to reason about the static environment; an uncertain part, similar to the uncertain parts in an IAF and that the agent has no control over; and the control part, that the agent controls and that can help the agent reach certain goals. The control part makes CAFs inherently dynamic.

Definition 34 (Control argumentation frameworks (Dimopoulos et al. 2018))**.** A *control argumentation framework* (CAF) is a triple $\mathcal{CAF} = \langle \mathcal{AF}, \mathcal{C}, \mathcal{U} \rangle$ where:

- $\mathcal{AF} = \left\langle \mathsf{Args}_F, \mathsf{Att}_F \right\rangle$, the fixed part, with $\mathsf{Att}_F \subseteq (\mathsf{Args}_F \cup \mathsf{Args}_U) \times (\mathsf{Args}_F \cup \mathsf{Args}_U)$;
- $\mathcal{C} = \left\langle \mathsf{Args}_C, \mathsf{Att}_C \right\rangle$, the control part, with $\mathsf{Att}_C \subseteq (\mathsf{Args}_C \times (\mathsf{Args}_F \cup \mathsf{Args}_C \cup \mathsf{Args}_U)) \cup ((\mathsf{Args}_F \cup \mathsf{Args}_C \cup \mathsf{Args}_U) \times \mathsf{Args}_C)$; and
- $\mathcal{U} = \left\langle \mathsf{Args}_U, \mathsf{Att}_U \cup \mathsf{Att}_U^{\leftrightarrow} \right\rangle$ the uncertain part, with $\mathsf{Att}_U, \mathsf{Att}_U^{\leftrightarrow} \subseteq (\mathsf{Args}_F \cup \mathsf{Args}_U) \times (\mathsf{Args}_F \cup \mathsf{Args}_U)$ and $\mathsf{Att}_U^{\leftrightarrow}$ is symmetric and irreflexive.

The sets Args_F, Args_C and Args_U are pairwise disjoint sets of arguments and Att_F, Att_C, Att_U, $\mathsf{Att}_U^{\leftrightarrow}$ are pairwise disjoint sets of attacks.

Thus, in addition to uncertainty about arguments and attacks, in CAFs there can also be uncertainty about the direction of an attack. The work on CAFs, specifically the problem of controllability, is related to enforcement (Section 3.3): find a subset of Args_C such that a desired set of fixed arguments becomes accepted in every completion. This requirement was relaxed by Mailly (2020), where it is now required that the desired set is accepted in at least one completion.

Computational complexity results as well as a QBF-based method for computing controllability are provided (Dimopoulos et al. 2018; Mailly 2020). Moreover, although the uncertain part of the framework is more specific and expressive in CAFs than in IAFs, complexity results obtained for IAFs can be utilized for the complexity analysis of and algorithms for CAFs (Baumeister, Järvisalo, et al. 2021), specifically the controllability problem. This is done by Niskanen, Neugebauer, et al. (2020), where the computational complexity study is expanded, the QBF-based method (Dimopoulos et al. 2018) is improved and SAT-based counterexample-guided abstraction refinement procedures are introduced. Neugebauer et al. (2021) introduce and study the nonempty existence problem for CAFs.

Control AFs have been applied to negotiation (Dimopoulos et al. 2021, 2019). Moreover, a probability distribution to the uncertain part is added in probabilistic CAFs (Gaignier et al. 2021). By considering probabilities, a distinction between different controllability configurations and completions can be made.

A generalized view on qualitative uncertainty and dynamics in abstract argumentation is taken by Yuste-Ginel and Herzig (2023). Where DL-PA (Dynamic Logic of Propositional Assignment (Balbiani et al. 2013)) is employed to encode IAFs and several of its extensions, to study uncertainty, as well as control AFs, to combine both uncertainty and dynamics. It is shown that the reasoning tasks typically studied with (extensions of) IAFs and CAFs can be captured with DL-PA, which also allows to use DL-PA model checkers, rather than the usual SAT-based approach, to decide those tasks.

Resolutions. Uncertainty can also be present in the preference relation among arguments. Given two arguments A and B that attack each other, preferences can help to decide between them. When argument A is preferred over argument B, then the attack from B to A cannot be successful and can therefore be removed. A *resolution* of an argumentation framework is then a framework such that of all the mutual attacks exactly one remains (Baroni and Giacomin 2005; Modgil 2006). A framework can have more than one resolution and preferences among arguments will influence the arguments that are accepted. Resolutions have since been integrated in the principles with which extension-based semantics are studied (Baroni and Giacomin 2007; van der Torre and Vesic 2018).

Probabilistic argumentation. So far, in this section, the focus was on qualitative uncertainty. In the literature, many approaches to probabilistic argumentation exist as well. Like with IAFs, not every interpretation is essentially dynamic. Uncertainty can, for example, be about ambiguity, completing enthymemes or believe in an argument, it can say something about the acceptance of the argument or its presence in the AF, see also the survey by Hunter, Polberg, et al. (2021). Probabilistic argumentation is applied in a dynamic context in persuasion dialogues. Specifically, to model the persuadee's beliefs, which helps to determine what arguments to put forward. In the work by Hunter (2016), possible counterarguments are presented to the persuadee, that will inform the persuader's next arguments. Moreover, a variety of operators to update the model of the persuadee are presented and studied (Hunter 2015; Hunter and Potyka 2017).

Thus, although one of the strengths of formal argumentation is its ability to handle uncertainty, the works in this section make the incompleteness and uncertainty explicit, in dynamic settings. Since incomplete and uncertain information is inherent to real-world settings, understanding this perspective on dynamics is crucial.

3.5 Belief Revision

An important research area in knowledge representation and reasoning is *belief revision* and *belief update* (Alchourrón et al. 1985; Katsuno and Mendelzon 1991; Rodrigues et al. 2011). Questions studied within this area and relevant for this survey are: when presented with new information, how to revise or update a knowledge base or set of beliefs? How can the change be kept to a minimum, while ensuring consistency? Are there further constraints, such as from the environment or known preferences?

Both belief revision and argumentation have a long history on their own, as well as together (Falappa, García, Kern-Isberner, et al. 2011), see also the overview by Falappa, Kern-Isberner, et al. (2009). In this section we recall some of the work on belief revision for dynamics in abstract argumentation.

Logic-based approach. Belief change operators are usually defined in terms of a propositional language. By translating AFs and their semantics into propositional formulas (Besnard and Doutre 2004), postulates (Alchourrón et al. 1985; Katsuno and Mendelzon 1991) can be used to study dynamics in abstract AFs. For example, minimal change revision operators are defined for skeptically accepted arguments (Coste-Marquis et al. 2014a) and for extensions (Coste-Marquis et al. 2014b). This work is further developed in the context of enforcement (Coste-Marquis et al. 2015; Doutre, Herzig, et al. 2014; Doutre, Maffre, et al. 2017; Dupin de Saint-Cyr et al. 2016), see below. The revision result as presented by Coste-Marquis et al. (2014b) is not necessarily represented by a single AF, this problem is tackled by considering two types of revision: revision-by-formula (a propositional formula encodes the set of extensions representing the change) and revision-by-AF (another framework provides the basis for the change) (Diller et al. 2018). The same problem is the motivation for the introduction of constrained IAFs (Mailly 2024a), which allow to express the uncertainty of a revision in a single framework.

Another logic-based approach is taken by Baumann and Brewka (2015) and Baumann and Linker (2019), in which Dung-logics are introduced to study AGM-style revision (Alchourrón et al. 1985) in abstract argumentation. These are a family of monotonic logics which formalize reasoning on the level of abstract AFs and for which ordinary and strong equivalence coincide. The existence of expansion and revision operators satisfying rephrased AGM postulates is shown (Baumann and Brewka 2015). The logics are further applied to study contraction (Baumann and Linker 2019). Interestingly, no such contraction operator exists in Dung-logics, since attacks might have to be removed, when arguments are removed.

AGM-style revision operators for ADFs were first characterized by Linsbichler and Woltran (2016), for preferred semantics. Moreover, revision by formulas for ADFs and all major semantics is studied (Heyninck et al. 2023). A distinction is made between bivalent (e.g., stable) and trivalent (e.g., complete, preferred and grounded) semantics, postulates for revision operators are provided and, where possible, revision operators are characterized.

Related to enforcement. Belief update is related to enforcement (recall Section 3.3) in various works. For example enforcement is extended to allow for incomplete information about the initial AF and the AF should satisfy a specified goal after the update (Bisquert, Cayrol, Dupin de Saint-Cyr, and Lagasquie-Schiex 2013b). Enforcement is then encoded in a propositional formula, which allows to enforce any goal that can be represented in a formula and it is not needed to know the whole AF beforehand. Postulates introduced by Katsuno and Mendelzon (1991) are reformulated to this specific setting. This work is further extended, where more properties and a more complete language are considered (Dupin de Saint-Cyr et al. 2016). Where Bisquert, Cayrol, Dupin de Saint-Cyr, and Lagasquie-Schiex (2013b) consider elementary operators, inspired by Cayrol, Dupin de Saint-Cyr, et al. (2010), these are refined (Dupin de Saint-Cyr et al. 2016).

Doutre, Herzig, et al. (2014) encode argumentation frameworks in DL-PA. Local updates (i.e., changing the attack relation) and modifications of the extensions of a framework are modeled. Moreover, both credulous and skeptical enforcement are studied. Then, the possibility to add or remove arguments is included as well (Doutre, Maffre, et al. 2017).

Enforcement is related to propositional belief revision by Haret et al. (2018). Enforcement is axiomatized and, specifically, enforcement w.r.t. admissibility is studied. It is then shown how these axioms correspond to those by Katsuno and Mendelzon (1991).

Related to repairs. A change to an AF can render the AF inconsistent: nothing can be derived from it. This is also a problem in belief revision. Therefore, Nouioua and Würbel (2014) introduce a revision operator which guarantees the existence of a stable extension.

Similarly, after an update, the beliefs of an agent can become inconsistent, for example because an update requires an argument to be `out` even though there is no attacker of it that is `in`. In order to still be able to derive some conclusions, it is shown that an AF can always be expanded to restore coherence and fallback believes are introduced by Booth, Kaci, et al. (2013).

Thus, utilizing belief revision and belief update operators to model dynamics in abstract argumentation allows to capture various perspectives on dynamics, including the representation of changes and goal-based changes. The extensive research on belief revision (Rodrigues et al. 2011) helps to advance the understanding of dynamic argumentation.

It is important to note that belief revision and formal argumentation are valuable, complementary approaches within the knowledge representation and reasoning community. By studying argumentation and belief change, their connection to other non-monotonic reasoning approaches can become clearer as well (Heyninck et al. 2023). Moreover, while incorporating one into the other is interesting, the most benefit might be realized by considering both as primary approaches (Baroni, Fermé, et al. 2022).

4 Dynamics of Structured Approaches to Argumentation

Historically, many problems and notions have first been studied for abstract accounts, before they have been considered for structured accounts. This is also the case with dynamics. In contrast to the previous section, here we will go into more detail about the works that we survey. We provide a little motivation, emphasize some specific features and/or results and highlight some observations especially relevant for the topic of this survey.

Given the similarities of the considered dynamic perspectives, in this section we follow the structure of the previous section. We start by work in which the change to the argumentation setting is central (Section 4.1) as well as work on efficient recomputation (Section 4.2). Then we consider goal-based changes (Section 4.3) and incomplete and uncertain information (Section 4.4). We conclude with work in which argumentation is combined with belief revision approaches (Section 4.5).

4.1 Changes to the Argumentation Setting

Most work on dynamics of structured approaches to argumentation concern a specific question, such as on equivalence, enforcement or belief change. There are, however, a few works that specifically aim to understand and improve the changes to an argumentation setting. Moreover, we also consider work on *(strong) equivalence* in this section.

Dynamic Argumentation Frameworks. In a dynamic setting, it might not be whole arguments or attacks that are added or removed, but rather the set of information or evidence that is updated. As a refinement to abstract argumentation frameworks, dynamic argumentation frameworks were introduced by Rotstein, Moguillansky, García, et al. (2008), in which dynamics is modeled by expanding or contracting the set of evidence, making arguments active or inactive.

Definition 35 (Dynamic argumentation frameworks (Rotstein, Moguillansky, García, et al. 2008))**.** A *dynamic argumentation framework* (DAF) is a pair $\langle \mathcal{E}, (\mathcal{U}, \mathcal{R}) \rangle$, where $\mathcal{E}$ is a set of evidence and $(\mathcal{U}, \mathcal{R})$ is a framework, where $\mathcal{U}$ is the set of universal arguments and $\mathcal{R} \subseteq \mathcal{U} \times \mathcal{U}$ is the attack relation between these arguments.

Arguments in a DAF have a claim and a support, where the latter is a set of premises, either from the set of evidence, or claims of other arguments. Active arguments are those arguments for which each premise is a claim of another active argument, or part of the set of evidence. By varying the set of evidence, static instances of DAFs are created, where the arguments are the active arguments, which can be constructed from the set of evidence.

This work was further extended (Rotstein, Moguillansky, García, et al. 2010), where a preference function over argumental structures is added and defeats are defined taking into account this function. Change can take place at several levels: evidence, but also arguments, conflicts and preferences. DAFs are the basis of Argument Theory Change (see Section 4.5.1). Moreover, they were used to study dynamics in a multi-agent setting (Thimm and García 2010), where argumentation games among a group of agents are characterized by using the dynamic structured approach to argumentation.

4.1.1 *Equivalence.*

Recall from Section 3.1 that strong equivalence (Oikarinen and Woltran 2011) is a dynamic variant of equivalence in which the extensions of two argumentation frameworks are not only equivalent but they remain equivalent when both AFs are expanded with a third framework. In structured approaches to argumentation, the structure of the arguments should be taken into account, since this determines the content of the extensions and the allowed expansions.

In logic-based argumentation. Strong equivalence as introduced for abstract argumentation (Oikarinen and Woltran 2011) is syntax dependent: they rely on the structure of the argumentation graph and therefore do not take the structure of the arguments into account. Even translating the abstract equivalence notions to a structured account proves insufficient. Therefore, new equivalence criteria are introduced for logic-based argumentation by Amgoud, Besnard, et al. (2014), based on the equivalence of (sets of) formulas. These criteria are based on the logical equivalence of the formulas in the knowledge base, the support of an argument and/or its conclusion.

By defining the core of a framework, equivalent, finite subsystems are constructed. It is then shown under what circumstances, based on the core, information is not lost when the knowledge base is expanded or contracted. The introduced criteria, as well as expansions (Baumann and Brewka 2010), have been further studied for argumentation settings based on logic programs (Nieves 2016).

In claim-augmented argumentation frameworks. In the abstract setting, equivalence is based on arguments: when all the extensions contain the same arguments, the frameworks are equivalent. It might, however, be that reasoning is based on the conclusions of the arguments and that there is more than one argument for a certain conclusion. Claim-augmented argumentation frameworks (Dvorák and Woltran 2020) assign to each argument a claim. As such, this approach lies between abstract argumentation and the various structured approaches.[3]

Definition 36 (Claim-augmented argumentation frameworks (Dvorák and Woltran 2020))**.** A *claim-augmented argumentation framework* (ClAF) is a triple $Cl\mathcal{AF} = \langle \mathsf{Args}, \mathsf{Att}, \mathsf{Cl} \rangle$, where the pair $\langle \mathsf{Args}, \mathsf{Att} \rangle$ is an AF and $\mathsf{Cl} : \mathsf{Args} \to C$ assigns to each argument in Args a claim from C.

It is said that a ClAF is *well-formed* if arguments with the same claim attack the same arguments.

Both ordinary and strong equivalence are studied, for both general and well-formed ClAFs (Baumann, Rapberger, et al. 2023). On the argument level, equivalence characterizations of strong equivalence are based on kernels known from the literature, as well as a new kernel for specific forms of stable and stage semantics. On the claim level, renaming is introduced. This allows to change the names of arguments arbitrarily, without changing the meaning of the ClAF. Then ordinary and strong equivalence up to renaming are defined and characterized. Generally, equivalence for ClAFs is one level harder than for AFs, up to the third level of the polynomial hierarchy. For strong equivalence and for well-formed ClAFs, however, tractable results are obtained.

In assumption-based argumentation. Although ClAFs allow for the study of equivalence on the claim-level, these are sometimes still too abstract for certain (dynamic) purposes (Rapberger and Ulbricht 2023, Example 9.3). In particular, two frameworks might seem equivalent on the claim-level, but the arguments involved might not be equally vulnerable to attacks, e.g., in one framework a claim might be based on a fact, while in the other framework the claim is defeasible. To overcome this, strong equivalence for ABA is studied by Rapberger and Ulbricht (2023).

Expansions in ABA are restricted by how the knowledge base can be expanded and therefore by what arguments and attacks can be added. As a result, deciding strong equivalence for ABA is coNP-hard. Therefore, claim and vulnerability augmented argumentation frameworks (cvAFs) are introduced. In cvAFs each argument is associated with a claim (like in ClAFs) as well as a set of vulnerabilities: the weaknesses of the argument, in which it could potentially be attacked.

Definition 37 (Claim and vulnerability augmented AFs (Rapberger and Ulbricht 2023))**.** Let $\mathcal{L}$ be a set of sentences. An *instantiated argument* is a pair $A = \langle \mathsf{vul}(a), \mathsf{cl}(a) \rangle$ where $\mathsf{vul}(a) \subseteq \mathcal{L}$ are the vulnerabilities of A and $\mathsf{cl}(a) \in \mathcal{L}$ is its conclusion.

A *claim and vulnerability augmented argumentation framework* (cvAF) is a pair $\mathrm{cv}\mathcal{AF} = \left\langle \mathsf{Args}_i, \mathsf{Att} \right\rangle$ where Args_i is a set of instantiated arguments and $\mathsf{Att} \subseteq \mathsf{Args}_i \times \mathsf{Args}_i$.

For cvAFs strong equivalence is studied, by introducing semantics-dependent kernels which modify the set of arguments, rather than the set of attacks as usual in the literature. It is then shown that deciding strong equivalence for cvAFs is tractable for the various semantics. Moreover, based on cvAFs, a fragment of ABA for which deciding strong equivalence is tractable is determined.

[3] Dvorák and Woltran (2020) introduced claim-augmented argumentation frameworks using the abbreviation CAF. Since this abbreviation was used for control argumentation frameworks (recall Definition 34) we use the abbreviation ClAF instead.

Thus, deciding strong equivalence in structured approaches to argumentation should not be based on the structure of the framework, but rather on the structure of the arguments. In particular, the conclusions of the arguments should be considered, as well as in which way the argumentation setting can be expanded.

4.2 Computational Complexity

Approaches to improve the efficiency of recomputation in abstract argumentation generally rely on the structure of the graph and the reachability of arguments, recall Section 3.2. In structured approaches to argumentation, updates might not be arguments or attacks, but formulas or rules. As a result, the structure of the arguments changes and solutions for abstract argumentation might not be immediately applicable.

In DeLP. A multi-agent setting is, inherently, a dynamic environment. Agents need to incorporate information from observations or perceptions and recompute their beliefs, possibly in real time. In order for agents to deal with such an environment, Observation-based DeLP (O-DeLP) is introduced (Capobianco, Chesñevar, et al. 2005) and further developed into Observation-based Possibilistic DeLP (OP-DeLP) (Capobianco and G. R. Simari 2009). Based on DeLP, an O-DeLP-program is a pair (Π, Δ), where Π is now a set of observations or perceptions, representing the information that an agent has. In an OP-DeLP program, the literals have a weight representing the certainty. A literal L is believed, if it is warranted.

Dialectical databases are introduced to simplify updates of the agents' beliefs. In these data structures, pre-compiled potential arguments, i.e., dialectical trees based only on the defeasible rules from an agent's O(P)-DeLP program, and the defeats between them are stored. When the set of observations of an agent is updated, it can be determined which pre-compiled arguments are applicable.

Incremental computation. Updates in DeLP can be the addition or removal of one or several strict or defeasible rules. The computational complexity of deciding whether there is an argument for a given literal and its status (both are on the second level of the polynomial hierarchy), calls for an efficient method of (re)computing the status of literals after an update. To this end, the idea of the incremental approach from (Alfano, Greco, Parisi, G. I. Simari, et al. 2021b) is applied to DeLP (Alfano, Greco, Parisi, G. I. Simari, et al. 2018, 2021a). The intuition of the incremental approach is similar to that of the abstract case, relying on relevant updated and influenced sets, but now hypergraphs derived from a DeLP-program are needed to deal with the structure of the arguments.

Thus, updates, such as new observations, require recomputation, which is a challenge especially in structured approaches to argumentation. In order to employ ideas used in abstract argumentation a notion of reachability is needed, which could be captured with hypergraphs. Another possible solution is to store potential arguments, based only on defeasible rules, which can be used when the required information is available.

4.3 Goal-Based Changes

In the abstract setting we covered three types of goal-based changes explicitly. These are also relevant for the structured setting. But the questions might be slightly different. For example, where enforcement was about arguments or sets of arguments becoming acceptable after a change to the argumentation setting, now this will be about formulas or sets of formulas which can also be assumptions or literals. We cover enforcement (Section 4.3.1), forgetting (Section 4.3.2) and repairs (Section 4.3.3).

4.3.1 *Enforcement.*

Recall, from Section 3.3, that enforcement in abstract argumentation is about adding arguments or attacks to the framework or adjusting the semantics, such that a desired (set of) argument(s) becomes acceptable. But, in structured approaches to argumentation such operations are not possible. Therefore, enforcement becomes about adjusting the knowledge base.

In a general argumentation setting. Enforcement operators in abstract argumentation do not take the structure of the arguments into account and might, therefore, overlook their interdependencies. With this in mind and, in addition to providing an enforcement operator for ADFs, an enforcement operator for a general structured approach to argumentation is introduced by Wallner (2020). The proposed structured enforcement operator gives an argumentation framework $\mathcal{AF}^\star = \langle \mathsf{Args}^\star, \mathsf{Att}^\star \rangle$ such that the desired set of arguments, constructed from a knowledge base, is part of a Sem-extension and the number of modified attacks is minimized. It is shown that $\mathsf{Args}^\star$ is constructed from the knowledge base; all arguments that can be constructed from the elements from which $\mathsf{Args}^\star$ are derived are also contained in $\mathsf{Args}^\star$ and $\mathsf{Att}^\star$ contains all the attacks between the arguments in $\mathsf{Args}^\star$. Computational complexity results are provided.

Similarly, adding one specific argument or attack is often not possible in a structured setting, as the knowledge base has to be adjusted and this might influence more than one argument. Therefore, in a structured setting, enforcement should be about (sets of) formulas rather than about (sets of) arguments. For the general setting of Borg and Straßer (2018), various conditions for the enforcement of sets of formulas are discussed by Borg and Bex (2021), such as the acceptance strategy and the consistency of the set of formulas which needs to be enforced. Results are based on the well-known correspondence between argumentation and maximally consistent subsets (Arieli, Borg, and Heyninck 2019) as well as notions of relevance from abstract argumentation (Caminada, Carnielli, et al. 2011).

In assumption-based argumentation. Like in abstract argumentation (recall Section 3.3) enforcement in structured approaches to argumentation can be studied by means of expansions of the argumentation setting. Enforcement of arguments and conclusions in ABA should, however, be based on expansions of the set of rules and the set of assumptions of the ABA framework. Constructing new arguments or attacks in ABA is constrained by the requirements of ABA. Therefore, enforcement in ABA is NP-hard and thus intractable (Rapberger and Ulbricht 2023).

Like for strong equivalence, claim and vulnerability augmented AFs (Definition 37) are introduced to identify a fragment of ABA in which enforcement is tractable (Rapberger and Ulbricht 2023). To this end, enforcement of (sets of) claims and arguments, where a desired (set of) claim(s) respectively (set of) argument(s) becomes credulous accepted after expanding the cvAF is defined and characterized. It is then shown that enforcement of a claim or argument in cvAFs is tractable for most semantics, but not for grounded semantics and enforcing sets of claims or arguments is NP-hard.

In ASPIC$^+$. Expansions (Baumann and Brewka 2010) make assumptions on what arguments or attacks can be added to the framework. For example, that all arguments can be attacked, that all attacks can be deleted, or that it is possible to add a single, specific argument or attack (Prakken 2023). Therefore, a refinement of expansions is introduced (Prakken 2022), where expansions are relative to a universal argumentation framework and expansions can be allowed or not.

Prakken (2024a, 2023) instantiates the abstract framework for expansions for ASPIC$^+$ and defines allowed expansions. Moreover, in addition to expanding the argumentation theory, it is also shown how an expansion with a set of arguments can be created. An extensive study on the implicit assumptions made in the abstract case is provided, showing that the complexity of the introduced structured account to argumentation is indeed needed.

Thus, when studying enforcement in a structured approach to argumentation the interdependencies between arguments need to be taken into account. It then becomes clear that enforcement should not be about arguments, but about formulas, since too much information is lost when abstracting away from the structure of the arguments and the nature of the attacks. The complexity of structured approaches to argumentation are needed to properly model expansions.

4.3.2 Forgetting. In abstract argumentation, forgetting can be syntactical or semantical (Baumann, Berthold, et al. 2025), recall Section 3.3, where arguments are removed from the framework, while keeping the change to the acceptability of the remaining arguments to a minimum. Two desiderata from the literature on forgetting in knowledge representation and reasoning that are extensively investigated are:

- *persistence*, that what needs to be forgotten is removed, without influencing the resulting conclusions; and
- *elimination*, that what needs to be forgotten is removed, together with the extensions in which it occurs.

Elimination was originally introduced in the context of abstract argumentation.

Forgetting in abstract argumentation was mostly about arguments. But, like in the case for enforcement, in the structured setting, simply removing an argument is generally not possible. Therefore, forgetting becomes about knowledge base elements, such as assumptions, formulas and rules.

In assumption-based argumentation. In the ABA setting assumptions, their contraries and atoms can be forgotten, rather than whole arguments or attacks between them, as is the case in the abstract setting. Forgetting different aspects of a *flat* ABA framework was first studied by Berthold, Rapberger, et al. (2023). For each type of forgetting, corresponding persistence and elimination desiderata are introduced and where possible tractable forgetting operators satisfying these desiderata are defined. It is shown that it is not always possible to define tractable forgetting operators, but that is intentional (Berthold, Rapberger, et al. 2023). It shows what can maximally be expected of an operator.

In both abstract argumentation and flat ABA, it is easier to define an operator that satisfies elimination, than it is to define one that satisfies persistence. This is also the case when it is no longer required that the ABA framework is flat (Berthold and Ulbricht 2024). But, persistence can be satisfied for complete semantics when no longer requiring that the framework after forgetting is flat. To show this, the correspondence between ABA and bipolar SETAFs (BSAFs) (Berthold, Rapberger, et al. 2024) is utilized. In the translation between ABA and BSAFs only arguments that are assumptions are kept. Therefore, forgetting in the work by Berthold and Ulbricht (2024) is about assumption forgetting.

In ASPIC$^+$. In ASPIC$^+$, forgetting can be done on any of the elements of an argumentation theory. Abderrazik and Doder (2025) study forgetting a formula and consider four desiderata. Two (formula deletion and argument persistence) are somewhat related to elimination and are reasonably easy to satisfy. The other two (conclusion steadiness and justification persistence) are related to persistence and are harder to satisfy. An operator is introduced which adjusts the set of rules, similar to the replace operator by Berthold, Rapberger, et al. (2023), as well as the naming function and makes only minor assumptions on the argumentation theory. It is shown that this operator satisfies all four desiderata.

Thus, forgetting in structured approaches to argumentation is not about arguments or attacks, but about formulas, assumptions, contraries or atoms and the elements of the framework are adjusted. Like in abstract argumentation, defining operators that satisfy elimination-like desiderata is reasonably easy, but defining operators that satisfy persistence-like desiderata is harder.

4.3.3 Repairing. When nothing can be concluded from a knowledge-based setting, a repair can help to draw conclusions. In the abstract setting (recall Section 3.3), diagnoses consisted of (sets of) arguments or attacks. In the structured case, repair is needed when no formulas (e.g., in ASPIC$^+$) or assumptions (e.g., in ABA) can be accepted. Moreover, rather than sets of arguments or attacks, a diagnosis could be a formula, assumption or rule.

In assumption-based argumentation. In an ABA setting, removing a single rule or assumption can result in a bigger modification of the corresponding AF than intended. Therefore, applying repairing operators from the abstract argumentation literature is not possible in ABA. In order to study repairing an ABA setting, six desiderata are proposed (Rapberger and Ulbricht 2024), including on the tractability of the operators, its effectiveness and persistence of derivations and conclusions. Three operators to repair are proposed: one which removes a set of assumptions, a second which, similarly, removes a set of rules and a third which turns rules defeasible. It is shown that each operator satisfies the desiderata, under minor assumptions. However, when requiring a minimal repair, the problem is no longer tractable, except for grounded semantics.

Thus, repairing settings of structured approaches to argumentation cannot be based on existing operators for abstract argumentation, as this would result in unnecessary big modifications of the setting. Instead, repairs should take place on the level of the elements of the structured setting (e.g., formulas and rules).

4.4 Incomplete and Uncertain Information

Incompleteness and uncertainty in dynamic abstract argumentation is modeled by distinguishing between certain and uncertain arguments and attacks (recall Section 3.4). In structured approaches to argumentation these arguments and attacks are constructed from knowledge (e.g., assumptions or premises) and rules (e.g., strict and defeasible rules or a (Tarskian) logic). Therefore, the incompleteness and uncertainty takes place on that level.

Stability and relevance. To ensure efficiency of inquiry dialogues (Walton and Krabbe 1995), one needs to know when new information will no longer change the conclusion (i.e, stability) or what questions to ask, in order to reach stability (i.e., relevance). To this end, stability was introduced in a variant of ASPIC$^+$ by Testerink et al. (2019) and further studied by Odekerken, Bex, et al. (2022) and Odekerken, Borg, et al. (2020). The choice for a variant of ASPIC$^+$ is based on the envisioned application: modeling inquiry dialogues for the Netherlands Police, the setting of which is easier to capture with a structured approach to argumentation. In addition to the usual language, contradiction function, set of rules and knowledge base, a set of queryables $\mathcal{Q}$ is introduced, such that $\mathcal{K} \subseteq \mathcal{Q} \subseteq \mathcal{L}$. These queryables can be added to the knowledge base during the inquiry. The result is an incomplete ASPIC$^+$ setting (Odekerken, Lehtonen, Borg, et al. 2023) and dynamics is represented with future argumentation theories.

Definition 38 (Future argumentation theories (Odekerken, Bex, et al. 2022))**.** A set of *future argumentation theories* ($F_{\mathcal{Q}}(\mathrm{AT})$) of an argumentation theory $\mathrm{AT} = (\mathrm{AS}, \mathcal{K})$ given a set of queryables consists of all argumentation theories $\mathrm{AT}' = (\mathrm{AS}, \mathcal{K}')$ with $\mathcal{K} \subseteq \mathcal{K}' \subseteq \mathcal{Q}$.

A conclusion is stable when the status is the same in all future argumentation theories. A queryable is relevant for a conclusion, when that conclusion is not yet stable and adding that queryable to the knowledge base can make the conclusion stable in a future argumentation theory (Odekerken, Lehtonen, Borg, et al. 2023). For grounded semantics stability is coNP-complete (Odekerken, Bex, et al. 2022) and relevance is Σ^2-complete (Odekerken, Lehtonen, Borg, et al. 2023). Further complexity results are provided (Odekerken, Lehtonen, Wallner, et al. 2025), including for more general ASPIC$^+$ settings.

Efficient algorithms. Given that stability and relevance are intractable problems (Odekerken, Bex, et al. 2022; Odekerken, Lehtonen, Borg, et al. 2023), various ways to improve feasibility of their computation have been investigated. Odekerken, Bex, et al. (2022) provide an approximation algorithm for stability for the variant of ASPIC$^+$ of their paper. Then, for grounded semantics, but with preferences, exact ASP-based algorithms for stability and relevance were introduced (Odekerken, Lehtonen, Borg, et al. 2023). These were further improved (Odekerken, Lehtonen, Wallner, et al. 2025), for example, all possible relevant queryables can be determined at once. The algorithms are empirically evaluated on real-world and synthetic data. It is shown that, although the problems are computationally hard, the efficiency of the ASP-based algorithms makes real-world applications feasible.

Instantiating IAFs. Baumeister, Järvisalo, et al. (2021) suggest several ways in which the elements of a structured argumentation setting can result in an IAF. IAFs can, however, be too abstract, resulting in similar problems as encountered with AFs (Prakken 2023; Prakken and Winter 2018). Therefore, the uncertainty is placed on the elements of the setting by Proietti and Yuste-Ginel (2025) and Yuste-Ginel and Proietti (2023). First, argument-incomplete abstract argumentation framework with dependencies are introduced. Where, in addition to the usual elements of an IAF (recall Definition 33), a set of dependencies between arguments is introduced. Second, rule-incomplete and premise-incomplete structured argumentation frameworks are introduced in the ASPIC$^+$ setting. Where the set of rules in an argumentation system, respectively the knowledge base are expanded with an uncertain part. The latter are based on work by Odekerken, Lehtonen, Borg, et al. (2023) and Odekerken, Lehtonen, Wallner, et al. (2025). It is then shown how the abstract and structured accounts can be compared and their relative expressivity is studied.

Resolutions. Mutual conflicts between arguments might be resolved with a preference relation in abstract argumentation, recall Section 3.4. But, simply applying a preference relation is not necessarily straightforward. For example, preferences might also be applicable to asymmetric attacks or to both attacks in a symmetric attack, it might not always be possible to resolve a conflict with a preference relation or adding preferences might have additional consequences. Therefore, resolutions should be studied with a structured approach to argumentation, where the structure of the arguments and the nature of the attacks is clear (Modgil and Prakken 2012).

To this end, ASPIC$^+$ is utilized by Modgil and Prakken (2012). To overcome the limiting assumptions from the abstract case, preference extensions of structured argumentation frameworks are defined, where the preference relation is expanded. If this results in a smaller set of defeats, it is a preference-based resolution. It is shown that, compared to resolutions as defined in abstract argumentation, the applied resolutions in ASPIC$^+$ correspond better to the (im)possibilities given the structure of the arguments and the attacks between them.

Enthymemes. So far, in Section 3.4 and in this section, the incompleteness was part of the argumentation setting from which arguments and the attacks between them are constructed. But, in human argumentation, arguments themselves are often incomplete. For example, they rely on common knowledge or are not sufficiently precise. Such arguments are called enthymemes. For a deductive argument $\langle \Phi, \phi \rangle$, referred to as real arguments by Hunter (2007), it is assumed that $\Phi \vdash \phi$ (Definition 26). An approximate argument is a pair $\langle \Phi, \phi \rangle$ without any constraints. Given a deductive argument $\langle \Phi, \phi \rangle$ an enthymeme for this argument is an approximate argument $\langle \Psi, \phi \rangle$ such that $\Psi \subset \Phi$ (Hunter 2007).

The challenge with enthymemes is to determine what information is missing in order to be able to reason with them. There are various ways in which arguments can be encoded into enthymemes and enthymemes can again be decoded. Usually, it is assumed that premises need to be added in order to complete the argument, by means of abduction (Black and Hunter 2012; Hunter 2007). Recently, decoding by removing information from the enthymeme was proposed (Ben-Naim et al. 2025). Enthymemes for dialogues have extensively been studied for logic-based argumentation (Black and Hunter 2012; Dupin de Saint-Cyr 2011; Hunter 2022), but also for ASPIC$^+$ (Hosseini et al. 2014; Orbe Leiva, García, et al. 2025; Xydis, Hampson, et al. 2020; Xydis, Moraru, et al. 2024) and DeLP (Orbe Leiva, Gottifredi, et al. 2023).

Thus, when modeling dialogues with a structured approach to argumentation, the setting is often incomplete by nature. What information to add in order to draw conclusions and reason with the arguments is a challenge, from both the content and the computational point of view. Since a structured approach is suitable for real-world applications (Odekerken, Bex, et al. 2022), it is worthwhile to tackle this challenge.

4.5 Belief Revision and Argumentation

Belief revision has been employed to study dynamics of structured approaches on several levels. In this section, we start with Argument Theory Change, an abstract theory for dynamics, based on dynamic argumentation frameworks (Definition 35). Then we consider how belief revision notions have been applied to understand

(Section 4.5.2), model (Section 4.5.3) and enrich (Section 4.5.4) dynamics in argumentation. We finish with a short section on the use of structured approaches to argumentation for belief revision.

4.5.1 Argument Theory Change. Argument Theory Change (ATC) (Rotstein, Moguillansky, Falappa, et al. 2008) is an abstract theory to which notions from belief revision can be applied to integrate dynamics in formal argumentation. Based on dynamic argumentation frameworks (recall Section 4.1), various notions similar to those defined for DeLP are introduced (e.g., (acceptable) argumentation lines and dialectical trees), in order to determine whether an argument is warranted. Like in dynamic AFs, this setting is dynamic since arguments can be activated and deactivated. The goal of ATC is to revise an AF by an argument, resulting in that argument being warrant. ATC has been studied in a variety of ways.

Rotstein, Moguillansky, Falappa, et al. (2008) apply change to the existing theory by deactivating arguments. Revision is defined as AGM-style expansion and contraction (Alchourrón et al. 1985) and the focus is on minimal change contraction. A complementary approach is taken by Moguillansky, Rotstein, et al. (2010), in which arguments, specifically defeaters of defeaters of the considered argument, are activated in order to establish the desired revision.

Argument Theory Change has also been applied to DeLP (Moguillansky, Rotstein, et al. 2008). The goal is to insert an argument into a DeLP-program, which is warranted after the revision. Arguments that need to disappear are selected and an incision function is applied. Minimal change is considered based on two principles.

A full characterization of ATCs for logic-based argumentation is provided by Moguillansky, Wassermann, et al. (2012). In such a setting, arguments cannot simply be removed, rather, the knowledge base needs to be adjusted. As a result, both the dynamics of knowledge bases and of AFs are studied. Unlike in classical belief revision approaches, by applying argumentation, it is not required that the knowledge base is consistent after the revision.

The dynamics of knowledge bases without consistency requirements is further explored, now in the context of DeLP (Moguillansky, Rotstein, et al. 2013), developing the work by Moguillansky, Rotstein, et al. (2008) further. Like the work by Rotstein, Moguillansky, Falappa, et al. (2008), the change is established by deactivation, this time by removing rules from the DeLP-program. Several forms of minimal change are considered, based on what arguments or rules are altered or the effect on other arguments.

Thus, the abstract theory of ATC provides a rich basis for the study of dynamics in argumentation, which is sufficiently general that it can be applied to abstract argumentation and various structured approaches to argumentation. By combining argumentation and belief revision the revision of knowledge bases without consistency requirements can be investigated.

4.5.2 Belief Revision to Understand Dynamics in Argumentation. Reasoning in argumentation is about the acceptability of arguments or their conclusions. In a dynamic setting, it is therefore essential to understand how the interplay between arguments influences the acceptability of these arguments.

In ASPIC⁺. To model revision and contraction in ASPIC⁺, *Argument Revision* is introduced (Snaith and Reed 2016). With this, revision is applied to arguments and their acceptability, rather than sets of beliefs. The proposed operator allows for all possible ways in which an argumentation theory can be revised (i.e, a given set of arguments can be constructed and is accepted after the revision) or contracted (i.e., the given set of arguments is no longer accepted). With Argument Revision, belief revision can be applied to the richer structure of ASPIC⁺, allowing to change each of its elements in order to reach the desired result.

In logic-based argumentation. The dynamics of logic-based argumentation is extensively studied (Moguillansky and G. R. Simari 2016). Inspired by set theoretic Tarskian semantics, interpretation structures are defined to reason about acceptability dynamics in argumentation, specifically how a rejected argument can become accepted. Via admissible and core sets the acceptability of an argument is studied, while for non-accepted arguments rejecting and remainder sets are considered (Moguillansky 2016). A minimal change revision operator is defined to illustrate the introduced theory.

Thus, traditional belief revision and contraction could be applied to premises or rules from which arguments are constructed, but these might not necessarily result in the desired argument to become (non-)accepted. Therefore, in structured approaches to dynamic argumentation, revision should be aimed at the acceptability of the desired arguments or conclusions, rather than a specific revision of the elements from which the arguments and their conclusions are constructed.

4.5.3 Belief Revision to Model Dynamics in Argumentation. In general, the goal of belief revision is to establish a desired goal by (minimally) changing, revising or updating a set of information (e.g., a knowledge base). Since argumentation is also constructed from sets of information (e.g., arguments, assumptions, premises, rules), belief revision might be used to turn argumentation settings dynamic.

Explanations. In the belief revision literature, like in the argumentation literature, a distinction is made between prioritized revision, i.e., the new information is accepted after the revision and non-prioritized revision, i.e., the new information is not necessarily accepted (Hansson 1999). Falappa, Kern-Isberner, et al. (2002) introduce non-prioritized revision operators, based on the idea that an explanation is requested before new, inconsistent information is incorporated into the knowledge base. As an example, it is shown how this idea can be applied for DeLP, by revising what knowledge (i.e., the rules of a DeLP-program) is defeasible and what knowledge is strict, requiring minimal change.

Enthymemes. As the information from which the argumentation setting is constructed might be incomplete or uncertain, especially in real-world scenarios, mistakes in the derived arguments or attacks can happen. In order to deal with such mistakes it is essential to know what arguments and attacks are based on deductive arguments and which are based on enthymemes (recall Section 4.4). To this end, enthymeme-based AFs are introduced (Mailly 2016).

Definition 39 (Enthymeme-based argumentation frameworks (Mailly 2016))**.** An *enthymeme-based argumentation framework* is a pair $\mathcal{F}(D, E) = \langle \mathsf{Args}, \mathsf{Att} \rangle$ where:

- $\mathsf{Args} = D \cup E$, the set of arguments are the deductive arguments (D) and the enthymemes (E);
- $\mathsf{Att} = \mathsf{Att}_D \cup \mathsf{Att}_E$, where $\mathsf{Att}_D \subseteq D \times D$ are the certain attacks and $\mathsf{Att}_E \subseteq (\mathsf{Args} \times \mathsf{Args}) \setminus (D \times D)$ are the questionable attacks.

Handling new information in enthymeme-based AFs can be based on existing revision approaches to dynamics in abstract AFs, for example with the translation-based work of Coste-Marquis et al. (2014a). What is essential here, is that a distinction is made between the deductive arguments and the enthymemes, which also determine which attacks are certain or necessary and which can be questioned. To this end, first, an integrity constraint can be defined, to ensure that the attacks between the certain arguments are not modified. Then revision can take place, when new information is received, after which a choice has to be made which revised AF is the best, based on the knowledge base and enthymemes.

Logic. Reasoning in argumentation can be captured by default justification logic (Pandžić 2022a), where justification logic (Artemov 2001) is combined with default reasoning as known from Reiter (1980). Specifically, rebut and undercut attacks question defeasible reasoning steps, which can be represented in default justification logic. Undermining attacks, however, question the premises of an argument, by providing new, conflicting, information. In order to capture such attacks, the set of premises needs to be adjusted, which requires a dynamic setting. This is done by Pandžić (2022b), where default reasoning and belief revision are combined in a justification logic setting, to define a logic that captures the three types of attacks in structured approaches to argumentation.

Thus, in order to model dynamics of structured approaches to argumentation, existing work on belief revision can be applied. This allows to revise the setting (e.g., by allowing for more types of attacks) without changing too much (i.e., minimal change) or affecting undesirable elements of the argumentation setting (e.g., attacks between deductive arguments).

4.5.4 Belief Revision to Enrich Dynamics in Argumentation. As mentioned before, argumentation is an inherently dynamic process, new information becomes available and one way to deal with that might be to simply add it to the knowledge base. But, as it turns out, this does not always result in the desired outcome. Therefore, belief revision techniques can be applied to improve the results of a dynamic argumentation setting.

Inconsistent knowledge bases. In order to properly deal with inconsistent knowledge bases, a model needs to be able to represent contradictory and uncertain information, answer queries on a knowledge base, and handle revisions of the knowledge base. To this end DeLP3E is introduced (Shakarian et al. 2016), which combines a structured approach to argumentation with probability. Uncertainty, for example about evidence, is captured via probabilistic logic (Nilsson 1986) in an environmental model. Background knowledge is captured via DeLP with presumptions (Martinez et al. 2012) in an analytical model. An annotation function associates elements from the environmental model with elements from the analytical model.

A DeLP3E-program is a triple of an environmental model, an analytical model and an annotation function. Each of these might be inconsistent, in which case belief revision is employed. For belief revision applied to the analytical model and the annotation function postulates are determined and revision operators are defined and studied. This work was further extended by G. I. Simari et al. (2016). Moreover, it was shown how the unified probabilistic argumentation frameworks introduced by Alfano, Leiva, et al. (2025) can be instantiated by DeLP3E, as well as a probabilistic version of ABA.

Multi-agent persuasion. In order to persuade an agent to believe the conclusion of an argument it is not only necessary to put forward such an argument, but to put forward an argument that the agent is most likely to accept. To this end, logic-based argumentation is combined with belief revision (Boella, Costa Pereira, et al. 2008). In addition to a set of beliefs, modeled as an argument base, agents come equipped with a set of desires: a set of formulas that the agent wants to achieve. This set of desires is not necessarily consistent, therefore, in order to determine what desires to achieve, a consistent set of goals is determined. The set of goals needs to be as appealing to the agent that is being persuaded as possible, such that it incorporates the new beliefs into both its public and private beliefs. A revision operator which compares how appealing a set of arguments is to the persuadee is proposed, to ensure that the agent beliefs the new argument.

Thus, real-world settings, whether inconsistent knowledge bases or multi-agent settings, are complex and, to properly model each of the aspects, argumentation can be combined with belief revision. Such a combined approach enriches the argumentation approach by allowing to decide on the information to incorporate or share and to deal with uncertainty, contradictions and revisions.

4.5.5 Argumentation for Belief Revision. So far, the work mentioned in this section applies belief revision to study dynamics of structured approaches to argumentation. There is also work that applies structured approaches to argumentation to model specific steps in the non-prioritized belief revision process.

The operator from Falappa, Kern-Isberner, et al. (2002), based on the idea that revision takes place after an explanation has been provided (recall Section 4.5.3) is further developed by Falappa, García, and G. R. Simari (2004). Central in this work is the Belief-Desire-Intention (BDI) model (Bratman 1987) and the need to allow for revisions. DeLP is applied to reason about beliefs and intentions and the idea of turning strict rules defeasible is the basis for the revision.

Another way to perform non-prioritized revision is by means of selective revision, where first a transformation function is applied, to determine whether the new information should be accepted and, if so, which parts. Krümpelmann et al. (2012) employs logic-based argumentation to define the transformation function. Two non-prioritized multiple base revision operators are introduced. Since the new information might not be consistent (with the original knowledge base), argumentative evaluation is applied to determine which parts of the new information should be accepted for revision.

Thus, one of the strengths of formal argumentation, whether a structured or abstract account, is its ability to deal with incomplete and inconsistent information. This can be utilized in order to create non-prioritized revision operators, where argumentation helps to determine what information should be considered for revision and in what way. The explicit structure of arguments and the conflict between them, make that a structured approach to argumentation is especially suitable, as it lies closer to formal logics and knowledge base representations.

5 Discussion

In this survey we have started with a brief overview of dynamic approaches to abstract argumentation (Section 3). We have considered changes to the argumentation setting, goal-based changes, reasoning with (explicitly) incomplete and uncertain information and the relation with belief revision, as well as some work on the computational complexity. For each we have highlighted the value of the research on this perspective. Then, we provided a more detailed overview on dynamics of structured approaches to argumentation (Section 4) where many of the notions introduced in the abstract setting returned. For the available work, we have provided some details on the motivation of the approach and the results and how these are important within the larger field of dynamic (structured approaches to) argumentation. See Table 1, at the end of the paper, for an overview of the reviewed literature. In line with the structure and aim of this survey, the overview on abstract approaches only contains some representative references, the overview on structured approaches contains almost all the reviewed literature. Below we discuss why understanding dynamics of structured accounts is important.

5.1 The Benefits of a Structured Account

An often returning observation in the works that we have surveyed is that abstract argumentation is too abstract to study the dynamics of argumentative reasoning. Instead, dynamics should be studied from a structured perspective.

Interdependencies. In argumentation, arguments often build on other arguments. In the abstract account of formal argumentation, such interdependencies are abstracted away and can, therefore, not be taken into account when changing the argumentation setting. An argumentation setting that keeps track of the interdependencies is therefore essential. For example, one of the structured approaches from Section 2, but also the general setting by Wallner (2020) or the subargument relation of Argument Theory Change (recall Section 4.5.1).

Conclusions. Arguments are often considered to have a specific conclusion which makes it possible to reason on the conclusion level, rather than on the argument level. On the conclusion level, we are not interested in a specific argument, but rather in a specific conclusion. As more than one argument for a conclusion might exist, it is the conclusions that we should reason with, not the arguments (Borg and Bex 2021; Dvorák and Woltran 2020).

Additions and removals. In abstract argumentation it is often assumed that it is possible to add or remove specific arguments or attacks without influencing the structure of the AF in other ways. Or, that preferences over arguments can be added such that they resolve only symmetric attacks. When we take the structure of the arguments into account, this is usually not possible. We should therefore look at the structure of the arguments and the elements from which they are constructed when changing the setting (Borg and Bex 2021; Modgil and Prakken 2012; Prakken 2024a, 2023; Rapberger and Ulbricht 2023, 2024)

Attacks. Similarly, it is often assumed that an argument can simply attack or be attacked by any argument in the framework. But, without knowing the weaknesses of an argument, it is not possible to decide what arguments could attack what other arguments. Thus, when changing the setting, knowing the structure of the arguments helps to determine the modified attack relation. This can, for example, already be achieved via defeat points (Prakken 2024a, 2023) or with claim and vulnerability augmented argumentation frameworks (Rapberger and Ulbricht 2023).

Minimal change. When revising an argumentation setting adding or removing an element from, for example, the premises or the knowledge base, can influence more than one argument or attack. Therefore, when defining minimal change, it needs to be determined what change should be minimized. This could, for example, be the elements from which the arguments are constructed, the arguments that are constructed or the acceptability of the arguments (Moguillansky 2016; Snaith and Reed 2016).

Revision. The revision of premises or rules might not necessarily lead to the desired (set of) argument(s) to be (non-)accepted. Therefore, revision should be about the acceptability of arguments or their conclusions (Snaith and Reed 2016).

Desiderata. Desiderata introduced at the abstract level might not be appropriate at the structured level. For example, because the desiderata are defined in terms of arguments, but conclusions at the structured level are defined in terms of the conclusions of an argument. Thus, when studying dynamics at the structured level, it is essential to determine what are the right desiderata, whether translated from the abstract level or introduced specifically (Abderrazik and Doder 2025; Amgoud, Besnard, et al. 2014; Rapberger and Ulbricht 2024; Shakarian et al. 2016).

Operators. Similarly, operators introduced at the abstract level might not be appropriate at the structured level. First, because such operators are usually defined on arguments and attacks. This leads to many of the above problems. But also, because the modifications to the argumentation setting would be unnecessarily big. For example, because removing one argument might affect many other arguments as well. The operators applied in the structured setting should therefore modify the elements (Rapberger and Ulbricht 2024).

The drawbacks of an entirely abstract approach to argumentation have been studied explicitly (Caminada and Wu 2011; Prakken 2023; Prakken and Winter 2018). Caminada and Wu (2011) do this with respect to the rationality postulates (Caminada and Amgoud 2007) and Prakken and Winter (2018) investigate and illustrate the dangers of encoding examples in an abstract form and of abstracting away the context. Prakken (2023) provides an extensive discussion on the implicit assumptions made in abstract expansions and enforcement as introduced by Baumann and Brewka (2010) and how these can be violated in the ASPIC$^+$-based setting of that paper. The discussed problems in these works are similar to some of the items above and, therefore, hold more generally for dynamics of structured approaches to argumentation.

Thus, the above demonstrates that in dynamic argumentation, the complexity of a structured approach, especially arguments for which it is known what the conclusions and weaknesses are, is necessary. This does, however, come with additional computational challenges.

5.2 Computational Complexity

Unfortunately, reasoning tasks are often more complex on the structured level than on the abstract level (Lehtonen, Odekerken, et al. 2024; Lehtonen, Rapberger, et al. 2023). For example, because the constructed AF from a structured setting is often exponential with respect to the size of the knowledge base (Amgoud, Besnard, et al. 2014; Lehtonen, Wallner, et al. 2017; Yun et al. 2020). This is especially a problem in a dynamic setting, where recomputation might be needed frequently.

As we have seen, however, there are various solutions already available in the literature. Potential arguments and their conflicts can be pre-compiled and stored, speeding up the recomputation of available arguments (Capobianco and G. R. Simari 2009), tractable fragments can be determined or only operators that are tractable can be defined (Rapberger and Ulbricht 2024) or efficient algorithms can be developed, for example adapting approaches that are successful for abstract accounts (Alfano, Greco, Parisi, G. I. Simari, et al. 2021a) or ASP-based algorithms (Odekerken, Lehtonen, Wallner, et al. 2025). The current computational complexity studies and their solutions in a dynamic structured setting focus mostly on ASPIC$^+$ and DeLP. Expanding this line of research is important, especially in applications.

Thus, the work on the computational complexity of static structured approaches is very recent. This (additional) complexity is something to consider when developing dynamic approaches, but it is not a reason to avoid dynamics of structured approaches to argumentation.

5.3 Applications

The above indicates that for a full theoretical understanding of dynamic argumentation, we need the structured account. From a practical perspective, this is the case as well. The real world is dynamic and as such, many applications will be dynamic as well.

A significant part of the formal argumentation literature, also that reviewed in this survey, is (very) theoretical. That does, however, not mean that there are no meaningful applications. See, for example, the overview by Atkinson et al. (2017). Although a thorough review of the available applications is beyond the scope of this survey, some pointers to other surveys are in place. The third volume of the Handbook of Formal Argumentation (Gabbay, Kern-Isberner, et al. 2024) contains several chapters on applications. For example, on social argumentation systems (Bikakis, Flouris, et al. 2024), legal reasoning (Bench-Capon et al. 2024), applications of dialogues (Xydis, Castagna, et al. 2024), applications for decision-making (Vesic and Yun 2024) and on argumentation and machine learning (Rago et al. 2024). Other application areas include chatbots (Castagna et al. 2024), explainable artificial intelligence (Cyras et al. 2021; Vassiliades et al. 2021) and the medical domain (Caroprese et al. 2022; Lindgren et al. 2021). An overview of software for formal argumentation was presented by Persiani et al. (2024).[4] Many of these operate in a dynamic environment, the focus is, however, not on understanding the dynamics. Below we highlight three applications which apply notions discussed in this survey.

Cybersecurity. A domain with a number of scenarios that dynamic argumentation can be applied to is that of cybersecurity. In this domain inconsistent knowledge bases are to be expected and a system should be able to handle this. Shakarian et al. (2016) and G. I. Simari et al. (2016) introduce DeLP3E and, as a running example, they show how it can be applied in the cyber-attribution problem. In such an application, the question is who is responsible for a cyberoperation. Another question related to cybersecurity is that of cyber threat analysis, for example incident response. How to handle this with DeLP3E is the main aim of Leiva et al. (2019). In these applications DeLP3E is especially suitable because it combines a structured approach to argumentation that can handle both probabilistic and defeasible reasoning in a dynamic environment.

Inquiry dialogues. Another existing application is that of inquiry dialogues (Walton and Krabbe 1995) applied at the Netherlands Police in several ways. As scenarios change, but the law does not, structured approaches to argumentation are especially suitable to model such applications (Odekerken, Bex, et al. 2022; Testerink et al. 2019). Therefore, the applications are based on a variant of ASPIC$^+$, where the knowledge base is constructed during the dialogue and the rules are based on the law. Central to each of these applications is that information is gathered to come to a decision and in order to increase efficiency, such inquiry dialogues should not take longer than necessary. To this end, *stability* and *relevance* are essential in these applications (Odekerken, Bex, et al. 2022).

[4]https://people.cs.umu.se/~tkampik/argtools/page/index.html.

Explanations. A further application is within explainable artificial intelligence (XAI). Robustness, a measure for whether the output remains the same when the AI model changes, is an important notion in explainable AI (Jiang et al. 2023; Miller 2019). An explanation is considered robust when it does not change when the model is slightly changed. Argumentation is a promising approach in XAI (Cyras et al. 2021), thus studying the robustness of argumentation-based explanations is essential. To this end, (strong) equivalence has been proposed by Rapberger and Toni (2024), to determine whether argumentation-based explanation methods are robust. Since a variety of explanation methods rely on a structured approach to argumentation, see e.g., work by Borg and Bex (2024) and Fan and Toni (2015), understanding (strong) equivalence in the structured account is important to ensure the applicability of argumentative XAI.

Thus, the work on applications of formal argumentation is often in dynamic domains. Some of these study dynamic properties explicitly, with structured approaches to argumentation. This shows the potential of formal argumentation, dynamics and a structured approach.

5.4 Conclusion and Outlook

As has been shown throughout this survey, there is a wealth of research on dynamic argumentation, covering a large variety of perspectives on dynamics. In this section, and in this survey in general, we have highlighted specifically the advantages of the research on dynamics of structured approaches to argumentation. Many applications will be inherently dynamic and can be based on structured approaches to argumentation. Moreover, when solely relying on abstract argumentation, implicit assumptions about the possible modifications of the argumentation framework as well as the structure of the arguments and the attacks between them, can result in problems when instantiating the arguments, for example with real-world scenarios.

This is not to say that work on dynamics of abstract argumentation is not valuable, not at all! Many useful notions have been first introduced and studied on the abstract level. Thanks to this, there is now a very rich landscape of perspectives on dynamic argumentation. What is needed though, is to ensure that the work on dynamics is instantiation proof and that the problems discussed in Section 5.1 are avoided.

The work on dynamics of structured approaches to argumentation, especially on goal-based changes and incomplete and uncertain information, is mostly very recent. There is, therefore, a lot of potential to expand this work. Both to establish a theoretical foundation, underpinning our understanding of dynamics and aimed at applications.

Theoretical. There is no need to consider one structured approach to argumentation superior to another. By studying dynamics for several approaches, we will be able to better understand the dynamic mechanisms in formal argumentation. Moreover, knowing how dynamics in these approaches are similar as well as different and what their individual strengths are, makes it possible to choose the right structured approach when designing and developing applications. Looking at Table 1, this becomes visible already. For example, goal-based dynamics has been explored mostly in ABA and ASPIC$^+$, incompleteness in ASPIC$^+$ and deductive argumentation and the combination with belief revision in DeLP and deductive argumentation.

Therefore, a first step is to continue with the recent trend of work on dynamics of structured approaches to argumentation. (Strong) equivalence is important in the reduction of the size of structured argumentation frameworks (Amgoud, Besnard, et al. 2014) as well as in XAI (Rapberger and Toni 2024). Given the positive results of claim and vulnerability augmented AFs for ABA (Rapberger and Ulbricht 2023), it would be useful to know if similar results could be achieved for other structured approaches.

A start has been made with defining operators for enforcement, forgetting and repairing in several structured approaches, especially for ABA, but many questions remain. For example, many desiderata from the abstract literature on forgetting (Baumann, Berthold, et al. 2025) have not been studied yet and the ones that have been considered might be too strong (Berthold, Rapberger, et al. 2023).

Although the study on belief revision and argumentation has been around for quite some time, recent work has shown that we can still learn a lot from their combination (Baroni, Fermé, et al. 2022; Heyninck et al. 2023) and it would be interesting to know how these new insights relate to structured approaches to argumentation.

Finally, for each of these questions, tractable operators and/or efficient algorithms will be essential when applying the structured approaches in dynamic settings.

Applications. In order to fully benefit from formal argumentation in AI, we need to utilize our theoretical understanding in applications. Given existing research and current trends in AI research, dialogues and XAI are especially suitable for this.

Although dialogues are beyond the scope of this survey, they take place in a dynamic setting. A large variety of literature is available, see e.g., the survey by Black, Maudet, et al. (2021) on argumentation-based dialogues, the overview by Xydis, Castagna, et al. (2024) on available applications of argumentation-based dialogues and the survey by Castagna et al. (2024) on argumentation-based chatbots. This literature, combined with a thorough theoretically understanding of dynamics and efficient algorithms, can bridge the gap between theory and feasible application (Odekerken, Bex, et al. 2022; Odekerken, Lehtonen, Wallner, et al. 2025).

Given that the world is dynamic, it is reasonable to expect that explanations need to be provided in a dynamic environment as well. To this end, explanations for the change of inference in abstract argumentation were introduced (Kampik and Cyras 2021) and, Kampik, Cyras, and Alarcón (2024) introduce change explanations for Quantitative Bipolar Argumentation Frameworks (QBAFs) (Baroni, Rago, et al. 2019). These works show that developing argumentation-based explanations for dynamic environments is a promising research direction, with which formal argumentation becomes more applicable.

An overview of the surveyed literature can be found in Table 1. In terms of future work, empty cells indicate that no research has been done in that direction. But, as mentioned in this section, research that fits into other cells would be valuable as well.

Thus, dynamics of structured approaches to argumentation has been shown to be a beneficial research direction within formal argumentation. Now that the advantage for a structured approach has been established and valuable results have been published, more in-depth research on the various notions of dynamics is called for. Extending our understanding of dynamics, developing the theoretical foundation and looking at applications are all possible future directions worth taking.

Table 1: Overview of the reviewed literature. The table only includes some representative papers on abstract approaches to dynamics. For structured approaches the table includes almost all the reviewed literature.

Approach	**Changes**	**Complexity**	**Goal-based**	**Incomplete**	**Belief revision**
Abstract	§3.1 (Bisquert, Cayrol, Dupin de Saint-Cyr, and Lagasquie-Schiex 2013a; Oikarinen and Woltran 2011)	§3.2 (Alfano, Greco, Parisi, G. I. Simari, et al. 2021b; Baroni, Giacomin, and Liao 2014; Baumann 2011)	§3.3 (Baumann, Berthold, et al. 2025; Baumann and Brewka 2010; Baumann, Doutre, et al. 2021; Ulbricht and Baumann 2019)	§3.4 (Baroni and Giacomin 2005; Baumeister, Järvisalo, et al. 2021; Odekerken, Borg, et al. 2024)	§3.5 (Falappa, Kern-Isberner, et al. 2009)

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Table 1: Overview of the reviewed literature. The table only includes some representative papers on abstract approaches to dynamics. For structured approaches the table includes almost all the reviewed literature. (Continued)

Approach	Changes	Complexity	Goal-based	Incomplete	Belief revision
ABA	§4.1.1 (Rapberger and Ulbricht 2023)		§4.3.1 (Rapberger and Ulbricht 2023) §4.3.2 (Berthold, Rapberger, et al. 2023; Berthold and Ulbricht 2024) §4.3.3 (Rapberger and Ulbricht 2024)		
ASPIC$^+$	§4.4 (Modgil and Prakken 2012)	§4.4 (Odekerken, Bex, et al. 2022; Odekerken, Lehtonen, Wallner, et al. 2025)	§4.3.1 (Prakken 2024a, 2023) §4.3.2 (Abderrazik and Doder 2025)	§4.4 (Odekerken, Bex, et al. 2022; Odekerken, Lehtonen, Wallner, et al. 2025) §4.4 (Proietti and Yuste-Ginel 2025) §4.4 (Hosseini et al. 2014; Orbe Leiva, García, et al. 2025; Xydis, Moraru, et al. 2024)	§4.5.2 (Snaith and Reed 2016)
DeLP		§4.2 (Alfano, Greco, Parisi, G. I. Simari, et al. 2021a; Capobianco and G. R. Simari 2009)		§4.4 (Orbe Leiva, Gottifredi, et al. 2023)	§4.5.1 (Moguillansky, Rotstein, et al. 2008, 2013) §4.5.3 (Falappa, Kern-Isberner, et al. 2002) §4.5.4 (Alfano, Leiva, et al. 2025; Shakarian et al. 2016) §4.5.5 (Falappa, García, and G. R. Simari 2004)
Deductive	§4.1.1 (Amgoud, Besnard, et al. 2014)			§4.4 (Black and Hunter 2012; Dupin de Saint-Cyr 2011; Hunter 2007, 2022) §4.5.3 (Mailly 2016)	§4.5.1 (Moguillansky, Wassermann, et al. 2012) §4.5.2 (Moguillansky and G. R. Simari 2016) §4.5.3 (Mailly 2016) §4.5.4 (Boella, Costa Pereira, et al. 2008) §4.5.5 (Krümpelmann et al. 2012)

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Table 1: Overview of the reviewed literature. The table only includes some representative papers on abstract approaches to dynamics. For structured approaches the table includes almost all the reviewed literature. (Continued)

Approach	Changes	Complexity	Goal-based	Incomplete	Belief revision
Other	§4.1 (Rotstein, Moguillansky, García, et al. 2010) §4.1.1 (Baumann, Rapberger, et al. 2023) §4.1.1 (Nieves 2016)		§4.3.1 (Borg and Bex 2021; Wallner 2020)		§4.5.1 (Moguillansky, Rotstein, et al. 2010; Rotstein, Moguillansky, Falappa, et al. 2008) §4.5.3 (Pandžić 2022b)

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