A SAT-based Approach for Argumentation Dynamics

Extended Abstract

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ABSTRACT

In the realm of multi-agent systems, argumentative dialogues for persuasion and negotiation involve autonomous agents exchanging arguments, necessitating continual re-evaluation of argument acceptability. This study introduces a novel approach using modern SAT solving techniques to dynamically reassess the acceptability status of arguments, aligning with various classical semantics. Our method uses the assumption mechanism in SAT solvers, distinguished by minimal assumptions, ensuring practicality.

KEYWORDS

Abstract Argumentation; Argumentation Dynamics; SAT

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1 INTRODUCTION

Abstract argumentation [10] is a robust tool for modeling conflicting information and providing specialized reasoning methods. Its versatile applications span various domains, particularly within multi-agent systems [19]. It serves as a foundation for defining protocols in multi-agent argument-based dialogues [4], crucial in automated negotiations [3] and persuasive interactions [5].

An *abstract argumentation framework* (AF) is a directed graph $\mathcal{F} = \langle \mathcal{A}, \mathcal{R} \rangle$ where $\mathcal{A}$ is a (non-empty and finite) set of *arguments* and $\mathcal{R} \subseteq \mathcal{A} \times \mathcal{A}$ is the *attack relation*. Given $a, b \in \mathcal{A}$, a *attacks* b when $(a, b) \in \mathcal{R}$, and for $S \subseteq \mathcal{A}$, S *attacks* b if $\exists a \in S$ which attacks b. Finally, S *defends* the argument $c \in \mathcal{A}$ if, for any b attacking c, S attacks b. Reasoning with AFs typically uses the concept of extensions, *i.e.* sets of jointly acceptable arguments. These extension-based semantics are primarily based on two properties: given $\mathcal{F} = \langle \mathcal{A}, \mathcal{R} \rangle$, $S \subseteq \mathcal{A}$ is *conflict-free* if $\forall a, b \in S$, $(a, b) \notin \mathcal{R}$; *admissible* if it is conflict-free and defends all its elements. In this paper, our primary focus lies on the following two types of extensions: $S \subseteq \mathcal{A}$ is a *complete extension* if it is admissible and it defends no argument in $\mathcal{A} \setminus S$; a *stable extension* if it is conflict-free and it attacks all the arguments in $\mathcal{A} \setminus S$. We write $\mathbf{co}(\mathcal{F})$ (resp. $\mathbf{st}(\mathcal{F})$) for the set of complete (resp. stable) extensions.

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Given $\sigma \in \{\mathbf{co}, \mathbf{st}\}$, we focus on solving the decision problems **DC**-σ (**D**ecide **C**redulous acceptability) and **DS**-σ (**D**ecide **S**keptical acceptability), formally defined respectively by answering the question: "Given an AF $\mathcal{F} = \langle \mathcal{A}, \mathcal{R} \rangle$ and an argument $a \in \mathcal{A}$, is a a member of *some* (resp. *each*) σ-extension of $\mathcal{F}$? "

We denote by $\mathbf{cred}_\sigma(\mathcal{F})$ (resp. $\mathbf{skep}_\sigma(\mathcal{F})$) the set of arguments that are credulously (resp. skeptically) accepted, meaning they lead to a 'YES' response in the problem **DC**-σ (resp. **DS**-σ). Reasoning with AFs is typically challenging [11]. Specifically, the problems outlined earlier often reside within the first level of the polynomial hierarchy. To be more precise, both $\mathbf{cred}_{\mathbf{co}}(\mathcal{F})$ and $\mathbf{cred}_{\mathbf{st}}(\mathcal{F})$ pose NP-complete challenges, while $\mathbf{skep}_{\mathbf{st}}(\mathcal{F})$ represents a coNP-complete problem. Notably, $\mathbf{skep}_{\mathbf{co}}(\mathcal{F})$ can be resolved using a polynomial algorithm. This paper centers on improving the resolution of problems that necessitate NP oracles.

Despite theoretical complexity, real-world performance of abstract argumentation solvers remains impressive, even with substantial problem sizes [22]. These solvers typically address this challenge by translating the abstract argumentation problem into a Conjunctive Normal Form (CNF) formula using an updated encoding proposed by [8]. Specifically, a semantics σ and an argumentation framework (AF) $\mathcal{F}$ are transformed into a propositional formula $\phi_\sigma(\mathcal{F})$ such that the formula's models correspond to the extensions of the AF. These formulas represent conflict-free sets, admissible sets, and extensions under both complete and stable semantics. Details on these encodings and their use in prominent argumentation solvers can be found in [17, 20]. Once encoded, modern SAT solvers (see [9] for SAT details) efficiently resolve the problem [12, 17, 20].

While SAT solvers excel in handling various problems, challenges persist, particularly in dynamic AFs requiring updates. Regularly invoking a SAT solver during complex debates with evolving argumentation structures can lead to significant runtime costs, especially when resetting the solver after each modification [1, 2]. In this work, we advance this context using sophisticated SAT-based techniques to compute solutions for **DC** and **DS** problems (NP- or coNP-complete). Our approach relies on incremental SAT solving [13] and assumptions [6, 13, 16], enabling the use of prior computations to expedite acceptability determination following framework modifications. Empirical comparisons with other state-of-the-art methods in dynamic AFs, including a naive baseline solving the problem from scratch after each update, highlight the superior performance of our approach.

2 THE CRUSTABRI SOLVER

SAT solvers deduce clauses from the initial problem [9]. In dynamic argumentation, our goal is to retain the same SAT solver and its learned clauses while adjusting the constraints to align with the evolving AF. If the clauses remains unchanged or becomes more refined, the previously learned clauses can assist in future decision-making. However, relaxing the clauses in the SAT solver makes it uncertain if the previously learned clauses are still consequences of the problem, except when new free variables are introduced.

To address this, assumption variables [13] are employed. Already used in static argumentation [17, 21], it encodes a relaxed version of the problem with additional (assumption) variables, allowing the representation of any set of constraints considered later. When assumption literals are set, the solver learns clauses as if these variables were determined by its internal decision-making process. Consequently, if a learned clause results from these artificial decisions, it becomes a consequence of the conjunction of the original formula and the assumption literals, enabling the utilization of learned clauses under assumptions in subsequent computations.

Employing assumptions in a dynamic context demands a meticulous formulation. If a state cannot be accurately encoded with a set of assumptions, it may necessitate a new encoding, rendering previous clauses obsolete. An excessively relaxed initial formula could also inflate the number of clauses and auxiliary variables for assumptions, introducing unnecessary computational overhead.

Attacks as assumptions. In an AF with a constant set of arguments, a practical approach involves assigning assumptions $s_{a,b}$ for each pair $(a,b) \in \mathcal{A}$. For instance, stable semantics requires $|\mathcal{A}|^2$ assumptions and $O(|\mathcal{A}|^2)$ clauses: $\psi'_{\mathbf{st}}(\mathcal{F}) = \bigwedge_{a\in\mathcal{A}}(a \vee \bigvee_{b\in\mathcal{A}}(s_{b,a} \wedge b)) \wedge \bigwedge_{a\in\mathcal{A}}(\bigwedge_{b\in\mathcal{A}}(\neg s_{b,a} \vee \neg a \vee \neg b))$. However, introducing a new argument weakens specific clauses, making this encoding unsuitable for dynamics. μ-toksia reserves fresh variables for future arguments by temporarily setting them to false using assumptions, with constraints determined by the current and reserved arguments.

Disjunction of attackers as assumptions. We present two encodings that exploit the unique structure of stable and complete semantics in a dynamic context, connecting assumptions to the disjunction of attackers (P_a variables of [17]). They use a minimal number of *active* assumptions, limited by the current number of arguments. The count of *active* clauses matches the number of clauses in static encodings. Assumptions link sets of attacks targeting a common argument. When attackers change, the previous set is deactivated by fixing the related assumption, while a new one is generated to validate the updated set of attackers.

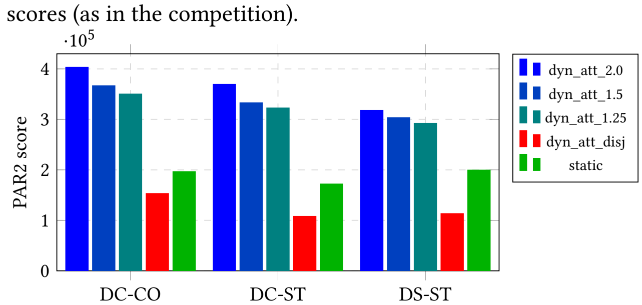
$$\psi^D_{\mathbf{st}}(\mathcal{F}) = \bigwedge_{a\in\mathcal{A}}(\neg s_a \vee a \vee \bigvee_{(b,a)\in\mathcal{R}} b) \quad (1.1)$$
$$\bigwedge_{a\in\mathcal{A}}(\bigwedge_{(b,a)\in\mathcal{R}}(\neg s_a \vee \neg a \vee \neg b)) \quad (1.2)$$

$$\psi^D_{\mathbf{co}}(\mathcal{F}) = \bigwedge_{a\in\mathcal{A}}(\neg a \vee \neg P_a) \quad (2.1)$$
$$\bigwedge_{a\in\mathcal{A}}(\neg s_a \vee a \vee \bigvee_{(b,a)\in\mathcal{R}} \neg P_b) \quad (2.2)$$
$$\bigwedge_{a\in\mathcal{A}}(\bigwedge_{(b,a)\in\mathcal{R}}(\neg s_a \vee \neg a \vee P_b)) \quad (2.3)$$
$$\bigwedge_{a\in\mathcal{A}}(\neg s_a \vee \neg P_a \vee \bigvee_{(b,a)\in\mathcal{R}} b) \quad (2.4)$$
$$\bigwedge_{a\in\mathcal{A}}(\bigwedge_{(b,a)\in\mathcal{R}}(\neg s_a \vee P_a \vee \neg b)) \quad (2.5)$$

$\psi_{\mathbf{st}}(\mathcal{F}) \equiv \psi^D_{\mathbf{st}}(\mathcal{F}) \wedge \bigwedge_{a\in\mathcal{A}} s_a$ and $\psi_{\mathbf{co}}(\mathcal{F}) \equiv \psi^D_{\mathbf{co}}(\mathcal{F}) \wedge \bigwedge_{a\in\mathcal{A}} s_a$ show the correctness of our encodings. For stable semantics, handling attacks involving a specific argument a is efficient. Setting s_a suffices for adding or removing an attack. Introducing a new variable s'_a encodes the new attack set $(\neg s'_a \vee a \vee \bigvee_{(b,a)\in\mathcal{R}} b$, and $\bigwedge_{(b,a)\in\mathcal{R}}(\neg s'_a \vee \neg a \vee \neg b))$. Replacing s_a with s'_a in the assumption set passed to the solver accounts for these changes. Adding a new argument a involves declaring a and s_a in the SAT solver and including s_a in the assumption set. Removing an argument entails eliminating all attacks involving it and setting its value with a unit clause. Concerning complete semantics, reencoding is necessary when a set of attacks change, following rules (2.2) to (2.5). Introducing a new variable a requires declaring P_a and adding (2.1).

3 EXPERIMENTAL EVALUATION

We compare our new approach (*dyn_att_disj*) with the dynamic attack assumptions method (*dyn_att*) and a baseline that creates a new AF for every state evolution (*static*). These were implemented in CRUSTABRI [18] and evaluated by replaying the 5^{th} ICCMA competition [14] on machines with Intel Xeon E5-2637 v4 processors and 128GB RAM (details at [15]). The *dyn_att* encoding introduces a key parameter: the number of arguments reserved for future additions during reencoding. In μ-toksia, this number is set to 2 (for n arguments at encoding time, n additional arguments are reserved). Recognizing its importance, we experimented with factors such as 2, 1.5, and 1.25. The results, presented in the following figure, categorize the approaches into three distinct groups based on PAR-2 scores (as in the competition).



Our approach, *dyn_att_disj*, achieved the top position across all tracks, highlighting its effectiveness. The *static* approach secured second place, consistently demonstrating strong performance. The various iterations of *dyn_att* approaches, using different factors, yielded comparable results in the third group. Interestingly, the impact of the factor in *dyn_att* encoding was less substantial than anticipated. Regardless of the factor, the *static* approach consistently outperformed *dyn_att*, emphasizing the insufficient benefits to compensate for encoding overhead. Focusing on the number of instances solved led to the same conclusions. Our *dyn_att_disj* approach showcased remarkable ability in leveraging past knowledge, aligning with amortization in modern SAT solvers [7].

4 CONCLUSION

This paper explores incremental SAT solving in dynamic argumentation, focusing on efficiently determining argument statuses during updates. Our novel encoding method proves more space-efficient than existing approaches, requiring fewer assumptions. Empirical evaluations demonstrate its clear superiority over the naive baseline and the current state-of-the-art method.

REFERENCES

[1] Gianvincenzo Alfano, Sergio Greco, and Francesco Parisi. 2017. Efficient Computation of Extensions for Dynamic Abstract Argumentation Frameworks: An Incremental Approach. In *Proceedings of the Twenty-Sixth International Joint Conference on Artificial Intelligence, IJCAI 2017, Melbourne, Australia, August 19-25, 2017*, Carles Sierra (Ed.). ijcai.org, 49–55. https://doi.org/10.24963/ijcai.2017/8

[2] Gianvincenzo Alfano, Sergio Greco, and Francesco Parisi. 2019. An Efficient Algorithm for Skeptical Preferred Acceptance in Dynamic Argumentation Frameworks. In *Proceedings of the Twenty-Eighth International Joint Conference on Artificial Intelligence, IJCAI 2019, Macao, China, August 10-16, 2019*, Sarit Kraus (Ed.). ijcai.org, 18–24. https://doi.org/10.24963/ijcai.2019/3

[3] Leila Amgoud, Yannis Dimopoulos, and Pavlos Moraitis. 2007. A General Framework for Argumentation-Based Negotiation. In *Argumentation in Multi-Agent Systems, 4th International Workshop, ArgMAS 2007, Honolulu, HI, USA, May 15, 2007, Revised Selected and Invited Papers (Lecture Notes in Computer Science, Vol. 4946)*, Iyad Rahwan, Simon Parsons, and Chris Reed (Eds.). Springer, 1–17. https://doi.org/10.1007/978-3-540-78915-4_1

[4] Ryuta Arisaka, Jérémie Dauphin, Ken Satoh, and Leendert van der Torre. 2022. Multi-agent Argumentation and Dialogue. *FLAP* 9, 4 (2022), 921–954. https://collegepublications.co.uk/ifcolog/?00056

[5] Ryuta Arisaka and Ken Satoh. 2018. Abstract Argumentation / Persuasion / Dynamics. In *PRIMA 2018: Principles and Practice of Multi-Agent Systems - 21st International Conference, Tokyo, Japan, October 29 - November 2, 2018, Proceedings (Lecture Notes in Computer Science, Vol. 11224)*, Tim Miller, Nir Oren, Yuko Sakurai, Itsuki Noda, Bastin Tony Roy Savarimuthu, and Tran Cao Son (Eds.). Springer, 331–343. https://doi.org/10.1007/978-3-030-03098-8_20

[6] Gilles Audemard, Jean-Marie Lagniez, and Laurent Simon. 2013. Improving Glucose for Incremental SAT Solving with Assumptions: Application to MUS Extraction. In *Theory and Applications of Satisfiability Testing - SAT 2013 - 16th International Conference, Helsinki, Finland, July 8-12, 2013. Proceedings (Lecture Notes in Computer Science, Vol. 7962)*, Matti Järvisalo and Allen Van Gelder (Eds.). Springer, 309–317. https://doi.org/10.1007/978-3-642-39071-5_23

[7] Gilles Audemard, Jean-Marie Lagniez, and Laurent Simon. 2013. Just-In-Time Compilation of Knowledge Bases. In *IJCAI 2013, Proceedings of the 23rd International Joint Conference on Artificial Intelligence, Beijing, China, August 3-9, 2013*, Francesca Rossi (Ed.). IJCAI/AAAI, 447–453. http://www.aaai.org/ocs/index.php/IJCAI/IJCAI13/paper/view/6754

[8] Philippe Besnard and Sylvie Doutre. 2004. Checking the acceptability of a set of arguments. In *10th International Workshop on Non-Monotonic Reasoning (NMR 2004), Whistler, Canada, June 6-8, 2004, Proceedings*, James P. Delgrande and Torsten Schaub (Eds.). 59–64. http://www.pims.math.ca/science/2004/NMR/papers.html

[9] Armin Biere, Marijn Heule, Hans van Maaren, and Toby Walsh (Eds.). 2021. *Handbook of Satisfiability - Second Edition*. Frontiers in Artificial Intelligence and Applications, Vol. 336. IOS Press. https://doi.org/10.3233/FAIA336

[10] Phan Minh Dung. 1995. On the Acceptability of Arguments and its Fundamental Role in Nonmonotonic Reasoning, Logic Programming and n-Person Games. *Artif. Intell.* 77, 2 (1995), 321–358. https://doi.org/10.1016/0004-3702(94)00041-X

[11] Wolfgang Dvorák and Paul E. Dunne. 2018. Computational Problems in Formal Argumentation and their Complexity. In *Handbook of Formal Argumentation*, Pietro Baroni, Dov Gabbay, Massimiliano Giacomin, and Leendert van der Torre (Eds.). College Publications, 631–688.

[12] Wolfgang Dvorák, Matti Järvisalo, Johannes Peter Wallner, and Stefan Woltran. 2014. Complexity-sensitive decision procedures for abstract argumentation. *Artif. Intell.* 206 (2014), 53–78. https://doi.org/10.1016/j.artint.2013.10.001

[13] Niklas Eén and Niklas Sörensson. 2003. Temporal induction by incremental SAT solving. In *First International Workshop on Bounded Model Checking, BMC@CAV 2003, Boulder, Colorado, USA, July 13, 2003 (Electronic Notes in Theoretical Computer Science, Vol. 89)*, Ofer Strichman and Armin Biere (Eds.). Elsevier, 543–560. https://doi.org/10.1016/S1571-0661(05)82542-3

[14] Matti Järvisalo, Tuomo Lehtonen, and Andreas Niskanen. 2023. Design of ICCMA 2023, 5th International Competition on Computational Models of Argumentation: A Preliminary Report (invited paper). In *Proceedings of the First International Workshop on Argumentation and Applications co-located with 20th International Conference on Principles of Knowledge Representation and Reasoning (KR 2023), Rhodes, Greece, September 2-8, 2023 (CEUR Workshop Proceedings, Vol. 3472)*, Oana Cocarascu, Sylvie Doutre, Jean-Guy Mailly, and Antonio Rago (Eds.). CEUR-WS.org, 4–10. https://ceur-ws.org/Vol-3472/invited1.pdf

[15] Matti Järvisalo, Tuomo Lehtonen, and Andreas Niskanen. 2023. ICCMA'23 competition website. https://iccma2023.github.io. Accessed: 2024-01-09.

[16] Jean-Marie Lagniez and Armin Biere. 2013. Factoring Out Assumptions to Speed Up MUS Extraction. In *Theory and Applications of Satisfiability Testing - SAT 2013 - 16th International Conference, Helsinki, Finland, July 8-12, 2013. Proceedings (Lecture Notes in Computer Science, Vol. 7962)*, Matti Järvisalo and Allen Van Gelder (Eds.). Springer, 276–292. https://doi.org/10.1007/978-3-642-39071-5_21

[17] Jean-Marie Lagniez, Emmanuel Lonca, and Jean-Guy Mailly. 2015. CoQuiAAS: A Constraint-Based Quick Abstract Argumentation Solver. In *27th IEEE International Conference on Tools with Artificial Intelligence, ICTAI 2015, Vietri sul Mare, Italy, November 9-11, 2015*. IEEE Computer Society, 928–935. https://doi.org/10.1109/ICTAI.2015.134

[18] Jean-Marie Lagniez, Emmanuel Lonca, and Jean-Guy Mailly. 2024. Crustabri_ipafair release 1.1.0 on GitHub. https://github.com/crillab/crustabri_ipafair/releases/tag/v1.1.0. Accessed: 2024-01-09.

[19] Peter McBurney, Simon Parsons, and Iyad Rahwan (Eds.). 2012. *Argumentation in Multi-Agent Systems - 8th International Workshop, ArgMAS 2011, Taipei, Taiwan, May 3, 2011, Revised Selected Papers*. Lecture Notes in Computer Science, Vol. 7543. Springer. https://doi.org/10.1007/978-3-642-33152-7

[20] Andreas Niskanen and Matti Järvisalo. 2020. μ-toksia: An Efficient Abstract Argumentation Reasoner. In *Proceedings of the 17th International Conference on Principles of Knowledge Representation and Reasoning, KR 2020, Rhodes, Greece, September 12-18, 2020*, Diego Calvanese, Esra Erdem, and Michael Thielscher (Eds.). 800–804. https://doi.org/10.24963/kr.2020/82

[21] Andreas Niskanen and Matti Järvisalo. 2020. Algorithms for Dynamic Argumentation Frameworks: An Incremental SAT-Based Approach. In *ECAI 2020 - 24th European Conference on Artificial Intelligence, 29 August-8 September 2020, Santiago de Compostela, Spain, August 29 - September 8, 2020 - Including 10th Conference on Prestigious Applications of Artificial Intelligence (PAIS 2020) (Frontiers in Artificial Intelligence and Applications, Vol. 325)*, Giuseppe De Giacomo, Alejandro Catalá, Bistra Dilkina, Michela Milano, Senén Barro, Alberto Bugarín, and Jérôme Lang (Eds.). IOS Press, 849–856. https://doi.org/10.3233/FAIA200175

[22] Matthias Thimm. 2015. Argumentation competition website. http://argumentationcompetition.org. Accessed: 2024-01-09.