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Computation of Clustered Argumentation Frameworks via Boolean Satisfiability

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Abstract

English abstract of your thesis

Kurzfassung

Deutsche Kurzfassung der Abschlussarbeit

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List of Acronyms and Symbols

AF	Argumentation Framework
AI	Artificial Intelligence
ASP	Answer Set Programming
cf	Conflict-Free
adm	Admissible
stb	Stable
BFS	Breadth First Search
DFS	Depth First Search

1 Introduction

We all encounter arguments in our lives frequently. When talking to friends, listening to political discussions, or even making decisions in our head. These arguments can get heated and complex since humans have different beliefs and motivations. Finding a common ground or a "correct" conclusion is complicated and sometimes impossible. However, these imperfections are what make us humans. Artificial Intelligence (AI), conversely, needs to act precisely and logically [5]. That is why much research is being done on knowledge representation and reasoning [4] [10].

When observing arguments objectively, we can distinguish between facts and conclusions. A fact represents a specific state in the real world. A conclusion on the other hand is a fact claimed by the logical relation of the promises. The relations are opposing facts (f.e. *the square x is red* and *the square x is blue*), which are contradicting each other. While accepting the correctness of facts is very important, refuting facts is even more critical in an argument.

If a fact or, i.e., an argument a is a counterargument of another argument b , we can say that a attacks b . With this generalization, we can abstract our model with directed graphs. The arguments are represented as nodes, and the attacks as directed edges [7]. With this abstraction, we can define Argumentation Frameworks (AFs) and use them to evaluate conclusions [9]. Drawing a conclusion from the AF can be challenging and tears down to the definition of semantics.

A semantic defines a subset of argument sets that satisfy the semantic-specific rules. The specific rules can be defined via a boolean formula. They can be used to encode the AFs to be solvable with different boolean solvers like Answer Set Programming (ASP) [2] or, as in our case, with a Boolean Satisfiability Solver (SAT-Solver) [1]. Unfortunately, drawing a conclusion from an AF can be challenging, e.g., it can be NP-complete to decide whether an argument is acceptable under a specific argumentation semantics [8].

TODO: Explain abstract faithful AF generation complex

One of the first papers describing the concept was written by Dung [6] in 1995. Since then, there has been more and more interest in AFs due to the artificial intelligence community. The argumentation systems and semantics have been modified and improved over the years, and another abstraction layer has been added. This specific abstraction layer is called *clustering* and generalizes multiple arguments into one bundled cluster [11]. Clustering is a technique to reduce the number of arguments without changing the conclusion, which in this instance would be the sets produced by a specific semantic. When producing a clustered (*abstract*) AF, which produces the same semantic sets as the non-clustered (*concrete*) AF, the abstract AF is defined to be *faithful*. While each concrete semantic set has a directly mapped abstract semantic set, not every abstract semantic set has to have a directly mapped concrete semantic set. If we create an

abstract AF that produces a semantic set that cannot be mapped to a concrete semantic set, we call it *spurious*.

When reducing the amount of arguments with clustering we have to pay attention to not abstract crucial facts, and thus, falsify accepted sets from the concrete AF or accept refuted ones. This would lead to a spurious abstraction and the abstract AF would not represent the concrete AF anymore. To preserve the representation of the concrete AF, we need to show faithfulness.

Creating abstract, faithful AFs can be challenging and is the main focus of this paper. We created one of the first tools [3] to produce an abstract AFs based on a concrete AFs. We cover different setups and usages, including different semantics and base functionalities:

- Generate semantic sets of a concrete- or abstract AF. The sets calculated iteratively or all at once. The covered semantics are Conflict-Free (cf), Admissible (adm), and Stable (stb), which can be selected throughout the project independently by a parameter in the command line.
- Determine faithfulness or spuriousness by providing two AFs. We provide two approaches, Breadth First Search (BFS) and Depth First Search (DFS), which alter the procedure. While BFS calculates all the semantic sets of the two AFs first and then compares them, DFS calculates iteratively a semantic set of the abstract AF and then verifies it with the concrete AF. The algorithm selection is done via a command line parameter.
- Concretize a set of arguments (i.e., pull out arguments from the cluster) given the concrete AF and an abstract AF (faithful or spurious), and provide faithfulness (by concretizing other arguments not specified in the concretize list as well). The user provides the concretized arguments via a command line parameter.
- ...

TODO: Further contributions

TODO: give pointers to why are non-trivial to obtain

TODO: Choice of methods to obtain results

TODO: How big AFs are still feasible to solve

2 Background

2.1 Argumentation Frameworks

TODO: What are AFs

TODO: Why are they used

TODO: Example

TODO: Definitions of Semantics

2.2 Clustering of Argumentation Frameworks

TODO: What are clusters

TODO: Why do we need clusters

TODO: Definition of Semantics

2.3 SAT-Solver

TODO: What are SAT-Solvers

TODO: Complexity of SAT-Problems

TODO: Where and how do we use SAT-Solvers in the research

3 Algorithm

3.1 Concretizing Singletons

Concretizing a list of arguments is done iteratively by deep copying the abstract AF F' to create a new AF F'' and mutating it. The mutation is guided by five steps considering the unchanged abstract AF F' and the concrete AF F . To improve the understanding of each step, we accompany the explanation with the example depicted in 3.3, where we concretize the arguments a and b .

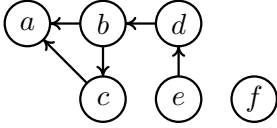


Figure 3.1: Concrete AF F

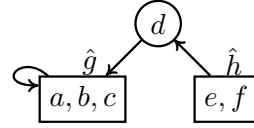


Figure 3.2: Abstract AF F'

Figure 3.3: Example: Concretization of arguments

Step 1: Each argument needing concretization is first removed from the parent cluster and added as a singleton in F'' . If an argument is not part of a cluster, we remove it and continue with the filtered list. We do not consider attacks in this step since they depend on the concrete- and abstract AFs.

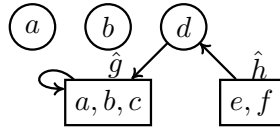


Figure 3.4: Concretized AF F'' after Step 1

Step 2: We add the new attacks from all concretized arguments to the remaining clusters. We must do this after removing the arguments from the clusters because if an argument a attacks argument b in the concrete AF, and b is part of the cluster F' in the abstract AF, by concretizing b , the attack (a, F') would not be persistent anymore.

Step 3: After adding the new attacks, we need to check which attacks from F' are still persistent in F'' . If an attack does not persist through the concretization, we remove it

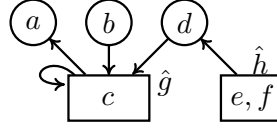


Figure 3.5: Concretized AF F'' after Step 2

in F'' . An attack is not persistent anymore; if we remove one of the arguments being attacked or attacked by argument a from the cluster f and no other attack exists, s.t. a is attacked from/attacking an argument within f . Selfattacks of clusters could also change by the concretization of arguments. Therefore, we need to check the clusters from which the arguments are concretized.

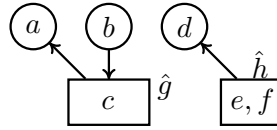


Figure 3.6: Concretized AF F'' after Step 3

Step 4: In this step we add the new attacks between the singletons. Due to the fact, that we copied all the attacks from F' , we only have to take into consideration the attacks from or to the concretized singletons. So instead of iterating over all singletons of the AF, we can limit the attack creation to the concretized singletons.

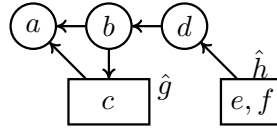


Figure 3.7: Concretized AF F'' after Step 4

Step 5: The last step is to clean up the argumentation framework F'' by removing all empty clusters and mutating the clusters with exactly one singleton to the mentioned singleton.

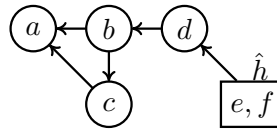


Figure 3.8: Concretized AF F'' after Step 5

3.2 Algorithmic Approach to Compute Faithful Clusterings

TODO: Concretize singletons of clustered AF algorithm

3.3 Heuristics and Refinements

TODO: Define every Heuristic and refinement we used for each semantic

4 Implementation

4.1 Creating AFs

TODO: Explain AF creation algorithms (Random + Grid-Based)

4.2 BFS and DFS Approach

TODO: BFS and DFS approach in current research + when BFS is better than DFS

4.3 Generating Semantic Sets

TODO: Semantic sets generation algorithm

4.4 Faithful/Spurious Determination

TODO: Determine faithful/spurious algorithm

5 Related Works

6 Conclusion

Bibliography

- [1] Leila Amgoud and Caroline Devred. “Argumentation frameworks as constraint satisfaction problems.” In: *Ann. Math. Artif. Intell.* 69.1 (2013), pp. 131–148. DOI: 10.1007/S10472-013-9343-0. URL: <https://doi.org/10.1007/s10472-013-9343-0>.
- [2] Günther Charwat, Johannes Peter Wallner, and Stefan Woltran. “Utilizing ASP for Generating and Visualizing Argumentation Frameworks.” In: *CoRR* abs/1301.1388 (2013). arXiv: 1301.1388. URL: <http://arxiv.org/abs/1301.1388>.
- [3] Pasero Christian. *argumentation-framework-clustering*. <https://github.com/p4s3r0/argumentation-framework-clustering>. 2024.
- [4] James P. Delgrande et al. “Current and Future Challenges in Knowledge Representation and Reasoning (Dagstuhl Perspectives Workshop 22282).” In: *Dagstuhl Manifestos* 10.1 (2024), pp. 1–61. DOI: 10.4230/DAGMAN.10.1.1. URL: <https://doi.org/10.4230/DagMan.10.1.1>.
- [5] Emmanuelle Dietz, Antonis C. Kakas, and Loizos Michael. “Editorial: Computational argumentation: a foundation for human-centric AI.” In: *Frontiers Artif. Intell.* 7 (2024). DOI: 10.3389/FRAI.2024.1382426. URL: <https://doi.org/10.3389/frai.2024.1382426>.
- [6] Phan Minh Dung. “On the Acceptability of Arguments and its Fundamental Role in Nonmonotonic Reasoning, Logic Programming and N-Person Games.” In: *Artificial Intelligence* 77.2 (1995), pp. 321–357. DOI: 10.1016/0004-3702(94)00041-x.
- [7] Phan Minh Dung. “On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games.” In: *Artificial Intelligence* 77.2 (1995), pp. 321–357. ISSN: 0004-3702. DOI: [https://doi.org/10.1016/0004-3702\(94\)00041-X](https://doi.org/10.1016/0004-3702(94)00041-X). URL: <https://www.sciencedirect.com/science/article/pii/000437029400041X>.
- [8] Wolfgang Dvorák et al. “The complexity landscape of claim-augmented argumentation frameworks.” In: *Artif. Intell.* 317 (2023), p. 103873. DOI: 10.1016/J.ARTINT.2023.103873. URL: <https://doi.org/10.1016/j.artint.2023.103873>.
- [9] Hector Geffner. “A Formal Framework for Clausal Modeling and Argumentation.” In: *Practical Reasoning, International Conference on Formal and Applied Practical Reasoning, FAPR '96, Bonn, Germany, June 3-7, 1996, Proceedings*. Ed. by Dov M. Gabbay and Hans Jürgen Ohlbach. Vol. 1085. Lecture Notes in Computer Science. Springer, 1996, pp. 208–222. DOI: 10.1007/3-540-61313-7\74. URL: https://doi.org/10.1007/3-540-61313-7%5C_74.

- [10] Dragos Constantin Popescu and Ioan Dumitrache. “Knowledge representation and reasoning using interconnected uncertain rules for describing workflows in complex systems.” In: *Inf. Fusion* 93 (2023), pp. 412–428. DOI: 10.1016/J.INFFUS.2023.01.007. URL: <https://doi.org/10.1016/j.inffus.2023.01.007>.
- [11] Zeynep G. Saribatur and Johannes Peter Wallner. “Existential Abstraction on Argumentation Frameworks via Clustering.” In: *Proceedings of the 18th International Conference on Principles of Knowledge Representation and Reasoning, KR 2021, Online event, November 3-12, 2021*. Ed. by Meghyn Bienvenu, Gerhard Lake-meyer, and Esra Erdem. 2021, pp. 549–559. DOI: 10.24963/KR.2021/52. URL: <https://doi.org/10.24963/kr.2021/52>.