

# FUDGE v3.3.4

Matthias Thimm

Artificial Intelligence Group  
University of Hagen  
Germany  
matthias.thimm@fernuni-hagen.de

Federico Cerutti

Department of Information Engineering  
University of Brescia  
Italy  
federico.cerutti@unibs.it

Mauro Vallati

School of Computing and Engineering  
University of Huddersfield  
United Kingdom  
m.vallati@hud.ac.u

**Abstract**—We present FUDGE v3.3.4, an abstract argumentation solver that tightly integrates satisfiability solving technology to solve a series of abstract argumentation problems. While most of the encodings used by FUDGE v3.3.4 derive from standard translation approaches, FUDGE v3.3.4 makes use of sophisticated encodings to solve the skeptical reasoning problem wrt. preferred semantics and problems wrt. ideal semantics.

## I. INTRODUCTION

An *abstract argumentation framework* AF is a tuple  $AF = (A, R)$  where  $A$  is a (finite) set of arguments and  $R$  is a relation  $R \subseteq A \times A$  [6]. For two arguments  $a, b \in A$  the relation  $aRb$  means that argument  $a$  attacks argument  $b$ . For a set  $S \subseteq A$  we define

$$\begin{aligned} S^+ &= \{a \in A \mid \exists b \in S, bRa\} \\ S^- &= \{a \in A \mid \exists b \in S, aRb\} \end{aligned}$$

We say that a set  $S \subseteq A$  is *conflict-free* if for all  $a, b \in S$  it is not the case that  $aRb$ . A set  $S$  *defends* an argument  $b \in A$  if for all  $a$  with  $aRb$  there is  $c \in S$  with  $cRa$ . A conflict-free set  $S$  is called *admissible* if  $S$  defends all  $a \in S$ .

Different semantics [1] can be phrased by imposing constraints on admissible sets. In particular, set  $E$

- is a *complete* (CO) extension iff it is admissible and for all  $a \in A$ , if  $E$  defends  $a$  then  $a \in E$ ,
- is a *grounded* (GR) extension iff it is complete and minimal,
- is a *stable* (ST) extension iff it is conflict-free and  $E \cup E^+ = A$ ,
- is a *preferred* (PR) extension iff it is admissible and maximal,
- is an *ideal* (ID) extension iff  $E \subseteq E'$  for each preferred extension  $E'$ ,  $E$  is admissible, and  $E$  is maximal,
- is a *semi-stable* (SST) extension  $E$  is admissible and  $E \cup E^+$  is maximal, and
- is a *stage* (STG) extension  $E$  is conflict-free and  $E \cup E^+$  is maximal.

All statements on minimality/maximality are meant to be with respect to set inclusion.

Given an abstract argumentation framework  $AF = (A, R)$  and a semantics  $\sigma \in \{CO, GR, ST, PR, ID, SST, STG\}$  we are interested in the following computational problems:

**SE- $\sigma$** : Given AF, compute some  $\sigma$ -extension.

**DC- $\sigma$** : Given AF and an argument  $a$ , decide whether  $a$  is in at least one  $\sigma$ -extension of AF.

**DS- $\sigma$** : Given AF and an argument  $a$ , decide whether  $a$  is in all  $\sigma$ -extensions of AF.

Note that DC- $\sigma$  and DS- $\sigma$  are equivalent for  $\sigma \in \{GR, ID\}$  as those extensions are uniquely defined [1]. For these, we will only consider DS- $\sigma$ .

The FUDGE v3.3.4 solver supports solving the above-mentioned computational problems wrt. all  $\sigma \in \{CO, GR, ST, PR, ID, SST, STG\}$ . In the remainder of this system description, we give a brief overview on the architecture of FUDGE v3.3.4 (Section II), highlight the changes made since the ICCMA'23 version (Section III), and conclude in Section IV.

## II. ARCHITECTURE

FUDGE v3.3.4 follows the standard reduction-based approach to solve the above-mentioned reasoning problems [2], [4] with the target formalism being the satisfiability problem SAT [3]. For example, given the problem SE-ST and an input argumentation framework  $AF = (A, R)$ , first, for each argument  $a \in A$ , we create propositional variables  $in_a$  and  $out_a$ , with the meaning that  $in_a$  (resp.  $out_a$ ) is true in a satisfying assignment iff the argument  $a$  is in (resp. attacked by) the stable extension to be found. Then

$$\Phi_1(AF) = \bigwedge_{a \in A} (\neg in_a \vee \neg out_a)$$

and

$$\Phi_2(AF) = \bigwedge_{a \in A} (out_a \Leftrightarrow \bigvee_{(b,a) \in R} in_b)$$

model the basic intuition behind these variables and, in particular, ensure conflict-freeness of the modelled extension. The constraint that all arguments not included in the extension must be attacked can be modelled by

$$\Phi_3(AF) = \bigwedge_{a \in A} (in_a \vee out_a)$$

Then the formula  $\Phi_1(AF) \wedge \Phi_2(AF) \wedge \Phi_3(AF)$  is satisfiable iff AF has a stable extension and a stable extension can be easily extracted from a satisfying assignment of  $\Phi_1(AF) \wedge \Phi_2(AF) \wedge \Phi_3(AF)$ . All reasoning problems on the first level

of the polynomial hierarchy [7] can be solved in a similar manner.

Particularly challenging problems are those wrt. preferred semantics as, in particular, *DS-PR* is  $\Pi_2^P$ -complete [7]. To solve that problem, we use the approach of [8]. This approach relies on the following observation<sup>1</sup>:

**Theorem 1** ([8]).  *$a \in A$  is skeptically accepted wrt. preferred semantics iff*

- 1) *there is an admissible set  $S$  with  $a \in S$  and*
- 2) *for every admissible set  $S$  with  $a \in S$  and every admissible set  $S'$  with  $S'RS$ , there is an admissible set  $S''$  with  $S' \cup \{a\} \subseteq S''$ .*

The above theorem states that we can decide skeptical acceptance wrt. preferred semantics by considering only those admissible sets that attack an admissible set containing the argument in question. As an admissibility check can be solved by a satisfiability check, similarly as above, the above insight leads to an algorithm that can solve *DS-PR* without actually computing preferred extensions.

Coming to ideal semantics, it is worth recalling [5, Theorem 3.3].

**Theorem 2** ([5, Theorem 3.3]). *An admissible set of arguments  $S$  is ideal iff for each argument  $a$  attacking  $S$  there exists no admissible set of arguments containing  $a$ .*

The interesting aspect of [5, Theorem 3.3] is that ideal semantics, although defined based on skeptical acceptance wrt. preferred semantics, does not rely on that notion. Moreover, in [8] we also prove that starting from the set of arguments which are not attacked by an admissible set, its largest admissible set is the ideal extension. We can therefore tweak the machinery we created for computing skeptical acceptance wrt. preferred semantics to compute the ideal extension too. The complete algorithm is presented in [8].

FUDGE v3.3.4 is written in C++ and uses the IPASIR<sup>2</sup> interface to connect to a satisfiability solver. It comes with CaDiCaL 2.1.0<sup>3</sup> pre-configured. FUDGE v3.3.4 improves over its previous version v2.4 submitted at ICCMA'21 by using a different method for calling the SAT solver, as well as streamlined encodings, and support for the semi-stable and stage semantics.

### III. CHANGES TO FUDGE v3.2.8 (ICCMMA'23 VERSION)

The most significant change is the adoption of the IPASIR interface to connect to any satisfiability solver. Further changes pertain to bug fixes and code streamlining.

### IV. SUMMARY

We presented FUDGE v3.3.4 a reduction-based solver for various problems in abstract argumentation. FUDGE v3.3.4 leverages on a mix of standard and novel SAT encodings to solve reasoning problems, with the aim of avoiding the costly

maximisation step that is characteristic of some of the abstract argumentation problems. The source code of FUDGE v3.3.4 is available at <https://github.com/aig-hagen/taas-fudge>.

### REFERENCES

- [1] Pietro Baroni, Martin Caminada, and Massimiliano Giacomin. An introduction to argumentation semantics. *The Knowledge Engineering Review*, 26(4):365–410, 2011.
- [2] Philippe Besnard, Sylvie Doutre, and Andreas Herzig. Encoding argument graphs in logic. In *International Conference on Information Processing and Management of Uncertainty in Knowledge-based Systems - IPMU 2014*, 2014.
- [3] Armin Biere, Marijn Heule, Hans van Maaren, and Toby Walsh, editors. *Handbook of Satisfiability*, volume 185 of *Frontiers in Artificial Intelligence and Applications*. IOS Press, 2009.
- [4] Federico Cerutti, Sarah A. Gaggl, Matthias Thimm, and Johannes P. Wallner. Foundations of implementations for formal argumentation. In Pietro Baroni, Dov Gabbay, Massimiliano Giacomin, and Leendert van der Torre, editors, *Handbook of Formal Argumentation*, chapter 15. College Publications, February 2018.
- [5] P. M. Dung, P. Mancarella, and F. Toni. Computing ideal sceptical argumentation. *Artificial Intelligence*, 171(10):642–674, 2007.
- [6] Phan Minh Dung. On the Acceptability of Arguments and its Fundamental Role in Nonmonotonic Reasoning, Logic Programming and n-Person Games. *Artificial Intelligence*, 77(2):321–358, 1995.
- [7] Wolfgang Dvořák and Paul E. Dunne. Computational problems in formal argumentation and their complexity. In Pietro Baroni, Dov Gabbay, Massimiliano Giacomin, and Leendert van der Torre, editors, *Handbook of Formal Argumentation*, chapter 14. College Publications, February 2018.
- [8] Matthias Thimm, Federico Cerutti, and Mauro Vallati. Skeptical reasoning with preferred semantics in abstract argumentation without computing preferred extensions. In *Proceedings of the 30th International Joint Conference on Artificial Intelligence (IJCAI'21)*, 2021.

<sup>1</sup>Define  $S'RS$  iff there is  $a \in S'$  and  $b \in S$  with  $(a, b) \in R$ .

<sup>2</sup><https://github.com/biotomas/ipasir>

<sup>3</sup><http://fmv.jku.at/cadical/>