Revisiting SAT Techniques for Abstract Argumentation

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COMMA 2020
Many existing solvers for abstract argumentation rely on reductions to satisfiability (SAT) problems. They employ existing SAT solvers for solving these subproblems. Different SAT solvers use different search strategies.

What is the impact of the choice of SAT solver?

**Our contributions:**
- miniAF: a lightweight and customizable AF solver based on SAT solving
- A general experimental evaluation on the impact of SAT solvers for solving abstract argumentation problems

See also [Gning, Mailly; SAFA20] for a very similar work.
Overview

1. Abstract argumentation
2. The reduction-based approach via SAT
3. Experiments
4. Summary
Definition (Dung, 1995)

An *abstract argumentation framework* (AA) $AF = (A, R)$ is a directed graph with nodes $A$ and directed edges $R \subseteq A \times A$. 
An extension $E$ is a set $E \subseteq A$ and is supposed to model a “plausible and jointly acceptable” set of arguments.

Definition

$E$ is **admissible** iff

1. for all $a, b \in E$ it is not the case that $aRb$,
2. for all $a \in E$, if $bRa$ then there is $c \in E$ with $cRb$

and it is **complete** if additionally

3. every argument $c$ that is defended by $E$, belongs to $E$

Definition

- $E$ is **grounded** if and only if $E$ is minimal (wrt. set inclusion).
- $E$ is **preferred** if and only if $E$ is maximal (wrt. set inclusion).
- $E$ is **stable** if and only if $E$ attacks all arguments $A \setminus E$. 
Example

\[ E = \{a_1, a_5\} \] is admissible, complete, preferred, and stable.

\[ E' = \emptyset \] is admissible, complete, and grounded.
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Let $\sigma \in \{\text{complete, preferred, } \ldots \}$

- Given $AF = (A, R)$, determine some $\sigma$-extension ($SE$)

- Given $AF = (A, R)$, determine all $\sigma$-extensions ($EE$)

- Given $AF = (A, R)$ and some $a \in A$, decide whether $a$ is contained in some $\sigma$-extension ($DC$)

- Given $AF = (A, R)$ and some $a \in A$, decide whether $a$ is contained in all $\sigma$-extension ($DS$)

Note on complexity (see e.g. [Dvořák, Dunne; 2018]):

- problems related to grounded semantics are tractable

- most other decision problems are on the first level of the polynomial hierarchy

- preferred-$DS$ is even $\Pi^P_2$-complete
Task: Find some stable extension

Argumentation framework $AF = (A, R)$

**Definition**
A stable extension $E \subseteq A$ is conflict-free and attacks every $a \in A \setminus E$.

Idea: model graph and semantics in propositional logic:
- Arguments: $in_a, in_b, in_c, \ldots$
- Conflict-freeness: $\bigwedge_{(X,Y)\in R} \neg(in_X \land in_Y)$
- Stability: $\bigwedge_{Y\in A} (\neg in_Y \iff \bigvee_{(X,Y)\in R} in_X)$
**Reduction to SAT 2/3**

\[ T_{AF} = \{ \bigwedge_{(X, Y) \in R} \neg (\text{in}_X \land \text{in}_Y), \bigwedge_{Y \in A} (\neg \text{in}_Y \iff \bigvee_{(X, Y) \in R} \text{in}_X) \} \]

**Theorem (Besnard, Doutre; 2004)**

AF has a stable extension iff \( T_{AF} \) has a model; every stable extension of AF corresponds to a model of \( T_{AF} \).

Reduction approach to AF reasoning:

\[
\begin{align*}
AF & \rightarrow T_{AF} & \rightarrow & \text{CNF} & \rightarrow & \text{SAT solver} & \rightarrow & \text{Extract extension}
\end{align*}
\]

- Similar encodings work for other semantics
- Can be used to solve tasks SE, EE, DS, DC
- Solvers: CoQuiAAS [Lagniez, Lonca, Mailly; 2019], ArgSemSAT [Cerutti et al.; 2017], \( \mu \)-toksia [Niskanen, Järvisalo; 2019], ...
Reduction to SAT 2/3

- AF $\rightarrow T_{AF} \rightarrow$ CNF $\rightarrow$ SAT solver $\rightarrow$ Extract extension

- 2 parameters:
  1. Encoding/encoding strategy
  2. SAT solver

- SAT instances of abstract argumentation problems have a very similar structure

- Different search strategies of different SAT solvers behave differently on
  - different domains,
  - different instance structures
  - different hardness categories

→ what is the impact of the choice of SAT solver?
→ what is the “best” search strategy for abstract argumentation?
miniAF

- Lightweight SAT-based argumentation solver written in C
  https://github.com/jklein94/miniAF
- Parameterisable with any SAT solver following the interface of the SAT competition
- Supports
  - Grounded semantics
  - Complete semantics
  - Preferred semantics
  - Stable semantics
- And tasks EE, SE, DC, DS
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**Setup**

**Aim:**
- Compare performance of miniAF using different SAT solvers

**Details:**
- tasks EE, SE, DC, DS, all four semantics
- ICCMA’17 benchmark data set and setting
- 12 SAT solvers (default and non-parallel configuration):
  - CaDiCal
  - Glucose
  - MapleLCMDistChronoBT-DL-v2.1
  - MapleLCMDistChronoBT-DL-v2.2
  - MapleLCMDistChronoBT-DL-v3
  - MapleLCMDistCBTcoreFirst
  - MergeSAT
  - PADC_Maple_LCM_Dist
  - PSIDS_MapleLCMDistChronoBT
  - PicoSAT
  - Relaxed_LCMDistChronoBT
  - optsat
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Insights

- Performance is generally comparable between hardness categories, but we observe some differences between categories and tasks.
- CaDiCal is significantly better than all other solvers for stable semantics.
- PicoSAT solver exhibit good results for the Very Easy, Easy and the DC instances of the Medium set, but is in the lower range for the Hard and Too Hard instances.
- Relaxed_LCMDistChronoBT system tends to achieve higher scores for the Hard and Too Hard instances, but lower scores for the Very Easy, Easy and Medium sets.
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Contributions:

▶ miniAF: a lightweight and customizable AF solver based on SAT solving
▶ A general experimental evaluation on the impact of SAT solvers for solving abstract argumentation problems

Future work:

▶ Configuration options of SAT solvers
▶ Comparison with other AF solvers
▶ Portfolio solvers

Thank you for your attention