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System Descriptions of the First International Competition on Computational Models of Argumentation (ICCMA’15)

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Preface

The objectives of the International Competition on Computational Models of Argumentation (ICCMA) are to provide a forum for empirical comparison of solvers, to highlight challenges to the community, to propose new directions for research and to provide a core of common benchmark problems and a representation formalism that can aid in the comparison and evaluation of solvers.

The First International Competition on Computational Models of Argumentation (ICCMA’15) has been conducted in the first half of 2015 and focused on reasoning tasks in abstract argumentation frameworks. Submitted solvers were tested on several artificially generated argumentation frameworks in terms of correctness and performance. More precisely, solvers were evaluated based on their performance in solving the following computational tasks:

1. Given an abstract argumentation framework, determine some extension
2. Given an abstract argumentation framework, determine all extensions
3. Given an abstract argumentation framework and some argument, decide whether the given argument is credulously inferred
4. Given an abstract argumentation framework and some argument, decide whether the given argument is skeptically inferred

The above computational tasks were to be solved with respect to the following standard semantics:

1. Complete Semantics
2. Preferred Semantics
3. Grounded Semantics
4. Stable Semantics

Developers of solvers could provide support for a subset of the above computational tasks and/or semantics were also welcomed to support further semantics.

This volume contains the system description of the 18 solvers submitted to the competition and therefore gives an overview on state-of-the-art of computational approaches to abstract argumentation problems. Further information on the results of the competition and the performance of the individual solvers can be found on at [http://argumentationcompetition.org/2015/](http://argumentationcompetition.org/2015/).

October 2015
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LabSAT-Solver: Utilizing Caminada’s Labelling Approach as a Boolean Satisfiability Problem

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Abstract. LabSAT is a solver for computing several reasoning tasks in abstract argumentation frameworks. It enumerates extensions of the complete, preferred, stable and grounded semantics. Further, LabSAT solves the problem of deciding credulously and skeptically. The solver utilizes the labelling approach by Caminada and translates it into a boolean satisfiability problem (SAT).

1 Description

LabSAT [1] is a solver for computing several reasoning tasks in abstract argumentation frameworks [2]. It utilizes the labelling approach by CAMINADA [3] and its encoding as a boolean satisfiability problem (SAT) by CERUTTI et al. [4] to compute several reasoning tasks for the complete, preferred, stable and grounded semantics. To solve the boolean satisfiability problem, the SAT solver lingeling (ayv-86bf266-140429) [5] is used.

LabSAT supports all 16 combinations of problems (enumerate, enumerate some, decide credulously and decide skeptically) and semantics (complete, preferred, stable and grounded). The supported file format is the Aspartix file format (apx).

For the implementation Java 7 is used. The connection to the SAT solver, which is implemented in C, is realized with the Java Native Interface (JNI). Every reasoning task is a combination of the type Problem and the type Reasoner. The abstract class Reasoner contains the encoding for the complete extensions. The encoding is adjusted or replaced by concrete classes, which extends the abstract class Reasoner. In addition, the abstract class Reasoner implements the interface Iterator, which allows iterative calls of the SAT solver. Concrete classes, which extend the abstract class Problem, use the Iterator and handle the results with regard to the problem. The computation is started by the method solve(reasoner: Reasoner) in the abstract class Problem.

I thank Prof. Dr. Armin Biere for granting permission to use lingeling during the ICCMA’15 contest.
1.1 Complete Extensions

The following definition describes the encoding of complete extensions of an abstract argumentation framework as given by Cerutti et al. [4] that is used in LabSAT.

**Definition 1 (Encoding of complete extensions (cf. [4])).** Given \( AF = (\mathcal{A}, \rightarrow) \), with \(|\mathcal{A}| = k\) and \(\phi : \{1, \ldots, k\} \rightarrow \mathcal{A}\) an indexing of \(\mathcal{A}\). The encoding of complete extensions defined on the variables in \(V(AF)\), is given by the conjunction of the clauses (1)-(5):

\[
\bigwedge_{i \in \{1, \ldots, k\}} ((I_i \lor O_i \lor U_i) \land (\neg I_i \lor \neg O_i) \land (\neg I_i \lor \neg U_i)) \quad (1)
\]

\[
\bigwedge_{\{i | \phi(i) = \emptyset\}} (I_i \land \neg O_i \land \neg U_i) \quad (2)
\]

\[
\bigwedge_{\{i | \phi(i) \neq \emptyset\}} \left( \neg I_i \lor \left( \bigvee_{j | \phi(j) \rightarrow \phi(i)} O_j \right) \right) \quad (3)
\]

\[
\bigwedge_{\{i | \phi(i) \neq \emptyset\}} \left( \neg O_i \lor \left( \bigvee_{j | \phi(j) \rightarrow \phi(i)} I_j \right) \right) \quad (4)
\]

\[
\bigwedge_{\{i | \phi(i) \neq \emptyset\}} \left( \left( \bigwedge_{j | \phi(j) \rightarrow \phi(i)} \neg U_i \lor \neg I_j \right) \land \left( \neg U_i \lor \left( \bigwedge_{j | \phi(j) \rightarrow \phi(i)} U_j \right) \right) \right) \quad (5)
\]

To determine all complete extensions, LabSAT iterates over all existing extensions and – after displaying the set of arguments that was retrieved – excludes the solution that resulted in satisfiable. Some extension is found by using the same mechanism, in this case the iterator is only called once.

The problem of deciding credulously is solved by adding a clause \((I_i)\) to the SAT solver. The clause ensures that the argument of search belongs to the result, if applicable. If some extension exists, the argument is credulously inferred.

To prove that an argument is in every complete extension, the solver uses the grounded extension. If the argument of search is in the minimal extension wrt. set inclusion, the argument is skeptically inferred.

1.2 Stable Extensions

To compute the stable extensions, additional clauses are added to the SAT solver. For every argument the label \texttt{undec} is excluded \((\neg U_i)\). The problems \texttt{enumerate} and \texttt{enumerate some} are computed in the same way as for the complete extensions. The same applies to the problem \texttt{decide credulously}.

In the case of deciding skeptically the iterator is called repeatedly until a counterexample – a set without the argument of search – is found. Otherwise, the argument is skeptically inferred.
1.3 Preferred Extensions

The preferred extensions are computed by using the PrefSAT algorithm published by Cerutti et al. [4]. The algorithm maximizes complete extensions wrt. set inclusion. The solver handles the problems enumerate, enumerate some and decide credulously in the same way as for the complete extensions. The problem decide skeptically is solved in the same way as for the stable extensions.

1.4 Grounded Extension

The grounded extension is computed without the use of a SAT solver. The algorithm used for the grounded extension is provided by Modgil/Caminada [6]. Since the grounded extension is unique, the problems enumerate and enumerate some are the same problem. The problems decide credulously and decide skeptically are identical problems as well. The grounded extension is computed directly and displayed or checked for the argument of search.

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ArgSemSAT-1.0: Exploiting SAT Solvers in Abstract Argumentation

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Abstract. In this paper we describe the system ArgSemSAT-1.0 which includes algorithms that efficiently address several decision and enumeration problems — associated to various semantics — in abstract argumentation.

1 Introduction

Dung’s abstract argumentation framework is one of the most widely used in computational argumentation by virtue of its simplicity and ability to capture a variety of more specific approaches as special cases. An abstract argumentation framework (AF) consists of a set of arguments and an attack relation between them. The concept of extension plays a key role in this simple setting: intuitively, it is a set of arguments which can “survive together.” Different notions of extensions and of the requirements they should satisfy correspond to alternative argumentation semantics. The main computational problems in abstract argumentation are related to extensions and can be partitioned into two classes: decision problems and functional problems [10].

In this paper we illustrate ArgSemSAT-1.0, a collection of algorithms [6–8] for solving enumeration and sceptical/credulous acceptance problems for grounded, complete, preferred and stable semantics.

2 Background

An argumentation framework [9] consists of a set of arguments⁴ and a binary attack relation between them.

Definition 1. An argumentation framework (AF) is a pair \( \Gamma = (A, R) \) where \( A \) is a set of arguments and \( R \subseteq A \times A \). We say that \( b \) attacks \( a \) iff \( \langle b, a \rangle \in R \), also denoted as \( b \rightarrow a \). The set of attackers of an argument \( a \) will be denoted as \( a^- \equiv \{ b : b \rightarrow a \} \).

⁴ In this paper we consider only finite sets of arguments: see [3] for a discussion on infinite sets of arguments.
The basic properties of conflict–freeness, acceptability, and admissibility of a set of arguments are fundamental for the definition of argumentation semantics.

**Definition 2.** Given an AF $\Gamma = \langle A, R \rangle$:

- a set $S \subseteq A$ is conflict–free if $\nexists a, b \in S$ s.t. $a \rightarrow b$;
- an argument $a \in A$ is acceptable with respect to a set $S \subseteq A$ if $\forall b \in A$ s.t. $b \rightarrow a$, $\exists c \in S$ s.t. $c \rightarrow b$;
- a set $S \subseteq A$ is admissible if $S$ is conflict–free and every element of $S$ is acceptable with respect to $S$.

An argumentation semantics $\sigma$ prescribes for any AF $\Gamma$ a set of extensions, denoted as $E_\sigma(\Gamma)$, namely a set of sets of arguments satisfying some conditions dictated by $\sigma$.

**Definition 3.** Given an AF $\Gamma = \langle A, R \rangle$:

- a set $S \subseteq A$ is a complete extension, i.e. $S \in E_{\text{CO}}(\Gamma)$, iff $S$ is admissible and $\forall a \in A$ s.t. $a$ is acceptable w.r.t. $S$, $a \in S$;
- a set $S \subseteq A$ is a preferred extension, i.e. $S \in E_{\text{PR}}(\Gamma)$, iff $S$ is a maximal (w.r.t. set inclusion) complete set;
- a set $S \subseteq A$ is the grounded extension, i.e. $S \in E_{\text{GR}}(\Gamma)$, iff $S$ is the minimal (w.r.t. set inclusion) complete set;
- a set $S \subseteq A$ is a stable extension, i.e. $S \in E_{\text{ST}}(\Gamma)$, iff $S$ is a complete set where $\forall a \in A \setminus S, \exists b \in S$ s.t. $b \rightarrow a$.

Each extension implicitly defines a three-valued labelling of arguments (cf. Def. 4). In the light of this correspondence, argumentation semantics can equivalently be defined in terms of labellings rather than of extensions (see [4, 2]). In particular, the notion of complete labelling [5, 2] provides an equivalent characterization of complete semantics, in the sense that each complete labelling corresponds to a complete extension and vice versa. Complete labellings can be (redundantly) defined as follows.

**Definition 4.** Let $\langle A, R \rangle$ be an argumentation framework. A total function $\text{Lab} : A \rightarrow \{\text{in}, \text{out}, \text{undec}\}$ is a complete labelling iff it satisfies the following conditions for any $a \in A$:

- $\text{Lab}(a) = \text{in} \iff \forall b \in a^- \text{Lab}(b) = \text{out}$;
- $\text{Lab}(a) = \text{out} \iff \exists b \in a^- : \text{Lab}(b) = \text{in}$;
- $\text{Lab}(a) = \text{undec} \iff \forall b \in a^- \text{Lab}(b) \neq \text{in} \land \exists c \in a^- : \text{Lab}(c) = \text{undec}$.

It is proved in [4] that:

- preferred extensions are in one-to-one correspondence with those complete labellings maximising the set of arguments labelled in;
- the grounded extension is in one-to-one correspondence with the complete labelling maximising the set of arguments labelled undec;
- stable extensions are in one-to-one correspondence with those complete labellings with no argument labelled undec.
ArgSemSAT-1.0 is a set of search algorithms in the space of complete extensions to identify also preferred, stable and the grounded extensions (enumeration problems) as well as solving decisions problems associated to those semantics, namely credulous and skeptical acceptance of an argument. ArgSemSAT-1.0 encodes the constraints corresponding to complete labellings of an AF as a SAT problem and then iteratively producing and solving modified versions of the initial SAT problem according to the needs of the search process. ArgSemSAT-1.0 has been implemented in C++, and exploits the Glucose SAT solver [1].

For instance, Alg. 1 shows the general idea of the current implementation in ArgSemSAT-1.0 for enumerating preferred extensions.

### Algorithm 1 Enumeration of Preferred Extensions

```
Input: Γ = ⟨A, R⟩
Output: Ep ⊆ \(2^{A}\)
Ep := Ø
cnf := \(\Pi(Γ) \land \bigvee_{a \in A} I^{-1}_a(a)\)
repeat
  cnfdf := cnf
  prefcand := Ø
  repeat
    lastcompfound := SATSOLV(cnf)
    if lastcompfound ≠ Ø then
      emptyundec := UNDECARGS(lastcompfound) = Ø
      prefcand := lastcompfound
      for a ∈ INARGS(lastcompfound) do
        cnfdf := cnfdf \land I^{-1}_a(a)
      end for
      remaining := FALSE
      for a ∈ OUTARGS(lastcompfound) do
        cnfdf := cnfdf \land O^{-1}_a(a)
        remaining := remaining \lor I^{-1}_a(a)
      end for
      for a ∈ UNDECARGS(lastcompfound) do
        remainingdf := remaining \land \neg I^{-1}_a(a)
        cnf := cnf \land remainingdf
      end for
      cnf := cnf \land remaining
    end if
  until (lastcompfound = Ø \lor emptyundec = Ø)
  if prefcand ≠ Ø then
    Ep := Ep \cup (INARGS(prefcand))
  end if
until (prefcand = Ø \lor prefcand = A)
if Ep = Ø then
  Ep = {Ø}
end if
return Ep
```

In Alg. 1, \(\Pi(Γ)\) is a CNF representing the constraints for complete labellings; \(\phi^{-1}: A \mapsto \mathbb{N}; I_j\) (resp. \(O_j\) and \(U_j\)) is a SAT variable identifying the case that the \(j\)-th argument is in (resp. out and undec); SATSOLV is a SAT solver which returns a
satisfiable assignment of variables or \( \varepsilon \) if UNSAT; \( \text{INARGS} \) (reps. \( \text{OUTARGS} \) and \( \text{UNDECARGS} \)) is a function that takes as input a variable assignment and returns the set of arguments labelled as \( \text{in} \) (resp. \( \text{out} \) and \( \text{undec} \)) in such an assignment.

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ArgTools: a backtracking-based solver for abstract argumentation

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Abstract. We present ArgTools, a system for reasoning with abstract argumentation frameworks. The system solves a number of argumentation problems under preferred, stable, complete and grounded semantics. ArgTools is a C++ implementation of a backtracking algorithm.

Keywords: algorithms, argumentation semantics, automated reasoning.

1 Introduction

Abstract argumentation frameworks (AFs), introduced in \cite{4}, are an important model of automated reasoning \cite{2}. An AF is a pair \((A, R)\) where \(A\) is a set of abstract arguments and \(R \subseteq A \times A\) is a binary relation. Argumentation semantics are concerned with defining the acceptable arguments in a given AF. There are a number of semantics for different motivations, see \cite{1} for an overview. Several problems related to argumentation semantics are computationally hard \cite{5}. Algorithms for solving these problems can be either direct or indirect \cite{3}. Indirect approaches are reduction-based methods such that the problem at hand is translated to another form to be solved by an off-the-shelf system. Direct approaches are dedicated algorithms that search for a solution to the input AF. In this paper we present ArgTools (short for Argumentation Tools), a system based on backtracking algorithms for solving problems under preferred, stable, complete and grounded semantics. In section 2 we give the definition of these semantics and specify the problems solved by ArgTools. Then, in section 3 we discuss the underlying approach of ArgTools. Lastly, in section 4 we conclude the paper.

2 Problems solved by ArgTools

We recall the definition of AFs, originally introduced in \cite{4}. An argumentation framework (or AF) is a pair \((A, R)\) where \(A\) is a set of arguments and \(R \subseteq A \times A\) is a binary relation, see figure 1 for an example AF. We refer to \((x, y) \in R\) as \(x\) attacks \(y\) (or \(y\) is attacked by \(x\)). We denote by \(\{x\}^-\) respectively \(\{x\}^+\) the subset of \(A\) containing those arguments that attack (resp. are attacked by) the argument \(x\).
Fig. 1. An AF, as a directed graph, with $A = \{a, b, c\}$ and $R = \{(a, b), (b, c), (c, b)\}$.

Given a subset $S \subseteq A$, then

- $x \in A$ is acceptable w.r.t. $S$ if and only if for every $(y, x) \in R$, there is some $z \in S$ for which $(z, y) \in R$.
- $S$ is conflict free if and only if for each $(x, y) \in S \times S$, $(x, y) \notin R$.
- $S$ is admissible if and only if it is conflict free and every $x \in S$ is acceptable w.r.t. $S$.
- $S$ is a preferred extension if and only if it is a $\subseteq$-maximal admissible set.
- $S$ is a stable extension if and only if it is conflict free and for each $x \notin S$ there is $y \in S$ such that $(y, x) \in R$.
- $S$ is a complete extension if and only if it is an admissible set such that for each $x$ acceptable w.r.t. $S$, $x \in S$.
- $S$ is the grounded extension if and only if it is the $\subseteq$-least complete extension.

ArgTools solves problems under preferred, stable, complete and grounded semantics. The problems are:

- Given an AF $H = (A, R)$, ArgTools enumerates all extensions of $H$.
- Given an AF $H = (A, R)$, ArgTools finds an extension of $H$.
- Given an AF $H = (A, R)$ and an argument $a \in A$, ArgTools decides whether $a$ is in some extension of $H$.
- Given an AF $H = (A, R)$ and an argument $a \in A$, ArgTools decides whether $a$ is in all extensions of $H$.

3 The approach of ArgTools

To give an idea about the approach of ArgTools we present algorithm 1 that enumerates all preferred extensions of a given AF. The algorithm is a backtracking procedure that traverses an abstract binary search tree. A core notion of the algorithm is related to the use of five labels: IN, OUT, MUST_OUT, BLANK and UNDEC. Informally, the IN label identifies arguments that might be in a preferred extension. The OUT label identifies an argument that is attacked by an IN argument. The BLANK label is for any unprocessed argument whose final label is not decided yet. The MUST_OUT label identifies arguments that attack IN arguments. The UNDEC label designates arguments which might not be included in a preferred extension because they might not be defended by any IN argument. To enumerate all preferred extensions algorithm 1 starts with BLANK as the default label for all arguments. This initial state represents the root node of the search tree. Then the algorithm forks to a left (resp. right) child (i.e. state)
ArgTools: a backtracking-based solver for abstract argumentation

by picking an argument, that is BLANK, to be labeled IN (resp. UNDEC). Every
time an argument, say $x$, is labeled IN some of the neighbour arguments’ labels
might change such that for every $y \in \{x\}^+$ the label of $y$ becomes OUT and for
evory $z \in \{x\}^- \setminus \{x\}^+$ the label of $z$ becomes MUST_OUT. This process, i.e.
forking to new children, continues until there is no argument with the BLANK
label. At this point, the algorithm captures the set $S = \{x \mid$ the label of $x$ is IN\}$
as a preferred extension if and only if there is no argument with the MUST_OUT
label and $S$ is not a subset of a previously found preferred extension (if such ex-
ists). Then the algorithm backtracks to find all preferred extensions. Figure 2
shows how algorithm 1 lists the preferred extensions of the AF of figure 1.

Algorithm 1: Enumerating all preferred extensions of an AF $H = (A, R)$.

1. $Lab : A \to \{IN, OUT, BLANK, MUST_OUT, UNDEC\}; \; Lab \leftarrow \emptyset;$
2. foreach $x \in A$ do $Lab \leftarrow Lab \cup \{(x, BLANK)\};$
3. foreach $(x, x) \in R$ do $Lab(x) \leftarrow UNDEC;$
4. $E \subseteq 2^A; \; E \leftarrow \emptyset;$
5. call build-preferred-extensions($Lab$);
6. report $E$ is the set of all preferred extensions;
7. procedure build-preferred-extensions($Lab$)
8. if $\nexists x$ with $Lab(x) = BLANK$ then
9. if $\nexists x$ with $Lab(x) = MUST_OUT$ then
10. $S \leftarrow \{y \mid Lab(y) = IN\};$
11. if $\forall T \in E \; S \not\subseteq T$ then $E \leftarrow E \cup \{S\};$
12. else
13. select any $x$ with $Lab(x) = BLANK;$
14. $Lab' \leftarrow Lab; \; Lab'(x) \leftarrow IN;$
15. foreach $y \in \{x\}^+$ do $Lab'(y) \leftarrow OUT;$
16. foreach $y \in \{x\}^- \setminus \{x\}^+$ do $Lab'(y) \leftarrow MUST_OUT;$
17. call build-preferred-extensions($Lab'$);
18. $Lab' \leftarrow Lab; \; Lab'(x) \leftarrow UNDEC;$
19. call build-preferred-extensions($Lab'$);
20. end procedure

4 Conclusion

ArgTools has been coded in the C++ language; the source code and the usage are
available at http://sourceforge.net/projects/argtools/. For space limitation we did not discuss (in full detail) the underlying algorithms of ArgTools;
for the full presentation of the algorithms we refer the reader to [7, 6]. However,
ArgTools incorporates new enhancements that we plan to present in future in
an extended article.
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CEGARTIX v0.4: A SAT-Based Counter-Example Guided Argumentation Reasoning Tool

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Abstract. We present CEGARTIX in version 0.4 for the International Competition on Computational Models of Argumentation (ICCMA) 2015. We describe the main parts of the software architecture, the main ideas behind the algorithm, ICCMA 2015 specific adaptations, and how to obtain CEGARTIX.

1 System Architecture

CEGARTIX (Counter-Example Guided Argumentation Reasoning Tool) [2] traverses the search space of a so-called base semantics of a given argumentation framework (AF) [1] to find preferred, semi-stable, or stage extensions. For preferred and semi-stable semantics the base semantics can either be complete or admissible semantics, while for stage semantics the base semantics comprises of the conflict-free sets. Each “step” in the traversal is delegated to a state-of-the-art complete Boolean satisfiability (SAT) solver. The main components of CEGARTIX’s system architecture are shown in Fig. 1. The system takes as input an AF in the “ASPARTIX format” [4], i.e., a list of facts in the answer-set programming (ASP) language. The main procedure drives the overall algorithm and (i) translates the given AF and reasoning task to a Boolean formula, (ii) modifies the formula or generates new formulas based on previously found extensions of the base semantics, and (iii) calls the specified SAT solver with the current formula and reads the returned model if it exists. CEGARTIX incorporates miniSAT (v2.2.0) [3] and clasp (v2.0.5) [5] (utilizing the clasp library and interface), and is able to write the formula to an external SAT solver that adheres to standard input and output of such solvers according to the SAT solver competitions [6].

2 Algorithm

Algorithm 1 shows the underlying procedure (“main procedure” in Fig. 1) for skeptical acceptance under preferred semantics, which is prototypical also for the
other variants. By $\sigma$ we denote the base semantics, i.e. the semantics we traverse for finding a preferred extension not containing the queried argument $\alpha$. After a shortcut for checking whether a $\sigma$-extension exists which attacks $\alpha$, we begin with the main algorithm which consists of two while loops. We first generate a $\sigma$-extension not contained in already visited extensions ($E$). Then this $\sigma$ extension is iteratively extended to a preferred extension in the inner while loop. If the inner while loop terminates, then we have found a preferred extension which is checked if it is a counterexample for skeptical acceptance of $\alpha$. Termination of the outer while loop signifies that we have exhausted the search space. More details can be found in [2], including the precise Boolean formulas used. For finding all preferred extensions, we simply omit the queried argument from consideration.

2.1 Supported Reasoning Tasks

CEGARTIX v0.4 supports the following reasoning tasks:

- Credulous acceptance under semi-stable, and stage semantics,
- Skeptical acceptance under preferred, semi-stable, and stage semantics,
- returning an arbitrary preferred extension, and
- enumerating all preferred extensions.
3 Competition Specific Settings

For ICCMA 2015, we have adapted CEGARTIX as follows. First, we extended the reasoning tasks by enumeration of all preferred extensions, and finding a single preferred extension. This modification is straightforwardly obtained by essentially omitting the queried argument from the main Algorithm 1. Furthermore, we fixed the base semantics (\(\sigma\) in Algorithm 1) to complete semantics. In earlier tests, complete semantics outperformed admissible semantics on some test instances [2]. We pre-set the SAT-solver to be clasp for the competition.

4 Web Access and License

CEGARTIX v0.4 is available on the web under http://www.dbai.tuwien.ac.at/research/project/argumentation/cegartix/. Since the software incorporates clasp, the whole software is licensed under GNU public license v2. We accompany the package with a readme file that explains usage. Overall, this version of CEGARTIX adheres to the ICCMA 2015 input and output specification; the shell script has to be called, which in turn calls CEGARTIX.

Acknowledgements

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Abstract. This paper describes Dungell, an open source Haskell implementation of Dung’s argumentation frameworks capable of solving decision and enumeration problems for grounded, complete, preferred, stable and semi-stable semantics. The Dungell application and its accompanying library provide an implementation that is closely aligned to the mathematical definitions, serving as a specification in its own right.

1 Introduction

The Dungell application and its accompanying library provide a Haskell implementation of Dung’s argumentation frameworks [2]. The library supplies implementations for the standard definitions and semantics, including grounded, complete, preferred and stable semantics, but also conflict-freeness, admissibility and various others.

In addition to Dung’s definitions, the implementation also provides implementations for the definitions and algorithms of the labelling approach to argumentation [1]. In particular, the library implements labelling algorithms and definitions for Dung’s four semantics and the semi-stable semantics.

2 Design philosophy

There are various other efficient solvers that exist for AFs, which are most likely faster than Dungell. Instead, the approach taken in the implementation of Dungell, is to provide an implementation that is as clear and close to the mathematical definitions as possible. The main reasons this approach is taken, is that:

– the library becomes intuitive, reproducible and easier to verify;
– the implemented definitions can more easily be converted to and proven correct in a theorem prover;
– the library can be used as a translation target.

The library also provides output formats readable by the current fastest implementations.
The combination of these features is intended to allow implementers of structured argumentation models to use Dungell to implement a translation from a structured model into Dungell, possibly performing formal verification as well. Further details of the implementation and the general design can be found in previous papers [3, 4, 5, 6].

3 Implementation of the enumeration of complete and preferred extensions

This section gives an illustration of the approach taken in Dungell by demonstrating how the enumeration of complete and preferred extensions are implemented in (a slightly stylised version of) Haskell. The code in this section is almost self-contained\(^1\).

An abstract argumentation framework consists of a set of arguments and a binary relation on these arguments, representing attack. The Haskell counterpart of this definition takes the form of an algebraic data type:

\[
\text{data DungAF arg} = \text{AF [arg] [(arg, arg)]}
\]

Note how this essentially is a transliteration of the mathematical definition, even if lists are used in place of sets. Additionally, the definition is parametrised on the type of argument, arg.

\[
A \rightarrow B \rightarrow C
\]

Fig. 1. An (abstract) argumentation framework

Given an argumentation framework using labels as the type of abstract argument we can represent this in Haskell using Strings.

\[
\text{type AbsArg} = \text{String}
\]

\[
a, b, c :: \text{AbsArg}
\]

\[
a = "A"; b = "B"; c = "C"
\]

\[
AF_1 :: \text{DungAF AbsArg}
\]

\[
AF_1 = \text{AF [a, b, c] [(a, b), (b, c)]}
\]

Haskell can define functions by pattern matching on the shape of an algebraic data type, splitting the definition into multiple lines for each type of shape. For example, the powerset function on lists, can be recursively defined as follows:

\[
\begin{align*}
\text{powerset} :: [a] \rightarrow [[a]]
\text{powerset} [\ ] &= [[]]
\text{powerset} (x : xs) &= \text{powerset} xs \uplus \text{map} (x) (\text{powerset} xs)
\end{align*}
\]

\(^1\) The complete source code of this section can be run by the Haskell compiler and can be downloaded at: http://www.cs.nott.ac.uk/~bmv/Code/dungell_iccma.lhs.
Given an argumentation framework for which we can check whether arguments are equal (\(Eq\ arg\)), it is possible to verify whether a list of arguments is conflict-free by checking that the list of attacks between those arguments is empty by using \(null\).

\[
\text{conflictFree} :: \text{Eq arg} \Rightarrow \text{DungAF arg} \rightarrow [\text{arg}] \rightarrow \text{Bool}
\]

\[
\text{conflictFree} (\text{AF def}) \text{args} = \text{null} [(a, b) | (a, b) \leftarrow \text{def}, a \in \text{args}, b \in \text{args}]
\]

Acceptability of an argument w.r.t. a set of arguments in an AF can be determined by verifying that all its attackers are in return attacked by an attacker in that set. The call \(\text{setAttacks af args b}\) returns \(True\) if any argument in the set \(\text{args}\) attacks the argument \(b\); the \(\text{and}\) function below is being equivalent to \(\land\).

\[
\text{acceptable} :: \text{Eq arg} \Rightarrow \text{DungAF arg} \rightarrow \text{arg} \rightarrow [\text{arg}] \rightarrow \text{Bool}
\]

\[
\text{acceptable af @ (AF def) a args} = \text{and} [\text{setAttacks af args b} | (b, a') \leftarrow \text{def}, a \equiv a']
\]

The characteristic function of an argumentation framework, calculates the set of arguments acceptable w.r.t. a given set of arguments. Admissibility of a set of arguments is then determined by verifying that the set is conflict-free and a subset of the characteristic function applied to that set. The \(\text{Ord arg}\) requires the argument type to be comparable, implying the existence of an equality (\(Eq\ arg\)) between arguments.

\[
f :: \text{Eq arg} \Rightarrow \text{DungAF arg} \rightarrow [\text{arg}] \rightarrow [\text{arg}]
\]

\[
f \text{af @ AF args'} = [a | a \leftarrow \text{args'}, \text{acceptable af a args}]
\]

\[
\text{admissible} :: \text{Ord arg} \Rightarrow \text{DungAF arg} \rightarrow [\text{arg}] \rightarrow \text{Bool}
\]

\[
\text{admissible af args} = \text{conflictFree af args} \land \text{args} \subseteq f \text{af args}
\]

Given an argumentation framework, the set of complete extensions can be calculated by taking all sets of arguments of the powerset of arguments of that AF, given that they are admissible and \(f_{AF} x \equiv x\).

\[
\text{completeF} :: \text{Ord arg} \Rightarrow \text{DungAF arg} \rightarrow [[\text{arg}]]
\]

\[
\text{completeF af @ AF args} =
\]

\[
\text{let} f_{AF} = f \text{af}
\]

\[
\text{in filter} (\lambda x \rightarrow \text{admissible af x} \land f_{AF} x \equiv x) (\text{powerset args})
\]

Finally, the set of preferred extensions can be obtained by applying an appropriate filter on the complete extension, i.e. a complete extension is also a preferred extension if it is not a subset of one the other complete extensions.

\[
\text{isPreferredExt} :: \text{Ord arg} \Rightarrow \text{DungAF arg} \rightarrow [[\text{arg}]] \rightarrow [\text{arg}] \rightarrow \text{Bool}
\]

\[
\text{isPreferredExt af exts ext} = \text{all} (\neg \circ (\text{ext} \subseteq)) \ (\text{delete ext exts})
\]

\[
\text{preferredF} :: \text{Ord arg} \Rightarrow \text{DungAF arg} \rightarrow [[\text{arg}]]
\]

\[
\text{preferredF af @ AF args} =
\]

\[
\text{let cs = completeF af}
\]

\[
\text{in filter} (\text{isPreferredExt af cs}) \text{ cs}
\]
4 Installation and usage instructions

The source code of the Dungell application is available under an open source license (BSD3). It can be downloaded and installed:

– as a bundled zip file, including external libraries at: http://www.cs.nott.ac.uk/~bmv/Code/dungell_bundled.zip;
– or as a Haskell library at: https://github.com/nebasuke/DungICCMA.

The user is required to install a recent Haskell distribution (GHC 7.8.4 or higher for the bundled zip file). After downloading the source files the Dungell executable can be compiled by using cabal install in the toplevel directory containing the Dungell.cabal file. Detailed usage and installation instructions can be found at: www.cs.nott.ac.uk/~bmv/DungICCMA/.

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ZJU-ARG: A Decomposition-Based Solver for Abstract Argumentation

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Abstract. This paper gives the system description of a solver for abstract argumentation ZJU-ARG submitted to the First International Competition on Computational Models of Argumentation (ICCMA'15). It adopts a decomposition-based approach to enumerate preferred extensions (labellings) of an abstract argumentation framework, and is implemented in Java. The efficiency of this solver highly depends on the topologies of argumentation frameworks.

1 System architecture

The solver ZJU-ARG is based on our previous work for efficient computation of argumentation semantics [1–6]. It enumerats all preferred labellings (or preferred extensions), and the grounded labelling (or the grounded extension) of an argumentation framework (AF). Given an AF, its extension(s) is(are) obtained by means of computing its labelling(s).

While the grounded labelling of an AF is computed directly by Modgil and Caminada’s algorithm [7], we use a decomposition-based approach originally presented in [1], to enumerate all preferred labellings:

Given an AF, it is preprocessed by differentiating accepted/rejected arguments and undecided arguments under grounded semantics, by means of computing its grounded labelling. Then, a modified framework (denoted as AF’) only containing the undecided arguments is decomposed into a set of sub-frameworks by exploiting its strongly connected components (SCCs). Here, sub-frameworks can be unconditioned and/or conditioned [6]. These sub-frameworks are organized into several layers conforming to the partial order of the SCCs of the AF’. Then, the preferred labellings of the AF’ are computed and combined incrementally, from the lowest layer in which each sub-framework is not restricted by other sub-frameworks, to the highest layer in which each sub-framework is at most restricted by the sub-frameworks located in the lower layers. In this step, the algorithms for computing the preferred labellings of each sub-framework are either Modgil and Caminada’s algorithm [7] or a revised version of this algorithm. Finally, each preferred labelling of AF’ is revised by adding the accepted and rejected arguments identified in the preprocessing step, to form a preferred labelling of the AF. Readers are referred to [5–7] for detailed notions, algorithms and empirical results of this approach.
Compared to the SCC-Recursiveness schema [8], an important characteristic of ZJU-ARG is that the concept of modularity of argumentation (in terms of sub-frameworks) is proposed and exploited. For further development of this notion, please refer to [9].

Since ZJU-ARG solver adopts the divide and conquer strategy, but without using more efficient algorithms to compute the semantics of each sub-framework, its efficiency highly depends on the topologies of argumentation frameworks.

The source code of ZJU-ARG as well as the instructions on how to use it are available at http://mypage.zju.edu.cn/en/beishui/685664.html.

2 Design choices and lessons learned

The first version of the solver was originally presented in [4–6], without considering the efficiency problem for competition. In this version, we add some additional components to meet the rules of the competition, but without considering the improvement of the efficiency of the solver. Some considerations to improve the solver are as follows.

First, since the efficiency of this solver highly depends on the topologies of argumentation frameworks, we will improve the solver in the following ways:

- Use the decomposition-based approach recursively.
- Propose an approach to decompose the AFs that are not sparse, by using some existing theories (for instance argumentation multipoles [9]).

Second, the solver could be made more efficient by replacing Modgil and Caminadas algorithms[7] for computing the labellings of each sub-framework with some more efficient algorithms.

Third, the current version of the solver is basically oriented to computing the preferred labellings of an AF. In our future work, we will extend it to be applicable under some other important semantics, such as stable and ideal, etc.

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ASPARTIX-V: Utilizing Improved ASP Encodings

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Abstract. ASPARTIX-V is a novel system for solving reasoning tasks for argumentation frameworks under preferred semantics. Similarly to its predecessor, it calls a state-of-the-art ASP solver with ASP encodings tuned for performance. We describe the system architecture, the main components, and how to obtain ASPARTIX-V.

1 System Architecture

ASPARTIX-V (Answer Set Programming Argumentation Reasoning Tool – Vienna) takes as input an argumentation framework (AF) \(\text{[1]}\) in \(\text{apx}\) format \(\text{[2]}\). Together with an answer-set programming (ASP) encoding for preferred semantics, the answer-sets are in a 1-to-1 correspondence with the preferred extensions of the given AF. Utilizing capabilities of modern ASP solvers, we can straightforwardly augment this workflow (see Fig. 1) to support the desired reasoning tasks. ASP solvers themselves offer enumeration of all answer-sets and returning an arbitrary one. For query-based reasoning, we add a single ASP constraint stating that the queried argument has to be outside the preferred extension (skeptical reasoning). Unsatisfiability of the resulting program means that the queried argument is skeptically accepted.

The underlying ASP solver is \textit{clingo 4.4} \([5, 6]\). We in particular make use of the conditional literal \([7, 4]\) language extension offered by \textit{clingo}.

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig1.png}
\caption{ASPARTIX-V system architecture}
\end{figure}
2 Novel ASP Encodings

The predecessor of ASPARTIX-V is ASPARTIX [2]. In both systems, preferred semantics is encoded as a disjunctive logic program. While the latter makes heavy use of so-called loop constructs in ASP, our new system is able to do without and uses conditional literals for enhancing performance. Intuitively, conditional literals allow to use, e.g., a dynamic head in a disjunctive rule that contains a literal iff its condition is true. The loop constructs can be avoided by alternative characterizations of preferred semantics.

We briefly sketch some of the main ideas of our novel encoding for preferred semantics. For both ASPARTIX and ASPARTIX-V the so-called saturation technique (which originates from the complexity analysis of disjunctive logic programs [3]) is employed. Intuitively, in the saturation technique encodings for preferred semantics we make a first “guess” for a set of arguments in the framework, and then verify if this set is admissible. To verify if this set is also subset maximal admissible, we perform a second guess and verify if this second guess is an admissible set that is a superset of the first guess. Usage of default negation within the saturation technique for the second guess is restricted, and thus in ASPARTIX a loop-style encoding checks if the second guess is admissible. Roughly, a loop construct in ASP checks a certain property for the least element in a set, and then “iteratively” for each (immediate) successor. If the property holds for the greatest element, it holds for all elements. In our encoding, the second guess is constructed using a disjunctive rule with a dynamic head. We illustrate the main idea in Listing 1.1.

Listing 1.1. Rule with dynamic head

\[
\text{witness}(Z) : \text{att}(Z,Y) \leftarrow \text{witness}(X), \text{att}(Y,X).
\]

The atoms with the predicate \text{witness} correspond to the second guess. After making sure that the second guess is non-empty (via another rule), this disjunctive rule with conditional literals “adds” for attacked witnesses other witnesses that defend them. The idea is to keep this second guess small to overcome computational overhead. Additional rules then verify if the witness set represents an admissible set that may be combined with the first guess to result in a larger admissible set. If this is the case, the first guess does not represent a preferred extension.

2.1 Supported Reasoning Tasks

ASPARTIX-V supports the following reasoning tasks:

– skeptical acceptance under preferred semantics,
– returning a single preferred extension, and
– enumerating all preferred extensions.
3 Competition Specific Settings

For conforming to the ICCMA 2015 specifications, we utilized a (slightly modified) bash script from the competition that in particular takes care of the correct output formatting. After initial explorative performance testing, we decided to use clingo in its default setting, i.e., not using non-standard heuristical settings.

4 Web Access and License

The novel encodings are available from \url{http://www.dbai.tuwien.ac.at/proj/argumentation/systempage/} under “encodings for clingo using conditional disjunction”. For running the encodings, clingo 4.4 is required, which can be downloaded from \url{http://potassco.sourceforge.net}. Notice that clingo 4.4 is published under the GNU public license (version 3).

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CoQuiAAS: Application of Constraint Programming for Abstract Argumentation *

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Abstract. This paper is a description of our proposal to use Constraint Programming techniques to develop a software library dedicated to argumentative reasoning. We present a library which offers the advantages to be generic and easily adaptable.

1 Introduction

An abstract argumentation framework (AF) [1] is a directed graph where the nodes represent abstract entities called arguments and the edges represent attacks between these arguments. The meaning of such a graph is determined by an acceptability semantics, which indicates which properties a set of arguments must satisfy to be considered as a ’solution’ of the problem; such a set of arguments is then called an extension.

To compute usual reasoning tasks (credulous or skeptical acceptance of an argument, computation of an extension, enumeration of all the extensions) for the classical semantics (grounded, stable, preferred, complete), we propose to use Constraint Programming techniques, since this domain already proposes some very efficient solutions to solve high complexity combinatorial problems. We are in particular interested in propositional logic and some formalisms derived from it. More precisely, we use some CNF formulae to solve problems from the first level of the polynomial hierarchy, and some encodings in the Partial Max-SAT formalism for higher complexity problems. We take advantage of these encodings to solve these reasoning tasks, using some state-of-the-art approaches and software, which have proven their practical efficiency.

We have encoded those approaches for argumentation-based reasoning in a software library called CoQuiAAS. The aim of CoQuiAAS is dual. First, we provide some efficient algorithms to tackle the main requests for the usual semantics. Then, our framework is designed to be upgradable: one may easily add some new parameters (request, semantics), or realize new algorithm for the tasks which are already implemented. A first version is available on-line: http://www.cril.univ-artois.fr/coquiaas.

2 Example of Logical Encoding

We take advantage of the encodings proposed by [2] to design an approach to compute the extensions of an argumentation framework, and also to determine if an argument is

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In this section, we only exemplify our approach on the stable semantics. Our encodings are based on propositional logic, defined with the usual connectives on the set of Boolean variables \( V_A = \{ x_{a_i} \mid a_i \in A \} \). The propositional variable \( x_{a_i} \) denotes the fact the argument \( a_i \) is accepted by \( F \). For a matter a readability, we use in the following \( a_i \) rather than \( x_{a_i} \). \( \Phi_{st}^F \) is a propositional formula from this language such that its models match the stable extensions of \( F \).

In addition to computing a single extension and enumerating every extension, this encoding also allows us to answer the other requests for the stable semantics:

- Computing one (resp. each) stable extension of \( F \) is equivalent to the computation of one (resp. each) model of \( \Phi_{st}^F \).
- \( a_i \) is credulously accepted by \( F \) w.r.t. the stable semantics iff \( \Phi_{st}^F \land a_i \not\models \bot \).
- \( a_i \) is skeptically accepted by \( F \) w.r.t. stable semantics iff \( \Phi_{st}^F \land \neg a_i \not\models \bot \).

A similar reasoning scheme from Besnard and Doutre encoding of complete semantics lead us to define a procedure for each reasoning task under the complete semantics. It is the case that unit propagation on the encoding of complete semantics allows to perform grounded reasoning, while preferred reasoning requires a transformation of the complete semantics encoding into a Partial Max-SAT instance such that each preferred extension correspond to one of its Maximal Satisfiable Set (MSS).

### 3 CoQuiAAS : Design of the Library

We have chosen the language C++ to implement CoQuiAAS to take advantage of the Object Oriented Programming (OOP) paradigm and its good computational efficiency. First, the use of OOP allows us to give CoQuiAAS an elegant conception, which is well suited to maintain and upgrade the software. Moreover, C++ ensures having high computing performances, which is not the case of some other OOP languages. At last, it makes easier the integration of coMSSExtractor, a C++ underlying tool we used to solve the problems under consideration.

coMSSExtractor [3] is a software dedicated to extract MSS/coMSS pairs from a Partial Max-SAT instance. As coMSSExtractor integrates the Minisat SAT solver [4] – which is used as a black box to compute MSSes – the API provided by coMSSExtractor allows us to use the API provided by Minisat to handle the requests that require a simple SAT solver. This way, CoQuiAAS does not need a second solver to compute the whole set of requests it is attended to deal with.

The core of our library is the interface `Solver`, which contains the high-level methods required to solve the problems. The method `initProblem` makes every required initialization given the input data. In the case of our approaches, it initializes the SAT solver or the coMSS extractor with the logical encoding corresponding to the AF, the semantics and the reasoning task to perform. The initialization step depends on the concrete realization of the `Solver` interface returned by the `SolverFactory` class, given the command-line parameters of CoQuiAAS. The method `computeProblem` is used to compute the result of the problem, and `displaySolution` prints the result into the dedicated output stream using the format expected by the competition.
The abstract class SATBasedSolver (respectively CoMSSBasedSolver) gathers the features and initialization common to each solver based on a SAT solver (respectively a coMSS extractor), for instance the method hasAModel which returns a Boolean indicating if the SAT instance built from the argumentation problem is consistent or not. Among the subclasses of SATBasedSolver, we built DefaultSATBasedSolver and its subclasses, which are dedicated to use the API of coMSSExtractor to take advantage of its SAT solver features, inherited from Minisat, to solve the problems. If the user wants to call any other SAT solver rather than coMSSExtractor – as soon as the given semantics is compatible with SAT encodings – a command-line option leads the SolverFactory to generate an instance of the class ExternalSATBasedSolver, which also extends SATBasedSolver. This solver class is initialized with a command to execute so as to call any external software able to read a CNF formula written in the DIMACS format, and to print a solution using the format of SAT solvers competitions. This class allows to execute the command provided to CoQuiAAS to perform the computation related to the problem. This feature enables, for instance, the comparison between the relative efficiency of several SAT solvers on the argumentation instances. The same pattern is present in the coMSS-based part of the library, with the class CoMSSBasedSolver, which can be instantiated via the default solver DefaultCoMSSBasedSolver, which uses coMSSExtractor, or via the class ExternalCoMSSBasedSolver to use any external software whose input and output correspond to coMSSExtractor ones, for the pairs request/semantics corresponding to our coMSS-based approaches.

Our design is flexible enough to make CoQuiAAS evolutive. For instance, it is simple to create a solver based on the API of another SAT solver than coMSSExtractor:
creating a new class **MySolver** which extends **SATBasedSolver** (and also, the interface, **Solver** which is the root of each solver) and implementing the required abstract methods (**initProblem**, **hasAModel**, **getModel** and **addBlockingClause**) is the only work needed. It is also possible to extend directly the class **Solver** and to implement its methods **initProblem**, **computeProblem** and **displaySolution** to create any kind of new solver. For instance, if we want to develop a CSP-based approach for argumentation-based reasoning, using encodings such that those from [5], we just need to add a new class **CSPBasedSolver** which implements the interface **Solver**, and to reproduce the process which lead to the conception of the SAT-based solvers, but using this time the API of a CSP solver (or an external CSP solver).

Once the solver written, we just need to give an option which executes CoQuiAAS, and to update the method **getSolverInstance** in the **SolverFactory**, which knows the set of the command-line parameters (stored in the map **opt**). For instance, the parameter `-solver MySolver` can be linked to the use of the class **MySolver** dedicated to the new solver. The code given below is sufficient to do that.

```java
if (opt["-solver"] == "MySolver") return new MySolver(...);
```

In the way we conceived the interface **Solver**, it is supposed that a solver is dedicated to a single problem and a single semantics. Thus, it is possible to implement a class which executes a unique algorithm, suited to a single pair (problem, semantics). For instance, [6] describes a procedure which determines if a given argument belongs to the grounded extension of an AF. We can consider the possibility to implement a class **GroundedDiscussion** which realizes the interface **Solver** to solve the skeptical decision problem under the grounded semantics using this dedicated algorithm.

This default behaviour of CoQuiAAS does not prevent the implementation of classes able to deal with several request for a given semantics, as soon as the **SolverFactory** returns an instance of the right solver for the considered semantics. Thus, thanks to the possibility to tackle each problem for a given semantics through a SAT instance (or a MSS problem), we have simplified the design of our solvers using a single class for each semantics, taking advantage of the **template** design pattern.

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ASPARTIX-D: ASP Argumentation Reasoning Tool - Dresden

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Abstract. ASPARTIX-D is a system designed to evaluate abstract argumentation frameworks. It consists of collection of answer-set programming (ASP) encodings together with an optimized ASP (resp. SAT) solver configuration for each reasoning problem. The system meets the requirements of the first International Competition on Computational Models of Argumentation (ICCMA 2015).

Keywords: abstract argumentation, ASPARTIX-D, answer-set programming, SAT solving, system

1 Motivation

ASPARTIX-D is the version of ASPARTIX [3,2] which has been further developed in Dresden. In particular, necessary modifications have been performed for the participation in the first International Competition on Computational Models of Argumentation (ICCMA 2015). ASPARTIX-D consists of a collection of answer-set programming (ASP) encodings together with dedicated solvers to compute certain abstract argumentation reasoning tasks. In the following we introduce the necessary background of abstract argumentation frameworks and give an overview of the performed evaluation and final configuration of the system.

2 Semantics and Reasoning Tasks

Abstract argumentation frameworks (AFs) are defined according to [1].

Definition 1. An argumentation framework (AF) is a pair \( F = (A, R) \) where \( A \) is a set of arguments and \( R \subseteq A \times A \) is the attack relation. The pair \((a, b) \in R\) means that \(a\) attacks \(b\). An argument \(a \in A\) is defended by a set \(S \subseteq A\) if, for each \(b \in A\) such that \((b, a) \in R\), there exists a \(c \in S\) such that \((c, b) \in R\).

Semantics for argumentation frameworks are given via a function \(\sigma\) which assigns to each \(AF = (A, R)\) a set \(\sigma(F) \subseteq 2^A\) of extensions. We shall consider here for \(\sigma\) the functions \(ST\), \(CO\), \(PR\), and \(GR\) which stand for stable, complete, preferred, and grounded semantics respectively.

1 http://argumentationcompetition.org/.
Definition 2. Let $F = (A, R)$ be an AF. A set $S \subseteq A$ is conflict-free (in $F$), if there are no $a, b \in S$, such that $(a, b) \in R$. $\text{cf}(F)$ denotes the collection of conflict-free sets of $F$. For a conflict-free set $S \in \text{cf}(F)$, it holds that

- $S \in ST(F)$, if each $a \in A \setminus S$ is attacked by $S$;
- $S \in CO(F)$, if each $a \in A$ defended by $S$ is contained in $S$;
- $S \in GR(F)$, if $S \in CO(F)$ and there is no $T \in CO(F)$ with $T \subset S$;
- $S \in PR(F)$, if $S \in CO(F)$ and there is no $T \in CO(F)$ with $T \supset S$.

Typical reasoning tasks for any AF $F = (A, R)$ and a semantics $\sigma$ are the following.

- $DC$-$\sigma$ credulous reasoning, decide whether $a \in A$ is contained in any $S \in \sigma(F)$;
- $DS$-$\sigma$ skeptical reasoning, decide whether $a \in A$ is contained in each $S \in \sigma(F)$;
- $EE$-$\sigma$ enumerate all extensions $S \in \sigma(F)$;
- $SE$-$\sigma$ return some extension $S \in \sigma(F)$.

2.1 Answer-Set Programming Encodings

ASPARTIX-D is a collection of ASP encodings as described in [3] and optimization encodings which we call in the following metasp encodings as given in [2]. These metasp encodings make use of the metasp optimization front-end for the ASP-package gringo & clasp (see [5] for more details).

The input AF should be specified in the ASPARTIX syntax, i.e. for each arguments $a \in A$ one specifies a fact $\text{arg}(a)$, and for each attack $(a, b) \in R$ the fact $\text{att}(a, b)$, should be generated. A typical call of ASPARTIX-D for the reasoning task $DC$-$ST$ looks as follows.

```
./aspartix.sh -p DC-ST -f <file> -fo apx -a <argument>
```

In general ASP encodings are designed to return all (resp. $n$) solutions to a given problem. For credulous and skeptical reasoning we are only interested in a $YES$ or $NO$ decision. As the ASP encodings use predicates $\text{in}/1$ and $\text{out}/1$ to guess the extensions we can perform the following simple modifications. In case of credulous reasoning we just add the argument $a \in A$ in question as the fact $\text{in}(a)$ to the program and check if there is one answer set. If this is the case then, the ASP-solver found one witness extension containing the argument $a$. Otherwise, if the program is unsatisfiable, we know there is no extension which contains $a$. For skeptical reasoning we perform a similar modification, where we add the fact $\text{out}(a)$ to the program. If the program is satisfiable, i.e. an answer set is found, we know that the argument $a$ can not be in each extension of the semantics $\sigma$. However, if the program is unsatisfiable, we obtain that $a$ is skeptically inferred.

3 Evaluation

The main goal of the evaluation was to find the most suitable encodings & solver configuration. As the potassco ASP solvers\(^2\) showed to perform very well for our purpose

\(^2\)http://potassco.sourceforge.net
we decided to test several options from the ASP solver Clingo 4.4 for the original encodings. Furthermore, we considered the gringo3.0.5 & clasp3.1.1 grounder & solver combination for the metasp encodings and the lp2sat & riss SAT Solver [4,7,6], for DC-{ST, CO, GR} and DS-{ST, CO, GR}.

As benchmarks, we considered a collection of frameworks which have been used by different research groups for testing before consisting of structured and randomly generated AFs, resulting in 5829 frameworks. In particular we used parts of the instances Federico Cerutti provided to us which have been generated towards an increasing number of SCCs [8]. Further benchmarks were used to test the system dynpartix and we included the instances provided by the ICCMA 2015 organizers.

The computation has been performed on an Intel Xeon E5-2670 running at 2.6 GHz. From the 16 available cores we used only every fourth core to allow a better utilization of the CPU’s cache. We applied a 15 minutes timeout and a maximum of 6.5 GB of main memory.

The tests showed in case of EE-PR and SE-PR the metasp encodings outperform all other options. Also surprisingly the metasp encodings for grounded semantics gave the best results, even though they are not adequate from a complexity point of view (see [2]). This might be due to the fact that the original encodings for grounded semantics use a certain loop construction which have a bad influence on the performance. For the decision tasks EE and SE of stable and complete semantics the clingo option --project returned the best results. Moreover, the lp2sat & riss combination gave better results for the reasoning tasks DC-CO and DS-CO on real problem instances.

The results of the evaluation led to the following final configuration.

| Task   | Used configuration                  |
|--------|-------------------------------------|
| GR:    | metasp encodings for all reasoning tasks |
| DC-ST  | original                            |
| DC-CO  | lp2sat & riss                       |
| DC-PR  | --configuration=auto                |
| DS-ST  | original                            |
| DS-CO  | lp2sat & riss                       |
| DS-PR  | original                            |
| EE-ST  | --project                           |
| EE-CO  | --project                           |
| EE-PR  | metasp                              |
| SE-ST  | --project                           |
| SE-CO  | --project                           |
| SE-PR  | metasp                              |

The system as well as the benchmarks used for the evaluation are available at https://ddll.inf.tu-dresden.de/web/Sarah_Alice_Gaggl/ASPARTIX-D.
4 Conclusion

The evaluation of different ASP-solver configurations and encoding types clearly showed that with optimized encodings one can obtain better results than only with specific solver options. However, the clingo option --project showed good results for several reasoning tasks. Furthermore, on real problem instances the SAT solver performed better for credulous and skeptical reasoning of complete semantics.

For future work we plan to expand the evaluation also for other argumentation semantics, as for nearly all of them ASP encodings exist (see http://www.dbai.tuwien.ac.at/research/project/argumentation/systempage/#download).

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ConArg2: A Constraint-based Tool for Abstract Argumentation

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Abstract. ConArg2 is a Constraint-programming tool oriented to the solution of problems related to extension-based semantics in Abstract Argumentation. It exploits Gecode, an efficient C++ toolkit for developing constraint-based systems and applications. The properties required by semantics are encoded into constraints, and arguments are assigned to 1 (i.e., true) if belonging to a valid extension for that semantics. Searching for solutions of problems (as enumerating extensions or checking argument-acceptance) takes advantage of well-known techniques as local consistency, different heuristics for trying to assign values to variables, and complete search-tree with branch-and-bound.

Description

ConArg (Argumentation with Constraints) is a Constraint-programming tool oriented to the solution of problems related to extension-based semantics in Abstract Argumentation [10]. Since the first versions of the tool [1,7], we have updated it with the purpose i) to solve further problems linked to weighted problems [6] and coalitions of arguments [9], and ii) to improve its performance over classical semantics, by using a benchmark assembled with random graph models [2,3,4,5]. The first version of ConArg [7,8] is based on the Java Constraint Programming solver³ (JaCoP), a Java library that provides a Finite Domain Constraint Programming paradigm [12]. The tool comes with a graphical interface, which allows the user to browse all the obtained extensions.

For the sake of performance, we have developed a second version of the tool, i.e., ConArg2, which has been submitted to the International Competition on Computational Models of Argumentation (ICCMA 2015)⁴. ConArg2 exploits Gecode 4.4.0⁵, an efficient C++ toolkit for developing constraint-based systems and applications. The properties of semantics are encoded into constraints, and arguments are assigned to 1 (true) if belonging to a valid extension for that semantics (0 otherwise). Searching for solutions takes advantage of classical

³ http://www.jacop.eu
⁴ http://argumentationcompetition.org/index.html
⁵ http://www.gecode.org
techniques, such as local consistency (through constraint propagation), different heuristics for trying to assign values to variables, and complete search-tree with branch-and-bound. We have also dropped the graphical interface of the first Java system, having a textual output only.

ConArg2 can be currently used to

– enumerate all conflict-free, admissible, complete, stable, grounded, preferred, semi-stable, ideal, and stage extensions;
– return one extension given one of the semantics above;
– check the credulous and sceptical acceptance for the conflict-free, admissible, complete, and stable semantics;
– find the $\alpha$-semantics described in [6].

From the home-page of ConArg\(^6\), it is possible to download both ConArg2 and ConArg (Java version). Moreover, we offer a visual Web-interface where to draw abstract frameworks (arguments and attacks as directed edges), and then solve some of the problems above. From the home-page it is possible to download ConArg2 compiled for Linux i386 and x64 machines.

The basic command-line usage is described in Fig. 1. Some practical examples are: to enumerate all admissible extensions: “conarg\_gecode -e admissible file.dl”, to check the sceptical acceptance of argument “a” with the stable semantics “conarg\_gecode -e stable -s a file.dl”, to compute all $\alpha$-complete extensions [6] with $\alpha = 3$ “conarg\_gecode -e a-complete -a 3 file.dl”. An input file file.dl follows the ASPARTIX format [11]: e.g., arg(a) for defining argument $a$, and att(a,b) for declaring an attack from $a$ to $b$.

We briefly show how we map AAFs to Constraint Satisfaction Problems (CSPs) [12] in ConArg2. A CSP can be defined as a triple $P = \langle V, D, C \rangle$, where $C$ is a set of constraints defined over the variables in $V$, each with domain $D$. Given a framework $\langle A, R \rangle$, we define a variable for each argument $a_i \in A$ ($V = \{a_1, a_2, \ldots, a_n\}$) and each of these arguments can be taken or not in an extension, i.e., the domain of each variable is $D = \{1,0\}$. As an example we report conflict-free and stable constraints, which can be respectively used to model the conflict-free and (in combination) stable semantics.

– Conflict-free constraints. If $R(a_i, a_j)$ is in the framework we need to prevent a solution to include both $a_i$ and $a_j$: $\neg(a_i = 1 \land a_j = 1)$. All other possible variable assignments ($a = 0 \land b = 1$), ($a = 1 \land b = 0$) and ($a = 0 \land b = 0$) are permitted.

– Stable constraints. If we have a node $a_i$ with multiple parents (in the Argumentation graph) $a_{f_1}, a_{f_2}, \ldots, a_{f_k}$, we need to add a constraint $\neg(a_i = 0 \land a_{f_1} = 0 \land \cdots \land a_{f_k} = 0)$. In words, if a node is not taken in an extension (i.e. $a_i = 0$), then it must be attacked by at least one of the taken nodes, that is at least a parent of $a_i$ needs to be taken in a solution (that is, $a_{f_j} = 1$). Moreover, if a node $a_i$ has no parent in the graph, it has to be included in every extension, i.e., $\neg(a_i = 0)$.

\[^6\] http://www.dmi.unipg.it/conarg/
Fig. 1. How to call ConArg2 from command-line.

Preferred extensions are found by assigning as more arguments as possible to 1 while searching for complete extensions. For this we use the Gecode heuristics \texttt{INT VAL MAX} (such value is always 1 in our model).

Given a semantics, the credulous acceptance for an argument \(a\) is checked by setting that argument to 1 and then halting as soon as an extension containing \(a\) is found (i.e., \(a\) is credulously accepted). In the worst case, all the search tree is explored without any result, i.e., \(a\) \textit{is not} credulously accepted. Checking the sceptical acceptance is a dual problem: given a semantics, we set \(a\) to 0 and then stop as soon as an extension containing \(a\) is found (i.e., \(a\) \textit{is not} credulously accepted). In the worst case, all the search tree is explored without any result, i.e., \(a\) \textit{is } sceptically accepted.

From the tests and comparisons we perform in [2,3,4,5], we obtain that ConArg behaves fast on lower-order semantics (admissible, complete, and stable ones). Moreover, we notice that our approach proves to be more efficient on some graph topologies than others. For instance, we deal with Barabasi-Albert random graph-models (and trees) better than Kleinberg or Erdős-Rényi models, considering the same \textit{nodes/edges} ratio.

In the future we would like to extend ConArg2 to solve coalition-based problems [9], and labelling-based extensions, where having an assignment domain wider than just \{\texttt{true}, \texttt{false}\} suggests the use of a constraint-based solver. Further possible extensions concern Bipolar Argumentation Frameworks, or Constrained-Argumentation Frameworks, where additional used-defined constraints can be adopted to select only some extensions of a given semantics (e.g., “when \(a\) is in,
then also $b$ must be in”). In addition, we are currently exploring applications of our tool as a reasoning engine for Cybersecurity problems and Decision-making.

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GRIS: Computing traditional argumentation semantics through numerical iterations.

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Abstract. This paper provides an outline of the Gabbay-Rodrigues Iterative Solver (GRIS). The solver can be used in decision and enumeration problems of the grounded and preferred semantics.

1 Introduction

The Gabbay-Rodrigues Iterative Solver (GRIS) is implemented in C++ and uses the Gabbay-Rodrigues Iteration Schema (see below) in the computation of the solution to the following classes of problems. Given an argumentation network \( \langle S, R \rangle \): to produce one or all of the extensions of the network under the grounded and preferred semantics; and given an argument \( X \in S \) to decide whether \( X \) is accepted credulously or sceptically according to one of these two semantics.

Problems to GRIS must be submitted according to probo’s syntax (see [2]).

GRIS is not currently able to handle the complete and stable semantics although their implementation would not pose any additional technical difficulties on top of what is already available.

2 Theoretical underpinnings

GRIS works with numerical argumentation networks where arguments are given initial values from \([0, 1]\) from which equilibrium values are calculated iteratively yielding traditional extensions via the following correspondence.

Definition 1 (Caminada/Gabbay-Rodrigues Translation). A labelling function \( \lambda \) and a valuation function \( V \) can be inter-defined by identifying the value 1 with the label \textbf{in}, the value 0 with the label \textbf{out} and assigning any node with a value in \((0, 1)\) with the label \textbf{und} and assigning a node with the label \textbf{und} with a suitable value in \((0, 1)\), e.g., 0.5.

The Gabbay-Rodrigues Iteration Schema. Let \( \langle S, R \rangle \) be an argumentation network and \( V_0 \) be an initial assignment of values from \([0, 1]\) to the nodes in \( S \). Let for each \( X \in S \), \( MA_i(X) = \max_{Y \in Att(X)} \{ V_i(Y) \} \) and the equation below define the value of \( X \) at the subsequent iterations (i.e., \( V_1, V_2, \ldots \)):

\[
V_{i+1}(X) = (1 - V_i(X)) \cdot \min \left\{ \frac{1}{2}, 1 - MA_i(X) \right\} + V_i(X) \cdot \max \left\{ \frac{1}{2}, 1 - MA_i(X) \right\}
\]
The set of all such equations constitutes the argumentation network’s GR system of equations [3]. For each \( X \in S \), the sequence of values \( V_0(X), V_1(X), \ldots \), etc., converges and the value \( V_e(X) = \lim_{i \to \infty} V_i(X) \) is defined as the equilibrium value of the node \( X \). For any assignment (resp., labelling function) \( f \), let \( in(f) = \{ X \in \text{dom } f \mid f(X) = 1 \) (resp., \( \text{in} \)) and \( out(f) = \{ X \in \text{dom } f \mid f(X) = 0 \) (resp., \( \text{out} \)). Caminada and Pigozzi have shown that any labelling function \( \lambda \) for an argumentation framework \( (S, R) \) can be turned into an admissible labelling function \( \lambda_{da} \) via a sequence of contraction operations that successively turn nodes illegally labelled \( \text{in} \) or \( \text{out} \) by \( \lambda \) into \( \text{und} \). Furthermore, each admissible labelling function \( \lambda_{da} \) can be turned into a complete labelling \( \lambda' \) by a sequence of expansion operations that successively turn nodes illegally labelled \( \text{und} \) by \( \lambda_{da} \) into \( \text{in} \) or \( \text{out} \) as appropriate. Since an expansion sequence stops when no \( \text{und} \) nodes remain illegally labelled, it follows that \( \lambda' \) is the minimal complete labelling such that \( \text{in}(\lambda_{da}) \subseteq \text{in}(\lambda') \) and \( \text{out}(\lambda_{da}) \subseteq \text{out}(\lambda') \) [1].

The Gabbay-Rodrigues Iteration Schema defined according to the equation above produces an equivalent result in a numerical context, except that no contractions or expansions are needed and the labelling \( \lambda' \) can be obtained from the equilibrium values of the sequences (see [3] for details). A labelling function \( \lambda \) such that for all \( X \in S \), \( \lambda(X) = \text{und} \) is, by definition, admissible, since it does not label any nodes \( \text{in} \) or \( \text{out} \). When an expansion sequence is then applied to \( \lambda \) resulting in the labelling function \( \lambda' \), as a result \( \lambda' \) will correspond to the smallest complete labelling for \( (S, R) \). The set \( \text{in}(\lambda') = \{ X \in S \mid \lambda'(X) = \text{in} \} \) will then correspond to the grounded extension of \( (S, R) \). In the numerical case, all we have to do is to assign all nodes with initial value \( V_0 \) in \((0, 1)\) (we use 0.5); compute their equilibrium values; and then define the grounded extension of \( (S, R) \) as the set of nodes with equilibrium value 1.

The above ideas constitute the basis of the GR Grounder module (see Fig. 1). In addition, the grounder can also be applied to a subnetwork of particular interest with optional given “conditioning” values during the course of a computation. The conditioning values are calculated in a previous step, and hence fixed, and simply fed into the equations. This allows the result of an individual strongly connected component (SCC) of the network to be computed provided the values of all of its conditioning nodes are known. Since non-trivial SCCs in a given layer are independent of each other, the computation of the results within a layer can potentially be done in parallel (a possible enhancement to the solver). Results of the SCCs are then carefully combined to provide answers to the decision and enumeration problems with respect to the required semantics.

One question of interest is of course how to determine the equilibrium values in a finite number of computations. This is done by approximation. Corollary 2.38 in [3] shows that all values converge to one of the values in \( \{0, 1, \frac{1}{2}\} \). The grounder stops iterating as soon as the maximum variation in node values between two successive iterations is smaller than or equal to the upper bound of the relative error introduced due to rounding in the calculations of the target machine. In

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1 Caminada and Pigozzi have shown that the set of complete labellings that are “bigger or equal” to a given labelling function has a unique smallest element [1, Theorem 11].
our 64-bit computer, this is $10^{-19}$. It is envisaged that the computation may be stopped much earlier if we can safely detect the convergence of all nodes to one of the values in $\{0, \frac{1}{2}, 1\}$. As it turns out, this is not the main bottleneck in the computation, as grounding can be computed relatively quickly even for larger networks. The computational complexity (and GRIS' current inability to complete the calculation of solutions for some classes of problems) mainly arises because of the management of multiple candidate assignments, which increase in proportion to the number and size of the SCCs and the number of network layers. This aspect of GRIS can be improved in a number of different ways.

3 System Overview

GRIS initially reads the problem specification passed as command line arguments, validates it and then validates the input network, exiting in case of error. The basic workflow for the computations involving the grounded and preferred semantics is depicted in Fig. 1, with the exception that in the grounded semantics, intermediate preferred solutions do not need to be generated and so the preferred solutions generator and partial preferred solutions datastore are not used. The solver starts by computing the strongly connected components of the network using a specially modified version of Tarjan’s algorithm [6] and arranging them into layers that can be used in successive computation steps as described in [4]. Once the layers are computed, the solver can identify the deepest layer level of computation needed according to the layer depth of the input argument and this can be used to terminate the computation of decision problems as early as possible.

For the computation of the solutions to the problems in the grounded semantics, the decomposition into layers is not strictly necessary. The GR Grounder can in principle be applied to the entire network at once and the nodes with equilibrium value 1 will correspond to the grounded extension of the entire network. However, since the computation of the SCCs and their arrangement into layers can be performed very efficiently with our version of the algorithms, this extra cost is offset by gains obtained through the computation by layers in all but a few special cases. Our strategy is then to feed the result of each layer into the next layer’s computation until either all layers are computed or we reach the maximum depth needed to establish the membership (or not) of the argument in the grounded extension (this strategy proves particularly efficient if the argument belongs to a layer of low depth).

Preferred Semantics. The solution of problems involving the preferred semantics involves the computation of partial network solutions to each layer. The key point in GRIS is that once the grounder is invoked for a particular SCC (using all required conditioning values), the resulting equilibrium values may contain undecided values, some of which could potentially be assigned the value 1 in a preferred extension. So our (naive) implementation assigns the value 1 to all such nodes and then corrects illegal values in a manner similar to that of the Modgil and Caminada’s labelling-based algorithms [5]. The results of every candidate solution are then propagated to the next layer using the grounder again.
and the whole process repeats. There is ample scope for optimisation here since undecided nodes that are attacked by a conditioning undecided argument cannot possibly be in any extension. Furthermore, in decision problems, a careful analysis of the argument involved may identify partial solutions of particular interest without the need to generate all partial solutions (the blind generation of partial solutions can quickly exhaust resources).

Solutions to the problems in the complete and stable semantics may also be computed with appropriate modifications, but these mechanisms have not been implemented in this version of the solver.

Fig. 1. Basic workflow of the preferred semantics calculator.

Obtaining GRIS: http://www.inf.kcl.ac.uk/staff/odinaldo/gris

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ASGL: Argumentation Semantics in Gecode and Lisp

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Abstract. ASGL is a solver for argumentation semantics, capable of answering queries with respect to grounded, complete, preferred, and stable semantics. It is built based on GECODE, a generic CSP solver. ASGL itself is mainly written in Common Lisp. This paper presents a description of its system components and, for a selection of the computational tasks, provides details on how ASGL approaches them.

1 Introduction

ASGL [6] is a solver for argumentation semantics. Given an argumentation framework $AF = (Ar, att)$, answers to queries with respect to grounded, complete, preferred, and stable semantics can be computed. Specifically, for each semantics, ASGL allows to enumerate one or all extensions and to report on the status of an argument, while taking either a credulous or a skeptical point of view [4].

ASGL is mainly written in Common Lisp and CLOS [7], with some parts written in C++, which is used for low-level parsing of the input file and, more importantly, to interface to GECODE [3], a generic CSP solver library, which is used in ASGL as a backend.

The plan of the paper is as follows. Section 2 presents GECODE and ECL [2], the Common Lisp implementation on which ASGL is built. Then, the realization of the computational tasks is exemplified with respect to grounded semantics in Section 3 and preferred semantics in Section 4. Finally, Section 5 details reductions of queries performed by ASGL.

2 System Components

GECODE, the generic constraint development environment, is a toolkit for developing constraint-based systems and applications. It is an efficient, generic CSP solver, featuring among others finite domain integer variables and finite set variables and constraints (see Section 4). Conceived as a C++ library, it can be easily integrated with other systems and it is designed to be open for extension
by user code. For instance, it is possible to program new search engines that can be regarded en par to the already built-in ones, such as depth-first search and branch-and-bound search, without requiring the user to dive into low-level code.

The abstraction that new search engines can be programmed with is called computation space [5]. A computation space, which is a first-class citizen, encapsulates a speculative computation involving constraints. New constraints can be posted on a space. Another space operation is to wait for it to become stable, i.e. for propagation to reach a fixpoint (see Section 3).

ECL is an implementation of Common Lisp that features a byte-code compiler, but can also compile to C code, which is then further compiled by the host’s native compiler. This allows for easy integration with C or C++ libraries. While bindings to such libraries are usually generated with a tool such as SWIG [1], ECL has a feature that makes this unnecessary. It allows the user by the use of an inline construct `ffi:c-inline` to directly emit fragments of C or C++ code as part of a Lisp function definition. These fragments are placed (almost) verbatim within the generated C code.

As an example, this allows for the definition of a Lisp function `space-status` for the aforementioned operation on a space, which calls the underlying GECODE method `status`.

```lisp
(defun space-status (space)
  (let ((status
            (ffi:c-inline (space) (:pointer-void) :int
"// wait for space to become stable, then retrieve status
Gecode::SpaceStatus status = (((Gecode::Space*)(#0))->status());
switch (status) {
  case Gecode::SS_FAILED: @(return 0) = 1; break;
  case Gecode::SS_SOLVED: @(return 0) = 2; break;
  case Gecode::SS_BRANCH: @(return 0) = 3; break;
  default: @(return 0) = 100; break;
}
))
(ecase status
  (1 :failed)
  (2 :solved)
  (3 :branch))))
```

ASGL makes use of typical Lisp features, such as CLOS, the Common Lisp Object System, macros (see Section 5) and first-class functions to orchestrate on a high level the parsing of the command-line arguments and input file, the creation and appropriately constraining of a computation space, the invocation of a search engine and then, finally, the formatting of the output.

3 Grounded Semantics

Exactly one grounded extension exists. It contains all the arguments which are not defeated, as well as that arguments which are directly or indirectly defended by non-defeated arguments. An algorithm to compute this extension in linear time is given by Caminada [4]; it progresses iteratively until a fixpoint is reached.
In ASGL, no special purpose algorithm for grounded semantics has been implemented. A computation space is created as for the other semantics with an array of $|Ar|$ boolean variables: ASGL uses an extension-based encoding for solutions. Constraints are then posted on the space and the status is queried by `space-status`, which first waits for the space to become stable, i.e. propagation to reach a fixpoint. Subsequently, the grounded extension can be read from the space by including all arguments whose corresponding variables are instantiated to `true`.

4 Preferred Semantics

The preferred extensions are all those complete extensions that are maximal with respect to set inclusion. In general, one or more preferred extensions may exist.

The task of computing some preferred extension is implemented in ASGL like a classical optimization problem with branch-and-bound search. As soon as one solution has been found, all further solutions are constrained to be better than the current solution. If no more solutions can be found, the current solution is maximal.

In the case of preferred extensions, an extension is better than another iff it is a proper superset of the other. In order to allow this kind of constraint to be posted, ASGL makes use of an additional set variable that represents the extension as a set. For consistency, the set variable is connected to the array of boolean variables by a channeling constraint. A branch-and-bound search engine is already part of standard GECODE. This allows for a straightforward implementation of this strategy. The search for a maximal solution is further supported by a value heuristic: When a choice needs to be made, an argument is considered to be included first, before it is considered to be excluded.

No built-in search engine in GECODE can be used to efficiently enumerate all preferred extensions. In the development of ASGL, an attempt has been made to implement a `multi-bab-engine` for this purpose. This engine essentially keeps a master computation space that stays unmodified by individual searches. Only a clone of the master is passed to the built-in branch-and-bound search engine. Whenever this engine finds a preferred extension, the master is constrained not to be a subset of this extension and the process repeats.

Unfortunately, this strategy turned out to be slower than filtering all complete extensions for maximality – at least for small input graphs. In the current version of ASGL, this work has therefore been abandoned in favor of this more simple approach. We expect that repeatedly restarting from the master space incurred too much overhead by repeating work already performed in previous invocations. This effect could possibly be mitigated by utilizing no-good learning or by employing more sophisticated variable ordering heuristics, such as accumulated failure count or activity that build on information gained from previous searches.
5 Reductions

ASGL allows the product of grounded, complete, preferred, and stable semantics and enumeration of some or all extensions, credulous and skeptical inference, in total 16 different problems to be solved. In this problem space numerous reductions are possible. ASGL currently makes use of the following rules, which are – thanks to Lisp macros – written exactly as given here in the source code:

1. (translate (:se :co) -> (:se :gr))
2. (translate (:ds :co) -> (:ds :gr))
3. (translate (:dc :pr) -> (:dc :co))

The first and second rule are quite simple: 1. When asked for some complete extension, one could simply compute the grounded extension. 2. a) If an argument is included in all complete extensions, it is also included in the grounded extension. b) The grounded extension is a subset of all complete extensions, therefore an argument included in the grounded extension is included in all complete extensions.

3. The third rule is more subtle. It states that whether an argument is included in some preferred extension can be reduced to the question of whether the argument is included in some complete extension. This can be shown like this: a) If an argument is included in some preferred extension, it is also included in some complete extension. b) If an argument is included in some complete extension, this extension is either maximal – a preferred extension or a preferred extension must exist that is a superset of the complete extension, hence it includes the argument.

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Abstract. This paper describes the system architecture of LamatzSolver-v0.1, a solver for extension generation of Dung’s abstract framework [4] in the contest of International Competition on Computational Models of Argumentation (ICCMA’15). The solver is implemented in Java and determines all extensions of grounded semantics. The algorithm used is oriented on the characteristic function [1, 4] and based on the Java-Collection-Framework.

Keywords: ArgumentContainer, Characteristic function, Grounded semantics, HashMap, Java-Collection-Framework

1 System architecture

The class LamatzSolver inherits all necessary methods from AbstractSolver of probo [3] for the command line interface which represents the unique possibility for the user to communicate with the system. LamatzSolver hands the input over to TgfParserAAS. Tgf is the only accepted data format. In comparison with the TgfParser from probo TgfParserAAS changed the representation of Dung’s abstract framework. Each argument is stored by its name in a class called ArgumentContainer. Furthermore this class stores each attack from and attack on in a HashMap. All ArgumentContainer are separately stored in a HashMap. The class AdvanceAAS investigates each argument about the attacks. If the HashMap “attacksFrom” is empty, the argument is also stored in another HashMap called “typeZero”. There are two more types of HashMaps “typeOne” and “typeTwo” beside the specified one. As explained, the system only generates the grounded extension but AdvanceAAS provides with these two additional HashMaps the opportunity to advance the system. HashMap “typeOne” stores arguments which can defend themself and HashMap “typeTwo” stores arguments that only can be defended by other arguments.

After preparation phase the class LamatzSolver gets a reference to AdvanceAAS and overhands this to class GroundedExtensionFinder. GroundedExtensionFinder
is now able to get all important information for generating the grounded extension. After determination GroundedExtensionFinder returns the HashMap “grounded”. Then the class LamatzSolver brings the grounded extension into the required form for probo.

Every return command is implemented with a public method. The determination of the HashMaps of AdvanceAAS as well as GroundedExtensionFinder are private and consequently not visible from the outside.

Fig. 1. System Architecture of LamatzSolver-v0.1

2 How the problem is solved

Finding the grounded extension is elementary for determination of other semantics. In fact it is really important getting a solution quickly. The algorithm of LamatzSolver-v0.1 can be described in five steps as follows:

1. Checks if HashMap “typeZero” is empty. If the answer is “yes” than a empty HashMap called “grounded” is being returned, otherwise the build() method will be called.
2. In the build() method each argument of HashMap “typeZero” is copied to the HashMap “grounded”.
3. Then the size of HashMap “grounded” is stored in a parameter “prev” and for each argument the defended arguments will be determined and added to the HashMap “grounded”. According to this each ArgumentContainer has a reference of the attacks on other arguments. These arguments are stored in a HashMap “out” [2] and the attacks of these arguments are candidates for the grounded extension. Then the method checks if all attackers of a candidate are defeated.
4. Step 3 is being repeated for HashMap “grounded” until the HashMap does not grow anymore. This is realized with a comparison of the current size of HashMap “grounded” and the parameter “prev”.
5. HashMap “grounded” will be returned.

In a nutshell GroundedExtensionFinder is an implementation of the characteristic function. The runtime depends on the problem. For example the problem “real4” from iccma2015\(^1\) delivers the following runtime\(^2\) result:

```
Start:
Attacks: 146530
Arguments: 100000
Size of grounded: 9568
Time elapsed: 0.41 Seconds
```

**Annotation:** This result is a Java console output from a separate class which is not part of LamatzSolver-v0.1.

3 Design choices and gained experience

There are two design choices made in LamatzSolver-v0.1. First is the implementation of sets in a mathematical sense and second the relation between arguments. Java provides for sets the Collections-Framework. Thus important operations for sets like \textit{intersect}, \textit{minus}, \textit{union} and \textit{complement} are possible. For a relation the Collection-Framework can be used too, but it is circuitous without a separate class. LamatzSolver-v0.1 uses a container class ArgumentContainer which stores the name of argument and the attacks from and on arguments. Sets like attacks are implemented as a HashMap. The advantage of a HashMap in comparison to other data structures as HashSet or Set is the access to the ArgumentContainer. HashSets or Sets have to be searched by an iterator from the beginning or the last element of the iterator. In a HashMap the key is sufficient for getting access to the object. In LamatzSolver-v0.1 HashMaps are organized with the key of the argument name and the value ArgumentContainer. This choice is based upon the fact that all information about an argument should be available at any point of runtime. Resources should simply be used for extension generation.

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4 System Description of LamatzSolver-v0.1

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ProGraph: towards enacting bipartite graphs for abstract argumentation frameworks

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Abstract. ProGraph was developed in Prolog and relies on bipartite graphs to partition the set of arguments in two classes: $in$ and $out$. The current version of ProGraph is able to determine some extension and decide whether a given argument is credulously inferred, both with respect to the stable semantics.

1 Bipartite graphs

Bipartite graphs have been successfully applied for several classes of problems (i.e., coverings, combinatorial applications, optimal spanning trees, general assignment problems) and within various domains (i.e., chemistry, communication networks, computer science) [1]. A graph $G$ is bipartite if the vertex set $V(G)$ can be partitioned into two sets $V_1$ and $V_2$ such that no vertices $v_i$ from the same set are adjacent. The special case of bipartite argumentation frameworks admit polynomial time algorithms for preferred and stable semantics [2, 3].

2 Implementation details

The task to determine an extension which attacks every argument which is not in that extension can be reduced to a relaxed partitioning problem in which the initial set of arguments is split into two partitions: $V_{in}$ and $V_{out}$ with the arguments from the second partition being free to attack each other. Given the argumentation framework $(A, R)$, we denote by $\{x\}^-$ the subset of $A$ containing those arguments that attack argument $x$, and by $\{x\}^+$ the set of arguments from $A$ that are attacked by $x$. The steps of the method are listed in algorithm 1.

Before the partitioning algorithm starts, the arguments are sorted such that they will be placed from the one who attacks the most to the one who attacks the less arguments. Consequently the first argument picked in each step of the partitioning algorithm is the one with the largest influence on the others. The algorithm picks a non-attacked argument $y$ (line 2) adds $y$ in the attackers extension (line 4) and then checks if any of the arguments attacked by $y$ is in partition $V_{in}$. If this is the case, the algorithm starts backtracking. Otherwise, the arguments attacked by the current argument are added in $V_{out}$ and the arguments attacked
| Algorithm 1: Partitioning algorithm. |
|-------------------------------------|
| **Input:** (A, R) - argumentation framework; |
| **Output:** V_in, V_out - partition of A with in and out arguments; |
| 1 V_in ← ∅, V_out ← ∅; |
| 2 A' ← sort(A) s.t. ∀ y_i, y_j ∈ A' with i < j → |{y_i}| > |{y_j}|; |
| 3 while ∃ y ∈ A \ (V_in ∪ V_out) do |
| 4 if ∃ y ∈ A' s.t. {y} = ∅ then |
| 5 select first y ∈ A' |
| 6 else |
| 7 select y ← first(A) |
| 8 if {y}^+ ∩ V_in ≠ ∅ then |
| 9 go to 4 |
| 10 else |
| 11 V_in ← V_in + {y} |
| 12 V_out ← V_out ∪ {y}^+ |
| 13 foreach a ∈ {y}^+ do |
| 14 update({a})^+ |

by them are updated in order to know how many possibly valid (i.e. members of A or V_in) arguments attack them. (lines 13-14). The steps are repeated until all arguments are partitioned or until all paths were tried and none succeeded.

If there are only attacked arguments left the algorithm will chose one of them and suppose it is not attacked (i.e. suppose its attacker will be placed in V_out). The mechanism that stops this from producing bad results is the verification step (lines 8-9), which stops the algorithm if at some point the attacker is to be placed in V_out.

3 Discussion and future work

ProGraph was developed as a semester project for the undergraduate level. We are currently investigating how metric properties and matrix characterisations of bipartite graphs can be exploited to develop heuristics for searching the preferred extensions [4] of an argumentation framework.

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DIAMOND: A System for Computing with Abstract Dialectical Frameworks

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Abstract This paper briefly describes the DIAMOND system, version 2.0.0, in its role as submission to the First International Competition on Computational Models of Argumentation (ICCMA). DIAMOND is essentially a collection of answer set programming (ASP) encodings of semantics of abstract dialectical frameworks (ADFs) together with a wrapper script that calls an ASP solver with adequate encodings for a given instance, semantics and reasoning problem.

1 Introduction

Abstract dialectical frameworks (ADFs) [Brewka and Woltran, 2010, Brewka et al., 2013] are a generalisation of Dung’s abstract argumentation frameworks (AFs) [Dung, 1995]. DIAMOND is a software system for reasoning with ADFs. Since ADFs generalise AFs, DIAMOND can also do reasoning with AFs. It is in this function that DIAMOND has been submitted as an entry in the First International Competition on Computational Models of Argumentation (ICCMA) [Cerutti et al., 2014]. This system description concentrates mainly on issues pertaining to the ICCMA, for further technical information on DIAMOND the reader may consult the recent paper [Ellmauthaler and Strass, 2014].

2 Design Motivations

The semantics of ADFs have been defined using a framework called approximation fixpoint theory [Denecker et al., 2000, 2003, 2004, Brewka et al., 2013, Strass, 2013]. There, knowledge bases of knowledge representation formalisms are mapped to operators (their so-called characteristic consequence operators) on an order-theoretic structure (for example a lattice, a meet-complete semi-lattice, or a complete partial order [Davey and Priestley, 2002]). Certain points of these operators (for example fixpoints, least fixpoints, postfixpoints, or maximal postfixpoints [Davey and Priestley, 2002]) then correspond to models of the knowledge base according to various semantics [Denecker et al., 2000, 2003, 2004, Brewka et al., 2013, Strass, 2013].

The DIAMOND system is designed around the central idea that the operator associated to a knowledge base is not only central to defining but also to computing the knowledge base’s semantics. As such, for different knowledge representation languages, DIAMOND provides ASP encodings that compute the characteristic operator for given knowledge bases. The knowledge representation languages thus implemented by DIAMOND are ADFs and by corollary AFs. Technically, AFs are implemented using a separate operator encoding that captures AFs’ three-valued one-step consequence
operator as obtained in [Strass, 2013]. Given an AF $F = (A, R)$ and a three-valued interpretation $v: A \rightarrow \{t, f, u\}$ of its arguments (viz., a labelling), the AF’s operator $\Gamma_F$ returns a new, revised interpretation $w = \Gamma_F(v)$ with

$$
w(a) = \begin{cases} 
t & \text{if } v(b) = f \text{ for all } (b, a) \in R \\
f & \text{if } v(b) = t \text{ for some } (b, a) \in R \\
u & \text{otherwise}
\end{cases}
$$

Then, AF semantics can be easily defined thus: an interpretation $v: A \rightarrow \{t, f, u\}$ is

- grounded for $F$ $\iff$ $v$ is the least fixpoint of $\Gamma_F$
- complete for $F$ $\iff$ $v = \Gamma_F(v)$
- preferred for $F$ $\iff$ $v = \Gamma_F(v)$ and $v$ is information-maximal
- stable for $F$ $\iff$ $v = \Gamma_F(v)$ and $v$ is two-valued

3 System Architecture

DIAMOND contains an ASP encoding that computes the operator $\Gamma_F$ for a given AF $F$. Additional encodings express the operator-based conditions from above, that is, different semantics. The wrapper script combines operator encoding and semantics encoding with a file specifying the instance information into a single logic program (by simply appending the files), and calls an ASP solver, in this case clingo [Gebser et al., 2011] (version 4.3.0), on the resulting logic program. The semantics encodings are designed such that answer sets of the combined logic program correspond one-to-one with interpretations satisfying the conditions of the respective semantics.

For each of the four semantics mentioned above, the ICCMA has four tracks according to the reasoning problems “return some extension” (SE), “enumerate all extensions” (EE), “decide credulous entailment of a given argument” (DC), “decide sceptical entailment of a given argument” (DS). DIAMOND solves problem SE by asking the ASP solver to return a single answer set if one exists. For problem EE, DIAMOND calls the ASP solver with an argument invoking it to return all answer sets of the logic program. For the entailment problems DC and DS, DIAMOND uses additional encodings that reduce the given problems to the answer set existence problem. The additional encoding for credulous entailment removes all answer sets (interpretations) where the argument in question is not true; some answer set remains iff the argument follows credulously. Conversely, the encoding for sceptical entailment removes all answer sets (interpretations) where the argument in question is true; some answer set remains iff the argument does not follow sceptically. From the ASP solver’s answer to the answer set existence problem, DIAMOND generates the answer to the original entailment problem.

4 Conclusion

DIAMOND is not optimised for usage with AFs. All encodings are straightforward implementations of mathematical definitions. The main focus when implementing DIAMOND’s encodings has been on simplicity and elaboration tolerance. The system is available at http://diamond-adf.sourceforge.net/.
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Carneades ICCMA: A Straightforward Implementation of a Solver for Abstract Argumentation in the Go Programming Language

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Abstract. The Carneades entry to the 2015 International Competition on Computational Models of Argument (ICCMA) is a straight-forward implementation of a solver for reasoning tasks in abstract argumentation frameworks [1]. All of the reasoning tasks (computing one or all extensions and deciding whether an argument is credulously or skeptically inferred) and Dung semantics (grounded, complete, preferred, stable) covered by the competition have been implemented. The solver has been implemented in Go, a mainstream statically-typed, procedural programming language with a C-like syntax, garbage collection, good built-in support for concurrency and a large standard library. The aim is to provide a concise and readable implementation suitable for pedagogical purposes, using only common and widely familiar programming constructs and with no dependencies on external libraries or programs.

Keywords: abstract argumentation frameworks, computational models of argument, grounded semantics

1 Introduction

The Carneades entry to the 2015 International Competition on Computational Models of Argument (ICCMA) is a straight-forward implementation of a solver for reasoning tasks in abstract argumentation frameworks [1]. While part of the open source Carneades project¹, this code was newly developed specifically for the ICCMA competition. The focus of the Carneades project has not been abstract argumentation, but rather structured argumentation. Nonetheless, Carneades has for some time included an implementation of a solver for Dung abstract argumentation frameworks, using grounded semantics. This solver was implemented to overcome a limitation of the original computational model of Carneades [2], which did not allow argument graphs to contain cycles, by mapping Carneades argument graphs to abstract argumentation frameworks in a manner similar to ASPIC+ [4].

¹ https://carneades.github.io/
The Carneades entry for the ICCMA competition implements all of the reasoning tasks (computing one or all extensions and deciding whether an argument is credulously or skeptically inferred) for all the semantics of abstract argumentation frameworks (grounded, complete, preferred, stable) covered by the competition.

2 System Architecture

The solver has been implemented in Go [6], a mainstream statically-typed, procedural programming language with a C-like syntax, garbage collection, good built-in support for concurrency and a large standard library.

The aim is to provide a concise and readable implementation suitable for pedagogical purposes, using only common and widely familiar programming constructs. Although the implementation of the tractable problems, using grounded semantics, is quite efficient, the simple generate-and-test algorithms implemented for the combinatorial problems are not expected to perform well compared to entries based on highly-optimized SAT and ASP solvers.

The implementation closely follows high-level specifications of abstract argumentation frameworks [5] and has not been optimized in any significant way, with perhaps one exception: The implementation of grounded semantics keeps track of whether a mutable labelling has changed, in its main loop, and exits the loop when no changes were made, without having to explicitly test whether two labellings are equivalent.

For the combinatorial problems, for complete, preferred and stable semantics, the solver generates and tests all subsets of the power set of the arguments in the framework. The subsets are generated using an algorithm found on the Web.\(^2\) Using this algorithm, every subset is generated and visited exactly once.

Using Go's support for first-class and higher-order functions, procedures were implemented for finding the first subset of arguments which satisfy a given predicate and for applying some procedure to each subset. Using functions implementing predicates for complete and stable extensions, it is then simple to find the first or all complete extensions and then to filter the complete extensions to find one or more which are also stable.

Implementing preferred semantics was only a bit more difficult. While iterating over the complete extensions, a list of candidate extensions is maintained. When a new complete extension is found, it replaces every candidate which is a subset of the new extension in the list of candidates.

3 Lessons Learned and Future Work

For preferred semantics, we first tried the algorithm in [3], but found that it performed much worse than the straightforward generate-and-test algorithm we

\(^2\) http://www.stefan-pochmann.info/spots/tutorials/sets_subsets/
settled on in the end. The algorithm in [3] appears to visit each member of the powerset of arguments in the framework more than once.

Argument sets are currently represented as hash tables, from arguments to boolean values. Simulating immutable operations on sets involves creating copies of the hash tables. An obvious first step toward improving the performance of this implementation would be to replace this representation with an immutable, persistent representation of argument sets optimized for subset and equality comparisons.

The Go programming language provides excellent support for concurrent algorithms, but we did not make use of this feature, since it is not yet clear to us how to refactor the program to make good use of concurrency. We considered implementing the generate and test procedures as separate tasks, communicating via a channel. We may try this, but expect that the testing task will not be able to keep up with the generation task, which takes at most only a few seconds, and thus not divide up the work well among the available processors.

We are pleased with the performance of the implementation of grounded semantics, which seems to be a bit faster than any other implementation we are familiar with, in our informal and unsystematic benchmark tests. Of course, the problems are all tractable when using grounded semantics, so this may not be especially interesting in the context of the ICCMA. Surely the combinatorial problems are more challenging and interesting for the purpose of the competition. However, in our experience grounded semantics is well suited for many practical applications of argumentation frameworks, so an efficient implementation may be of some interest for developers of such applications.

Our implementation of the combinatorial problems is not nearly as efficient as the Tweety reference implementation [7], in Java, although Go and Java have comparable performance. On the other hand, our implementation in Go is considerably shorter and more readable, presumably due to Go being a less verbose programming language. That said, in the future we may try to optimize our implementation, learning from the Tweety implementation.

4 Downloading and Installing the Code

The source code of the Carneades ICCMA entry is available on Github at https://github.com/carneades/carneades-4.

Prerequisites for building the system are:

- Go, http://golang.org/, and
- Git, http://git-scm.com/

To build the system:
Set the GOPATH environment variable to a directory for Go packages, e.g.

$ mkdir ~/go
$ typeset -x GOPATH=~/go
Use the `go` tool to get, build and install the `carneades-iccma` executable from Github:

```bash
$ go get github.com/carneades/carneades-4/internal/cmd/carneades-iccma
```

The `carneades-iccma` executable should now be installed in

```
$GOPATH/bin/carneades-iccma
```

You can execute the program using this full path. Alternatively, add `$GOPATH/bin` to your `PATH` environment. You can then execute the command directly, as in

```bash
$ carneades-iccma -p EE-GR -f ...
```

These instructions are subject to change. See the `INSTALL.md` file for current instructions.

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PrefMaxSAT: Exploiting MaxSAT for Enumerating Preferred Extensions

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Abstract. In this paper we introduce PrefMaxSAT, a solver that exploits an efficient encoding of preferred extensions search for abstract argumentation, using the MaxSAT approach.

1 Introduction

The main computational problems in abstract argumentation include decision and construction problems, and turn out to be computationally intractable for most of argumentation semantics [6]. In this paper we focus on the extension enumeration problem for the preferred semantics, i.e. constructing all preferred extensions for a given AF: its solution provides complete information about the justification status of arguments and subsumes the solutions to the other problems.

In this paper, we propose an efficient encoding of preferred extensions search using unweighted MaxSAT. The maximum satisfiability problem is the problem of identifying the maximum number of clauses, of a given boolean formula, that can be made true together by an assignment of the involved variables. In unweighted MaxSAT, two classes of clauses are considered: hard and soft. The former must be always satisfied, while the number of soft clauses satisfied is the object of the maximisation. The interested reader is referred to [7] for a detailed introduction. MaxSAT can be considered as a generalisation of the SAT problem, which looks for a variable assignment that satisfies all the clauses at the same time.
2 Background

An argumentation framework \([5]\) consists of a set of arguments\(^4\) and a binary attack relation between them.

**Definition 1.** An argumentation framework \((AF)\) is a pair \(\langle A, R \rangle\) where \(A\) is a set of arguments and \(R \subseteq A \times A\). We say that \(b\) attacks \(a\) iff \((b, a) \in R\), also denoted as \(b \rightarrow a\). The set of attackers of an argument \(a\) will be denoted as \(a^- \triangleq \{b : b \rightarrow a\}\), the set of arguments attacked by \(a\) will be denoted as \(a^+ \triangleq \{b : a \rightarrow b\}\).

Each \(AF\) has an associated directed graph where the vertices are the arguments, and the edges are the attacks.

The basic properties of conflict–freeness, acceptability, and admissibility of a set of arguments are fundamental for the definition of argumentation semantics.

**Definition 2.** Given an \(AF \Gamma = \langle A, R \rangle\):

- a set \(S \subseteq A\) is a conflict–free set of \(\Gamma\) if \(\not\exists a, b \in S\) s.t. \(a \rightarrow b\);
- an argument \(a \in A\) is acceptable with respect to a set \(S \subseteq A\) of \(\Gamma\) if \(\forall b \in A\) s.t. \(b \rightarrow a\), \(\exists c \in S\) s.t. \(c \rightarrow b\);
- a set \(S \subseteq A\) is an admissible set of \(\Gamma\) if \(S\) is a conflict–free set of \(\Gamma\) and every element of \(S\) is acceptable with respect to \(S\) of \(\Gamma\).

An argumentation semantics \(\sigma\) prescribes for any \(AF \Gamma\) a set of extensions, denoted as \(E_{\sigma}(\Gamma)\), namely a set of sets of arguments satisfying the conditions dictated by \(\sigma\). Here we recall the definitions of preferred (denoted as \(\mathcal{PR}\)) semantics.

**Definition 3.** Given an \(AF \Gamma = \langle A, R \rangle\), a set \(S \subseteq A\) is a preferred extension of \(\Gamma\), i.e. \(S \in \mathcal{E}_{\mathcal{PR}}(\Gamma)\), iff \(S\) is a maximal (w.r.t. \(\subseteq\)) admissible set of \(\Gamma\).

As discussed in \([3, 4]\) the search for admissible sets can be encoded using propositional logic formulae.

**Definition 4.** Given an \(AF \Gamma = \langle A, R \rangle\), \(L\) a propositional language, and \(v : A \rightarrow L\):

\[
adm_\Gamma = \bigwedge_{a \in A} \left( v(a) \supset \bigwedge_{b \rightarrow a} \neg v(b) \right) \land \left( v(a) \supset \bigwedge_{b \rightarrow a} \bigvee_{c \rightarrow b} v(c) \right)
\]

The models of \(adm_\Gamma\) corresponds to the admissible sets of \(\Gamma\).

\(^4\) In this paper we consider only finite sets of arguments: see \([2]\) for a discussion on infinite sets of arguments.
3 The MaxSAT Encoding

The approach we propose, called \textbf{prefMaxSAT}, is based on MaxSAT to identify the maximal admissible extensions, namely preferred extensions. Each step of the search process requires the solution of a MaxSAT problem. Precisely, the algorithm is based on the idea of encoding the constraints corresponding to admissible labellings of an AF as a MaxSAT problem, and then iteratively producing and solving modified versions of the initial problem.

Given an AF $\Gamma = \langle A, R \rangle$ we are interested in identifying a boolean formula, composed by hard and soft clauses, such that each assignment satisfying all the hard clauses of the formula corresponds to an admissible labelling, and each assignment satisfying the hard clauses and maximising the number of soft clauses satisfied corresponds to a preferred labelling.

\textbf{Definition 5.} Given an AF $\Gamma = \langle A, R \rangle$, $\mathcal{L}$ a propositional language and $v : A \rightarrow \mathcal{L}$, the unweighted MaxSAT encoding for preferred semantics of $\Gamma$, $\Pi_\Gamma$, is given by the conjunction of the hard clauses listed below:

$$\bigwedge_{\{a \in A | a^- = \emptyset\}} v(a)$$ (1)

$$\bigwedge_{\{a \in A | a^- \neq \emptyset\}} \left( \bigwedge_{b \rightarrow a} (\neg v(a) \lor \neg v(b)) \right)$$ (2)

$$\bigwedge_{\{a \in A | a^- \neq \emptyset\}} \left( \neg v(a) \lor \left( \bigvee_{\{c \in A | \exists b, c \rightarrow b \land b \rightarrow a\}} v(b) \right) \right)$$ (3)

and by the conjunction of the following soft clauses:

$$\bigwedge_{a \in A} v(a)$$ (4)

The hard clauses of Definition 5 can be related to the definition of admissible sets (Def. 2): clauses (2) enforce the conflict-freeness; clauses (3) ensure that each argument in the admissible set is defended.

Finally, soft clauses (4) are used for maximising the number of arguments included in the admissible set, thus identifying preferred extensions. To this end, let us consider a function $\alpha$ that, given a variable assignment $T$, returns $S \subseteq A$ such that $a \in S$ iff $v(a) \equiv \top$ in $T$.

4 Implementation Details

To enumerate all the preferred extension, \textbf{prefMaxSAT} exploits a MaxSAT solver able to prove unsatisfiability too: it accepts as input a CNF formula,
composed by soft and hard clauses, and returns a variable assignment maximally satisfying the formula if it exists. If no variable assignment satisfies the hard constraints, \( \varepsilon \) should be returned.

Initially, the original AF is encoded in a CNF, as depicted in Definition 5. The CNF is then provided to the MaxSAT solver. If a variable assignment that maximally satisfies the formula is returned: (i) the corresponding labelling is saved in the list of found preferred extensions; (ii) a hard clause for eliminating the solution is added to the CNF; (iii) a hard clause forcing to include different arguments is added to the CNF; (iv) the process is repeated. If the MaxSAT solver returned \( \varepsilon \), \( \text{prefMaxSAT} \) ends and provides the set of found preferred extensions.

The algorithm has been implemented in C++, and exploits the open-wbo MaxSAT framework [8], using glucose3.0 [1]. The latest version can be downloaded from http://sourceforge.net/projects/prefmaxsat/ and it should be noted that \( \text{prefMaxSAT} \) can be used with any MaxSAT system supporting the DIMACS format.

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ASSA: Computing Stable Extensions with Matrices

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Abstract. Abstract argumentation frameworks with countably many arguments can be presented in a matrix form. We have created reasoning tasks based on matrix operations, that can answer whether a given set of arguments is part of an argumentation extension. Our solver, ASSA, is written in Java and implements the stable semantics of an argumentation framework, giving us the opportunity to participate in ICCMA’15 competition.

Keywords: Argumentation, semantics, stable extension, matrix

1 The Project

Argumentation theory tries to mimic the process of reasoning. It is often used by agents to reason under dynamic environments, e.g. which alternative to choose. Agents perform tasks under incomplete information, thus decisions must be precise and easily computable. Agents need a tool that is able to produce extensions under specific semantics to help them decide what their next move should be.

For what follows, we assume that the reader is familiar to basic matrix tools and operations [5] as well as the fundamentals on argumentation frameworks [2, 1, 3]. We have created a theory on how to use mathematical matrix operations, to navigate through argumentation frameworks. We then used this method to compute extensions in an abstract argumentation framework.

The computational complexity for multiplying two matrices with \( n \) digit numbers using the “default” algorithm is \( O(n^3) \) [6]. Of course there are methods that can optimize this result [6, 4]. Because of this complexity our algorithm can handle argumentation frameworks with not many arguments. First we present any abstract argumentation framework into its adjacency matrix.

Definition 1. Let \( AF = (\mathcal{A}, \mathcal{R}) \) be an argumentation framework. Define its adjacency matrix \( A = (a_{i,j}) \) as follows: 

\[
  a_{i,j} = \begin{cases} 
1 & \text{if } (i,j) \in \mathcal{R} \\
0 & \text{if } (i,j) \notin \mathcal{R} 
\end{cases}
\]
It is important to know who attacks who. The “tail” of an outgoing attack is represented by the row of the adjacency matrix and each column represents the “tip” of the attack. Therefore, element $a_{3,4}$ can represent the attacks from argument $a_3$ to argument $a_4$ while element $a_{4,3}$ can represent the attacks from $a_4$ to $a_3$.

We then represent any given set of arguments as a column vector. Having these two matrices we can perform matrix operations to navigate through the argumentation framework.

**Definition 2.** Let $AF = \langle A, R \rangle$ be an argumentation framework with $A$ its adjacency matrix and $S \subseteq A$. Set $S$ is represented by a column vector $S_{n \times 1} = (s_i, 1)$, where $s_i = \begin{cases} 1 & \text{if } a_i \in S \\ 0 & \text{if } a_i \notin S \end{cases}$

**Proposition 1.** Let $A$ be the adjacency matrix of an argumentation framework $AF = \langle A, R \rangle$ and $S \subseteq A$ be a set of arguments with $S$ its column vector (resp. $S^T$ row vector) representation. The product $AS$ (resp. $S^T A$) is a column (resp. row) vector where the entry $(AS)_{i,1}$ (resp. $(S^T A)_{1,i}$) shows how many times argument $a_i \in A$ attacks (resp. is attacked by) $S$.

With the help of matrix operations we can answer question such as which arguments in $A$ attack (resp. are attacked by) a specific set of arguments. In this way it is like using a series of matrix tools to navigate through the argumentation framework. Many times, crucial information may get lost throughout the process and therefore a gentle manipulation is needed. A method to keep track of the information that might be used at a later point is useful.

**Proposition 2 (conflict free test).** Let $AF = \langle A, R \rangle$ be an argumentation framework and $A$ its adjacency matrix. Let $S \subseteq A$ be a given set of arguments with $S$ its column vector representation. Let $\Gamma = S^T A$. $S$ passes the conflict free test if and only if whenever $\gamma_i \neq 0 \in \Gamma$ then $s_i = 0 \in S$.

By constructing a matrix multiplication we can answer if a given set of arguments $S$ is conflict free. When a row matrix passes (resp. fails) the test we conclude that $S$ is (resp. is not) conflict free.

**Proposition 3 (stable extensions test).** Let $AF = \langle A, R \rangle$ be an argumentation framework with adjacency matrix $A$. Let $S \subseteq A$ be a given set of arguments and $S$ the column vector of $S$ and $\Gamma = S^T A$. The set $S$ passes the stable extensions test if and only if:

1. $S$ passes the conflict free test, and
2. $\forall i$ such that $s_i = 0, \gamma_i \neq 0$.

Note that for the stable extension test we do not use the admissibility test. Intuitively, attacking anything that is “outside” of you means that you attack all your attackers. This is true since passing the conflict free test shows that there do not exist attacks coming “inside” of you thus any existing attacks should be from “outside” and you attack them back anyway.
Informally, we try to introduce a mathematical approach based on matrix operations to research, and answer questions of the form: “Is set $S$ an extension accordingly to a semantic $\sigma$”? We accomplish this by converting the argumentation framework as well as the set $S$ into a matrix form $\mathcal{A}$ and $\mathcal{S}$ respectively. We then perform matrix tools and operations to extract knowledge and answer questions for set $S$, i.e. is $S$ conflict free, admissible, ground or complete? At a later point we want to expand our theory on other semantics as well.

\section{ICCM\textsuperscript{A}'15 Competition}

In order to participate in ICCMA’15 competition we slightly changed our algorithm to fit the rules of this contest. Specifically, we decided not to handle each set of arguments as an individual and try to answer questions based on this set, but to find all possible cases of such sets and combine them into a massive matrix $\mathcal{S}'$. Each $\mathcal{S}'$ column is one of the instances of $S$ sets.

After building our solver, ASSA, and we were able to handle stable extensions, we discovered that our approach is time consuming and the computational hardness exponentially grows as the number of arguments become bigger and bigger. For example, in order to consider all possible combinations for an argumentation framework with $n$-many arguments, we have to compute a matrix $\mathcal{S}'$, with $2^n$ columns. It was not much of a surprise when we discovered that our solver runs out of memory after compiling it with an argumentation framework with more than twenty arguments. We know that the result we provide suffers from the computations complexity that follows matrix operations. In a later version of ASSA, we plan to fix this by computing matrix $\mathcal{S}'$ in a smarter way. We think that by checking some critical arguments at an early stage may reduce the size, and therefore the computational complexity, as well as the memory our solver needs. Nonetheless, one can overcome this problem by running ASSA under powerful parallel computers and then distribute matrix $\mathcal{S}'$ to several machines that can handle $\mathcal{S}'$ as one matrix.

In conclusion, being part of a competition is intriguing. We have learned a lot just by trying to implement our theory. Our solver is still at version one and we hope that at a later point we can make it run faster and may be answer questions of a more complicated nature. By finding stable extensions, we can also find some complete extensions by definition. Unfortunately, this kind of questions is not part of ASSA. We have decided to provide support only for questions related to stable semantics:

- Given an abstract argumentation framework, determine some extension
- Given an abstract argumentation framework, determine all extensions
- Given an abstract argumentation framework and some argument, decide whether the given argument is credulously inferred
- Given an abstract argumentation framework and some argument, decide whether the given argument is skeptically inferred
3 Description

Our solver is written in Java and uses the trivial graph format. Beside the desire to get a good score, competitions are always interesting and informative. Due to the former, we decided to participate in this contest despite the fact that there is room for improvement on how fast ASSA can perform. We believe that our idea is unique and we hope that many researches will get inspired.

On receiving a file containing the argumentation framework in tgf form we read it and create its matrix representation, $A$. We then create all possible instances of selected arguments and combine them into a matrix, $S'$. Based on matrix operations and specifically left and right matrix multiplication we can navigate inside the argumentation. Finding then which arguments attack other arguments and which arguments are under attack, we extract all conflict free sets. Based on some comparison to the system output matrices and $S'$, we then find all stable extensions.

What we have learned while implementing the solver is that a more targeted selection of arguments is necessary as ASSA can quickly run out of memory. Our solver contains the folders bin, classes, data, lib and src. Under the data folder a tgf file format is expected. To run ASSA under bin, click compile and then click Solver. Results are printed on the screen.

References

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