Abstract Dialectical Frameworks*
Properties, Complexity, and Implementation

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Outline

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**Motivation - Argumentation**

- Situated in the intersection between
  - Philosophy,
  - Artificial Intelligence, and
  - several application domains.

- Formal approach to **nonmonotonic reasoning** with potentially inconsistent knowledge

**Concerns of Argumentation Models**

- representation of **arguments**
- representation of **relations** between arguments
- finding “acceptable” **sets of arguments** with **semantics**
  - acceptable set is an extension
  - arguments are **defeasible** during resolving of extensions

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Motivation - ADFs

- **Dung’s Argumentation Framework**
  - introduced by [Dung, 1995]
  - simple
  - powerful
- Dung’s AF can only model attack relations natively
- More complex relations need auxiliary constructs

- **Abstract Dialectical Frameworks**
  - introduced by [Brewka and Woltran, 2010]
  - generalization of Dung’s AF
  - total functions specify relation types (acceptance conditions)
  - bipolar Abstract Dialectical Frameworks (BADFs) restrict relation types to be attacking or supporting
  - some semantics are only defined for BADFs
Main contributions

- Alternative representations for ADFs with useful properties
- Generalized and unrestricted stable model semantics for ADFs
- Implementation of a software system to compute the extensions under several semantics
Definition (pForm-ADF)

A pForm-ADF is a pair $D = (S, AC)$, where

- $S$ is a set of statements
- $AC = \{AC_s\}_{s \in S}$ is the set of acceptance conditions, where each statement has exactly one associated condition.

An acceptance condition $AC_s$ is a propositional formula $\psi$.

Definition (model semantics)

Let $D = (S, AC)$ be a pForm-ADF. $M \subseteq S$ is a model of $D$ if for each $s \in S$, $M \in mod_p(AC_s)$ iff $s \in M$, holds. $model_{pADF}(D)$ is the set of models for the pForm-ADF $D$. 
Propositional Formula ADF

Example (pForm-ADF)

\[ S = \{A, B, C\} \]
\[ AC = \{AC_A, AC_B, AC_C\} \]
\[ AC_A = B \]
\[ AC_B = A \]
\[ AC_C = \neg B \]

models = \{\{A, B\}, \{C\}\}
Propositional Formula ADF

Example (pForm-ADF)

\[ S = \{A, B, C, D\} \]
\[ AC = \{AC_A, AC_B, AC_C, AC_D\} \]
\[ AC_A = \top \]
\[ AC_B = \neg A \]
\[ AC_C = A \]
\[ AC_D = (\neg B \land C) \lor (B \land \neg A) \]
\[ \text{models} = \{\{A, C, D\}\} \]
Stable model semantics

It is based on the transformation from an ADF to a BADF:

- splits acceptance conditions with dependent links
- one AC with supporting character
- one AC with attacking character
- done by additional criteria in the ACs

Example

\[ AC_s = (a \land b) \lor (\neg a \land c) \mapsto s' \lor s'' \]
\[ AC_{s'} = ((a \land b) \lor (\neg a \land c)) \land a \]
\[ AC_{s''} = ((a \land b) \lor (\neg a \land c)) \land \neg a \]
Stable model semantics

- stable semantics for bipolar pForm-ADFs
- generalization lifts the restriction of bipolar ADFs

**Definition ((generalized) stable model for pForm-ADFs)**

Let $D = (S, AC)$ be a (bipolar) pForm-ADF. A model $M$ of $D$ is a stable model if $M$ is the least model of the reduced pForm-ADF $D^M = (S^M, AC^M)$ obtained from $D$ by

(I) eliminating all nodes not contained in $M$, s.t. $S^M = S \cap M$,

(II) for all $s \in S^M$ substitute in $AC_s$ all $a \in \text{atoms}(AC_s)$ with $\bot$ if $a \notin S^M$,

(III) for all $s \in S^M$ substitute in $AC_s$ all $a \in \text{atoms}(AC_s)$ with $\bot$ if $a \in \text{att}(AC_s)$.

(IV) for all $s \in S^M$, if $\{a_1, \ldots, a_n\}$ is the set of all selected dependent variables in $AC_s$ and $M$ then $AC^M_s = AC_s \land a_1 \land \ldots \land a_n$
ASP encoding

- Encoding for all semantics [Ellmauthaler and Wallner, 2012]
- Based on pForm-ADF representation
- Utilize different logic programming techniques
  - Guess & Check
  - Saturation
  - Optimization
  - Subset-maximality
  - Iterations
- Implementation uses the Potassco Answer Set Solving Collection [Gebser et al., 2011]
ASP Encoding

Example (Instance format)

\[
\begin{align*}
\text{statement}(a). & \quad \text{ac}(a,b). & \quad \text{supp}(b,a). \\
\text{statement}(b). & \quad \text{ac}(b,a). & \quad \text{supp}(a,b). \\
\text{statement}(c). & \quad \text{ac}(c,\text{neg}(b)). & \quad \text{att}(b,c).
\end{align*}
\]

Example

\[
\begin{align*}
\text{sup} & \quad \text{att} \\
A & \quad B & \quad C \\
\text{sup} & \quad \text{att}
\end{align*}
\]

Model semantics

\[
\begin{align*}
\text{in}(X) & :- \neg \text{out}(X), \text{statement}(X). \\
\text{out}(X) & :- \neg \text{in}(X), \text{statement}(X). \\
& :- \text{in}(X), \text{ac}(X,F), \text{nomodel}(F). \\
& :- \text{out}(X), \text{ac}(X,F), \text{ismodel}(F).
\end{align*}
\]
Achievements - Implementation

- **Implementation** for the following semantics
  - conflict-free set
  - model
  - linktype distinction
  - stable model
  - admissible set
  - preferred model
  - well-founded model

- Preliminary **benchmark tests** for BADFs with up to 30 statements and up to 8 links per statement
Achievements - Theoretical

- **Alternative Representations** for ADFs
  - Propositional Formula ADFs
  - Hypergraph ADFs
- **Subclass for BADFs** on pForm-ADFs (**monotone** pForm-ADF)
- ADF $\rightarrow$ BADF transformation
- Unrestricted **generalized stable models semantics**
- **Complexity results** for link-type decision problem for ADFs ($\text{coNP}$-complete)
- **Complexity results** for the generalized stable model semantics ($\text{CA}^{\text{monotone}} = \text{NP}$-complete)
- **Counter-examples** where AF based inter-semantics relations for ADFs do not hold
Many different approaches based on Dung’s AF, like

- Constraint Argumentation Frameworks (CAF) [Coste-Marquis et al., 2006],
- Extended Argumentation Frameworks (EAF) [Modgil, 2009],
- Argumentation Frameworks with Recursive Attacks (AFRA) [Baroni et al., 2011],
- Context Based Argumentation [Brewka and Eiter, 2009], and
- Managed Multi Context Systems (mMCS) [Brewka et al., 2011].

Carneades [Gordon et al., 2007]

- is used for law interpretation
- utilizes another approach
- multiple stages of computation
- one fixed stage can be simulated with ADFs [Brewka and Gordon, 2010]
Future Work

- **Further investigations** of inter-semantic relations and possibly revamping some semantics
- **Further investigation** of the correspondence between stable model semantics and the Gelfond-Lifschitz reduct for Logic Programming
- **Simulations** of CAF, EAF, AFRA, ... with ADFs
- **Enhance** mMCS with ADFs
- **Optimization** of the implementation
- **Utilization** of other argumentation systems for AFs (e.g. CEGARTIX, DYNPARTIX)


