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A Comprehensive Analysis of the cf2 Argumentation Semantics:

From Characterization to Implementation

Sarah Alice Gaggl

Institute of Informationsystems, Vienna University of Technology

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FACULTY OF !NFORMATICS

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Motivation

- Argumentation is one of the major fields in Artificial Intelligence (AI).
- Applications in diverse domains (legal reasoning, multi-agent systems, social networks, e-government, decision support).
- Concept of abstract Argumentation Frameworks (AFs) [Dung, 1995] is one of the most popular approaches.
- Arguments and a binary attack relation between them, denoting conflicts, are the only components.
- Numerous semantics to solve the inherent conflicts by selecting acceptable sets of argument.
- Admissible-based versus naive-based semantics.
- Development of competitive systems.

Motivation ctd.

cf2 Semantics

- is based on decomposition of the framework along its strongly connected components (SCCs) [Baroni et al., 2005];
- does not require to defend arguments against attacks;
- allows to treat cycles in a more sensitive way than other semantics;
- is not well studied, due to quite complicated definition.

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Goals of the Thesis

- Answer-set programming encodings for *cf2*.
- Alternative characterization.
- Verification of behavior on concrete instances.
- Identification of possible redundancies.
- Complete complexity analysis.

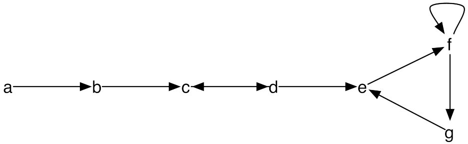
Outline

1. Background on abstract argumentation frameworks and semantics
2. Alternative characterization of $cf2$
3. Combining $cf2$ and stage semantics
4. Redundancies and strong equivalence
5. Computational complexity
6. Implementations
7. Conclusion

Abstract Argumentation Framework [Dung, 1995]

An abstract argumentation framework (AF) is a pair $F = (A, R)$, where A is a finite set of arguments and $R \subseteq A \times A$. Then $(a, b) \in R$ if a attacks b. Argument $a \in A$ is defended by $S \subseteq A$ (in F) iff, for each $b \in A$ with $(b, a) \in R$, S attacks b.

Example

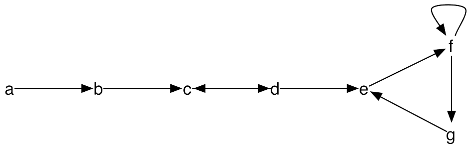


Semantics for AFs

Let $F = (A, R)$ and $S \subseteq A$, we say

- S is conflict-free in F, i.e. $S \in cf(F)$, if $\forall a, b \in S$: $(a, b) \notin R$;
- $S \in cf(F)$ is maximal conflict-free or naive (in F), i.e. $S \in naive(F)$, if $\forall T \in cf(F)$, $S \not\subset T$.

Example



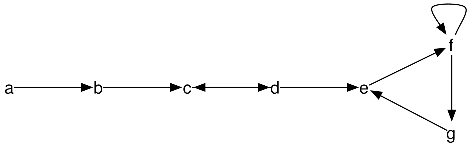
$$naive(F) = \{\{a, d, g\}, \{a, c, e\}, \{a, c, g\}\}.$$

Naive-based Semantics

Let $F = (A, R)$ and $S \subseteq A$. Let $S_R^+ = S \cup \{b \mid \exists a \in S$, s. t. $(a, b) \in R\}$ be the range of S. Then, a set $S \in cf(F)$ is

- a stable extension (of F), i.e. $S \in stable(F)$, if $S_R^+ = A$;
- stage in F, i.e. $S \in stage(F)$, if for each $T \in cf(F)$, $S_R^+ \not\subset T_R^+$.

Example



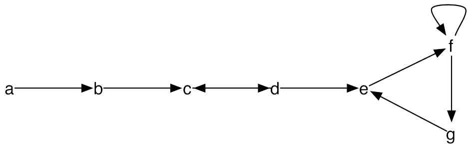
$$stable(F) = \emptyset, stage(F) = \{\{a, d, g\}, \{a, c, e\}, \{a, c, g\}\}.$$

Admissible-based Semantics

Then, $S \in cf(F)$ is

- admissible in F, i.e. $S \in adm(F)$, if each $a \in S$ is defended by S;
- a preferred extension (of F), i.e. $S \in pref(F)$, if $S \in adm(F)$ and for each $T \in adm(F)$, $S \not\subset T$.

Example



$$adm(F) = \{\emptyset, \{a\}, \{c\}, \{d\}, \{a,c\}, \{a,d\}\}, pref(F) = \{\{a,c\}, \{a,d\}\}.$$

cf2 Semantics

- One of the SCC-recursive semantics introduced in [Baroni et al., 2005].
- Naive-based semantics.
- Handles odd- and even-length cycles in a uniform way.
- Can accept arguments out of odd-length cycles.
- Can accept arguments attacked by self-attacking arguments.
- Satisfies most of the evaluation criteria proposed in [Baroni and Giacomin, 2007].

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Further Notations, let $F = (A, R)$

- $SCCs(F)$: set of strongly connected components of F,
- $C_F(a)$: the unique set $C \in SCCs(F)$, s.t. $a \in C$,
- $F|_S = ((A \cap S), R \cap (S \times S))$: sub-framework of F w.r.t. S,
- $F|_S - S' = F|_{S \setminus S'}$, $F - S = F|_{A \setminus S}$.

Definition ($D_F(S)$)

Let $F = (A, R)$ be an AF and $S \subseteq A$. An argument $b \in A$ is component-defeated by S (in F), if there exists an $a \in S$, such that $(a, b) \in R$ and $a \notin C_F(b)$. The set of arguments component-defeated by S in F is denoted by $D_F(S)$.

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cf2 Extensions [Baroni et al., 2005]

Let $F = (A, R)$ be an argumentation framework and S a set of arguments. Then, S is a *cf2* extension of F, i.e. $S \in cf2(F)$, iff

- $S \in naive(F)$, in case $|SCCs(F)| = 1$;
- otherwise, $\forall C \in SCCs(F)$, $(S \cap C) \in cf2(F|_C - D_F(S))$.

$S \in cf2(F)$ iff,

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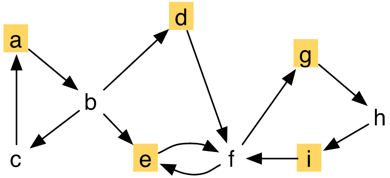
$S = \{a, d, e, g, i\}$, $S \in cf2(F)$?



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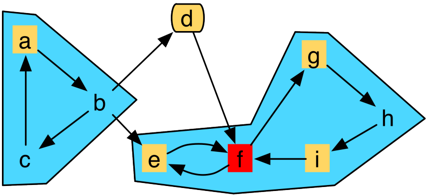
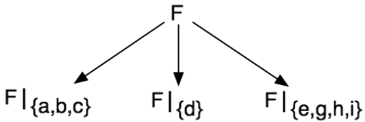
$S = \{a, d, e, g, i\}$, $S \in cf2(F)$? $C_1 = \{a, b, c\}$, $C_2 = \{d\}$, $C_3 = \{e, f, g, h, i\}$ and $D_F(S) = \{f\}$.





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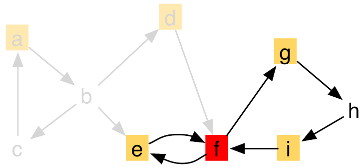

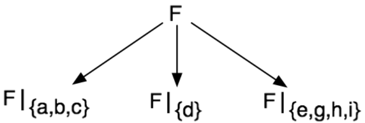

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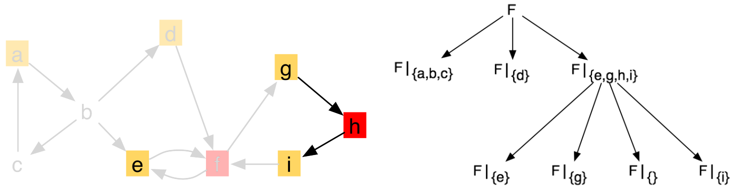
$S = \{a, d, e, g, i\}$, $S \in cf2(F)$? $C_4 = \{e\}$, $C_5 = \{g\}$, $C_6 = \{h\}$, $C_7 = \{i\}$
and $D_{F|_{\{e,g,h,i\}}}(\{e, g, i\}) = \{h\}$.



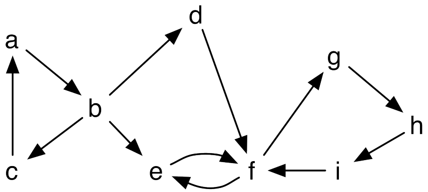
Alt. Characterization of *cf2*

- Original definition of *cf2* is rather cumbersome to be directly encoded in ASP due to the recursive computation of different sub-frameworks.
- In alternative characterization we shift the recursion to a certain set of arguments.
- This enables to directly
  - guess a set S;
  - check whether S is a naive extension of a certain instance of F.

Separation

An AF $F = (A, R)$ is called separated if for each $(a, b) \in R$, there exists a path from b to a. We define $[[F]] = \bigcup_{C \in SCCs(F)} F|_C$ and call $[[F]]$ the separation of F.

Example



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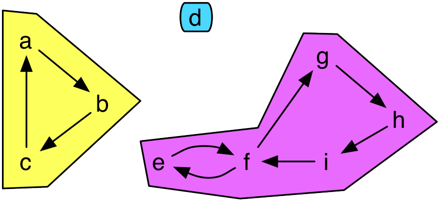

Alt. Characterization of $cf2$ ctd.

Reachability

Let $F = (A, R)$ be an AF, B a set of arguments, and $a, b \in A$. We say that b is reachable in F from a modulo B, in symbols $a \Rightarrow_F^B b$, if there exists a path from a to b in $F|_B$.

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Definition ($\Delta_{F,S}$)

For an AF $F = (A, R)$, $D \subseteq A$, and a set S of arguments,

$$\Delta_{F,S}(D) = \{a \in A \mid \exists b \in S : b \neq a, (b, a) \in R, a \not\Rightarrow_F^{A \setminus D} b\},$$

and $\Delta_{F,S}$ be the least fixed-point of $\Delta_{F,S}(\emptyset)$.

Alt. Characterization of *cf2* ctd.

cf2 Extensions [Gaggl and Woltran, 2012]

Given an AF $F = (A, R)$.

$$cf2(F) = \{S \mid S \in naive(F) \cap naive([[F - \Delta_{F,S}]])\}.$$

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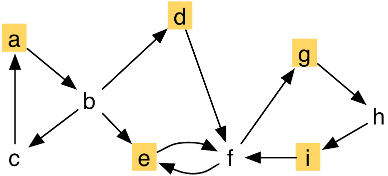

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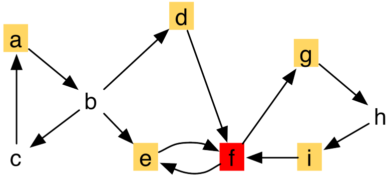

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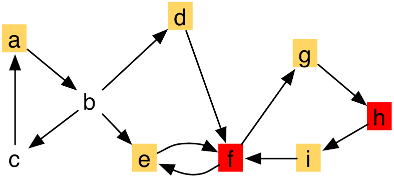

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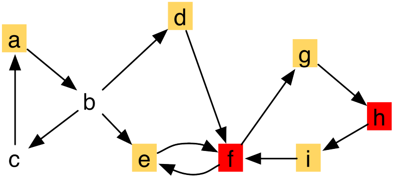

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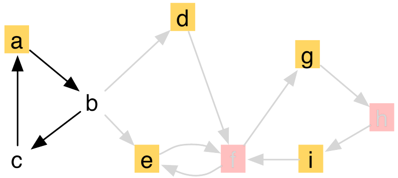
Example

$S = \{a, d, e, g, i\}$, $S \in naive(F)$, $\Delta_{F,S} = \{f, h\}$, $S \in naive([[F - \Delta_{F,S}]])$, thus $S \in cf2(F)$.



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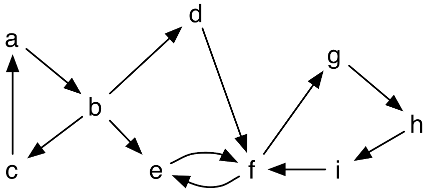
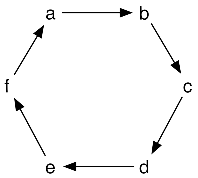


- *cf2* produces questionable results on AFs with cycles of length ≥ 6.

Example

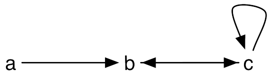


$$\textit{cf2}(F) = \textit{naive}(F) = \{\{a,d\},\{b,e\},\{c,f\},\{a,c,e\},\{b,d,f\}\};$$
$$\textit{stage}(F) = \{\{a,c,e\},\{b,d,f\}\}.$$

Shortcomings of *cf2* and Stage

- *cf2* produces questionable results on AFs with cycles of length ≥ 6.
- The grounded extension is not necessarily contained in every stage extension.
  - Stage semantics does not satisfy directionality.

Example



$$stage(F) = \{\{a\}, \{b\}\} \text{ but } cf2(F) = ground(F) = \{\{a\}\}.$$

Combining *cf2* and stage

We combine *cf2* and stage semantics [Dvorák and Gaggl, 2012a], by

- using the SCC-recursive schema of the *cf2* semantics and
- instantiate the base case with stage semantics.

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stage2 Extensions

For any AF F,

$$stage2(F) = \{S \mid S \in naive(F) \cap stage([[F - \Delta_{F,S}]])\}.$$

$stage2$ Examples

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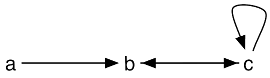

$$stage2(F) = cf2(F) = \{\{a\}\}, \text{ where } stage(F) = \{\{a\}, \{b\}\}.$$

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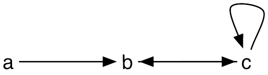

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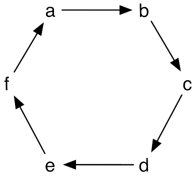
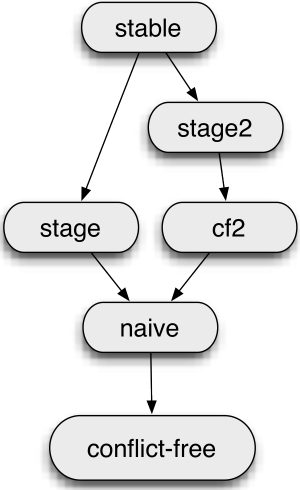


$stage2(G) = stage(G) = \{\{a,c,e\},\{b,d,f\}\}$, but
$cf2(G) = naive(F) = \{\{a,d\},\{b,e\},\{c,f\},\{a,c,e\},\{b,d,f\}\}$.

Relations between Semantics



- Argumentation is a dynamic reasoning process.
- Which effect has additional information w.r.t. a semantics?
- Which information does not contribute to results no matter which changes are performed?
- Identification of kernels to remove redundant attacks [Oikarinen and Woltran, 2011].

Definition

Two AFs F and G are strongly equivalent to each other w.r.t. a semantics σ, in symbols $F \equiv_s^\sigma G$, iff for each AF H, $\sigma(F \cup H) = \sigma(G \cup H)$.

Theorem

For any AFs F and G, $F \equiv_s^{cf2} G$ iff $F = G$.

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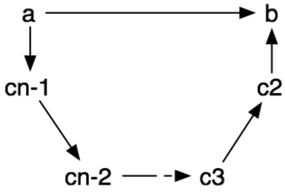

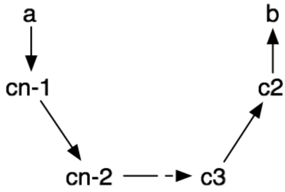

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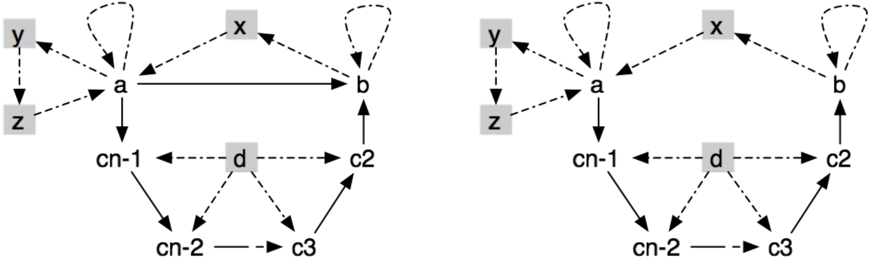

$$H = (A \cup \{d, x, y, z\}, \{(a,a), (b,b), (b,x), (x,a), (a,y), (y,z), (z,a), (d,c) \mid c \in A \setminus \{a,b\}\}).$$

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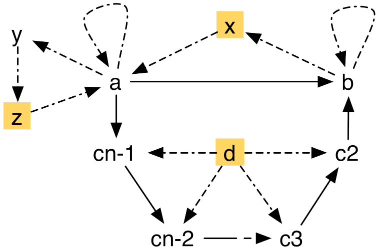

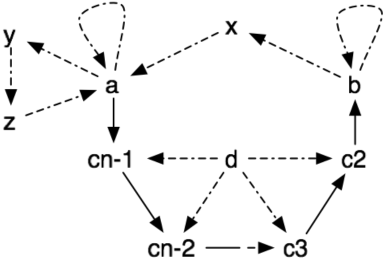

Let $E = \{d, x, z\}$, $E \in cf2(F \cup H)$ but $E \notin cf2(G \cup H)$.

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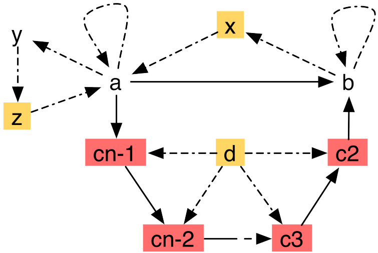

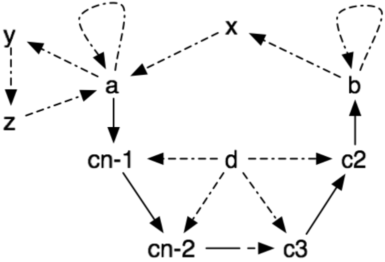

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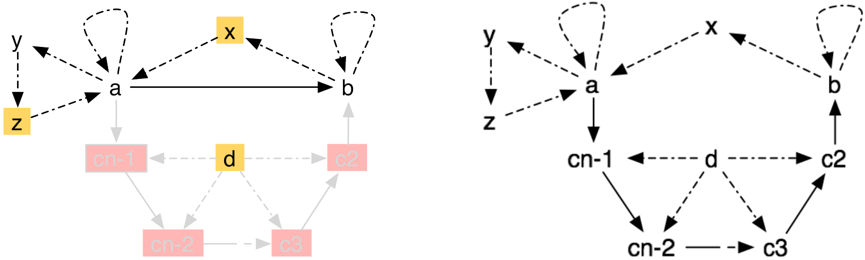

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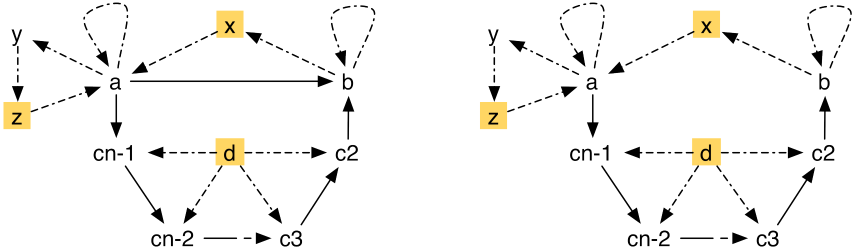
For any AFs F and G, $F \equiv_s^{cf2} G$ iff $F = G$.



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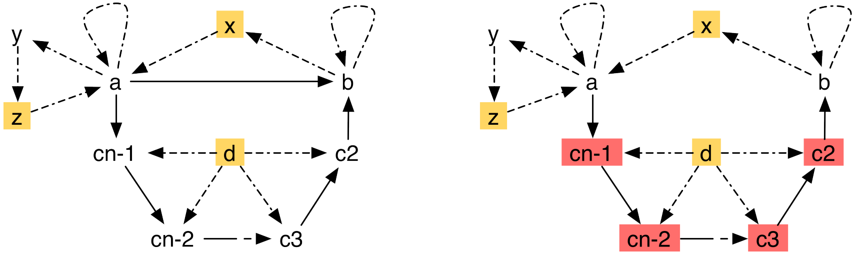

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Strong Equivalence w.r.t. *cf2*

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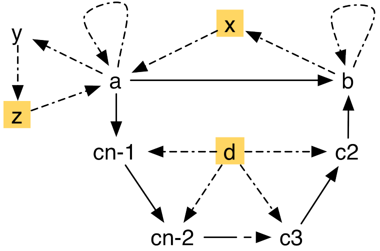

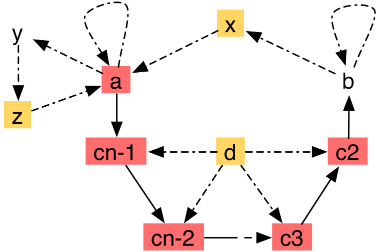

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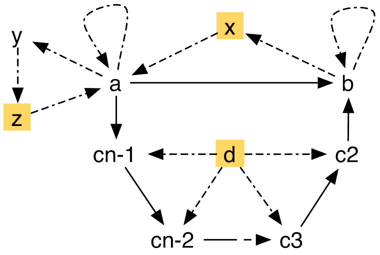

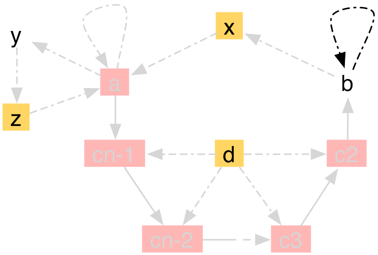

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- No matter which AFs $F \neq G$, one can always construct an H s.t. $cf2(F \cup H) \neq cf2(G \cup H)$;

SE w.r.t. *cf2* and *stage2*

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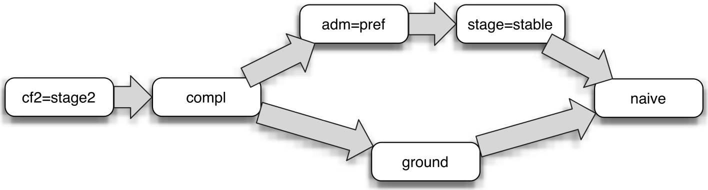
- For *stage2* semantics also strong equivalence coincides with syntactic equivalence.

Succinctness Property

An argumentation semantics σ satisfies the succinctness property or is maximal succinct iff no AF contains a redundant attack w.r.t. σ.

Comparing Semantics w.r.t. SE



Complexity Analysis

	Ver	*Cred*	*Skept*	$Exists^{\neg\emptyset}$
naive	in P	in P	in P	in P
stable	in P	NP-c	coNP-c	NP-c
cf2	in P	NP-c	coNP-c	in P
stage	coNP-c	Σ_2^P-c	Π_2^P-c	in P
stage2	coNP-c	Σ_2^P-c	Π_2^P-c	in P

Table: Computational complexity of naive-based semantics.

Reduction-based Approach

- Answer-set Programming (ASP) encodings for *cf2* and *stage2*.
- Saturation vs. `metasp` encodings for *stage2*.
- All encodings incorporated in the system ASPARTIX [Egly et al., 2010].

Direct Approach

- Labeling-based algorithms for *cf2* and *stage2*.

Web-Application

`http://rull.dbai.tuwien.ac.at:8080/ASPARTIX`

Conclusion

- Alternative characterization for *cf2* to avoid the recursive computation of sub-frameworks.
- *stage2* semantics overcomes problems of *cf2*.
- Strong equivalence w.r.t. *cf2* (resp. *stage2*) coincides with syntactic equivalence.
- Provided the missing complexity results for *cf2* (resp. *stage2*).
- Implementation in terms of ASP and labeling-based algorithms.

Future Work

- Further relations to other semantics like intertranslatability.
- Optimizations of ASP encodings.
- Development of appropriate instantiation methods for naive-based semantics.
- Other combinations of semantics in the alternative characterization, like $sem(F) = \{S \mid \sigma(F) \cap \tau([[F - \Delta_{F,S}]])\}$.

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Tractable Fragments

	$cf2$	$stage2$	$stable$	$stage$
$Cred_{\sigma}{}^{acycl}$	in P	in P	P-c	P-c
$Skept_{\sigma}{}^{acycl}$	in P	in P	P-c	P-c
$Cred_{\sigma}{}^{even-free}$	NP-c	coNP-h	P-c	Σ_2^P-c
$Skept_{\sigma}{}^{even-free}$	coNP-c	coNP-h	P-c	Π_2^P-c
$Cred_{\sigma}{}^{bipart}$	in P	in P	P-c	P-c
$Skept_{\sigma}{}^{bipart}$	in P	in P	P-c	P-c
$Cred_{\sigma}{}^{sym}$	in P	in P$/\Sigma_2^P*$	in P	in P$/\Sigma_2^P*$
$Skept_{\sigma}{}^{sym}$	in P	in P$/\Pi_2^P*$	in P	in P$/\Pi_2^P*$

Table: Complexity results for special AFs (* with self-attacking arguments).