Deciding Acceptance in Incomplete Argumentation Frameworks

Andreas Niskanen[1] Daniel Neugebauer[2]
Matti Järvisalo[1] Jörg Rothe[2]

February 10 @ AAAI 2020, New York City, NY, USA

[1] HIIT, Department of Computer Science, University of Helsinki, Finland
[2] Institut für Informatik, Heinrich-Heine-Universität Düsseldorf, Germany

Motivation

Argumentation

- Active and vibrant area of modern AI research
- Central formalism for reasoning in abstract argumentation: *argumentation frameworks (AFs)* [Dung, 1995]

Uncertainty

- Arises naturally in various argumentative settings
  - Dynamic changes [Doutre and Mailly, 2018]
  - Local views of a global framework
  - Uncertainty in the underlying knowledge base

Natural generalization of AFs for reasoning under uncertainty: *incomplete argumentation frameworks*

[Baumeister et al., 2018b, Baumeister et al., 2018a]

Motivation

Argumentation

- Active and vibrant area of modern AI research
- Central formalism for reasoning in abstract argumentation: *argumentation frameworks (AFs)* [Dung, 1995]

Uncertainty

- Arises naturally in various argumentative settings
  - Dynamic changes [Doutre and Mailly, 2018]
  - Local views of a global framework
  - Uncertainty in the underlying knowledge base

Natural generalization of AFs for reasoning under uncertainty: *incomplete argumentation frameworks*

[Baumeister et al., 2018b, Baumeister et al., 2018a]

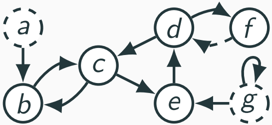
Incomplete Argumentation Frameworks

$IAF = (A, A^?, R, R^?)$, where

- A and R are **definite** arguments and attacks,
- $A^?$ and $R^?$ are **uncertain** arguments and attacks,

with $R, R^? \subseteq (A \cup A^?) \times (A \cup A^?)$.

No uncertain elements $\rightarrow$ standard AF



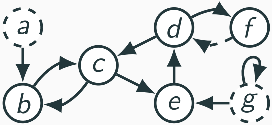
Completion: An AF containing all definite elements and any uncertain elements

Incomplete Argumentation Frameworks

$IAF = (A, A^?, R, R^?)$, where

- A and R are **definite** arguments and attacks,
- $A^?$ and $R^?$ are **uncertain** arguments and attacks,

with $R, R^? \subseteq (A \cup A^?) \times (A \cup A^?)$.



No uncertain elements $\rightarrow$ standard AF

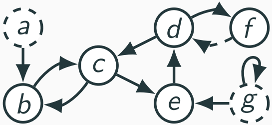
Completion: An AF containing all definite elements and any uncertain elements

Incomplete Argumentation Frameworks

$IAF = (A, A^?, R, R^?)$, where

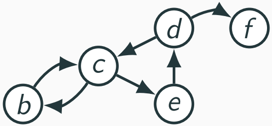
- A and R are **definite** arguments and attacks,
- $A^?$ and $R^?$ are **uncertain** arguments and attacks,

with $R, R^? \subseteq (A \cup A^?) \times (A \cup A^?)$.



No uncertain elements $\rightarrow$ standard AF

Completion: An AF containing all definite elements and any uncertain elements



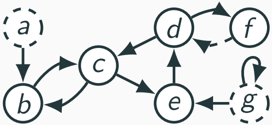
Incomplete Argumentation Frameworks

$IAF = (A, A^?, R, R^?)$, where

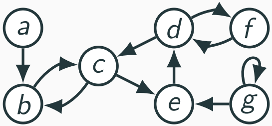
- A and R are **definite** arguments and attacks,
- $A^?$ and $R^?$ are **uncertain** arguments and attacks,

with $R, R^? \subseteq (A \cup A^?) \times (A \cup A^?)$.

No uncertain elements $\rightarrow$ standard AF



Completion: An AF containing all definite elements and any uncertain elements

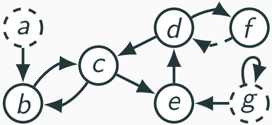


Incomplete Argumentation Frameworks

$IAF = (A, A^?, R, R^?)$, where

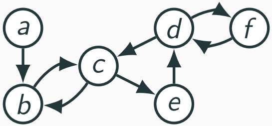
- A and R are **definite** arguments and attacks,
- $A^?$ and $R^?$ are **uncertain** arguments and attacks,

with $R, R^? \subseteq (A \cup A^?) \times (A \cup A^?)$.



No uncertain elements $\rightarrow$ standard AF

Completion: An AF containing all definite elements and any uncertain elements



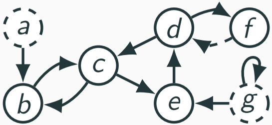
Incomplete Argumentation Frameworks

$IAF = (A, A^?, R, R^?)$, where

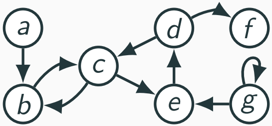
- A and R are **definite** arguments and attacks,
- $A^?$ and $R^?$ are **uncertain** arguments and attacks,

with $R, R^? \subseteq (A \cup A^?) \times (A \cup A^?)$.

No uncertain elements $\rightarrow$ standard AF



Completion: An AF containing all definite elements and any uncertain elements



Acceptance Problems in IAFs

Given $AF = (A, R)$, **semantics** characterize jointly accepted subsets of arguments called **extensions**

- Required to be **conflict-free** ($\textsc{cf}$): independent sets
- In this work: **admissible** ($\textsc{ad}$) and **stable** ($\textsc{st}$)

An argument $a \in A$ is

- **credulously** accepted (CA): a is in **some** extension
- **skeptically** accepted (SA): a is in **all** extensions

Given $IAF = (A, A^?, R, R^?)$, acceptance of $a \in A$ holds

- **possibly** (P) if it holds for **some** completion
- **necessarily** (N) if it holds for **all** completions

Four variants: PCA, PSA, NCA, NSA [Baumeister et al., 2018a]

Acceptance Problems in IAFs

Given $AF = (A, R)$, **semantics** characterize jointly accepted subsets of arguments called **extensions**

- Required to be **conflict-free** (CF): independent sets
- In this work: **admissible** (AD) and **stable** (ST)

An argument $a \in A$ is

- **credulously** accepted (CA): a is in **some** extension
- **skeptically** accepted (SA): a is in **all** extensions

Given $IAF = (A, A^?, R, R^?)$, acceptance of $a \in A$ holds

- **possibly** (P) if it holds for **some** completion
- **necessarily** (N) if it holds for **all** completions

Four variants: PCA, PSA, NCA, NSA [Baumeister et al., 2018a]

Acceptance Problems in IAFs

Given $AF = (A, R)$, **semantics** characterize jointly accepted subsets of arguments called **extensions**

- Required to be **conflict-free** ($\textsc{cf}$): independent sets
- In this work: **admissible** ($\textsc{ad}$) and **stable** ($\textsc{st}$)

An argument $a \in A$ is

- **credulously** accepted (CA): a is in **some** extension
- **skeptically** accepted (SA): a is in **all** extensions

Given $IAF = (A, A^?, R, R^?)$, acceptance of $a \in A$ holds

- **possibly** (P) if it holds for **some** completion
- **necessarily** (N) if it holds for **all** completions

Four variants: PCA, PSA, NCA, NSA [Baumeister et al., 2018a]

Contributions

- **Complexity results** for new variants of skeptical acceptance
  - From polynomial-time to second-level completeness
- **Algorithms** for deciding acceptance in IAFs
  - Boolean satisfiability based encodings and algorithms
  - Empirical evaluation of the proposed approaches
- Establish conditions on **redundant atomic changes** in IAFs
  - Crucial observations in terms of practical performance

Contributions

- **Complexity results** for new variants of skeptical acceptance
    - From polynomial-time to second-level completeness
- **Algorithms** for deciding acceptance in IAFs
    - Boolean satisfiability based encodings and algorithms
    - Empirical evaluation of the proposed approaches
- Establish conditions on **redundant atomic changes** in IAFs
    - Crucial observations in terms of practical performance

Contributions

- **Complexity results** for new variants of skeptical acceptance
  - From polynomial-time to second-level completeness
- **Algorithms** for deciding acceptance in IAFs
  - Boolean satisfiability based encodings and algorithms
  - Empirical evaluation of the proposed approaches
- Establish conditions on **redundant atomic changes** in IAFs
  - Crucial observations in terms of practical performance

Possible Existence and Skeptical Acceptance (PExSA)

s-PExSA

Given: $IAF = (A, A^?, R, R^?)$ and an argument $a \in A$.

Question: Is there a completion AF^* of IAF such that

- AF^* has an **s** extension and
- a is included in all **s** extensions?

For **necessary** variant: quantify **universally** over completions

Note: skeptical acceptance **trivial** under CF and AD

→ **exclude empty set** → $\text{CF}_{\neq\emptyset}$ and $\text{AD}_{\neq\emptyset}$

Possible Existence and Skeptical Acceptance (PExSA)

s-PExSA

Given: $IAF = (A, A^?, R, R^?)$ and an argument $a \in A$.

Question: Is there a completion AF^* of IAF such that

- AF^* has an **s** extension and
- a is included in all **s** extensions?

For **necessary** variant: quantify **universally** over completions

Note: skeptical acceptance **trivial** under CF and AD

→ **exclude empty set** → $\text{CF}_{\neq\emptyset}$ and $\text{AD}_{\neq\emptyset}$

Possible Existence and Skeptical Acceptance (PExSA)

s-PExSA	
Given:	$IAF = (A, A^?, R, R^?)$ and an argument $a \in A$.
Question:	Is there a completion AF^* of IAF such that • AF^* has an **s** extension and • a is included in all **s** extensions?

For **necessary** variant: quantify **universally** over completions

Note: skeptical acceptance **trivial** under CF and AD

$\rightarrow$ **exclude empty set** $\rightarrow$ $\mathrm{CF}_{\neq\emptyset}$ and $\mathrm{AD}_{\neq\emptyset}$

Complexity Results for Skeptical Acceptance

	s-ExSA	**s**-PSA	**s**-PExSA	**s**-NSA	**s**-NExSA
$\text{CF}_{\neq\emptyset}$	**in P**	**in P**	**in P**	**in P**	**in P**
$\text{AD}_{\neq\emptyset}$	**DP-c.**	**$\mathbf{\Sigma_2^P}$-c.**	**$\mathbf{\Sigma_2^P}$-c.**	coNP-c.	**$\mathbf{\Pi_2^P}$-c.**
ST	DP-c.	Σ_2^P-c.	**$\mathbf{\Sigma_2^P}$-c.**	coNP-c.	**$\mathbf{\Pi_2^P}$-c.**

New results highlighted.

Complexity Results for Skeptical Acceptance

	s-ExSA	**s**-PSA	**s**-PExSA	**s**-NSA	**s**-NExSA
$\text{CF}_{\neq\emptyset}$	**in P**	**in P**	**in P**	**in P**	**in P**
$\text{AD}_{\neq\emptyset}$	DP-c.	Σ_2^P-c.	Σ_2^P-c.	coNP-c.	Π_2^P-c.
ST	DP-c.	Σ_2^P-c.	Σ_2^P-c.	coNP-c.	Π_2^P-c.

Under $\text{CF}_{\neq\emptyset}$ reasoning is **tractable**.

Complexity Results for Skeptical Acceptance

	s-ExSA	**s**-PSA	**s**-PExSA	**s**-NSA	**s**-NExSA
$\text{CF}_{\neq\emptyset}$	in P	in P	in P	in P	in P
$\text{AD}_{\neq\emptyset}$	DP-c.	$\boldsymbol{\Sigma_2^P}$**-c.**	$\boldsymbol{\Sigma_2^P}$**-c.**	coNP-c.	Π_2^P-c.
ST	DP-c.	$\boldsymbol{\Sigma_2^P}$**-c.**	$\boldsymbol{\Sigma_2^P}$**-c.**	coNP-c.	Π_2^P-c.

Under $\text{CF}_{\neq\emptyset}$ reasoning is **tractable**.

From PSA to PExSA: no complexity jump

Complexity Results for Skeptical Acceptance

	s-ExSA	**s**-PSA	**s**-PExSA	**s**-NSA	**s**-NExSA
$\text{CF}_{\neq\emptyset}$	in P	in P	in P	in P	in P
$\text{AD}_{\neq\emptyset}$	DP-c.	Σ_2^P-c.	Σ_2^P-c.	coNP-c.	$\mathbf{\Pi_2^P}$**-c.**
ST	DP-c.	Σ_2^P-c.	Σ_2^P-c.	coNP-c.	$\mathbf{\Pi_2^P}$**-c.**

Under $\text{CF}_{\neq\emptyset}$ reasoning is **tractable**.

From PSA to PExSA: no complexity jump

From NSA to NExSA: from first to second level

SAT Encodings for PCA and NSA

Propositional formulas:

- $\varphi_?(IAF)$ encodes valid completions
- $\varphi_{\mathbf{s}}(IAF)$ for $\mathbf{s} \in \{\mathrm{AD}_{\neq\emptyset}, \mathrm{ST}\}$ encodes the semantics by generalizing standard encodings to IAFs [Besnard and Doutre, 2004]

For example, $\varphi_{\mathrm{ST}}(IAF)$ is

$$\varphi_{\mathrm{CF}}(IAF) \wedge \bigwedge_{a \in A \cup A^?} \left((\neg x_a \wedge y_a) \rightarrow \bigvee_{(b,a) \in R \cup R^?} (x_b \wedge y_b \wedge r_{b,a}) \right)$$

Properties:

- $\varphi_?(IAF) \wedge \varphi_{\mathbf{s}}(IAF) \wedge x_a$ is SAT iff $\mathbf{s}$-PCA is *accept*
- $\varphi_?(IAF) \wedge \varphi_{\mathbf{s}}(IAF) \wedge \neg x_a$ is UNSAT iff $\mathbf{s}$-NSA is *reject*

One call to a SAT solver suffices.

SAT Encodings for PCA and NSA

Propositional formulas:

- $\varphi_?(IAF)$ encodes valid completions
- $\varphi_{\mathbf{s}}(IAF)$ for $\mathbf{s} \in \{\mathrm{AD}_{\neq\emptyset}, \mathrm{ST}\}$ encodes the semantics by generalizing standard encodings to IAFs [Besnard and Doutre, 2004]

For example, $\varphi_{\mathrm{ST}}(IAF)$ is

$$\varphi_{\mathrm{CF}}(IAF) \wedge \bigwedge_{a \in A \cup A^?} \left((\neg x_a \wedge y_a) \rightarrow \bigvee_{(b,a) \in R \cup R^?} (x_b \wedge y_b \wedge r_{b,a}) \right)$$

Properties:

- $\varphi_?(IAF) \wedge \varphi_{\mathbf{s}}(IAF) \wedge x_a$ is SAT iff $\mathbf{s}$-PCA is *accept*
- $\varphi_?(IAF) \wedge \varphi_{\mathbf{s}}(IAF) \wedge \neg x_a$ is UNSAT iff $\mathbf{s}$-NSA is *reject*

One call to a SAT solver suffices.

SAT Encodings for PCA and NSA

Propositional formulas:

- $\varphi_?(IAF)$ encodes valid completions
- $\varphi_{\mathbf{s}}(IAF)$ for $\mathbf{s} \in \{\mathrm{AD}_{\neq\emptyset}, \mathrm{ST}\}$ encodes the semantics by generalizing standard encodings to IAFs [Besnard and Doutre, 2004]

For example, $\varphi_{\mathrm{ST}}(IAF)$ is

$$\varphi_{\mathrm{CF}}(IAF) \wedge \bigwedge_{a \in A \cup A^?} \left((\neg x_a \wedge y_a) \rightarrow \bigvee_{(b,a) \in R \cup R^?} (x_b \wedge y_b \wedge r_{b,a}) \right)$$

Properties:

- $\varphi_?(IAF) \wedge \varphi_{\mathbf{s}}(IAF) \wedge x_a$ is SAT iff $\mathbf{s}$-PCA is *accept*
- $\varphi_?(IAF) \wedge \varphi_{\mathbf{s}}(IAF) \wedge \neg x_a$ is UNSAT iff $\mathbf{s}$-NSA is *reject*

One call to a SAT solver suffices.

CEGAR Algorithm for PExSA

Input: $IAF = (A, A^?, R, R^?)$, $a \in A$, $\mathbf{s} \in \{\textsc{ad}_{\neq\emptyset}, \textsc{st}\}$

$\varphi \leftarrow \textsc{Abstraction}(IAF, a)$
while true **do**
  $(sat, \tau) \leftarrow \mathrm{SAT}(\varphi)$
  if *sat* = *false* **then** return *reject*
  $AF^* \leftarrow \textsc{Completion}(\tau)$
  $(sat, \tau) \leftarrow \mathrm{SAT}(\textsc{Check}(IAF, AF^*, a))$
  if *sat* = *false* **then** return *accept*
  $\varphi \leftarrow \varphi \wedge \textsc{Refine}(IAF, AF^*)$
end while

Goal: search for a witness completion for $\textsc{PExSA}$

CEGAR Algorithm for PExSA

Input: $IAF = (A, A^?, R, R^?)$, $a \in A$, $\mathbf{s} \in \{\textsc{ad}_{\neq\emptyset}, \textsc{st}\}$

$\varphi \leftarrow \textsc{Abstraction}(IAF, a)$

while true **do**

$(sat, \tau) \leftarrow \mathrm{SAT}(\varphi)$

if $sat = false$ **then** return *reject*

$AF^* \leftarrow \textsc{Completion}(\tau)$

$(sat, \tau) \leftarrow \mathrm{SAT}(\textsc{Check}(IAF, AF^*, a))$

if $sat = false$ **then** return *accept*

$\varphi \leftarrow \varphi \wedge \textsc{Refine}(IAF, AF^*)$

end while

Abstraction: PCA as an overapproximation in NP

Initialized via $\varphi_?(IAF) \wedge \varphi_{\mathbf{s}}(IAF) \wedge x_a$

CEGAR Algorithm for PExSA

Input: $IAF = (A, A^?, R, R^?)$, $a \in A$, $\mathbf{s} \in \{\textsc{ad}_{\neq\emptyset}, \textsc{st}\}$

$\varphi \leftarrow \textsc{Abstraction}(IAF, a)$

while true **do**

$(sat, \tau) \leftarrow \text{SAT}(\varphi)$

if $sat = false$ **then** return *reject*

$AF^* \leftarrow \textsc{Completion}(\tau)$

$(sat, \tau) \leftarrow \text{SAT}(\textsc{Check}(IAF, AF^*, a))$

if $sat = false$ **then** return *accept*

$\varphi \leftarrow \varphi \wedge \textsc{Refine}(IAF, AF^*)$

end while

Call SAT solver on abstraction:

Is there a completion where *a* is credulously accepted?

CEGAR Algorithm for PExSA

Input: $IAF = (A, A^?, R, R^?)$, $a \in A$, $\mathbf{s} \in \{\text{AD}_{\neq\emptyset}, \text{ST}\}$

$\varphi \leftarrow \text{Abstraction}(IAF, a)$

while true **do**

$(sat, \tau) \leftarrow \text{SAT}(\varphi)$

if $sat = false$ **then** return *reject*

$AF^* \leftarrow \text{Completion}(\tau)$

$(sat, \tau) \leftarrow \text{SAT}(\text{Check}(IAF, AF^*, a))$

if $sat = false$ **then** return *accept*

$\varphi \leftarrow \varphi \wedge \text{Refine}(IAF, AF^*)$

end while

Abstraction UNSAT: no such completion found

$\rightarrow$ Reject query

CEGAR Algorithm for PExSA

Input: $IAF = (A, A^?, R, R^?)$, $a \in A$, $\mathbf{s} \in \{\textsc{ad}_{\neq\emptyset}, \textsc{st}\}$

$\varphi \leftarrow \textsc{Abstraction}(IAF, a)$
while true **do**
$(sat, \tau) \leftarrow \mathrm{SAT}(\varphi)$
if *sat* = *false* **then** return *reject*
$AF^* \leftarrow \textsc{Completion}(\tau)$
$(sat, \tau) \leftarrow \mathrm{SAT}(\textsc{Check}(IAF, AF^*, a))$
if *sat* = *false* **then** return *accept*
$\varphi \leftarrow \varphi \wedge \textsc{Refine}(IAF, AF^*)$
end while

Abstraction SAT: obtain candidate witness completion AF^* represented by truth assignment τ

CEGAR Algorithm for PExSA

Input: $IAF = (A, A^?, R, R^?)$, $a \in A$, $\mathbf{s} \in \{\text{AD}_{\neq\emptyset}, \text{ST}\}$

$\varphi \leftarrow \textsc{Abstraction}(IAF, a)$

while true **do**

$(sat, \tau) \leftarrow \text{SAT}(\varphi)$

if $sat = false$ **then** return *reject*

$AF^* \leftarrow \textsc{Completion}(\tau)$

$(sat, \tau) \leftarrow \text{SAT}(\textsc{Check}(IAF, AF^*, a))$

if $sat = false$ **then** return *accept*

$\varphi \leftarrow \varphi \wedge \textsc{Refine}(IAF, AF^*)$

end while

Is argument a skeptically accepted in AF^*?

Check for a counterexample extension via $\varphi_{\mathbf{s}}(AF^*) \wedge \neg x_a$

CEGAR Algorithm for PExSA

Input: $IAF = (A, A^?, R, R^?)$, $a \in A$, $\mathbf{s} \in \{\textsc{ad}_{\neq\emptyset}, \textsc{st}\}$

$\varphi \leftarrow \textsc{Abstraction}(IAF, a)$

while true **do**

$(sat, \tau) \leftarrow \mathrm{SAT}(\varphi)$

if $sat = false$ **then** return *reject*

$AF^* \leftarrow \textsc{Completion}(\tau)$

$(sat, \tau) \leftarrow \mathrm{SAT}(\textsc{Check}(IAF, AF^*, a))$

if $sat = false$ **then** return *accept*

$\varphi \leftarrow \varphi \wedge \textsc{Refine}(IAF, AF^*)$

end while

Check UNSAT: no counterexample extension found in AF^*

$\rightarrow$ Accept query

CEGAR Algorithm for PExSA

Input: $IAF = (A, A^?, R, R^?)$, $a \in A$, $\mathbf{s} \in \{\textsc{ad}_{\neq\emptyset}, \textsc{st}\}$

$\varphi \leftarrow \textsc{Abstraction}(IAF, a)$
while true **do**
$(sat, \tau) \leftarrow \text{SAT}(\varphi)$
if $sat = false$ **then** return *reject*
$AF^* \leftarrow \textsc{Completion}(\tau)$
$(sat, \tau) \leftarrow \text{SAT}(\textsc{Check}(IAF, AF^*, a))$
if $sat = false$ **then** return *accept*
$\varphi \leftarrow \varphi \wedge \textsc{Refine}(IAF, AF^*)$
end while

Refine abstraction by excluding current completion AF^* via
$\bigvee_{a \in A^*} \neg y_a \vee \bigvee_{a \in A^? \setminus A^*} y_a \vee \bigvee_{(a,b) \in R^*} \neg r_{a,b} \vee \bigvee_{(a,b) \in R^? \setminus R^*} r_{a,b}$

CEGAR Algorithm for PExSA

Input: $IAF = (A, A^?, R, R^?)$, $a \in A$, $\mathbf{s} \in \{\textsc{ad}_{\neq\emptyset}, \textsc{st}\}$

$\varphi \leftarrow \textsc{Abstraction}(IAF, a)$
while true **do**
$(sat, \tau) \leftarrow \text{SAT}(\varphi)$
if *sat* = *false* **then** return *reject*
$AF^* \leftarrow \textsc{Completion}(\tau)$
$(sat, \tau) \leftarrow \text{SAT}(\textsc{Check}(IAF, AF^*, a))$
if *sat* = *false* **then** return *accept*
$\varphi \leftarrow \varphi \wedge \textsc{Refine}(IAF, AF^*)$
end while

This long clause excludes exactly one non-solution.
Can we do better?

Towards Stronger Refinements: Preservation of Extensions

Given $IAF = (A, A^?, R, R^?)$, completion $AF^* = (A^*, R^*)$, counterexample extension $E \in \mathbf{s}(AF^*)$.

Goal: characterize **atomic changes** to AF^* which preserve the counterexample extension.

Adding argument $a \in A^? \setminus A^*$
If there is a definite attack (b, a) with $b \in E$,
adding a to AF^* has no effect on E being an extension.

Removing argument $a \in A^? \cap A^*$
If $a \notin E$, removing a from AF^* has no effect on E still being an extension.

Similar results for **attacks** in paper! [Rienstra et al., 2015]

Towards Stronger Refinements: Preservation of Extensions

Given $IAF = (A, A^?, R, R^?)$, completion $AF^* = (A^*, R^*)$, counterexample extension $E \in \mathbf{s}(AF^*)$.

Goal: characterize **atomic changes** to AF^* which preserve the counterexample extension.

Adding argument $a \in A^? \setminus A^*$
If there is a definite attack (b, a) with $b \in E$,
adding a to AF^* has no effect on E being an extension.

Removing argument $a \in A^? \cap A^*$
If $a \notin E$, removing a from AF^* has no effect on E still being an extension.

Similar results for **attacks** in paper! [Rienstra et al., 2015]

Towards Stronger Refinements: Preservation of Extensions

Given $IAF = (A, A^?, R, R^?)$, completion $AF^* = (A^*, R^*)$, counterexample extension $E \in \mathbf{s}(AF^*)$.

Goal: characterize **atomic changes** to AF^* which preserve the counterexample extension.

Adding argument $a \in A^? \setminus A^*$
If there is a definite attack (b, a) with $b \in E$,
adding a to AF^* has no effect on E being an extension.

Removing argument $a \in A^? \cap A^*$
If $a \notin E$, removing a from AF^* has no effect on E still being an extension.

Similar results for **attacks** in paper! [Rienstra et al., 2015]

Towards Stronger Refinements: Preservation of Extensions

Given $IAF = (A, A^?, R, R^?)$, completion $AF^* = (A^*, R^*)$, counterexample extension $E \in \mathbf{s}(AF^*)$.

Goal: characterize **atomic changes** to AF^* which preserve the counterexample extension.

Adding argument $a \in A^? \setminus A^*$
If there is a definite attack (b, a) with $b \in E$,
adding a to AF^* has no effect on E being an extension.

Removing argument $a \in A^? \cap A^*$
If $a \notin E$, removing a from AF^* has no effect on E still being an extension.

Similar results for **attacks** in paper! [Rienstra et al., 2015]

Strong Refinement for IAFs

Input: $IAF = (A, A^?, R, R^?)$, $a \in A$, $\mathbf{s} \in \{\text{AD}_{\neq\emptyset}, \text{ST}\}$

$\varphi \leftarrow \textsc{Abstraction}(IAF, a)$
while true **do**
  $(sat, \tau) \leftarrow \text{SAT}(\varphi)$
  if *sat* $=$ *false* **then** return *reject*
  $AF^* \leftarrow \textsc{Completion}(\tau)$
  $(sat, \tau) \leftarrow \text{SAT}(\textsc{Check}(IAF, AF^*, a))$
  if *sat* $=$ *false* **then** return *accept*
  $\varphi \leftarrow \varphi \wedge \textsc{Refine}(IAF, AF^*, \textsc{Extension}(\tau))$
end while

Strong refinement: instead of excluding exactly the current completion AF^*, take into account those atomic changes which still preserve the counterexample extension $\rightarrow$ shorter clause

Empirical Evaluation

Benchmark Setup

- Instances: 4200 IAFs generated from ICCMA'17 AFs
  - Parameter: probability p of element being uncertain
- Per-instance timeout: 900 seconds

Implementation: taeydennae

- Includes GLUCOSE (version 4.1) as the SAT solver
- Available online in open source

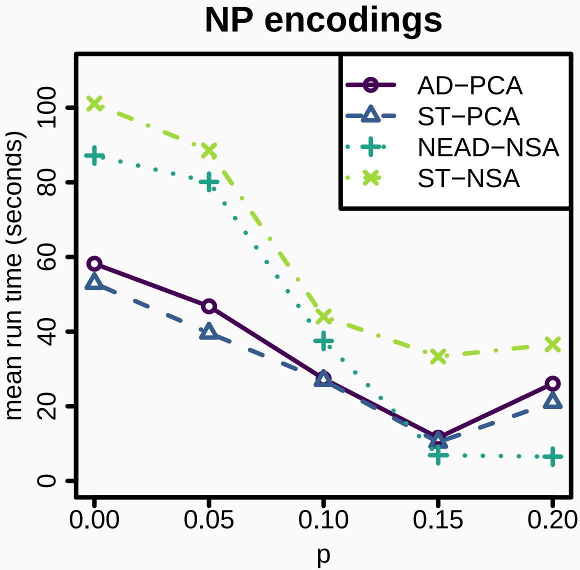
Empirical Evaluation

Benchmark Setup

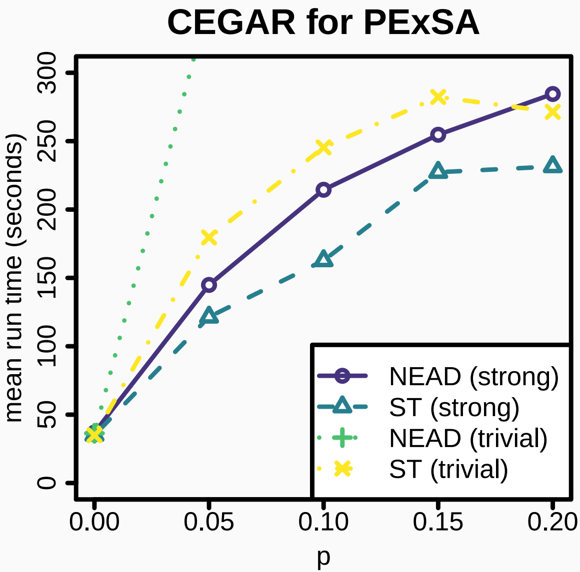
- Instances: 4200 IAFs generated from ICCMA'17 AFs
    - Parameter: probability *p* of element being uncertain
- Per-instance timeout: 900 seconds

Implementation: taeydennae

- Includes Glucose (version 4.1) as the SAT solver
- Available online in open source


NP encodings
AD−PCA
ST−PCA
NEAD−NSA
ST−NSA
mean run time (seconds)
0
20
40
60
80
100
0.00
0.05
0.10
0.15
0.20
p

Results for Second-Level CEGAR



Paper Summary

- Generalizations of the skeptical acceptance problem in IAFs
- **Complexity results** for the new variants
- **Algorithms** for reasoning about acceptance in IAFs
  - Direct SAT encodings
  - SAT-based CEGAR procedures
- Conditions for **redundant atomic changes** to completions from the perspective of preserving an extension
  - Central to scaling up the CEGAR algorithms
- **Implementation** in open source: `https://bitbucket.org/andreasniskanen/taeydennae`

See you at the poster!

Paper Summary

- Generalizations of the skeptical acceptance problem in IAFs
- **Complexity results** for the new variants
- **Algorithms** for reasoning about acceptance in IAFs
  - Direct SAT encodings
  - SAT-based CEGAR procedures
- Conditions for **redundant atomic changes** to completions from the perspective of preserving an extension
  - Central to scaling up the CEGAR algorithms
- **Implementation** in open source: `https://bitbucket.org/andreasniskanen/taeydennae`

See you at the poster!

Baumeister, D., Neugebauer, D., and Rothe, J. (2018a).
Credulous and skeptical acceptance in incomplete argumentation frameworks.
In *Proc. COMMA*, volume 305 of *FAIA*, pages 181–192. IOS Press.

Baumeister, D., Neugebauer, D., Rothe, J., and Schadrack, H. (2018b).
Verification in incomplete argumentation frameworks.
Artif. Intell., 264:1–26.

Besnard, P. and Doutre, S. (2004).
Checking the acceptability of a set of arguments.
In *Proc. NMR*, pages 59–64.

Doutre, S. and Mailly, J. (2018).
Constraints and changes: A survey of abstract argumentation dynamics.
Argument & Computation, 9(3):223–248.

Dung, P. M. (1995).
On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and *n*-person games.
Artif. Intell., 77(2):321–357.

Rienstra, T., Sakama, C., and van der Torre, L. (2015).
Persistence and monotony properties of argumentation semantics.
In *Proc. TAFA*, volume 9524 of *LNCS*, pages 211–225. Springer.