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Synthesizing Argumentation Frameworks from Examples

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Motivation: The study of **computational aspects of argumentation** is an active area of modern AI research. Recent studies on the problem of **realizability** in the context of Dung's **argumentation frameworks**.

Contributions:
- **Introduce the problem** of AF synthesis as a natural generalization of realizability
- **Complexity analysis** for multiple AF semantics
- **Algorithms** based on constraint optimization
- **Implementation** and empirical evaluation

AF SYNTHESIS: DEFINITIONS AND COMPLEXITY

ARGUMENTATION FRAMEWORKS

A directed graph $F = (A, R)$, where

- A is the set of **arguments**
- $R \subseteq A \times A$ is the **attack relation**
  - $(a, b) \in R$: a attacks b

Semantics σ define sets of jointly accepted arguments or **extensions**

- Independent sets with specific properties, e.g. self-defence

Realizability: given σ and extensions, is there an AF representing **exactly** these?

AF SYNTHESIS

Given sets of extensions and non-extensions as weighted **positive** and **negative** examples, construct closest AF representing them.

Cost of an AF F: the sum of the weights of examples **not satisfied**

Input: (A, E^+, E^-, σ), where

- A is a non-empty set of **arguments**
- E^+, E^- are sets of **examples**
- σ is an AF **semantics**

Task: Find the closest AF in terms of minimizing the cost

COMPUTATIONAL COMPLEXITY

	general	$E^+ = \emptyset$	$E^- = \emptyset$
Conflict-free	NP-c	trivial	trivial
Admissible	NP-c	trivial	trivial
Stable	NP-c	trivial	NP-c

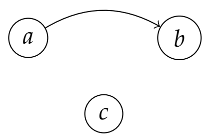
- Complete digraph satisfies all negative examples $\Rightarrow E^+ = \emptyset$ trivial
- Empty digraph satisfies all positive examples under conflict-free and admissible $\Rightarrow E^- = \emptyset$ trivial
- NP-hardness follows by a reduction from the Boolean satisfiability problem
- Note: Under stable semantics even the case $E^- = \emptyset$ is NP-complete!

Example: AF synthesis under different semantics

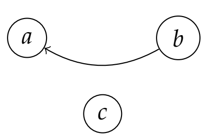
Input:

positive E^+	negative E^-
$e_1 = (\{a,b\}, 1)$	$e_4 = (\{a\}, 1)$
$e_2 = (\{a,c\}, 1)$	$e_5 = (\{a,b,c\}, 5)$
$e_3 = (\{b,c\}, 5)$	

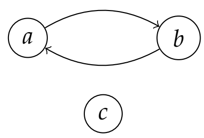
Solutions:



Conflict-free



Admissible



Stable

AF SYNTHESIS VIA MAXIMUM SATISFIABILITY

(Weighted partial) MaxSAT: a Boolean **optimization paradigm**.

Input: Hard clauses and weighted soft clauses
Task: Find a truth assignment that satisfies all hard clauses and maximizes the sum of the weights of satisfied soft clauses.

Encoding AF synthesis as MaxSAT: declare Boolean **variables**

- $r_{a,b}$ for all $a, b \in A$, true iff attack (a, b) included
- Ext^e_σ for all $e \in E^+ \cup E^-$, true iff e is a σ-extension

Hard clauses encode the problem structure: for all examples e,

$$\mathrm{Ext}^e_\sigma \leftrightarrow \varphi_\sigma(e)$$

where $\varphi_\sigma(e)$ encodes that e is a σ-extension.
Soft clauses encode the objective function:

- for all positive examples e, Ext^σ_e
- for all negative examples e, $\neg\mathrm{Ext}^\sigma_e$

Weights of soft clauses according to weights of examples.

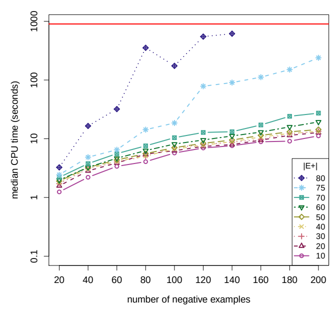
$$\varphi_{cf}(e) = \bigwedge_{a,b \in e} \neg r_{a,b}$$

$$\varphi_{adm}(e) = \varphi_{cf}(e) \wedge \bigwedge_{a \in e} \bigwedge_{b \in A \setminus e} \left(r_{b,a} \rightarrow \bigvee_{c \in e} r_{c,b} \right)$$

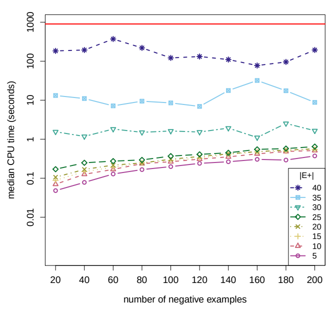
$$\varphi_{stb}(e) = \varphi_{cf}(e) \wedge \bigwedge_{a \in A \setminus e} \left(\bigvee_{b \in e} r_{b,a} \right)$$

System AFSynth and benchmarks available at:
`cs.helsinki.fi/group/coreo/afsynth`

EMPIRICAL EVALUATION



Admissible semantics.



Stable semantics.