Towards Preprocessing for Abstract Argumentation Frameworks

Stefan Woltran

Based on joint work with
Ringo Baumann, Wolfgang Dvořák and Thomas Linsbichler

July 3rd, 2017

Prologue

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On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games. Artif. Intell., 77(2):321–358, 1995.

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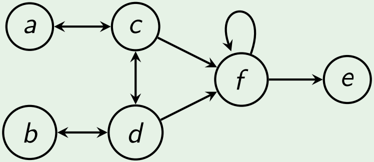
- "The idea of argumentational reasoning is that a statement is believable if it can be argued successfully against attacking arguments."
- "[...] a formal, abstract but simple theory of argumentation is developed to capture the notion of acceptability of arguments."

Prologue

Argumentation Frameworks

... thus abstract away from everything but attacks (calculus of opposition)

Example



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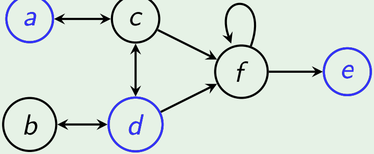

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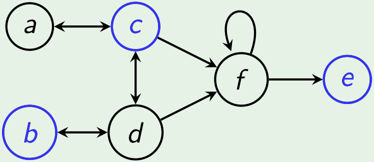

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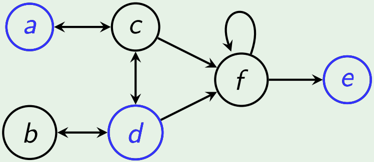

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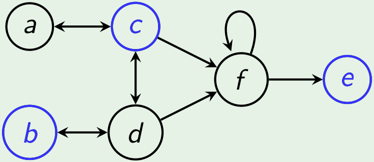

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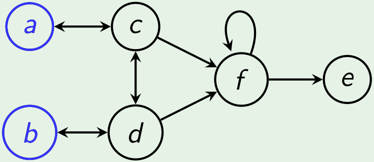

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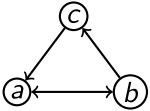
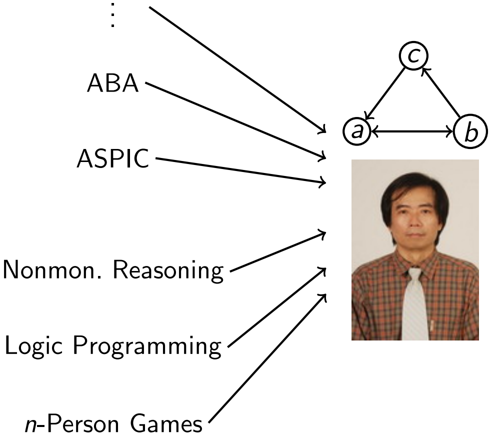


Nonmon. Reasoning

Logic Programming

n-Person Games

Prologue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ABA
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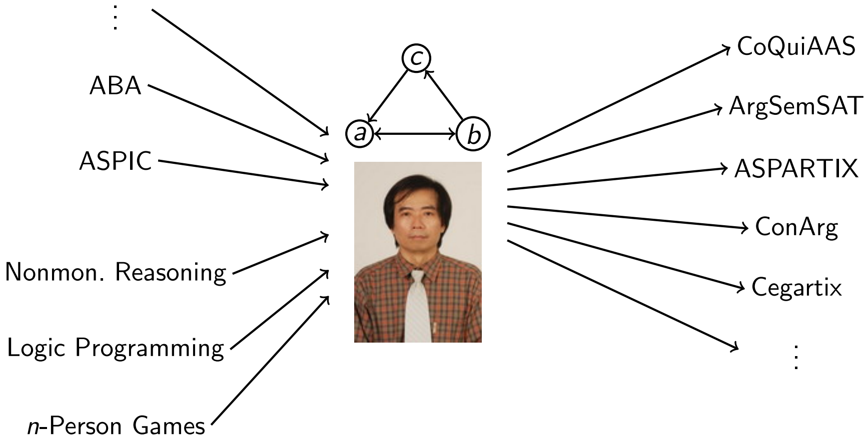
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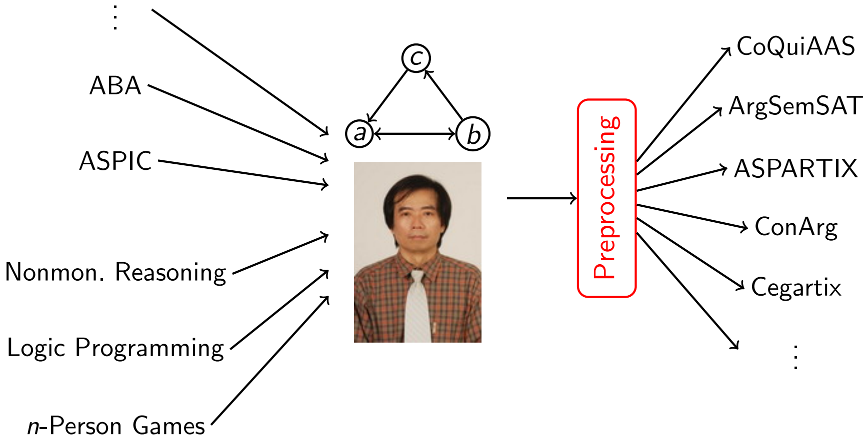

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Outline

- Quick Background on Argumentation Frameworks
- The Role of Preprocessing
- Theoretical Foundations
- Building a Preprocessing Machine
- Conclusions and Open Questions

Background

Definition

An argumentation framework (AF) is a pair (A, R) where

- $A \subseteq U$ is a finite set of arguments and
- $R \subseteq A \times A$ is the attack relation representing conflicts.

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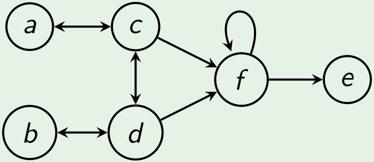

$F = \big(\{a, b, c, d, e, f\},$
$\{(a, c), (c, a), (c, d), (d, c), (d, b), (b, d), (c, f), (d, f), (f, f), (f, e)\}\big)$

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Stable Extensions

Given an AF $F = (A, R)$, a set $E \subseteq A$ is a stable extension of F, if

- E is conflict-free in F (i.e., for each $a, b \in E$, $(a, b) \notin R$),
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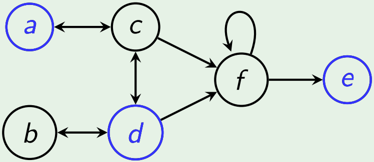

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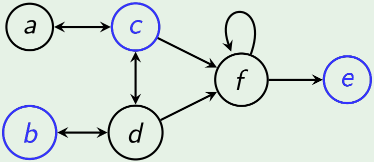

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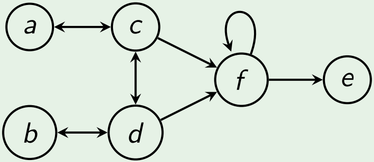

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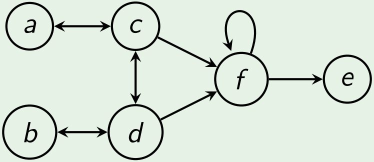

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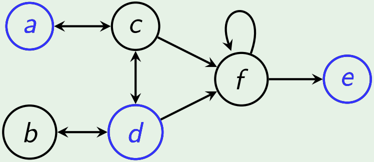

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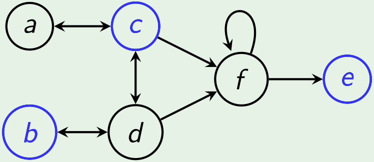

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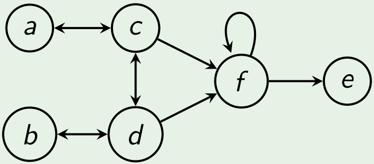

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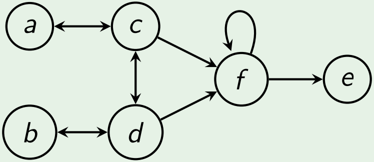

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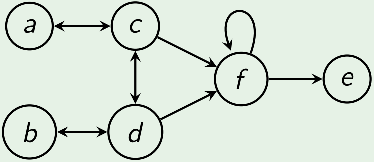

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Preferred Extensions

Given an AF $F = (A, R)$, a set $E \subseteq A$ is a preferred extension in F, if

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- there is no admissible set $T \subseteq A$ of F with $T \supset E$.

$\Rightarrow$ Maximal admissible sets (w.r.t. set-inclusion).

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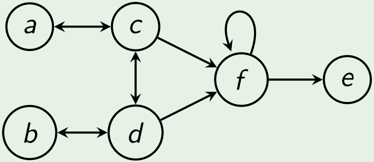

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Further Semantics

For (A, R) and $E \subseteq A$, $E_R^{\oplus} = E \cup \{b \mid (a, b) \in R\}$ denotes the range.

- complete: admissible sets that contain all defended arguments
- semi-stable: admissible sets with subset-maximal range
- stage: conflict-free sets with subset-maximal range

Unique-status semantics:

- groundedsubset-minimal complete set
- ideal: subset-maximal *adm* set contained in each *pref* extension

Background

σ	$Cred_\sigma$	$Skept_\sigma$	Ver_σ	NE_σ
cf	in L	trivial	in L	in L
grd	P-c	P-c	P-c	in L
stb	NP-c	coNP-c	in L	NP-c
adm	NP-c	trivial	trivial	NP-c
comp	NP-c	P-c	in L	NP-c
ideal	in Θ_2^P	in Θ_2^P	in Θ_2^P	in Θ_2^P
pref	NP-c	Π_2^P-c	coNP-c	NP-c
sem	Σ_2^P-c	Π_2^P-c	coNP-c	NP-c
stage	Σ_2^P-c	Π_2^P-c	coNP-c	in L

Background - ICCMA'17

(http://www.dbai.tuwien.ac.at/iccma17/)

Home | Calls | Rules | Participation | Submissions | Results | Organization

ICCMA 2017

The tasks supported by the solvers are summarized in the following table:

	D3	CO				PR				ST				SST				STG				GR		ID	
		DC	DS	SE	EE	DC	DS	SE	EE	DC	DS	SE	EE	DC	DS	SE	EE	DC	DS	SE	EE	DC	SE	DC	SE
argmat olpb		1	1	1	1					1	1	1	1									1	1		
argmat dvisat	1	1	1	1	1	1	1	1	1	1	1	1	1									1	1	1	1
argmat-mpg	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
argmat-sat	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ArgSemSAT		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1					1	1		
ArgTools		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ASPrMin									1																
cegartix	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Chimaerarg									1				1												
ConArg	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CoQuiAAS	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
EqArgSolver	1	1	1	1	1	1	1	1	1	1	1	1	1									1	1		
gg-sts	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
goDIAMOND	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
heureka		1	1	1	1	1	1	1	1	1	1	1	1									1	1		
pyglaf	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Preprocessing

- Preprocessing refers to a family of simplifications which are computationally easy to perform and are equivalence preserving
  - SAT: tautology elimination, clause subsumption, ...
- Proved very successful in SAT and QSAT solving
- Preprocessing in the context of argumentation poses some additional challenges (nonmonotonicity!)

Preprocessing

Journal of Artificial Intelligence Research 53 (2015) 127-168 Submitted 1/15; published 6/15

Clause Elimination for SAT and QSAT

Marijn Heule MARIJN@CS.UTEXAS.EDU
Department of Computer Science,
The University of Texas at Austin, USA

Matti Järvisalo MATTI.JARVISALO@CS.HELSINKI.FI
HIIT, Department of Computer Science,
University of Helsinki, Finland

Florian Lonsing FLORIAN.LONSING@TUWIEN.AC.AT
Institute of Information Systems,
Vienna University of Technology, Austria

Martina Seidl MARTINA.SEIDL@JKU.AT
Armin Biere BIERE@JKU.AT
Institute for Formal Models and Verification,
Johannes Kepler University Linz, Austria

Abstract

The famous archetypical NP-complete problem of *Boolean satisfiability* (SAT) and its PSPACE-complete generalization of *quantified Boolean satisfiability* (QSAT) have become central declarative programming paradigms through which real-world instances of various computationally hard problems can be efficiently solved. This success has been achieved through several breakthroughs in practical implementations of decision procedures for SAT and QSAT, that is, in SAT and QSAT solvers. Here, simplification techniques for conjunctive normal form (CNF) for SAT and for prenex conjunctive normal form (PCNF) for QSAT — the standard input formats of SAT and QSAT solvers—have recently proven very effective in increasing solver efficiency when applied before (i.e., in *preprocessing*) or during (i.e., in *inprocessing*) satisfiability search.

In this article, we develop and analyze clause elimination procedures for pre- and inprocessing. Clause elimination procedures form a family of (P)CNF formula simplification techniques which remove clauses that have specific (in practice polynomial-time) redundancy properties while maintaining the satisfiability status of the formulas. Extending known procedures such as tautology, subsumption, and blocked clause elimination, we introduce novel elimination procedures based

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Marijn Heule MARIJN@CS.UTEXAS.EDU
Department of Computer Science,
The University of Texas at Austin, USA

Matti Järvisalo
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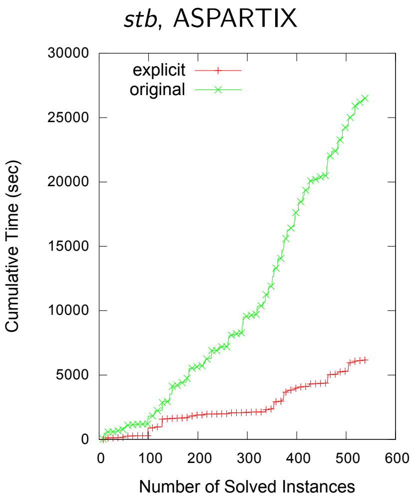
Example from the QBF world:

- Preprocessor Bloqqer solved 471 of 1130 instances from QBFEVAL'16.
- DepQBF solves 556 instances without preprocessing, but 817 with preprocessing.

Preprocessing for Argumentation – Some Experiments



Effect of (non equivalence-preserving) modifications with instances from the ICCMA 2015 stable generator.

Theoretical Foundations

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- a suitable notion of equivalence . . .
- which allows to verify which subparts of AFs can be simplified . . .
- under different semantics

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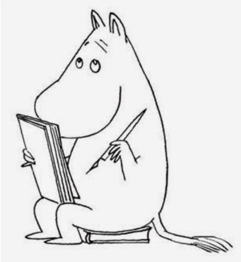


More precisely, we want to find pairs (F, F') such that replacing F by F' in any AF G does not change the extensions of G (under certain assumptions)

Definition

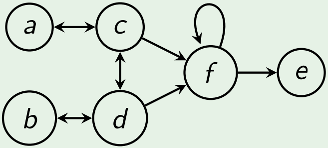
Given a semantics σ. Two AFs F and F' are (standard) equivalent w.r.t. σ (in symbols $F \equiv^{\sigma} F'$) iff $\sigma(F) = \sigma(F')$.

Definition

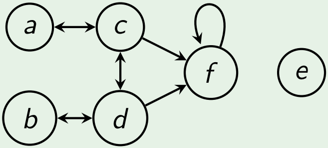
Given a semantics σ. Two AFs F and F' are strongly equivalent w.r.t. σ (in symbols $F \equiv^{\sigma}_{\mathcal{S}} F'$) iff $F \cup H \equiv^{\sigma} F' \cup H$ holds for each AF H.

Theoretical Foundations – Notions of Equivalence

Example

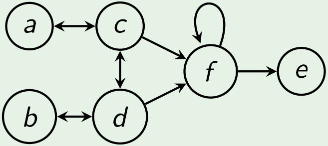


$\equiv^{stb}$

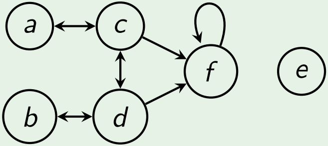


$stb(F) = \{\{a, d, e\}, \{b, c, e\}\}$ $\quad$ $stb(F') = \{\{a, d, e\}, \{b, c, e\}\}$

Example



$\equiv_{\mathcal{S}}^{stb}$



Follows from results in [Oikarinen & W, 2011].

Theoretical Foundations – Notions of Equivalence

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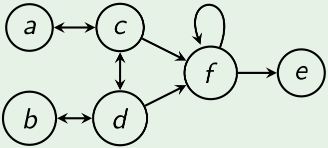
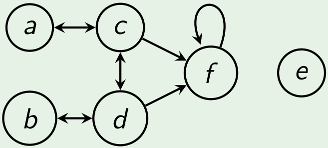


$\not\equiv^{pref}$

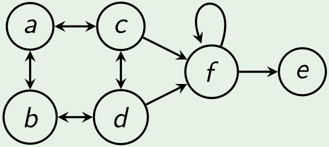


$pref(F) =$
$\{\{a, d, e\}, \{b, c, e\}, \{a, b\}\}$

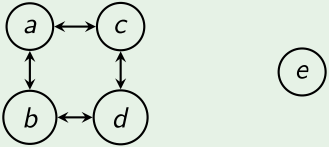
$pref(F') =$
$\{\{a, d, e\}, \{b, c, e\}, \{a, b, e\}\}$

Theoretical Foundations – Notions of Equivalence

Example



$\equiv^{stb}$



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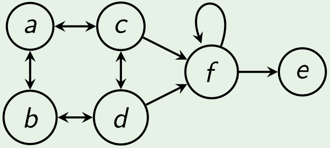
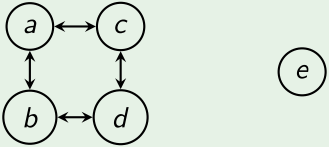


$\not\equiv^{stb}_{\mathcal{S}}$



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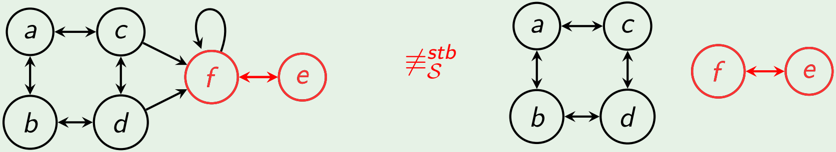

$stb(F \cup H) = \{\{a, d, e\}, \{b, c, e\}, \{a, b, e\}\}$ but $stb(F' \cup H) = \{\{a, d, e\}, \{b, c, e\}, \{a, b, e\}, \{a, d, f\}, \{b, c, f\}\}$

Theoretical Foundations – Main Results

Observations:

- Standard equivalence is too weak for our purpose
- Strong equivalence is too restricted
  - For self-loop free AFs F, F': $F \equiv^{\sigma}_{\mathcal{S}} F'$ iff $F = F'$!

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We thus require a notion of equivalence which takes into account the neighborhood in an adequate way.

Definition

Given a semantics σ and arguments $C \subseteq U$. Two AFs F and F' are *C-relativized equivalent* w.r.t. σ (in symbols $F \equiv^{\sigma}_{C} F'$) iff $F \cup H \equiv^{\sigma} F' \cup H$ holds for each AF H not containing arguments from C.

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- for $C = \emptyset$, C-relativized equivalence coincides with strong equivalence
- for $C = U$, C-relativized equivalence is just standard equivalence

Theoretical Foundations – Main Results

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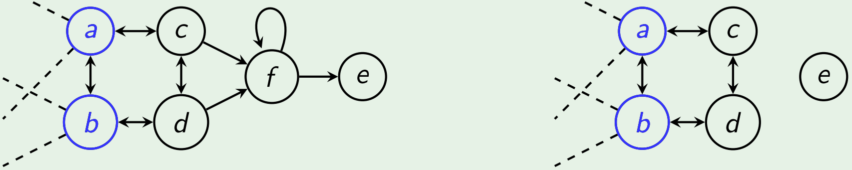
Example with $C = \{c, d, e, f\}$



Theoretical Foundations – Main Results

We first define a parameterized notion of the semantics.

Definition

Let $F = (A, R)$, $C \subseteq U$. The C-restricted stable extensions of F are

$$stb_C(F) = \{E \in cf(F) \mid A \cap C \subseteq E_F^{\oplus}\}$$

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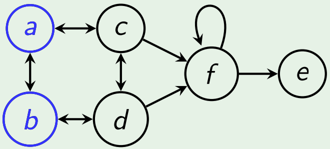

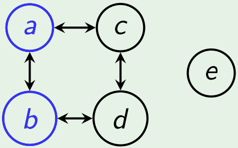

$stb_C(F) = \{\{a, d, e\}, \{b, c, e\}, \{d, e\}, \{c, e\}\}$

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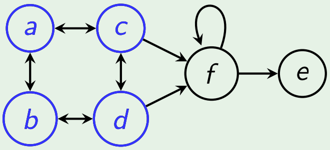
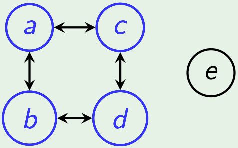
Example with $C = \{e, f\}$





$stb_C(F) = \{\{a, d, e\}, \{b, c, e\}, \{d, e\}, \{c, e\}\}$

$stb_C(F') = \{\{a, d, e\}, \{b, c, e\}, \{d, e\}, \{c, e\}, \{a, e\}, \{b, e\}, \{e\}\}$

Theoretical Foundations – Main Results

For other semantics, such variants can be defined accordingly.

Definition

Let F be an AF, $C \subseteq U$. We define

$$\begin{aligned} adm_C(F) &= \{E \in cf(F) \mid E_F^- \cap C \subseteq E_F^+\} \\ pref_C(F) &= \{E \in adm_C(F) \mid \text{ for all } D \in adm_C(F) \text{ with} \\ &\quad E \setminus C = D \setminus C, E_F^+ \setminus C \subseteq D_F^+ \setminus, E_F^- \setminus E_F^+ \supseteq D_F^- \setminus D_F^+ : \\ &\quad E \cap C \not\subset D \cap C\} \end{aligned}$$

Theoretical Foundations – Main Results

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\end{aligned}
$$

For complete and grounded semantics, similar definitions can be given by using a parameterized version of the characteristic function.

Theoretical Foundations – Main Results

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\end{aligned}
$$

For complete and grounded semantics, similar definitions can be given by using a parameterized version of the characteristic function.

Theorem

Let F be an AF and $C \subseteq U$. Then, the following relations hold:
$stb_C(F) \subseteq pref_C(F) \subseteq comp_C(F) \subseteq adm_C(F)$; $grd_C(F) \subseteq comp_C(F)$.

Theoretical Foundations – Main Results

Theorem

Let F, F' be AFs and $C \subseteq U$. Then, $F \equiv_C^{stb} F'$ iff jointly

(1) $stb_C(F) = stb_C(F')$;

(2) *if* $stb_C(F) \neq \emptyset$, $A(F) \setminus C = A(F') \setminus C$;

(3) *for all* $E \in stb_C(F)$, $E_F^+ \setminus C = E_{F'}^+ \setminus C$.

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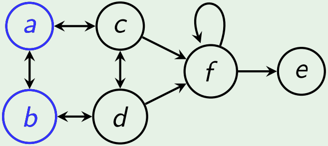

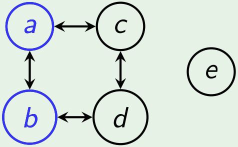

Recall (1) $stb_C(F) = stb_C(F') = \{\{a, d, e\}, \{b, c, e\}, \{d, e\}, \{c, e\}\}$;
(2) and (3) also hold.

Theoretical Foundations – Main Results

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Let F, F' be AFs and $C \subseteq U$. Then, $F \equiv^{stb}_C F'$ iff jointly

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(3) *for all* $E \in stb_C(F)$, $E^+_F \setminus C = E^+_{F'} \setminus C$.

- For $C = U$, (1)–(3) reduce to $stb(F) = stb(F')$;
- For $C = \emptyset$, we have
  (1) $cf(F) = cf(F')$,
  (2) $A(F) = A(F')$,
  (3) for all $E \in cf(F)$, $E^+_F = E^+_{F'}$, i.e. F, F' coincide except for attacks from self-attacking arguments

  (equals known results for strong equivalence).

Theoretical Foundations – Main Results

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Let F, F' be AFs and $C \subseteq U$. Then, $F \equiv_C^{stb} F'$ iff jointly

(1) $stb_C(F) = stb_C(F')$;

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Similar characterization results can be shown for the other main semantics.

Theoretical Foundations – Main Results

Replacement Theorem

For AFs F, F', G and $C \subseteq U$ such that $A(F) \cup A(F') \subseteq C$, $(A(G) \setminus A(F)) \cap C = \emptyset$, and F is a sub-AF of G, let $B = (A(F))^{\oplus}_{G} \cup (A(F))^{-}_{G}$ and $F^G = (B, R(G) \cap (B \times B))$.
Then, $F^G \equiv^{\sigma}_{C} F^G[F/F']$ implies $G \equiv^{\sigma} G[F/F']$.

Theoretical Foundations – Main Results

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Example

Odd-length cycles $(a_1, \ldots, a_n, a_1)$ can be simplified under the stable semantics for any AF where the cycle has exactly one incoming attack (b, a_1) as follows:

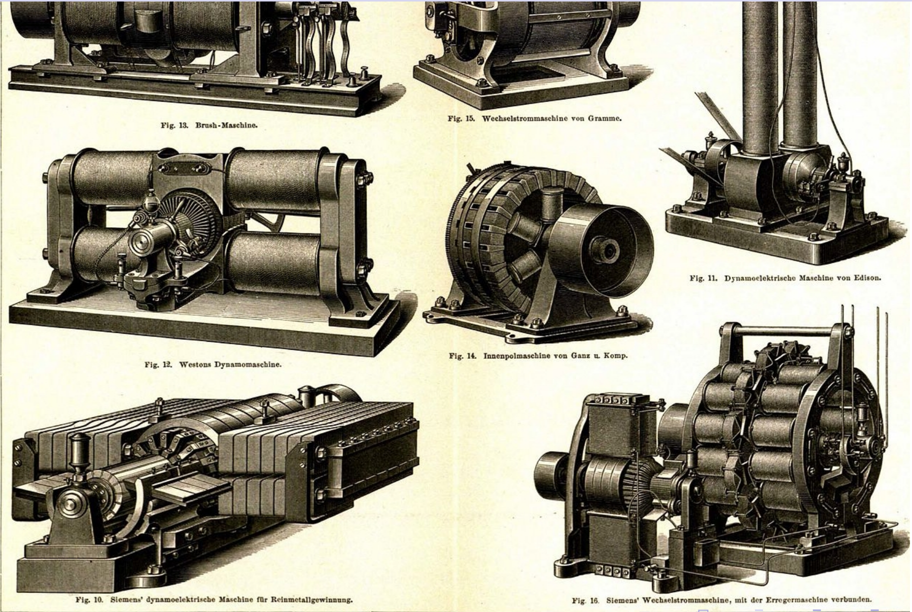
- make a_1 self-attacking
- remove all a_i with odd $i \neq 1$ plus adjacent attacks

Theoretical Foundations – Main Results

Some complexity results:

σ	*grd*	*stb*	*adm*	*comp*	*pref*
$F \equiv^{\sigma}_{\mathcal{S}} G$	in L	in L	in L	in L	in L
$F \equiv^{\sigma} G$	P-c	coNP-c.	coNP-c.	coNP-c.	Π^P_2-c.
$F \equiv^{\sigma}_{C} G$	coNP-c.	coNP-c.	coNP-c.	coNP-c.	Π^P_2-c.

Building a Preprocessing Machine - Our Vision



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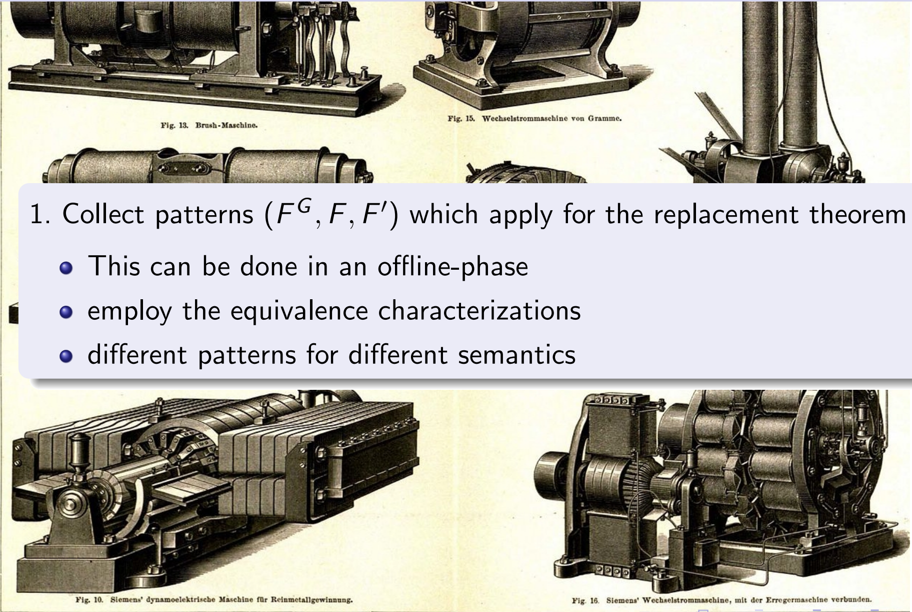


1. Collect patterns (F^G, F, F') which apply for the replacement theorem
   - This can be done in an offline-phase
   - employ the equivalence characterizations
   - different patterns for different semantics

Building a Preprocessing Machine - Our Vision

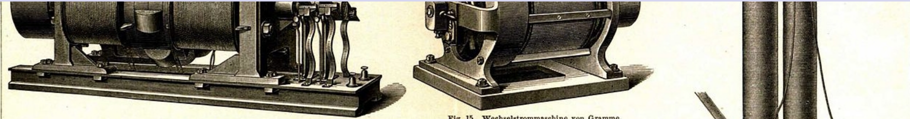


Fig. 13. Brush-Maschine.

Fig. 15. Wechselstrommaschine von Gramme.

2. Build a tool that scans a given AF for possible application of the replacement patterns (F^G, F, F')

- Requires efficient implementation of subgraph-isomorphism problem
- sort out which size of subgraphs allow for efficient scanning for patterns
- integrate other known simplifications (computation of grounded extension) and interleave this with the applied replacements

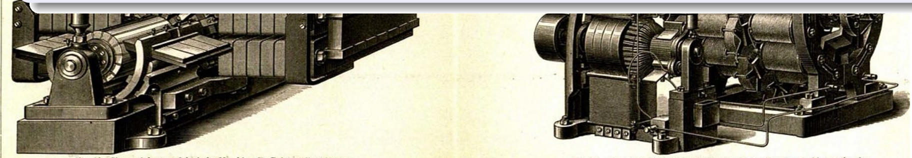
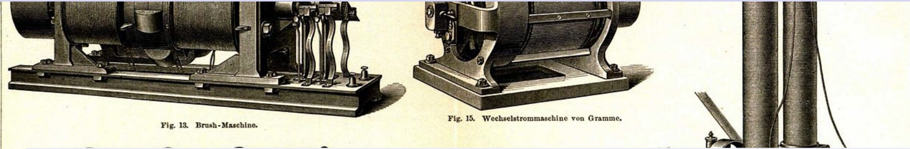


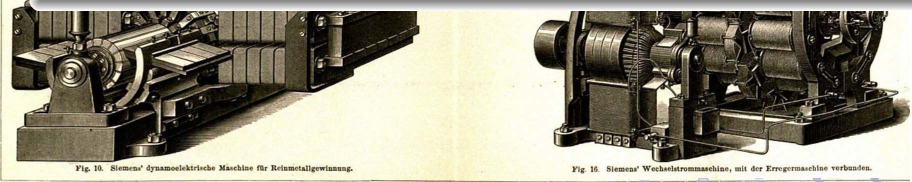
Fig. 10. Siemens' dynamoelektrische Maschine für Reinmetallgewinnung.

Fig. 16. Siemens' Wechselstrommaschine, mit der Erregermaschine verbunden.

Building a Preprocessing Machine - Our Vision



3. Experimental Evaluation and Fine-Tuning
   - which replacements actually help solvers?
     - Preprocessing on the argumentation level should go beyond preprocessing on encodings
   - identification of "promising regions" (e.g. potential separation into SCCs)
   - integration of ML techniques



Conclusion

- Abstract argumentation a central formalism in AI
- ICCMA has stipulated development of solvers
- In other domains, preprocessing recognized as a crucial step to improve efficiency
- Nonmonotonic nature of argumentation semantics makes life complicated

In this talk:

- Introduced a suitable notion of equivalence to seek for simplification patterns
- Discussion of next steps towards practical realization of a preprocessing tool
  - Recall: this is beneficial for all solvers!

Future Work and Open Questions

- Understand C-relativized equivalence for further semantics
- What can be done for acceptance problems?
- Claim: preprocessing could be more powerful if we allow to shift from AFs to a more general formalism (for instance, SETAFs)
  - however, this requires solvers for this general formalism

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Thanks for your attention and enjoy LPNMR!

References

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