Abstract Argumentation – All Problems Solved?

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Prologue

Argumentation is the study of processes "concerned with how assertions are proposed, discussed, and resolved in the context of issues upon which several diverging opinions may be held".
[Bench-Capon and Dunne: Argumentation in AI. Artif. Intell., 171:619-641, 2007]

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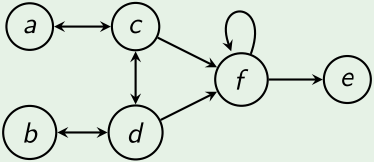
- "The idea of argumentational reasoning is that a statement is believable if it can be argued successfully against attacking arguments."
- "[...] a formal, abstract but simple theory of argumentation is developed to capture the notion of acceptability of arguments."

Prologue

Argumentation Frameworks

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

Example



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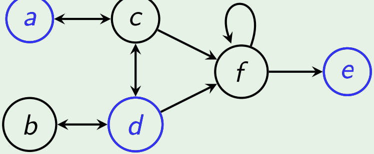

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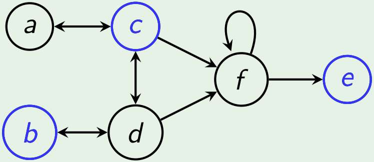

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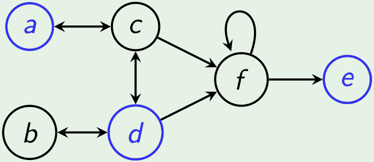

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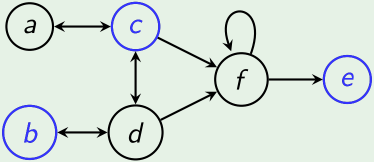

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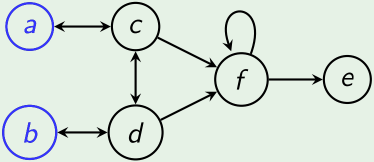

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Prologue

How to obtain such frameworks?
. . . identify conflicting information

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How to obtain such frameworks?
...identify conflicting information
(it is everywhere!)

Domain	Argument	Attack	Aim
People	person	"dislike"	coalition formation
DSupport	statement	"conflict"	conflict resolution
BBS	message	reply	identify opinion leaders
KB	(Φ, α)	$\neg\alpha \in Cn(\Phi')$	inconsistency handling
LP	derivation	viol. assumption	comparison LP semantics
DL	support chain	viol. justification	nonmonotonic logics

Outline

- Background on Argumentation Frameworks
- State of the Art and Open Questions
  1. Complexity
  2. Expressibility (Signatures and Numbers)
  3. Translations
  4. Explicit-Conflict Conjecture
  5. Dynamics (Strong Equivalence and Enforcement)
  6. Labellings and some further issues
- Conclusion

Background

Definition

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

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

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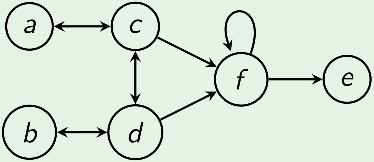

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$\{(a, c), (c, a), (c, d), (d, c), (d, b), (b, d), (c, f), (d, f), (f, f), (f, e)\}\big)$

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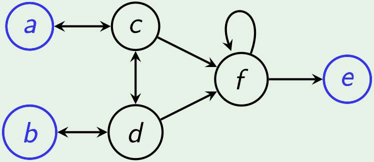

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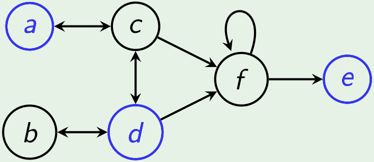

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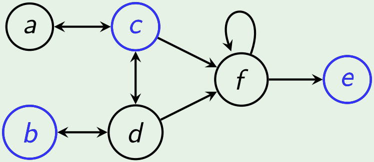

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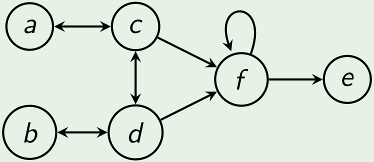

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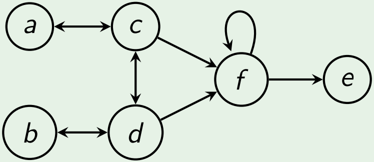

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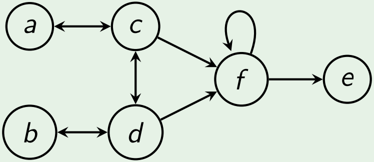

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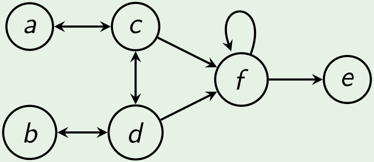

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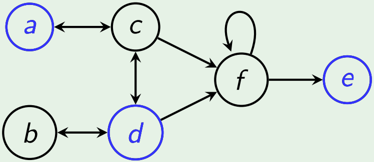

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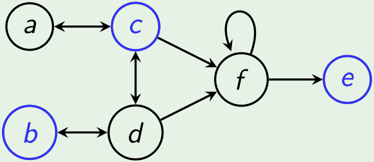

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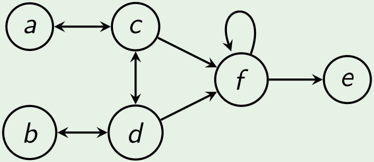

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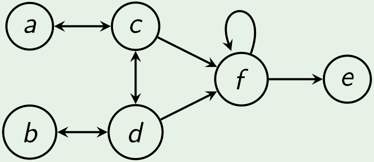

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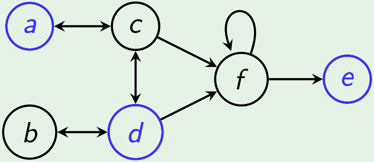

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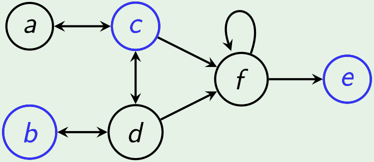

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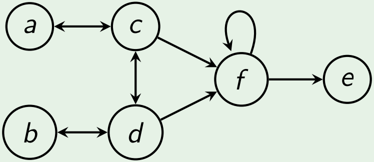

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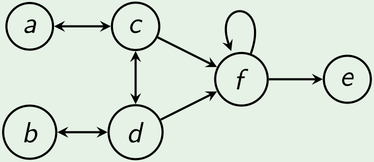

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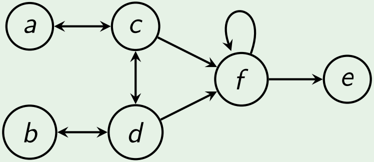

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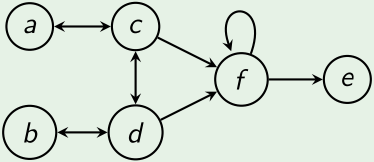

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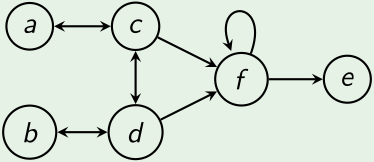

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Further Semantics

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

- semi-stable (*sem*): admissible sets with subset-maximal range
- stage: conflict-free sets with subset-maximal range

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Unique-status semantics:

- grounded (*grd*): subset-minimal complete set
- ideal: subset-maximal *adm* set contained in each pref extension
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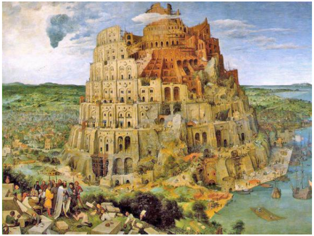
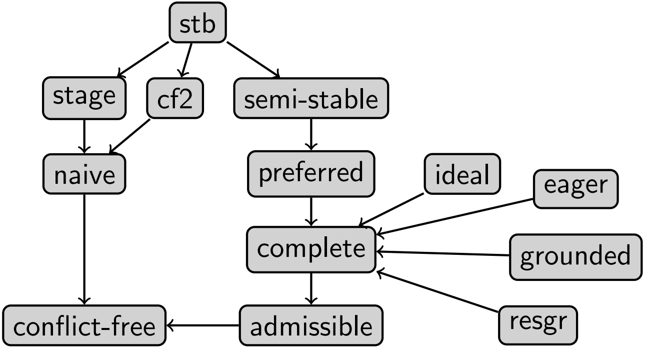
Other semantics we touch in this talk:

- naive (subset-maximal conflict-free sets)
- cf2
- resolution-based grounded (*resgr*)

State of the Art



Meanwhile, an invasion of semantics!
Bug or feature?



Issue 1: Complexity

σ	$Cred_\sigma$	$Skept_\sigma$	Ver_σ	NE_σ
cf	in L	trivial	in L	in L
naive	in L	in L	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
resgr	NP-c	coNP-c	P-c	in P
cf2	NP-c	coNP-c	in P	in L
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
eager	Π_2^P-c	Π_2^P-c	D_2^P-c	Π_2^P-c

Issue 1: Complexity

Some observations for ideal semantics

It is known that $Cred_{ideal}$ is coNP-hard, Ver_{ideal} is D^P-hard, and NE_{ideal} is NP-hard. Moreover,

- If $Cred_{ideal}$ is NP-hard, then $Cred_{ideal}$ is Θ_2^P-complete.
- If $Cred_{ideal}$ is in coNP, then NE_{ideal} is NP-complete.
- If $Cred_{ideal}$ is in coNP, then Ver_{ideal} is D^P-complete.

Some further open questions

- P-hardness for Ver_{cf2}
- problems defined on subclasses of graphs and parameterized complexity

Issue 2: Expressibility

Definition

The signature of a semantics σ is defined as

$$\Sigma_\sigma = \{\sigma(F) \mid F \text{ is an AF } \}.$$

Thus signatures capture all what a semantics can express.

Issue 2: Expressibility

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Thus signatures capture all what a semantics can express.

Some Notation

Call a set of sets of arguments $\mathcal{S}$ extension-set. Moreover,

- $Args_{\mathcal{S}} = \bigcup_{S \in \mathcal{S}} S$
- $Pairs_{\mathcal{S}} = \{\{a, b\} \mid \exists E \in \mathcal{S} \text{ with } \{a, b\} \subseteq E\}$

Example

Given $\mathcal{S} = \{\{a, d, e\}, \{b, c, e\}, \{a, b\}\}$:
$Args_{\mathcal{S}} = \{a, b, c, d, e\}$,
$Pairs_{\mathcal{S}} = \{\{a, b\}, \{a, d\}, \{a, e\}, \{b, c\}, \{b, e\}, \{c, e\}, \{d, e\}\}$

Issue 2: Expressibility

Definition

An extension-set $\mathcal{S}$ is called

- tight if $\mathcal{S}$ is incomparable and for all $E \in \mathcal{S}$ and all $a \in Args_{\mathcal{S}} \setminus E$ there exists $e \in E$ such that $\{a, e\} \notin Pairs_{\mathcal{S}}$
- pref-closed if for each $A, B \in \mathcal{S}$ with $A \neq B$, there exist $a, b \in (A \cup B)$ such that $\{a, b\} \notin Pairs_{\mathcal{S}}$

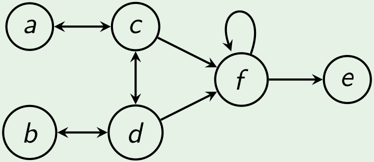
Proposition

- $\Sigma_{stb} = \{\mathcal{S} \mid \mathcal{S} \text{ is tight }\}$
- $\Sigma_{pref} = \{\mathcal{S} \neq \emptyset \mid \mathcal{S} \text{ is pref-closed }\}$

Further exact characterizations avaliable for *cf*, *adm*, *sem*, *stage*, and *naive*.

Issue 2: Expressibility

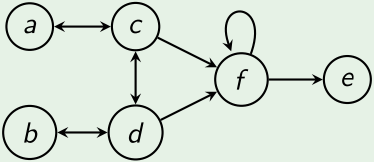
Example



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

Issue 2: Expressibility

Example



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

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How to adapt the AF to replace $\{a, b\}$ by $\{a, b, d\}$ in $pref(F)$?

Issue 2: Expressibility

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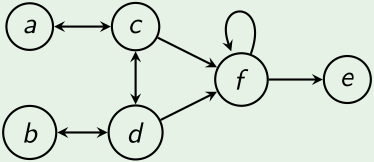

$pref(F) = \{\{a, d, e\}, \{b, c, e\}, \{a, b\}\}$

Question:

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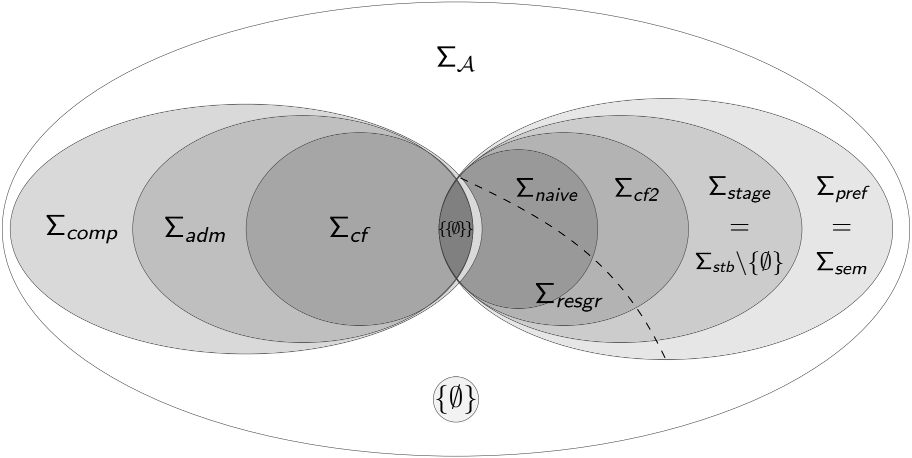
Impossible! $\{\{a, d, e\}, \{b, c, e\}, \{a, b, d\}\}$ is not pref-closed.
(An extension-set $\mathcal{S}$ is pref-closed if for each $A, B \in \mathcal{S}$ with $A \neq B$, there exist $a, b \in (A \cup B)$ such that $\{a, b\} \notin Pairs_{\mathcal{S}}$)

Issue 2: Expressibility



Exact characterization for complete, *resgr*, and *cf2* semantics open.

Issue 2: Expressibility

Proposition

For $\sigma \in \{stb, sem, pref, stage, naive\}$ the maximal number of σ-extensions that can be obtained by an AF with n arguments is

$$\sigma^{max}(n) = \begin{cases} 1 & \text{if } n \leq 1, \\ 3^s & \text{if } n \geq 2 \text{ and } n = 3s, \\ 4 \cdot 3^{s-1} & \text{if } n \geq 2 \text{ and } n = 3s+1, \\ 2 \cdot 3^s & \text{if } n \geq 2 \text{ and } n = 3s+2. \end{cases}$$

For $\sigma \in \{adm, cf\}$, clearly $\sigma^{max}(n) = 2^n$.

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For $\sigma \in \{adm, cf\}$, clearly $\sigma^{max}(n) = 2^n$.

Question: What about $\sigma^{max}(n)$ for the remaining (non unique-status) semantics, in particular complete?

Issue 3: Translations

Definition

Call a mapping τ from AFs to AFs translation if $\tau(F)$ can be computed in log space with respect to the size of F. Moreover, for semantics σ, σ', τ is

- exact (for $\sigma \Rightarrow \sigma'$) if for every AF F, $\sigma(F) = \sigma'(\tau(F))$
- faithful (for $\sigma \Rightarrow \sigma'$) if for every AF $F = (A, R)$, $\sigma(F) = \{E \cap A \mid E \in \sigma'(\tau(F))\}$ and $|\sigma(F)| = |\sigma'(\tau(F))|$.

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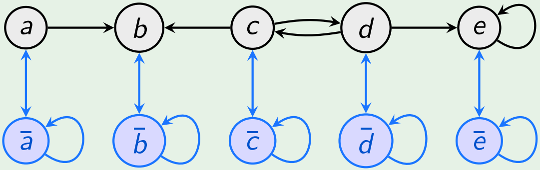
Gives another account on expressibility:

- more fine-grained than computational complexity
- equal signatures do not imply mutual translations

Proposition

The transformation τ mapping each AF (A, R) to (A', R'), with $A' = A \cup \bar{A}$ and $R' = R \cup \{(a, \bar{a}), (\bar{a}, a), (\bar{a}, \bar{a}) \mid a \in A\}$, is an exact translation for *adm* $\Rightarrow$ *comp*, *naive* $\Rightarrow$ *stage* and *pref* $\Rightarrow$ *sem*.

Example



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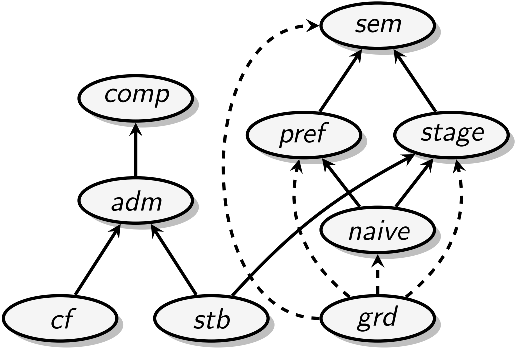
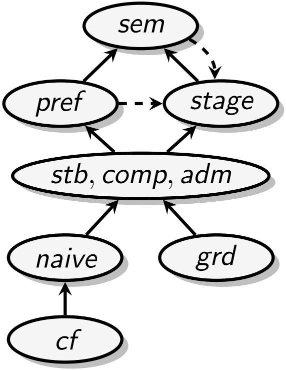


Exact translations.



Faithful translations.

Issue 4: Conflict-Explicit Conjecture

Definition

We call an AF $F = (A, R)$ conflict-explicit under σ iff for each $a, b \in A$ such that $\{a, b\} \notin Pairs_{\sigma(F)}$, $(a, b) \in R$ or $(b, a) \in R$ (or both)

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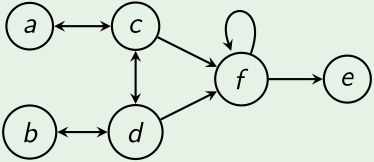

$stb(F) \ = \big\{\{a, d, e\}, \{b, c, e\}\big\}$ ... F is not conflict-explicit under stb

Issue 4: Conflict-Explicit Conjecture

Conflict-Explicit Conjecture (Stable Case)

For each AF $F = (A, R)$ there exists an AF $F' = (A, R')$ which is conflict-explicit under the stable semantics and equivalent to F, i.e. $stb(F) = stb(F')$

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Why important? Why tricky? . . . attend our presentation on Friday!

Issue 5: Dynamics

Definition

Two AFs F, G are strongly equivalent wrt. σ (in symbols $F \equiv_s^\sigma G$), if for any H, $\sigma(F \cup H) = \sigma(G \cup H)$

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$(A, R) \equiv_s^{stb} (B, S)$ iff $A = B$ and $R^k = S^k$ where
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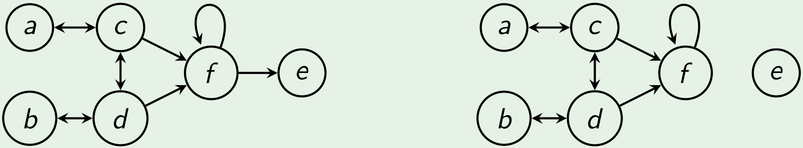
Two AFs strongly equivalent under stable semantics



Issue 5: Dynamics

Kernels

Given an AF $F = (A, R)$. We can have different kernels $F^{k\alpha} = (A, R^{k\alpha})$:

- $R^{k1} = R \setminus \{(a,b) \mid a \neq b, (a,a), (b,b) \in R\}$
- $R^{k2} = R \setminus \{(a,b) \mid a \neq b, (a,a) \in R, \{(b,a), (b,b)\} \cap R \neq \emptyset\}$
- $R^{k3} = R \setminus \{(a,b) \mid a \neq b, (b,b) \in R, \{(a,a), (b,a)\} \cap R \neq \emptyset\}$
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Proposition

For any two AFs F and G, we have that $F \equiv_s^\sigma G$ iff

- $F^{k1} = G^{k1}$ for $\sigma = comp$
- $F^{k2} = G^{k2}$ for $\sigma \in \{adm, pref, sem, ideal, eager\}$
- $F^{k3} = G^{k3}$ for $\sigma \in \{grd, resgr\}$
- $F^{k4} = G^{k4}$ for $\sigma \in \{stb, stage\}$
- $F = G$ for $\sigma = cf2$

Issue 5: Dynamics

Enforcing. Observation:

Let $F = (A, R)$ be an AF. Then for any $S \in \mathit{cf}(F)$, there is an AF $F' = (A', R')$ with $A \subseteq A'$, $R \subseteq R'$ such that $S \in \sigma(F')$ $(\sigma \in \{\mathit{adm}, \mathit{comp}, \mathit{naive}, \mathit{stb}, \mathit{pref}, \mathit{stage}, \mathit{sem}\})$.

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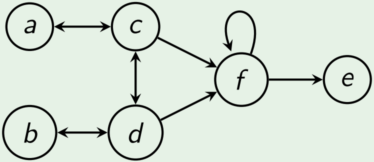
Example: Enforcing $\{a, b\}$ under *stb*



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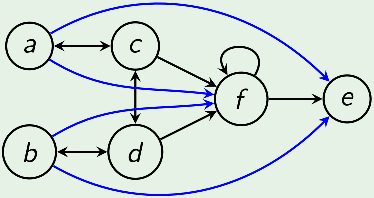

Issue 5: Dynamics

More general attempt:

- do not allow for any enhancement (use relation Φ between AFs); e.g. strong, normal, weak expansions
- what is the minimal number of attacks to be added?

Proposition

Let $N^F_{\sigma,\Phi}(C)$ be the mininum number of attacks to be added (possibly infinite) to enforce C in F under semantics σ. Then, for any F and C,

$$N^F_{stb,\Phi}(C) \geq N^F_{sem,\Phi}(C) \geq N^F_{pref,\Phi}(C) = N^F_{comp,\Phi}(C) = N^F_{adm,\Phi}(C)$$

For several Φ exact numbers $N^F_{\sigma,\Phi}$ for *adm*, *comp*, *pref* and *stb* known
sem is much harder to characterize due to missing local criteria!

Issue 6: Labellings

Definition

Given an AF (A, R), a function $\mathcal{L} : A \to \{in, out, undec\}$ is a labeling iff the following conditions hold:

- $\mathcal{L}(a) = in$ iff for each b with $(b, a) \in R$, $\mathcal{L}(b) = out$
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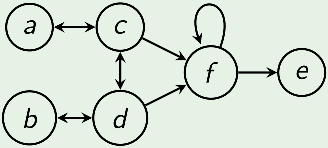
- 1-1 correspondence between preferred labelings and preferred extensions
- similar definitions for other semantics avaliable
- labellings provide additional information about arguments not contained in extension

Issue 6: Labellings

Example: Preferred Labelings



Issue 6: Labellings

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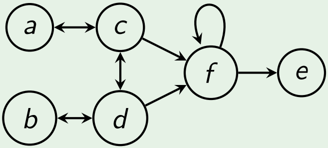

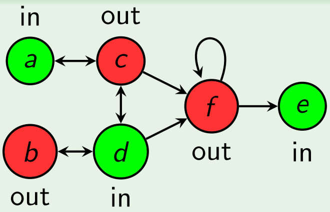

Issue 6: Labellings

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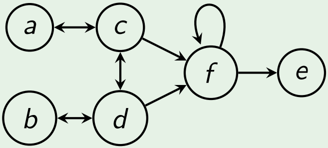

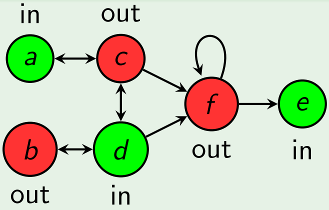

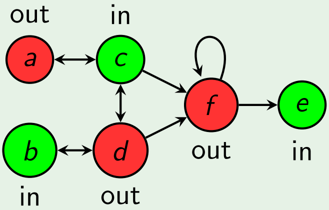

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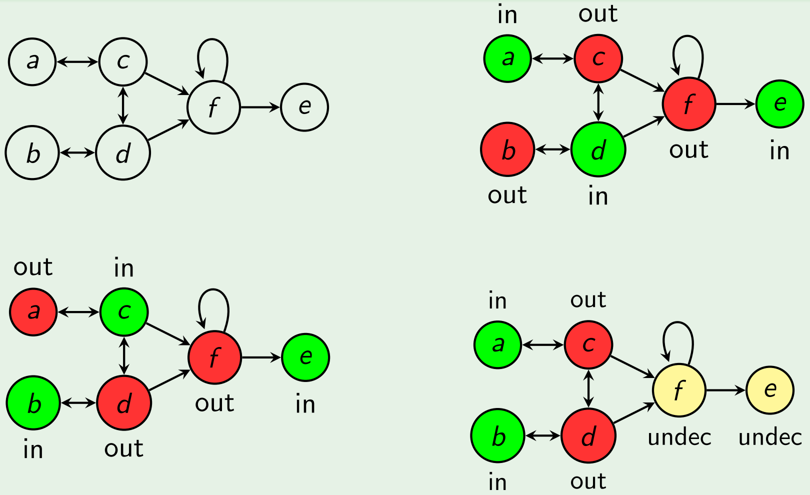


Issue 6: Labellings

Most we have discussed before, in particular

- Signatures
- Translations
- Strong Equivalence
- Enforcement

is still unexplored for labellings.

Some final other issues

- Modularization: which properties of semantics can be obtained locally and put together suitably
  - ⇒ recall SCC recursive semantics
  - ⇒ interesting relation to dynamic programming algorithms for AFs
- From weaker notions of equivalence (projection) to I-O-specifications.
- Does every finitary AF posses a *cf2* extension? ...

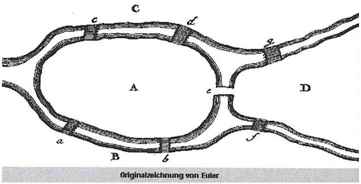
Conclusion

Summary

- Argumentation a highly active area in AI
- Dung's abstract frameworks a gold standard within the community
- AFs provide account of how to select acceptable arguments solely on basis of an attack relation between them
- Useful analytical tool with a variety of semantics and add-ons
- Huge body of theoretical results, but some surprisingly simple questions still unresolved.

Conclusion

Isn't that all just graph theory?



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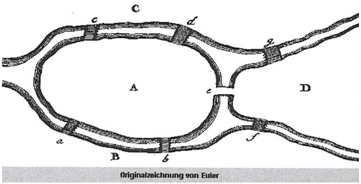
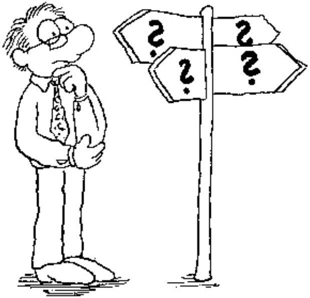


No ...

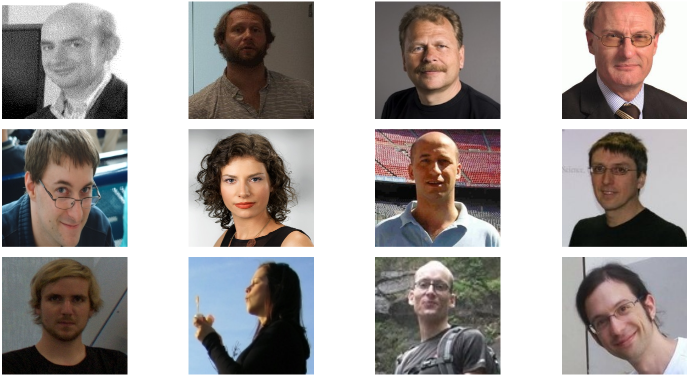
- Edges have different meaning (connection vs. attack)
- Paths have different meaning (reachability vs. defense)
- Different abstraction model
- Still,
  - stable extensions ⇔ independent dominating sets
  - several graph classes also important in Argu (acyclic, bipartite, ...)
  - and some of our problems/results might also be of interest for graph theory people

Future Research Directions



- Abstract away from concrete semantics
- Incorporate theoretical results to systems
- ... and solve the open problems!

Thanks and Credits go to:



...any many more!

See you at COMMA 2014. Sept 9 – 12, Scotland.

http://comma2014.arg.dundee.ac.uk/

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