Theory and Practice of Formal Argumentation

EASSS 2023, Prague, July 2023

- Outline of the tutorial
  - Introduction to Argumentation
  - Abstract Argumentation Frameworks
  - Computation of AAF Extensions using Logic Programming
  - Extensions of Abstract Argumentation Frameworks
  - Structured Argumentation Frameworks
  - Real-world Applications of Formal Argumentation

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Extensions of AAFs

- Extending the notion of attack
- Preferences in abstract argumentation
- Incorporating the notion of support
- Introducing weights on arguments or attacks
- Abstract Dialectical Frameworks

Joint attacks

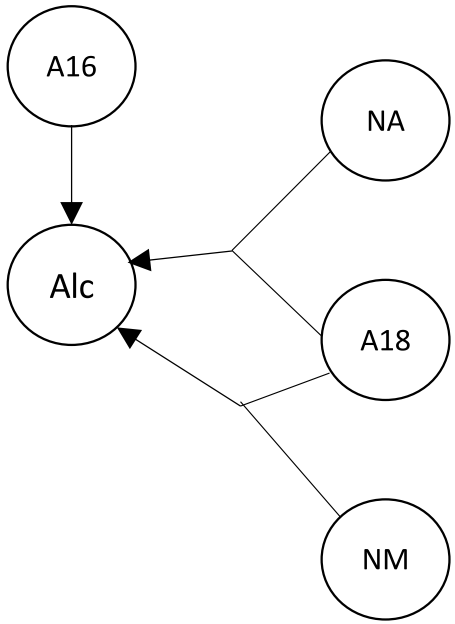
- In AAF, attacks are binary, i.e. from a single argument to another single argument.
- SETAF (Framework with Sets of Attacking Arguments)*
  - An extension of AAF supporting joint attacks.
  - **Joint attack**: Two or more arguments jointly attack another argument.
  - The joint attack is effective only if all the arguments in the set of attacking arguments are accepted.

* *Søren Holbech Nielsen and Simon Parsons (2007). A generalization of Dung's abstract framework for argumentation: Arguing with sets of attacking arguments. In Proceedings of the 3rd International Workshop on Argumentation in Multi-Agent Systems, pages 54–73, 2007.*

Joint attacks: A motivating example

In the UK, one is allowed to consume alcohol in public,
unless one is under 16,
or one is under 18 and not accompanied by an adult,
or one is under 18 and not having a meal.

Modelling the example In SETAF



Alc: Allowed to consume alcohol in public
A16: Aged under 16
A18: Aged under 18
NA: Not accompanied by an adult
NM: Not having meal

A18 and NA **jointly attack** Alc
A18 and NM **jointly attack** Alc
A16 attacks Alc

Second-order attacks

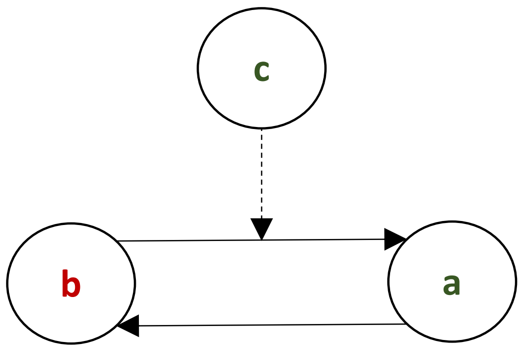
- In AAF, attacks are directed to arguments.
- EAF (Extended Argumentation Framework)*
    - An extension of AAF supporting second-order attacks.
    - A **simple attack** is an attack directed from an argument to another argument.
    - A **second-order attack** is an attack directed from an argument to a simple attack.
    - Second-order attacks provide a way to represent preferences over arguments.

* *Sanjay Modgil (2009). Reasoning about preferences in argumentation frameworks. Artificial Intelligence, 173:901-934.*

Second-order attacks: A motivating example

P: Today will be dry in London since the BBC forecast sunshine. (**a**)
Q: Today will be wet in London since CNN forecast rain. (**b**)
P: But the BBC are more trustworthy than CNN. (**c**)

Modelling
the example
In EAF



(a, b), (b, a): Simple attacks
(c, (a, b)): Second-order attack. It expresses a preference of **a** over **b**.

b does not successfully attack **a**, because of the attack from **c**, so **a** becomes justified

Motivating example (extended)

P: Today will be dry in London since the BBC forecast sunshine. (**a**)

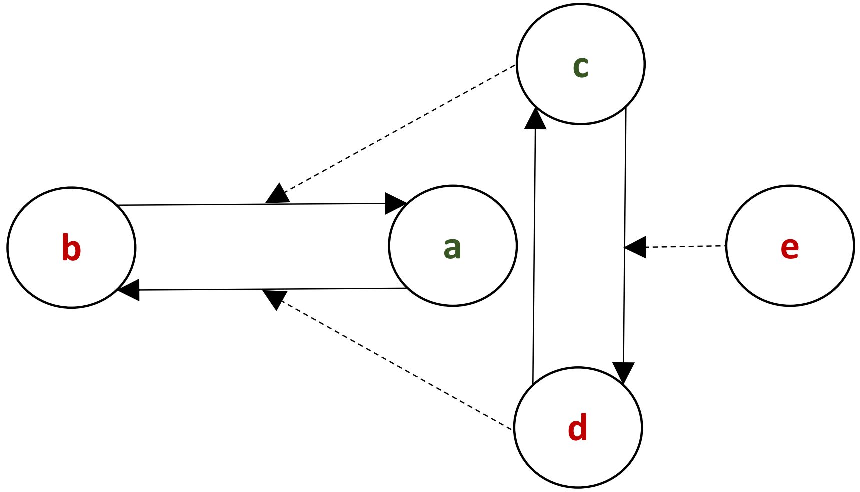
Q: Today will be wet in London since CNN forecast rain. (**b**)

P: But the BBC are more trustworthy than CNN. (**c**)

Q: However, statistically CNN are more accurate forecasters than the BBC. (**d**)

Q: And basing a comparison on statistics is more rigorous and rational than basing a comparison on your instincts about their relative trustworthiness. (**e**)

Modelling the example In EAF



{e, d, b} is an admissible, preferred, complete and stable extension of this EAF

Recursive attacks

- AFRA (Argumentation Framework with Recursive Attacks)*
  - An extension of AAF supporting high-order (recursive) attacks.
  - An **attack** is directed from an argument to an argument or attack.
  - Recursive attacks provide a way to represent preferences over arguments or model decision processes.

* *Pietro Baroni, Federico Cerutti, Massimiliano Giacomin, and Giovanni Guida (2011). AFRA: Argumentation framework with recursive attacks. International Journal of Approximate Reasoning, 52: 19-37.*

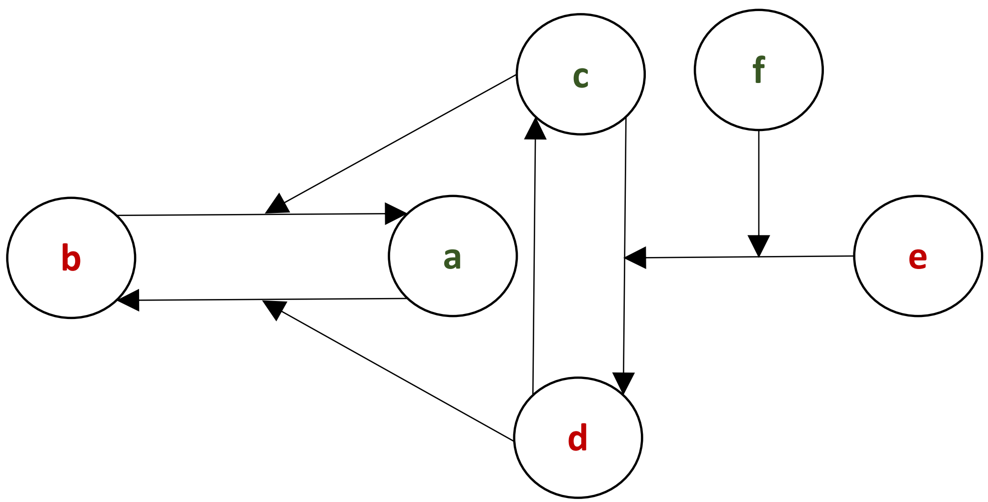
Recursive attacks: A motivating example

…

Q: And basing a comparison on statistics is more rigorous and rational than basing a comparison on your instincts about their relative trustworthiness. (**e**)

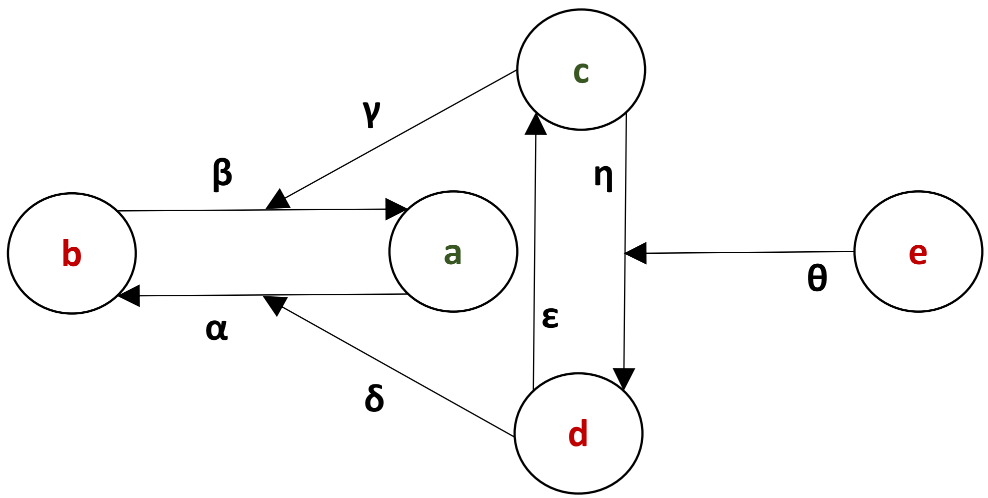
P: However, BBC has recently changed its whether forecast model, no information on the new model is available; therefore statistics on CNN loses prevalence over personal opinion about BBC (**f**)

Modelling the example In AFRA



The attack from **f** is a higher order attack, which cannot be expressed in EAF.

AFRA: Example



Examples of defeat

θ directly defeats **η**

ε directly defeats **c**

ε indirectly defeats **γ**

…

Complete extension

{e, θ, d, ε, δ, β, b}

Preferences in abstract argumentation

- Preferences are used in abstract argumentation to represent the comparative strength of arguments.
- A Preference-based Argumentation Framework (PAF) is a tuple $(\mathbf{A}, \mathbf{R}, \geq)$ where $\mathbf{A}$ is a set of arguments, $\mathbf{R} \subseteq \mathbf{A} \times \mathbf{A}$ is a binary attack relation and $\geq\, \subseteq \mathbf{A} \times \mathbf{A}$ is a second binary relation over $\mathbf{A}$, called preference relation.*
- Notation
  - we write $\mathbf{a} \geq \mathbf{b}$ as a shorthand for $(\mathbf{a}, \mathbf{b}) \in\, \geq$
  - we write $\mathbf{a} > \mathbf{b}$ iff $(\mathbf{a}, \mathbf{b}) \in\, \geq$ and $(\mathbf{b}, \mathbf{a}) \notin\, \geq$

* *Leila Amgoud and Claudette Cayrol (2002). Inferring from inconsistency in preference-based argumentation frameworks. International Journal of Approximate Reasoning, 29(2):125-169.*

Reductions: from PAF to AAF

- To compute the extensions of a PAF $(A, R, \geq)$ extensions we can reduce it to an AAF (A, R'). The extensions of the PAF are the extensions of the corresponding AAF.
- Reduction 1: an attack succeeds only when the attacked argument is not preferred to the attacker
- Formally: for all $a, b \in A$: $(a, b) \in R'$ iff $(a, b) \in R$ and $b \not> a$
- Remark: It may lead to non conflict-free extensions
- Example: Consider a PAF with $A=\{a, b\}$, $R=\{(a, b)\}$ and $b > a$. This is reduced to the AAF with $A=\{a, b\}$ and $R'=\{\}$. $\{a, b\}$ is an extension of the AAF, and, therefore, of the PAF using any of the semantics.

Reductions: from PAF to AAF

- Reduction 2: extension of Reduction 1 that enforces an attack from an argument to another when the former is preferred but attacked by the latter.
- Formally: for all $\mathbf{a, b} \in \mathbf{A}$: $\mathbf{(a, b)} \in \mathbf{R'}$ iff
  - $\mathbf{(a, b)} \in \mathbf{R}$ and $\mathbf{b} \not> \mathbf{a}$ or
  - $\mathbf{(b, a)} \in \mathbf{R}$, $\mathbf{(a, b)} \notin \mathbf{R}$ and $\mathbf{a} > \mathbf{b}$
- Remark: There is no way to defeat a preferred argument.

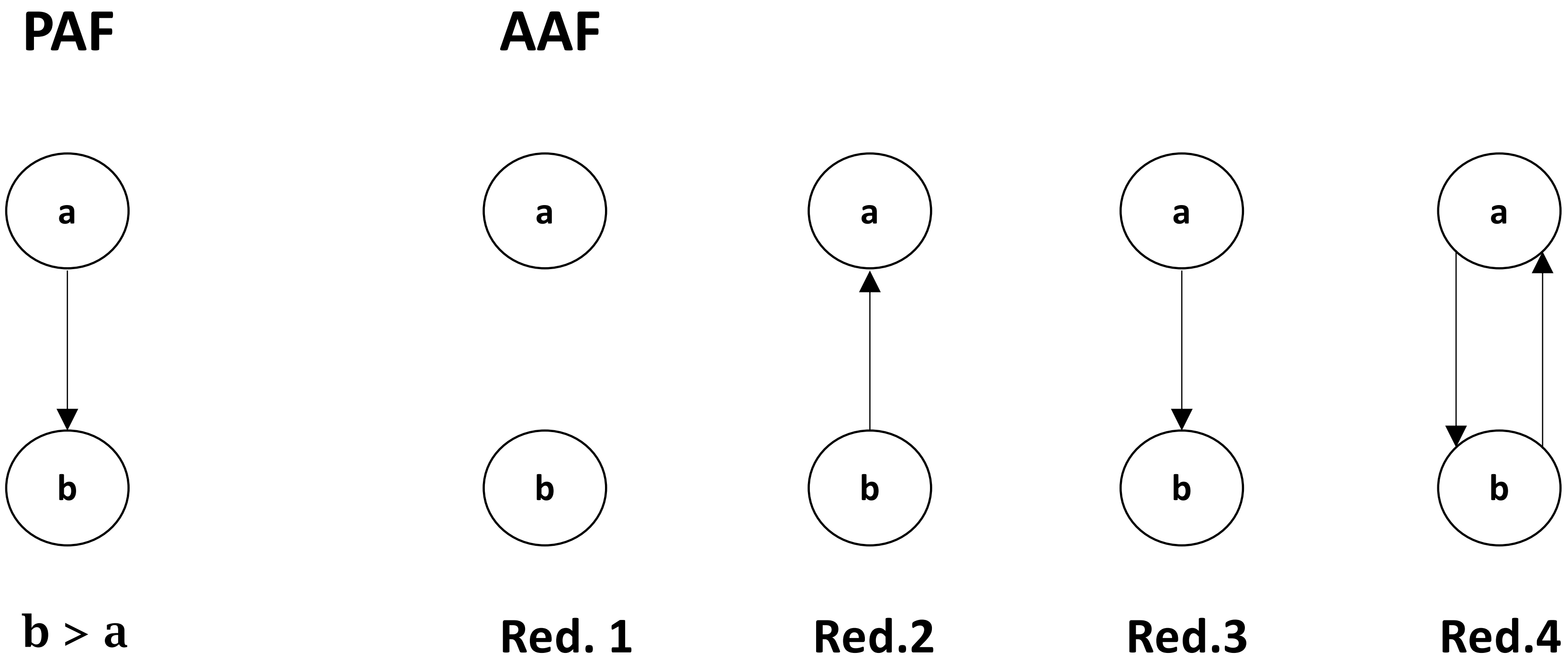
Reductions: from PAF to AAF

- Reduction 3: extension of Reduction 1 that retains the attacks that cannot be resolved using preferences.
- Formally: for all $\mathbf{a}, \mathbf{b} \in \mathbf{A}$: $(\mathbf{a}, \mathbf{b}) \in \mathbf{R'}$ iff
  - $(\mathbf{a}, \mathbf{b}) \in \mathbf{R}$ and $\mathbf{b} \not> \mathbf{a}$ or
  - $(\mathbf{a}, \mathbf{b}) \in \mathbf{R}$ and $(\mathbf{b}, \mathbf{a}) \notin \mathbf{R}$
- Remark: It makes successful attacks from less preferred arguments.

Reductions: from PAF to AAF

- Reduction 4: Combines the ideas of all other approaches.
- Formally: for all $\mathbf{a}, \mathbf{b} \in \mathbf{A}$: $(\mathbf{a}, \mathbf{b}) \in \mathbf{R'}$ iff
  - $(\mathbf{a}, \mathbf{b}) \in \mathbf{R}$ and $\mathbf{b} \not> \mathbf{a}$ or
  - $(\mathbf{b}, \mathbf{a}) \in \mathbf{R}$, $(\mathbf{a}, \mathbf{b}) \notin \mathbf{R}$ and $\mathbf{a} > \mathbf{b}$ or
  - $(\mathbf{a}, \mathbf{b}) \in \mathbf{R}$ and $(\mathbf{b}, \mathbf{a}) \notin \mathbf{R}$

Differences between the reductions



Where are the preferences derived from?

- In structured argumentation, preferences over arguments are derived from the internal structure of the arguments, e.g.
  - Preferences may be associated with the specificity of arguments
  - Preferences may be derived from the preferences over the elements that the arguments consist of
- In abstract argumentation
  - Preferences may be associated with the values that the arguments promote (value-based argumentation frameworks)
  - Preferences may be the result of argument-based reasoning (hierarchical extended argumentation frameworks)

Value-based Argumentation Frameworks

- In dialogues, the acceptability of an argument does not only depend on the argument itself and its counter-arguments, but also on the audience to which it is addressed.
- In such cases, we need to take into account the values that the arguments promote and the preference of the audience over these values.
- Example: Consider suppose that two parents discuss whether their son
  - can watch the football game on the TV (**a**) or
  - whether he should prepare for his exam (**b**)
  - Argument **a** promotes their son's **sociability**, while argument **b** promotes his **education**.
  - The preference between the two arguments depends on the relevant importance of the values they promote.

Bipolar Argumentation Frameworks

- They extend AAF with a binary support relation on the set of arguments.
- A Bipolar Argumentation Framework (BAF) is a tuple $(\mathbf{A}, \mathbf{R}, \mathbf{S})$ where $\mathbf{A}$ is a set of arguments, $\mathbf{R} \subseteq \mathbf{A} \times \mathbf{A}$ is a binary attack relation and $\mathbf{S} \subseteq \mathbf{A} \times \mathbf{A}$ is a binary support relation over $\mathbf{A}$.*
- A **supported attack** from $\mathbf{a_1}$ to $\mathbf{a_n}$ exists iff there exists a sequence of arguments $\mathbf{a_1,\ldots,a_n}$ such that $\mathbf{(a_1,a_2),(a_2,a_3),\ldots,(a_{n\text{-}2},a_{n\text{-}1})} \in \mathbf{S}$ and $\mathbf{(a_{n\text{-}1},a_n)} \in \mathbf{R}$
- A **secondary attack** from $\mathbf{a_1}$ to $\mathbf{a_n}$ exists iff there exists a sequence of arguments $\mathbf{a_1,\ldots,a_n}$ such that $\mathbf{(a_1,a_2)} \in \mathbf{R}$ and $\mathbf{(a_2,a_3), (a_3,a_4),\ldots, (a_{n\text{-}1},a_n)} \in \mathbf{S}$

* *Claudette Cayrol and Marie-Christine Lagasquie-Schiex (2005). On the acceptability of arguments in bipolar argumentation frameworks. In Symbolic and Quantitative Approaches to Reasoning with Uncertainty, 8th European Conference, ECSQARU 2005, Proceedings, pages 378-389.*

BAF: An example

Consider the following arguments exchanged during the meeting of the editorial board of a newspaper:

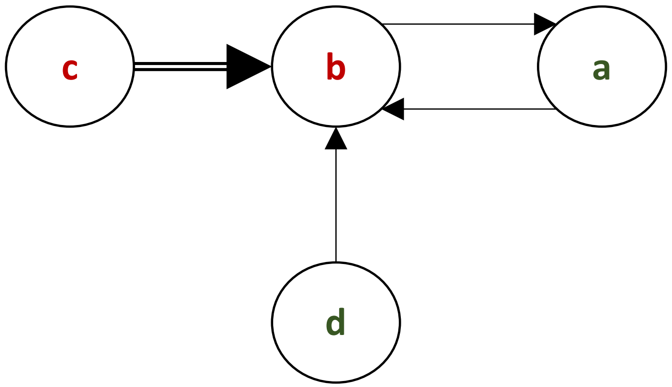
Information I concerning person P should be published. (**a**)

Information I is private, so P denies publication. (**b**)

I is an important information concerning P's son. (**c**)

P is the new prime minister, so everything related to P is public. **(d)**

Modelling the example In BAF



(a, b), (b, a), (d, b): Direct attacks

(c, b): Support

(c, a): Supported attack

Argumentation Framework with Necessities*

- Additionally to the attack relation, AFNs include a binary necessity relation.
- **Necessity** is a special kind of support: if an argument **a** supports another argument **b**, then **a** is necessary to obtain **b**.
  - If **b** is accepted then **a** should also be accepted
  - If **a** is not accepted then **b** cannot be accepted

* *Farid Nouioua and Vincent Risch (2011). Argumentation frameworks with necessities. In Scalable Uncertainty Management - 5th International Conference, SUM 2011, Dayton, OH, USA, October 10-13, 2011. Proceedings, pages 163-176.*

Weighted argumentation

- In AAF, all arguments and all attacks are equal in strength.
- Some recent extensions of AAF incorporate the notions of weighted arguments or attacks to represent the strength of arguments or attacks.
- This allows for more sophisticated modelling and analysis of conflicting information.
- A common problem that these studies deal with is how to compute the acceptability of an argument in a weighted argumentation framework.

Weighted argumentation graphs

- In weighted argumentation graphs, each argument has a **weight** in the interval [0,1] representing its basic strength.
- A Weighted Argumentation Graph (WAG) is a tuple $(\mathbf{A}, \mathbf{w}, \mathbf{R})$ where $\mathbf{A}$ is a set of arguments, $\mathbf{R} \subseteq \mathbf{A} \times \mathbf{A}$ an attack relation and $\mathbf{w}$ a function from $\mathbf{A}$ to [0.1].
- **Graded Semantics**: An acceptability semantics is a function assigning a numerical value (**acceptability degree**) to every argument in a WAG. This value is derived from the aggregation of the basic strength of the argument and the overall strengths of its attackers.

* *Leila Amgoud, Jonathan Ben-Naim, Dragan Doder, and Srdjan Vesic (2017). Acceptability semantics for weighted argumentation frameworks. In Proc. of the 26th International Joint Conference on Artificial Intelligence, (IJCAI'17), pages 56–62.*

Examples of graded semantics

- Weighted max-based semantics
  - Follows a multiple-steps process
  - Favours the quality of attackers over their cardinality

$$\mathtt{f}_{\mathtt{m}}^{\mathtt{i}}(a) = \begin{cases} w(a) & \textit{if } i = 0 \\ \frac{w(a)}{1+\max_{b \in \mathtt{Att}_{\mathbf{G}}(a)} \mathtt{f}_{\mathtt{m}}^{\mathtt{i-1}}(b)} & \textit{otherwise} \end{cases}$$

$$\mathtt{Deg}_{\mathbf{G}}^{\mathtt{Mbs}}(a) = \lim_{i \to \infty} \mathtt{f}_{\mathtt{m}}^{\mathtt{i}}(a)$$

- Weighted card-based semantics
  - Follows a multiple-steps process
  - Favours the number of attackers over their quality

$$\mathtt{f}_{\mathtt{c}}^{\mathtt{i}}(a) = \begin{cases} w(a) & \textit{if } i = 0 \\ \frac{w(a)}{1+|\mathtt{AttF}_{\mathbf{G}}(a)| + \frac{\sum_{b \in \mathtt{AttF}_{\mathbf{G}}(a)} \mathtt{f}_{\mathtt{c}}^{\mathtt{i-1}}(b)}{|\mathtt{AttF}_{\mathbf{G}}(a)|}} & \textit{otherwise} \end{cases}$$

$$\mathtt{Deg}_{\mathbf{G}}^{\mathtt{Cbs}}(a) = \lim_{i \to \infty} \mathtt{f}_{\mathtt{c}}^{\mathtt{i}}(a)$$

- Weighted h-Categorizer semantics
  - Follows a multiple-steps process
  - Takes into account the strength of all attackers

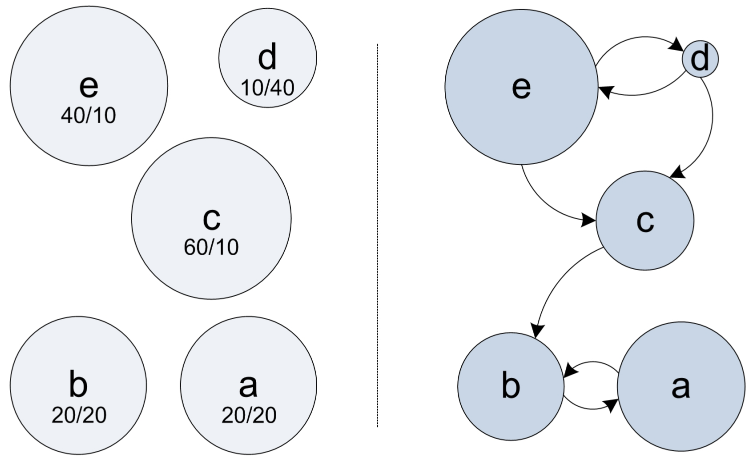
$$\mathtt{f}_{h}^{i}(a) = \begin{cases} w(a) & \textit{if } i = 0; \\ \frac{w(a)}{1+\sum_{b_i \in \mathtt{Att}_{\mathbf{G}}(a)} \mathtt{f}_{h}^{i-1}(b_i)} & \textit{otherwise.} \end{cases}$$

$$\mathtt{Deg}_{\mathbf{G}}^{\mathtt{Hbs}}(a) = \lim_{i \to +\infty} \mathtt{f}_{h}^{i}(a)$$

Social Argumentation Frameworks*

- Strength of argument determined by its votes and the strength of its attackers
- Extends Dung's AF with a function mapping each argument to the numbers of positive and negative votes
- Semantics (social model):

$$M\left(a\right) = \tau\left(a\right) \curlywedge \neg \curlyvee \left\{M\left(a_i\right) : a_i \in \mathcal{R}^{-}\left(a\right)\right\}$$



* *J. Leite, J. Martins (2011). Social abstract argumentation, Proc. Twenty-Second International Joint Conference on Artificial Intelligence (IJCAI'11), pp.2287–2292.*

Probabilistic argumentation*

- In probabilistic argumentation frameworks, each argument is assigned a probability denoting the degree of belief that the argument is acceptable.
- A probability function **P** on a set **X** is a function **P: 2^{X} → [0, 1]** satisfying:

$$\sum_{Y \in 2^X} P(Y) = 1$$

- Let **AF={A, R}** be an AAF and **P** a probabilistic function on **A**. The probability of an argument **a** ∈ **A** is defined as

$$P(a) = \sum_{a \in Y \subseteq A} P(Y)$$

* *A. Hunter and M. Thimm (2017). Probabilistic reasoning with abstract argumentation frameworks. Journal of Artificial Intelligence Research, 59:565–611.*

Constraints on the probability function

- Epistemic labelling of arguments

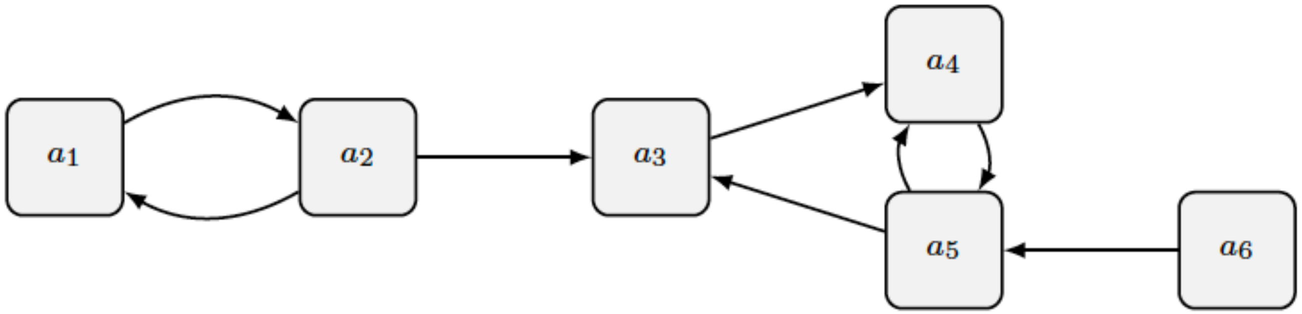
  (i) $\boldsymbol{L_P}$**(a) = in** iff **P(A) > 0.5**

  (ii) $\boldsymbol{L_P}$**(a) = out** iff **P(A) < 0.5**

  (iii) $\boldsymbol{L_P}$**(a) = undec** iff **P(A) = 0.5**

- The probability function is:
  - **Coherent** if for every two arguments **a**, **b** such that **a→b**: **P(a) ≤ 1 - P(B)**
  - **Rational** if for every two arguments **a**, **b** such that **a→b**: **P(a) > 0.5 implies P(B) ≤ 0.5**
  - **Founded** if for every argument **a** that receives no attacks: **P(a) = 1**
  - **Trusting** if for every **a** s.t. for every **b** that attacks **a, P(b) < 0.5, then P(a) > 0.5**
  - **Optimistic** if for every argument **a**: **P(a) ≥ 1 – ∑P(b)** (for all **b** that attack **a**)

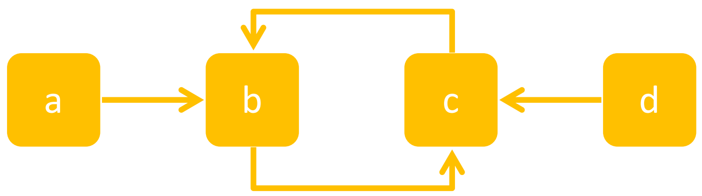
An example



	a_1	a_2	a_3	a_4	a_5	a_6	
P_1	0.2	0.7	0.6	0.3	0.6	1	founded and trusting
P_2	0.7	0.3	0.5	0.5	0.2	0.4	coherent and rational
P_3	0.7	0.3	0.7	0.3	0	1	coherent, rational, founded, trusting and optimistic
P_4	0.7	0.8	0.9	0.8	0.7	1	founded, trusting and optimistic

Abstract Dialectical Frameworks*

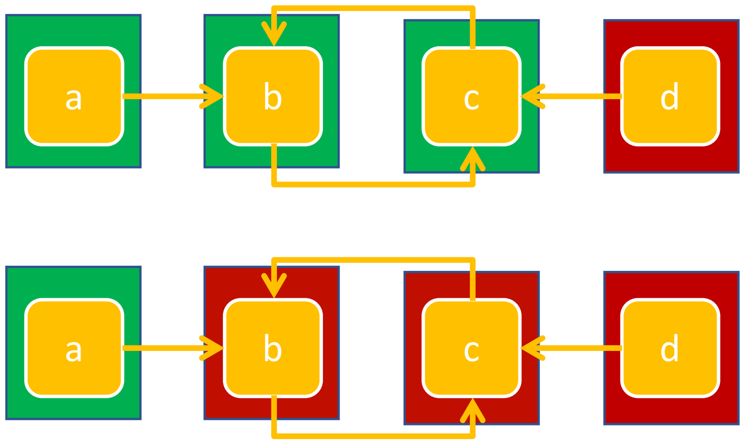
- A generalization of AAFs allowing the expression of arbitrary relationships among arguments.
  - Acceptance of an argument is determined in an arbitrary way by the acceptance of connected arguments
  - Acceptance conditions in the form of propositional formulas
  - Example:
    - $C(a) = T$
    - $C(b) = \neg a \vee c$
    - $C(c) = b \wedge \neg d$
    - $C(d) = F$



* *G. Brewka, S. Ellmauthaler, H. Strass, J. P. Wallner, and S. Woltran (2013). Abstract Dialectical Frameworks Revisited. In Proceedings of the 23rd International Joint Conference on Artificial Intelligence (IJCAI), pages 803-809.*

ADF semantics

- Analogous to AAF semantics
  - Admissible, complete, etc.
- Find a pair of sets of **accepted** and **rejected** arguments (*interpretation*) that is consistent with the arguments' acceptance conditions
- Expressed as a mapping from arguments to true/false: **m: A → {t, f}**
- Example:
  - C(a) = T
  - C(b) = ¬a ∨ c
  - C(c) = b ∧ ¬d
  - C(d) = F



ADFs as an argumentation middleware

- ADFs can represent several types of relationships among arguments that are used in AAFs and their extensions:
  - **Simple attack** (e.g., from *b* to *a*): $\boldsymbol{\varphi_a = \neg b}$
  - **Joint attack** (e.g., from *b*, *c* to *a*): $\boldsymbol{\varphi_a = \neg b \vee \neg c}$
  - **Necessity or evidential support** (e.g. from *b* to *a*): $\boldsymbol{\varphi_a = b}$
- There are also extensions of ADFs that include:
  - **Weight on links** (weighted ADFs)
  - **Preferences on links** (prioritized ADFs)

Summing up

- Extensions of AAFs extend the expressivity of AAFs with
  - Other kinds of attacks (joint attacks, second-order attacks, recursive attacks)
  - Other kinds of relations among arguments (e.g. support)
  - Preferences on arguments
  - Weights on arguments or attacks
  - Arbitrary relationships between arguments (ADFs)
- Trade-off between expressive power and complexity
- Choosing the right frameworks depends on
  - The modelling requirements of the application
  - The expected size of the argumentation graphs
  - The available computational resources

Structured Argumentation Frameworks

- Rule-based Argumentation (ASPIC+) (Modgil and Prakken, 2014)
- Deductive Argumentation (Besnard and Hunter, 2014)
- Assumption Based Argumentation (Toni, 2014)
- Defeasible Logic Programming (Garcia and Simari, 2014)

Structured Argumentation

- A more detailed formalization of arguments concerned with how arguments are constructed and when an argument attacks another argument.
- Features of structured argumentation frameworks
  - Formal language for representing knowledge
  - Arguments constructed from the available knowledge
  - The premises and claim of the argument are made explicit
  - Relationship between premises and claim is formally defined
  - Attacks among arguments are formally defined
  - Defeat = Attack + Preference

ASPIC+: Main Ideas

- Arguments are **inference graphs** where
  - **Nodes** are well founded formulae of a logical language $\mathcal{L}$
  - **Links** are applications of **inference rules**
    - $\mathcal{R}_s$ = **Strict** rules (ϕ_1, ..., $\phi_n \rightarrow \phi$); or
    - $\mathcal{R}_d$= **Defeasible** rules (ϕ_1, ..., $\phi_n \Rightarrow \phi$)
  - Reasoning starts from a knowledge base $\mathcal{K} \subseteq \mathcal{L}$
- **Defeat**
  - Attack on conclusion, premise or inference rule
  - Takes into account preferences over arguments
- Acceptability of arguments: based on the semantics of AAFs

Argumentation System

- An **argumentation system** is a triple *AS* = ($\mathcal{L}$,$\mathcal{R}$,*n*) where:
  - $\mathcal{L}$ is a **logical language** with negation (¬)
  - $\mathcal{R} = \mathcal{R}_s \cup \mathcal{R}_d$ is a set of **strict** ($\phi_1,\ldots,\ \phi_n \rightarrow \phi$) and **defeasible** ($\phi_1,\ldots,\ \phi_n \Rightarrow \phi$) inference rules
  - n: $\mathcal{R}_d \rightarrow \mathcal{L}$ is a **naming convention** for defeasible rules

- Notation:
  - $-\phi = \neg\phi$ if ϕ does not start with a negation
  - $-\phi = \psi$ if ϕ is of the form $\neg\psi$

Argumentation Theory

- A **knowledge base** in *AS* = ($\mathcal{L}$,$\mathcal{R}$,*n*) is a set $\mathcal{K} \subseteq \mathcal{L}$
- $\mathcal{K}$ is a partition $\mathcal{K}_n \cup \mathcal{K}_p$ with:
  - $\mathcal{K}_n$ = **necessary** premises
  - $\mathcal{K}_p$ = **ordinary** premises
- An **argumentation theory** is a pair *AT* = (AS, $\mathcal{K}$) where AS is an argumentation system and $\mathcal{K}$ a knowledge base in AS

Structure of an argument

- An **argument** A on the basis of an argumentation theory is:
  - $\boldsymbol{\phi}$ if $\phi \in \mathcal{K}$
    - Prem(A) = $\{\phi\}$, Conc(A) = ϕ, Sub(A) = $\{\phi\}$, DefRules(A) = $\emptyset$
  - $\boldsymbol{A_1, \ldots, A_n \rightarrow \phi}$ if $A_1, \ldots, A_n$ are arguments such that there is a strict inference rule Conc(A_1), ..., Conc(A_n) $\rightarrow \phi$
    - Prem(A) = Prem(A_1) $\cup \ldots \cup$ Prem(A_n)
    - Conc(A) = ϕ
    - Sub(A) = Sub(A_1) $\cup \ldots \cup$ Sub(A_n) $\cup \{A\}$
    - DefRules(A) = DefRules(A_1) $\cup \ldots \cup$ DefRules(A_n)
  - $\boldsymbol{A_1, \ldots, A_n \Rightarrow \phi}$ if $A_1, \ldots, A_n$ are arguments s.t. there is a defeasible inference rule Conc(A_1), ..., Conc(A_n) $\Rightarrow \phi$
    - Prem(A) = Prem(A_1) $\cup \ldots \cup$ Prem(A_n)
    - Conc(A) = ϕ
    - Sub(A) = Sub(A_1) $\cup \ldots \cup$ Sub(A_n) $\cup \{A\}$
    - DefRules(A) = DefRules(A_1) $\cup \ldots \cup$ DefRules(A_n) $\cup \{A_1, \ldots, A_n \Rightarrow \phi\}$

Types of arguments

- An argument A *is:*
  - **Strict** if DefRules(A) = $\emptyset$
  - **Defeasible** if not strict
  - **Firm** if Prem(A) $\subseteq \mathcal{K}_n$
  - **Plausible** if not firm

Examples of arguments in ASPIC+

- Consider an argumentation theory with:
  - $\mathcal{R}_s = \{s_1, s_2\}$, $\mathcal{R}_d = \{d_1, d_2, d_3, d_4, d_5\}$, where:

    $d_1: p \Rightarrow q$ $\quad$ $d_4: u \Rightarrow v$ $\quad$ $s_1: p, q \rightarrow r$

    $d_2: s \Rightarrow t$ $\quad$ $d_5: v, x \Rightarrow \neg t$ $\quad$ $s_2: v \rightarrow \neg s$

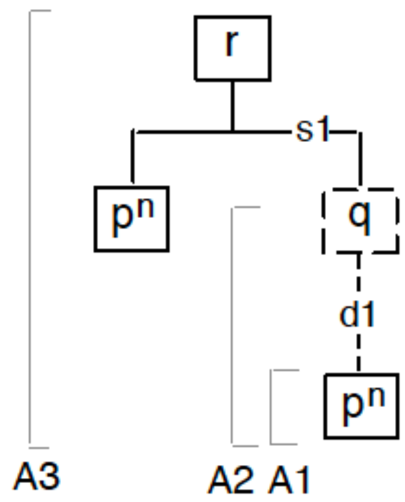
    $d_3: t \Rightarrow \neg d_1$
  - $\mathcal{K}_n = \{p\}$, $\mathcal{K}_p = \{s, u, x\}$
- Some arguments we can construct are:

  $\boldsymbol{A_1: p}$ $\quad$ $\boldsymbol{A_2: A_1 \Rightarrow q}$ $\quad$ $\boldsymbol{A_3: A_1, A_2 \Rightarrow r}$
  - A_1 is strict and firm while A_2 and A_3 are defeasible and firm
  - We can also construct

  $\boldsymbol{B_1: s}$ $\quad$ $\boldsymbol{B_2: B_1 \Rightarrow t}$ $\quad$ $\boldsymbol{B_3: B_2 \Rightarrow \neg d_1}$

  $\boldsymbol{C_1: u}$ $\quad$ $\boldsymbol{C_2: C_1 \Rightarrow v}$ $\quad$ $\boldsymbol{C_3: C_2 \Rightarrow \neg s}$

  $\boldsymbol{D_3: x}$ $\quad$ $\boldsymbol{D_4: C_2, D_3 \Rightarrow \neg t}$

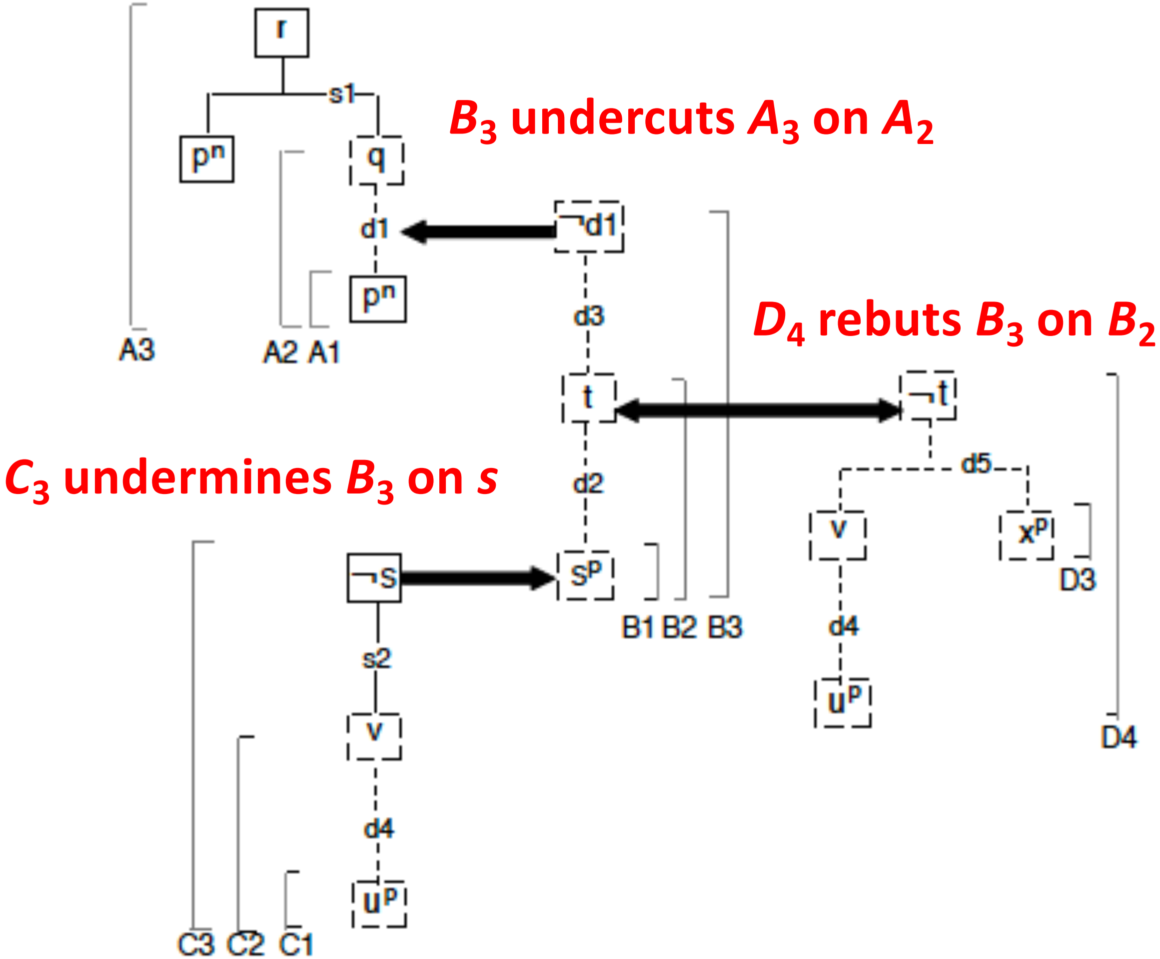


Attack

- *A* **undermines** *B* (on ϕ) if
  - Conc(*A*) = $-\phi$ for some $\phi \in$ Prem(*B*)/ $\mathcal{K}_n$;
- *A* **rebuts** *B* (on *B′*) if
  - Conc(*A*) = -Conc(*B′*) for some *B′* $\in$ Sub(*B)* with a defeasible top rule
- *A* **undercuts** *B* (on *B′*) if
  - Conc(*A*) = -n(*r*) for some *B′* $\in$ Sub(*B*) with defeasible top rule *r*

- *A* **attacks** *B* iff *A* undermines or rebuts or undercuts *B.*

Examples of attacks in ASPIC+



Structured Argumentation Framework

- A **structured argumentation framework** (*SAF*) defined by an argumentation theory *AT* is a triple (*Args,C*, $\leq_a$) where
  - *Args* = {*A* | *A* is an argument on the basis of *AT*}
  - *C* is the attack relation on *Args*
  - $\leq_a$ is a preference ordering on *Args*
- A ***c-SAF*** is a *SAF* in which all arguments have consistent premises

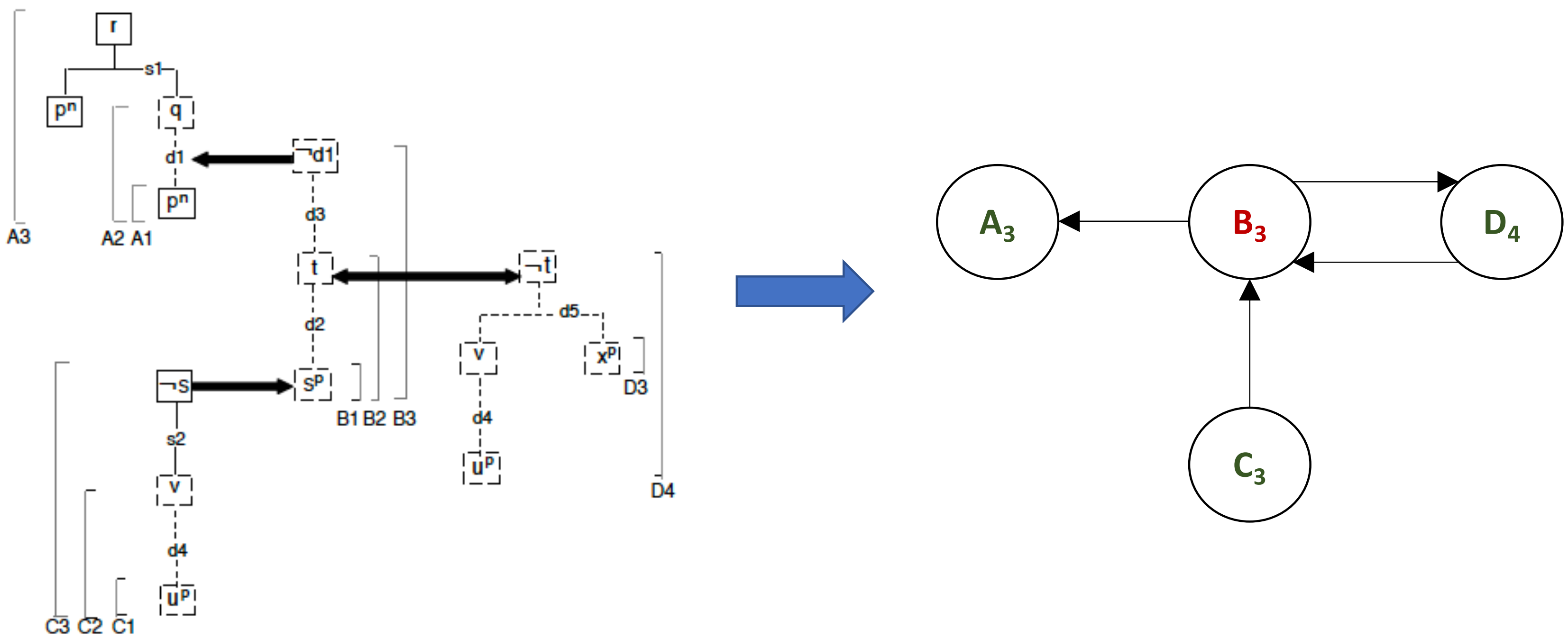
Defeat

- Given a SAF = (*Args,C*, $\leq_a$) and arguments *A*, *B* $\in$ *Args* :
- *A* **defeats** *B* iff for some *B'* $\in$ Sub(*B*)
  - *A* undermines or rebuts *B* on *B'* **and not *A*** $<_a$ ***B'***
    - (*A* $<_a$ *B' iff A* $\leq_a$ *B' and not B'* $\leq_a$ *A*)
  - *A* undercuts *B* on *B'*

- General constraint: A $<_a$ B if B is strict and firm and A is defeasible or plausible.

Generating AAFs from SAFs

- An AAF corresponding to a *SAF* = $(Args, C, \leq_a)$ a pair $(Args, R)$ where
  - *R* is the defeat relation on *Args* defined by *C* and $\leq_a$.



Deductive Argumentation

Argumentation Graph	Defines how arguments and counter-arguments are composed into a graph
Counterarguments	Defines when an argument attacks another argument
Arguments	Defines how an argument is constructed from the base logic
Base Logic	Defines the logical language and the consequence or entailment relation

Base Logic

- A logic is defined by a language $\mathcal{L}$ and a consequence relation $\vdash_i$
- Examples of base logic:
  - Simple logic
  - Classical logic
  - Non-monotonic logics
  - Temporal logics
  - Description logics
  - Paraconsistent logics

Deductive arguments

- Given a base logic (a language $\mathcal{L}$ and a consequence relation $\vdash_i$), a **deductive argument** is a pair **⟨Φ, α⟩** where $\boldsymbol{\Phi \vdash_i \alpha}$
  - **Φ** is the support or premises or assumptions of the argument
  - **α** is the claim or conclusion of the argument
- For an argument *A* = ⟨Φ, α⟩:
  - Support(*A*) = Φ
  - Claim(*A*) = α
- An argument ⟨Φ, α⟩
  - satisfies the **consistency constraint** when Φ is consistent
  - satisfies the **minimality constraint** when there is no $\Psi \subset \Phi$, such that $\Psi \vdash_i \alpha$

Arguments based on classical logic

- For a set of classical logic formulae **Φ** and a classical logic formula **α**, **⟨Φ, α⟩** is a **classical logic argument** iff
  - **$\Phi \vdash \alpha$**
    - $\vdash$ is the standard consequence relation of classical logic
  - **$\Phi \nvdash \bot$**
    - Φ is consistent
  - **there is no $\Psi \subset \Phi$, such that $\Psi \vdash \alpha$**
    - Φ is minimal
- An example:

`⟨{∀X.multipleOfTen(X)→even(X), ¬even(77)}, ¬multipleOfTen(77)}⟩`

Classical logic attacks

- Let *A* and *B* two classical logic arguments:
  - *A* is a **classical defeater** of *B* if **Claim(*A*)** $\vdash \neg\bigwedge \varphi_i \mid \varphi_i \in$ **Support(*B*)**
    - e.g. ⟨ {a ∨ b, c}, (a ∨ b) ∧ c ⟩ is a classical defeater of ⟨ {¬a, ¬b}, ¬a ∧ ¬b ⟩
  - *A* is a **classical direct defeater** of *B* if $\exists\ \varphi_i \in$ **Support(*B*) s.t. Claim(*A*)** $\vdash \neg\varphi_i$
    - e.g. ⟨ {a ∨ b, c}, (a ∨ b) ∧ c ⟩ is a classical direct defeater of ⟨ {¬a ∧ ¬b}, ¬a ∧ ¬b ⟩
  - *A* is a **classical undercut** of *B* if $\exists\ \varphi_1, \ldots, \varphi_n \in$ **Support(*B*) s.t. Claim(*A*)** $\vdash \neg\bigwedge_{1 \ldots n} \varphi_i$
    - e.g. ⟨ {¬a ∧ ¬b}, ¬(a ∧ b) ⟩ is a classical undercut of ⟨ {a, b, c}, a ∧ b ∧ c ⟩
  - *A* is a **classical direct undercut** of *B* if $\exists\ \varphi_i \in$ **Support(*B*) s.t. Claim(*A*)** $\equiv \neg\varphi_i$
    - e.g. ⟨ {¬a ∧ ¬b}, ¬a ⟩ is a classical direct undercut of ⟨ {a, b, c}, a ∧ b ∧ c ⟩
  - *A* is a **classical canonical undercut** of *B* if **Claim(*A*)** $\equiv \neg\bigwedge \varphi_i \mid \varphi_i \in$ **Support(*B*)**
    - e.g. ⟨ {¬a ∧ ¬b}, ¬(a ∧ b ∧ c) ⟩ is a classical canonical undercut of ⟨ {a, b, c}, a ∧ b ∧ c ⟩

Classical logic attacks (cont'd)

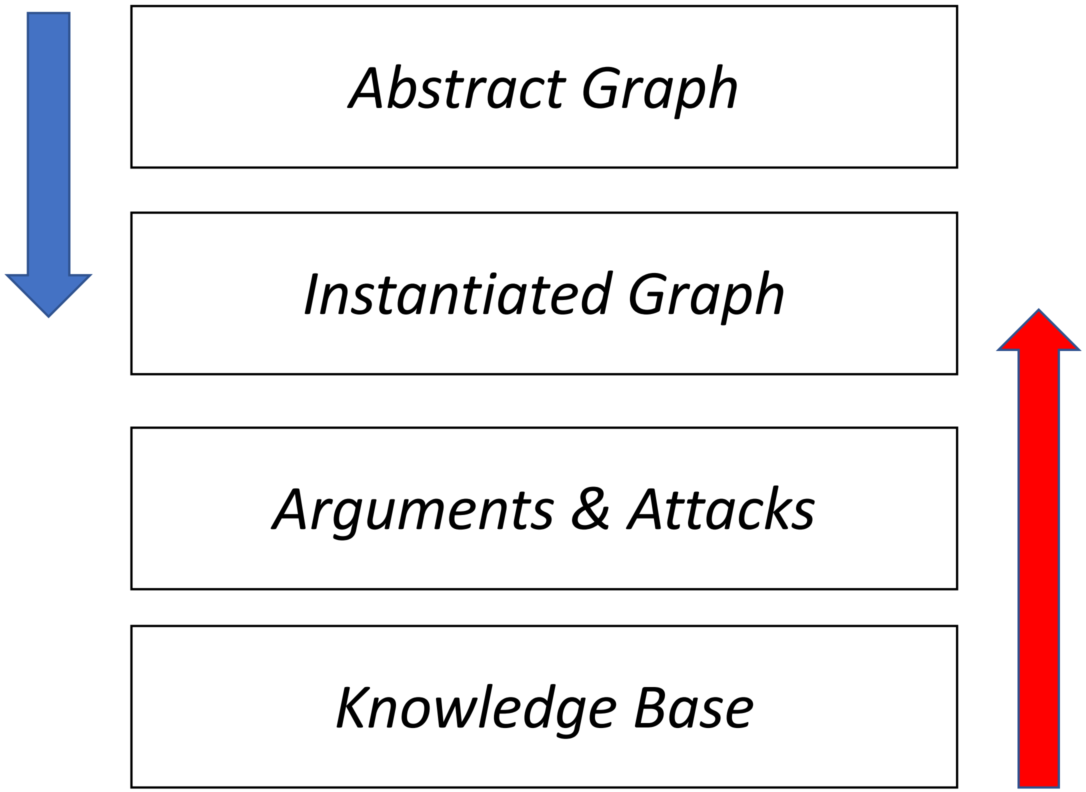
- Let *A* and *B* two classical logic arguments:
  - *A* is a **classical rebuttal** of *B* if **Claim(*A*) ≡ ¬ Claim(*B*)**
    - e.g. ⟨ {a, a → b}, (b ∨ c) ⟩ is a classical rebuttal of ⟨ {¬a ∧ ¬b, ¬c}, ¬ (b ∨ c) ⟩
  - *A* is a **classical defeating rebuttal** of *B* if **Claim(*A*) ⊢ ¬ Claim(*B*)**
    - e.g. ⟨ {a, a → b}, b ⟩ is a classical defeating rebuttal of ⟨ {¬a ∧ ¬b, ¬c}, ¬ (b ∨ c) ⟩

Examples of classical logic arguments & attacks

- Propositional logic arguments
  - A = ⟨{lowCostFly, luxFly, lowCostFly,luxFly→goodFly}, goodFly⟩
  - B = ⟨{¬lowCostFly ∨ ¬luxFly}, ¬lowCostFly ∨ ¬luxFly⟩
  - B is a classical undercut of A
- First-order logic arguments
  - A = ⟨{bird(Tweety), ∀X.bird(X)→flies(X)}, flies(Tweety)⟩
  - B = ⟨{∃X. bird(X)∧¬flies(X)}, ¬∀X.bird(X)→flies(X)⟩
  - B is a classical direct undercut of A

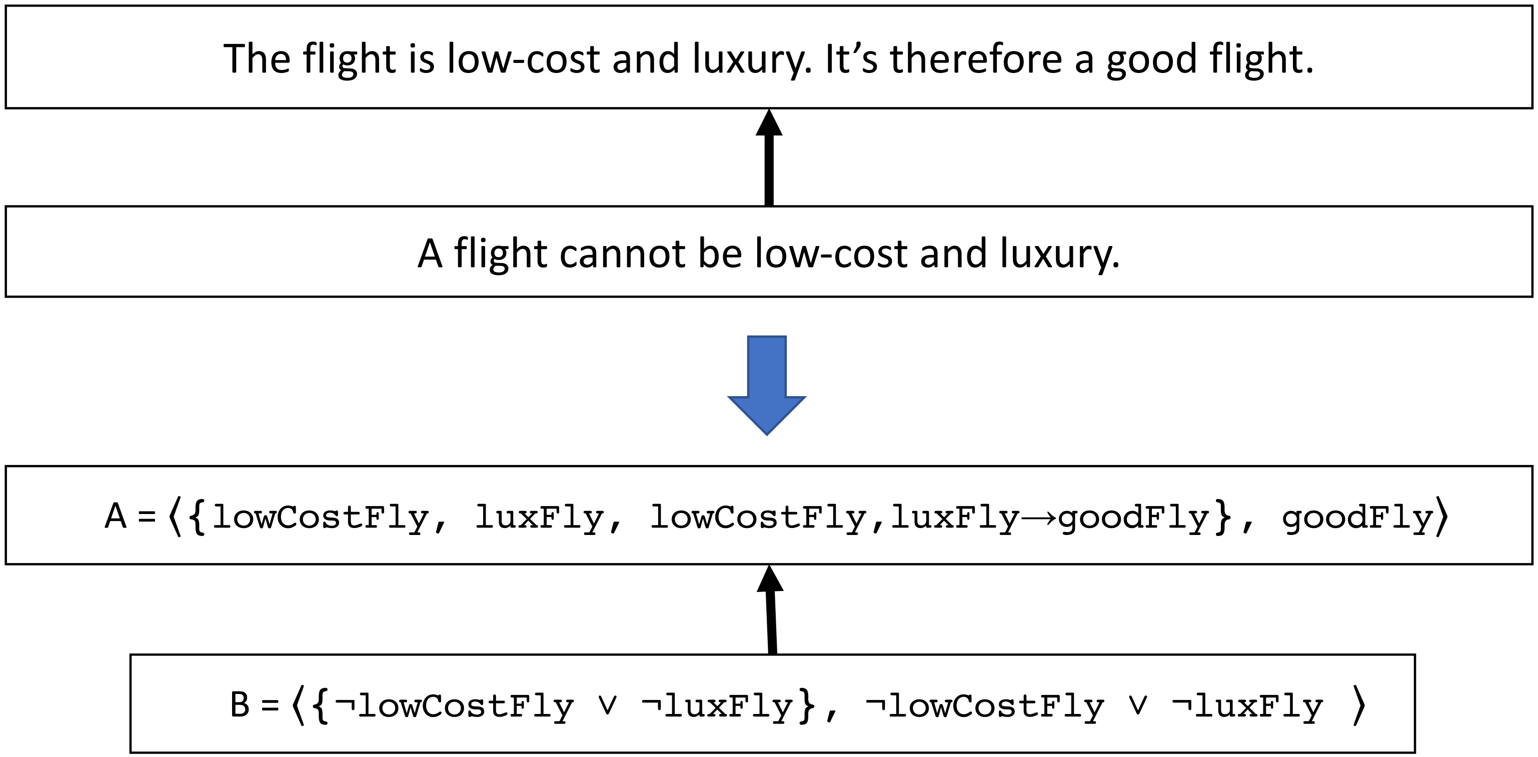
Approaches to constructing argument graphs

Descriptive approach:
- **Input**: an abstract argument graph
- **Output**: an instantiated argument graph



Generative approach:
- **Input**: knowledge base
- **Output**: an instantiated argument graph

Generating an instantiated graph

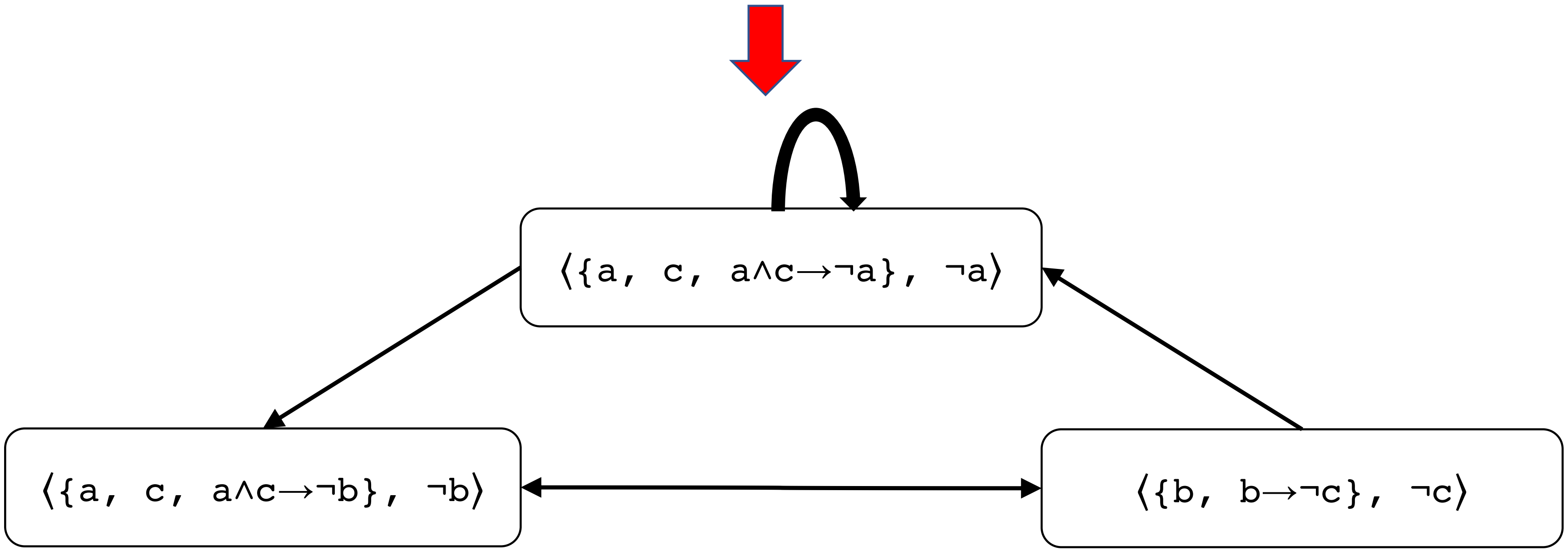


Generating an abstract graph

- Consider the simple logic knowledge base:

  {a, b, c, a∧c→¬a, b→¬c, a∧c→¬b}

- And let all arguments involve one more rules



Assumption-based Argumentation

- A **deductive system** is a pair ($\mathcal{L}$, $\mathcal{R}$) where
  - $\mathcal{L}$ is a logical language
  - $\mathcal{R}$ is a set of rules ($\phi_1, \ldots, \phi_n \rightarrow \phi$) over $\mathcal{L}$
- An **assumption-based argumentation framework** is a tuple ($\mathcal{L}$, $\mathcal{R}$, $\mathcal{A}$, ~)
  - ($\mathcal{L}$, $\mathcal{R}$) is a deductive system
  - $\mathcal{A} \subseteq \mathcal{L}$, $\mathcal{A} \neq \emptyset$ is a set of **assumptions**
  - No rule has an assumption as conclusion
  - ~ is a total mapping from $\mathcal{A}$ into $\mathcal{L}$. ~a is the **contrary** of a
- An **argument S ⊢ p** is a deduction of **p** from a set **S** $\subseteq \mathcal{A}$.
- Argument S ⊢ p **attacks** argument S' ⊢ p' iff p = ~q for some q $\in$ S’
- Acceptability semantics similar to the semantics of AAFs
- Read more about ABA in (Toni, 2014)

Defeasible Logic Programming (DeLP)

- An argumentation system based on logic programming
- Elements of a **Defeasible Logic Program**
  - A set of facts
  - A set of strict and defeasible rules
  - A binary argument ordering
- An **argument (*A*, *L*)** is a defeasible derivation for *L* (similar to ASPIC+)
- Argument *A* **attacks** argument *B* at sub-argument B' iff the conclusions of *A* and *B'* are inconsistent. *A* **defeats** *B* iff *A* attacks *B* on *B' and* $A \not< B'$
- Game-theoretic acceptability semantics
- Read more about DeLP in (Garcia and Simari, 2014)

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Applications of Argumentation

- Argumentation on the Web
  - The Argument Web
  - Argument search on the Web
  - Online debate platforms
- Argumentation in Medicine
- Argumentation in Law

The Argument Web

ARG-tech
Centre for Argument Technology

- An Online Ecosystem of Tools, Systems and Services for Argumentation (Reed et al., 2017), https://arg-tech.org/index.php/research/
- The **Argument Interchange Format**
  - An ontology of arguments
  - Models arguments at different levels of abstraction
  - Aims to facilitate the exchange of data between different argumentation tools and agent-based applications.
  - Integrates elements of argumentation theories from different disciplines: formal argumentation, multi-agent systems, informal logics
  - Available in several formats (OWL, XML, JSON, Prolog, SVG, etc.)

The Argument Web

ARG-tech
Centre for Argument Technology

- **OVA** (Online Visualisation of Argument): http://ova.arg-tech.org/
  - A web drag-and-drop interface for analysing textual arguments
  - Manual annotation of the argumentative structure of natural language text
  - Based on the Argument Interchange Format
  - Arguments can be saved on the Argument Web
  - Other similar tools
    - DebateGraph, https://debategraph.org/
    - RationaleOnline, https://www.rationaleonline.com/
- Collaborative analysis of arguments
  - **OVA 2.0**: allows multiple analysts to work together on a single analysis
  - **AnalysisWall**: a large, shared workspace (high-resolution touchscreen) running bespoke argument analysis software

AnalysisWall

ARG-tech
Centre for Argument Technology

Source: https://arg-tech.org

The Argument Web

ARG-tech
Centre for Argument Technology

- **Argugrader** (Argument Pedagogy): http://www.argugrader.com/
  - Students prepare their argument analysis in OVA
  - Argugrader compares submissions over model answers using graph matching algorithms and produces a grade and textual feedback
- Dialogue applications
  - **Arvina** (web-based discussion s/w): https://arg-tech.org/index.php/arvina/
  - **Argublogging** (dialogue application for bloggers)
- **AIFdb Corpora**: http://corpora.aifdb.org/
  - Corpora of argument in several different languages from various domains as diverse as mediation, pedagogy, politics, broadcast debate, eDemocracy and financial discussion

Argument Search

- Technology that finds pro and con arguments for controversial issues
- **args.me**: https://www.args.me/
  - Indexes debate portal arguments
  - Retrieves and ranks relevant arguments in response to queries.
- **ArgumenText**: https://www.argumentsearch.com/
  - Indexes diverse web pages
  - Mines relevant arguments in response to queries
- **PerspectroScope**: https://perspectroscope.seas.upenn.edu/
  - Similar to ArgumentText for debate portals and Wikipedia texts

Searching for arguments in args.me

args — abolish the death penalty

Page 1 of 639 arguments, 326 pro, 313 con (retrieved in 0.4s)

Pro

#1 No execution of the innocent
http://www.bbc.co.uk (81 other sources...)
As long as human justice remains fallible, the risk of executing the innocent can never be eliminated.

#2 Everyone has a right to live
http://www.amnesty.org (102 other sources...)
Everyone has an inalienable human right to live, even those who commit murder.

#3 Death penalty fails to deter
http://www.procon.org (24 other sources...)
There is no scientific proof that executions have a greater deterrent effect than life imprisonment.

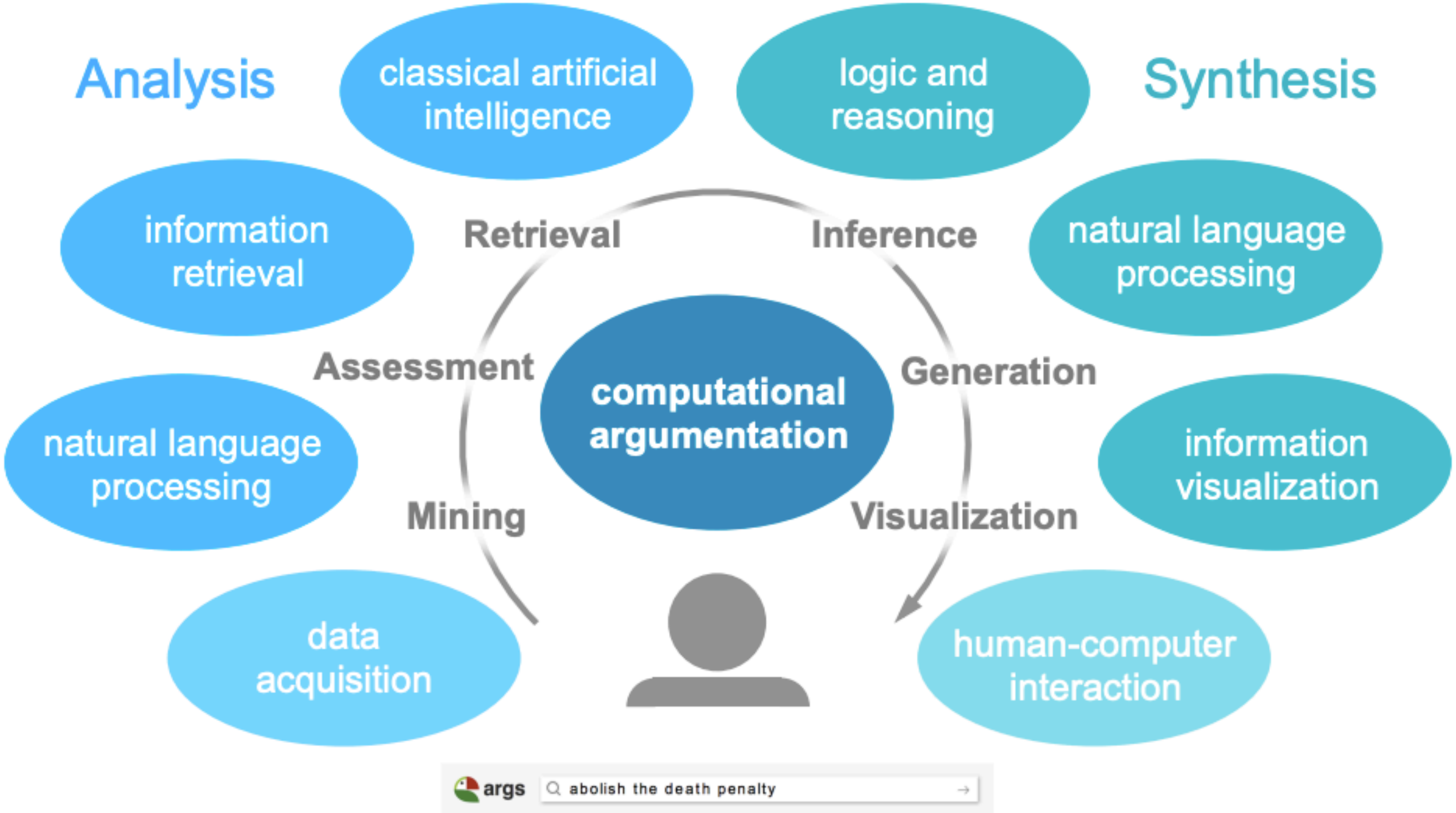
Con

#1 Retribution
http://www.bbc.co.uk (36 other sources...)
Real justice requires people to suffer for their wrongdoing in a way adequate for the crime.

#2 Death penalty deters
http://www.debate.org (15 other sources...)
By executing convicted murderers, would-be murderers are deterred from killing people.

#3 Prevention of re-offending
http://www.bbc.co.uk (25 other sources...)
Those executed cannot commit further crimes. Imprisonment does not protect sufficiently.

Argument Search: Tasks

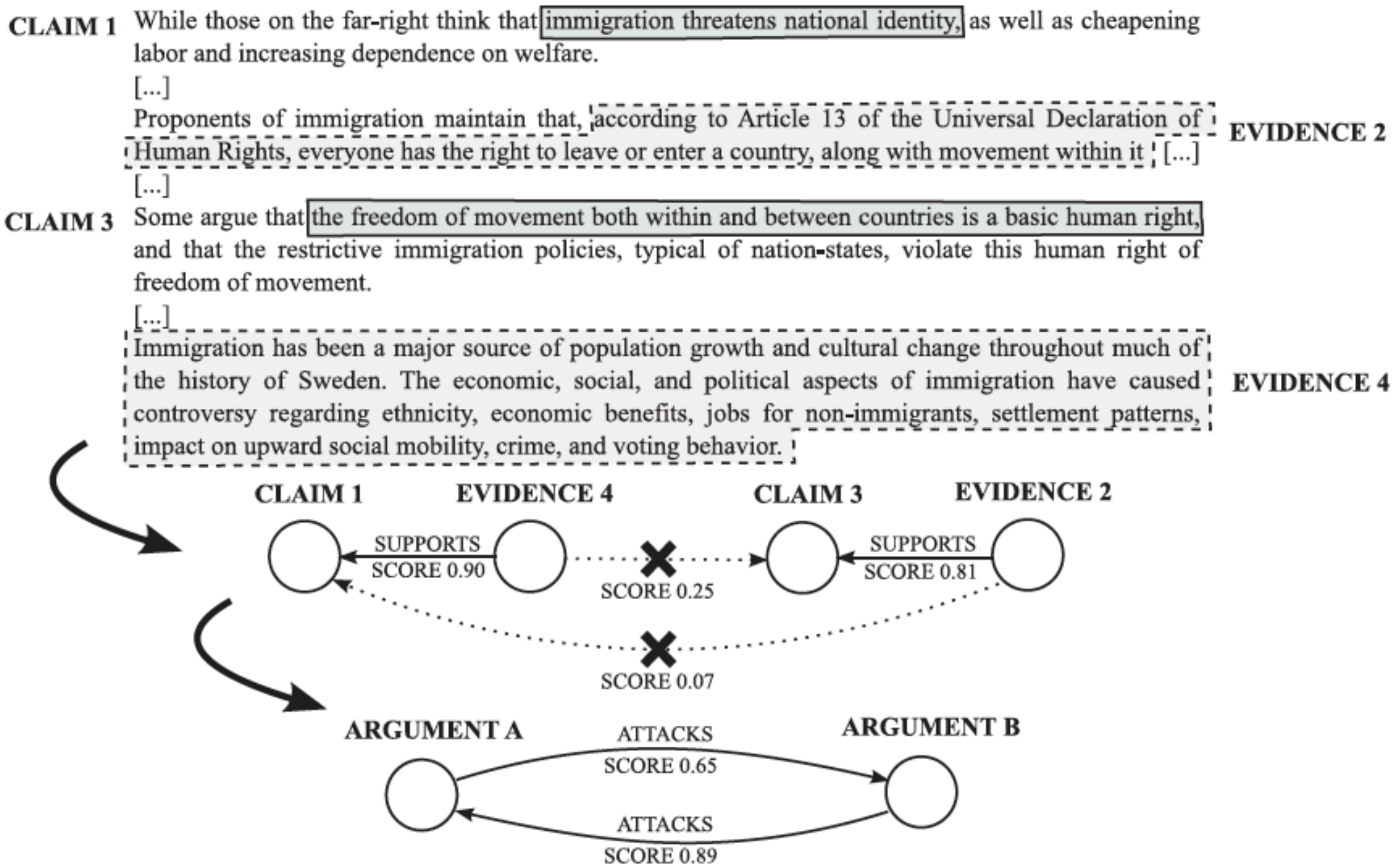


Read more about args.me in (Wachsmuth et al., 2017)

Argument mining

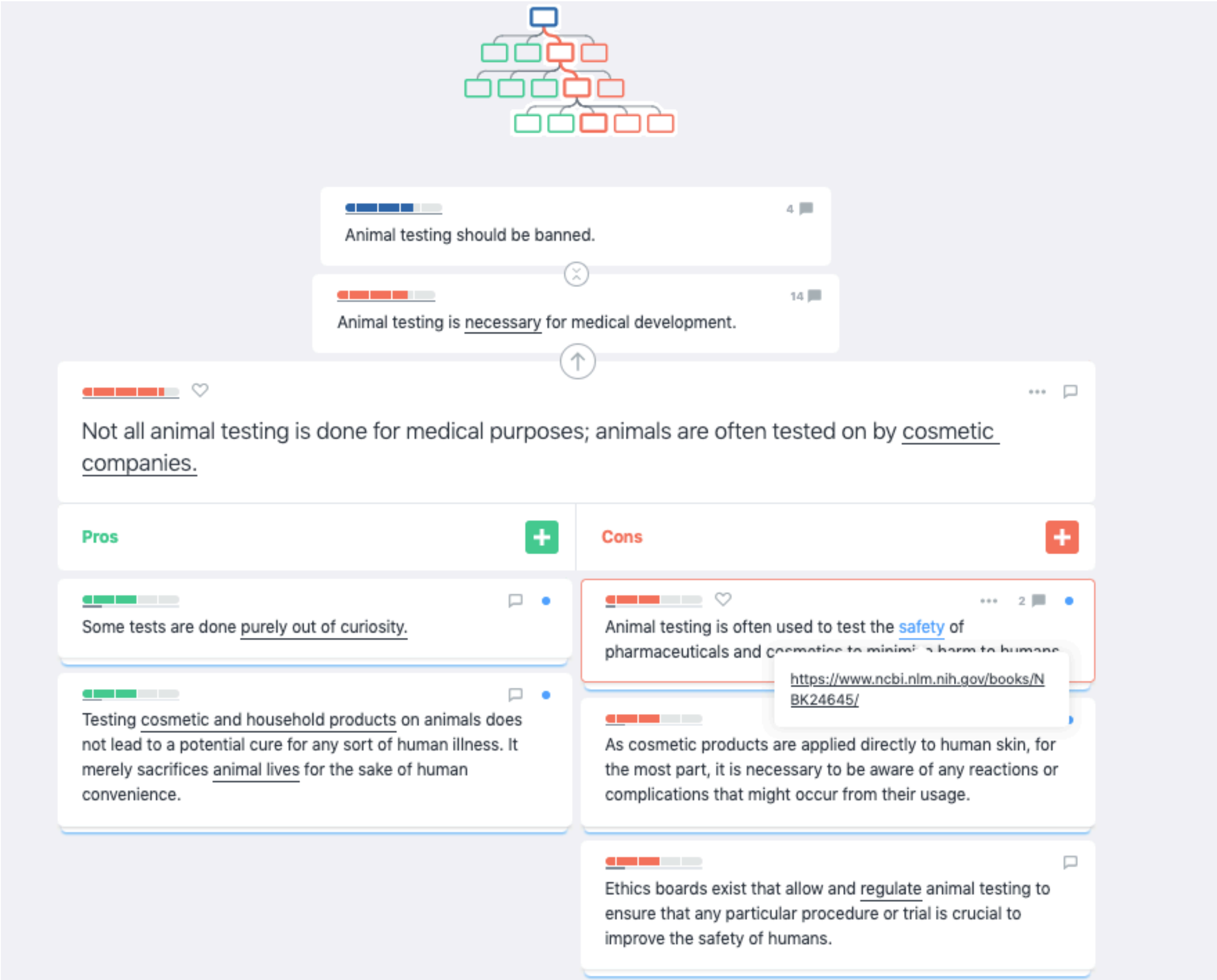
- Core task is many argument-based applications
- Automatic identification of arguments and their relations in natural language text
- A challenging problem involving several NLP tasks:
  - Sentence classification
  - Sentiment analysis
  - Named entity recognition
  - Link prediction
  - Discourse relation classification
  - Etc.
- See (Lippi and Torroni, 2016) for a recent survey

Argument mining: an example



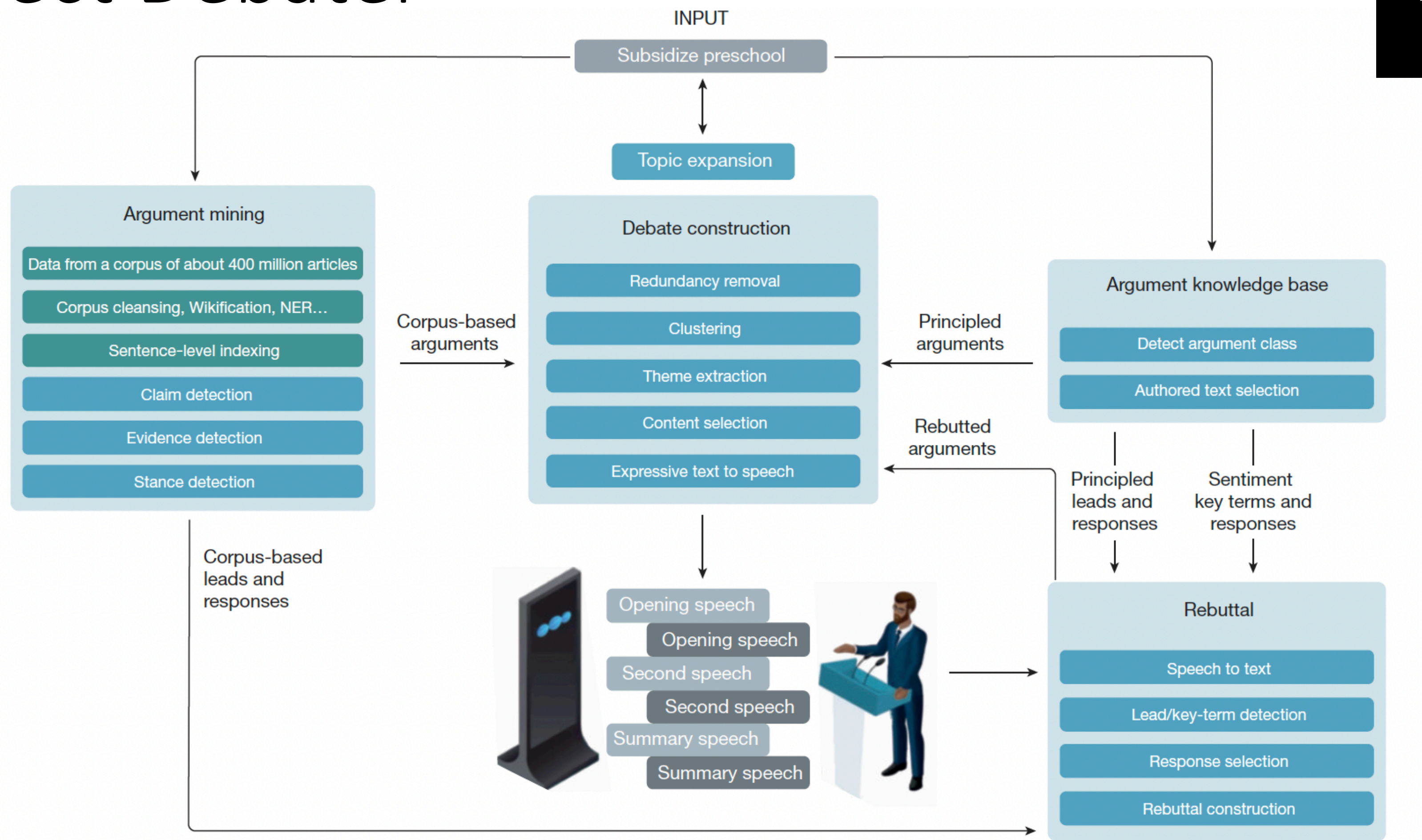
Debate platforms

- Platforms where web users can participate in debates
  - Users can create debates, post pro/con arguments and vote on other users' arguments.
  - Tools for evaluating arguments and visualising debates
  - Examples: Kialo.com, Debate.org, createdebate.com, debategraph.org
- Social Argumentation Frameworks (Leite and Martins, 2011)
  - Extension of Abstract Argumentation Frameworks
  - Evaluation of arguments in debates based on the votes they have received and the strength of the opposing arguments
  - Frameworks considering argument support
    - Quantitative Argumentation Debate Framework (Rago et al., 2016)
    - Multi-Aspect Comment Evaluation Framework (Patkos et al., 2016)



An online debate in Kialo.com

Project Debater



Read more about the Project Debater at: https://research.ibm.com/interactive/project-debater/

Argumentation in Medicine

- Medical information: complex, heterogeneous, incomplete, inconsistent
- Medical decision support
  - **Capsule** (Walton et al., 1997) helps family doctors with drug prescription. Arguments pro and con a drug based on similar past cases and patient record.
- Evidence-based research
  - Framework that produces argument-based personalised recommendations for treatment based on the results of clinical trials (Hunter and Williams, 2012).
- Behaviour change
  - Automated persuasion system that selects convincing arguments for persuading a patient to change behaviour (e.g. take more exercise) (Hunter, 2018)

Argumentation in Law

- Legal reasoning is essentially argumentative
- Case-based reasoning
  - **HYPO** (Ashley, 1990) and **CATO** (Aleven, 2003): Use of arguments to model how lawyers make use of past decisions when arguing a case.
  - Argument-based model of precedent (Horty and Bench-Capon, 2012)
- Practical reasoning
  - Modelling legal arguments using argument schemes (Atkinson et al., 2005)
- Evidential reasoning
  - Evidential Argumentation System (Oren and Norman, 2008)
  - Use of formal argumentation systems to model Wingmore charts and reason about legal evidence (Bex et al., 2003)

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- F.J. Bex, H. Prakken, C. Reed, D.N. Walton (2003). Towards a formal account of reasoning about evidence: argumentation schemes and generalisations, Artificial Intelligence and Law 12 (2003) 125–165.

Bibliographic Resources on Argumentation

- Books on Argumentation
  - Handbook of Formal Argumentation, vol.1 & 2
  - Elements of Argumentation (Besnard and Hunter, 2008)
  - Argumentation in AI (Eds: I. Rahwan and G. Simari, 2009)
- AI Journals and Conferences
- Journal: Argument & Computation
- Conferences & workshops on argumentation
  - Conference on Computational Models of Argument
  - Workshop on Argumentation in Multiagent Systems
  - Workshop Computational Models of Natural Argument
  - Workshop Theory and Applications of Formal Argumentation
  - Workshop on Argument Strength
- International Competition on Computational Models of Argumentation