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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Introduction to Argumentation

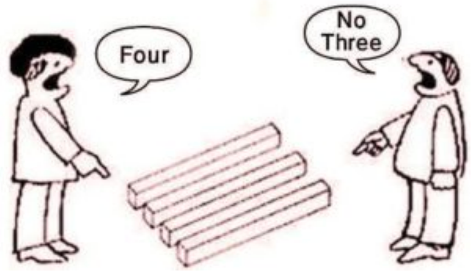
- Main Concepts
  - Argumentation, Argument, Argumentation theory
- Informal approaches
- Formal approaches
  - Argumentation-based inference
  - Argumentation-based dialogues

What is argumentation

- An everyday human activity
- Exchange of arguments on a topic
- Resolving conflicts of opinion
- Influencing the thoughts or views of others
  - ”*the ability to consider, for a given question, the elements that are useful to persuade someone*” (Aristotle)
- A way of thinking
- A cognitive process
- Drawing conclusions based on evidence, which may be incomplete or contradictory

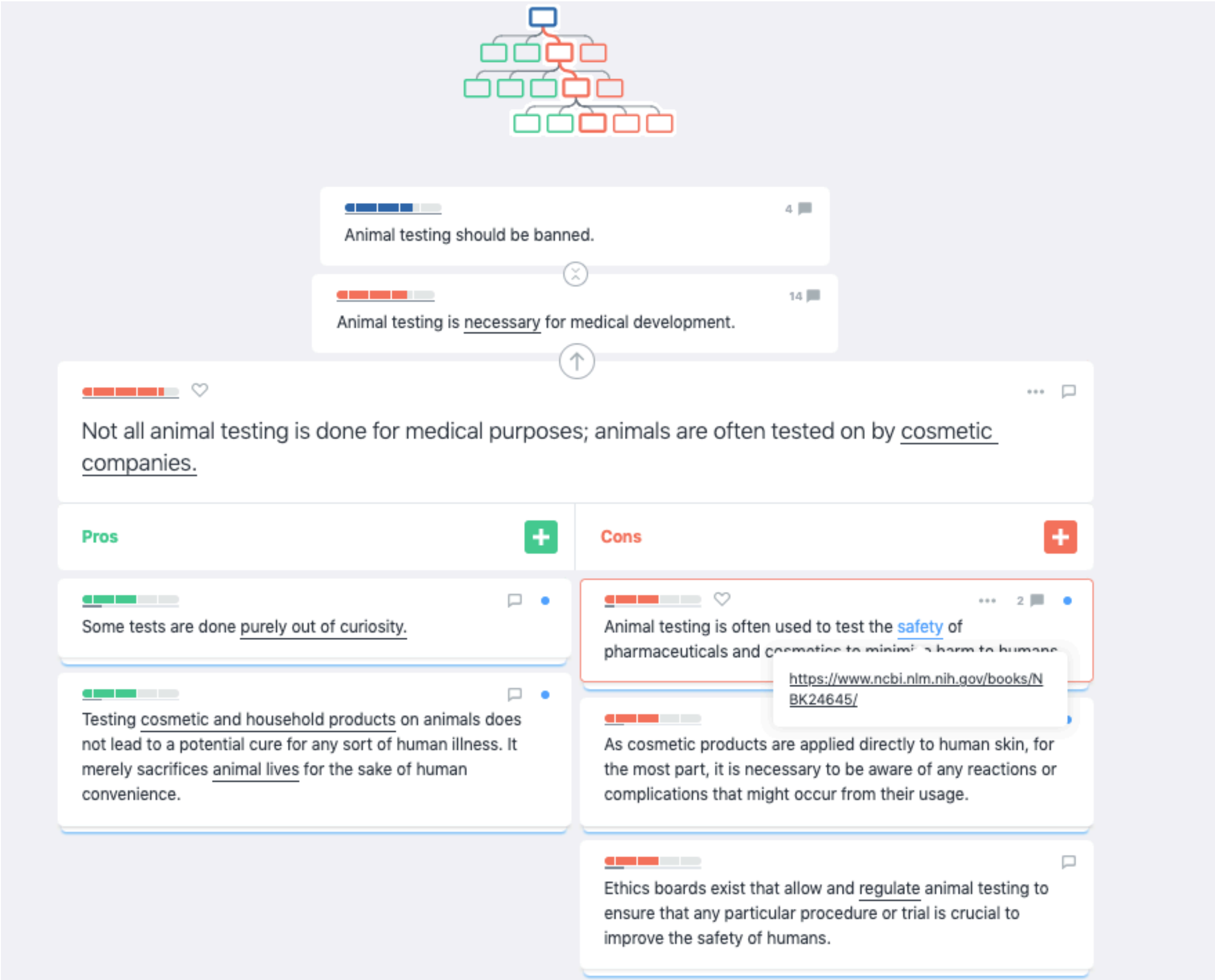
A formal definition

- "*a verbal, social, and rational activity aimed at convincing a reasonable critic of the acceptability of a standpoint by putting forward a constellation of propositions justifying or refuting the proposition expressed in the standpoint.*"
  - Eemeren, F. H. v., & Grootendorst, R. (2004). A Systematic Theory of Argumentation: The Pragma-dialectical Approach. Cambridge University Press.
- Discursive activity ("social", "aimed at convincing a reasonable critic")
- Cognitive activity ("verbal", "rational")



What is argument

- “*any group of propositions of which one is claimed to follow from the others, which are regarded as providing support or grounds for the truth of that one*”
  - Copi, I.M., & Cohen, C. (2002). Introduction to Logic (11th ed.). Upper Saddle River (NJ): Prentice Hall.
- “*the giving of reasons to support or criticize a claim that is questionable, or open to doubt*”
  - D.N. Walton. Fundamentals of Critical Argumentation. Cambridge University Press, Cambridge, 2006.



An online debate in Kialo.com

How does argumentation work?

- Identifying arguments and counter-arguments relevant to an issue
  - "*Animal testing is necessary for medical development*"
  - "*Not all animal testing is done for medical purposes; animals are often tested on by cosmetic companies*"
- Weighing, comparing or evaluating arguments
  - Is the argument valid?
  - Is the supporting evidence valid and strong?
  - How do the different argument appeal to us?
  - What do we value most?
- Drawing a conclusion
  - Decide whether to agree/disagree with banning animal testing

What types of information does it involve?

- Certain (absolutely correct)
  - Dogs are animals.
  - Animals have been used in medical testing.
- Uncertain
  - Animal testing may be best tool to defeat COVID-19.
- Objective (can be observed, measured or verified)
  - Mice share more than 98% DNA with humans.
- Subjective (based on beliefs or opinions)
  - I believe that testing on animals is unethical.
- Hypothetical
  - Animal testing will be banned within the next decade.

Argumentation theory

- "*The study of argumentation in all its manifestations and varieties, irrespective of the intellectual backgrounds, primary research interests and angles of approach of the theorists*"
  - van Eemeren F.H., Garssen B., Krabbe E.C.W., Snoeck Henkemans A.F., Verheij B., Wagemans J.H.M. (2014) Argumentation Theory. In: Handbook of Argumentation Theory. Springer, Dordrecht.
- Disciplines that study argumentation
  - Philosophy
  - Communication studies
  - Informal Logic
  - Cognitive psychology
  - Linguistics
  - Artificial Intelligence

Argumentation in AI

- Formal models of argumentation
- Computer programs that model or support argumentative tasks
  - Identifying arguments, evaluating arguments, drawing conclusions, etc.

- Systems for argumentation-based inference
  - compute conclusions drawn from a given body of possibly incomplete, inconsistent or uncertain information
- Systems for argumentation-based dialogue
  - model argumentation as verbal interaction aimed at resolving conflicts of opinion
  - argumentation protocols, strategies, etc.

Toulmin’s model of argumentation*

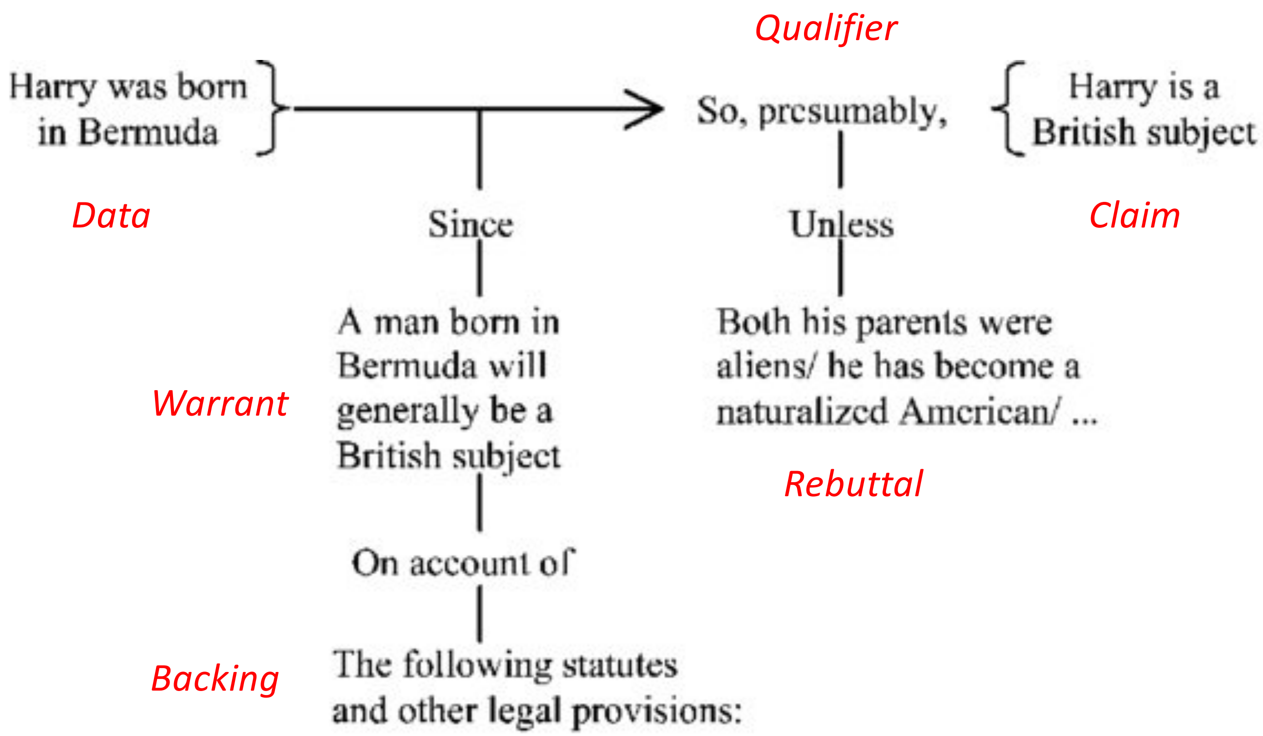
- An attempt to describe the elements of argumentation in a non-formal way (informal logic).
- A procedural model of the layout of an argument
- Assessment of arguments depends on the context
- Formal (logic-based) methods are not suitable for evaluating arguments.

* *Toulmin, S. E. (1958). The uses of argument. Cambridge, England: Cambridge University Press. (updated ed. 2003).*

Toulmin’s model of argumentation

- 1st step: Express a claim that you wish your audience to accept (**claim**)
- 2nd step: Provide the data to support the claim (**data**)
- 3rd step: Provide reasons why the data justify the claim (**warrant**)
- 4th step: Provide evidence to support the warrant (**backing**)
- 5th step: Consider situations that the claim might not be true (**rebuttal**)
- 6th step: Decide the degree to which the claim holds (**qualifier**)

An example (Toulmin, 1958)



Walton's argumentation schemes*

- A form of argumentation that has to do with practical decisions in situations where exact knowledge is insufficient to yield a decisive solution to the problem.
- A defeasible kind of reasoning: Once new evidence or facts appear, initial conclusions may be invalidated.
- Arguments may be challenged by critical questions.
- Argumentation scheme: a template that represents a common type of argument used in everyday dialogues

* *Walton, D. N. (1996). Argumentation schemes for presumptive reasoning. Mahwah, NJ: Lawrence Erlbaum.*

Argument from Position to know

- **Major Premise**: Source *a* is in position to know about things in a certain subject domain *S* containing proposition *p*.
- **Minor Premise**: *a* asserts that *p is true* (*false*)
- **Conclusion**: *p is true* (*false*)
- **Critical Questions**:
  - CQ1: Is *a* in position to know whether *p is true* (*false*)?
  - CQ2: Is *a* honest (trustworthy, reliable) source?
  - CQ3: Did *a* assert that *p is true* (*false*)?

- Example: A passer-by who looks familiar with the city said that the main train station is two blocks away. So, it should be two blocks away.

Walton’s argumentation schemes

- Argument from witness testimony
- Argument from popular opinion
- Argument from popular practice
- Argument from example
- Argument from composition
- Argument from division
- Argument from oppositions
- Argument from alternatives
- Argument from verbal classification
- Argument from definition to verbal classification
- Argument from vagueness of a verbal classification
- Argument from arbitrariness of a verbal classification
- Argument from interaction of act and person
- Argument from values
- Argument from the group and its members
- Practical reasoning argument
- Argument from waste
- Argument from sunk costs
- Argument from correlation to cause
- Argument from sign
- Argument from evidence to a hypothesis
- Argument from consequences
- Argument from threat
- Argument from fear appeal
- Argument from danger appeal
- Argument from need for help
- Argument from distress
- Argument from commitment
- Ethotic argument
- Generic ad hominem argument
- Pragmatic inconsistency argument
- Argument from inconsistent commitment
- Circumstantial ad hominem argument
- Argument from bias
- Bias ad hominem argument
- Argument from gradualism
- Slippery slope argument

Walton, Douglas N.; Reed, Chris; Macagno, Fabrizio (2008). Argumentation schemes. Cambridge; New York: Cambridge University Press.

Formal models for argumentation-based inference

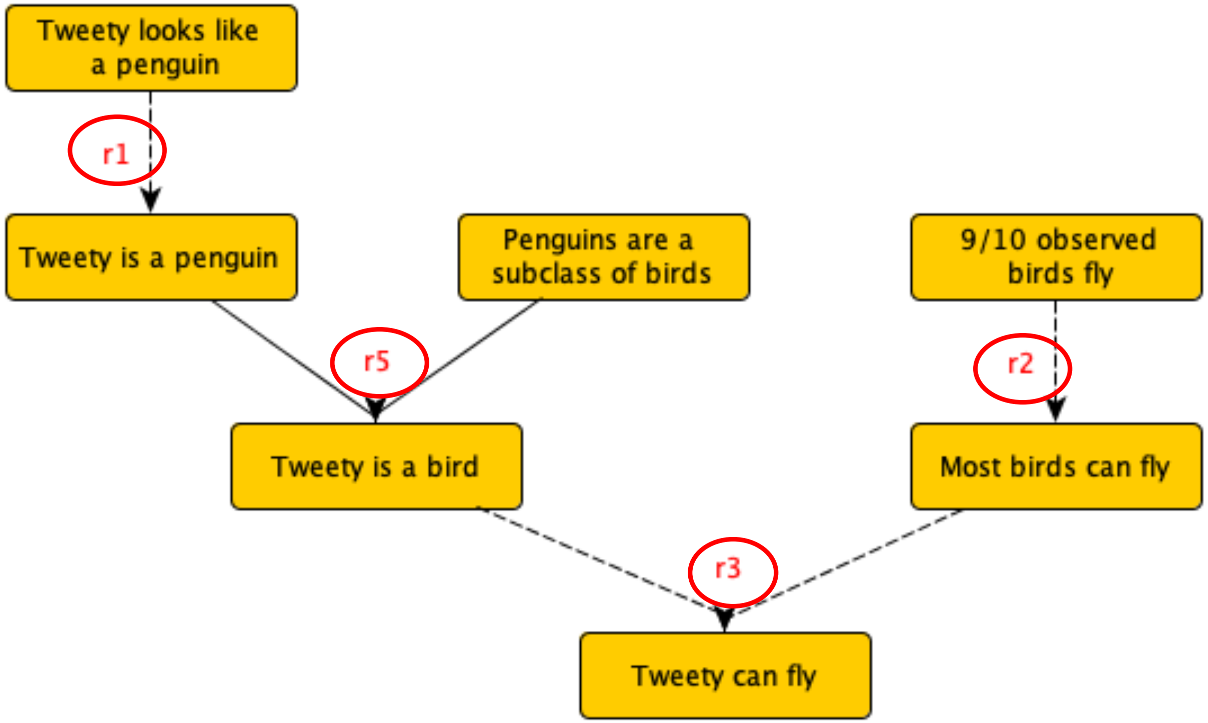
- Commonsense reasoning (including argumentation) often involves incomplete or inconsistent information
- Limitation of deductive reasoning: If information is incomplete, then nothing useful can be deductively derived, while if it is inconsistent, then anything is deductively implied
- Non-monotonic logics allow ‘jumping to conclusions’ in the absence of information to the contrary.
- Argumentation is a non-monotonic process.

Pollock's model of argument*

- Argument is an inference graph in which a final conclusion is inferred from the premises via intermediate conclusions
- Inference rules (*reasons*) are of two kinds:
  - Deductive (*conclusive*)
  - Defeasible (*prima facie*)
- Arguments can be defeated on its defeasible reasons
  - attack the conclusion of a defeasible inference by supporting a conflicting conclusion (*rebutting defeater*)
  - attack the defeasible inference itself without supporting a conflicting conclusion (*undercutting defeater*)

* *Pollock, J.L. (1987). Defeasible reasoning. Cognitive Science, 11:481-518*

An argument supporting that Tweety can fly



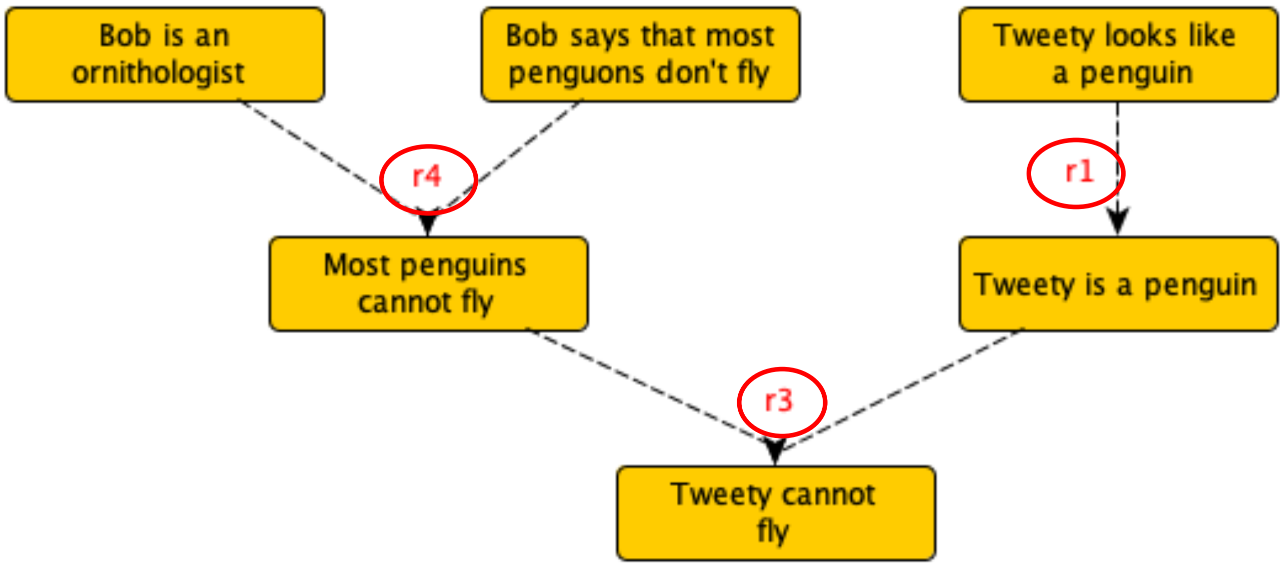
r_1: That an object looks like having property *P* is a defeasible reason for believing that the object has property *P*

r_5: That *P*s are a subclass of *Q*s and *a* is a *P* is a deductive reason for believing that *a* is a *Q*

r_2: That a large percentage of people (more than 50%) observed *P*s are *Q*s is a defeasible reason for believing that most *P*s are *Q*s

r_3: That most *P*s are *Q*s and *x* is a *P* is a defeasible reason for believing that *x* is a *Q*

A rebutting defeater

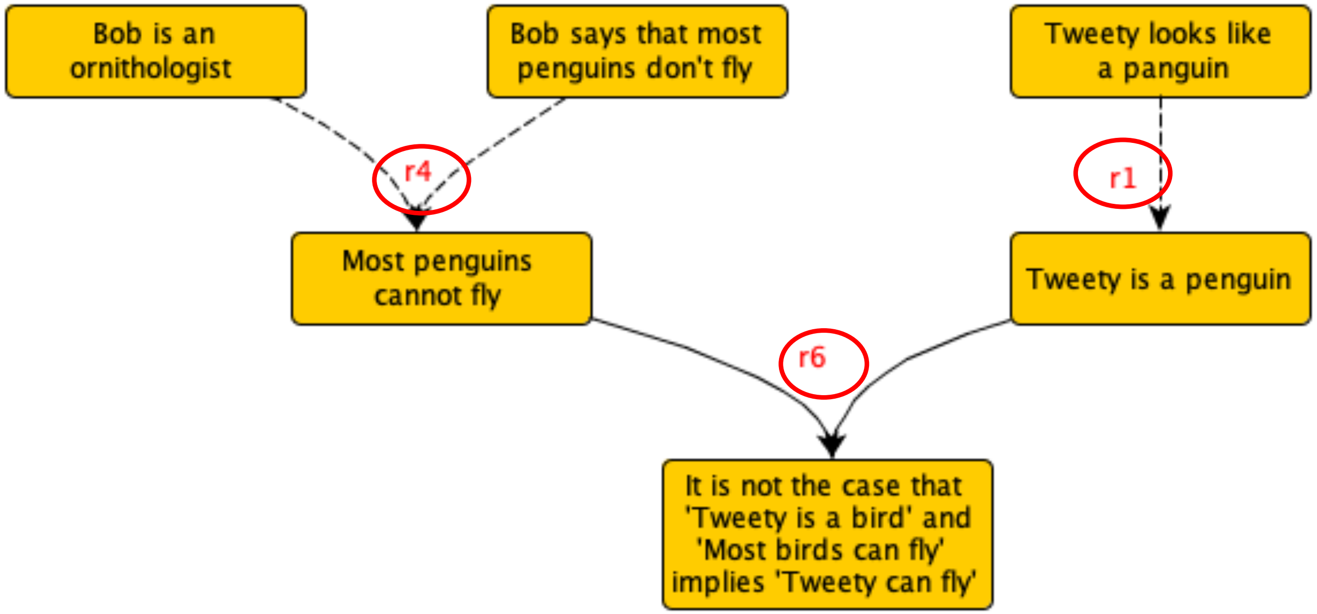


***r*₁**: That an object looks like having property *P* is a defeasible reason for believing that the object has property *P*

***r*₄**: That an ornithologist says φ about penguins is a defeasible reason for believing φ

***r*₃**: That most *P*s are *Q*s and *x* is a *P* is a defeasible reason for believing that *x* is a *Q*

An undercutting defeater



r_1: That an object looks like having property *P* is a defeasible reason for believing that the object has property *P*

r_4: That an ornithologist says φ about penguins is a defeasible reason for believing φ

r_6: That *x* is an *R*, most *R*s are not *Q*s and *R*s are a subclass of *P*s is a deductive reason for believing ¬ r_3

Abstract Argumentation Frameworks*

- A simple but elegant model for argument evaluation based on two notions: argument and attack
- The acceptability of an argument depends only on the attacks it receives and not on its internal structure.
- “The one who has the last word loughs”
  - When someone makes a claim and that is the end of the discussion, the claim stands. But when there is an opponent raising a counter-argument to the claim, the claim is no longer accepted.

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

Can Tweety fly?

Accepted because the only argument that attacks it has been rejected

Rejected because it is attacked by an argument that has been accepted

Accepted because it receives no attacks

Abstract vs. Structured Argumentation

- Abstract Frameworks
  - Each argument is regarded as atomic (no internal structure)
  - Dung's AAF and its extensions
    - Attacks on attacks, joint attacks, support relation, preferences, weights, etc.
  - Other approaches
    - Abstract Dialectical Frameworks
- Structured Frameworks
  - They use a formal language for representing knowledge
  - Arguments can be constructed from the available knowledge
  - The premises and claim of the argument are made explicit
  - Relationship between premises and claim is formally defined
  - ASPIC, ABA, Deductive argumentation, DeLP

Argumentation-based dialogues

- Two or more agents aim to resolve a conflict of opinion by verbal means
- Relevant information
  - Content of the arguments
  - Knowledge, beliefs, preferences, goals of the agents
  - Credibility of the agents
  - Changes in an agent's knowledge and beliefs
  - Context of the dialogue

Classification of dialogues

- Persuasion
  - Aims to change the audience's opinions or beliefs
- Negotiation
  - Aims to resolve a conflict of opinion by reaching a deal
- Information seeking
  - Aims to enrich an agent's knowledge
- Deliberation
  - Aims to reach a decision on a course of action
- Inquiry
  - Aims to prove a disputable or questionable proposition

Walton, D.N. and Krabbe, E.C.W. (1995). Commitment in Dialogue. Basic Concepts of Interpersonal Reasoning. State University of New York Press, Albany, NY.

Formal dialogue systems: Components

- A dialogue goal
- A set of participants (at least two) and a set of roles
- A logic $\boldsymbol{L}$ consisting of a topic language $\boldsymbol{L_t}$ and a set $\boldsymbol{R}$ of inference rules over $\boldsymbol{L_t}$
- A communication language $\boldsymbol{L_c}$ specifying the types of speech acts the participants can perform during the dialogue
- A context $\boldsymbol{K} \subseteq \boldsymbol{L_t}$ specifying the common prior knowledge of the participants
- A belief base $\boldsymbol{B_a} \subseteq \boldsymbol{L_t}$ for each agent *a* specifying the agent's knowledge and beliefs

Formal dialogue systems: Components

- A set of commitments $\boldsymbol{C_a} \subseteq \boldsymbol{L_t}$ for each agent *a* specifying the agent's publicly declared points of view about a proposition
- A set of effect rules ***C*** for $\boldsymbol{L_c}$, specifying the effects of each statement on the commitments of the participants
- A protocol ***P*** for $\boldsymbol{L_c}$, specifying the allowed speech acts at each stage of a dialogue
- A set of outcome rules defining the outcome of a dialogue

A formal model for persuasion dialogues*

- Dialogue goal: Resolution of a conflict of opinion about one or more propositions (topics), $T \subseteq L_t$
- Roles: For each topic $t \in T$, there is a set of proponents of *t*, $prop(t) \subseteq A$ (*A is the set of participants*) and a set of opponents of t, $opp(t) \subseteq A$
- The outcome rules define for a dialogue *d*, context *K* and topic *t* the winners and losers with respect to *t*

* *Prakken, H. (2006). Formal systems for persuasion dialogue. The Knowledge Engineering Review, 21:163–188.*

A formal model for persuasion dialogues

- Communication language

claim φ	The speaker asserts that φ is the case.
why φ	The speaker challenges that φ is the case and asks for reasons why it would be the case.
concede φ	The speaker admits that φ is the case.
retract φ	The speaker declares that she is not committed (any more) to φ.
φ since S	The speaker provides reasons why φ is the case.
question φ	The speaker asks another participant's opinion on whether φ is the case.

A formal model for persuasion dialogues

- Protocol

Speech act	**Possible replies**
claim φ	*why* φ, *claim* $\neg\varphi$, *concede* φ
why φ	φ *since* S, *retract* φ
concede φ	
retract φ	
φ *since* S	*why* ψ ($\psi \in S$), *concede* ψ ($\psi \in S$)
question φ	*claim* φ, *claim* $\neg\varphi$, *retract* φ

A formal model for persuasion dialogues

- Effect rules
  - *a* denotes a participant, *m* a dialogue move, *d* the sequence of previous moves

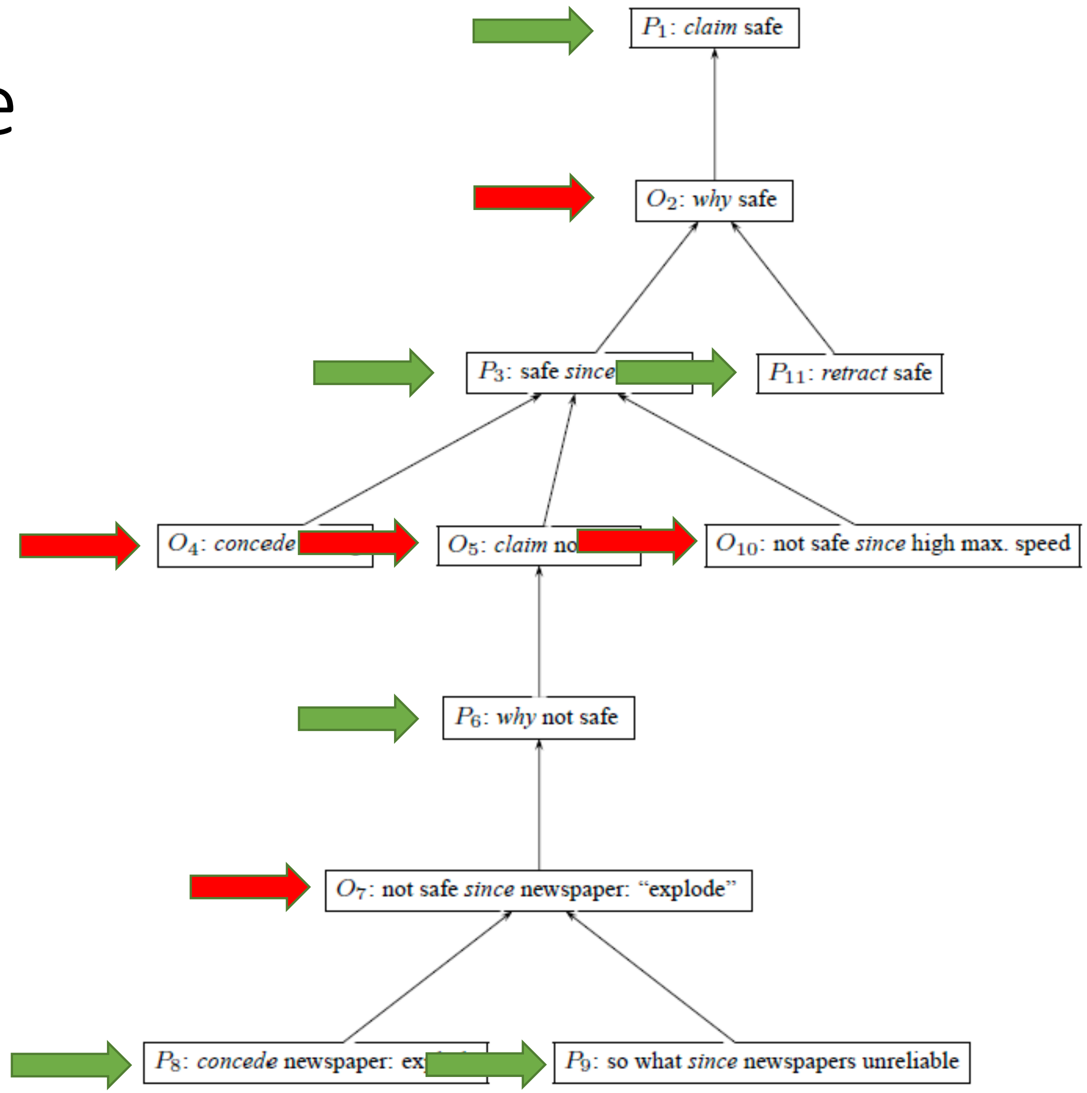
- If $a(m)$ = *claim* φ then $C_a(d,m) = C_a(d) \cup \{\varphi\}$
- If $a(m)$ = *why* φ then $C_a(d,m) = C_a(d)$
- If $a(m)$ = *concede* φ then $C_a(d,m) = C_a(d) \cup \{\varphi\}$
- If $a(m)$ = *retract* φ then $C_a(d,m) = C_a(d) - \{\varphi\}$
- If $a(m)$ = φ *since* S then $C_a(d,m) = C_a(d) \cup \{\varphi\} \cup S$

An example persuasion dialogue

- Paul: My car is safe.
- Olga: Why is your car safe?
- Paul: Since it has an airbag.
- Olga: That is true but this does not make your car safe.
- Paul: Why does that not make my care safe?
- Olga: Since the newspapers recently reported on airbags expanding without cause.
- Paul: Yes, that is what the newspapers say but that does not prove anything, since newspaper reports are very unreliable sources of technological information.
- Olga: Still your car is still not safe, since its maximum speed is very high
- Paul: OK, I was wrong that my car is safe.

Model of the dialogue

Move	C_P	C_O
P_1	safe	
O_2		
P_3	safe, airbag	
O_4		airbag
O_5		airbag, ¬safe
P_6		
O_7		airbag, ¬safe, newspaper
P_8	safe, airbag, newspaper	
P_9	safe, airbag, newspaper, unreliable	
O_{10}		airbag, ¬safe, newspaper, high-speed
P_{11}	airbag, newspaper, unreliable	



Research in argumentation-based dialogue

- Less advanced than argumentation-based inference
- Research in formal models of dialogue
  - Focused mostly on communication languages and protocols
- Research in agent behaviour
  - Focused on strategies, tactics, heuristics
  - Influenced by game theory

Abstract Argumentation Frameworks

- Main Ideas & Definitions
- Acceptability Semantics

AAFs: Main Ideas*

- Arguments are defeasible entities that may attack each other
- The acceptance of an argument depends only on the status of the arguments that attack it.
- The structure, the origin and any other information about the arguments are abstracted away.
- Acceptability semantics formally define which arguments are accepted and which are rejected.

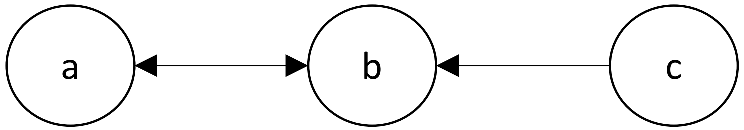
* *Dung, P.M. (1995). On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming, and n-person games. Artificial Intelligence, 77:321-357, 1995.*

AAFs: Definitions

- An **argumentation framework** is a directed graph, the nodes of which are **arguments**, whereas the edges represent **attacks** among the arguments.

- $\mathbf{AF = \{A, R\}, R \subseteq A \times A}$
  - $\mathbf{A}$ is a set of arguments
  - $\mathbf{R}$ is a binary relation on A
  - If $\mathbf{(a, b) \in R}$ then we say that $\mathbf{a}$ **attacks** $\mathbf{b}$
  - A set of arguments $\mathbf{S \subseteq A}$ attacks an argument $\mathbf{b \in A}$ iff there is an argument $\mathbf{a \in S}$ that attacks $\mathbf{b}$
  - A set of arguments $\mathbf{S \subseteq A}$ is **conflict-free** iff there are no arguments $\mathbf{a, b \in S}$ such that $\mathbf{a}$ attacks $\mathbf{b}$

AAFs: An example



Argumentation Framework

AF = {A, R}
A = {a, b, c}
R = {(a,b),(b,a),(c,b)}

Conflict-free sets of arguments

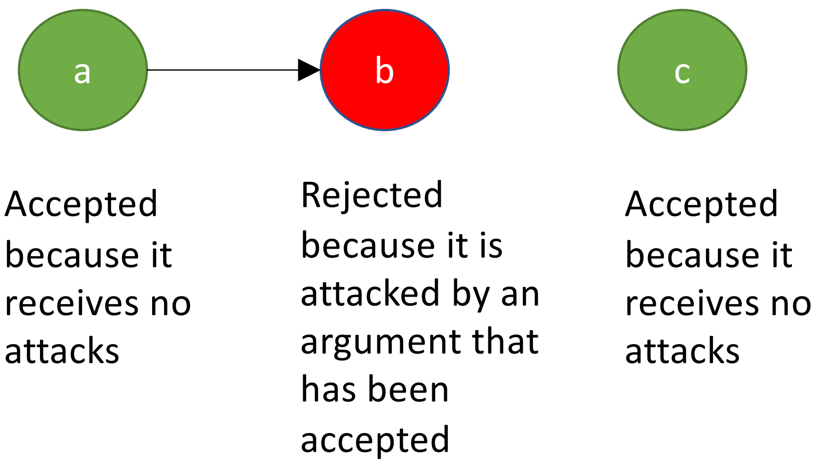
{}, {a}, {b}, {c}, {a,c}

Attacks by sets of arguments

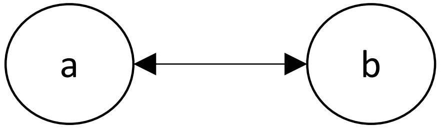
{a} attacks b
{b} attacks a
{c} attacks b
{a, b} attacks a
{a, b} attacks b
{a, c} attacks b
{b, c} attacks a
{b, c} attacks b
{a, b, c} attacks a
{a, b, c} attacks b

Evaluation of arguments

- An argument is accepted if it does not receive any attacks.
- An argument is rejected if there is a counter-argument that has been accepted.
- An argument that does not attack and is not attacked by any other argument does not affect the acceptability of the other arguments.



A more complex case



- Arguments that are in conflict cannot be both accepted
- Should we accept neither or either of them?

- Scenario 1:
  - a: The weather in Cuba is great, let's go there for our holidays.
  - b: The tickets to Cuba are expensive, let's go somewhere else.

Accept either

- Scenario 2:
  - a: Alice: Bob committed the murder. I was him in the crime scene.
  - b: Bob: I didn't do it. Alice did it. She hated the victim!

Accept neither

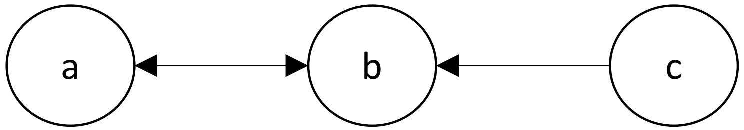
Extension-based acceptability semantics

- The acceptability of arguments can be defined using the notion of extensions.
- An **extension** of an argumentation framework $\mathbf{AF = \{A, R\}}$ is a set of arguments $\mathbf{E} \subseteq \mathbf{A}$ that we can reasonably accept.
- An **extension-based semantics** provides a formal way for identifying extensions (i.e. selecting sets of arguments that are reasonable to accept), according to some criterion.

Admissibility

- The notion of admissible sets of arguments can be regarded as the minimum requirement for a set of arguments to be accepted.
- A set of arguments $\mathbf{S} \subseteq \mathbf{A}$ **defends an argument** $\mathbf{a} \in \mathbf{A}$ iff it attacks any argument $\mathbf{b} \in \mathbf{A}$ that attacks a
- A set of arguments $\mathbf{E} \subseteq \mathbf{A}$ is **admissible** iff it is conflict-free and defends all its elements.

Admissibility (example)

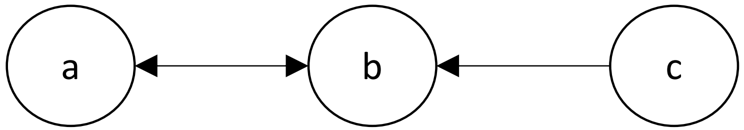


Conflict-free	Admissible	
{}	✓	It receives no attacks
{a}	✓	It defends itself from b
{b}	✗	It doesn't defend itself from c
{c}	✓	It receives no attacks
{a,c}	✓	It defends itself from b

Complete semantics

- Complete semantics is based on the notion of admissibility
  - A complete extension must be an admissible set of arguments
- It additionally requires accepting any argument that can be defended by an admissible set of arguments
- A set of arguments $\mathbf{E} \subseteq \mathbf{A}$ is **a complete extension** of $\mathbf{AF} = \{\mathbf{A}, \mathbf{R}\}$ iff it is admissible and contains all the arguments it defends

Complete semantics (example)



Conflict-free	Admissible	Complete
{}	✓	✗
{a}	✓	✗
{b}	✗	✗
{c}	✓	✗
{a,c}	✓	✓

It defends c but doesn’t contain it

It defends c but doesn’t contain it

It is not admissible

It defends a but doesn’t contain it

It contains all the arguments it defends

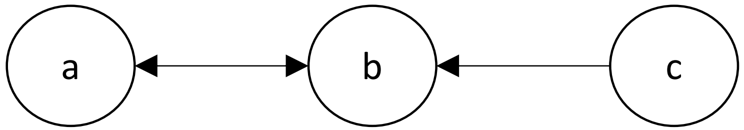
Grounded semantics

- The most conservative (sceptical) semantics regarding the number of arguments it accepts.
- It accepts only the arguments we cannot avoid to accept
- A set of arguments $\mathbf{E} \subseteq \mathbf{A}$ is **a grounded extension** of $\mathbf{AF} = \{\mathbf{A}, \mathbf{R}\}$ iff it is the minimal (w.r.t. set inclusion) complete extension of $\mathbf{AF}$

Minimal and maximal sets

- If $\mathbf{S}$ is set of sets
  - A set $\mathbf{X} \in \mathbf{S}$ is minimal iff there is no set $\mathbf{Y} \in \mathbf{S}$ such that $\mathbf{Y} \subset \mathbf{X}$
  - A set $\mathbf{X} \in \mathbf{S}$ is maximal iff there is no set $\mathbf{Y} \in \mathbf{S}$ such that $\mathbf{X} \subset \mathbf{Y}$
- For example, if $\mathrm{S} = \{\{e\}, \{a,b\}, \{a,c\}, \{a,b,c\}, \{a,b,d\}, \{a,b,e\}, \{a,b,c,e\}\}$
  - The minimal sets are: $\{e\}$, $\{a,b\}$, $\{a,c\}$
  - The maximal sets are: $\{a,b,d\}$, $\{a,b,c,e\}$

Grounded semantics (example)



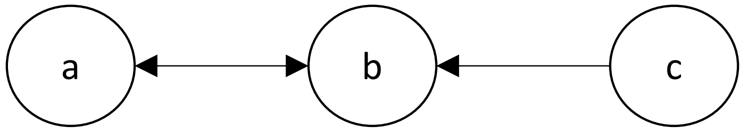
Conflict-free	Admissible	Complete	Grounded
{}	✓	✗	✗
{a}	✓	✗	✗
{b}	✗	✗	✗
{c}	✓	✗	✗
{a,c}	✓	✓	✓

The only complete extension is also a grounded extension

Preferred semantics

- The most credulous semantics.
- It accepts as many arguments as possible
- A set of arguments $\mathbf{E} \subseteq \mathbf{A}$ is **a preferred extension** of $\mathbf{AF} = \{\mathbf{A}, \mathbf{R}\}$ iff it is a maximal (w.r.t. set inclusion) complete extension of $\mathbf{AF}$

Preferred semantics (example)



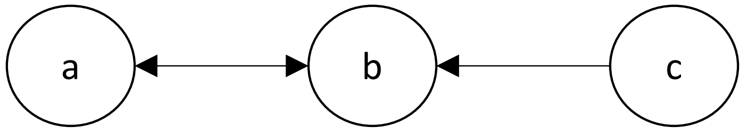
Conflict-free	Admissible	Complete	Grounded	Preferred
{}	✓	✗	✗	✗
{a}	✓	✗	✗	✗
{b}	✗	✗	✗	✗
{c}	✓	✗	✗	✗
{a,c}	✓	✓	✓	✓

The only complete extension is also a preferred extension

Stable semantics

- It requires that every argument is either accepted or attacked by an accepted argument (and is therefore rejected).
- A set of arguments $\mathbf{E} \subseteq \mathbf{A}$ is **a stable extension** of $\mathbf{AF} = \{\mathbf{A}, \mathbf{R}\}$ iff it is conflict-free and attacks all arguments in $\mathbf{A} / \mathbf{E}$

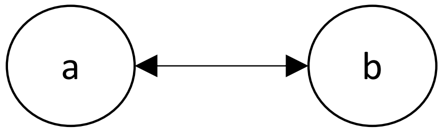
Stable semantics (example)



Conflict-free	Admissible	Complete	Grounded	Preferred	Stable
{}	✓	✗	✗	✗	✗
{a}	✓	✗	✗	✗	✗
{b}	✗	✗	✗	✗	✗
{c}	✓	✗	✗	✗	✗
{a,c}	✓	✓	✓	✓	✓

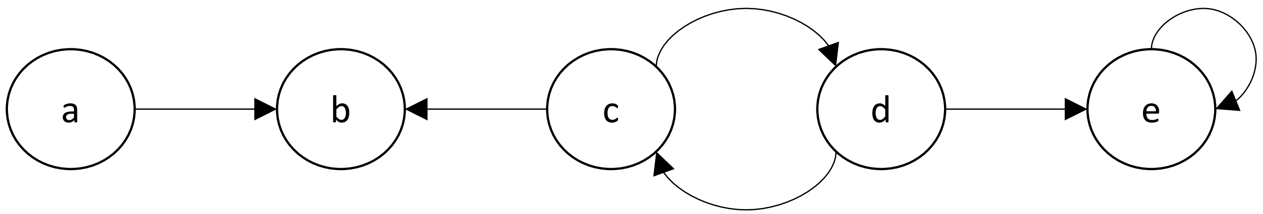
It attacks the arguments it doesn't contain.

More examples



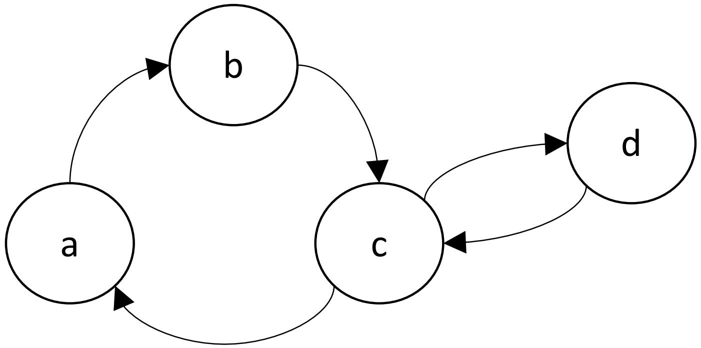
Admissible	Complete	Grounded	Preferred	Stable
{}	✓	✓	✗	✗
{a}	✓	✗	✓	✓
{b}	✓	✗	✓	✓

More examples



Admissible	Complete	Grounded	Preferred	Stable
{}	✗	✗	✗	✗
{a}	✓	✓	✗	✗
{a,c}	✓	✗	✓	✗
{a,d}	✓	✗	✓	✓
{c}	✗	✗	✗	✗
{d}	✗	✗	✗	✗

More examples



Admissible	Complete	Grounded	Preferred	Stable
{}	✓	✓	✗	✗
{d}	✗	✗	✗	✗
{a,d}	✓	✗	✓	✓

Properties of extensions

- The empty set is always admissible.
- There is always a preferred extension.
- The grounded extension is the intersection of all complete extensions and is unique.
- No stable extension is empty but there are argument frameworks for which there is no stable extension.
    - Consider for example this: **A** = **{a, b, c}**, **R** = **{(a,b),(b,c),(c,a)}**
- Every stable extension is also a preferred extension.
- If an argument graph has no cycle then there is a single extension that is stable, preferred, complete and grounded.

Labelling-based acceptability semantics*

- Each argument in the framework is assigned a **label**:
  - **Lab(a)** = **in**: the argument is accepted
  - **Lab(a)** = **out**: the argument is rejected
  - **Lab(a)** = **undec**: the argument is neither accepted nor rejected
- A **labelling-based semantics** provides a way to select "reasonable" labellings among all the possible ones, according to some criterion.

* *Pietro Baroni, Martin Caminada and Massimiliano Giacomin (2011). An introduction to argumentation semantics. The Knowledge Engineering Review , Volume 26 , Issue 4 , December 2011, pp. 365-410*

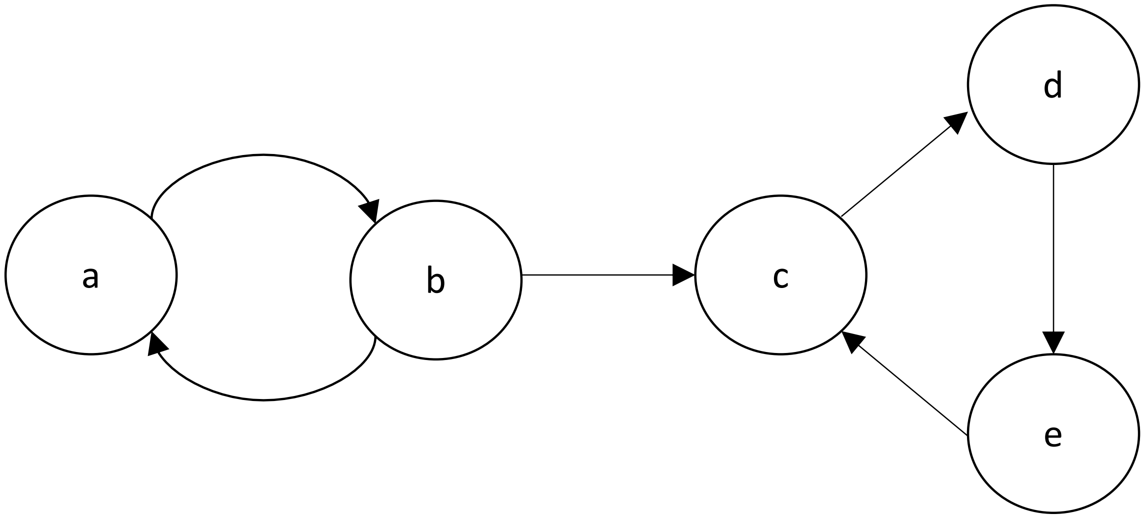
Other proposed semantics

- Semi-stable semantics
  - Guarantees that every argumentation framework has an extension.
  - Coincides with stable semantics when there is at least one stable extension.
  - A set of arguments $\mathbf{E} \subseteq \mathbf{A}$ is **a semi-stable extension** of $\mathbf{AF} = \{\mathbf{A}, \mathbf{R}\}$ iff it is a complete extension and $\mathbf{E} \cup \mathbf{E}^{+}$ is maximal among the complete extensions.
  - $\mathbf{E}^{+}$ denotes the set of arguments attacked by $\mathbf{E}$
  - Every semi-stable extension is also a preferred extension.
- Ideal semantics
  - Similar to but less sceptical (it accepts more arguments) than grounded semantics
  - A set of arguments $\mathbf{E} \subseteq \mathbf{A}$ is **an ideal extension** iff it is a maximal admissible subset of every preferred extension.
  - Unique extension, superset of the grounded extension.

Other proposed semantics

- Eager semantics
  - Similar to but less sceptical than ideal semantics
  - A set of arguments $\mathbf{E} \subseteq \mathbf{A}$ is **an eager extension** iff it is a maximal admissible subset of every semi-stable extension.
  - Unique extension, superset of the ideal extension.
- Stage semantics
  - Similar to semi-stable semantics
  - A set of arguments $\mathbf{E} \subseteq \mathbf{A}$ is **a stage extension** of $\mathbf{AF} = \{\mathbf{A}, \mathbf{R}\}$ iff it is conflict-free and $\mathbf{E} \cup \mathbf{E}^{+}$ is maximal among the conflict free subsets of A.
  - A stage extension is not necessarily an admissible set.
- Naive semantics
  - A set of arguments $\mathbf{E} \subseteq \mathbf{A}$ is **naive extension** iff it is a maximal conflict-free set.

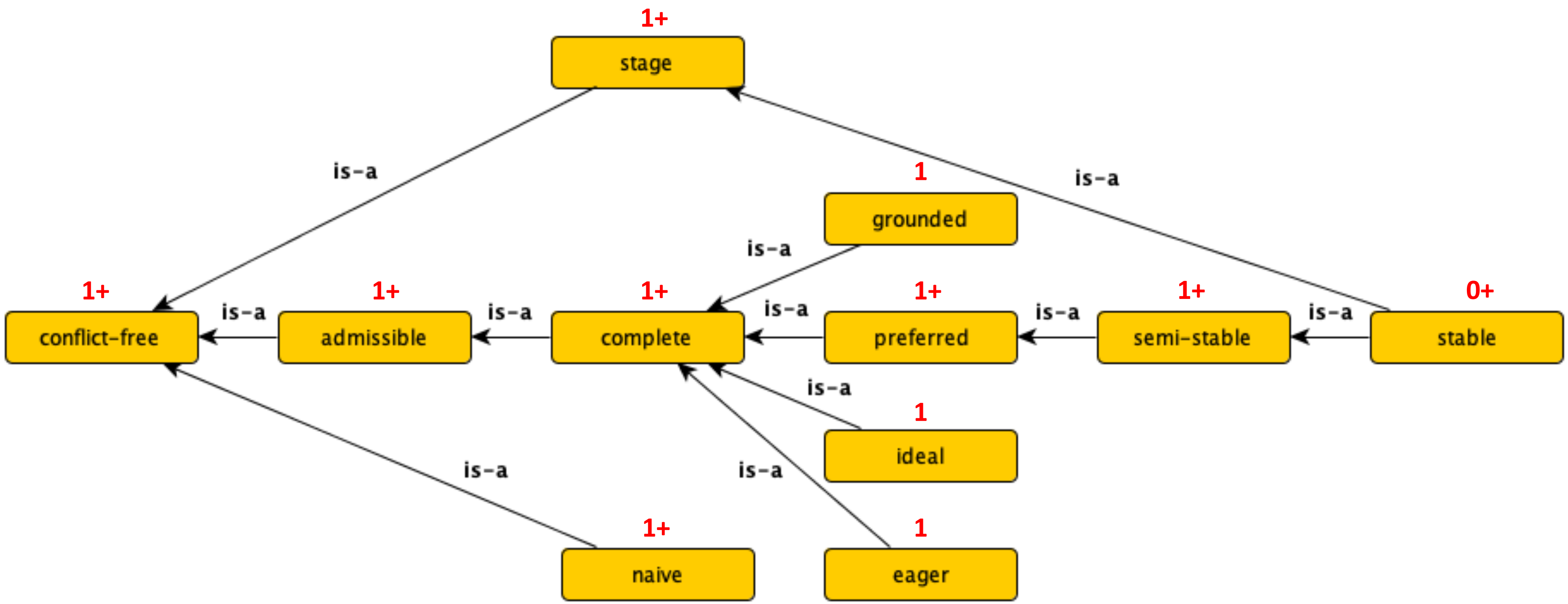
An Example



Extensions

Complete:	{}, {a}, {b,d}
Grounded:	{}
Preferred:	{a}, {b,d}
Stable:	{b,d}
Semi-stable:	{b,d}
Ideal:	{}
Eager:	{b,d}
Stage:	{b,d}
Naive:	{a,c}, {a,d}, {a,e}, {b,d}, {b,e}

Classification and cardinality of semantics



Principle-based analysis of semantics

- Aims to address questions such as:
  - *How do we know that the currently considered set of semantics is sufficient or complete?*
  - *How to choose one semantics from the set of alternatives in a particular application?*
  - *How to guide the search for new and hopefully better argumentation semantics?*
- Principles for argumentation semantics
  - Admissibility, Strong admissibility, Reinstatements, I-Maximality, etc.
  - *Leendert Van der Torre and Srdjan Vesic (2018). The Principle-Based Approach to Abstract Argumentation Semantics, Handbook of Formal Argumentation, volume 1, pages 797–838. College Publications.*

Summing up

- Abstract Argumentation Frameworks is a **simple** but **powerful** model of arguments and argumentation-based inference.
  - **Simple:** It treats arguments as atomic entities (without an internal structure) and uses a single binary relation to model any type of attack.
  - **Powerful:** It enables many different ways of assessing the acceptability of arguments (acceptability semantics), each implementing a different form of non-monotonic reasoning.
  - It has been shown that several non-monotonic logics (Default Logic, Defeasible Logic, Logic Programming with negation as failure, etc.) are instances of Abstract Argumentation Frameworks.

Computation of AAF Extensions

- Argumentation solvers: Programs that compute the extensions of argumentation frameworks under the different semantics.
- Argumentation solvers for AAF
  - Reduction-based approach: reduces the problem at hand into another formalism to exploit existing solvers from the other formalism (SAT, CSP, ASP, etc.)
  - Direct approach: design algorithms to directly solve the problem
  - *Federico Cerutti, Sarah A. Gaggl, Matthias Thimm, and Johannes P. Wallner. Foundations of implementations for formal argumentation. In Handbook of Formal Argumentation, chapter 15. College Publications, 2018*
- ASPARTIX
  - An AAF solver based on Answer-Set Programming
  - *U. Egly, S.A. Gaggl , S. Woltran. Answer-set programming encodings for argumentation frameworks. Argument & Computation. 2010;1(2):147-77. doi: 10.1080/19462166.2010.486479*