Introduction to
Structured Argumentation

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Computational models of argument

Abstract argumentation

Structured Argumentation

Decision making
Sense making

Dialogical Argumentation

Persuasion
Negotiation
Distributed decision making
Graphical representations of argumentation have a long history (see for example Wigmore, Toulmin, etc.)

\[ A_1 = \text{Patient has hypertension so prescribe diuretics} \]

\[ A_2 = \text{Patient has hypertension so prescribe betablockers} \]

\[ A_3 = \text{Patient has emphysema which is a contraindication for betablockers} \]

[See Dung (AIJ 1995)]
Abstract argumentation: Winning arguments

Green means the argument “wins” and red means the argument “loses”.

[See Simari+Loui (AIJ 1992); Pollock (AIJ 1995), etc.]
Abstract argumentation: Skeptical and credulous views

(Credulous) It seems reasonable to accept either argument in the following argument graph.

\[ A_1 = \text{Mary says Italy is the best destination for our holidays} \]
\[ A_2 = \text{Pietro says Canada is the best destination for our holidays} \]

(Skeptical) It seems reasonable to accept neither argument in the following argument graph.

\[ A_1 = \text{John says Mike committed the murder} \]
\[ A_2 = \text{Mike says John committed the murder} \]
Abstract argumentation: Coalitions

Arguments can work together as a coalition by attacking other arguments.

Let $\Gamma \subseteq A$ be a set of arguments.

- $\Gamma$ attacks $B \in A$ iff there is an argument $A \in \Gamma$ such that $A$ attacks $B$. 

\[
\begin{array}{c|c|c|c}
 & A_1 & A_2 & A_3 \\
\hline
\emptyset & & & \\
\{A_1\} & \checkmark & & \\
\{A_2\} & & \checkmark & \\
\{A_3\} & & & \checkmark \\
\{A_1, A_2\} & \checkmark & \checkmark & \\
\{A_1, A_3\} & & \checkmark & \\
\{A_2, A_3\} & \checkmark & \checkmark & \\
\{A_1, A_2, A_3\} & \checkmark & \checkmark & \\
\end{array}
\]
Abstract argumentation: Conflictfree

The following gives a requirement that should hold for a coalition of arguments to make sense. If it holds, it means that the arguments in the set offer a consistent view on the topic of the argument graph.

**Conflictfree sets of arguments**

A set \( \Gamma \subseteq \mathcal{A} \) of arguments is **conflictfree** iff there are no \( A, B \) in \( \Gamma \) such that \( A \) attacks \( B \).

\[
\begin{array}{cccccccc}
\{\} & \{A_1\} & \{A_2\} & \{A_3\} & \{A_1, A_2\} & \{A_1, A_3\} & \{A_2, A_3\} & \{A_1, A_2, A_3\} \\
\checkmark & \checkmark & \checkmark & \checkmark & \checkmark & \checkmark & \checkmark
\end{array}
\]

[See Dung (AIJ 1995)]
Abstract argumentation: Admissibility

Arguments can defend other arguments from attack

Let $\Gamma \subseteq \mathcal{A}$ be a conflict-free set of arguments.

- $\Gamma$ defends $A \in \mathcal{A}$ iff for each argument $B \in \mathcal{A}$, if $B$ attacks $A$ then $\Gamma$ attacks $B$.

Admissible sets of arguments

A set $\Gamma \subseteq \mathcal{A}$ of arguments is **admissible** iff $\Gamma$ is conflict-free and defends all its elements.

The intuition here is that for a set of arguments to be accepted, we require that, if any one of them is challenged by a counterargument, then they offer grounds to challenge, in turn, the counterargument. There always exists at least one admissible set: The empty set is always admissible.
Abstract argumentation: Defended

The function Defended(Γ) returns all arguments defended by Γ

Let Γ ⊆ A be a conflict-free set of arguments,

1. Defended(Γ) = {A ∈ A | Γ defends A}.

- Defended(∅) = {A₃}
- Defended({A₁}) = {A₁, A₃}
- Defended({A₂}) = {A₃}
- Defended({A₃}) = {A₁, A₃}
- Defended({A₁, A₃}) = {A₁, A₃}
Abstract argumentation: Maximal and minimal sets

Maximal and minimal sets w.r.t. set inclusion

Let $\Phi$ be a set of sets

- $X \in \Phi$ is minimal iff there is no $Y \in \Phi$ such that $Y \subset X$
- $X \in \Phi$ is maximal iff there is no $Y \in \Phi$ such that $X \subset Y$

For example,

- Let $\Phi = \{\{5\}, \{1, 2\}, \{1, 3\}, \{1, 2, 4\}, \{1, 2, 3\}, \{1, 3, 5\}, \{1, 2, 3, 5\}\}$
- The minimal sets are $\{5\}$, $\{1, 2\}$, and $\{1, 3\}$.
- The maximal sets are $\{1, 2, 4\}$ and $\{1, 2, 3, 5\}$
The notion of admissible sets of arguments can be regarded as the minimum requirement for a set of arguments to be accepted.

**Extensions of an argument graph**

Let $\Gamma$ be a conflict-free set of arguments, and let $\text{Defended} : \mathcal{P}(A) \mapsto \mathcal{P}(A)$ be a function such that $\text{Defended}(\Gamma) = \{ A \in A \mid \Gamma \text{ defends } A \}$.

1. $\Gamma$ is a **complete extension** iff $\Gamma = \text{Defended}(\Gamma)$
2. $\Gamma$ is a **grounded extension** iff it is the minimal (w.r.t. set inclusion) complete extension.
3. $\Gamma$ is a **preferred extension** iff it is a maximal (w.r.t. set inclusion) complete extension.
4. $\Gamma$ is a **stable extension** iff it is a preferred extension that attacks all arguments in $A \setminus \Gamma$.

In general, the grounded extension provides a skeptical view on which arguments can be accepted, whereas each preferred extension take a credulous view on which arguments can be accepted.

[See Dung (AIJ 1995)]
Abstract argumentation: Examples

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<td>{A_1, A_4}</td>
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The diagram shows the relationships between arguments A1, A2, A3, A4, and A5.
Abstract argumentation: Some developments

- **Bipolar argumentation:** Introduction of a support relation (e.g. A supports B denotes A is accepted only if B is accepted).

- **Preference-based argumentation:** Introduction of a preference relation over arguments which can be used to ignore attacks (e.g. an attack by A on B is ignored when B is preferred to A).

- **Probabilistic argumentation:** Introduction of probability distribution to capture uncertainty.
  - **Epistemic approach:** Probability distribution over the power set of arguments denoting belief in argumentations.
  - **Constellations approach:** Probability distribution over the subgraphs of the argument graph denoting uncertainty of what is the actual argument graph.

- **Argument dynamics:** Determining what needs to be added/removed from an argument graph to change the status of an argument from accepted to unaccepted (or vice versa).
## Abstract argumentation: Pros and cons

### Pros
- An argument graph provides a simple and intuitive representation of a controversial topic.
- Various dialectical semantics by Dung, and others, provide valuable insights into the nature of argumentation.
- Various tools have been developed for analysing arguments in terms of abstract argumentation.

### Cons
- Arguments in abstract argumentation are atomic.
  - They cannot be broken down.
  - They do not have an internal structure.
  - They cannot be combined.
- There is no formal definition for arguments or attacks.
Some frameworks for structured argumentation

- Deductive argumentation ([Hunter, Besnard, Cayrol, Amgoud, et al](#))
- Defeasible logic programming ([Simari, et al](#))
- Assumption-based argumentation ([Toni, et al](#))
- ASPIC+ ([Prakken, et al](#))

See the special issue in *Argument & Computation*, volume 5 (1), 2014, for tutorials on each of these frameworks.
Overview of deductive argumentation

- Descriptive graphs
- Generative graphs
- Counterarguments
- Arguments
- Base logic
### Choice of base logic

Here we focus on **simple logic** and **classical logic**, but other options include non-monotonic logics, conditional logics, temporal logics, description logics, and paraconsistent logics.

### A few definitions for base logic

- Let $\mathcal{L}$ be a language for a logic, and let $\vdash_i$ be the consequence relation for that logic.

- If $\alpha$ is an atom in $\mathcal{L}$, then $\alpha$ is a **positive literal** in $\mathcal{L}$ and $\neg \alpha$ is a **negative literal** in $\mathcal{L}$.

- For a literal $\beta$, the **complement** of $\beta$ is defined as follows:
  - If $\beta$ is a positive literal, i.e. it is of the form $\alpha$, then the complement of $\beta$ is the negative literal $\neg \alpha$,
  - if $\beta$ is a negative literal, i.e. it is of the form $\neg \alpha$, then the complement of $\beta$ is the positive literal $\alpha$. 

Arguments

Definition for deductive argument

- Given a base logic $\vdash$, a **deductive argument** is an ordered pair $\langle \Phi, \alpha \rangle$ where $\Phi \vdash \alpha$.
- $\Phi$ is the support, or premises, or assumptions of the argument, and $\alpha$ is the claim, or conclusion, of the argument.
- For an argument $A = \langle \Phi, \alpha \rangle$, the function $\text{Support}(A)$ returns $\Phi$ and the function $\text{Claim}(A)$ returns $\alpha$.

Examples

- $\langle \{\text{report(rain)}, \text{report(rain)} \rightarrow \text{carry(umbrella)}\}, \text{carry(umbrella)} \rangle$
- $\langle \{\text{study(Sid, logic)}, \neg\text{study(Sid, logic)}\}, \text{KingOfFrance(Sid)} \rangle$
The consistency constraint

An argument \( \langle \Phi, \alpha \rangle \) satisfies the **consistency constraint** when \( \Phi \) is consistent.

Example

If we assume the consistency constraint, then the following are not arguments.

\[
\langle \{ \text{study}(\text{Sid}, \text{logic}), \neg \text{study}(\text{Sid}, \text{logic}) \}, \\
\quad \text{study}(\text{Sid}, \text{logic}) \leftrightarrow \neg \text{study}(\text{Sid}, \text{logic}) \rangle
\]

\[
\langle \{ \text{study}(\text{Sid}, \text{logic}), \neg \text{study}(\text{Sid}, \text{logic}) \}, \text{KingOfFrance}(\text{Sid}) \rangle
\]

Consistency constraint is not essential

If we assume the base logic is a paraconsistent logic (such as Belnap's four valued logic), and we do not impose the consistent constraint, then the following are arguments.

\[
\langle \{ \text{study}(\text{Sid}, \text{logic}) \land \neg \text{study}(\text{Sid}, \text{logic}) \}, \text{study}(\text{Sid}, \text{logic}) \rangle
\]

\[
\langle \{ \text{study}(\text{Sid}, \text{logic}) \land \neg \text{study}(\text{Sid}, \text{logic}) \}, \neg \text{study}(\text{Sid}, \text{logic}) \rangle
\]
**The minimality constraint**

An argument \( \langle \Phi, \alpha \rangle \) satisfies the minimality constraint when there is no \( \Psi \subset \Phi \) such that \( \Psi \vdash \alpha \).

**Example**

If we assume the minimality constraint, then the following is not an argument.

\[
\langle \{ \text{report(rain)}, \text{report(rain) \rightarrow carry(umbrella)}, \text{happy(Sid)} \}, \\
\text{carry(umbrella)} \rangle
\]
Simple logic

- Simple logic is based on a language of literals and simple rules where each simple rule is of the form $\alpha_1 \land \ldots \land \alpha_k \rightarrow \beta$ where $\alpha_1$ to $\alpha_k$ and $\beta$ are literals.

- The consequence relation is modus ponens (i.e. implication elimination) as defined next.

$$\Delta \vdash_s \beta \text{ iff there is an } \alpha_1 \land \ldots \land \alpha_n \rightarrow \beta \in \Delta$$

and for each $\alpha_i \in \{\alpha_1, \ldots, \alpha_n\}$ either $\alpha_i \in \Delta$ or $\Delta \vdash_s \alpha_i$

Example

Let $\Delta = \{a, b, a \land b \rightarrow c, c \rightarrow d\}$. Hence, $\Delta \vdash_s c$ and $\Delta \vdash_s d$. However, $\Delta \not\vdash_s a$ and $\Delta \not\vdash_s b$. 
Arguments based on simple logic

**Simple argument**

Let $\Delta$ be a simple logic knowledgebase. For $\Phi \subseteq \Delta$, and a literal $\alpha$, $\langle \Phi, \alpha \rangle$ is a **simple argument** iff $\Phi \vdash_s \alpha$ and there is no proper subset $\Phi'$ of $\Phi$ such that $\Phi' \vdash_s \alpha$.

**Example**

Let $p_1$, $p_2$, and $p_3$ be the following formulae.

\[
\begin{align*}
p_1 &= \text{oilCompany}(\text{BP}) \\
p_2 &= \text{goodPerformer}(\text{BP}) \\
p_3 &= \text{oilCompany}(\text{BP}) \land \text{goodPerformer}(\text{BP}) \rightarrow \text{goodInvestment}(\text{BP})
\end{align*}
\]

Then $\langle \{p_1, p_2, p_3\}, \text{goodInvestment}(\text{BP}) \rangle$ is a simple argument.
Arguments based on classical logic

Classical logic argument

A classical logic argument from a set of formulae \( \Delta \) is a pair \( \langle \Phi, \alpha \rangle \) such that

1. \( \Phi \subseteq \Delta \)
2. \( \Phi \nvdash \bot \)
3. \( \Phi \vdash \alpha \)
4. there is no \( \Phi' \subset \Phi \) such that \( \Phi' \vdash \alpha \).

Example

The following classical argument uses a universally quantified formula in contrapositive reasoning to obtain the following claim about number 77.

\[
\langle \{ \forall X. \text{multipleOfTen}(X) \rightarrow \text{even}(X), \neg \text{even}(77) \}, \neg \text{multipleOfTen}(77) \rangle
\]
Counterarguments based on simple logic

Rebut and undercut for simple logic

For simple arguments $A$ and $B$, we consider the following type of simple attack:

- $A$ is a **simple undercut** of $B$ if there is a simple rule $\alpha_1 \wedge \cdots \wedge \alpha_n \rightarrow \beta$ in $\text{Support}(B)$ and there is an $\alpha_i \in \{\alpha_1, \ldots, \alpha_n\}$ such that $\text{Claim}(A)$ is the complement of $\alpha_i$.

- $A$ is a **simple rebut** of $B$ if $\text{Claim}(A)$ is the complement of $\text{Claim}(B)$.

Examples

$A_1 = \langle\{\text{efficientMetro}, \text{efficientMetro} \rightarrow \text{useMetro}\}, \text{useMetro}\rangle$

$A_2 = \langle\{\text{strikeMetro}, \text{strikeMetro} \rightarrow \neg\text{efficientMetro}\}, \neg\text{efficientMetro}\rangle$

$A_3 = \langle\{\text{govDeficit}, \text{govDeficit} \rightarrow \text{cutGovSpending}\}, \text{cutGovSpending}\rangle$

$A_4 = \langle\{\text{weakEconomy}, \text{weakEconomy} \rightarrow \neg\text{cutGovSpending}\}, \neg\text{cutGovSpending}\rangle$
Counterarguments based on simple logic

Example of defeasible reasoning

The first argument $A_1$ captures the general rule that if $workDay$ holds, then $useMetro(Sid)$ holds.

$$A_1 = \langle \{workDay, normal, workDay \land normal \rightarrow useMetro(Sid)\}, useMetro(Sid) \rangle$$

$$A_2 = \langle \{workAtHome(Sid), workAtHome(Sid) \rightarrow \neg normal\}, \neg normal \rangle$$

Here we use normal as an assumption of normality for using the rule.
### Counterarguments based on classical logic

**Counterarguments**

If $\langle \Phi, \alpha \rangle$ and $\langle \Psi, \beta \rangle$ are arguments, then

- $\langle \Phi, \alpha \rangle$ **rebut** $\langle \Psi, \beta \rangle$ iff $\alpha \vdash \neg \beta$
- $\langle \Phi, \alpha \rangle$ **undercut** $\langle \Psi, \beta \rangle$ iff $\alpha \vdash \neg \wedge \Psi$

**Direct undercut**

A **direct undercut** for an argument $\langle \Phi, \alpha \rangle$ is an argument of the form $\langle \Psi, \neg \phi_i \rangle$ where $\phi_i \in \Phi$.

**Example using classical logic**

$$\langle \{\beta, \beta \to \alpha\}, \alpha \rangle \text{ rebuts } \langle \{\gamma, \gamma \to \neg \alpha\}, \neg \alpha \rangle$$

$$\langle \{\gamma, \gamma \to \neg \beta\}, \neg (\beta \wedge (\beta \to \alpha)) \rangle \text{ undercuts } \langle \{\beta, \beta \to \alpha\}, \alpha \rangle$$

$$\langle \{\delta \to \neg \beta\}, \neg \beta \rangle \text{ is a direct undercut for } \langle \{\alpha, \beta\}, \alpha \wedge \beta \rangle$$
A rebut denotes a disagreement with the claim, whereas an undercut denotes a disagreement with the support (i.e. a disagreement of the explanation or justification).

**Example**

- $a =$ “garlic is horrible”
- $b =$ “this dish contains garlic”
- $c =$ “this dish is horrible”
Example

Essentially, the attack says that the flight cannot be both a low cost flight and a luxury flight.

\[
\langle \{ \text{lowCostFly}, \text{luxuryFly}, \text{lowCostFly} \land \text{luxuryFly} \rightarrow \text{goodFly} \}, \text{goodFly} \rangle
\]

\[
\langle \{ \neg \text{lowCostFly} \lor \neg \text{luxuryFly} \}, \neg \text{lowCostFly} \lor \neg \text{luxuryFly} \rangle
\]
Counterarguments based on classical logic

Example with first-order predicate formulae

Because Tweety is a bird, and birds fly, there is a bird that flies. But, there is a bird that doesn’t fly, and so it is not the case that all birds fly.

\[
\langle \{ \text{bird(tweety)}, \forall X. \text{bird}(X) \rightarrow \text{fly}(X) \}, \exists X. \text{bird}(X) \land \text{fly}(X) \rangle
\]

\[
\langle \{ \exists X. \text{bird}(X) \land \neg \text{fly}(X) \}, \neg \forall X. \text{bird}(X) \rightarrow \text{fly}(X) \rangle
\]

Another example with first-order predicate formulae

Some students know nothing. But, they all know their own name.

\[
\langle \{ \exists X. \forall Y. \neg \text{knows}(X, Y) \}, \exists X. \forall Y. \neg \text{knows}(X, Y) \rangle
\]

\[
\langle \{ \forall X. \text{knows}(X, \text{name}(X)) \}, \forall X, \exists Y. \text{knows}(X, Y) \rangle
\]
### Some kinds of classical attack

Let $A$ and $B$ be two classical arguments.

- **A is a classical defeater** of $B$ if $\text{Claim}(A) \vdash \neg \bigwedge \text{Support}(B)$.

- **A is a classical direct defeater** of $B$ if

  \[
  \exists \phi \in \text{Support}(B) \text{ s.t. } \text{Claim}(A) \vdash \neg \phi
  \]

- **A is a classical undercut** of $B$ if

  \[
  \exists \Psi \subseteq \text{Support}(B) \text{ s.t. } \text{Claim}(A) \equiv \neg \bigwedge \Psi
  \]

- **A is a classical direct undercut** of $B$ if

  \[
  \exists \phi \in \text{Support}(B) \text{ s.t. } \text{Claim}(A) \equiv \neg \phi
  \]

- **A is a classical canonical undercut** of $B$ if $\text{Claim}(A) \equiv \neg \bigwedge \text{Support}(B)$.

- **A is a classical rebuttal** of $B$ if $\text{Claim}(A) \equiv \neg \text{Claim}(B)$.

- **A is a classical defeating rebuttal** of $B$ if $\text{Claim}(A) \vdash \neg \text{Claim}(B)$. 

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**Counterarguments based on classical logic**
Counterarguments based on classical logic

Examples of attack functions/relations

\[ \langle \{ a \lor b, c \}, (a \lor b) \land c \rangle \text{ is a classical defeater of } \langle \{ \neg a, \neg b \}, \neg a \land \neg b \rangle \]
\[ \langle \{ a \lor b, c \}, (a \lor b) \land c \rangle \text{ is a classical direct defeater of } \langle \{ \neg a \land \neg b \}, \neg a \land \neg b \rangle \]
\[ \langle \{ \neg a \land \neg b \}, \neg (a \land b) \rangle \text{ is a classical undercut of } \langle \{ a, b, c \}, a \land b \land c \rangle \]
\[ \langle \{ \neg a \land \neg b \}, \neg a \rangle \text{ is a classical direct undercut of } \langle \{ a, b, c \}, a \land b \land c \rangle \]
\[ \langle \{ \neg a \land \neg b \}, \neg (a \land b \land c) \rangle \text{ is a classical canonical undercut of } \langle \{ a, b, c \}, a \land b \land c \rangle \]
\[ \langle \{ a, a \rightarrow b \}, b \lor c \rangle \text{ is a classical rebuttal of } \langle \{ \neg a \land \neg b, \neg c \}, \neg (b \lor c) \rangle \]
\[ \langle \{ a, a \rightarrow b \}, b \rangle \text{ is a classical defeating rebuttal of } \langle \{ \neg a \land \neg b, \neg c \}, \neg (b \lor c) \rangle \]
An arrow from $D_1$ to $D_2$ indicates that $D_1 \subseteq D_2$. 

Counterarguments based on classical logic
Argument graphs

Approaches to generating argument graphs

- **Descriptive graphs** Here we assume that the structure of the argument graph is given, and the task is to identify the premises and claim of each argument. Therefore the input is an abstract argument graph, and the output is an instantiated argument graph.

- **Generative graphs** Here we assume that we start with a knowledgebase (i.e. a set of logical formula), and the task is to generate the arguments and counterarguments (and hence the attacks between arguments). Therefore, the input is a knowledgebase, and the output is an instantiated argument graph.
Example of abstract graph and descriptive graph

The flight is low cost and luxury, therefore it is a good flight

A flight cannot be both low cost and luxury

\[ A_1 = \langle \{ \text{lowCostFly, luxuryFly, lowCostFly } \land \text{luxuryFly } \rightarrow \text{goodFly} \} , \text{goodFly} \rangle \]

\[ A_2 = \langle \{ \neg(\text{lowCostFly } \land \text{luxuryFly}) \} , \neg\text{lowCostFly} \lor \neg\text{luxuryFly} \rangle \]
Argument graphs

Example of abstract graph

$A_1 = \text{Patient has hypertension so prescribe diuretics}$

$A_2 = \text{Patient has hypertension so prescribe betablockers}$

$A_3 = \text{Patient has emphysema which is a contraindication for betablockers}$
Example of descriptive graph using classical logic with integrity constraint

\[
\begin{align*}
\text{bp}(\text{high}) \\
\text{ok}(\text{diuretic}) \\
\text{bp}(\text{high}) \land \text{ok}(\text{diuretic}) \quad \rightarrow \quad \text{give}(\text{diuretic}) \\
\neg \text{ok}(\text{diuretic}) \lor \neg \text{ok}(\text{betablocker}) \\
\text{give}(\text{diuretic}) \land \neg \text{ok}(\text{betablocker})
\end{align*}
\]

\[
\begin{align*}
\text{bp}(\text{high}) \\
\text{ok}(\text{betablocker}) \\
\text{bp}(\text{high}) \land \text{ok}(\text{betablocker}) \quad \rightarrow \quad \text{give}(\text{betablocker}) \\
\neg \text{ok}(\text{diuretic}) \lor \neg \text{ok}(\text{betablocker}) \\
\text{give}(\text{betablocker}) \land \neg \text{ok}(\text{diuretic})
\end{align*}
\]

\[
\begin{align*}
\text{symptom(emphysema)}, \\
\text{symptom(emphysema)} \rightarrow \neg \text{ok}(\text{betablocker}) \\
\neg \text{ok}(\text{betablocker})
\end{align*}
\]
Example of generative graph using simple logic

Let \( \Delta = \{ a, b, c, a \land c \rightarrow \neg a, b \rightarrow \neg c, a \land c \rightarrow \neg b \} \).
Argument graphs

Consider $\Delta = \{a, b, a \rightarrow \neg a, b \rightarrow \neg a, a \rightarrow \neg b\}$, let the arguments be those that involves one or more rules.
Need for meta-level information

Normally, meta-level information is also needed for logical argumentation.

Examples of meta-level information

- Preferences over formulae to give a preference over arguments [see for example Amgoud and Cayrol 2002].
  - Preference for premises that are based on more reliable sources
  - Preference for claims that meet more important goals

- Use probability theory to quantify uncertainty of each argument (e.g. probability that premises are true, or probability that the argument comes from a reliable source, etc).

- Use meta-level argumentation to reason about the quality of arguments (e.g. argumentation about whether proponents for arguments are qualified to argue about a topic).
Drug X is an effective treatment for improving survival

However, strokes are a serious side-effect

- $p = \text{“problematic treatment”},$
- $s = \text{“effective treatment for improving survival”},$
- $r = \text{“strokes are a serious side-effect”}.$

$A_1 = \langle \{\neg p, \neg p \rightarrow s\}, s \rangle$

$A_2 = \langle \{r, r \rightarrow p\}, p \rangle$

<table>
<thead>
<tr>
<th>Model</th>
<th>p</th>
<th>s</th>
<th>r</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>$m_1$</td>
<td>false</td>
<td>true</td>
<td>true</td>
<td>0.35</td>
</tr>
<tr>
<td>$m_2$</td>
<td>false</td>
<td>true</td>
<td>false</td>
<td>0.35</td>
</tr>
<tr>
<td>$m_3$</td>
<td>true</td>
<td>true</td>
<td>true</td>
<td>0.12</td>
</tr>
<tr>
<td>$m_4$</td>
<td>true</td>
<td>false</td>
<td>true</td>
<td>0.18</td>
</tr>
</tbody>
</table>

$P(A_1) = P(m_1) + P(m_2) = 0.7$

$P(A_2) = P(m_3) + P(m_4) = 0.3$
Conclusions

- Argumentation is an important cognitive process for dealing with incomplete and inconsistent information.

- Computational models of argument provide a range of insights into argumentation.
  - Abstract argumentation captures the dialectical nature of argumentation.
  - Logical argumentation captures the internal structure of arguments and attacks.
  - Dialogical argumentation captures protocols and strategies for multiple agents to argue together.

- Argumentation technology offers promising solutions for a range of applications.

- Many interesting and important research questions remain (e.g. finding good target languages for representing natural language arguments as structured arguments)