Learning Argumentation Frameworks

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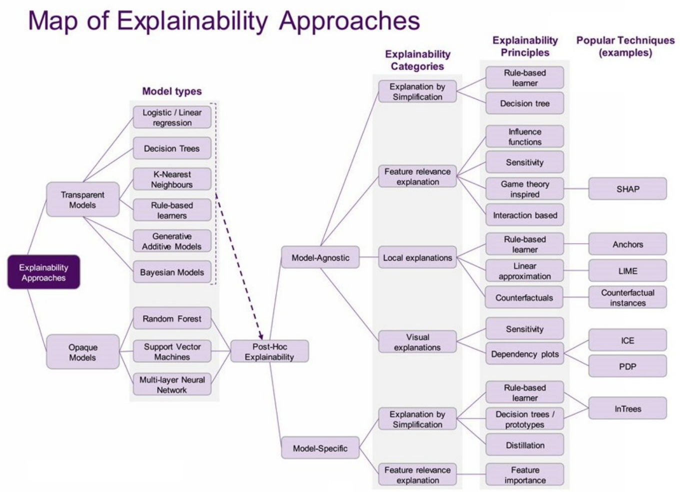
Outline

1. Context (Explainable AI, Argumentation)
2. Part I: Learning Abstract Argumentation Frameworks
3. Part II: Learning Assumption-Based Argumentation Frameworks
4. Future work

Context: eXplainable AI (XAI)



From "Principles and Practice of Explainable ML"; Belle&Papantonis 2021

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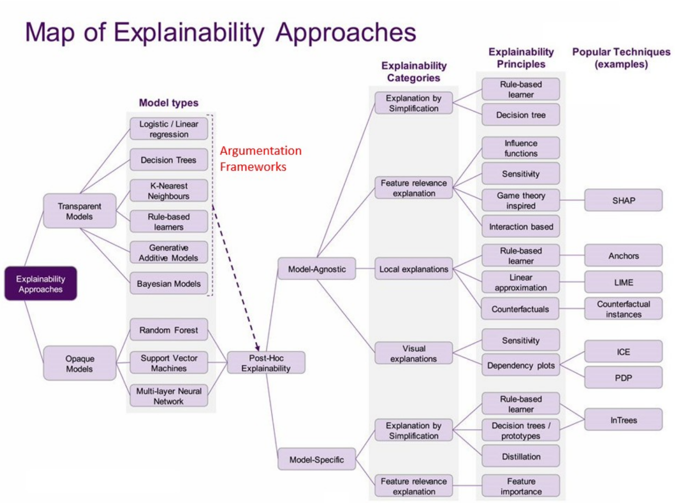

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Context: Human-oriented XAI

- “Looking at how humans explain to each other can serve as a useful starting point for explanation in AI”
  [from *Explanation in AI: Insights from the social sciences. Miller; AIJ 2019*]

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- "The majority of what might look like causal attributions turn out to look like argumentative claim-backings"
  [from *Explaining in conversation: Towards an argument model. Antaki,Leudar. Journal of Social Psychology 1992*]

Context: Argumentation

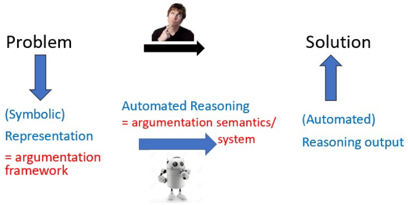

Figure: Argumentation for KR

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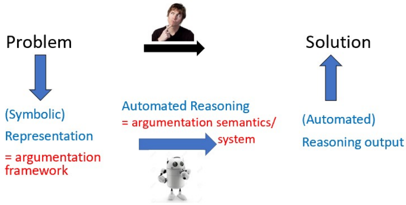

Figure: Argumentation for KR

- Various argumentation frameworks, e.g. Abstract Argumentation (AA) and Assumption-Based Argumentation (ABA), with lots of applications

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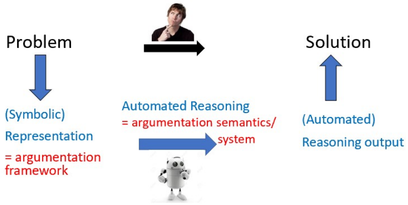

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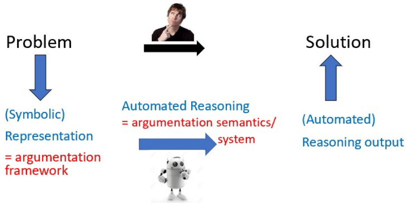

Figure: Argumentation for KR

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- *Can these argumentation frameworks be learnt?*

In this talk I will present two approaches to learn AA and ABA frameworks from "examples"

Argumentation: An illustration

Am I eligible to claim for UK & European Breakdown & Recovery Assistance?

You need to think about whether the insurance meets your needs and whether you can claim when you need to.

You are covered for:

- ✔ UK and European Breakdown Assistance for account holder(s) in any private car that they are travelling in
- ✔ Anyone driving a private car registered to the account holder and which is being used with his/her permission. Where the account is in joint names then up to 2 private cars can be covered
- ✔ Assistance provided at home and on the roadside with national recovery and onward travel
- ✔ No call out limit
- ✔ No excess payable

You are not covered for:

- The cost of replacement parts and associated labour to repair the vehicle
- Private cars not registered to the account holder(s) unless the account holder(s) are in the vehicle at the time of the breakdown
- Motorcycles, motorhomes, caravanettes, commercial vehicles (all types), vans, pick up trucks and vehicles being used for hire and reward purposes (such as taxis)
- Vehicles that do not have a valid MOT or are not serviced or maintained in line with manufacturer guidelines
- Vehicles that are more than 7 metres in length, 2.3 metres wide, 3 metres high and weigh more than 3.5 tonnes when fully loaded

Nationwide

Argumentation: An illustration

COVERED FOR: UK/EU Breakdown Assistance for account holder(s) in any private car they are travelling in
NOT COVERED FOR: private cars not registered to the account holder(s) unless in the vehicle at the time of the breakdown

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$c(mary)$ is (dialectically) "good"/"strong" and Mary is covered

Part I: Learning Abstract Argumentation Frameworks

1. Background (AA frameworks)
2. Problem
3. Solution

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- Dung: On the acceptability of arguments and its fundamental role in nonmonotonic reasoning, logic programming and n-person games. AIJ 1995
- Cyras, Satoh, Toni: Abstract Argumentation for Case-Based Reasoning. KR2016
- Cocarascu, Stylianou, Cyras, Toni: Data-Empowered Argumentation for Dialectically Explainable Predictions. ECAI 2020

Background: AA frameworks

$\langle Args, Att \rangle$ where

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Grounded extension

- Let G_0 be the set of unattacked arguments in $Args$.
- For each $i \in \mathbb{N}$, let $G_{i+1} \subseteq Args$ be the set of arguments that G_i *defends* (by attacking all arguments attacking G_i).

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$\{c(mary), in(mary)\}$ is grounded, $\{in(mary)\}$ is not

Problem: An example (thanks to Guilherme Paulino-Passos)

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The park council deliberates about the interpretation of this rule. So far, it has decided the following:

1. When a young man complained that he was not allowed to use a bicycle in the park, the council decided in his favour.
2. In a similar situation, but regarding a motorized bicycle, the council rejected the complaint.
3. When an ambulance entered the park to rescue an elderly person who was feeling sick, it was considered acceptable.
4. When an unspecified vehicle entered the park to rescue a sick person, this was also considered acceptable.

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How will the park council decide on a new case?
(How can we use the past cases to reason about a new one?)

Problem: An example (thanks to Guilherme Paulino-Passos)

- Past cases:
  1. young man's bicycle
  2. motorized bicycle
  3. ambulance to rescue sick elderly person
  4. unspecified vehicle to rescue sick person
- New case:
  - a pickup truck enters the park in order to rescue a sick person

How will the park council decide on this new case?
(How can we use the past cases to reason about a new one?)

Problem

Given

- a dataset D of *cases* of the form (S, o)
  (S *features*, $o \in \{+, -\}$ *outcome*)

  e.g. $D = \{(\{health\_emergency, motor, ambulance\}, +), (\{bicycle, motor\}, -)\}$

  - D is *consistent* iff there is no S such that $(S, +), (S, -) \in D$.
    Suppose D is consistent.

- a *default* outcome $d \in \{+, -\}$

  e.g. $d = -$

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Determine/Explain

- the outcome of a *focus case* (with features) N

  e.g. $N = \{health\_emergency, motor\}$

Solution: AA-CBR (Example)

Given

- $D = \{(\{b\}, +), (\{h\}, +), (\{b, m\}, -), (\{h, m, a\}, +)\}$ (note: D is consistent)
- default outcome: $-$
- $N = \{h, m\}$

Solution: AA-CBR (Example)

Given

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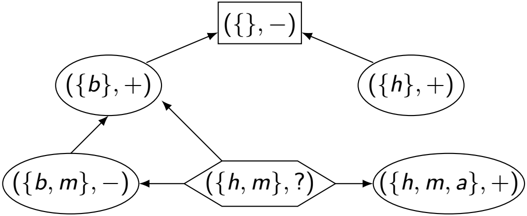

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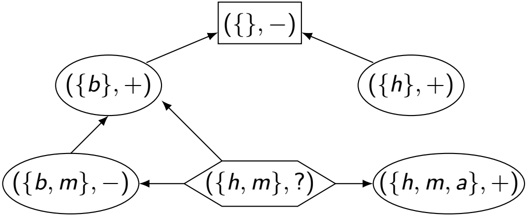

The grounded extension is $G = \{(\{h, m\}, ?), (\{h\}, +)\}$.
As $(\{\}, -) \notin G$, the AA-CBR outcome of $(\{h, m\}, ?)$ is $+$.

General definition: AA Framework

Let $Args = D \cup \{(N, ?)\} \cup \{(\{\}, d)\}$.

- for $(X, o_X), (Y, o_Y) \in D \cup \{(\{\}, d)\}$, $(X, o_X)\, Att\, (Y, o_Y)$ iff
  1. $o_X \neq o_Y$, and (different outcomes)
  2. $Y \subset X$, and (specificity)
  3. $\nexists (Z, o_X)$ with $Y \subset Z \subset X$ (concision)
- for $(Y, o_Y) \in D$, $(N, ?)\, Att\, (Y, o_Y)$ iff
  $Y \not\subset N$ (irrelevance)

e.g. $(\{bicycle\}, +)$ attacks $(\{\}, -)$,
$(\{health\_emergency, motor\}, ?)$ attacks $(\{health\_emergency, motor, ambulance\}, +)$

General definition: Outcomes

We denote the opposite of an outcome $o \in \{+, -\}$ as $\bar{o}$, in the intuitive way:

- $\bar{o} = -$, if $o = +$
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We say that the **outcome for the new case N** is:

- d, if $(\{\}, d)$ is in the grounded extension G,
- $\bar{d}$, otherwise

General definition: Properties

Definition (Nearest cases)

For a case base CB and a new case N, a past case $(X, o_X) \in CB$ is **nearest** to N if $X \subseteq N$, and there is no $(Y, o_Y) \in CB$ such that $Y \subseteq N$ and $X \subset Y$.

Theorem

G contains all the nearest past cases to N.

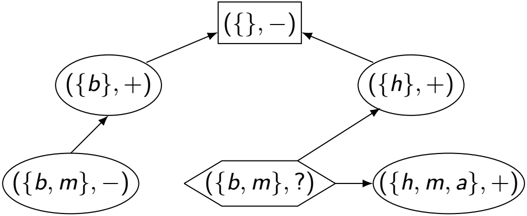
Theorem (Unique past case)

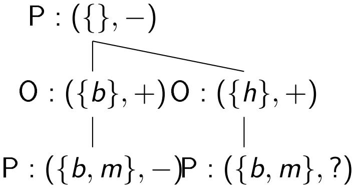
If there is a unique nearest case (X, o) to N, then the AA outcome of N is o.

Explanations in AA-CBR

- Return nearest cases
  - typical way in CBR
  - shows conflicting evidence in past cases
- Can we do better?
  - Idea: use dispute trees

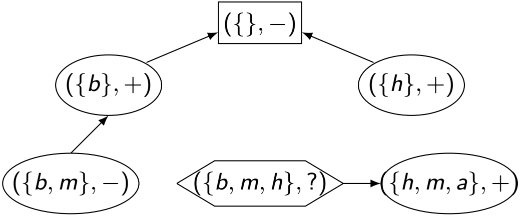
Dispute trees - default outcome

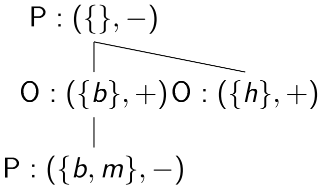




grounded dispute tree

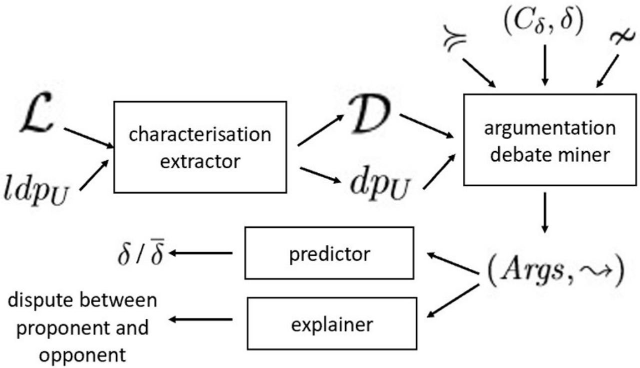
Dispute trees - non-default outcome





maximal dispute tree

Learning AA frameworks: Beyond AA-CBR



- Tabular data (discrete)
- Unstructured data (sentiment analysis)

Part II: Learning ABA Frameworks

1. Background (ABA frameworks and Logic Programming)
2. Problem
3. Solution

Bibliography

- Bondarenko, Dung, Kowalski, Toni: An Abstract, Argumentation-Theoretic Approach to Default Reasoning. AIJ 1997
- Proietti, Toni: Learning Assumption-based Argumentation Frameworks. IJCLR 2022

Background: ABA Frameworks

An *ABA framework* is a tuple $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{} \rangle$ where

- $\langle \mathcal{L}, \mathcal{R} \rangle$ is a deductive system, with $\mathcal{L}$ a *language* and $\mathcal{R}$ a set of *(inference) rules* of the form $s_0 \leftarrow s_1, \ldots, s_m$ $(m \geq 0, s_i \in \mathcal{L}$, for $1 \leq i \leq m)$;
- $\mathcal{A} \subseteq \mathcal{L}$ is a (non-empty) set of *assumptions*;
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Example (using schemata)

- $\mathcal{L} = \{p(X), q(X), r(X), a(X), b(X) | X \in \{1, 2\}\}$;
  $\mathcal{R} = \{p(X) \leftarrow a(X), \quad q(X) \leftarrow b(X), \quad r(1) \leftarrow true\}$;
- $\mathcal{A} = \{a(X), b(X)\}$;
- $\overline{a(X)} = q(X), \quad \overline{b(X)} = r(X)$.

Background: Logic programming

Flat ABA frameworks $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{} \rangle$ where $\mathcal{L}$ is a set of atoms amount to *(normal) logic programs*.

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Example (as logic program)

$p(X) \leftarrow not\, q(X)$
$q(X) \leftarrow not\, r(X)$
$r(1) \leftarrow$

Background: (flat) ABA/Logic programming semantics

- ABA:
  - *arguments* are deductions of claims using rules and supported by assumptions,
  - *attacks* are directed at the assumptions in the support of arguments;
  - Abstract Argumentation-style extension-based semantics

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Example (from earlier slide)

$\mathcal{L} = \{\ldots\}; \quad \mathcal{R} = \{q(X) \leftarrow b(X), \quad r(1) \leftarrow true\};$

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- $\{\} \vdash r(1)$ *attacks* $\{b(1)\} \vdash q(1)$,
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  etc

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Various notions of "acceptable" extensions (sets of arguments)

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Various notions of "acceptable" extensions (sets of arguments)

One-to-one correspondence between models of logic programs and acceptable extensions in flat ABA
e.g. well-founded model $\sim$ grounded extension

Problem: An example (Dimopoulos-Kakas 1995)

- Given

1) **Background knowledge** (ABA framework):

$$\mathcal{R} = \{ \quad bird(X) \leftarrow penguin(X), \\ penguin(X) \leftarrow superpenguin(X), \\ bird(a) \leftarrow, \; bird(b) \leftarrow, \\ penguin(c) \leftarrow, \; penguin(d) \leftarrow, \\ superpenguin(e) \leftarrow, superpenguin(f) \leftarrow \}$$

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3) **Negative Examples**: $\{flies(c), flies(d)\}$

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  2) **Positive Examples**: $\{flies(a), flies(b), flies(e), flies(f)\}$
  3) **Negative Examples**: $\{flies(c), flies(d)\}$
- Determine an ABA framework "generalising" the examples

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1) **Background knowledge** (ABA framework):

$$\mathcal{R} = \{ \quad bird(X) \leftarrow penguin(X),$$
$$penguin(X) \leftarrow superpenguin(X),$$
$$bird(a) \leftarrow,\ bird(b) \leftarrow,$$
$$penguin(c) \leftarrow,\ penguin(d) \leftarrow,$$
$$superpenguin(e) \leftarrow, superpenguin(f) \leftarrow \}$$

2) **Positive Examples**: $\{flies(a), flies(b), flies(e), flies(f)\}$
3) **Negative Examples**: $\{flies(c), flies(d)\}$

- Determine an ABA framework "generalising" the examples

$$\mathcal{R}' = \{flies(X) \leftarrow bird(X), \alpha_1(X),$$
$$c\text{-}\alpha_1(X) \leftarrow penguin(X), \alpha_2(X),$$
$$c\text{-}\alpha_2(X) \leftarrow superpenguin(X)\} \cup \mathcal{R}$$
$$\mathcal{A}' = \{\alpha_1(X), \alpha_2(X)\} \quad \text{with } \overline{\alpha_i(X)}' = c\text{-}\alpha_i(X)$$

Problem: Formally

- $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{} \rangle \models s$ indicates that $s \in \mathcal{L}$ is the claim of an argument accepted in all or some (stable, grounded, ...) extensions of $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{} \rangle$.

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- An example e
  is *covered* by $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{} \rangle$ iff $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{} \rangle \models e$ and
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- Given background knowledge $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{} \rangle$, positive examples $\mathcal{E}^+$ and negative examples $\mathcal{E}^-(\mathcal{E}^+ \cap \mathcal{E}^- = \emptyset)$,
  the **goal of ABA learning** is to construct $\langle \mathcal{L}', \mathcal{R}', \mathcal{A}', \overline{}' \rangle$ with $\mathcal{R} \subseteq \mathcal{R}'$, $\mathcal{A} \subseteq \mathcal{A}'$ and $\forall \alpha \in \mathcal{A}$, $\overline{\alpha}' = \overline{\alpha}$, such that:

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- *Folding.* Given rules ρ_1: $H \leftarrow Eqs_1, B_1, B_2$ and ρ_2: $K \leftarrow Eqs_1, Eqs_2, B_1$ in $\mathcal{R}$, replace ρ_1 by ρ_3: $H \leftarrow Eqs_2, K, B_2$. Thus, $\mathcal{R}' = (\mathcal{R} \setminus \{\rho_1\}) \cup \{\rho_3\}$.

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- *Assumption Introduction.* Replace $\rho_1 : H \leftarrow Eqs, B$ in $\mathcal{R}$ by $\rho_2 : H \leftarrow Eqs, B, \alpha(X)$ where variables in X are taken from $vars(H) \cup vars(B)$ and $\alpha(X)$ is a (possibly new) assumption with contrary $\chi(X)$. Thus,
  - $\mathcal{R}' = (\mathcal{R} \setminus \{\rho_1\}) \cup \{\rho_2\}$,
  - $\mathcal{A}' = \mathcal{A} \cup \{\alpha(X)\}$,
  - $\overline{\alpha(X)}' = \chi(X)$, and $\overline{\beta}' = \overline{\beta}$ for all $\beta \in \mathcal{A}$.

Solution: Requirements

- Let $\langle \mathcal{L}', \mathcal{R}', \mathcal{A}', \overline{}' \rangle$ be obtained by applying any of Folding, Equality Removal and Subsumption to $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{} \rangle$ to modify rules with p in the head.
  If $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{} \rangle \models p(t)$ *then* $\langle \mathcal{L}', \mathcal{R}', \mathcal{A}', \overline{}' \rangle \models p(t)$*.*

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- Let $p(t_1), p(t_2)$ be atoms such that $p(t_1) \neq p(t_2)$ and $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{} \rangle \models p(t_1)$ and $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{} \rangle \models p(t_2)$.

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  There exists $\langle \mathcal{L}', \mathcal{R}', \mathcal{A}', \overline{}' \rangle$ *obtained from* $\langle \mathcal{L}, \mathcal{R}, \mathcal{A}, \overline{} \rangle$ *by applying Assumption Introduction to modify rules with p in the head and then Rote Learning to add rules for the contraries of the assumptions, such that* $\langle \mathcal{L}', \mathcal{R}', \mathcal{A}', \overline{}' \rangle \models p(t_1)$ *and* $\langle \mathcal{L}', \mathcal{R}', \mathcal{A}', \overline{}' \rangle \not\models p(t_2)$.

An illustration

$$\begin{aligned}
\text{Given } \mathcal{R} = \{&\mathit{step}(1,2) \leftarrow, \mathit{step}(1,3) \leftarrow, \mathit{step}(2,4) \leftarrow, \mathit{step}(2,5) \leftarrow, \\
&\mathit{step}(4,6) \leftarrow, \mathit{step}(5,2) \leftarrow, \mathit{busy}(3) \leftarrow, \mathit{busy}(6) \leftarrow\}; \\
\mathcal{E}^+ &= \{\mathit{free}(1), \mathit{free}(2), \mathit{free}(5)\}, \\
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- *Rote Learning* introduces

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$$\begin{aligned}\text{Given } \mathcal{R} &= \{step(1,2) \leftarrow, step(1,3) \leftarrow, step(2,4) \leftarrow, step(2,5) \leftarrow,\\ &\quad step(4,6) \leftarrow, step(5,2) \leftarrow, busy(3) \leftarrow, busy(6) \leftarrow\};\\ \mathcal{E}^+ &= \{free(1), free(2), free(5)\},\\ \mathcal{E}^- &= \{free(3), free(4), free(6)\};\end{aligned}$$

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- By *Equality Removal*, we get
  $$\mathit{free}(X) \leftarrow \mathit{step}(X, Y) \tag{3}$$

An illustration (Continued)

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- Rule (3) $free(X) \leftarrow step(X, Y)$ covers $\mathcal{E}^+$ as well as $free(4) \in \mathcal{E}^-$.

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$$free(X) \leftarrow step(X, Y), \alpha(X, Y) \quad (4)$$

An illustration (Continued)

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- Then, we add positive and negative examples for $c\text{-}\alpha(X,Y)$:
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The final learnt set of rules is $\mathcal{R} \cup \{(4), (6)\}$.

Explanations: Dispute trees?

Mary (m): account holder traveling in friend's car (c); car breaks down

$\mathcal{R}$: $cov(m, c) \leftarrow ah(m), tr(m, c), pr(c), not\ \neg cov(m, c)$

$\neg cov(m, c) \leftarrow \neg reg(c, m), not\ cov'(m, c)$

$cov'(m, c) \leftarrow in(m, c)$

$ah(m) \leftarrow \qquad tr(m, c) \leftarrow \qquad pr(c) \leftarrow$

$\neg reg(c, m) \leftarrow \qquad in(m, c) \leftarrow$

$\mathcal{L}$: Herbrand base of $\mathcal{R}$ plus (all) NAF literals

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P : $\{not\ \neg cov(m,c)\} \vdash cov(m,c)$

|

O : $\{not\ cov'(m,c)\} \vdash \neg cov(m,c)$

|

P : $\{\} \vdash cov'(m,c)$

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