An Algorithm for Adapting Cases Represented in an Expressive Description Logic

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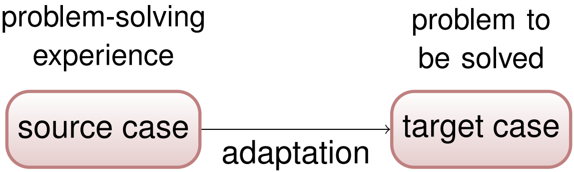
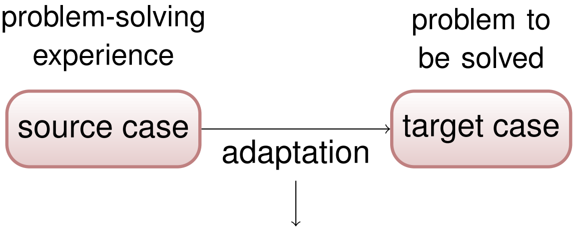
Introduction





consistency test

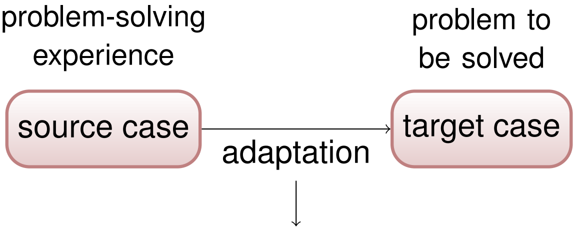
➤ tableaux method

Propositional Logic (PL)

Fragments of First Order Logic (FOL)

➥ $\mathcal{ALC}$ (extends PL, is a FOL fragment)

⋮



consistency test and revision

➤ tableaux method + extension

- Propositional Logic (PL)
- Fragments of First Order Logic (FOL)
  - ➥ $\mathcal{ALC}$ (extends PL, is a FOL fragment)
  - ⋮

Adaptation in CBR

Cases

- A case describes an experience
  (in general, a problem-solving experience)

Example: a cooking recipe

`Source`: a starter dish with raw carrots and vinaigrette

DK: Domain Knowledge

- General knowledge about the domain of application
- Knowledge in complement of the cases

Example

- Ingredient classes: `vegetable`, `root`
- The roots considered are: `carrot`, `parsnip`, and `celery`.
- Parsnips, carrots, and celeries can be grated.
- Raw parsnip are not edible.

Reasoning objective: making the target case precise

`Target` : case with an incomplete description
(The "solution part" is missing.)

Example

`Target`: I want a starter without carrots.

Reasoning objective: making the target case precise

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Example

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Adaptation principle:

Reusing the source case to solve the target case (i.e., making it precise)

Reasoning objective: making the target case precise

`Target` : case with an incomplete description
(The "solution part" is missing.)

Example

`Target`: I want a starter without carrots.

Adaptation principle:

Reusing the source case to solve the target case (i.e., making it precise)

The inconsistencies must be dealt with.

Example: `Source` is inconsistent with `Target`

Carrots are inconsistent with the target case.

Adaptation

So, we need

- A mean for detecting inconsistencies
- a mean to solve it

Adaptation

So, we need

- A mean for detecting inconsistencies
  - $\rightarrow$ tableaux algorithm
- a mean to solve it

Adaptation

So, we need

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- a mean to solve it
  - $\rightarrow$ extension of the tableaux algorithm

Adaptation

So, we need

- A mean for detecting inconsistencies
  - → tableaux algorithm
- a mean to solve it
  - → extension of the tableaux algorithm

Example of an adaptation of `Source` to `Target`:

`CompletedTarget`: starter obtained by substituting in `Source` carrots with celeries

Representation formalism: $\mathcal{ALC}$

- $\mathcal{ALC}$ is a description logic (DL)

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- In this talk: use of the well-known syntax of FOL

Representation formalism: $\mathcal{ALC}$

- $\mathcal{ALC}$ is a description logic (DL)
- It extends PL
  (i.e., it is an *expressive* DL)
- It is a fragment of FOL (up to the syntax)
- In this talk: use of the well-known syntax of FOL
- In the paper: use of the $\mathcal{ALC}$ syntax with technical details on the algorithm

Representation of DK, Source, and Target

In $\mathcal{ALC}$ within FOL syntax:

$$\begin{array}{rll} \mathtt{DK} = & & \forall x\ \mathtt{gratedRawCarrot}(x) \Leftrightarrow \mathtt{carrot}(x) \wedge \mathtt{raw}(x) \wedge \mathtt{grated}(x) \\ & \wedge & \forall x\ \mathtt{root}(x) \Leftrightarrow \mathtt{carrot}(x) \vee \mathtt{parsnip}(x) \vee \mathtt{celery}(x) \\ & \wedge & \forall x\ \mathtt{parsnip}(x) \Rightarrow \neg \mathtt{raw}(x) \end{array}$$

$$\begin{array}{rll} \mathtt{Source}(\sigma) = & & \mathtt{starter}(\sigma) \wedge \exists y\ \mathtt{ing}(\sigma, y) \wedge \mathtt{gratedRawCarrot}(y) \\ & \wedge & \exists y\ \mathtt{ing}(\sigma, y) \wedge \mathtt{vinaigrette}(y) \end{array}$$

$$\mathtt{Target}(\theta) = \mathtt{starter}(\theta) \wedge \neg(\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{carrot}(y))$$

Representation of DK, Source, and Target

In $\mathcal{ALC}$ under NNF within FOL syntax:

$$\mathtt{DK} = \begin{array}{rl} \forall x & \neg\mathtt{gratedRawCarrot}(x) \vee (\mathtt{carrot}(x) \wedge \mathtt{raw}(x) \wedge \mathtt{grated}(x)) \\ \wedge & \mathtt{gratedRawCarrot}(x) \vee \neg\mathtt{carrot}(x) \vee \neg\mathtt{raw}(x) \vee \neg\mathtt{grated}(x) \\ \wedge & \neg\mathtt{root}(x) \vee \mathtt{carrot}(x) \vee \mathtt{parsnip}(x) \vee \mathtt{celery}(x) \\ \wedge & \mathtt{root}(x) \vee (\neg\mathtt{carrot}(x) \wedge \neg\mathtt{parsnip}(x) \wedge \neg\mathtt{celery}(x)) \\ \wedge & \neg\mathtt{parsnip}(x) \vee \neg\mathtt{raw}(x) \end{array}$$

$$\mathtt{Source}(\sigma) = \begin{array}{rl} & \mathtt{starter}(\sigma) \wedge \exists y\ \mathtt{ing}(\sigma, y) \wedge \mathtt{gratedRawCarrot}(y) \\ \wedge & \exists y\ \mathtt{ing}(\sigma, y) \wedge \mathtt{vinaigrette}(y) \end{array}$$

$$\mathtt{Target}(\theta) = \mathtt{starter}(\theta) \wedge \forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$$

Adaptation (reminder)

So, we need

- A mean for detecting inconsistencies
  - $\rightarrow$ tableaux algorithm
- a mean to solve it
  - $\rightarrow$ extension of the tableaux algorithm

The tableau method

The tableau method (1/3)

- A classical deductive method in PL and on decidable fragments of FOL
- Input: a knowledge base $\mathtt{KB}$
(a formula or a set of formulas interpreted conjunctively)

$\rightarrow$ Objective: determining whether $\mathtt{KB}$ is consistent is not

Example: $\mathtt{Source}(\theta)$ is in contradiction with $\mathtt{Target}(\theta)$, given $\mathtt{DK}$

$\mathtt{DK} \wedge \mathtt{Source}(\theta) \wedge \mathtt{Target}(\theta)$ is inconsistent

The tableau method (2/3)

- Principle:
  - Some formalism-dependent transformation rules are applied on formulas to produce new (deduced) formulas, whenever it is possible.
  - `KB` is inconsistent *iff* there is a clash in every branch.

The tableau method (3/3) Ex. on $\texttt{DK} \wedge \texttt{Source}(\theta) \wedge \texttt{Target}(\theta)$

$$\texttt{DK} \wedge \texttt{Source}(\theta) \wedge \texttt{Target}(\theta)$$

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$$\texttt{DK} \wedge \texttt{Source}(\theta) \wedge \texttt{Target}(\theta)$$

$$\texttt{DK}$$

$$\texttt{Source}(\theta)$$

$$\texttt{Target}(\theta)$$

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$$\mathtt{DK}$$

$$\mathtt{Source}(\theta)$$

$$\mathtt{Target}(\theta)$$

$$\mathtt{starter}(\theta)$$

$$\exists y \ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$$

$$\exists y \ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$$

$\mathtt{DK} \land \mathtt{Source}(\theta) \land \mathtt{Target}(\theta)$

$\mathtt{DK}$

$\mathtt{Source}(\theta)$

$\mathtt{Target}(\theta)$

$\mathtt{starter}(\theta)$

$\exists y\ \mathtt{ing}(\theta, y) \land \mathtt{gratedRawCarrot}(y)$

$\exists y\ \mathtt{ing}(\theta, y) \land \mathtt{vinaigrette}(y)$

$\forall y\ (\neg \mathtt{ing}(\theta, y) \lor \neg \mathtt{carrot}(y))$

$$\mathtt{DK} \land \mathtt{Source}(\theta) \land \mathtt{Target}(\theta)$$

$$\mathtt{DK}$$

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$$\exists y\ \mathtt{ing}(\theta, y) \land \mathtt{vinaigrette}(y)$$

$$\forall y\ (\neg\mathtt{ing}(\theta, y) \lor \neg\mathtt{carrot}(y))$$

$$\mathtt{ing}(\theta, a) \land \mathtt{gratedRawCarrot}(a)$$

$$\mathtt{DK} \wedge \mathtt{Source}(\theta) \wedge \mathtt{Target}(\theta)$$

$$\mathtt{DK}$$

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$$\mathtt{Target}(\theta)$$

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$$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$$

$$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$$

$$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$$

$$\mathtt{ing}(\theta, a)$$

$$\mathtt{gratedRawCarrot}(a)$$

The tableau method (3/3) Ex. on $\mathtt{DK} \wedge \mathtt{Source}(\theta) \wedge \mathtt{Target}(\theta)$

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$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$

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$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$

$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$

$\mathtt{ing}(\theta, a)$

$\mathtt{gratedRawCarrot}(a)$

$\neg\mathtt{gratedRawCarrot}(a) \vee (\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)) \ldots$

The tableau method (3/3) Ex. on $\mathtt{DK} \wedge \mathtt{Source}(\theta) \wedge \mathtt{Target}(\theta)$

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$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$

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$\neg \mathtt{gratedRawCarrot}(a) \vee (\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)) \ldots$

$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$

$\neg \mathtt{gratedRawCarrot}(a)$

$\mathtt{DK} \wedge \mathtt{Source}(\theta) \wedge \mathtt{Target}(\theta)$

$\mathtt{DK}$

$\mathtt{Source}(\theta)$

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$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$

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$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$

$\mathtt{ing}(\theta, a)$

$\mathtt{gratedRawCarrot}(a)$

$\neg \mathtt{gratedRawCarrot}(a) \vee (\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)) \ldots$

$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$

$\neg \mathtt{gratedRawCarrot}(a)$

$\square$

The tableau method (3/3) Ex. on $\texttt{DK} \wedge \texttt{Source}(\theta) \wedge \texttt{Target}(\theta)$

$$\forall y\ (\neg\texttt{ing}(\theta, y) \vee \neg\texttt{carrot}(y))$$

$$\texttt{ing}(\theta, a) \wedge \texttt{gratedRawCarrot}(a)$$

$$\texttt{ing}(\theta, a)$$

$$\texttt{gratedRawCarrot}(a)$$

$$\neg\texttt{gratedRawCarrot}(a) \vee (\texttt{carrot}(a) \wedge \texttt{raw}(a) \wedge \texttt{grated}(a))\ldots$$

$$\texttt{carrot}(a) \wedge \texttt{raw}(a) \wedge \texttt{grated}(a)$$

$$\neg\texttt{gratedRawCarrot}(a)$$

$$\square$$

$$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$$

$$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$$

$$\mathtt{ing}(\theta, a)$$

$$\mathtt{gratedRawCarrot}(a)$$

$$\neg\mathtt{gratedRawCarrot}(a) \vee (\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a))\ldots$$

$$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$$

$$\mathtt{carrot}(a)$$

$$\mathtt{raw}(a)$$

$$\mathtt{grated}(a)$$

$$\neg\mathtt{gratedRawCarrot}(a)$$

$$\square$$

The tableau method (3/3) Ex. on $\texttt{DK} \land \texttt{Source}(\theta) \land \texttt{Target}(\theta)$

$$\forall y\ (\neg \texttt{ing}(\theta, y) \lor \neg \texttt{carrot}(y))$$

$$\texttt{ing}(\theta, a) \land \texttt{gratedRawCarrot}(a)$$

$$\texttt{ing}(\theta, a)$$

$$\texttt{gratedRawCarrot}(a)$$

$$\neg \texttt{gratedRawCarrot}(a) \lor (\texttt{carrot}(a) \land \texttt{raw}(a) \land \texttt{grated}(a)) \ldots$$

$$\texttt{carrot}(a) \land \texttt{raw}(a) \land \texttt{grated}(a)$$

$$\neg \texttt{gratedRawCarrot}(a)$$

$$\square$$

$$\texttt{carrot}(a)$$

$$\texttt{raw}(a)$$

$$\texttt{grated}(a)$$

$$\neg \texttt{ing}(\theta, a) \lor \neg \texttt{carrot}(a)$$

$$\forall y\ (\neg\texttt{ing}(\theta, y) \vee \neg\texttt{carrot}(y))$$

$$\texttt{ing}(\theta, a) \wedge \texttt{gratedRawCarrot}(a)$$

$$\texttt{ing}(\theta, a)$$

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$$\neg\texttt{gratedRawCarrot}(a) \vee (\texttt{carrot}(a) \wedge \texttt{raw}(a) \wedge \texttt{grated}(a)) \ldots$$

$$\neg\texttt{gratedRawCarrot}(a) \qquad \texttt{carrot}(a) \wedge \texttt{raw}(a) \wedge \texttt{grated}(a)$$

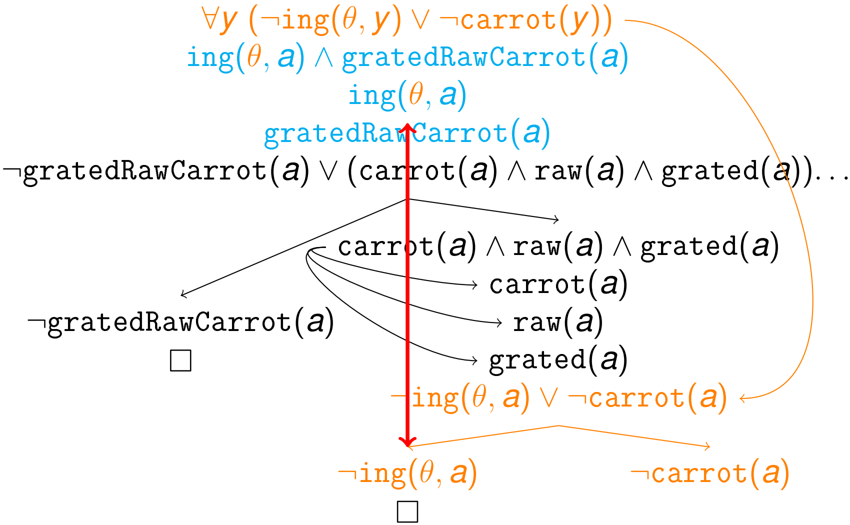
$$\square \qquad \texttt{carrot}(a)$$

$$\texttt{raw}(a)$$

$$\texttt{grated}(a)$$

$$\neg\texttt{ing}(\theta, a) \vee \neg\texttt{carrot}(a)$$

$$\neg\texttt{ing}(\theta, a) \qquad \neg\texttt{carrot}(a)$$


∀y (¬ing(θ, y) ∨ ¬carrot(y))
ing(θ, a) ∧ gratedRawCarrot(a)
ing(θ, a)
gratedRawCarrot(a)
¬gratedRawCarrot(a) ∨ (carrot(a) ∧ raw(a) ∧ grated(a))...
carrot(a) ∧ raw(a) ∧ grated(a)
carrot(a)
raw(a)
grated(a)
¬gratedRawCarrot(a)
□
¬ing(θ, a) ∨ ¬carrot(a)
¬ing(θ, a)
¬carrot(a)
□

The tableau method (3/3) Ex. on $\mathtt{DK} \land \mathtt{Source}(\theta) \land \mathtt{Target}(\theta)$

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$$\mathtt{ing}(\theta, a) \land \mathtt{gratedRawCarrot}(a)$$
$$\mathtt{ing}(\theta, a)$$
$$\mathtt{gratedRawCarrot}(a)$$
$$\neg \mathtt{gratedRawCarrot}(a) \lor (\mathtt{carrot}(a) \land \mathtt{raw}(a) \land \mathtt{grated}(a))\ldots$$

$$\neg \mathtt{gratedRawCarrot}(a)$$
$$\square$$

$$\mathtt{carrot}(a) \land \mathtt{raw}(a) \land \mathtt{grated}(a)$$
$$\mathtt{carrot}(a)$$
$$\mathtt{raw}(a)$$
$$\mathtt{grated}(a)$$
$$\neg \mathtt{ing}(\theta, a) \lor \neg \mathtt{carrot}(a)$$

$$\neg \mathtt{ing}(\theta, a)$$
$$\square$$

$$\neg \mathtt{carrot}(a)$$
$$\square$$

$$\forall y\ (\neg \mathtt{ing}(\theta, y) \vee \neg \mathtt{carrot}(y))$$
$$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$$
$$\mathtt{ing}(\theta, a)$$
$$\mathtt{gratedRawCarrot}(a)$$
$$\neg \mathtt{gratedRawCarrot}(a) \vee (\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)) \ldots$$

$$\neg \mathtt{gratedRawCarrot}(a)$$
$$\Box$$

$$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$$
$$\mathtt{carrot}(a)$$
$$\mathtt{raw}(a)$$
$$\mathtt{grated}(a)$$
$$\neg \mathtt{ing}(\theta, a) \vee \neg \mathtt{carrot}(a)$$

$$\neg \mathtt{ing}(\theta, a)$$
$$\Box$$

$$\neg \mathtt{carrot}(a)$$
$$\Box$$

Adaptation by reestablishing consistency

Adaptation by correction of $\texttt{DK} \wedge \texttt{Source}(\theta) \wedge \texttt{Target}(\theta)$

- Pretend that $\texttt{Source}(\sigma)$ solves $\texttt{Target}(\theta)$
  - $\texttt{Source}(\theta)$

Adaptation by correction of $\mathtt{DK} \land \mathtt{Source}(\theta) \land \mathtt{Target}(\theta)$

- Pretend that $\mathtt{Source}(\sigma)$ solves $\mathtt{Target}(\theta)$
  - $\mathtt{Source}(\theta)$
- If $\mathtt{Source}(\theta)$ is consistent with $\mathtt{Target}(\theta)$:
  $\mathtt{CompletedTarget} = \mathtt{DK} \land \mathtt{Source}(\theta) \land \mathtt{Target}(\theta)$

Adaptation by correction of $\mathtt{DK} \wedge \mathtt{Source}(\theta) \wedge \mathtt{Target}(\theta)$

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- Else, minimal change on $\mathtt{Source}(\theta)$: keep as much as possible from the consequences of $\mathtt{DK} \wedge \mathtt{Source}(\theta)$

Adaptation by correction of $\mathtt{DK} \wedge \mathtt{Source}(\theta) \wedge \mathtt{Target}(\theta)$

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- Else, minimal change on $\mathtt{Source}(\theta)$: keep as much as possible from the consequences of $\mathtt{DK} \wedge \mathtt{Source}(\theta)$
- Apply tableau method

Adaptation by correction of $\texttt{DK} \wedge \texttt{Source}(\theta) \wedge \texttt{Target}(\theta)$

- Pretend that $\texttt{Source}(\sigma)$ solves $\texttt{Target}(\theta)$
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- If $\texttt{Source}(\theta)$ is consistent with $\texttt{Target}(\theta)$: $\texttt{CompletedTarget} = \texttt{DK} \wedge \texttt{Source}(\theta) \wedge \texttt{Target}(\theta)$
- Else, minimal change on $\texttt{Source}(\theta)$: keep as much as possible from the consequences of $\texttt{DK} \wedge \texttt{Source}(\theta)$
- Apply tableau method
  - To generate the consistent branches S_i from $\texttt{DK} \wedge \texttt{Source}(\theta)$

Adaptation by correction of $\mathtt{DK} \wedge \mathtt{Source}(\theta) \wedge \mathtt{Target}(\theta)$

- Pretend that $\mathtt{Source}(\sigma)$ solves $\mathtt{Target}(\theta)$
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- Else, minimal change on $\mathtt{Source}(\theta)$: keep as much as possible from the consequences of $\mathtt{DK} \wedge \mathtt{Source}(\theta)$
- Apply tableau method
  - To generate the consistent branches S_i from $\mathtt{DK} \wedge \mathtt{Source}(\theta)$
  - To generate the consistent branches T_j from $\mathtt{DK} \wedge \mathtt{Target}(\theta)$

Adaptation by correction of $\mathtt{DK} \wedge \mathtt{Source}(\theta) \wedge \mathtt{Target}(\theta)$

- Pretend that $\mathtt{Source}(\sigma)$ solves $\mathtt{Target}(\theta)$
  - ➤ $\mathtt{Source}(\theta)$
- If $\mathtt{Source}(\theta)$ is consistent with $\mathtt{Target}(\theta)$: $\mathtt{CompletedTarget} = \mathtt{DK} \wedge \mathtt{Source}(\theta) \wedge \mathtt{Target}(\theta)$
- Else, minimal change on $\mathtt{Source}(\theta)$: keep as much as possible from the consequences of $\mathtt{DK} \wedge \mathtt{Source}(\theta)$
- Apply tableau method
  - To generate the consistent branches S_i from $\mathtt{DK} \wedge \mathtt{Source}(\theta)$
  - To generate the consistent branches T_j from $\mathtt{DK} \wedge \mathtt{Target}(\theta)$
  - To generate the (inconsistent) branches B_{ij} from each $S_i \wedge T_j$

Adaptation by correction of $\mathtt{DK} \wedge \mathtt{Source}(\theta) \wedge \mathtt{Target}(\theta)$

- Pretend that $\mathtt{Source}(\sigma)$ solves $\mathtt{Target}(\theta)$
  - $\mathtt{Source}(\theta)$
- If $\mathtt{Source}(\theta)$ is consistent with $\mathtt{Target}(\theta)$: $\mathtt{CompletedTarget} = \mathtt{DK} \wedge \mathtt{Source}(\theta) \wedge \mathtt{Target}(\theta)$
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  - To generate the consistent branches T_j from $\mathtt{DK} \wedge \mathtt{Target}(\theta)$
  - To generate the (inconsistent) branches B_{ij} from each $S_i \wedge T_j$
- Repair (some of) the B_{ij}'s

Adaptation by correction of $\mathtt{DK} \land \mathtt{Source}(\theta) \land \mathtt{Target}(\theta)$

- Pretend that $\mathtt{Source}(\sigma)$ solves $\mathtt{Target}(\theta)$
  - ➤ $\mathtt{Source}(\theta)$
- If $\mathtt{Source}(\theta)$ is consistent with $\mathtt{Target}(\theta)$: $\mathtt{CompletedTarget} = \mathtt{DK} \land \mathtt{Source}(\theta) \land \mathtt{Target}(\theta)$
- Else, minimal change on $\mathtt{Source}(\theta)$: keep as much as possible from the consequences of $\mathtt{DK} \land \mathtt{Source}(\theta)$
- Apply tableau method
  - To generate the consistent branches S_i from $\mathtt{DK} \land \mathtt{Source}(\theta)$
  - To generate the consistent branches T_j from $\mathtt{DK} \land \mathtt{Target}(\theta)$
  - To generate the (inconsistent) branches B_{ij} from each $S_i \land T_j$
- Repair (some of) the B_{ij}'s
- Use of a cost function to give a priority in the repairs

$$\texttt{DK} \wedge \texttt{Source}(\theta)$$

$$\texttt{DK}$$

$$\texttt{Source}(\theta)$$

$$\texttt{starter}(\theta)$$

$$\exists y\ \texttt{ing}(\theta, y) \wedge \texttt{gratedRawCarrot}(y)$$

$$\exists y\ \texttt{ing}(\theta, y) \wedge \texttt{vinaigrette}(y)$$

$$\texttt{ing}(\theta, a) \wedge \texttt{gratedRawCarrot}(a)$$

$$\texttt{ing}(\theta, a)$$

$$\texttt{gratedRawCarrot}(a)$$

$$\texttt{carrot}(a) \wedge \texttt{raw}(a) \wedge \texttt{grated}(a)$$

$$\texttt{carrot}(a)$$

$$\texttt{raw}(a)$$

$$\texttt{grated}(a)$$

$$\texttt{carrot}(a) \vee \texttt{parsnip}(a) \vee \texttt{celery}(a)$$

$$\texttt{root}(a)$$

$$\neg\texttt{parsnip}(a)\ [\ldots]$$

$$S_1$$

$$\texttt{DK} \wedge \texttt{Target}(\theta)$$
$$\texttt{DK}$$
$$\texttt{Target}(\theta)$$
$$\texttt{starter}(\theta)$$
$$\forall y\ (\neg\texttt{ing}(\theta, y) \vee \neg\texttt{carrot}(y))$$
$$\neg\texttt{ing}(\theta, a) \vee \neg\texttt{carrot}(a)$$
$$\neg\texttt{gratedRawCarrot}(a) \vee (\texttt{carrot}(a) \wedge \texttt{raw}(a) \wedge \texttt{grated}(a))$$
$$\texttt{gratedRawCarrot}(a) \vee \neg\texttt{carrot}(a) \vee \neg\texttt{raw}(a) \vee \neg\texttt{grated}(a)$$
$$\neg\texttt{root}(a) \vee \texttt{carrot}(a) \vee \texttt{parsnip}(a) \vee \texttt{celery}(a)$$
$$\texttt{root}(a) \vee \neg\texttt{carrot}(a) \wedge \neg\texttt{parsnip}(a) \wedge \neg\texttt{celery}(a)$$
$$\neg\texttt{parsnip}(a) \vee \neg\texttt{raw}(a)$$

T_1	T_2	…	…
$\neg\texttt{carrot}(a)$	$\neg\texttt{carrot}(a)$	$\ldots$	$\ldots$
$\texttt{celery}(a)$	$\texttt{parsnip}(a)$		
$\texttt{root}(a)$	$\texttt{root}(a)$		
$\texttt{grated}(a)$	$\texttt{grated}(a)$		
$\texttt{raw}(a)$	$\neg\texttt{raw}(a)$		
T_1	T_2		

$S_1 \wedge T_1$

$\mathtt{DK} \wedge \mathtt{Source}(\theta)$	$\mathtt{DK} \wedge \mathtt{Target}(\theta)$
$\mathtt{DK}$	$\mathtt{DK}$
$\mathtt{Source}(\theta)$	$\mathtt{Target}(\theta)$
$\mathtt{starter}(\theta)$	$\mathtt{starter}(\theta)$
$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$	$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$
$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$	$\neg\mathtt{ing}(\theta, a) \vee \neg\mathtt{carrot}(a)$
$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$	$\neg\mathtt{gratedRawCarrot}(a) \vee (\ldots)$
$\mathtt{ing}(\theta, a)$	$\mathtt{gratedRawCarrot}(a) \vee \ldots$
$\mathtt{gratedRawCarrot}(a)$	$\neg\mathtt{root}(a) \vee \ldots$
$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$	$\mathtt{root}(a) \vee \ldots$
$\mathtt{carrot}(a)$	$\neg\mathtt{parsnip}(a) \vee \neg\mathtt{raw}(a)$
$\mathtt{raw}(a)$	$\neg\mathtt{carrot}(a)$
$\mathtt{grated}(a)$	$\mathtt{celery}(a)$
$\mathtt{carrot}(a) \vee \mathtt{parsnip}(a) \vee \mathtt{celery}(a)$	$\mathtt{root}(a)$
$\mathtt{root}(a)$	$\mathtt{grated}(a)$
$\neg\mathtt{parsnip}(a)$	$\mathtt{raw}(a)$

$\square \pm \mathtt{carrot}(a)$

$S_1 \wedge T_1$

$\texttt{DK} \wedge \texttt{Source}(\theta)$

$\texttt{DK}$

$\texttt{Source}(\theta)$

$\texttt{starter}(\theta)$

$\exists y\ \texttt{ing}(\theta, y) \wedge \texttt{gratedRawCarrot}(y)$

$\exists y\ \texttt{ing}(\theta, y) \wedge \texttt{vinaigrette}(y)$

$\texttt{ing}(\theta, a) \wedge \texttt{gratedRawCarrot}(a)$

$\texttt{ing}(\theta, a)$

$\texttt{gratedRawCarrot}(a)$

$\texttt{carrot}(a) \wedge \texttt{raw}(a) \wedge \texttt{grated}(a)$

$\texttt{carrot}(a)$

$\texttt{raw}(a)$

$\texttt{grated}(a)$

$\texttt{carrot}(a) \vee \texttt{parsnip}(a) \vee \texttt{celery}(a)$

$\texttt{root}(a)$

$\neg\texttt{parsnip}(a)$

$\texttt{DK} \wedge \texttt{Target}(\theta)$

$\texttt{DK}$

$\texttt{Target}(\theta)$

$\texttt{starter}(\theta)$

$\forall y\ (\neg\texttt{ing}(\theta, y) \vee \neg\texttt{carrot}(y))$

$\neg\texttt{ing}(\theta, a) \vee \neg\texttt{carrot}(a)$

$\neg\texttt{gratedRawCarrot}(a) \vee (\ldots)$

$\texttt{gratedRawCarrot}(a) \vee \ldots$

$\neg\texttt{root}(a) \vee \ldots$

$\texttt{root}(a) \vee \ldots$

$\neg\texttt{parsnip}(a) \vee \neg\texttt{raw}(a)$

$\neg\texttt{carrot}(a)$

$\texttt{celery}(a)$

$\texttt{root}(a)$

$\texttt{grated}(a)$

$\texttt{raw}(a)$

~~$\Box \bot \texttt{carrot}(a)$~~

$S_1 \wedge T_1$

$\mathtt{DK} \wedge \mathtt{Source}(\theta)$	$\mathtt{DK} \wedge \mathtt{Target}(\theta)$
$\mathtt{DK}$	$\mathtt{DK}$
$\mathtt{Source}(\theta)$	$\mathtt{Target}(\theta)$
$\mathtt{starter}(\theta)$	$\mathtt{starter}(\theta)$
$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$	$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$
$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$	$\neg\mathtt{ing}(\theta, a) \vee \neg\mathtt{carrot}(a)$
$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$	$\neg\mathtt{gratedRawCarrot}(a) \vee (\dots)$
$\mathtt{ing}(\theta, a)$	$\mathtt{gratedRawCarrot}(a) \vee \dots$
$\mathtt{gratedRawCarrot}(a)$	$\neg\mathtt{root}(a) \vee \dots$
$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$	$\mathtt{root}(a) \vee \dots$
~~$\mathtt{carrot}(a)$~~	$\neg\mathtt{parsnip}(a) \vee \neg\mathtt{raw}(a)$
$\mathtt{raw}(a)$	$\neg\mathtt{carrot}(a)$
$\mathtt{grated}(a)$	$\mathtt{celery}(a)$
$\mathtt{carrot}(a) \vee \mathtt{parsnip}(a) \vee \mathtt{celery}(a)$	$\mathtt{root}(a)$
$\mathtt{root}(a)$	$\mathtt{grated}(a)$
$\neg\mathtt{parsnip}(a)$	$\mathtt{raw}(a)$

~~$\square \bot \mathtt{carrot}(a)$~~

$S_1 \wedge T_1$

$\mathtt{DK} \wedge \mathtt{Source}(\theta)$

$\mathtt{DK}$

$\mathtt{Source}(\theta)$

$\mathtt{starter}(\theta)$

$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$

$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$

$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$

$\mathtt{ing}(\theta, a)$

$\mathtt{gratedRawCarrot}(a)$

~~$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$~~

~~$\mathtt{carrot}(a)$~~

$\mathtt{raw}(a)$

$\mathtt{grated}(a)$

$\mathtt{carrot}(a) \vee \mathtt{parsnip}(a) \vee \mathtt{celery}(a)$

$\mathtt{root}(a)$

$\neg\mathtt{parsnip}(a)$

$\mathtt{DK} \wedge \mathtt{Target}(\theta)$

$\mathtt{DK}$

$\mathtt{Target}(\theta)$

$\mathtt{starter}(\theta)$

$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$

$\neg\mathtt{ing}(\theta, a) \vee \neg\mathtt{carrot}(a)$

$\neg\mathtt{gratedRawCarrot}(a) \vee (\ldots)$

$\mathtt{gratedRawCarrot}(a) \vee \ldots$

$\neg\mathtt{root}(a) \vee \ldots$

$\mathtt{root}(a) \vee \ldots$

$\neg\mathtt{parsnip}(a) \vee \neg\mathtt{raw}(a)$

$\neg\mathtt{carrot}(a)$

$\mathtt{celery}(a)$

$\mathtt{root}(a)$

$\mathtt{grated}(a)$

$\mathtt{raw}(a)$

~~$\square \bot \mathtt{carrot}(a)$~~

$S_1 \wedge T_1$

$\mathtt{DK} \wedge \mathtt{Source}(\theta)$

$\mathtt{DK}$

$\mathtt{Source}(\theta)$

$\mathtt{starter}(\theta)$

$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$

$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$

$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$

$\mathtt{ing}(\theta, a)$

~~$\mathtt{gratedRawCarrot}(a)$~~

~~$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$~~

~~$\mathtt{carrot}(a)$~~

$\mathtt{raw}(a)$

$\mathtt{grated}(a)$

$\mathtt{carrot}(a) \vee \mathtt{parsnip}(a) \vee \mathtt{celery}(a)$

$\mathtt{root}(a)$

$\neg\mathtt{parsnip}(a)$

$\mathtt{DK} \wedge \mathtt{Target}(\theta)$

$\mathtt{DK}$

$\mathtt{Target}(\theta)$

$\mathtt{starter}(\theta)$

$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$

$\neg\mathtt{ing}(\theta, a) \vee \neg\mathtt{carrot}(a)$

$\neg\mathtt{gratedRawCarrot}(a) \vee (\ldots)$

$\mathtt{gratedRawCarrot}(a) \vee \ldots$

$\neg\mathtt{root}(a) \vee \ldots$

$\mathtt{root}(a) \vee \ldots$

$\neg\mathtt{parsnip}(a) \vee \neg\mathtt{raw}(a)$

$\neg\mathtt{carrot}(a)$

$\mathtt{celery}(a)$

$\mathtt{root}(a)$

$\mathtt{grated}(a)$

$\mathtt{raw}(a)$

~~$\square\ \bot\ \mathtt{carrot}(a)$~~

$S_1 \wedge T_1$

$\texttt{DK} \wedge \texttt{Source}(\theta)$

$\texttt{DK}$

$\texttt{Source}(\theta)$

$\texttt{starter}(\theta)$

$\exists y\ \texttt{ing}(\theta, y) \wedge \texttt{gratedRawCarrot}(y)$

$\exists y\ \texttt{ing}(\theta, y) \wedge \texttt{vinaigrette}(y)$

~~$\texttt{ing}(\theta, a) \wedge \texttt{gratedRawCarrot}(a)$~~

$\texttt{ing}(\theta, a)$

~~$\texttt{gratedRawCarrot}(a)$~~

~~$\texttt{carrot}(a) \wedge \texttt{raw}(a) \wedge \texttt{grated}(a)$~~

~~$\texttt{carrot}(a)$~~

$\texttt{raw}(a)$

$\texttt{grated}(a)$

$\texttt{carrot}(a) \vee \texttt{parsnip}(a) \vee \texttt{celery}(a)$

$\texttt{root}(a)$

$\neg\texttt{parsnip}(a)$

$\texttt{DK} \wedge \texttt{Target}(\theta)$

$\texttt{DK}$

$\texttt{Target}(\theta)$

$\texttt{starter}(\theta)$

$\forall y\ (\neg\texttt{ing}(\theta, y) \vee \neg\texttt{carrot}(y))$

$\neg\texttt{ing}(\theta, a) \vee \neg\texttt{carrot}(a)$

$\neg\texttt{gratedRawCarrot}(a) \vee (\dots)$

$\texttt{gratedRawCarrot}(a) \vee \dots$

$\neg\texttt{root}(a) \vee \dots$

$\texttt{root}(a) \vee \dots$

$\neg\texttt{parsnip}(a) \vee \neg\texttt{raw}(a)$

$\neg\texttt{carrot}(a)$

$\texttt{celery}(a)$

$\texttt{root}(a)$

$\texttt{grated}(a)$

$\texttt{raw}(a)$

~~$\square \bot \texttt{carrot}(a)$~~

$S_1 \land T_1$

$\mathtt{DK} \land \mathtt{Source}(\theta)$	$\mathtt{DK} \land \mathtt{Target}(\theta)$
$\mathtt{DK}$	$\mathtt{DK}$
$\mathtt{Source}(\theta)$	$\mathtt{Target}(\theta)$
$\mathtt{starter}(\theta)$	$\mathtt{starter}(\theta)$
~~$\exists y\ \mathtt{ing}(\theta, y) \land \mathtt{gratedRawCarrot}(y)$~~	$\forall y\ (\neg\mathtt{ing}(\theta, y) \lor \neg\mathtt{carrot}(y))$
$\exists y\ \mathtt{ing}(\theta, y) \land \mathtt{vinaigrette}(y)$	$\neg\mathtt{ing}(\theta, a) \lor \neg\mathtt{carrot}(a)$
~~$\mathtt{ing}(\theta, a) \land \mathtt{gratedRawCarrot}(a)$~~	$\neg\mathtt{gratedRawCarrot}(a) \lor (\ldots)$
$\mathtt{ing}(\theta, a)$	$\mathtt{gratedRawCarrot}(a) \lor \ldots$
~~$\mathtt{gratedRawCarrot}(a)$~~	$\neg\mathtt{root}(a) \lor \ldots$
~~$\mathtt{carrot}(a) \land \mathtt{raw}(a) \land \mathtt{grated}(a)$~~	$\mathtt{root}(a) \lor \ldots$
~~$\mathtt{carrot}(a)$~~	$\neg\mathtt{parsnip}(a) \lor \neg\mathtt{raw}(a)$
$\mathtt{raw}(a)$	$\neg\mathtt{carrot}(a)$
$\mathtt{grated}(a)$	$\mathtt{celery}(a)$
$\mathtt{carrot}(a) \lor \mathtt{parsnip}(a) \lor \mathtt{celery}(a)$	$\mathtt{root}(a)$
$\mathtt{root}(a)$	$\mathtt{grated}(a)$
$\neg\mathtt{parsnip}(a)$	$\mathtt{raw}(a)$

~~$\square \bot \mathtt{carrot}(a)$~~

$S_1 \wedge T_1$

$\mathtt{DK} \wedge \mathtt{Source}(\theta)$

$\mathtt{DK}$

~~$\mathtt{Source}(\theta)$~~

$\mathtt{starter}(\theta)$

~~$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$~~

$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$

~~$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$~~

$\mathtt{ing}(\theta, a)$

~~$\mathtt{gratedRawCarrot}(a)$~~

~~$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$~~

~~$\mathtt{carrot}(a)$~~

$\mathtt{raw}(a)$

$\mathtt{grated}(a)$

$\mathtt{carrot}(a) \vee \mathtt{parsnip}(a) \vee \mathtt{celery}(a)$

$\mathtt{root}(a)$

$\neg\mathtt{parsnip}(a)$

$\mathtt{DK} \wedge \mathtt{Target}(\theta)$

$\mathtt{DK}$

$\mathtt{Target}(\theta)$

$\mathtt{starter}(\theta)$

$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$

$\neg\mathtt{ing}(\theta, a) \vee \neg\mathtt{carrot}(a)$

$\neg\mathtt{gratedRawCarrot}(a) \vee (\ldots)$

$\mathtt{gratedRawCarrot}(a) \vee \ldots$

$\neg\mathtt{root}(a) \vee \ldots$

$\mathtt{root}(a) \vee \ldots$

$\neg\mathtt{parsnip}(a) \vee \neg\mathtt{raw}(a)$

$\neg\mathtt{carrot}(a)$

$\mathtt{celery}(a)$

$\mathtt{root}(a)$

$\mathtt{grated}(a)$

$\mathtt{raw}(a)$

~~$\square \pm \mathtt{carrot}(a)$~~

$S_1 \wedge T_1$

~~$\mathtt{DK} \wedge \mathtt{Source}(\theta)$~~

$\mathtt{DK}$

~~$\mathtt{Source}(\theta)$~~

$\mathtt{starter}(\theta)$

~~$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$~~

$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$

~~$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$~~

$\mathtt{ing}(\theta, a)$

~~$\mathtt{gratedRawCarrot}(a)$~~

~~$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$~~

~~$\mathtt{carrot}(a)$~~

$\mathtt{raw}(a)$

$\mathtt{grated}(a)$

$\mathtt{carrot}(a) \vee \mathtt{parsnip}(a) \vee \mathtt{celery}(a)$

$\mathtt{root}(a)$

$\neg\mathtt{parsnip}(a)$

$\mathtt{DK} \wedge \mathtt{Target}(\theta)$

$\mathtt{DK}$

$\mathtt{Target}(\theta)$

$\mathtt{starter}(\theta)$

$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$

$\neg\mathtt{ing}(\theta, a) \vee \neg\mathtt{carrot}(a)$

$\neg\mathtt{gratedRawCarrot}(a) \vee (\ldots)$

$\mathtt{gratedRawCarrot}(a) \vee \ldots$

$\neg\mathtt{root}(a) \vee \ldots$

$\mathtt{root}(a) \vee \ldots$

$\neg\mathtt{parsnip}(a) \vee \neg\mathtt{raw}(a)$

$\neg\mathtt{carrot}(a)$

$\mathtt{celery}(a)$

$\mathtt{root}(a)$

$\mathtt{grated}(a)$

$\mathtt{raw}(a)$

~~$\square \bot \mathtt{carrot}(a)$~~

$S'_1 \wedge T_1$

~~$\mathtt{DK} \wedge \mathtt{Source}(\theta)$~~	$\mathtt{DK} \wedge \mathtt{Target}(\theta)$
$\mathtt{DK}$	$\mathtt{DK}$
~~$\mathtt{Source}(\theta)$~~	$\mathtt{Target}(\theta)$
$\mathtt{starter}(\theta)$	$\mathtt{starter}(\theta)$
~~$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$~~	$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$
$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$	$\neg\mathtt{ing}(\theta, a) \vee \neg\mathtt{carrot}(a)$
~~$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$~~	$\neg\mathtt{gratedRawCarrot}(a) \vee (\ldots)$
$\mathtt{ing}(\theta, a)$	$\mathtt{gratedRawCarrot}(a) \vee \ldots$
~~$\mathtt{gratedRawCarrot}(a)$~~	$\neg\mathtt{root}(a) \vee \ldots$
~~$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$~~	$\mathtt{root}(a) \vee \ldots$
~~$\mathtt{carrot}(a)$~~	$\neg\mathtt{parsnip}(a) \vee \neg\mathtt{raw}(a)$
$\mathtt{raw}(a)$	$\neg\mathtt{carrot}(a)$
$\mathtt{grated}(a)$	$\mathtt{celery}(a)$
$\mathtt{carrot}(a) \vee \mathtt{parsnip}(a) \vee \mathtt{celery}(a)$	$\mathtt{root}(a)$
$\mathtt{root}(a)$	$\mathtt{grated}(a)$
$\neg\mathtt{parsnip}(a)$	$\mathtt{raw}(a)$

~~$\Box \bot \mathtt{carrot}(a)$~~

$$S_1 \wedge T_2$$

$\mathtt{DK} \wedge \mathtt{Source}(\theta)$

$\mathtt{DK}$

$\mathtt{Source}(\theta)$

$\mathtt{starter}(\theta)$

$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$

$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$

$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$

$\mathtt{ing}(\theta, a)$

$\mathtt{gratedRawCarrot}(a)$

$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$

$\mathtt{carrot}(a)$

$\mathtt{raw}(a)$

$\mathtt{grated}(a)$

$\mathtt{carrot}(a) \vee \mathtt{parsnip}(a) \vee \mathtt{celery}(a)$

$\mathtt{root}(a)$

$\neg\mathtt{parsnip}(a)$

$\square \pm \mathtt{carrot}(a)$

$\mathtt{DK} \wedge \mathtt{Target}(\theta)$

$\mathtt{DK}$

$\mathtt{Target}(\theta)$

$\mathtt{starter}(\theta)$

$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$

$\neg\mathtt{ing}(\theta, a) \vee \neg\mathtt{carrot}(a)$

$\neg\mathtt{gratedRawCarrot}(a) \vee (\ldots)$

$\mathtt{gratedRawCarrot}(a) \vee \ldots$

$\neg\mathtt{root}(a) \vee \ldots$

$\mathtt{root}(a) \vee \ldots$

$\neg\mathtt{parsnip}(a) \vee \neg\mathtt{raw}(a)$

$\neg\mathtt{carrot}(a)$

$\mathtt{parsnip}(a)$

$\mathtt{root}(a)$

$\mathtt{grated}(a)$

$\neg\mathtt{raw}(a)$

$\square \pm \mathtt{raw}(a)$

$$S_1 \wedge T_2$$

$\mathtt{DK} \wedge \mathtt{Source}(\theta)$

$\mathtt{DK}$

$\mathtt{Source}(\theta)$

$\mathtt{starter}(\theta)$

$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$

$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$

$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$

$\mathtt{ing}(\theta, a)$

$\mathtt{gratedRawCarrot}(a)$

$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$

$\mathtt{carrot}(a)$

$\mathtt{raw}(a)$

$\mathtt{grated}(a)$

$\mathtt{carrot}(a) \vee \mathtt{parsnip}(a) \vee \mathtt{celery}(a)$

$\mathtt{root}(a)$

$\neg\mathtt{parsnip}(a)$

~~$\Box \pm \mathtt{carrot}(a)$~~

$\mathtt{DK} \wedge \mathtt{Target}(\theta)$

$\mathtt{DK}$

$\mathtt{Target}(\theta)$

$\mathtt{starter}(\theta)$

$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$

$\neg\mathtt{ing}(\theta, a) \vee \neg\mathtt{carrot}(a)$

$\neg\mathtt{gratedRawCarrot}(a) \vee (\ldots)$

$\mathtt{gratedRawCarrot}(a) \vee \ldots$

$\neg\mathtt{root}(a) \vee \ldots$

$\mathtt{root}(a) \vee \ldots$

$\neg\mathtt{parsnip}(a) \vee \neg\mathtt{raw}(a)$

$\neg\mathtt{carrot}(a)$

$\mathtt{parsnip}(a)$

$\mathtt{root}(a)$

$\mathtt{grated}(a)$

$\neg\mathtt{raw}(a)$

$\Box \pm \mathtt{raw}(a)$

$S'_1 \wedge T_2$

~~$\mathtt{DK} \wedge \mathtt{Source}(\theta)$~~	$\mathtt{DK} \wedge \mathtt{Target}(\theta)$
$\mathtt{DK}$	$\mathtt{DK}$
~~$\mathtt{Source}(\theta)$~~	$\mathtt{Target}(\theta)$
$\mathtt{starter}(\theta)$	$\mathtt{starter}(\theta)$
~~$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$~~	$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$
$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$	$\neg\mathtt{ing}(\theta, a) \vee \neg\mathtt{carrot}(a)$
$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$	$\neg\mathtt{gratedRawCarrot}(a) \vee (\ldots)$
$\mathtt{ing}(\theta, a)$	$\mathtt{gratedRawCarrot}(a) \vee \ldots$
~~$\mathtt{gratedRawCarrot}(a)$~~	$\neg\mathtt{root}(a) \vee \ldots$
~~$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$~~	$\mathtt{root}(a) \vee \ldots$
~~$\mathtt{carrot}(a)$~~	$\neg\mathtt{parsnip}(a) \vee \neg\mathtt{raw}(a)$
$\mathtt{raw}(a)$	$\neg\mathtt{carrot}(a)$
$\mathtt{grated}(a)$	$\mathtt{parsnip}(a)$
$\mathtt{carrot}(a) \vee \mathtt{parsnip}(a) \vee \mathtt{celery}(a)$	$\mathtt{root}(a)$
$\mathtt{root}(a)$	$\mathtt{grated}(a)$
$\neg\mathtt{parsnip}(a)$	$\neg\mathtt{raw}(a)$
~~$\Box\pm\mathtt{carrot}(a)$~~	$\Box\pm\mathtt{raw}(a)$

$S'_1 \wedge T_2$

~~$\mathtt{DK} \wedge \mathtt{Source}(\theta)$~~	$\mathtt{DK} \wedge \mathtt{Target}(\theta)$
$\mathtt{DK}$	$\mathtt{DK}$
~~$\mathtt{Source}(\theta)$~~	$\mathtt{Target}(\theta)$
$\mathtt{starter}(\theta)$	$\mathtt{starter}(\theta)$
~~$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$~~	$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$
$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$	$\neg\mathtt{ing}(\theta, a) \vee \neg\mathtt{carrot}(a)$
$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$	$\neg\mathtt{gratedRawCarrot}(a) \vee (\ldots)$
$\mathtt{ing}(\theta, a)$	$\mathtt{gratedRawCarrot}(a) \vee \ldots$
~~$\mathtt{gratedRawCarrot}(a)$~~	$\neg\mathtt{root}(a) \vee \ldots$
~~$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$~~	$\mathtt{root}(a) \vee \ldots$
~~$\mathtt{carrot}(a)$~~	$\neg\mathtt{parsnip}(a) \vee \neg\mathtt{raw}(a)$
$\mathtt{raw}(a)$	$\neg\mathtt{carrot}(a)$
$\mathtt{grated}(a)$	$\mathtt{parsnip}(a)$
$\mathtt{carrot}(a) \vee \mathtt{parsnip}(a) \vee \mathtt{celery}(a)$	$\mathtt{root}(a)$
$\mathtt{root}(a)$	$\mathtt{grated}(a)$
$\neg\mathtt{parsnip}(a)$	$\neg\mathtt{raw}(a)$
~~$\square\pm\mathtt{carrot}(a)$~~	~~$\square\pm\mathtt{raw}(a)$~~

$S_1' \wedge T_2$

~~$\mathtt{DK} \wedge \mathtt{Source}(\theta)$~~

$\mathtt{DK}$

~~$\mathtt{Source}(\theta)$~~

$\mathtt{starter}(\theta)$

~~$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$~~

$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$

$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$

$\mathtt{ing}(\theta, a)$

~~$\mathtt{gratedRawCarrot}(a)$~~

~~$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$~~

~~$\mathtt{carrot}(a)$~~

~~$\mathtt{raw}(a)$~~

$\mathtt{grated}(a)$

$\mathtt{carrot}(a) \vee \mathtt{parsnip}(a) \vee \mathtt{celery}(a)$

$\mathtt{root}(a)$

$\neg\mathtt{parsnip}(a)$

~~□±$\mathtt{carrot}(a)$~~

$\mathtt{DK} \wedge \mathtt{Target}(\theta)$

$\mathtt{DK}$

$\mathtt{Target}(\theta)$

$\mathtt{starter}(\theta)$

$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$

$\neg\mathtt{ing}(\theta, a) \vee \neg\mathtt{carrot}(a)$

$\neg\mathtt{gratedRawCarrot}(a) \vee (\ldots)$

$\mathtt{gratedRawCarrot}(a) \vee \ldots$

$\neg\mathtt{root}(a) \vee \ldots$

$\mathtt{root}(a) \vee \ldots$

$\neg\mathtt{parsnip}(a) \vee \neg\mathtt{raw}(a)$

$\neg\mathtt{carrot}(a)$

$\mathtt{parsnip}(a)$

$\mathtt{root}(a)$

$\mathtt{grated}(a)$

$\neg\mathtt{raw}(a)$

~~□±$\mathtt{raw}(a)$~~

$S''_1 \wedge T_2$

~~$\mathtt{DK} \wedge \mathtt{Source}(\theta)$~~

$\mathtt{DK}$

~~$\mathtt{Source}(\theta)$~~

$\mathtt{starter}(\theta)$

~~$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{gratedRawCarrot}(y)$~~

$\exists y\ \mathtt{ing}(\theta, y) \wedge \mathtt{vinaigrette}(y)$

$\mathtt{ing}(\theta, a) \wedge \mathtt{gratedRawCarrot}(a)$

$\mathtt{ing}(\theta, a)$

~~$\mathtt{gratedRawCarrot}(a)$~~

~~$\mathtt{carrot}(a) \wedge \mathtt{raw}(a) \wedge \mathtt{grated}(a)$~~

~~$\mathtt{carrot}(a)$~~

~~$\mathtt{raw}(a)$~~

$\mathtt{grated}(a)$

$\mathtt{carrot}(a) \vee \mathtt{parsnip}(a) \vee \mathtt{celery}(a)$

$\mathtt{root}(a)$

$\neg\mathtt{parsnip}(a)$

~~□±$\mathtt{carrot}(a)$~~

$\mathtt{DK} \wedge \mathtt{Target}(\theta)$

$\mathtt{DK}$

$\mathtt{Target}(\theta)$

$\mathtt{starter}(\theta)$

$\forall y\ (\neg\mathtt{ing}(\theta, y) \vee \neg\mathtt{carrot}(y))$

$\neg\mathtt{ing}(\theta, a) \vee \neg\mathtt{carrot}(a)$

$\neg\mathtt{gratedRawCarrot}(a) \vee (\ldots)$

$\mathtt{gratedRawCarrot}(a) \vee \ldots$

$\neg\mathtt{root}(a) \vee \ldots$

$\mathtt{root}(a) \vee \ldots$

$\neg\mathtt{parsnip}(a) \vee \neg\mathtt{raw}(a)$

$\neg\mathtt{carrot}(a)$

$\mathtt{parsnip}(a)$

$\mathtt{root}(a)$

$\mathtt{grated}(a)$

$\neg\mathtt{raw}(a)$

~~□±$\mathtt{raw}(a)$~~

- $S_1 \wedge T_1$ requires less repair than $S_1 \wedge T_2$
- In fact, $S_1 \wedge T_1$ requires strictly less repair than $S_1 \wedge T_j$ ($j \neq 1$)
- Therefore:

$$\texttt{CompletedTarget} = S_1' \wedge T_1$$

- In other words:
  to adapt your raw and grated carrots with vinaigrette,
  substitute carrots with celery
  (better than parsnips, since raw parsnips cannot be eaten)

Conclusion and Future Work

Conclusion

- Extension of the tableau method to adaptation in CBR
- Studied and implemented for $\mathcal{ALC}$
  (and propositional logic which is a fragment of $\mathcal{ALC}$)
- A prototype working with $\mathcal{ALC}$ has been developed.
- Complexity $\geq$ consistency test:
  - EXPTime-hard for $\mathcal{ALC}$
  - Much quicker for practical applications

Future Work

- Deeper study of the properties of this adaptation
- Links with other approaches of adaptation
- Towards an efficient implementation
  - What are the optimizations of the tableaux method that are compatible with our extension?
- Generalisation to more expressive DLs
  - E.g., to $\mathcal{ALC}(\mathtt{D})$ whith a numerical concrete domain