Case Adaptation with Modal Logic: The Modal Adaptation

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Abstract. In the CBR cycle, adaptation is the process that aims at filling the "gap" between the current situation and a previous situation retrieved from memory. In this paper, tools from modal logic are investigated to come up with a "modal" modeling of adaptation. The intuition is that adaptation dynamically extends an agent's beliefs about the world so that it can envision possible worlds in which the target constraints are satisfied. Following this idea, the adaptation process is formulated as a model construction problem in the S4 modal logic.

1 Introduction

Case-based reasoning (CBR [19]) consists in reusing past experiences, called *source cases* (denoted by `Srce`), in order to create a new representation, called the *target case* (denoted by `Tgt`), satisfying a set of constraints $\mathcal{Q}$. A CBR system follows a set of steps such as identifying the current situation, retrieving a past case, adapting this case to fit the current situation, evaluating the proposed solution, and updating the system's knowledge to learn from experience [1]. The adaptation step is the part of the CBR cycle in which the retrieved source case `Srce` is modified in order to create a target case `Tgt` that satisfies the set of constraints $\mathcal{Q}$.

In this paper, tools from modal logic are investigated to come up with a "modal" modeling of adaptation. The intuition is that adaptation dynamically (by this we mean, during the reasoning process) extends an agent's beliefs about the world so that it can envision possible worlds in which the target constraints are satisfied. Following this idea, the adaptation process is formulated as a model construction problem in the S4 modal logic. Then, to ensure that these new possible worlds are similar to the ones that were already witnessed by the agent (or, said differently, that learning the target case would result in a minimal change in the agent's knowledge), we propose to model adaptation as a planning task, so that applying this minimality principle amounts to solving the frame problem in a modal logic of actions.

The paper is organized as follows. The next section introduces the basic ideas of the method through a motivating scenario. Sec. 3 gives some basic definitions and hypotheses about CBR. Sec. 4 recalls basic notions about modal logic and Sec. 5 presents a formalization of adaptation in the modal logic S4. Sec. 6 presents a modeling of adaptation as a planning problem and Sec. 7 its formalization in the $\mathcal{LAPD}$ action logic.

Sec. 8 presents a solution of the introductory example. Sec. 9 situates the approach among related works. Sec. 10 concludes the paper and gives future work.

2 Idea of the Method

Let us consider the following example in the cooking domain, inspired from [12].

Léon is about to invite Thècle to dinner. Léon has some experience about cooking meals for his hosts. In particular, he remembers that some time ago he had proposed to Simone a meal with salad (denoted by the propositional variable s) and beef (b): $\texttt{Srce} = s \wedge b$. Léon is quite confident in his ability to cook this meal well, and he thinks Thècle might like it, so he would like very much to cook it for Thècle. But Léon knows that Thècle is vegetarian (v). So if this meal was to be cooked for Thècle, it would need to be adapted into a vegetarian version.

In this cooking scenario, performing adaptation would mean answering the question: "How can Léon reuse his previous experience with Simone to make up a vegetarian meal for Thècle?". In the following, we'll see the main principles on which modal adaptation relies to solve this issue.

Idea #1: Use possible-worlds semantics to reason upon the case universe. This corresponds to the intuition that by committing to some adaptation knowledge, a CBR agent envisions new possible states of the world, each of which corresponds to a potential modification of the retrieved source case. People often do little adaptation, so an adaptation by copy (i.e., setting $\texttt{Tgt} = \texttt{Srce}$) might be sufficient if the retrieved source case $\texttt{Srce}$ already satisfies the constraints of $\mathcal{Q}$. Otherwise, adaptation knowledge is used to find a possible world (or many) in which the target constraints $\mathcal{Q}$ are satisfied. If there are many solutions, the latter can be ordered according to a performance measure.

Léon knows beef is meat ($b \to m$) and considers that a vegetarian meal is a meal with no meat ($m \leftrightarrow \neg v$). Adaptation by copy would not be sufficient here, because cooking the same meal (i.e., simply setting $\texttt{Tgt} = \texttt{Srce}$) would be inconsistent with the constraints imposed on the meal (the meal would not be vegetarian). To create a meal for Thècle, he would need to imagine how to modify the original recipe so that the resulting meal is vegetarian. Among the (possibly many) vegetarian adaptations of the meal, some would be preferred by Léon because they are more tasty to him.

Idea #2: Decompose adaptation into a sequence of adaptation actions. Decomposing adaptation in simple adaptation steps captures the fact that the target case $\texttt{Tgt}$ is produced by a series of local modifications of the retrieved source case $\texttt{Srce}$. This is often the case when adaptation knowledge comes as a set of transformation operators.

Léon knows many ways to adapt a recipe. For example, he knows that hashed beef can be replaced by the same amount of silken tofu pureed. He also knows a few ingredients, like chives or sesame seeds that could complement well a tofu salad. Léon needs to imagine a sequence of such modifications of the original recipe for which the resulting meal is vegetarian. Among all possible sequences of modifications of the recipe Léon can imagine that verify the target constraints, the one chosen by Léon consists in replacing beef (b) by tofu (t) in the original recipe, and then adding chives (c). So the retained solution is $\texttt{Tgt} = s \wedge t \wedge c$.

3 CBR: Definitions and Hypotheses

Case-based inference is a kind of hypothetical reasoning that aims at interpreting a new situation w.r.t. the agent's prior memory and knowledge. These notions are formalized as follows.

3.1 Agent's Memory and Knowledge

Agent's memory. Let $\mathcal{U}$ be a set (called the *case universe*). An element s of $\mathcal{U}$ is called a *case* and represents a possible experience. Among the cases of $\mathcal{U}$, some actually happened, were witnessed by the agent and retained in memory. These cases, the *case base*, constitute the memory of the agent and are represented as a set $\mathcal{S}$ (Fig. 1). An element `Srce` of $\mathcal{S}$ is called a *source case*.

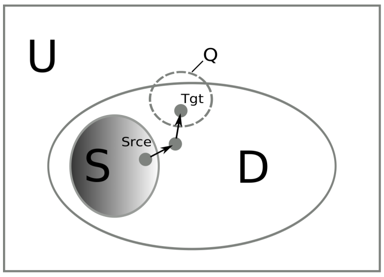

Fig. 1. A schematic view of the agent's memory and knowledge, with (U) the case universe, (S) the case base, (D) the cases consistent with the domain knowledge.

Agent's domain knowledge. To model the agent's domain knowldge, a subset $\mathcal{D}$ of $\mathcal{U}$ is introduced to represent the set of cases that the agent knows to be admissible given her knowledge of the application domain.

Adaptability relation. What enables the agent to go beyond its memory and envision new possible cases is adaptation knowledge, which is modeled by a binary relation $\rightarrow_A$, called the *adaptability* relation between cases. For $(s,s') \in \mathcal{U} \times \mathcal{U}$, $s \rightarrow_A s'$ holds iff s can be adapted into s'. The $\rightarrow_A$ relation is reflexive (s can be adapted into itself), and transitive (if s can be adapted into s' and s' can be adapted into s'', then s can be adapted into s''). The $\rightarrow_A$ relation is assumed to be known. Adaptation knowledge is assumed to have been acquired, either "on the fly" (during the reasoning process) or pre-encoded e.g., in a set of adaptation rules or operators.

CBR knowledge base. A CBR knowledge base $\mathcal{K} = \{\mathcal{U}, \mathcal{S}, \mathcal{D}, \rightarrow_A\}$ is a relational structure on $\mathcal{U}$, i.e., a set $\mathcal{U}$ (the case universe) equipped with a set of relations $\mathcal{S}$, $\mathcal{D}$, and $\rightarrow_A$.

3.2 CBR Inference

The agent's perception of the current situation is modeled by a subset $\mathcal{Q}$ of $\mathcal{U}$ (drawn as a dashed circle on Fig. 1). The CBR inference consists in constructing a target case `Tgt` in order to account for this current situation. This construction follows a set of rationality principles:

(1) `Tgt` is consistent with the agent's perception of the current situation (`Tgt` $\subseteq \mathcal{Q}$);
(2) `Tgt` is consistent with the agent's domain knowledge (`Tgt` $\subseteq \mathcal{D}$);
(3) learning `Tgt` results in a minimal change in the agent's knowledge;
(4) learning `Tgt` optimizes a performance measure P.

(1) express the fact that the solution must be consistent with the agent's perception. (2) assumes that it is also consistent with the agent's knowledge of the domain, so that the latter need not be revised during learning. (3) is a minimality principle, that requires that the cognitive effort to make up the solution from existing memory and knowledge should be as low as possible. (4) assumes the existence of a performance measure P, that is used to estimate the quality of the solution from the perspective of the end-user.

4 Reasoning on Relational Structures: Modal Logic

Up to now, no language was introduced to represent cases. In this section, cases are represented in propositional logic. Due to the relational nature of CBR knowledge bases, modal logic seems to be a good formalism to come up with a modeling of adaptation.

Modal logic [5] is a formalism for working on relational structures. Given a set of propositional symbols $\Phi = \{p, q, \ldots\}$, and a modality symbol $\Box$, the set of well-formed formulas of the basic multimodal language is defined as follows:

$$\phi \ ::= \ p \mid \bot \mid \neg \phi \mid \phi \vee \psi \mid \Box \phi$$

for all $p \in \Phi$. Connectors $\wedge$, $\rightarrow$, and $\leftrightarrow$ can be obtained as follows: $\phi \wedge \psi ::= \neg(\neg \phi \vee \neg \psi)$, $\phi \rightarrow \psi ::= \neg \phi \vee \psi$, and $\phi \equiv \psi ::= (\phi \rightarrow \psi) \wedge (\psi \rightarrow \phi)$. $\top$ abbreviates $\neg \bot$. A formula ϕ is said to be classical if it contains no modalities.

Such a language is interpreted on models (called Kripke models). A model $\mathcal{M}$ is a triple $(W, R_\Box, V)$ where W is a non-empty set of *possible worlds* (or *states*), $R_\Box$ is a binary relation on W (called an *accessibility relation*), and V (the *valuation*) is a function whose domain is Φ and whose range is 2^W, that states for each propositional symbol in which worlds it is true. A Kripke model is thus inherently a relational structure $(W, R_\Box, V(p), V(q), \ldots)$ that equips W with a binary relation $R_\Box$ and a set of unary relations $V(p)$, $p \in \Phi$ [4]. To talk about a particular world w_0, one may use a *pointed model* $(\mathcal{M}, w_0)$. Formulas are interpreted on models as follows. For a model $\mathcal{M}$ and a world $w \in W$ we write $\mathcal{M}, w \Vdash \phi$ for "the formula ϕ is true at world w in a model $\mathcal{M}$". We define $\mathcal{M}, w \Vdash \phi$ by induction:

$$\begin{array}{ll}
\mathcal{M}, w \Vdash p & \text{iff } \ w \in V(p) \quad \text{where } p \in \Phi \\
\mathcal{M}, w \Vdash \bot & \text{never} \\
\mathcal{M}, w \Vdash \neg\, \phi & \text{iff not } \mathcal{M}, w \Vdash \phi \\
\mathcal{M}, w \Vdash \phi \vee \psi & \text{iff } \ \mathcal{M}, w \Vdash \phi \ \text{ or } \ \mathcal{M}, w \Vdash \psi \\
\mathcal{M}, w \Vdash \Box\, \phi & \text{iff } \ \forall\, w'(w R_{\Box}\, w' \text{ implies } \mathcal{M}, w' \Vdash \phi)
\end{array}$$

Alternatively, $\diamond\, \phi$ abbreviates $\neg\, \Box\, \neg\, \phi$. Its semantics is then given by:

$$\mathcal{M}, w \Vdash \diamond\, \phi \qquad \text{iff } \ \exists\, w'(w R_{\diamond}\, w' \text{ implies } \mathcal{M}, w' \Vdash \phi)$$

Among the questions to be answered about modal logic formulas and their truth values w.r.t. models, the *satisfiability problem* is formulated as: given a formula ϕ, is there a model $\mathcal{M}$ and a world w such that $\mathcal{M}, w \Vdash \phi$? Related to this problem is the *model construction problem*, which consists in computing such a model. A formula ϕ is *valid* (noted $\Vdash \phi$) if it is true for all models and worlds.

The axiomatization is made up of the following axiom schemas and inference rules:

PL. All tautologies of classical propositional logics are valid
MP. From ϕ and $\phi \rightarrow \psi$ infer ψ
K($\Box$)**.** $\Box(\phi \rightarrow \psi) \rightarrow (\Box\phi \rightarrow \Box\psi)$
G($\Box$)**.** From ϕ infer $\Box\phi$

PL and **MP** ensure that the language extends propositional logic. Together with **K** (*Distribution axiom*) and **G** (*Generalization Rule*), they form the minimal modal logic K. **K** says that the agent "knows the consequences of his knowledge". **G** says that if ϕ is valid, it is safe to infer $\Box\, \phi$ (a valid formula is in particular true in all worlds the agent considers possible).

5 Modal Adaptation

In this section, adaptation is formulated as a model construction problem in the $S4$ modal logic.

In a possible-world semantics, each world w of W models a possible "state of affairs", so it is used to model the case universe $\mathcal{U}$, i.e., $W = \mathcal{U}$. A source case is represented by a classical formula `Srce` and by a world $w_{\texttt{Srce}}$ in which this formula is true ($w_{\texttt{Srce}} \Vdash \texttt{Srce}$). The modal operator $\Box$ is used to represent laws, that is, facts that are true in all situations. As a result, the domain knowledge `DK` is expressed as a set of formulas of the form $\Box\, \phi$, where ϕ is classical. The modal operator $\Box$ is also used to represent the adaptability relation: $R_{\Box} = \rightarrow_A$. The reflexive and transitive properties of $\rightarrow_A$ are ensured by adding constraints to the admissible models, in the form of two axioms:

T($\Box$)**.** $\Box\phi \rightarrow \phi$
4($\Box$)**.** $\Box\phi \rightarrow \Box\Box\phi$

The logic K together with the additional axioms **T** (the *Reflexivity* axiom) and **4** (the *Transitivity* axiom) make the logic $S4$. Target constraints $\mathcal{Q}$ are expressed as a *goal*, i.e., a formula of the form $\diamond\,\mathtt{Q}_{\mathtt{Tgt}}$, where $\mathtt{Q}_{\mathtt{Tgt}}$ is classical. The adaptation of a source case $\mathtt{Srce}$ consists in constructing a model for the following formula:

$$\Vdash (\mathtt{Srce} \wedge \mathtt{DK} \wedge \mathtt{AK}) \rightarrow \diamond \mathtt{Q}_{\mathtt{Tgt}} \qquad \text{(Adaptation of } \mathtt{Srce}\text{)}$$

Solving this equation ensures that when the constraints of the domain and adaptation knowledge hold, there exists a world reachable through adaptation knowledge in which the target constraints $\mathcal{Q}$ are verified.

However, the above equation does not account for the two last rationality principles of the CBR inference: (3) principle of minimal change, and (4) optimization of a performance measure. These principles need to be further specified, e.g., with additional constraints on the models. There are many ways to ensure (3). One of them is to define a distance between cases that is assumed to reflect the learning effort, and to use this distance to retrieve the most similar source case. Another way to apply belief revision techniques to revise the retrieved source case, as in [12]. In this paper, we choose to express adaptation as a planning problem, so that enforcing (3) is reduced to solving the frame problem in an action language.

6 Modeling Adaptation as Planning

In this section, adaptation is modeled as a planning problem, i.e., as a problem of finding a sequence of actions that leads from a given initial state to a given goal state.

Adaptation as a planning problem. When adaptation knowledge is given as a set Γ of adaptation actions, the adaptation of a retrieved source case $\mathtt{Srce}$ can be formulated as a planning problem in the case universe $\mathcal{U}$: each adaptation action $\alpha \in \Gamma$ is modeled by a binary relation $\xrightarrow{\alpha}$, with $\xrightarrow{\alpha} \subseteq \rightarrow_A$. Adapting a retrieved source case $\mathtt{Srce}$ consists in finding a sequence $\alpha_1, \alpha_2, \ldots, \alpha_n$ of actions (with $\alpha_i \in \Gamma$) that leads from a given initial state (the retrieved source case $\mathtt{Srce}$) to a given goal state (a target case $\mathtt{Tgt}$ with $\mathtt{Tgt} \in \mathcal{D} \cap \mathcal{Q}$). That is, to construct a path:

$$\mathtt{Srce} = s_0 \xrightarrow{\alpha_1} s_1 \xrightarrow{\alpha_2} s_2 \ldots s_{n-1} \xrightarrow{\alpha_n} s_n = \mathtt{Tgt}$$

with $\mathtt{Srce} \in \mathcal{S}$, $\alpha_i \in \Gamma$, $(s_i, s_{i+1}) \in \xrightarrow{\alpha_{i+1}}$, and $\mathtt{Tgt} \in \mathcal{D} \cap \mathcal{Q}$.

The frame problem. The frame problem [14] is a hypothesis of inertia that states that the environment does not change arbitrarily when actions are executed. An action should leave the world unchanged except for the sole properties of what it acts upon. Applied to adaptation, this means that adaptation actions should leave a case unchanged except for the properties of the case that it acts upon. For example, replacing apple by pear in a recipe should be done by preserving the quantities of all other ingredients.

7 Formalization using the $\mathcal{LAPD}$ Modal Language

A formalization is presented using the logic $\mathcal{LAPD}$, which extends the logic of action and plans ($\mathcal{LAP}$) to provide a solution to the frame problem.

The $\mathcal{LAP}$ modal language. $\mathcal{LAP}$ [7] is a propositional multimodal logic that uses a modal operator $[\alpha]$ for each atomic action α and a modal operator $\Box$ which is used to represent laws, that is, facts that are true in all situations. $\langle\alpha\rangle$ abbreviates $\neg\,[\alpha]\neg\,\phi$. $\langle\alpha_1;\alpha_2;\ldots;\alpha_n\rangle$ abbreviates $\langle\alpha_1\rangle\langle\alpha_2\rangle\ldots\langle\alpha_n\rangle$. The informal meaning of $[\alpha]\phi$ is "ϕ is true after the execution of action α", while the meaning of $\Box\phi$ is "ϕ is always true, independently of the state we are in". The axiomatization is made up of the axiom schemas and inference rules of Sec. 4 and Sec. 5, plus:

K($[\alpha]$). $[\alpha](\phi \to \psi) \to ([\alpha]\phi \to [\alpha]\psi)$
I($\Box$,$[\alpha]$). $\Box\phi \to [\alpha]\phi$

K is the distribution axiom for $[\alpha]$ modalities and **I** says that $\Box$ interacts with every $[\alpha]$ in the sense that $\Box\,\phi \;\to\; [\alpha]\,\phi$. The inference rule **G**($[\alpha]$) can be derived from **G**($\Box$) and **I**($\Box$,$[\alpha]$), so the logic of $[\alpha]$ is S4. From **4**($\Box$) and **I**($\Box$,$[\alpha]$) we can prove $\Box\,A \to [\alpha_1][\alpha_2]\ldots[\alpha_n]A$ for any $n \geq 1$, which reflects the informal meaning that we want for $\Box\,A$: "A is true at any state, after any sequence of actions".

Formalization of adaptation in $\mathcal{LAP}$. A modality $[\alpha]$ is introduced for each adaptation action $\alpha \in \Gamma$. Adaptation knowledge ($\mathtt{AK}$) is made of two axioms for each action α:

(*effect law* for α)
 an axiom of the form $\Box\,(A \to [\alpha]B)$ where A (resp., B) is a conjunction of literals stating which are the preconditions (resp., the effects) of executing the action α;
(*executability law* for α)
 the axiom $\Box\,\langle\alpha\rangle\top$, which says that the action α is always executable.

Adaptation of a source case $\mathtt{Srce}$ is a model construction task. We wish to find pointed models $(\mathcal{M}, w_{\mathtt{Srce}})$ and sequences of actions $\alpha_1, \alpha_2, \ldots, \alpha_n$ (with $\alpha_i \in \Gamma$) such that:

$$\mathcal{M}, w_{\mathtt{Srce}} \Vdash_{\mathcal{LAP}} \langle\alpha_1;\alpha_2;\ldots;\alpha_n\rangle(\mathtt{DK} \wedge \mathtt{Q}_{\mathtt{Tgt}}) \qquad \text{(Adaptation of } \mathtt{Srce} \text{ in } \mathcal{LAP})$$

Handling the frame problem: $\mathcal{LAPD}$. The solution adopted in [6] to handle the frame problem in $\mathcal{LAP}$ is to introduce a ternary relation Δ, called the *contextual dependence* relation. which states what literals are subject to change as a result of each action and in which context. For α an action, p a propositional symbol, and C a classical formula, $\Delta(\alpha, p, C)$ is noted "α $\mathtt{influences}$ p $\mathtt{if}$ C" and means that the truth value of p can be changed by the action α in the context C. Thus, all literals that are not explicitely declared as subject to change see their truth value preserved after the execution of the action. The interested reader is refered to [6] for more details on the $\mathcal{LAPD}$ language.

Implementation with modal tableaux. As noted in [6], the $\mathcal{LAPD}$ axiom schemas and inference rules can be easily translated into graph rewriting rules for the LoTREC [8] theorem prover. LoTREC applies a stepwise graph rewriting approach to generate all models of a formula. It starts with a labelled graph containing initially a node labelled with a formula, and applies graph rewriting rules to reflect the constraints imposed by the logic under study on its models. The theoretical complexity is EXPTIME but it strongly depends on the number of adaptation actions and their preconditions. Besides, it seems safe to limit the length of the generated adaptation paths (e.g., set an upper bound to 3 or 4) since a long adaptation path means a low similarity.

8 The Cooking Example Solved

In this section, a solution of the cooking example proposed at the beginning of the paper is presented.

In this example we start with the following knowledge base:

$$\begin{aligned}
&\texttt{Srce} = s \wedge b\\
&\texttt{DK} = \{\Box\,(b \to m),\ \Box\,(v \leftrightarrow \neg\, m)\}\\
&\texttt{AK} = \{\Box\,(m \to [\alpha_0]\,(t \wedge \neg\, m)),\ \Box\,\langle\alpha_0\rangle\top,\ \Box\,(s \wedge t \to [\alpha_1]\,c),\ \Box\,\langle\alpha_1\rangle\top\}\\
&\Delta = \{\alpha_0 \texttt{ influences } t \texttt{ if } m, \alpha_0 \texttt{ influences } m \texttt{ if } m\\
&\qquad \alpha_0 \texttt{ influences } b \texttt{ if } m,\ \alpha_1 \texttt{ influences } c \texttt{ if } s \wedge t\}
\end{aligned}$$

and the goal of adaptation is to solve the following equation:

$$\models_{\mathcal{LAPD}} (\texttt{Srce} \wedge \texttt{DK} \wedge \texttt{AK}) \to \diamond v$$

The constraints $\mathcal{Q} = v$ imposed on the target case $\texttt{Tgt}$ express the fact that the resulting meal must be vegetarian. The retrieved source case $\texttt{Srce}$ represents a meal with salad (s) and beef (b). The domain knowledge $\texttt{DK}$ consists in two laws: the first one expresses that beef (b) is meat (m) and the second one that a vegetarian meal is a meal that contains no meat. Adaptation knowledge consists in two actions α_0 and α_1: α_0 can be applied to replace meat by tofu, and α_1 to add chives to a tofu salad. As for action dependencies, α_0 can only modify the truth value of t and of all known types of meats (that is, b and m), and α_1 can only modify the truth value of chives (c).

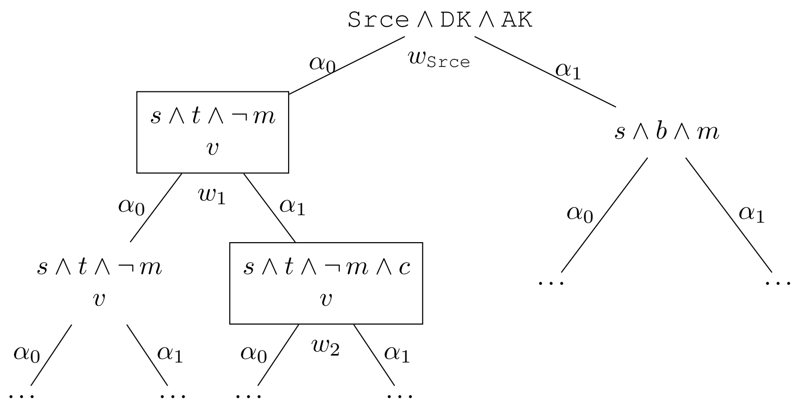

Fig. 2. An excerpt of the graph constructed by LoTREC in the cooking example.

Fig. 2 shows an excerpt of the graph constructed by LoTREC for this knowledge base. The root node corresponds to the world $w_{\texttt{Srce}}$ (the retrieved source case $\texttt{Srce}$)

and each node correspond to a possible world (a potential case). Edges correspond to transition between worlds (adaptation actions $\alpha_i \in \Gamma$). The two boxed nodes correspond to some worlds w_1 and w_2 where the constraints $\mathcal{Q}$ are satisfied (v is true), so the formulas that label these nodes describe possible target cases `Tgt`. If no search strategy is specified, the graph construction task may never end: all sequences $\alpha_1\alpha_2\ldots\alpha_n$ of actions ($\alpha_i \in \Gamma$) are tried, for all $n \in \mathbb{N}$.

9 Related Work

Modal adaptation belongs to the constraint-based adaptation approaches in that adaptation is reduced to a model construction problem in a suitable logical formalism. Constraint-based adaptation views adaptation as a constraint satisfaction problem. As a global approach, constraint-based adaptation fails to capture local modifications of the source case but considers at once all possible solutions of an adaptation and chooses among those by applying an optimization principle. Adaptation knowledge comes as a set of constraints which reflect the allowed combinations for `Srce`, `Tgt`, and `DK` (the domain knowledge). In revision-based adaptation [12] for example, the optimization principle is to retain as much as possible features of `Srce` while keeping the system's knowledge consistent (principle of minimal change). Other examples of constraint-based adaptations include adaptation using CSP techniques [18], adaptation as an optimization problem [20]. One limitation of constraint-based adaptations is that they are tailored to performing only a single modification of the source case, thus making it difficult to incorporate domain-dependent adaptation rules [17].

However, in modal adaptation, CBR knowledge bases are modeled as relational structures, which makes it natural to express adaptation as a sequence of atomic actions. By doing so it borrows from another type of approach, that we will call *rewriting-based* adaptation, which decomposes adaptation into a sequence of simple adaptation steps. Rewriting-based adaptation views the adaptation space as an abstract reduction system ($\mathcal{U}$,$\rightarrow$) where $\mathcal{U}$ is a set of states (the case universe) and $\rightarrow$ is a binary relation on $\mathcal{U}$ (the adaptability relation) which is structured by adaptation knowledge. Examples of adaptations following this idea include adaptation by abstraction/specialization [2, 3] case-based substitution [9, 15], adaptation using transformation operators [16, 10], adaptation by reformulation [11, 13]. Decomposing adaptation in simple adaptation steps better captures the fact that `Tgt` is produced by a series of local modifications of `Srce` but requires that a search strategy is specified, be it an A* search procedure or a search for a path of minimal cost [3]. It also allows to come up with an explanation of the proposed solution in terms of the different substeps followed to reach it. Besides, it enables to chain complex adaptation rules such as "in non-sweet salad dishes, replace vinegar by lemon and add sugar".

10 Conclusion and Future Work

In this paper, CBR knowledge bases are modeled as relational structures and adaptation is expressed as a standard reasoning task of modal logic. The objective is to design constraint-based adaptations that are more intuitive and in which complex adaptation rules can be chained to create a solution. An advantage of doing so is that it allows to reuse existing theorem provers to compute all candidate solutions. Future work include an implementation in the LoTREC theorem prover and some extensive testing.

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