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A Unified 2D Representation of Fuzzy Reasoning, CBR, and Experience Based Reasoning

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Abstract

Fuzzy reasoning, case-based reasoning (CBR) and experience-based reasoning (EBR) or natural reasoning have been seriously studied for years. However, these studies essentially can be considered as a 1-dimensional approach, because their reasoning paradigm is 1-dimensional. This paper will propose a 2-dimensional (2D) approach that represents fuzzy reasoning, CBR, and EBR in a unified way. This approach also integrates many reasoning paradigms such as abduction, deduction and similarity-based reasoning into a unified treatment. The proposed approach will facilitate research and development of fuzzy reasoning, knowledge/experience management, knowledge-based systems, and CBR.

Keywords

Fuzzy reasoning, case-based reasoning, experience-based reasoning, abduction, 2-dimensional (2D) representation, experience management

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A Unified 2D Representation of Fuzzy Reasoning, CBR, and Experience Based Reasoning

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Abstract: Fuzzy reasoning, case-based reasoning (CBR) and experience-based reasoning (EBR) or natural reasoning have been seriously studied for years. However, these studies essentially can be considered as a 1-dimensional approach, because their reasoning paradigm is 1-dimensional. This paper will propose a 2-dimensional (2D) approach that represents fuzzy reasoning, CBR, and EBR in a unified way. This approach also integrates many reasoning paradigms such as abduction, deduction and similarity-based reasoning into a unified treatment. The proposed approach will facilitate research and development of fuzzy reasoning, knowledge/ experience management, knowledge-based systems, and CBR.

Keywords: Fuzzy reasoning, case-based reasoning, experience-based reasoning, abduction, 2-dimensional (2D) representation, experience management.

1 Introduction

Fuzzy reasoning [21], case-based reasoning (CBR) [13] and experience-based reasoning (EBR) [18] or natural reasoning and also traditional reasoning paradigms such as deduction [9], abduction [17] and similarity-based reasoning (SBR) [11] have been seriously studied in computer science and artificial intelligence (AI) with many applications in engineering [21], commerce [11], business and management [12], to name a few. However, these studies essentially can be considered as a 1-dimensional (1D) approach, because the fundamental inference rule of each of these reasoning paradigms is represented in a 1D way. This 1D representation limits their own development and isolates them from each other, although some interrelationships between fuzzy reasoning and CBR have been studied [13]. This paper will fill this gap by proposing a 2-dimensional (2D) approach that represents fuzzy reasoning, CBR, and EBR in a unified way. This approach also integrates many reasoning paradigms such as abduction, deduction and SBR into a unified treatment. The proposed approach will facilitate research and development of fuzzy reasoning, knowledge/experience management, knowledge-based systems, and CBR.

2 Fundamentals

Any intelligent system can only give the answers to problems in a *possible world,* which corresponds to a scenario in the real world [11]. Based on this idea, the possible world of problems, W_p, and the possible world of solutions, W_s, are the whole world of an agent [9] to use an intelligent systems to do everything that he can. If an agent considers a CBR system as a function h from W_p to W_s, it is meaningless to discuss the image of $h(x)$ if $x \notin W_p$. Therefore, the agent can only know and work in the world $W_p \times W_s$. For example, in a CBR e-sale system, the possible world of problems, W_p, might consist of [5]:

- Properties of goods
- Normalized queries of customers
- Knowledge of customer behavior
- General knowledge of business, and so on.

And the possible world of solutions, W_s, consists of:

- Price of goods
- Customized answers to the queries of customers
- General strategies for attracting customers to buy the goods, and so on.

It should be noted that if we assume that P is the subset of problem or antecedent descriptions and Q is the subset of solution or action descriptions [8], then it is obvious that P and Q are subsets of W_p and W_s respectively. A conditional proposition, $p \to q$, can be denoted as an ordered pair (p, q), where $p \in P$ and $q \in Q$. Further, if we assume that W_p is a dimensional world, then W_s is another dimensional world. Therefore, we can use a coordinate system to represent these two dimensional worlds consisting of W_p and W_s.

3 A 2D Representation of Fuzzy Reasoning

In propositional logic, reasoning basically belongs to deductive reasoning. Reasoning is performed by a number of inference rules [11], in which the most commonly used is *modus ponens* (MP):

$$\begin{array}{l} P \to Q \\ \underline{P \qquad} \\ \therefore\ Q \end{array} \tag{1}$$

where P and Q represent compound propositions. One of the most important features of this reasoning is that it satisfies the transitive law, and then this reasoning can be performed as many times or steps as required with the preservation of validity of the result of the inference. This means that the reasoning in traditional logic is a multistep reasoning.

Fuzzy reasoning in fuzzy logic is basically generalized from the deductive reasoning in traditional logic with the exception of its computational process [17]. Its reasoning is based on the following *generalized modus ponens* [13]:

$$\begin{array}{l} P \rightarrow Q \\ \underline{P'} \\ \therefore\ Q' \end{array} \tag{2}$$

where P and Q represent fuzzy propositions, P' is approximate to P, that is, $P' \sim P$. Model (2) is also commonly represented in the following form in fuzzy logic [21]:

$$\begin{array}{l} \text{If } x \text{ is } P \text{ Then } y \text{ is } Q \\ \underline{x \text{ is } P' \qquad\qquad} \\ \therefore\ y \text{ is } Q' \end{array} \tag{3}$$

For instance,

$$\begin{array}{ll} \text{IF a tomato is red} & \text{THEN the tomato is ripe} \\ \underline{\text{This tomato is very red}} & \\ \text{Conclusion:} & \text{This tomato is very ripe} \end{array} \tag{4}$$

As we know, inference rules play a central role in reasoning paradigms of AI. For example, one of the main inference rules for fuzzy reasoning is the generalized modus ponens Model (2). Based on the discussion in Section 2, Model (2) can be represented in a 2-dimensional (2D) way as shown in Fig. 1, where the node pointed to by an arrow represents the conclusion of the inference, the small cycle denotes the (fuzzy) proposition p'. Further, the point denoted by (p', q'), $(\neg p', q')$ $(\neg p', \neg q')$ and $(p', \neg q')$ will be in the 1st, 2nd, 3rd and 4th quadrant respectively (Similar explanations are valid for other figures in this paper). Therefore, fuzzy reasoning can be considered as a first quadrant reasoning because it only takes the 1st quadrant of the coordinate system.

For fuzzy reasoning, (p, q) means $p \rightarrow q$, and p' is a fuzzy proposition approximate or close to fuzzy proposition p, and then the conclusion inferred from the fuzzy reasoning based on Model (2) is q'.

It should be noted that when $p \equiv p'$, then $q \equiv q'$, the generalized *modus ponens* will degenerate to classic *modus ponens.* The 2D representation of *modus ponens* will be simpler than that in Fig. 1, which we do not discuss any more.

4 A 2D Representation of CBR and SBR

CBR is a reasoning paradigm based on previous experiences or cases that are the operational definition of experiences; that is, a case-based reasoner solves new problems by adapting solutions that were used to solve old problems [13]. Therefore, we call CBR a form of experience-based reasoning [11], briefly,

$$\text{CBR:= Experience-based reasoning} \tag{5}$$

CBR is based on two principles about the nature of the world [6]. The first principle is that the world is regular: similar problems have similar solutions. Consequently, solutions to similar prior problems are a useful starting point for new problem solving. The second principle is that the types of problems that an agent encounter tend to recur. Hence, future problems are likely to be similar to current problems. When the two principles hold, CBR is an effective reasoning paradigm.

The first principle also implies that EBR is based on the experience principle, for example, in business activities it is usually true that “Two cars with similar quality features have similar prices.” However, from a logical viewpoint, this is a kind of similarity-based reasoning (SBR) [4]. In other words, SBR can be considered as a special and operational form of EBR. Therefore, CBR can be considered as a kind of SBR from a logical viewpoint [13].

$$\text{CBR: = Similarity-based reasoning} \tag{6}$$

Similar to the inference engine in expert systems (ESs), one can also use a CBR engine (CBRE) to denote the inference engine in CBR system (CBRS); that is,

$$\text{CBRS} = \text{CB} + \text{CBRE} \tag{7}$$

where CB is the case base. CBRE performs similarity-based reasoning, while the inference engine in ESs performs traditional deductive reasoning.

In CBR, similarity based reasoning is realized by the following model [13].

$$\frac{\begin{array}{c} P \to Q \\ P' \end{array}}{\therefore \;\; Q'} \tag{8}$$

where, $P \in W_p$ and $Q \in W_s$ represent a problem description and the corresponding solution description respectively; that is, P' is the current problem description which is similar to P, $P' \sim P$, $P \to Q$ is a case stored in the CB. The CBR is to find a solution, Q', to the current problem P', and $Q' \sim Q$. Therefore, CBR or SBR based on Model (8) can also be represented in a 2D way as shown in the Fig. 2.

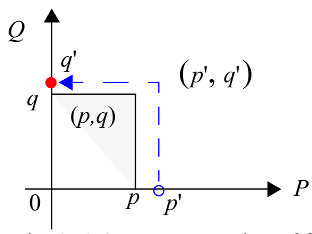

Fig. 1. A 2D representation of fuzzy reasoning

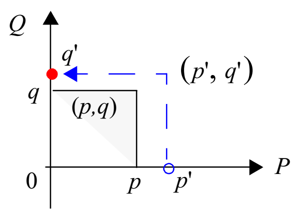

Fig. 2. A 2D representation of CBR and SBR

In this 2D representation, p' and p, q' and q, and (p, q) are the concrete application form of P' and P, Q' and Q, and $P \to Q$ in CBR respectively.

Comparing Fig. 1 with Fig. 2, we find that the 2D representation of fuzzy reasoning and that of CBR and SBR are the same, although they have different semantic interpretations and operational algorithms for performing their own reasoning paradigms based on different real world scenarios. Further, CBR and SBR can also be considered a first quadrant reasoning.

It should be noted that the above 2D representation of CBR is an abstract form of the Leake’s model of CBR [4][6].

Based on the above examination, the interesting question arises: Are there other quadrant reasoning paradigms?

5 A Unified 2D Representation of EBR

Experience-based reasoning (EBR) is a reasoning paradigm based on prior experiences. EBR as a technology has been used in many applications [12][14]. Taking into account research and development of CBR, Sun and Finnie [12][18] proposed eight different inference rules for EBR which cover all possibilities of EBR, as shown in Table 1. These inference rules are listed in the first row, and their corresponding general forms with respect to classic logic are shown in the second row respectively [12]. Their corresponding fuzzy logic based forms are shown in the third row respectively [16], which can also be considered as similarity based inference rules respectively taking into account SBR. Because four of them, *modus ponens* (MP), *modus tollens* (MT), *abduction* and *modus ponens with trick* (MPT) are well-known in AI and computer sciences [9][10][11], we do not go into them any more, and focus on reviewing two of the other four inference rules in some detail.

Table 1: Experience-based reasoning: Eight inference rules.

MP	MT	abduction	MTT	AT	MPT	IMP	IMPT
P, $P \rightarrow Q$, $\therefore Q$	$\neg Q$, $P \rightarrow Q$, $\therefore \neg P$	Q, $P \rightarrow Q$, $\therefore P$	$\neg Q$, $P \rightarrow Q$, $\therefore P$	Q, $P \rightarrow Q$, $\therefore \neg P$	P, $P \rightarrow Q$, $\therefore \neg Q$	$\neg P$, $P \rightarrow Q$, $\therefore \neg Q$	$\neg P$, $P \rightarrow Q$, $\therefore Q$
P', $P \rightarrow Q$, $\therefore Q'$	$\neg Q'$, $P \rightarrow Q$, $\therefore \neg P'$	Q', $P \rightarrow Q$, $\therefore P'$	$\neg Q'$, $P \rightarrow Q$, $\therefore P'$	Q', $P \rightarrow Q$, $\therefore \neg P'$	P', $P \rightarrow Q$, $\therefore \neg Q'$	$\neg P'$, $P \rightarrow Q$, $\therefore \neg Q'$	$\neg P'$, $P \rightarrow Q$, $\therefore Q'$

Inverse modus ponens (IMP) is an inference rule in EBR [12]. For example, if John has enough money, then John will fly to China. Now John does not have sufficient money, then we can conclude that John will not fly to China.

The last inference rule for EBR is *inverse modus ponens with trick* (IMPT) [16]. The difference between IMPT and IMP is "with trick", this is because the reasoning performer tries to use the trick of "make a feint to the east and attack in the west"; that is, he gets Q rather than $\neg Q$ in the *inverse modus ponens*.

It should be noted that the inference rules "with trick" such as MTT, AT, MPT and IMPT are non-traditional inference rules. However, they are really abstractions of some EBR, although few have tried to formalize them. The "with trick" is only a semantic explanation for such models. One can give other explanations for them. For example, one can use "against expectation" instead of "with trick" to explain results of stock trading. Then s/he can use inference rules of "against expectation" to identify and discover the against expectation patterns in the stock trading databases [20].

So far, we have examined fuzzy reasoning, CBR, SBR, and EBR. However, their relationship seems not clear or at least lacks a graphic evidence. Further, the existing studies on them can be essentially considered as one dimensional (1D) approach, because the fundamental inference rule of each of these reasoning paradigms is represented in a 1D way. Based on the discussion in Section 3 and Section 4, we represent the other seven inference rules in a coordinate system, in what follows. We will briefly discuss each of the 2D representations owing to the space limitation.

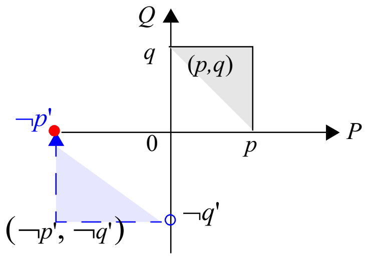

Fig. 3. A 2D representation of fuzzy MT

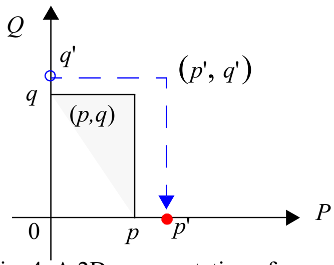

Fig. 4. A 2D representation of fuzzy abduction

Fig. 3 shows the 2D representation of fuzzy *modus tollens* (MT) in EBR, which demonstrates that any reasoning paradigms based on (fuzzy or similarity-based) MT are a non-first quadrant reasoning, because it involves the quantities in the first and third quadrant, we can call it first-third quadrant reasoning.

Fig. 4 shows the 2D representation of fuzzy abduction in EBR, which demonstrates that any reasoning paradigms based on (fuzzy or similarity-based) abduction are a first quadrant reasoning.

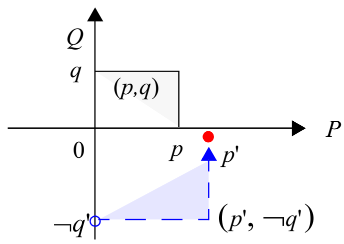

Fig. 5. A 2D representation of fuzzy MTT

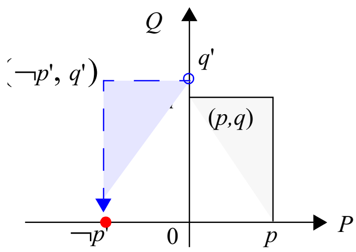

Fig. 6. A 2D representation of fuzzy AT

Fig. 5 shows the 2D representation of (fuzzy or similarity-based) *modus tollens with trick* (MTT) in EBR, which demonstrates that any reasoning paradigms based on (fuzzy or similarity-based) MTT are a non-first quadrant reasoning, but a first-fourth quadrant reasoning.

Fig. 6 shows the 2D representation of (fuzzy or similarity-based) *abduction with trick* (AT) in EBR, which demonstrates that any reasoning paradigms based on (fuzzy or similarity-based) AT are a non-first quadrant reasoning, but a first-second quadrant reasoning.

Fig. 7 shows the 2D representation of (fuzzy or similarity-based) *modus ponens with trick* (MPT) in EBR, which demonstrates that any reasoning paradigms based on (fuzzy or similarity-based) MPT are a non-first quadrant reasoning, but a first-fourth quadrant reasoning.

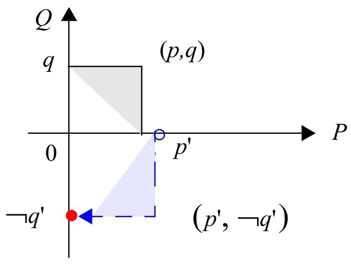

Fig. 7. A 2D representation of fuzzy MPT

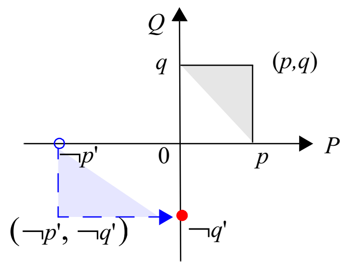

Fig. 8. A 2D representation of fuzzy IMP

Fig. 8 shows the 2D representation of (fuzzy or similarity-based) inverse *modus ponens* (IMP) in EBR, which demonstrates that any reasoning paradigms based on (fuzzy or similarity-based) IMP are a non-first quadrant reasoning, but a first-third quadrant reasoning.

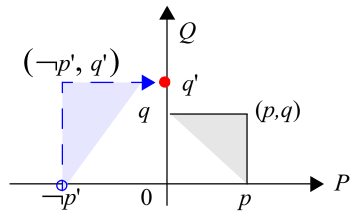

Fig. 9. A 2D representation of fuzzy IMPT

Fig. 9 shows the 2D representation of (fuzzy or similarity-based) *inverse modus ponens* with trick (IMPT) in EBR, which demonstrates that any reasoning paradigms based on (fuzzy or similarity-based) IMPT are a non-first quadrant reasoning, but a first-second quadrant reasoning.

6 Concluding Remarks

This paper examined fuzzy reasoning, CBR, similarity based reasoning and EBR. It then proposed a 2D approach that represents fuzzy reasoning, CBR, and EBR in a unified way. This approach also integrated many reasoning paradigms such as abduction, deduction and similarity-based reasoning into a unified treatment. The proposed approach will facilitate research and development of fuzzy systems, knowledge/experience management, knowledge-based systems, and case-based reasoning.

In future work, we will examine the 2D reasoning properties (such as continuity of reasoning paradigms) of fuzzy reasoning, CBR, similarity based reasoning and EBR and look at the application of the proposed 2D representation of reasoning paradigms in AI, e-commerce and e-services.

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