Engineering Applications of Artificial Intelligence 41 (2015) 1–16

Contents lists available at ScienceDirect

Engineering Applications of Artificial Intelligence

journal homepage: www.elsevier.com/locate/engappai

Improvement of online adaptation knowledge acquisition and reuse in case-based reasoning: Application to process engineering design

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ARTICLE INFO

Article history:
Received 16 October 2013
Received in revised form
23 September 2014
Accepted 26 January 2015

Keywords:
Case based reasoning
Constraint satisfaction problems
Interactive adaptation method
Online knowledge acquisition
Failure diagnosis and repair

ABSTRACT

Despite various publications in the area during the last few years, the adaptation step is still a crucial phase for a relevant and reasonable Case Based Reasoning system. Furthermore, the online acquisition of the new adaptation knowledge is of particular interest as it enables the progressive improvement of the system while reducing the knowledge engineering effort without constraints for the expert. Therefore this paper presents a new interactive method for adaptation knowledge elicitation, acquisition and reuse, thanks to a modification of the traditional CBR cycle. Moreover to improve adaptation knowledge reuse, a test procedure is also implemented to help the user in the adaptation step and its diagnosis during adaptation failure. A study on the quality and usefulness of the new knowledge acquired is also driven.

As our Knowledge Based Systems (KBS) is more focused on preliminary design, and more particularly in the field of process engineering, we need to unify in the same method two types of knowledge: contextual and general. To realize this, this article proposes the integration of the Constraint Satisfaction Problem (based on general knowledge) approach into the Case Based Reasoning (based on contextual knowledge) process to improve the case representation and the adaptation of past experiences. To highlight its capability, the proposed approach is illustrated through a case study dedicated to the design of an industrial mixing device.

1. Introduction

Preliminary design in the industrial domain is a complex and decisive phase in the design process. In economic terms, Douglas (1998) has shown that the cost of this phase represents between 10% and 20% of the entire project cost but decisions taken during this stage impact 80–90% of the total cost. In process engineering (more particularly focused in this study) the total cost saving in industrial application ranges from 20% to 60% according to Harmsen (1999). Consequently, this design task has experienced significant improvement to new computer-aided design methods and tools whose contributions have led to rapid development taking into account quality, safety, operability, economic and environmental performances.

Among the new approaches to address this phase, Knowledge Based Systems (KBS) offer many possibilities and potentialities to support design decisions. Effective knowledge acquisition, reuse and valorization are increasingly important assets for firms in order to provide competitive advantages. Furthermore, KBS propose useful and original solutions without imposing limits to creativity as underlined by Cortes Robles et al. (2009) and Schimtt et al. (1997). KBS intend to rapidly integrate the new scientific knowledge coming from the fast pace of technological evolutions, and to provide users with knowledge access. Indeed, in industrial practices to reduce significantly the design time and cost, it is common to start an activity relying on a previously solved experience, and then to modify and adapt it to match the new requirements. Consequently, KBS are suitable for numerous industrial activities like preliminary design because it avoids starting from a scratch since some choices are neither to do nor to question. Thus the control of the knowledge is a necessity (i) to realize (design and manage process), (ii) to decide, (iii) to create new knowledge, (iv) to preserve the knowledge capital of an organization, and (v) to impel innovation. As the environment and the activities evolve rapidly, one of our main challenges is to propose a system that includes a phase to update the knowledge stored, but also to improve the confidence and quality of the knowledge monitored during activities. Nevertheless, the elaboration of KBS is still a difficult and extensive task, while approaches have been proposed to overcome these issues. Scientific expectations are mainly in knowledge representation, modeling, reuse and maintenance because they are tremendous knowledge engineering tasks.

However, the requirements evolve and improvements of current advanced KBS are mandatory to meet the current context

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http://dx.doi.org/10.1016/j.engappai.2015.01.015
0952-1976/

needs such as more agility and reactivity. Besides these needs, for design applications, KBS must also enhance their dynamic dimension to encourage rapid and flexible responses to some choices and to spread their impacts in the rest of the design process. This dynamic aspect in the adaptation phase of the KBS is a key milestone for knowledge reuse and continuous improvement of the performance of the system. Thus one goal of this study is to propose a KBS meeting these requirements of dynamic.

This paper is more focused on process engineering, which is the part of engineering that deals with processes that convert raw materials into more useful or/and valuable products through several transformations, under economic, environmental, safety, and energy constraints. A chemical process can be decomposed into individual sub-processes called unit operations: chemical reactors, separators, mixers, heat exchangers, etc. Due to the new industrial context, this discipline has undergone significant changes that strongly affect the design phase: the design and production of specialty products with high added value, introduction of numerous innovations on multi-functional units to ensure process intensification, and so on. As a result, a huge amount of new knowledge was and is still created. Optimization and heuristic approaches were the traditional methods to address the process design issues. For the former, we have a mathematical representation of the problem with the formulation of a multi-criteria objective function. However, the drawbacks of this approach are as follows: a huge computational effort, the difficulty to include uncertainties and ill-defined problem. The most important disadvantage is probably that the solution is closely dependent on the initial set of possible alternatives represented under the form of a superstructure. Consequently, it depends on the knowledge of the design team and not on the whole knowledge available. For the latter, process engineer has many heuristics for the traditional design problem, but for the new multi-functional units they are still to be created. Furthermore, as noticed by Li and Kraslawski (2004) their major limitations are their impossibility to manage the interactions between different design levels and the difficulty to handle multi-objective problems. This is due to the sequential nature of this approach.

Due to both the limitations of traditional methods and the mutation of the industrial context, there is a need to find new efficient approaches to capitalize the new implicit and explicit design knowledge. As a consequence, different KBS have emerged in process design based on methods such as Conflict Based Approaches and Case Based Reasoning (CBR). The first ones are based on modified TRIZ methods and tools to make them more easily applicable in the process engineering domain like in the studies of Li et al. (2003) and Negny et al. (2012). These approaches are more focused on the phase of the research of new concepts. CBR is also suitable because numerous design problems become recurrent and these experiences can be easily reused. Their applications to assist in design decisions have been studied and improved for process design in the last decades as demonstrated in Negny et al., (2010). But CBR suffers from three major drawbacks. The first two are knowledge elicitation and case adaptation. These drawbacks are commonly encountered in numerous CBR systems as proved by Chebel-Morello et al. (2013), who explained that the time of knowledge workers dedicated to these phases is, respectively, 37.7% and 45.9% of their total time. The third drawback is more specific to the application of CBR in design, where two categories of knowledge, i.e. contextual (corresponding to past experiences) and general (corresponding to rules, constraints, etc.), must be combined to support a wide range of design decisions on the one hand, and to improve the quality of the solution on the other. Unfortunately, CBR systems only aim to encompass contextual knowledge. Thus the challenge of this work is to raise the level of maturity of KBS for process engineering design; as a consequence, the objective of this work is twofold:

- From the process engineering design point of view, the aim is to improve the current CBR systems, which are mainly focused on the system to design (unit operation or the process) but not on design method but also to include the dynamic aspect. Moreover, the proposition concerns an approach that combines the two kinds of knowledge, previously cited.
- From the knowledge management point of view, the goal is to minimize the knowledge elicitation effort during the adaptation phase. Another important objective is to evaluate the quality and usefulness of the acquired adaptation knowledge in order to increase the skills of the CBR system.

Concerning the first point, among Artificial Intelligence (AI) approaches to capitalize and reuse knowledge Constraint Satisfaction Problem (CSP) has also been successfully applied in various activities and more particularly in design applications. CBR and CSP rely, respectively, on contextual and general knowledge. Due to this complementarity, this paper proposes coupling these two approaches, to address the adaptation problem in CBR. The main motivation is to achieve a synergy that produces a better knowledge exchange, capitalization and reuse.

For the dynamic aspect, several issues must be solved, with different approaches proposed in the literature. Karray et al. (2014) suggested using a trace based system whose goal is to extract new knowledge rules about transitions and activities in the maintenance process. Traces are considered as knowledge containers. This interesting approach is well suited for very dynamic and reactive system as in the maintenance field, but in the domain of design the time constants are lower. In another approach Craw (2009) transforms the traditional CBR into an agile one. In accordance with this work and with the work of Cordier et al. (2007), the traditional CBR cycle is modified to introduce an interactive process with the expert in the reuse step in order to create an online knowledge acquisition, but also to add agility to our KBS.

Concerning the second point to develop our adaptation method, we were interested in the different approaches proposed in the literature. Adaptation in CBR has been widely studied in the 1990's (Smyth and Keane, 1996; Pu and Parvis, 1995, 1997; Voss, 1997; Hanks and Weld, 1995; Craw et al., 2006), but no general models have emerged. Since then, this CBR step has received little attention as confirmed by the analysis of the research theme in the CBR literature realized by Greene et al. (2008). However, the recent evolutions on differential adaptation proposed by Fuchs et al. (2014) seem to give promising ways for an operational formalization of adaptation, while it is currently limited to numerical problems. The main idea is that small variations between problems are related to variations between solutions as in differential calculus. More generally, Chebel-Morello et al. (2013) have classified the main strategies to deal with the adaptation problem into three categories: (i) Adaptation Knowledge Acquisition that aims to obtain adaptation knowledge and to model them through general methods and techniques; Lieber et al. (2004) and Lieber (2007) provide a comparison and an overview on this strategy. (ii) Specific adaptation strategies depending on the application domain or on the case study. (iii) General adaptation methods independent of the application. For instance the method based on the dependency between problem and solution descriptors is the most advanced and used: Fuchs et al. (2000) for computer configuration, Chebel-Morello et al. (2013) for diagnostic. As one motivation of this paper is to improve the efficiency and accuracy of a CBR system for process engineering design, the adaptation method proposed is based on adaptation knowledge acquisition