Efficient Case-Based Structure Generation for Design Support

KATY BÖRNER
Indiana University, SLIS, Bloomington, IN 47405, USA (E-mail: katy@indiana.edu)

Abstract. This paper describes a general approach to support case-based structure generation named Conceptual Analogy (Börner 1997). The approach can be used to support design tasks in domains that do not allow the acquisition of a complete and consistent set of constraints or rules but that do provide a larger set of past experiences. The experiences – also called cases – may resemble for example CAD data of room layouts or pipe systems. Thus, cases represent solutions to particular problems without an explicit, a priori separation of problem and solution variables. The paper starts with a description and formalization of the case-based structure generation task and a discussion of why standard case-based reasoning and other approaches are not applicable. Then, the new approach of Conceptual Analogy (CA) is introduced. CA applies conceptual clustering to organize cases represented by graphs into hierarchical classes of structurally similar cases. These case classes are then represented by concepts. Given a problem, i.e., a partial solution, the hierarchy of concepts is searched for applicable concepts, i.e., concepts that allow the generation of at least one solution to the given problem. Applicable concepts are used to generate a set of solutions that can be ordered according to their quality. Properties of the approach as well as complexity results are presented. An architectural design domain and task where the approach has been applied successfully, is used for illustration and for practical evaluation. Finally, the approach and its implementation are compared to two systems that aim at the support of similar design tasks. The paper concludes with an assessment of the future direction of this research.

Keywords: analogical reasoning, case-based design, case-based reasoning, conceptual clustering, concept representation, structural similarity

1. Introduction

Design tasks are inherently complex. Oftentimes, it is not possible to acquire a complete and consistent set of constraints or rules. This might be due to a poor ratio of knowledge acquisition time to the time saved by using the system or to the fact that domain experts might have a hard time externalizing their knowledge. Therefore, rule-based approaches or constraint satisfaction techniques cannot be applied to support human designers. For some tasks, a set of prior experiences – so-called cases – is available and case-based reasoning (CBR) (Kolodner 1992) seems to be the natural problem solving method. In CBR, domain knowledge is stored in four knowledge containers as identified by (Richter 1995): the case base, the vocabulary used...
to represent cases, the similarity measure, and solution transformations. We assume that the knowledge required to evaluate solutions is included in the container for solution transformation. Reasoning proceeds via the CBR cycle comprising retrieve, reuse, revise, and retain as described in (Aamodt and Plaza 1994).

However, in some architectural design tasks, which we call case-based structure generation tasks, the knowledge about the similarity between a new and a previous problem or about valid adaptations (solution transformations) of past cases is hard or impossible to acquire. This leaves cases, their vocabulary, and general quality criteria such as 'solutions should resemble past cases as close as possible' as the only knowledge available for design support. Even worse, cases resembling CAD designs of buildings represent solutions only. Information about which part of the solution represents the original problem is lost. The question that this paper tries to answer is: Is there a way to support case-based structure generation tasks efficiently?

The paper starts with a description and formalization of case-based structure generation tasks. It explains why existing approaches cannot be applied efficiently. Based on this, the approach of Conceptual Analogy is introduced. Basic notions and notations are given and knowledge organization and analogical reasoning are explained. Main features of the approach are presented and complexity results are discussed. Following this, the implementation of the approach and its application in the domain of architectural design is demonstrated. Finally, we relate the approach to other research in case-based design and conclude with an outlook.

2. Case-based structure generation

Design is concerned with the composition of an artefact from single parts that may be either known and given or just newly created. Constraints on the artefact may be rigidly or informally defined. In design, experts refer to past cases frequently and research in case-based design is growing continuously (Oxman and Voß 1996; Maher and Pu 1997; Voß 1997b; Börner 1998a).

Subsequently, we introduce a specific design task, named case-based structure generation. It has a number of features that differ from standard case-based reasoning tasks.

First of all, cases that resemble CAD drawings of built houses represent solutions to particular problems without an explicit, a priori separation of problem and solution variables.

Second, problems are completed by (partial) transfer of past cases showing a high structural similarity. However, design solutions are hardly ever identical. Frequently, two or more previous solutions must be combined to