ARTIFICIAL INTELLIGENCE IN COMPUTATIONAL ENGINEERING

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Editor

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Preface

Despite all the reservations about what is loosely called artificial intelligence (AI) which are still being expressed in the community of researchers and engineers working in the field of computational engineering, there can be little doubt that AI will have in the future a major impact on the engineering profession. Although the computer-based technologies of the 1970s have provided effective tools for the development of useful large-scale programs in almost every field of engineering, these technologies are clearly not adequate to deal with all such problems and there is enough evidence that at least some of them may be treated more effectively by completely new computer methods. From robotics to risk control and process diagnosis, from natural language processing to structural design optimization, few engineering disciplines seem to be able ultimately to escape the possibilities offered by the AI-based computing systems of the future.

Methods of computational engineering have been traditionally based on formalisms and laws of quantitative knowledge, which make it possible to formulate problem-governing equations and to work out analytical or numerical solution techniques for them. However, apart from the science of quantitative knowledge, it has been widely recognized that the art of qualitative knowledge is indispensible for solving large compound problems in modern engineering. Qualitative knowledge, as a rule employed only in the 'background' and thus virtually inaccessible to the casual observer, is decisive in splitting the overall problem into subtasks and in handling problems that are to difficult to describe in the precise language of formal theories. Typical problems we have in mind are those without purely algorithmic solutions such as preliminary and detailed design, large optimization problems, controlling parameters in large-scale non-linear computations and risk assessment.

So far, no monograph on the use of AI concepts in engineering has been published and the available publications are casually scattered over journals, conference proceedings and internal reports. By providing a collection of very representative articles this volume has been prepared to accelerate the closing of the communication gap between scientists working in different engineering areas and those using AI concepts. Particular emphasis is placed on subjects which traditionally rely on novel computer techniques such as computational mechanics, computer-aided design and optimization methods. The chapters included address successful applications of AI techniques to solve realistic engineering problems.

Because of the novelty of the subject, its enormous scope and the lack of broadly accepted methodologies, it was difficult to come up with a division of the volume into parts grouping contributions dealing with separate, clear-cut topics. The most logical structure of the book was finally believed to be achieved by splitting it into Part I, which groups contributions dealing with problems of engineering analysis, and Part II consisting of chapters devoted to design optimization.

The book opens with Chapter 1, written by J. Ganguly, E. Kausel and D. Sriram. They describe a knowledge-based system that can provide expert advice on the seismic behaviour of structural systems. The nature of the knowledge structures and the reasoning mechanisms that are involved in the domain of seismic engineering are discussed. The system has been implemented in PROLOG while procedural tasks are implemented in C. The system is capable of understanding restricted natural language input.

Work towards the development of a knowledge-based system which might be an aid in the management of the safety of a project is described in Chapter 2 by D. I. Blockley. Case histories of projects are collected in the form of event sequence diagrams into a hierarchically structured set of concepts and relations. An open-world mathematics of interval probability as a theory of evidential support is introduced.

T. Krauthammer in Chapter 3 puts emphasis on the need to combine symbolic and numeric approaches in order to assess realistically structural damage following a major disaster, such as a flood or an explosive event. A risk analysis of a concrete gravity dam illustrates the general discussion of engineering evaluation for hazard prevention.

A consultation system for constitutive modelling of materials in solid mechanics is discussed in Chapter 4 by J. Ambroziak and M. Kleiber. Selection of a material model (i.e. of equations describing the material's thermo-mechanical properties) is an important task in correctly posing and solving boundary value problems typical of the non-linear mechanics of deformable bodies. The authors critically discuss features routinely present in existing expert system shells and explain reasons for employing a version of the blackboard framework in this work.

P. Wriggers and N. Tarnow indicate in Chapter 5 that controlling finite element algorithms by expert systems may turn out to be highly beneficial in cases where calculations do not depend entirely on algorithms but also on heuristic data. In the implementation discussed in this work an interface relates the numerical results of finite element computations to the rules of an expert system. Complex non-linear calculations illustrate the effectiveness of the coupled system.

In the closing chapter of Part I of this volume D. Hartmann identifies areas within the computational mechanics field in which expert system applications seem to be promising. A pilot program in the form of a 'solution assistant' for the numerical analysis of plane stress problems is described.

Part II of the book starts with Chapter 7 by K. Schittkowski and R. Zotemantel in which they introduce an interactive programming system that supports the whole life-cycle of the solution process of a mechanical structural optimization problem. Given the geometry of the structure by means of a finite element description, the system guides the user to define an appropriate optimization problem. The system is self-learning and uses rules for proposing a suitable optimization algorithm or remedies in an error situation.

The concept of statistical machine learning has been applied by D. A. Hoeltzel and W. H. Chieng in Chapter 8 to a sample database of non-linear programming problems. Conclusions have been drawn about a type of optimization problem and a corresponding sequence of non-linear programming solution algorithms. A program with the capability of learning from statistical pattern recognition is discussed.

M. L. Das and S. K. Ghosh emphasize in Chapter 9 that heuristics have always been used in multistory building design. In this contribution the authors attempt to formalize the use of some of these heuristics by presenting a workable knowledge-based expert system for selection of the cast-in-place slab type of multistory buildings.

In Chapter 10 P. Hajela and J. L. Chen describe the implementation of an expert system that provides interactive assistance in tasks related to the optimum synthesis of structural systems. These tasks include finite element modelling of the problem domain, building an optimum design model and selection of optimization strategies and parameters for the problem.

P. Y. Papalambros takes as a starting point in Chapter 11 the fact that the overall computational cost in optimal design is dominated by function and gradient evaluations of the constraint functions. This necessitates the use of active set strategies where only a subset of the original constraint set is used for computation in any particular iteration. A framework for developing knowledge-based active set strategies is described, motivated in part by application to aircraft structures.

In the closing chapter, D. Aunay, S. Aunay, D. Chorlay, G. Touzot and M. Vayssade emphasize that the coupling of existing AI and numerical programs implies several difficulties and conflicts. A new software architecture is proposed, which is designed to simplify the implementation of coupled methods. The architecture is based on an object-oriented data manager and on a stretchable set of independent commands. Two specific examples are considered to illustrate the chapter: the first deals with an intelligent user interface and the second with shape optimization under technological constraints.

The book should attract the interest of researchers, graduate students and innovative practitioners who employ computer techniques in the fields of mechanical, aeronautical and civil engineering and design. Computer scientists will find in the book a useful overview of several up-to-date applications of AI.

Michał Kleiber

PART I
Assessment of Structural Behaviour

1

QSEIS: a system for deriving qualitative seismic behaviour of structural systems from structural descriptions

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1. INTRODUCTION

The analysis and design of complex or critical facilities, such as tall buildings, nuclear power plants, offshore structures, or cable-stayed bridges, requires that these facilities be made safe against the effect of earthquake-induced loads in seismic areas. The various stages involved in the design of these facilities are as follows:

(1) *Problem identification.* The problem, necessary resources, target technology, etc., are identified.
(2) *Specification generation.* Design requirements and performance specifications are listed.
(3) *Concept generation.* The selection or synthesis of potential design solutions, such as a structural system, is performed. Several alternative designs may be proposed.
(4) *Analysis.* The response of the system to external effects is determined by means of appropriate models.
(5) *Evaluation.* Solutions generated during the concept generation stage are evaluated for consistency with respect to the specifications. If several designs are feasible, then an appropriate evaluation function is used to determine the best.
(6) *Detailed design.* The components of the chosen system are such that all applicable constraints (or specifications) are satisfied.
(7) *Design review.* The detailed design is checked for global consistency.

There may be significant deviations between the properties of components assumed or generated at the concept generation stage and those determined at the detailed design stage, which would necessitate a reanalysis. The process continues until a satisfactory or optimal design is obtained.

Currently, several sophisticated computer programs exist that allow us to perform analysis and design of complex structures. However, none of these programs has any reasoning capability. Users of numerical packages must anticipate the behaviour prior to analysis. The purpose of the analysis is usually to confirm the anticipated behaviour. Furthermore, the responsibility of validating the computer outputs lies entirely with the user.

A number of human mental activites, such as developing computer programs, performing symbolic mathematical manipulations, engaging in commonsense reasoning, processing natural language, making engineering decisions, are all said to require 'intelligence'. Computer scientists have been fairly successful in developing prototypical computer programs for performing the above-mentioned tasks. One may say that such systems possess artifical intelligence (AI) to some extent. Ultimately the goal of AI is to develop an information processing theory of intelligence that can be used to design intelligent machines as well as explicate intelligent behaviour of human beings.

In the recent past, AI techniques in the form of knowledge-based expert systems (KBES) have begun to emerge from computer science laboratories into industrial settings. KBES are computer programs that use knowledge in a given field (formalized in a knowledge base) as well as inference procedures to address problems whose solutions require significant human expertise (an overview of KBES is provided in [20]). The KBES technology has been applied successfully to a wide variety of problems ranging from diagnosing diseases, evaluating potential mineral deposits, identifying structures of complex organic materials to designing buildings, VLSI chips, etc. (an extensive bibliography in engineering is provided in [20]). A major difficulty in developing KBES is in representing and using knowledge that human experts use in problem solving. This problem is compounded by the fact that human expertise is often empirical and even imprecise. Most KBES such as SACON [2,3], which was developed as an intelligent front end to a finite element analysis program, rely on a technique known as rule-based deduction. In such systems, the expert knowledge is represented as a large set of rules, and these rules are used to guide a conversation between the system and the user and finally to deduce a conclusion. Hence, current KBES are limited because they have little or no knowledge of the underlying physics of a problem. In addition, these KBES cannot reason about the behaviour of physical systems in a qualitative manner, as experienced engineers normally do.

In this paper, we describe QSEIS, a KBES, that can provide expert advice on the seismic behaviour of structural systems, based on heuristic expert knowledge and qualitative reasoning capabilities. We discuss the nature of knowledge structures and reasoning mechanisms that are involved in the domain of seismic engineering (section 2). QSEIS consists of a layered knowledge base and a friendly interface (section 3). The knowledge base consists of heuristic rules as well as more fundamental knowledge or laws based on principles of mechanics. The heuristic knowledge has been implemented as rules while an attempt has been made to implement the