Coupled Expert Systems for Engineering Design

Systèmes experts: «couplés» en conception

Gekoppelte Expertensysteme für den Ingenieurentwurf

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SUMMARY
This paper reviews the development of coupled expert systems for engineering design. AI-based symbolic processing and traditional numerical processing are combined in a coupled expert system. Various approaches to coupling are discussed. Several coupled knowledge-based expert systems developed by the author and his associates are described briefly.

RESUME
Cet article passe en revue le développement de systèmes experts dits «couplés» dans le domaine de la conception. Programmation symbolique et programmation numérique traditionnelle sont combinées dans les systèmes experts «couplés». Différentes approches de «couplage» sont débattues. Plusieurs systèmes experts à base de connaissance «couplés» développés par l'auteur et ses associés sont décrits dans cet article.

ZUSAMMENFASSUNG
Dieser Beitrag bespricht die Entwicklung gekoppelter Expertensysteme für den Ingenieurentwurf. Dabei werden traditionelle numerische Methoden mit auf künstlicher Intelligenz basierenden symbolverarbeitenden Methoden kombiniert. Verschiedene Koppelungsarten werden besprochen und anhand von bereits entwickelten Expertensystemen erläutert.

INTRODUCTION

A large number of knowledge-based expert systems has been reported in the literature during the last few years. With a few exceptions, these systems are primarily concerned with symbolic processing of experiential knowledge often expressed in the form of production rules. The problem of integrated engineering design consists of the conceptual design, preliminary design, structural analysis, and the final detailed design. Thus, an integrated engineering design requires extensive numerical processing in addition to symbolic processing of heuristics and experiential knowledge. This paper reviews briefly several coupled knowledge-based expert systems developed by the author and his associates during the past few years. Readers interested in the details of these systems should refer to the references given at the end of the paper.

RTEXPERT

RTEXPERT (for Roof Truss EXPERT) is a coupled expert system for detailed design of three different types of roof trusses, namely, flat Pratt, pitched Pratt, and Fink trusses (Adeli and Al-Rijleh, 1987). RTEXPERT can advise the user on the appropriate type of the roof truss, selection of the layout of the truss, and the loading. It also presents the final detailed design of the selected truss. The basis of design is the American Institute of Steel Construction specification (AISC, 1980). The truss is designed for dead, live, snow, and wind loads in accordance with the American National Standard Institute specification (ANSI, 1982). RTEXPERT has a comprehensive graphic interface for displaying the truss configuration, cross-sections, loading, and deformed shape. Information about individual members is presented through multi-window graphics-text displays.

RTEXPERT has been developed on an IBM Personal Computer with two floppy disk drives and 512K of RAM. The knowledge base and explanation facility of RTEXPERT have been developed using INSIGHT 2+ expert system shell (Level Five Research, 1986). The mathematical computations, graphic algorithms, and data file manipulation routines have been developed in Turbo Pascal.

BTEXPERT

BTEXPERT (for Bridge Truss EXPERT) is a prototype expert system for optimum (minimum weight) design of bridge trusses (Adeli and Balasubramanyam, 1988a&b). The scope of BTEXPERT is limited to the optimum design of four types of bridge trusses, i.e., Pratt, Parker, parallel-chord K truss, and curved-chord K truss for a span range of 100-500 ft. Design constraints and the moving loads acting on the bridge are based on the American Association of State Highway and Transportation Officials (AASHTO) specifications (AASHTO, 1983).

Bridges are to be designed for combined dead and live (moving) loads. Live loads are usually specified by design specifications. AASHTO live loads are used in BTEXPERT. These loads can be classified into three categories : Two-axle truck (H 15 and H 20), two-axle truck plus one-axle semitrailer (HS 15 and HS 20), and uniform lane loadings consisting of a distributed load of uniform intensity but variable length and a single moving concentrated load. A heuristic approach has been developed for finding the maximum compressive and tensile forces in the members of a bridge truss based on the classification of the shape of the influence line diagrams (ILD's) and the type of AASHTO live loads.

The optimum design of a bridge truss consists of selecting the right combination of the cross-sectional areas of the truss members so as to satisfy all the design constraints and produce a least weight truss. For achieving this, a hybrid optimization algorithm has been developed for minimum weight design of bridge trusses subjected to moving loads (Adeli and Balasubramanyam, 1988b). In this algorithm, an efficient zero order explicit approximation is combined with a more accurate but less efficient explicit stress constraint formulation.

BTEXPERT has been developed using the Expert System Development Environment (ESDE) (IBM, 1986b & c) and the Expert System Consultation Environment (ESCE) (IBM, 1986a & c) implemented in Pascal/VS. The first program is used to develop expert systems and in particular the knowledge bases. The second program provides facilities for executing them. The two programs are collectively referred to as the Expert System Environment (ESE). The analysis and optimization algorithms have been coded in FORTRAN 77.

For performing numerical processing and for graphics interface, BTEXPERT uses procedures implemented in FORTRAN 77. Therefore, an interface has been developed in PASCAL/VS interfacing the knowledge base of BTEXPERT implemented in ESE to the interactive bridge truss optimization program implemented in FORTRAN 77. The interface consists of a number of procedures written in PASCAL/VS and use ESE utility functions. They transfer information from ESE to numerical and graphical processors and acquire information from the numerical processors and transfer it to ESE. This information may be in the form of values of control parameters, and/or the knowledge about the sequence of application of the numerical algorithm, and/or the results obtained from the numeric processors (Adeli and Balasubramanyam, 1988b).

SDL and STEELEX

SDL (for Structural Design Language) is a domain-specific expert system development environment implemented in INTERLISP for building coupled knowledge-based expert systems for integrated design of structures (Paek and Adeli, 1988a and 1988b). The complex body of knowledge needed for detailed design of a structure is fractionated into smaller and manageable knowledge sources which are organized into a hierarchy of cooperating conceptual specialists. SDL has been used to develop an expert system for integrated design of steel building structures consisting of moment-resisting frames, called STEELEX (Paek and Adeli, 1988c). STEELEX designs the beams and columns making the frame as well as the moment-resisting connections. STEELEX has a multi-window graphics interface that can display orthographic and isometric views of the structure and moment-resisting connections.

EXOPT

EXOPT is a prototype coupled knowledge-based system for large scale structural design optimization (Adeli and Balasubramanyam, 1988b). The domain of EXOPT is limited to optimization of plane trusses under arbitrary multiple loading conditions subjected to user-specified stress, displacement, and fabricational constraints. In order to make use of the trend information obtained during the optimization cycles, design variable classification and heuristic constraint deletion strategies have been implemented in EXOPT. Symbolic processing is done through the use of the IBM ESE and numerical processing is performed in FORTRAN 77.

PG-BRIDGE1

PG-BRIDGE1 is a prototype knowledge-based expert system for optimum design of stiffened and unstiffened, homogeneous and hybrid steel plate girders used in highway bridges (Adeli and Mak, 1988&1989). The basis of design is the American Association of State Highway and Transportation Officials (AASHTO) specifications (AASHTO, 1983). The plate girders are subjected to the live (moving) loads of the AASHTO specifications.

A robust mathematical optimization algorithm has been developed for minimum weight design of multispan steel plate girders used in highway bridges employing the generalized geometric programming technique (Adeli and Chompooming, 1988). The total weight of the plate girder is used as the objective or minimization function. The design constraints are based on the AASHTO specifications. The design variables are the flange width and thickness, the web depth and thickness, and the width and thickness of transverse stiffeners, and the spacing of the intermediate stiffeners. In the optimization algorithm, the nonlinear primal problem is transformed to an equivalent standard linear programming problem via double condensation.

PG-BRIDGE1 is developed using the IBM ESE described previously. Numerical processing is performed in external programs written in FORTRAN 77. In order to link the graphics interface and load the FORTRAN utility functions, an execution file ESXGLBL is invoked automatically each time the ESE is loaded.

FRAMEX

FRAMEX is a coupled knowledge-based expert system for integrated design of rectangular multistory steel buildings in which AI-based symbolic processing is integrated with numerical processing and data base management techniques (Adeli and Chen, 1989). The vertical lateral force-resisting systems in the building are limited to moment-resisting frames located on the perimeter of the structure.

FRAMEX starts with the preliminary design and presents the final detailed design. The basis of steel design is the recently-developed American Institute of Steel Construction (AISC) Load and Resistance Factor Design (LRFD) specifications (AISC, 1986). The loading on the structure can be various combinations of dead load, live load, snow load, wind load, and earthquake load. The computations of live, wind, and earthquake loads are according to the last edition of Uniform Building Code (UBC, 1988). The snow load is calculated on the basis of the American National Standards Institute (ANSI) minimum design loads specifications (ANSI, 1982).

FRAMEX has been developed on an IBM Personal Computer (PC) with 640 KB of Random Access Memory (RAM), a 360 KB floppy disk drive, and a 20 MB hard disk drive.

Symbolic processing in FRAMEX is done using the Personal Consultant (PC) Plus expert system shell (TI, 1987a&b). Developed by Texas Instrument in 1987, PC Plus is a microcomputer-based expert system environment implemented in LISP. PC Plus provides an English-like language, called Abbreviated Rule Language (ARL), an explanation facility, and the ability to interact with external programs developed in procedural languages and dBASE III data files and Lotus 1-2-3 spreadsheets. Numerical processing for structural analysis, member selection in preliminary design and redesign, optional LRFD procedural code checking, and graphics interface is done in Turbo Pascal. Figure 1 shows the architecture of FRAMEX schematically.

Data base files used in FRAMEX are classified into static and dynamic data files. The static data files contain the data which are not changed during a consultation with the system. There are four such static data files. One of them is a dBASE III data base file with extension .DBF. The remaininng

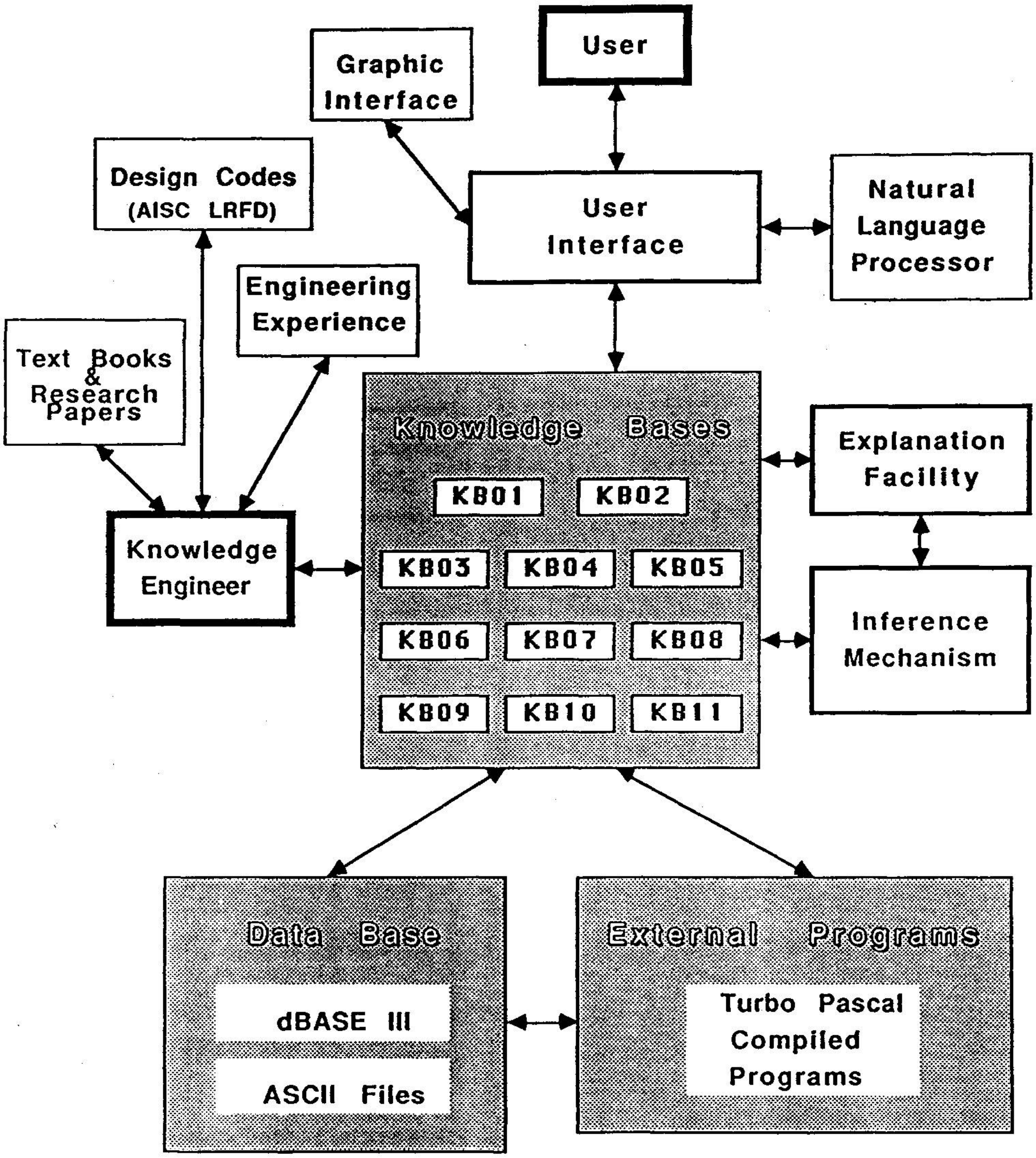

Figure 1 Architecture of FRAMEX

three data files are ASCII database files with extension .DAT. Figure 2 shows how the four static data files are used by the knowledge bases.

During the complicated design process various types and quantities of data are generated. The large quantity of data must be managed properly and efficiently. FRAMEX manages the data created during the consultation process through 30 dynamic data files. The contents of these data files are changed during a consultation with FRAMEX. Details of the dynamic data files generated by knowledge bases and Turbo Pascal programs are given in Adeli and Chen (1989). Figure 2 also shows how the dynamic data files are generated and used by various knowledge bases and external programs.

SDLS

We are currently developing a prototype Structural Design Learning System (SDLS) in a combination of Prolog and Pascal languages (Adeli and Yeh, 1990). The machine learning approach used is Explanation-Based Learning (EBL). A relatively new approach in machine learning, EBL appears to produce a more reliable generalization without the inductive bias observed in the similarity-based learning developed earlier. SDLS includes a modified implementation of EBL in Prolog, where the two stages of explanation and generalization are combined into one stage. A more formal definition of the operationality criterion suitable for the domain of structural design is proposed and used in SDLS.

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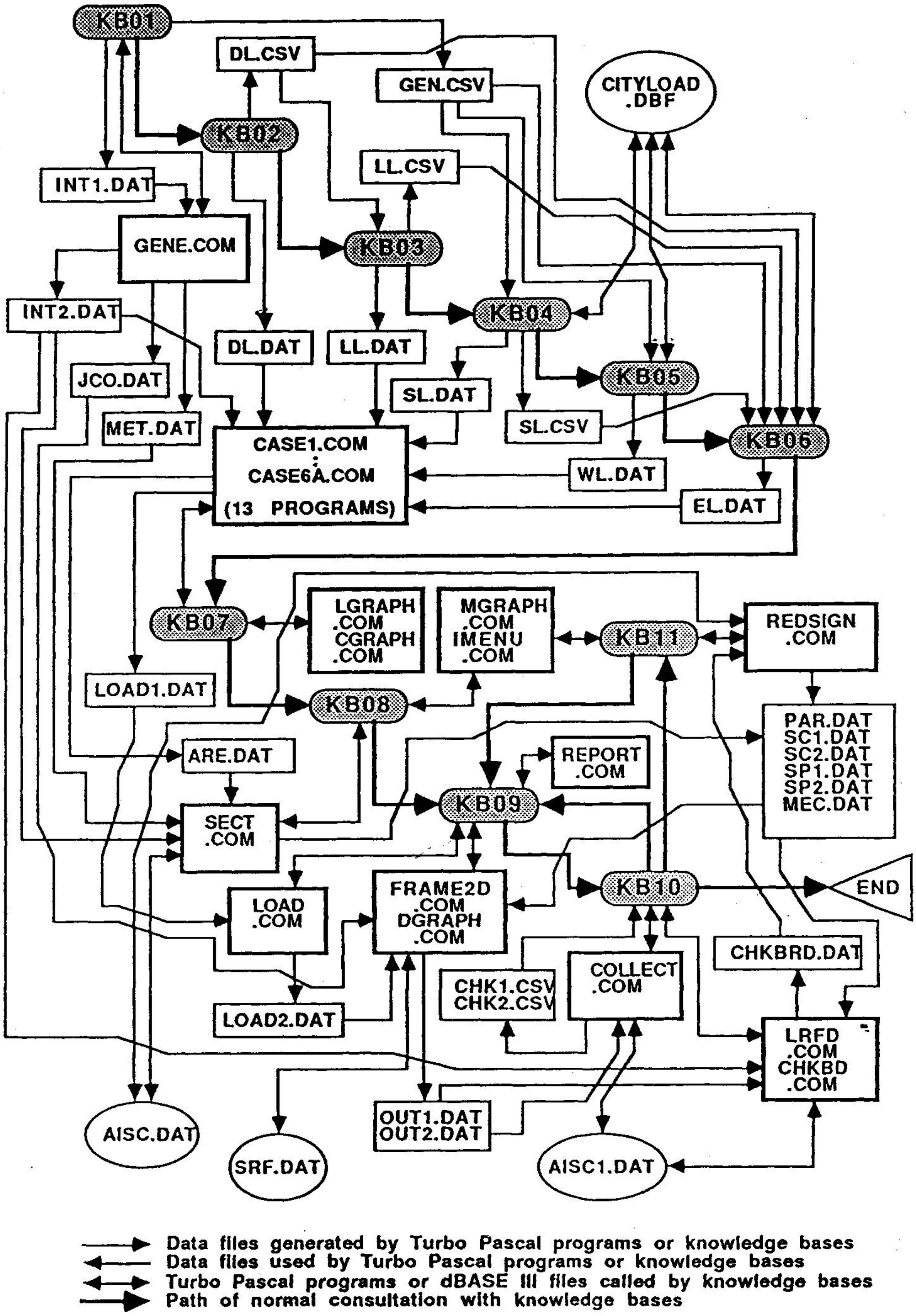

Figure 2 Path of consultation and the relationship of knowledge bases, data bases, and external Turbo Pascal programs

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