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TOWARDS EXPERT SYSTEMS IN DIGITAL MAPPING

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We hear much these days about expert systems or knowledge-based systems, which are an important subfield of artificial intelligence. The expression suggests intelligence, artificially created and it evokes different feelings in the lay public, ranging from astonishment to sorcery. Are we on the verge of creating machines that will rival human intelligence? Can we expect systems that will automatically solve our problems in digital mapping and successfully compete with human experts?

John McCarthy is said to have introduced the expression "artificial intelligence" during the Dartmouth conference in 1956. People have since time immemorial been fascinated by the idea that man might be able to create a machine with mental capabilities of a human. The robot is a recent example of this fascination; in the middle ages clocks were regarded as "intelligent", just because something created by man could indicate the time of the day.

What constitutes intelligent behavior in humans or machines is subject of ongoing debates. It does not come as a surprise that there is no unified definition of AI (as artificial intelligence is commonly abbreviated). Elaine Rich defines it as the study of how to make computers do things at which, at the moment, people are better [RICH83]. Those who are most embarrassed by the implied arrogance of the expression "artificial intelligence" prefer the term "machine intelligence".

When computers first were introduced the general public was astounded that a machine was able to carry out thousands of multiplications of 10-digit numbers in a second. However, within a decade computers had become common-place, astonishment waned, and the public started to accept them as ordinary products. But then computers were applied to solving new problems that no one had thought possible for a machine. And again did history repeat itself: whatever seems to astound us to day evokes only yawns after a few years.

The whole field of artifical intelligence is booming. What was only a tiny research-oriented community a few years ago is now one of the fastest growing segments of the computer business. So what is in it for us?

The purpose of this paper is to provide the non-specialist with the basic concepts of expert systems and elaborate on the major differences to traditional and therefore more familiar programming approaches. This groundwork serves as a base to assess potential applications in digital mapping and to generally judge the impact in our field. The paper deals with the subject on a general level, omitting lots of unnecessary details that usually distracts a novice away from the basic principles and burdens him with lots of jargon. Technical terms are introduced whenever appropriate and inevitable, the terms are also summarized in the glossary. Even though emphasis is placed on a general understanding how expert systems work, the paper is not a tutorial nor is it survey of the field.

Those who are interested in a more detailed understanding of expert systems are referred to the many textbooks that are now available. An excellent introduction to the subject is provided by Waterman [WATE85] or Hayes-Roth [HAYE83], both with an extensive bibliography.

EXPERT SYSTEM TECHNOLOGY

Background

Computers were invented with the main idea of carrying out massive amounts of calculations as found, for example, in simulation problems and large equation systems. If the system design, -the von Neumann architecture-, is more and more criticized after forty years of its inception, one should never forget the original objective for its design. After an initial period of mere "number crunching", the need for better programming methods had lead to the development of higher languages, such as FORTRAN, PASCAL, COBOL, just to mention a few.

With advanced hardware and more suitable software, new applications were tackled and successively mastered. Huge amounts of data needed to be stored in an organized fashion for interrogating and easy up-dating by data base systems. While the first generation allowed for processing data, the new generation added information processing capabilities, addressing such applications as word processing, data base management and (interactive) graphics. Evidently, information is no longer restricted to numbers only, but includes text and graphics as well. Aerotriangulation, map projections or surveying calculations are typical examples of our field for data processing, while computer-aided cartography and photogrammetry, or land (geographical) information systems draw heavily on the information processing capabilities.

Yet another form of processing is on the verge to become a powerful method that will enable us to approach new problems which are defied traditional computer solutions. This new generation is loosely termed "knowledge processing". It has been realized for quite some time that human experts do not solve problems by performing laborious mathematical computations. Instead they choose symbols to represent objects, processes and their relationships. Then various strategies and heuristics (rules over the thumb) are applied to manipulate the symbols and to arrive at an acceptable solution.

Generation	Software	Hardware
1st	- machine code	- vacuum tubes
2nd	- higher level languages (COBOL, FORTRAN etc)	- Transistors - magnetic core memory
3rd	- time sharing - operating systems - virtual memory	- IC memory - minicomputers - magnetic disk storage
4th	- new languages (PASCAL, MODULA etc) - DBMS	- microprocessors, PC - VLSI - networking
5th	- knowledge-based SW - expert systems - natural language processing	- parallel processing - RISC architecture - VHSIC - optical disk storage

Table 1
The computer generations

AI in its quest to develop computer programs that could somehow think and solve problems that would be considered intelligent if done by a human, tries to mimic the human problem-solving ability. In the beginning the solution was sought in general methods that could be applied in a broad class of problems. However, this strategy proofed fruitless. It was not until a few years ago that AI scientists began to realize that the real problem-solving capability of a program stems from the knowledge it possesses, not just from inference schemas it employs. The message is plain: to make a program intelligent, a lot of specific knowledge about some problem area is needed. A new way was found to make intelligent programs: the era of expert systems began.

Organization of Expert Systems

Expert systems are sophisticated computer programs that manipulate knowledge to solve problems efficiently in a narrow problem area. Figure 1 depicts the key components of an expert system: the knowledge base, the data base, the inference engine and the human interface.

Knowledge Base

The heart of any expert system is its knowledge base that is information the computer program needs to behave intelligently. The knowledge is explicit and must be organized such that decision making is easily possible. Several techniques exist to represent knowledge, with the rule-based method (or production rules) the most widely used. The other methods are: frames, semantic nets, scripts, lists and predicate calculus.

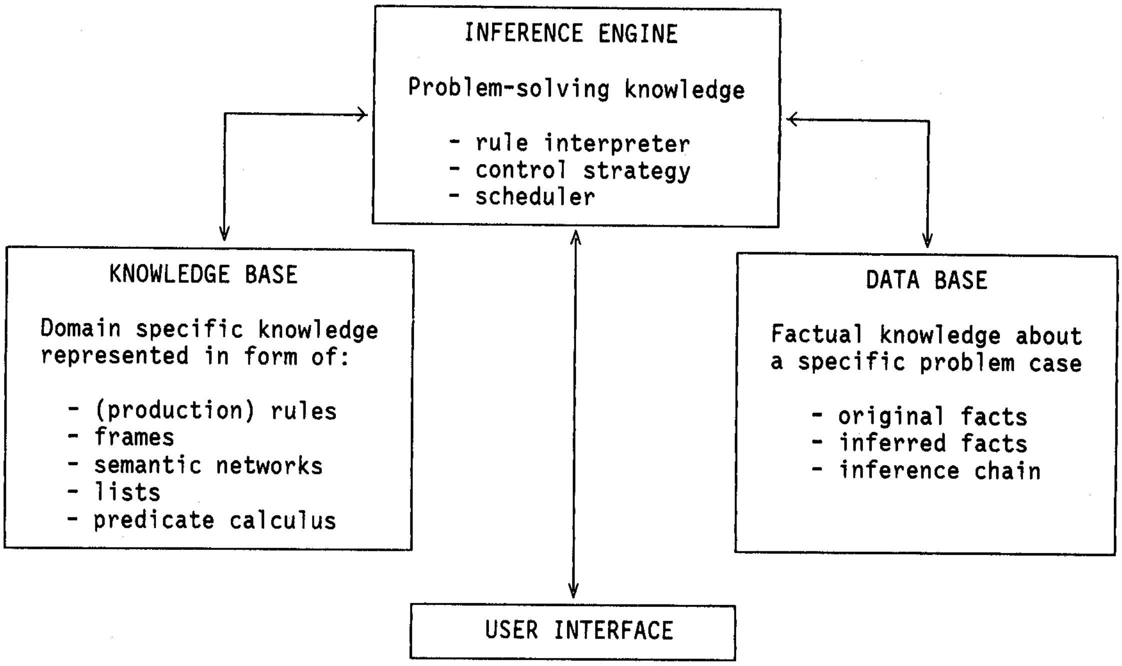

Figure 1:
General block diagram of an expert system

Production rules are popular because their format is extremely flexible. Almost any kind of knowledge can be written to match the IF-THEN format. The left-hand side of the rule (IF part) expresses some condition (premise), while the THEN part states a conclusion or action. If the premises are true (condition met), the right-hand part is also true and if implemented, the rule is said to be fired.

Below some examples are given:

1) IF a polygon is closed AND its length is less than Lmin THEN the polygon represents a symbol

2) IF a symbol is rectangular AND its location is in a street THEN the symbol is a manhole with a certainty factor of 0.9.

The IF part may contain more than one premise. The certainty factor is a number between 0 and 1 and it indicates the confidence we have in the truthfulness of the conclusion.

A wide variety of knowledge can be represented with rules, originating from different sources, e.g. from textbooks or from an expert. In this case it is normally called empirical knowledge that the expert gained over a long time of solving problems in his special field.

Each rule represents an individual piece of knowledge that is normally related to many other rules. All the rules linked together establish a line of reasoning. For example, the conclusion of a rule may become the premise of another.

Data Base

The data base contains a broad range of information about the current status of the particular problem case to be solved. Since it records the facts about the case it is also referred to as the fact base. Known facts are stored there initially. Then new facts derived from the inference processes, are added. Thus the data base always reflects the current facts during the problemsolving process.

The initial facts may be established during a question/answer session in the beginning or they may result from computations or pre-processes.

The data base keeps also track of all the rules fired and their sequence. This can later be used for explaining the inference process.

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The Inference Engine

The inference engine (also inference machine) is software that implements a search and patternmatching operation. It examines the rules in a particular sequence and is looking for matches to the current conditions stored in the data base. As rules matching conditions are found, the rules are fired, thereby initiating the actions specified. The execution of a rule may add new facts to the data base, that is, new knowledge about the case is available that in turn may cause the firing of new rules. The searching and matching process continues until a final conclusion is reached.

When searching sequentially a large data base for a match, it may come to what is called a combinatorial explosion. That is, the pattern-matching operations will soon exhaust even main frame computers. A clever search strategy is of essence. Useless searches should be aborted and more promising alleys should be explored. What strategy should be employed depends on the way the knowledge is represented as well as on the particular problem at hand. Expert system shells come with an inference engine taking the burden off the programmer. On the other extreme, lower-level languages, e. g. LISP and PROLOG, require to design and to develop the inference engine.

AI research focuses on improving the search strategy. Two basic approaches are known for quite some time and are called forward and backward chaining. In forward chaining, the inference engine attempts to match a fact in the data base to the situation stated in the IF part of a rule. The inference engine begins with the first known fact and searches the rule base looking for premises that matches it.

In backward chaining, the inference machine starts with a fact in the data base, called hypothesis. The THEN part of the rules are then examined for a match and the data base is updated with the conditions of that rule. The right side of the rules are repeatedly compared for a match until the hypothesis is proved.

If a backward chaining method is employed, all of the hypotheses must be known. That is, all the possible outcomes, choices or selections are to be identified in the beginning.

User Interface

The user communicates with the expert system through the user interface. The expert system may ask questions and present menues as a comfortable way for the user to answer questions and input initial information about the problem he wants to solve.

Example

At the Ohio State University we are currently engaged on a project that deals with the interpretation of raster scanned map data. Many applications require digitizing existing maps and there is an ever increasing demand on digitized map data. For example, every geographical information system (GIS) needs map data for its data base, before the system can be put into operation. Whenever data bases with geographic information are established, the input comes generally from existing maps.

Three different approaches are used to digitize maps. The manual digitization of maps is a very tedious and time consuming process, but still very much in use. Another approach is that of using line-following systems. Here, the operator is relieved from manually placing a cursor on every point to be digitized.

The third method does not require the operator to be in the loop, because scanners digitize the map automatically. Conceptually, a high resolution grid is placed over the map (e.g. with a resolution of 0.1 mm) and the scanner determines the grid cells (raster elements) that carry information. This leads basically to a raster representation of the map with the raster elements either being on or off.

Although such a representation can be achieved without any problems, it is yet useless to be input into a data base, because the semantic information is not explicit, for it is buried in the raster elements. The recognition of symbols and objects, as well as the various relations among objects constitutes still the major stumbling block for putting scanning systems into practical use on a broad base. Considerable human effort is required to make explicit the semantic information.

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We address this issue by employing expert system technology. The knowledge-base consists of rules that are encapsulated from map interpretation experts. For illustrating the basic mechanism of an expert system we assume that the map has been scanned and preprocessed, including vectorization of strings of raster elements. This information forms the initial facts of the data base. Let us now look at a polygon P1 that can be described by the facts F1 - F3:

F1:	P1 is closed AND P1 has a total length of L1	original facts
F2:	P1 linetype is black AND linetype is solid	
F3:	P1 consists of 3 vectors	
F4:	P1 = symbol	new, inferred facts
F5:	P1 = triangle AND azimuth of base = 98 grads.	
F6:	P1 = monument	

The knowledge-base contains all the information a human map interpreter usually puts to work when confronted with our problem case. In contrast to the inference engine's knowledge that is related to general problem-solving techniques, the specific knowledge encoded in the knowledge-base is problem dependant. It is also referred to as domain knowledge. Among the hundreds of rules, a few are given here that may apply to recognize the meaning of polygon P1.

R1: IF P closed AND L < Lmin THEN P = symbol
R2: IF P = 3 vectors THEN symbol = triangle
R3: IF P = 4 vectors AND vectors of same length THEN symbol = quadrangle
R4: IF P = 4 vectors AND vectors not of same length THEN symbol = rectangle
,
,
R(i-1): IF symbol = triangle then compute azimuth of base
R(i): IF symbol = triangle AND 95 < azimuth of base < 105 THEN symbol = monument
,
,

In a forward chaining expert system the facts are compared with the rules. When the IF part of a rule is satisfied by the facts, the action specified by the THEN part is performed.

Let us take fact F1 and let us assume L1 < Lmin. The left-hand side of rule R1 matches F1 and the rule fires, resulting in the new fact F4, stating that P is a symbol. F4 is added to the data base and the matching of facts against rules continues. Fact F2 does not match any IF part, but F3 does. Rule R2 is now fired, the new facts F5 (symbol is a triangle) is added to the data base. Next, rule R(i-1) is executed, adding the missing azimuth of the triangle's base to fact F(5). Finally, the facts F2 and F5 satisfy the IF part of rule R(i) and its consequence leads to the solution.

The matching of facts to the IF part of rules produces an inference chain that can be stored and displayed upon request for explaining how the system derived at a solution. Our little example produces the following inference chain:

R1 ----> P = symbol and F(3) } ----> P = triangle azimuth of base F(2) } ----> P = monument

It may be obvious even from this small example that in case of large knowledge-bases long inference chains may occur that are valid but may be not necessarily related to finding a solution. Perhaps a backward-chaining strategy may solve the problem more efficiently. In this case we would put forward the hypothesis that P1 is a monument. Since the fact P1 = monument does not exist in the original data base, we have to infer it. Rule R(i) expresses the desired result. The left part of R(i) is matched against the facts, however, non of the conclusions exist. The search continues now by checking the IF part of R(i) with the THEN part of other rules. R2 and R4 are identified and since their IF parts match to the data base, the inference process comes to a halt and the hypothesis is proved.

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Difference of Expert Systems to Conventional Programs

The main difference between expert systems and conventional programs lies not in the delivery of expertise, for many conventional programs can perform "expert" tasks. Rather, it lies on the one hand in the different degree of separation between the dynamics of what and when to perform a task, and the non-procedural, application-domain knowledge on the other hand.

In early programs, code and data were often intermixed. Languages developed during the fourth generation (see Table 1) make clearer separation between data and programming constructs. However, the computer is still given a step-by-step procedure that specifies how the data is to be used to reach an answer. Conventional programs are based on an algorithm that can be regarded as a detailed mathematical model of the particular problem area. The difference between several executions of the program lies in the data, but the way how to find a solution remains unchanged.

In contrast to conventional programs, in expert systems the computer is not instructed specifically how to solve a problem, it is merely presented with it. Based on the knowledge the expert system is provided with about a problem area, plus its inference capabilities determine the way of finding a solution. Referring back to the little example presented, we do not instruct the computer what rules have to be fired, as it would be the case in conventional programs.

POTENTIAL APPLICATIONS OF EXPERT SYSTEMS IN DIGITAL MAPPING

From the previous discussions it should be clear that expert systems are suited for solving nonalgorithmic problems. For many applications, it is usually impossible to define the total flow of actions taken by a human problem-solver. Expertise is, however, often describable in bits and pieces, each relating to some small situation context and its appropriate action. The inference engine is threading these pieces of knowledge together dynamically at run-time.

It is rather difficult to describe in general terms whether or not expert system technology is appropriate to solve a problem. The decision should not be driven by enthusiasm about a new method, rather, it should be based on a careful analysis if it is possible, justified and appropriate. Waterman presents in [WATE85] necessary requirements for the decision process, summarized in Table 2.

Requirements to make use of expert systems		
possible	justifiable	appropriate
Task does not require common sense	Solution has a high payoff	Task requires symbol manipulation
Task requires only cognitive skills	Human expertise lost or scarce	Task requires heuristic manipulation
Experts can articulate their methods	Expertise needed in different locations	Task is not too easy
Genuine experts exist	Expertise needed in hostile environment	Task has practical value
Experts agree on a solution		Task is of manageable size
Task is not too difficult		
Task is not poorly understood		

Table 2

Requirements and characteristics to determine if application of expert system is possible justifiable and appropriate

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The development of an expert system is possible if all the requirements listed in the first column of Table 3 are satisfied. The possibility, however, does not yet answer the question if the development is justified. One or more of the criteria in column 2 should be true. In column 3 are listed the characteristics that make the use of expert systems appropriate.

Several authors explored the applicability of expert system technology to digital mapping, including photogrammetry. Pendleton [PEND87] reports about efforts undertaken by the National Ocean Service's Charting and Geodetic Services (NOS/C&GS). After identifying tasks performed by cartographers which are good candidates for the application of expert systems, a demonstration system has been successfully developed.

Graklanoff developed a method of rating production processes in the areas of mapping, charting and geodesy for amenability to expert systems technology ([GRAK83]). Candidate tasks are assessed using six criteria. Assessments were made for seventeen high-level cartographic production processes using this methodology.

Sarjakoski explores the potential of expert system technology for aerial triangulation with a study of the knowledge typically used in aerotriangulation ([SARJ86]).

The problems expert systems are suitable for solving may be grouped into the categories summarized in Table 2.

Control

Control is a very common computer application. While many applications are adequately dealt with algorithmic control processes, an expert system can sometimes greatly improve the performance of a system. Sometimes an algorithm cannot be found to provide the kind of control desired.

The application area of control is not of great importance in our field, for the systems used, algorithmic control mechanism exist.

CONTROL
DEBUGGING
DESIGN
DIAGNOSIS
INSTRUCTION
INTERPRETATION
PLANNING
PREDICTION
REPAIR

Table 3

Generic Expert System Categories

Design

Design expert systems are already widely used, mainly for designing printed circuit boards, buildings and mechanical parts of all kinds. Given a set of product or system specifications (data base), the expert system is designing a system based on special information that has been put into the knowlegde base by interviewing human design experts.

There are designing tasks in our field suitable for using expert system technology. A good example is the design of an optimal camera set-up in close-range applications, considering the various constraints, such as instruments to be used for measuring or restitution, accuracy aspects, physical and geometrical constellations at the site, just to mention a few.

Other examples are flight planning, the design of geodetic networks or configuring data bases of geographical information systems.

Diagnosis

In contrast to debugging systems, diagnosis expert systems do not prescribe a solution to remedy the malfunction of a system. Some of the most famous expert systems have been developed in the medical domain to assist doctors in diagnosing a patient's problem.

Diagnosis expert systems are of some relevance to our field, for example by helping an operator to detect blunders or to locate other problems associated with the adjustment of large photogrammetric blocks (see [SARJ86]).

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Instruction

Several instruction expert systems have been developed to teach students how to solve problems in their field of expertise. By using the explanation facilities of the system, the student can be made aware of the sequence of rules being used to reach a conclusion.

Computer-aided instruction (CAI) systems present information to the student, ask questions and evaluate answers. Often, CAI systems are designed in a fixed manner, not taking into account the different background and skills of students. An expert system can help to interpret the student's knowledge and will not only diagnose weaknesses but may also be able to suggest corrective actions.

The use of computers for instructional purposes has been neglected in our field. The complex systems offered by the manufacturers usually lack of a state-of-the-art user interface and efficient instruction material, leaving a novice operator in a state of low production and dissatisfaction. By using expert system technology, combined with CAI programs, a more efficient training and subsequently a better use of instruments could be reached.

Interpretation

One of the best applications for an expert system is interpretation. As demonstrated with the example given above, the expert system is given inputs consisting of observations and other data. Then the inference engine attempts to infer a particular situation, based on its domain knowledge.

Interpretation expert systems have been built to interpret aerial imagery ([MCKE85]). Others are proposed for the interpretation of engineering drawings. Map interpretation systems could greatly expedite the tedious process of digitizing and encoding existing maps.

Planning and Prediction

Planning applications are for example project management, military tactics and strategy and automatic software generation. Prediction systems in our field may eventually be used in conjunction with design systems if it comes to predict the accuracy behaviour or some other future status.

CONCLUSIONS

Expert systems represent an exciting, relatively new programming methodology, one that evolved as an important subarea of artificial intelligence. Many successful applications are beginning to appear in medicine, business, finance and engineering. Also, many tools for building expert systems, for example shells and programming environments are now commercially available. Expert systems expand the use of computers to many applications that could previously be performed only by human experts.

The commercialization of AI, reports about successful developments of expert systems and claims for its capabilities did not only generate high expectations but brought on some myths and is perhaps pushing the public's expectations beyond what can be delivered in the foreseeable future. Automatic acquisition and compilation of knowledge is still very much an AI research topic.

When inventions or new technologies emerge from (pure) research, several steps are typically involved till the practitioner in the field can make use of them. The steps, sketched in figure 2, are spanning years if not decades.

Let's take aerotriangulation as an example. The prerequisites were of course computers and methods from linear algebra for solving large equation systems. Then research activities began at universities and corporations. It took nearly fifteen years from the first research activities in the mid-1950's till the first programs performed satisfactorily outside research labs. Only after this initial research period would manufacturers and software houses begin with the development of aerotriangulation programs and make them subsequently available to the photogrammetric practice.

Without any doubt, there are many tasks in digital mapping that are appropriate for expert system development. Some of these tasks are rather mundane and they do not capture the attention from researchers in photogrammetry and cartography. At first glance it may appear that the solution of problems like placing geographic names on map, interpreting aerial photographs or digitized maps do not lend themselves into a scientific endavour like an adjustment problem with an impressive mathematical model seems to do.

In conclusion, more research with expert system technology is required in our field before the potential of this new programming approach can be fully exploited. There is no short cut from the present stage to the broad application by mapping organizations.

(pure) research	---->	inventions new technologies and methodologies
applied research	---->	apply general methods to specific applications. Refine methods.
development	---->	take methods from research and develop robust products and market them.
user	---->	takes developed products into operation

Figure 2
Cycles from invention to practical use

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ABSTRACT

Expert systems represent an exciting new programming methodology, one that emerged as a subfield of artificial intelligence. In contrast to conventional programs, expert systems manipulate knowledge rather than data. The computer is not told how to solve a problem, it is merely presented with it, and then the expert system determines the way of finding a solution, based on the knowledge about a specific application-domain and based on problem-solving knowledge.

There are several tasks in digital mapping that are appropriate for expert system development. However, more research at universities and corporations have to be carried out, before robust expert systems in our field can be effectively taken into operation by mapping companies.

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The paper provides the non-specialist with the basic concepts of expert systems and explains the difference to traditional programming methods. Emphasis is placed on a simple example of a digital mapping application and on an evaluation of suitable tasks for expert system developments.

AUF DEM WEG ZU EXPERTENSYSTEMEN IN DER DIGITALEN KARTIERUNG

ZUSAMMENFASSUNG

Expertensysteme sind eine relativ neue Programmierungstechnik, die aus Forschungen der künstlichen Intelligenz hervorgegangen ist. Im Gegensatz zu konventionellen Programmen werden bei Expertensystemen nicht Daten sondern Wissen manipuliert. Dem Rechner wird nicht eine detaillierte Befehlsfolge übergeben, sondern nur eine Beschreibung des zu lösenden Problems. Das Expertensystem findet aufgrund des anwendungsspezifischen Wissens und mit Hilfe von spezieller Problemlösungs-Software eine befriedigende Lösung.

Expertensysteme sind zur Lösung verschiedener Probleme in digitaler Kartierung geeignet. Bevor jedoch Systeme auf breiter Basis Eingang in die Praxis finden werden, sind Forschungsarbeiten mit der neuen Methode erforderlich.

Der vorliegende Artikel richtet sich an Nichtspezialisten in Expertensystemen. Nachdem das grundsätzliche Konzept erläutert wird, folgt eine Gegenüberstellung zu traditionellen Programmierungstechniken. Anschließend wird das Konzept auf ein kleines Beispiel aus unserem Gebiet angewendet. Schließlich folgt eine Untersuchung, welche Probleme in digitaler Kartierung für die Anwendung von Expertensytemen geeignet sind.

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