Mixing structural simulation models with expert systems

Mixing Structural Simulation Models with Expert Systems

Utilisation conjointe des modèles de simulation structurale et des systèmes experts

Verknüpfung von strukturierten Simulationsmodellen und Expertensystemen

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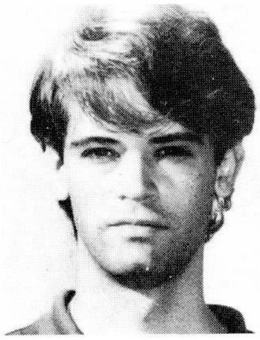

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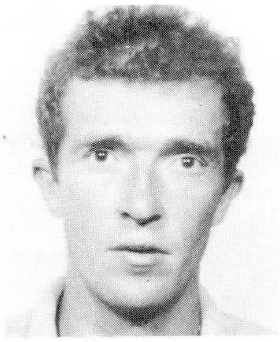

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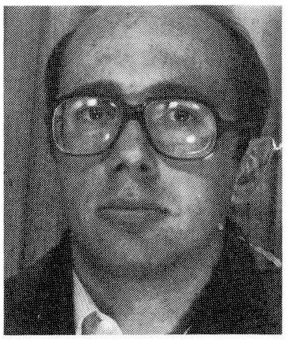

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ABSTRACT
ERASME is a multi expert system for pavement defect diagnosis and rehabilitation, which is interfaced with four structural simulation models. At first, we present the project objectives. The concepts we use to encode knowledge are shown in the second section: blackboard-like architecture, multiple reasoning, multi expert systems. The third section concerns the knowledge representation: associational and causal knowledge, Generate & Test & Debug Paradigm. At last, an example of solving process is proposed in the fourth section.

RESUME
ERASME est un système expert multiple, pour le diagnostique des défauts des chaussées et leurs réparations, qui est interfacé avec quatre modèles de simulation structurale. Nous présentons d'abord les objectifs du projet. Les concepts que nous utilisons pour le codage de la connaissance sont montrés dans la deuxième partie: architecture type «blackboard», raisonnement multiple, systèmes experts multiples. La troisième partie concerne la représentation de la connaissance: connaissance associative et causale, génération & test & correction. Enfin, un exemple d'un processus de résolution est proposé dans la quatrième partie.

ZUSAMMENFASSUNG
ERASME ist ein vielfältiges Expertensystem für die Diagnose von Defekten bei Strassenbelägen und deren Reparaturen. Das Expertensystem ist mit vier Simulationsmodellen verknüpft. Zuerst wird das Projekt beschrieben. Das Konzept für die Kodierung der Grundlagen ist im zweiten Teil aufgezeigt: Aufbautyp «black board», vielschichtige Grundlagen, vielfältige Expertensysteme. Der dritte Teil behandelt die Darstellung des Wissens: verbundenes und ursächliches Wissen, Entstehen & Testen & Korrigieren. Im vierten Teil wird ein Beispiel einer Lösungsfindung beschrieben.

1 ERASME OBJECTIVES

ERASME is a three year old project for building a multi expert system for highway rehabilitation.

1.1 Solving Process

Following HALL [3], evaluation of a pavement and development of feasible rehabilitation alternatives is perfomed according to the following steps :

1. Evaluation of present condition,

2. Construction of different pavement assessments,

3. Prediction of future condition without rehabilitation,

4. Selection of rehabilitation approach,

5. Prediction of each rehabilitation approach,

6. Cost analysis of each rehabilitation approach,

7. Physical testings as needed.

Those steps are performed along diagnosis, prediction and design stages.

1.2 A user assessment

Before or while developing an expert system, it is important to pay attention to the expected user ! ERASME should be available to decision makers in the field of pavement rehabilitation at the regional services level. Our average user manages 3000 kilometers of minor roads. He analyses 300 kilometers each year. That leads to about 30 worksites. He spends a 50 million francs budget (that is approximately 7,5 million dollars). Using ERASME he should save at least 2.5 % on his budget. In FRANCE, ERASME should have about one hundred such users.

1.3 Diagnoses services

The user must be able to get diagnosis information about a particular section that worries him. He can either submit his case of interest to the generalist or make use of the skills of the specialists.

In the first case, the generalist will take care of the problem. He will call on adequate specialists to treat the problem.

In the second case, only the selected specialist skills will be called for. The expert system will focus its attention on the user's particular point of interest.

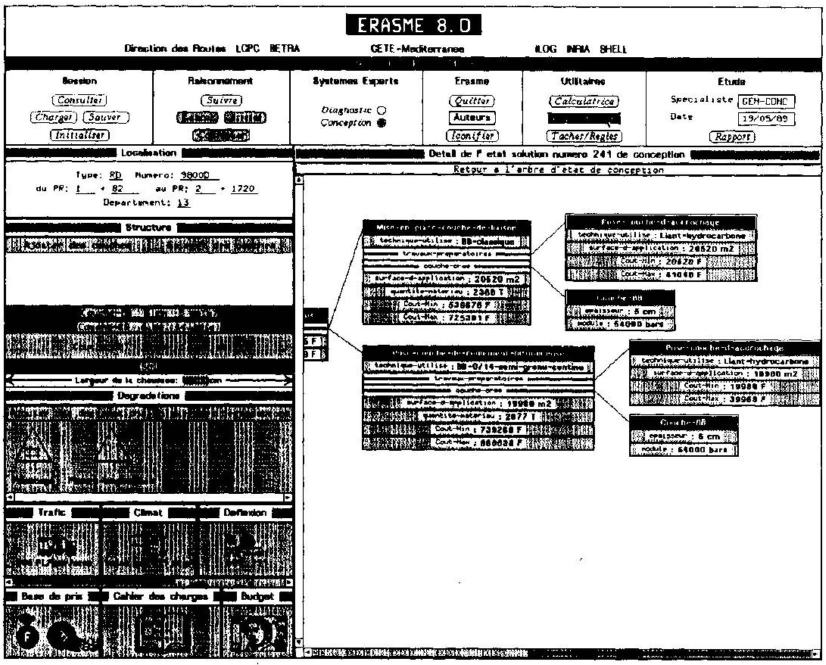
The specialist " pavement frost resistance" can either calculate a roadblock due to icy roads or evaluate past frost damages on the pavement.

1.4 Design services

Design follows a wholescale analysis, that is a diagnosis undertaken by the generalist expert for diagnosis.

Before actual design, the main specifications are drawn up by the user. These specifcations are expressed in terms of life service, surface course adherence, life time ...They constitue the requirement.

Generally, ERASME will propose several successful rehabilitaion techniques. For every proposed solution, a life-cost analysis will be performed.



1.5 Prediction services

Following HALL [3], we think that a pavement evaluation system which can only identify current rehabilitation needs has limited usefulness as a pavement management tool. In order to assist decision makers, the expert system must be able to predict pavement evolution in case of no rehabilitation.

This facility should enable pavement managers to assess the consequences of a work report.

1.6 Incomplete Data

Available information is sometimes scarce, in particular for low traffic roads (laboratory tests such as deflection or in-situ material tests). The pavement manager would like to know which laboratory tests he should require in order to assess pavement state and choose a reliable and cost-effective rehabilitation technique. When information is lacking, the system will propose several concurrent diagnosis and associated rehabilitation techniques. In a second stage, it will indicate the laboratory tests that would reduce the number of these concurrent diagnoses.

1.7 User Interface

We made much effort to create a user friendly interface featuring icons, mouse, windows and various editors.

2. THE SYSTEM ARCHITECTURE

2.1 The Multi Specialist Kernel

As the number of human experts involved in the projet is about twenty, a multi specialist architecture has been selected in order to produce a modular software. ERASME is in fact built on the model of blackboards [4]. It is a collection of simple cooperating knowledge bases, called specialists, where each one embodies specialized knowledge such as : frost resistance, asphalt concrete, struture adequation toward traffic, etc... It enables modular knowledge formalization and modular encoding.

As the system is developed by several persons (currently four), the software engineering modularity concept is of great interest. It enables easy internal modifications and greatly facilitates debugging. Furthermore, an incomplete system can be tested.

Whereas operational competence is distributed among specialists, structural knowledge is global and shared by all of them.

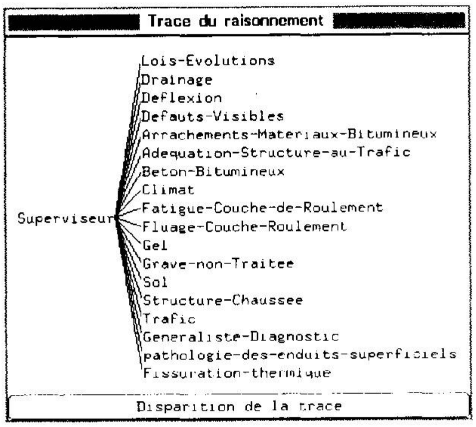


Figure 1 The Supervisor and its specialists

2.2 Structural Knowledge

Concepts involved in pavement diagnosis and rehabilitation are represented by SMECI [6] frames, including classes and instances. The global data base is a collection of such instances calleds *objects*.

The value of an object's slot may be either an integer, a real, a string, an object or a list of such values. Slot value may also be constrained by an interval or a list of possible values. Slot value may also be constrained by interval or a list of possible values. As the value of a slot may be another object, instances may be connected through slots values and form a net.

A class defines the structure of a family of objects in terms of slots. Classes are refined by standard subclass trees which specify default values, range constraints and specific methods. A class inherits methods, values and contraints from its ancestor, unless it redefines them.

Structural knowledge includes such classes as : *Pavement, degradation, traffic etc...* The following figures show the icons associated to the Degradation classes.

Deductions are carried out by production rules whose premises and actions operate on objects. The system records its deductions within slot values and new objects.

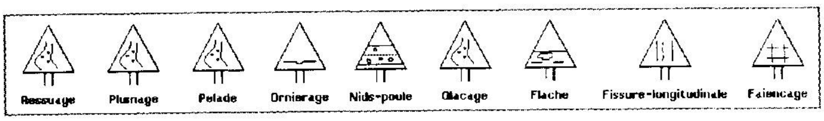


Figure 2 : Icons associated to Degradation classes

2.3 Multiple Reasoning

The SMECI shell provides multiple states that are similar to ART viewpoints [1] and KEE multiple worlds [2]. However, SMECI states cannot be merged.

An expert system programmed in SMECI states starts its reasoning from an initial state. Rules of current rule base generate states that are *sons* of the current state. If a rule has several instantiations, it produces one state per instantiation. If several rules fire, each one produces its own state. In order to prevent combinatorial explosion, it is possible to specify, for each rule base, the maximum number of applicable rules. It is also possible to prune the tree by mean of contradiction rules.

The next figure shows a state tree produced by ERASME :

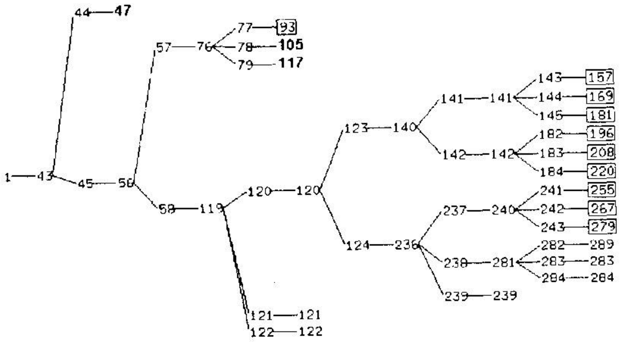


Figure 3: A state tree

2.4 Reasoning upon Reasoning

It is possible to have several expert systems in the same SMECI environment and make them work together.

In SMECI, an expert system is an object, instance of a system class called *Expert System*. Each expert system has its own knoledge base (classes, rules, methods) and data base and derives its own reasoning tree.

In order to construct its own reasoning tree, one expert system can look over the resuls previously attained by its colleagues. That feature is called *Reasoning upon reasoning.*

At present time, ERASME is a collection of two expert systems. The first one is in charge of pavement assessment or diagnosis. The second one is able to design rehabilitation techniques associated to previously attained diagnoses.

3. KNOWLEDGE REPRESENTATION

The following concerns the diagnosis expert system of ERASME.

3.1 Structural Simulation Models

In the field of pavement Engineering, knowledge is generally associated to causal models[1].

Often, causal models are implemented in terms of **Structural Simulation Models**.

Causal models can be used to predict the behaviour of a *known object.*

ERASME is interfaced with four structural Simulation Models : Gel (frost resistance), Alize (structural analysis), Ornier (asphalt concrete fow), Fistherm (asphalt concrete thermic cracking)[2].

3.2 Associational and Causal Knowledge

When causal models are available, pavement engineers use two types of knowledge :

1. **Causal knowledge** which map causes to effects,

2. **Associational Knowledge** which map effects to causes.

Associational rules could be automatically derived from causal rules by simply reindexing the later [5]. This would lead to the setting up of a huge number of associational rules.

In fact, experts use only a few associational rules which derives from their own experience. Associational rules encode two important abstractions of the causal domain models [5] :

. encapsulation of interactions,

. encoding of problem solving knowledge.

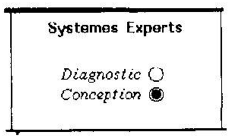


Figure 4: Expert System Selector

[1] However, some of pavement behaviors remain unclear or unknown : *unbound materials flow,soil behaviour,etc.*

[2] **Gel, Alize and Fistherm** belong to the Laboratoire Central des Ponts et chaussées, PARIS, FRANCE and **Ornier** to the Shell Compagny

3.3 Cooperation betwen Associational and Causal Knowledge

The Generate & Test & Debug paradign was published by MR. SIMMONS [5].

3.3.1 Generate, Test and Debug

The diagnosis expert system of ERASME has three main stages in its solving process :

1. **Generate**, it builds a model of the pavement according to some reasonable hypotheses set up by itself,

2. **Test**, it simulates the behaviour of the pavement given the proposed model in order to determine the validity of the hypothesis. If the test is successful, the hypotheses are accepted. Otherwise, the last stage is undertaken.

3. **Debug**, given the results of the testing stage, it emits suspicions in order to modify some of the previously defined hypotheses.

The system use **associational rules** to set up reasonable hypotheses and emits suspicions upon previously defined hypotheses.

```
DEBRULE     hypothesize-binder-class

LET         pavement a Pavement
            surface -course a Layer AMONG 1^Layers^pavement

IF          class^binder^asphalt^surface-course = () AND
            geographic-area^pavement = south-of-France

THEN ACTION
                 $ (hypothesize class^binder^asphalt^surface-course '40/50)

ENDRULE
```

Figure 5 : An hypothesizing rule

ERASME uses causal knowledge in the testing stage, including the **four Structural Simulation Models** it is interfaced with.

Specialists declare at the beginning of the reasoning process which hypotheses they are concerned with, in such a way that the supervisor may trigger them again when hypotheses are updated.

Such a triggering leads the specialist to carry out again its reasoning process, according to new hypotheses values.

3.3.2 Suspicions

In the *Debug* phase, the system undertakes a reasoning process with the following steps :

1. some of its specialists express *suspicions* on certain hypotheses according to some *suspecting rule*,

2. it generates one line of reasoning per suspicion,

3. each suspicion is sent to the competent specialist which

   . modifies some hypotheses,

   . or generates another suspicion,

given the current suspicion and according to some *debugging rule*,

4. it reprocesses some of its reasoning process.

```
DEBRULE      suspect-granulate-high-dosage

LET          pavement a Pavement
                   tear-out a Degradations of prototype tear-out
                         among degradations^pavement
                   coat a Material of prototype Surface-coat
                         among material^1^layers^pavement
                   granulate a Granulate among granulates^coat

IF           appearance^tear-out = first-winter AND
                   spot^granulate = no AND
                   modality^tear-out = generalised

THEN ACTION
                   $ (suspect granulate 'dosage 'high)

ENDRULE
```

Figure 6 : A suspecting rule

Suspicions leads to the construction of alternative worlds. Each leaf node of the diagnosis state tree describes a model that accounts for the real pavement.

4. EXAMPLE OF ERASME

This section shows an example of ERASME diagnosis expert system utilization. Let's suppose that the user consults ERASME by means of the supervisor which will act as a generalist expert calling specialists.

4.1 Request on an Example

The supervisor emits the first request :

R1 : visible-defects of pavement

It is routed by the supervisor to the Visible Defects Analysis specialist (VDA) which defines the surface state of the pavement. VDA emits a request :

R2 : definition of structure

The VDA specialist is then interrupted to let the Structure specialist (ST) answer *R2*. ST initializes the pavement structure.

After the two specialists reasoning, the supervisor is in possession of general data allowing it to carry out a diagnosis.

Suppose that the surface state presents a significant rut. The supervisor decides to consult three specialists : Structure Adequation to Traffic (SAT), Wearing Course Fatigue (WCF) and Frost Resistance (FR).

It emits three requests in order to trigger the specialists:

R3 : adequation of structure,

R4 : degradation of wearing course,

R5 : frost damage of structure.

After specialists consultation and some Structural Simulation Programs execution, three situations may happen :

1. The supervisor decides to stop reasoning. It evaluates the current state as a diagnosis because data are coherent. Every symptom has an identified cause, the diagnosis is archieved.

2. The supervisor detects incoherence. It may emit a suspicion on the value of an object slot and reprocess a part of previous reasoning.

3. The supervisor detects contradictions like in 2), but it is not able to emit any suspicion. The current state is tagged as contradictory and is abandoned.

4.2 Suspicions on an Example

We pursue the preceding example and let's suppose that the expert system produced only one line of reasoning. The last state contains the following important facts :

the structure is adequate with respect to traffic, there is no fatigue of wearing course, there is no frost damage of structure.

Anyway, the current state is considered incoherent because the importance of the rut is high. Then the supervisor suspects the traffic is under evaluated.

The suspicion is transmitted to the Traffic specialist. It reprocesses its reasoning according to new data about traffic evaluation.

Some tasks contain rules that refer a suspicion in their premises as shown in figure 7.

```
LET     suspicion a Suspicion
If      slot^suspicion = evaluation AND
        object^suspicion = traffic AND
        value^suspicion = under-evaluated
THEN
        number-trucks^traffic = 3/2 * number-trucks^traffic
```

Figure 7 : A debugging rule

The new value of the slot *number-trucks* of traffic leads the supervisor to fire again SAT, WCF and FR because all of them declared that this slot was an hypothesis they were sensitive to.

Emitting a suspicion produces non monotonic reasoning by the mean of hypothesis dependency declaration.

5 CONCLUSIONS

Heterogenous Knownledge Pavement Engineering is a complex task which involves very different knowledge. One has to use several different schemes to encode Pavement Engineering knowledge.

Causal models Civil engineering is a domain where causal models represent a large part of existing knowledge. Causal models are sometimes available as structural simulation programs.

A lot of calculations For solving a particular problem, ERASME makes a lot of calculations (up to 150 executions).

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