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PROPAGATION OF IMPRECISION AND UNCERTAINTY IN "SOFT", A GEOGRAPHICAL FUZZY EXPERT SYSTEM FOR SPACE MANAGEMENT AND PLANNING.

ABSTRACT

This paper describes the process of knowledge interpretation and propagation of imprecision and uncertainty in a geographical expert system for decision making in space management and planning. The problem is to evaluate compatibility between a possible space assignment A and a setting S of the geographical space.

SOFT organizes fuzzy neighbourhoods of S on different scale levels. Then it determines the possibility measure (by using MAX-MIN operator) of each required pounded condition for A and each geographical attribute of each S's neighbourhood.

The different possibility measures which are obtained are then combined using either MIN operator (if pessimistic point of view of global compatibility between A and S) or the calculus of the median (if "medium" exigence about this compatibility). The result expresses the possibility of successfully setting up of A on S.

KEYWORDS

Space management planning - expert system - possibility theory - operational geography.

INTRODUCTION

The objective of this paper is to present and discuss one particular and limited point of the construction of SOFT, an expert system in space management and planning : the formalization and propagation on uncertainty about geographical space assignment.

SOFT is a currently built expert system which will be able to aid for decision making in :

- choice of an assignment for a geographical given setting,
- choice of an optimal setting for a given activity or more generally for a given land-use,
- simulation about different types of land-use which can be setted up in a given geographical space.

The "environment" of SOFT is a fuzzy one, at once by adopting fuzzy informations, making approximate reasoning and proposing diagnostics in fuzzy terms. In other terms, by accepting imprecision and uncertainty in all the steps of SOFT's conception, building and running.

So, our task is to show the major points of representation and propagation of uncertainty in SOFT. In this sense, the present work completes previous ones (ROLLAND-MAY, 1984, 1985, 1986) and represents a developpment of one point of our work about "space representation in SOFT" (ROLLAND-MAY, 1986).

It uses for its general framework the theory of possibility (ZADEH 1978, 1983, DUBOIS-PRADE, 1985). Its originality consists on "spatialization" of their formalized notions and theoretical approach.

Part 1 presents the basis of SOFT, at once from a theorical and from a more concrete point of view. Part 2 treats about imprecision and uncertainty in SOFT's knowledge representation : our key-idea is that all knowledge must be represented according to space scale fuzzy levels.

Part 3 gives theoretical framework for propagation of imprecision and uncertainty in inference task by presentation of an algorithm of knowledge interpretation process.

I - THE BASIS OF SOFT

1. What is a fuzzy geographical space ?

1.1. ROLLAND-MAY (1984) presents and formalizes a fuzzy geographical space as a imperfectly or incompletely delimited space so that it can be defined fuzzy fringes of spatial indetermination.

1.2. Graph 1 illustrated the logical process of defining fuzzy geographical space.

It follows that we can distinguish :

- imprecise fuzzy spaces : their elements belong more or less to them
- uncertain fuzzy spaces : without evaluing the membership of its element, one's not able to decide with entire certainty if an element belongs to it. So, uncertainty suits to incomplete knowledge about the elements of the space
- complex fuzzy spaces : they are at once imprecise and uncertain.

2. SOFT will be a fuzzy system (Graph. 2)

Consequently, our decision support system in space management and planning has to :

- work with imprecise informations about the geographical space,
- infer from uncertain informations which human experts have formulated about their own experiences, personal evaluations and more or less subjective judgments, in other words about personal heuristics,
- propose decision making which will traduce in imprecise and uncertain propositions about geographical space the propagation of the constraints, represented by imprecision and uncertainty, through the different processes of SOFT.

II - IMPRECISION AND UNCERTAINTY IN KNOWLEDGE REPRESENTATION OF SOFT

SOFT is a fuzzy system :

- its foundamental framework is based on fuzzy spatialization,
- knowledge base includes imprecise and uncertain informations,
- base of facts represents a fuzzy digitalization of geographical space.

1. Framework of SOFT : set of space scale fuzzy level

Let's define a set of space scale levels like :

S : {ponctual, local, supralocal, large, regional, supraregional}

S induced a suit of included subspaces so that :

ponctual space ⊂ local space ⊂ ------- ⊂ supraregional space.

This space scale levels are fuzzy ones on the sense of ZADEH's possibility theory.

They are linguistic terms of the fuzzy linguistic variable "space width". Each of one is defined by a possibility distribution into an interval I of $\mathbb{R}$.

The lower bound of $\mathbb{R}$ is the lowest possible value of "space width" : 0 ; the upper bound is the highest value of space width. It depends from the treated geographical context.

2. Knowledge representation

2.1. A spatialized representation of each type of space assignment

2.1.1. Realizing of a fuzzy pattern of a space assignment

The major points of such a pattern are :

- a "spatialization" of each space assignment by organizing of all required conditions according to the defined levels
- a representation of imprecision and uncertainty of each condition. So Graph 3 indicates :

  p_i : "pound" of the condition for the assignmen

  v_i : measure or fuzzy evaluation of this required condition.

2.1.2. Expression by production rules

So Graph 3 will be expressed by :

if A & B & C .... & Z then $\mathcal{A}$ (w)

where : A, B, C.... Z are fuzzy expressed conditions as shown in graph 3.

w is the degree of "possibility" of the successfull realization of the assignment $\mathcal{A}$.

3. Fuzzy facts representation : the cartographical working base

Geographical space for which SOFT will be expert is to be digitalized and loaded in working base.

So it is covered with a network, each unit-mesh being defined by a set of :

- quantitative measured attributes,
- or (and) linguistic variables defined as show above by linguistic terms.

4. Conclusion remark

So SOFT has to infer decisions based on approximate reasoning and imprecise and uncertain knowledge. How do these constraints be propaged through the different steps on SOFT's running ?

III - IMPRECISION AND UNCERTAINTY CONSTRAINT'S PROPAGATION IN KNOWLEDGE INTERPRETATION PROCESS

1. Problematic

1.1. Let $\mathcal{A}$ be a given assignment to be affected to a geographical setting S.

1.2. $\mathcal{A}$ is defined by a fuzzy pattern which organizes the required conditions according to the space scale fuzzy levels.

1.3. S's environment is automatically defined by a set of included subspaces called fuzzy neighbourhoods like "ponctual" one, "local" one, "supralocal" one... (ROLLAND-MAY, 1986).

1.4. The problem is to test the "compatibility" between $\mathcal{A}$ and S and its neighbourhoods ; it means that regional neighbourhood of S must satisfy regional conditions of $\mathcal{A}$, and that for all defined levels.

The knowledge interpretation process is shown in following described algorithm.

2. Algorithm of knowledge interpretation process

2.1. Step 1

Searching the fuzzy pattern of $\mathcal{A}$.

It is in the PROLOG-form as a set of production rules :

$$
\begin{array}{lll}
(\mathcal{A},w) & : & \mathcal{A}\text{level } 0 \ \& \ \mathcal{A}\text{level } 1 \ \& \ \mathcal{A}\text{level } 2. \\
\mathcal{A}\text{level } 0 & : & A_0 \ \& \ B_0 \ \& \ C_0 \ldots\ldots \ \& \ N_0. \\
\mathcal{A}\text{level } 1 & : & A_1 \ \& \ B_1 \ \& \ \ldots\ldots\ldots . \\
\mathcal{A}\text{level } 2 & : & A_2 \ \& \ B_2 \ \& \ \ldots\ldots\ldots .
\end{array}
\qquad (1)
$$

where :

- the left side of the rule is the conclusion,
- the terms of the right side must be successively satisfied if the conclusion is to be satisfied.

so : $\mathcal{A}$level 0 is satisfied if A_0 at first, then B_0, then C_0 .... are satisfied.

Searching the conditions of a given level

Let's study the case of level 0. We have a second set of rules.

$$
\begin{array}{lll}
A_0 & : & [\text{list } A_0]. \\
B_0 & : & [\text{list } B_0]. \\
| & & \\
N_0 & : & [\text{list } N_0].
\end{array}
$$

where each list is a set of sublists as shown in graph 4. The 2d sublist is the condition part of the rule.

Example concerning A_0 : sublist 2 is in the form :

$$[(l_o, c_o, p_o, v_o)]$$

where :

- c_o is a 2 - uple : (object, linguistic variable)
  or : (object, quantitative one)
- v_o is the measure of the variable or a linguistic term } each of this "evaluation" can be defined by a possibility distribution $\mu_{c_o}(s)$
- p_o is the weight of c_o for $\mathcal{A}$.

so the formulation can be expressed by :

$$\left(l_o, \text{(price, unit ground), very high, } 0.8\right)$$

where "very high" is represented by the 4 - uple:

(6500, 10 000, 1500, 1000)

2.2. Compatibility between $\mathcal{A}$ and S's neighbourhood on level 0

2.2.1. Let V_o be S's neighbourhood of S on level 0.

V_o is a set of n "meshes" of geographical network

$$V_o = \{m_i, \; i = 1, n\}$$

2.2.2. SOFT builds, for level 0 and condition c_i its geographical fact by searching the corresponding attribute and its value into each mesh.

The fact F_{oc_i} may be the set :

$$\{(m_1, v_1) \text{ and } (m_2, v_2) \text{ and } \ldots\ldots\ldots (m_n, v_n)\}$$

2.2.3. The "compatibility of mesh m_1 and condition c_i is the possibility measure of m_1 according to c_i (DUBOIS-PRADE, 1985)

$$C\,(m_1 \; ; \; c_i) = \pi\,(m_i \; ; \; c_1) =$$

$$\bigvee_{s \in S} \left[\frac{1}{p_i} \cdot \left(\mu_{c_i}(s) \wedge \mu_{m_1}(s)\right)\right] \qquad (2)$$

where
- S is the interval of the real line in which c_i is defined
- $\mu_{c_i}(s)$ is the possibility distribution of the evaluation of the required condition

- $\mu_{m_l}(s)$ is the possibility distribution of the evaluation of the geographical corresponding attribute
- p_i is the weight of c_i

2.2.4. The compatibility of S's neighbourhood on level_o and condition c_i is defined as :

$$C(V_o\ ;\ c_i) = \bigwedge_{l=1,n} C(m_l\ ;\ c_i) \qquad (3)$$

By choosing the MINoperator we take the more pessimistic point of view of compatibility between c_i and V_o.

If our point of view is larger, we can also choice

- the median of the values of $C(m_l\ ;\ c_i)$
- the MAX of these values.

2.2.5. Compatibility between V_o and all required conditions for $\mathcal{A}$ on level 0

Sub-steps 2.2.2. to 2.2.4. are repeated for all required conditions.

So we define :

$$C(V_o, \mathcal{A}_o) = \bigvee_{i=1}^{r_o} C(V_o\ ;\ c_i)$$

and more generally :

$$C_l(V_l, \mathcal{A}_l) = \bigvee_{i=1}^{r_l} C(V_l\ ;\ c_i) \qquad (4)$$

where : l is the considered level : $l = 1, k$

r_l is the number of conditions on the level l.

Remark : MAX operator in (4) can be another one like median (medium point of view) or MIN (pessimistic point of view).

2.3. Propagation of uncertainty in the procedure

The first line of (1) gives the general production rule where :

- $\mathcal{A}$ is the studied assignment
- w is the heuristically defined degree of possibility of $\mathcal{A}$'s success if the conditions are satisfied.

So w represents the expert's uncertainty about the strength of the logical implication from the right to the left side of the rule.

2.3.1. According to LESMO (1982), we define so possibility measure of the compatibility between $\mathcal{A}$ and a setting S of a geographical space :

$$\Pi(\mathcal{A}; S) = \bigwedge\left[w, \bigwedge_{l=1}^{k} \left(C_l(V_l, \mathcal{A}_l)\right)\right] \qquad (5)$$

in other words, the global compatibility between an assignment $\mathcal{A}$ and a setting is depending :

- on first, from w, degree of possibility of successfull realizing of $\mathcal{A}$ according to its required conditions,
- on other hand, from the concrete realizing of this required conditions in S and its environment.

CONCLUSION

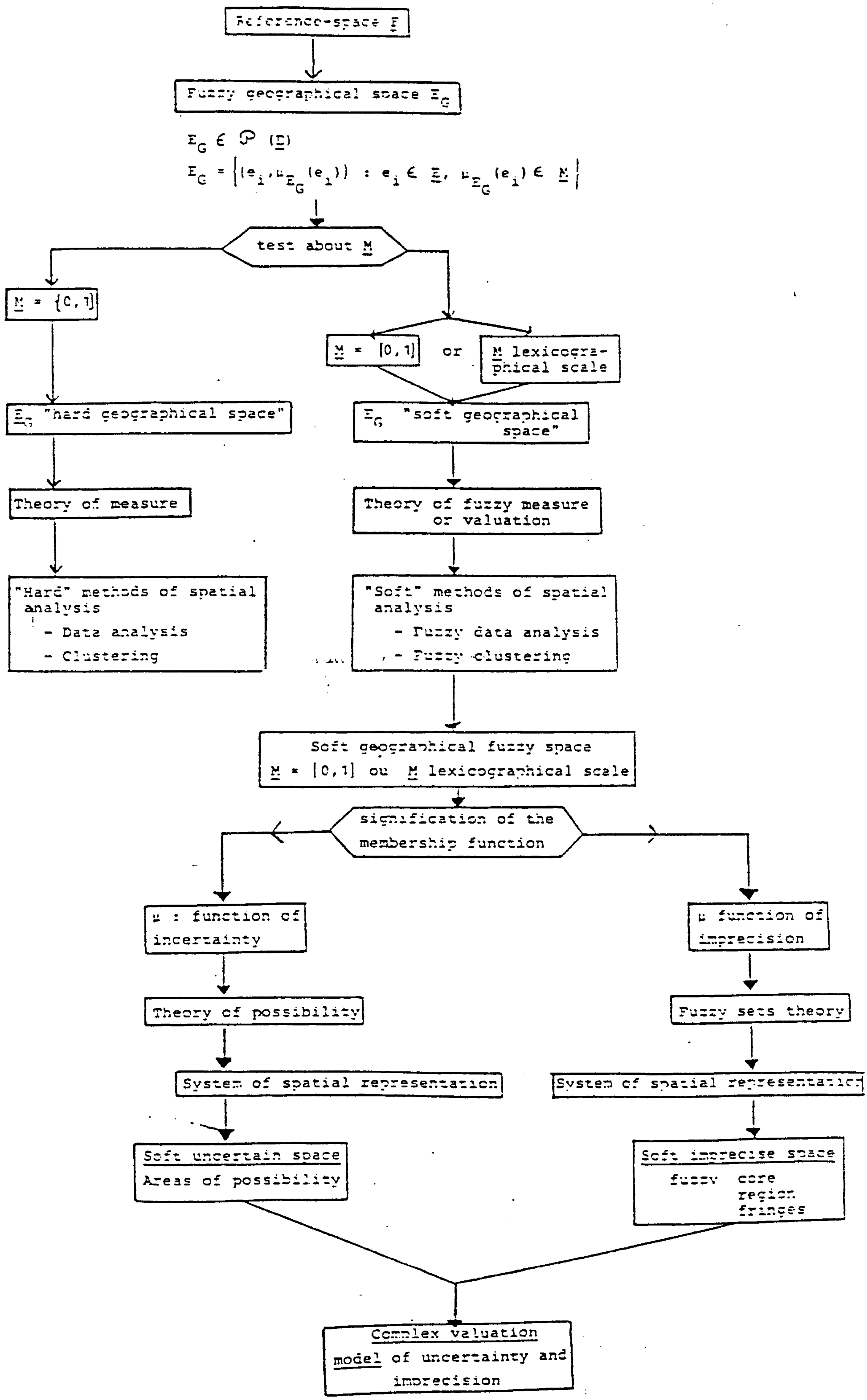
SOFT's interest in such an approach is double :

- from a geographical point of view it applies the axiomatic bases of fuzzy geographical space, which is, in our sense, rich of axiomatical and operational applications ; in particular, it developpes in geographical space analysis the notion of uncertainty, at once in space defining and in formalizing uncertain variable-structure.

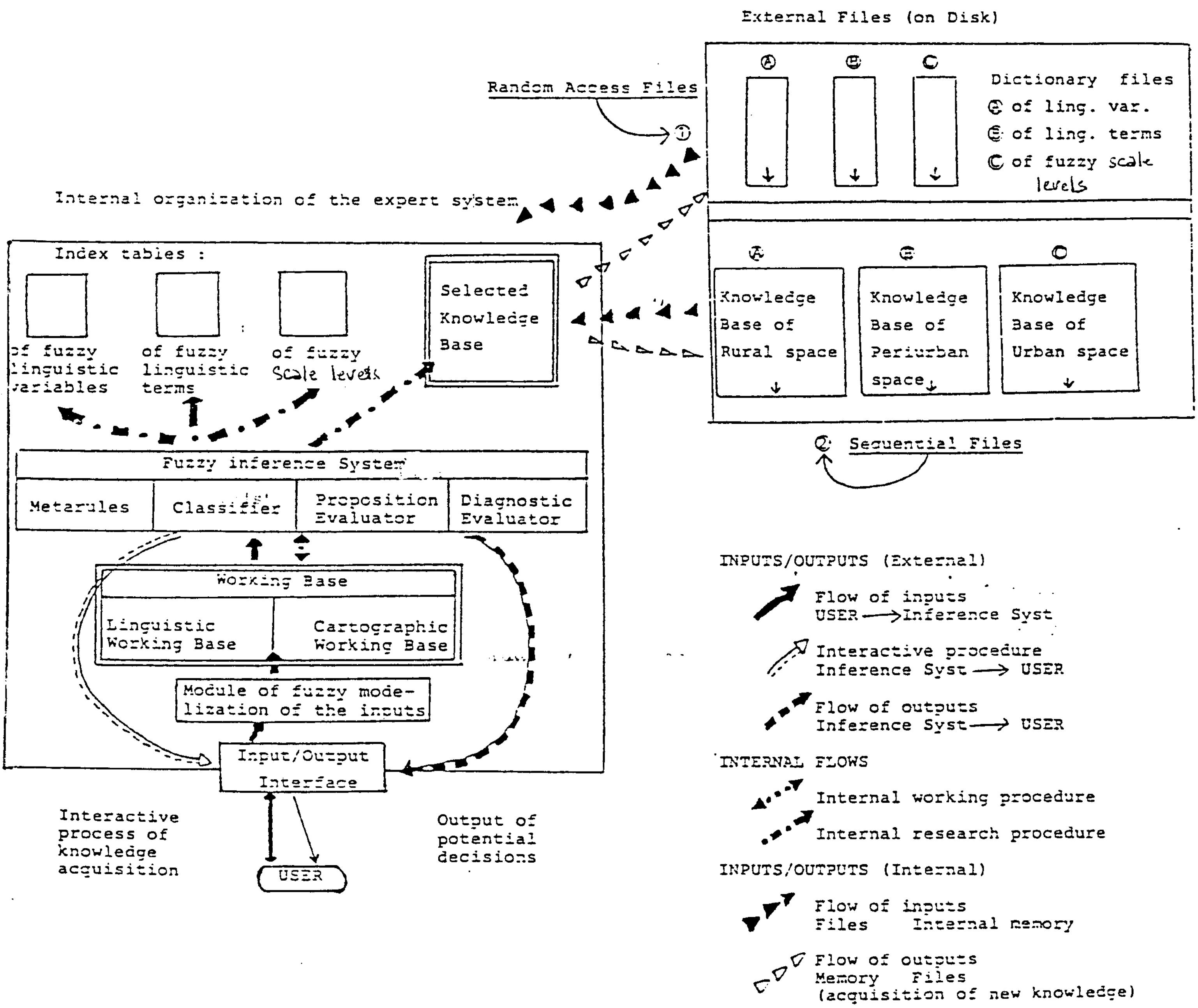
- from an operational point of view, SOFT will be a system able to made approximate reasoning about imprecise and uncertain space knowledges and represent so a very flexible tool in space management and planning.

However, this great compatibility between SOFT and "fuzzy" reality requires an important work of fuzzy formalization of human expert's knowledges and experiences. More as never, geography must be a largely open and pluridisciplinarly science if it will succeed in operational applications.

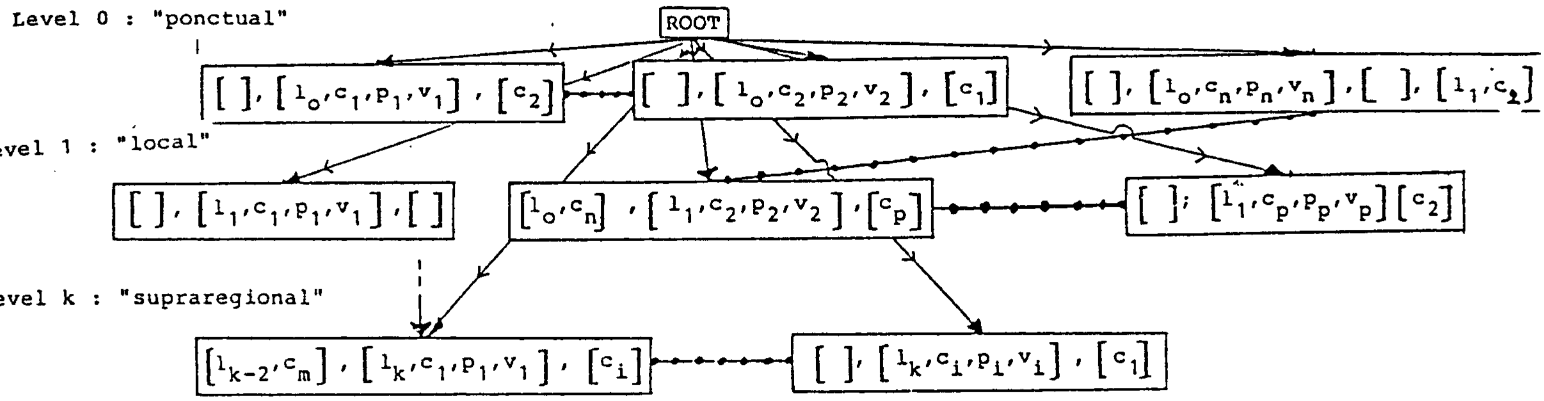
GRAPH 1 - FUZZY APPROACH OF GEOGRAPHICAL SPACE



GRAPH 2 - GENERAL DESIGN OF "SOFT"



· FUZZY PATTERN OF A SPACE ASSIGNMENT $\mathcal{A}$



Explication

[ ] [ ] [ ] [ ] Condition-list

[ ] first sublist : level and cond. number of a "father"

$[l_i, c_i, p_i, v_i]$ 2d sublist : l_i : level number
c_i : condition name
p_i : pound of cond. $\in [0,1]$
v_i : precise of fuzzy value of the condition

[ ] 3d sublist : "brother" of the cond. (on the same level)

[ ] 4th sublist : level and cond. number of a "son" if exists

•–•–• "Internal" relations

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