A Symbolic of Geographic Space Through Remote Sensing

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Abstract: Based on the simultaneous representation and simulation of two know-how [statistical and data analysis skill on one hand, thematic knowledge (here geography) on the other hand], the CIME system is built on a classical inference engine. Its purpose is to monitor and optimise the sequential implementation of numerical treatments in order to make thematical maps. This paper intends to present the methodological basis, the structure and implementation of CIME. These techniques could be generalised to other thematic mapping and other areas.

Key-words: cartography, expert-system, numerical treatment, production rule, remote sensing, segmentation, treatment scheme.

INTRODUCTION

Cartography by remote sensing is a way not only of exposing knowledge but also of *producing* it. The methodologies involved in that process are often very complex (especially in the mountainous areas) as the number of tools utilized is high: radiometry, vegetation and texture indexes, topographical, slope and illumination models. In other words, the labelling of the objects utilized by the cartographical process (i.e. the pixels [elementary points on a satellite imagery]) can be achieved through the utilization of numerous attributes. At the same time, in order to speed up the production of maps, to avail of reliable elaboration and control procedures, theses methodologies need to be reproductible and if possible automatized. These reproductibility and automatization cannot be achieved unless the procedures are formalized. Utilizing numerical treatments, these require two types of distinct technical know-how: statistical and computer programming on one hand, thematic knowledge on the other hand. Each of these know-how is refering to distinct spheres of knowledge and implementation methods. If each and every problem encountered by the thematicians require a specific methodology, the procedures of these methodologies are much less numerous: based on the representation and the simultaneous simulation of the two know-hows [statistical and data analysis skill on one hand, thematic knowledge (here geography) on the other hand], CIME System (Intelligent cartography in mountain environment), build on a classical inference motor, was originaly meant for driving and optimizing the sequential activation of numerical treatments in view of mapping vegetation and land-use in Central Nepal, but this technique is also utilizable by other thematic researches and/or for other areas. The purpose of this article is to present the methodological set-up, the architecture and the implementation of CIME applied to Landsat and Spot images.

1.- Why an Expert System?

1.-1.- Map, Knowledge and cartography by remote sensing

The knowledge of the environment, the societies and their production systems cannot be conceived without a cartographical representation: the speech does not account for all the interrelations of their components. Graphics and associated modellisations make the description of these systems easier by revealing multi-causal circular relations. Nevertheless, the space of their construction is of no reality. Now the notions of homogeneïty-heterogeneïty, limits, discontinuity, proximity, center and periphery do play an increasing role in geographical analysis and in the study of the state and/or evolution of systems such as landscapes, societies, political units, production systems...: the cartography alone allows to represent not only simultaneous spatial interrelations of the elements of a said system but also the state of these elements. The map cannot say all but is alone to express the knowledge of space.

Cartography cannot be reduced to a mean of communication of acquired information: one can identify two types of maps. One is the *synthetic map* which is a document where information collected on the ground is represented: no new information is produced during the process of the elaboration of the map which is merely a mean of communication. On the contrary, the *analityc map* is prospective and its elaboration requires an analysis of images (aerial photos or satellite images) in order to identify objects, their limits and their states as per the type of map wanted, the technique of analysis and the nature of the more or less extensive ground knowledge which will be amplified and modified by the map. Such a cartography is a mean of *production* not only of *knowledge* but also of *questions* and *directions of investigation* by *the identification and caracterization of the object of the study.*

This type of knowledge production, to which remote sensing does belong, also requires a temporal dimension as no functional natural or human system is fixed and the very notion of equilibrium has to be conceived in terms of capacity of a system to constantly reorganize itself under the differential evolutions of each of its elements and the external disturbances. It becomes then necessary to be able to apprehend the rythm of each component of the system: repetitive mapping allows the comparison of the mapped object with itself. It also allows to put new questions on its nature. Furthermore, when an action has to be undertaken in an area (i.e. a development programme for example), a quick knowledge of the problems and their evolutions is utmost necesary in order to be able to elaborate the modalities of this action and to monitor it: little or no time can be devoted to researches and elaboration of the knowledge.

Finally, if a methodology of cartography has to produce a knowledge of the mapped object in time and space (and, if necessary, the conditions of an action on this object), it has also to allow its comparison with other objects of the same order, that is to say their own cartography. In order to meet all these needs at bearable money and time costs, that the taxonomies should be compatible does not suffice: the method itself has to be reproductible. The problems and the methods elaborated to solve them are often so complex that this reproductibility is neither possible nor even thought of: in the majority of the cases, the map is the objective not the methodology of its production. At best, the procedure is explained, a succession of steps that one has to reprogram. The necessity and difficulty of a systematization and a reproduction of the methods and the need of a mass production make then necessary the formalization and the automatization of the production of maps. Thus becomes evident the interest of a procedure like the*Expert System* which separates the methodology and the specificity of each thematic problem, allowing a formalization and the automatization of the construction of thematic maps. Even withstanding the necessary reproductibility, the utilization of an expert system is justified by causes belonging to the process of cartography itself.

1.2.- The procedure

The strategy of CIME simulates the strategy of a human expert who adopts a supervised procedure to elaborate a thematic map, in the present case, the cartography by remote sensing of vegetation and landuse in the Center of Nepal [Blamont & Méring 87]. In other words, the procedure is the partition of a 2-D space (a satellite image) by a succession of numerical treatments on values (the variables) associated to its elementary points (the pixels). Patches of contiguous pixels [*test-plots*] will be identified through a research on the ground, grouped into classes and named after a coherent list, considered as complete, of vegetation units and forms of landuse (forming what is called the landscape of the area) defined *before* the image analysis. They will be the base of the treatments and used for the identification of all the others. The objective of the system is to classify the *pixels* belonging to the *test-plots*, defined by the thematician. To classify them, a common supervised procedure is used: one part of the test plots, called *triaining plots*, is used to define a chain of various segmentations of the numerical variables. The other part, the *control plots*, is used to verify the segmentations. Thanks to the differenciation of internal validation (for example the *Kolmogorov-Smirnov* distance in the case of non parametric discrimination) and external validation by *a posteriori* utilization of control plots, other classification methods can be utilized in the framework of the same general strategy, provided their result is also a segmentation of the variables. The final aim is the identification, the caracterization and the assimilation of the resting unidentified pixels to the landscape units.

At each step, the expert utilizes numerical treatments after having defined their entry variables. The analysis of the results of this first step will tell him whether to interupt the procedure or to select new methods (or other variable of the same method) in order to better the classification. He can also elaborate other chains of treatment; he has then to compare the results of all his chains and choose "the best" to classify the whole mage: the human expert supervises the activation of the treatments, controls the results and chooses the best chains.

1.3.- Why a simulation of the procedure ?

1.3.1.- A complex procedure

1.3.1.1.- Important number of descriptors:

The very nature of the studied area is a very complex one and the sources of the complexificaton are of two kinds:

The nature of the landscape units :

• The multiplicity of landscape units; the altitudinal amplitudes are very important: upto 4,000 to 5,000 m on one single versant. As a result, the gradation of climate goes from subtropical to alpine. The gradations of the vegetation and landuse are further multiplied by the numerous exposures (to sunlight and/or monsoon winds) and situations inside the massif.

• The size of the landscape units; as a result of the steepness of the slopes, the gradation of the vegetation is very quick and each grade is very narrow.

• The margins: the limits between the different vegetation types are mostly natural ones, that is to say gradual. But they are also fuzzy between *natural* landscape units and the cultivated areas: generally these areas are bordered by grazed areas where the vegetation grows denser with the distance to the fields: they often have to be considered as landscape units as such.

• The management of the environment: forests are overexploited and the most accessible slopes are evidently the most vulnerable: big differences in utilization between gentle and near slopes and steep and far away ones add a new factor of differenciation to the natural diversity.

The conditions of image shooting :

• The influence of lighting conditions: at the time of image shooting (0930), solar elevation is low and the ligthings of the versants stand in very high contrasts. Comparable landscape units have widely different radiometry.

• Haze effects: The different lighting conditions do also cause differences in the state of the atmosphere over different versants: haze is more frequent and important over shadowy versants than over lighted versants; thus the radiometry is not of the same kind and the signals cannot be interpreted the same way. This only would justify separate treatments.

The nature of the complexity introduced by all these factors makes necessary the utilization of a high number of variables associated to the pixels. These variables are of three orders:

• Some belong to the image itself: the radiometry.

• others are obtained by calculation from these values: for example, texture indexes caracterizing, in a given spectral band, the variability of the values around a given pixel. They can also be indexes caracterizing more accurately certain categories of components on the ground. In that case they are generally obtained through the combination of spectral bands (for example, green vegetation indexes, combinations of red and infrared bands).

• Others are external to the satellite data: here, the altitude, the slope and the lighting and the time of image shooting.

1.3.1.2.- Variety of iconic forms:

the objects directly treated by the system are pixels belonging to the test plots. Nevertheless, although the pixels are considered individually in the system, the procedures of numerical treatments refer to the plots as wholes, that is to say groups of topologically near pixels. The difference in the modes of representation adopted for numerical treatments and for symbolic treatment corresponds to a difference of status of the procedures operated in these two phases. Furthermore, the notion of classe refers to the geographical limits of a zone, for example "clear oak forest" or dense fir forest". Nevertheless, it is necessary to note that, although the pixel definition (around 80 meters) is comparable to the size of some of the geographical objects studied, the knowledge of these objects has no relation with the knowledge of the pixels.

1.3.1.3. Constant control procedure:

Rather than to test all possible chains, at each step contol procedures allow the operator to stop or to go on with a definite chain.

1.3.2.- A changing procedure:

Due to the numerous factors of heterogeneïty and as the congruence between their effects is very high, on one hand, and as no method of signal correction seems reliable enough, on the other hand, the image is divided in sectors in which the influence of the lighting conditions on the radiometry is marginal when compared with the influence of the vegetation and landuse covers. Three sectors have been identified: the versants which face the sun and receive direct lighting (*lighted sectors*), the versants which receive only indirect lighting (*shadowy sectors*) and versants receiving grazing lighting or on which the alternance of lighted and shadowy sectors is at the scale of the pixels (*grazing light sectors*).

As the natures of the landscapes and of the radiometry are different from one type of versant to the other, there is no reason for the relevance of the variables and the order of their utilization to be the same for the three types of sectors: generally the sequences or chains differ, which obliges the operator to work out three different procedures and requires a know-how which generally does not belong to the epistemic domain of the thematician. Thus, the procedure has been rendered independant from the order of introduction of the variables: in other words, the proposed expert system does not require from the thematician any other knowledge than the one of his thematic field.

2.- The system: knowledge and numerical procedures

In the terminology of Expert Systems, the pixels are represented as *objects, frames* or as *contexts* (following EMYCIN terminology), and the objective of the system is to pilot the activation of chains of procedures through the synthesis of symbolic data (decription of the thematic, of the area and the objectives of the cartography) and numerical data (the results the activated procedures and the values of the attributes of the frames) [vide (Mering & al 1988) and (Ganascia 1984)].

2.1.- The nature of the knowledge:

The knowledge to be introduced into the system is of various domains: one can work out a typology of these domains which will depend on the chosen thematic.

2.1.1.- Thematic and terrain knowledge

The thematic knowledge (taxinomy [:hierarchysed organization of a legend], and the problematic knowledge [elements of organization of a discourse or an interrogation on the taxinomy and establishing relations between its elements others than vicinity or encasing]) are at the origin of each specific mapping project and will determine the elaboration of the legend. The terrain knowledge (the local formalization of the taxinomy) will be collected accordingly to the specific questions raised from the precedent and will be utilized in the elaboration of the test plots.

2.1.2 Knowledge about appearence of geographic entities on images.

This knowledge allows thematicians to delimit significant entities on the image from their iconic attributes such as color, texture and shape. Thematicians may also know about topographic relations between entities (proximity, adjacency, imbrication), and about the structural relation between entities ("part of whole" relation).

Expert systems in *vision* invoke this kind of knowledge. These systems have been built up in order to analyse natural scene [LEVINE 81] and aerial photographs of suburban areas [NAGAO 80].

At the opposite, our system is not based on simulation of the visual process. As a matter of fact, one has to analyse the remote sensing scene according to a given topic, such as lithology, soils, vegetation, landuse and therefore to elaborate entities which in many cases, are not perceptible on the image from a constant level of observation. On the image of MSS6 band of the Salme scene in Central Nepal (fig 1), one can *see* the main features of a mountainous land such as shadowy valleys, sharp crestlines, versants with various orientations and lightings. But one does not *see* the various types of vegetation such as forests, grass-lands or fields under cultivation. On the resulting thematic map (fig 2) vegetation is represented throuh a given taxonomy, but the relief is no more perceptible: the visual analysis has only a relative part in the analysis process.

The knowledge about iconic expression of landscape units is given to the system through a *prototype data base* composed of test plots. Each pixel of a test- zone is described by attributes such as radiometric values corresponding to the four Mss bands and a textural index[1]. The other attributes of the pixels such as altitude, slope and illumination cannot be considered as pertinent for a visual analysis. In this case, knowledge about expected appearence of the landscape units on MSS data is too much ambiguous and incomplete to be taken into account in the system. With high resolution images such as SPOT, we hope that one can make clear this kind of knowledge in so far as perceptible iconic entities can obviously be interpreted as entities of the landscape under analysis according to their texture and shape.

2.1.3 The activation of numerical treatments

As it does not simulate vision, the system needs to have an explicit knowledge on *how to* elaborate iconic entities corresponding to geographic ones. In this version, the system has a semantic knowledge of the image segmentation techniques. It can therefore activate a technique which is in the conclusion part of a production rule. It also analyze and control the results given by the techique.

The techniques recognized by the system are automatic classification techniques. In this system the interpretation can only be performed through the test plot data base. Therefore we simulate a classical supervised approach of analysis, and we select only supervised classification techniques. In this version we call for a non parametric discrimination method based on the minimization of the bayesian risk [CELEUX 80]. The basic method consist in splitting the set of pixels within two classes . The splitting operation correspond to the thresholding of a the most discriminant quantitative variable according to the bayesian risk criteria in reference to the two theoric classes. the two resulting subsets are called *segments* . When there are more than one descriptive variable, a single iteration will generally not be enough to determine the segments. If one of the two resulting segments satisfies the stop criteria, it becomes a *terminal segment* . If not, the whole procedure is applied to this segment.

The system explicitly invokes the previous method and defines all the formal context of its release (instant of execution, set of data to be processed, calling parameters). Then it processes analysis and control of the numerical results, decides about their acceptance. If accepted as available, the results are integrated to the factual database.

The present system can monitor supervised segmentation methods, each segment being associated to a set of theorical classes.

2.2. Knowledge representation

As told in the former paragraphs, the knowledge that has been invoked comes from various domains such as geography, statistics and image analysis. But here, we do not take into account the domain of the knowledge but only the function of it in the resolution process. Therefore we distinguish two kind of knowledges: descriptive knowledge and procedural knowledge.

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[1] the local standard deviation computed with a sliding window (3x3 pixels) on the MSS 6 image

2.2.1 Descriptive knowledge:

Descriptive knowledge are formalized by assertions containing a set of informations describing the characteristics of the entities under analysis.

In our system, we have formalized knowledge about iconic entities, that is the control pixels, as well as knowledge about thematic concepts, such as geographical concepts. For example, the two following assertions:

-"pixel number 12 is associated to the oak forest class "

-"the scene is situated in a mountainous area"

are treated identically by the inference engine "facts" that is as elements of the descriptive database.

Each pixel is described by a set of attributes having either symbolic or numeric values:

- r1,r2,r3,r4 : the four radiometric values corresponding to the four MSS bands
- a : the altitude (evaluated by the MNT)
- p : the slope (evaluated by the MNT)
- e : the illumination at the shooting time (evaluated from MNT and the coordinates of the center of the scene)
- cl : the symbolic name of the class represented by the corresponding test plot.
- cl_afterwards : the list of the symbolic names of the potential classes after a step of analysis

Each pixel is described as an *object* described by all its attributes. The other sort of knowledge, such as the geographical situation of the zone, are considered as attributes describing a single object called *general object.*

The present system can distinguish only two kind of objects : the local ones (ie pixel) and the general one (ie context). In the next version, other kind of objects would be avalaible.

2.2.2 The procedural knowledge

The procedural knowledge defines, how to get an information from already established facts, through a propositional mode. In CIME, this kind of knowledge is represented as individual production rules which have the following declarative form:

If Conditions
Then Conclusions

The content of the Conclusions part can be whether assertions like in the Conditions part, or actions, that is, executions of a given procedure. All the rules are given in bulk. For example the following one is linked to the thematic knowledge about the vegetation altitudinal levels:

rule (1): If
there is an altitudinal level,
altitude < 20,
Then
class_afterwards is not grass-land
class_afterwards is not oak- forest
class_afterwards is not fir-forest
class_afterwards is not rhododendron-forest.

This rule says that, certain types of vegetation cover being absent under a given altitude, one has to eliminate them from the class_afterwards label at the current step.

The following rule enables the execution of the classification numerical method called "dnp":

rule (2): If
the region is a shadow region,
selected classification method is dnp,
Then

execute dnp on the radiometric variables,
step = 1,
state = radiometric analysis,
count resulting segments.

This rule provides the context of the execution of a numerical method, so that the method is applied only to the pixels belonging to a shadow region.

In the conclusion part, input descriptors (here the radiometric ones) of the pixels to be classified are selected, the chain and the step are labeled with respectively a symbolic and numeric label, and the resulting segments are computed.

3. About new tools : From CIME to CIME2

As is exposed in the other paper presented here[1], a landscape, considered as a system, is complex in the sense that it is a emboitement of sub-systems consisting of complex elements that an analysis at a different scale will consider as systems proper : a village territory is composed by a cultivated area and a non-cultivated area (forests and pastures) : the forests are considered by the botanists as complex systems whose organization and evolution depend on their own numerous elements (fauna and flora) but also on their exploitation by man : the cultivated area is itself composed by landholdings and their fields and houses whose repartition is organized following a pattern, fields are not honogeneous, a village is composed by houses, gardens, ways and squares...

The hierarchisation of landscape units and thematic concepts is visible on a map by the legend which is generally not a simple catalog of objects but has classes and sub-classes which are organised following the object of the cartography. For example, there are at least to ways to express the reapartition of forests : classify them by types of trees and then describe the state of the forest (dense or degraded) or, inversely, classify them by the density (dense or savanic, for example) and then by the species. As far as the satellite imagery is concerned, one pixel (most of the time heterogenous, for the thematic) represents almost never a landscape unit whereas a group of pixels does and, on the other hand, separate groups of pixels form a thematic entity which might have to be considered as a whole.

In the first version of CIME, the syntactic tools for knowledge representation as well as the schemes for knowledge exploitation did not allow to take these aspects into account. In particular, CIME enables to describe only one type of iconic entities : the pixels. The other kinds of factual knowledge are described by means of only one type named general type. The weakness of the representation made it difficult to take into account the dynamic transformation of the image. Similarly, the processes were described in a rigid way as directly executable procedures, which rendered impossible to take into account the reasoning consisting of choosing a process and then executing a program. Finally, CIME knew only one description level of the thematic taxinomy, and consequently could not serve a thorough knowledge representation of the scene content.

These are the reasons why we considered the development of CIME2, which is not an expert system but rather a consistent set of software tools (language for knowledge representation and exploitation scheme) for the development of expert systems in the field of thematic interpretation of remote sensing imagery.

We shall briefly describe how we have represented structural and conceptual hierarchies previously called forth, as well as how we have implemented the building of image processing sequences through production rules

3.1. The interpretation process

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[1] see *Machine Learning and Knowledge Acquisition Applied to Cartography.* (D. Blamont, J.-G. Ganascia)

In order to produce a map, we have to developp a system which, from thematic concepts and one (or more) given image(s), allow to transform dynamically the initial iconic data in order to produce a labelled image, that is an image composed of entities which have been thematically interpreted.

Schematically, we consider that at each step of the analysis, a transformation generates a partition of the image. Each part may be more or less accurately thematically interpreted, the final goal being to reduce as far as possible the ambiguity and inaccuracy of the interpretation. To achieve this, we can use two kinds of strategy : a "down-top" strategy where the image transformation, starting from initial iconic data, results in grouping dynamically iconic entities which may be interpreted by means of more and more abstract concepts ; a "top-down" strategy where the image transformation, starting from thematic data, results in decomposing the image into iconic entities interpretable by means of these concepts. Most of the time, the specialist alternates the two strategies. The image transformations are performed by numerical procedures selected and activated by the system as shown in the diagram of table 1.

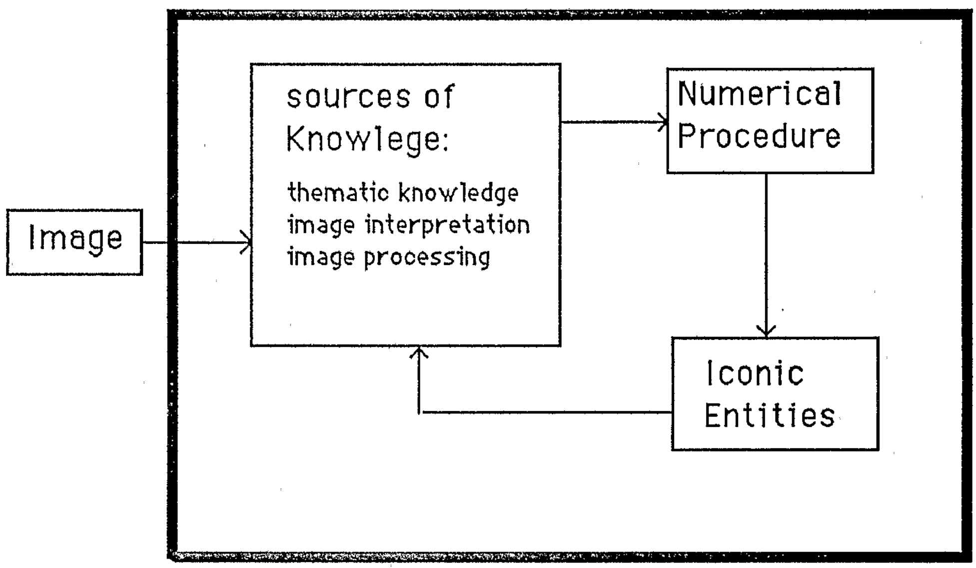


Table 1 : The process of image interpretation

We have now to describe the elements to be actually handled by the system, namely : the image data, the thematic knowledge and the processing.

3.2. Image and iconic entities

Any operation of image analysis is based on the definition of the elements of the image on which the analysis will focus. The elaboration of a formal system of image representation implies the definition of primitives, or basic elements of the representation.

A *primitive,* denoted Pi, is a fragment of the image consisting of a set of points. The most elementary primitive is a point of the image or pixel. A set of attributes is associated with it. These attributes may be its radiometry, its location with respect to a given reference, but may also include exogenous data coming from other sources than the information provided by remote sensing, such as the altitude, the slope, etc.

An *entity* is defined as a fragment of the image which groups a set of primitives that satisfy certain constraints (e.g. such as the definition of numerical limits for an attribute). Note that in the general case, the form of the entities depends on the order in which the initial data (primitives or attributes) are taken into account. A connected entity will be called a *region* and a set made up with various regions will be called an *object*

The description of an entity implies the description of the spatial distribution of the primitives composing it. We call first-order descriptors those which involve the intrinsic characteristics of the image, as is the case with the *histogram* and the *bivariate histogram.*

We call second-order descriptors those which imply the analysis of combined characteristics of pairs or groups of primitives defined by a relationship (e.g. the proximity) as is the case with co-occurrence matrices. Besides, we need high level descriptors, such as topographic descriptors to be able to assess *proximity* , *adjacency*. or *overlapping* The case *inclusion* of two entities is treated in a special way. Indeed, as said previously about the interpretation process (see § 3.1), the image is transformed dynamically, which means that entities are aggregated or separated at one step or other in the process. To store this transformation, we must be able to go through the structural hierarchy of the iconic entities (from the whole to the parts). In particular, the thematic interpretation should include the capacity of deducing the thematic content of an entity from the content of its components. For instance, if the pixels of a region have already been interpreted as pixels belonging exclusively to the "vegetation" category, it should be possible to deduce that this interpretation holds for the region. Besides, in order to compute first- and second-order descriptors of any entity, the entities of lower level have to be accessible. Considering the different modes of image transformation (separation and grouping), we can only go through two consecutive levels of this hierarchy.

3.3. Thematic knowledge

3.3.1. The taxinomy of thematic entities

We consider that prior to any image analysis, thematic concepts are available, that allow to interpret the scene. As we have seen, these concepts are organized into a taxinomy :

The symbolic representation of a one-dimensional taxinomy only requires the symbolic definition of the entities under consideration. Then, symbolic names are listed without describing the kind of relationships existing between the entities. For example, we define the following list: forest, cultivated areas, grassland.

A multi-level taxinomy requires to select an appropriate key-word to express the type of implicit hierarchical relationship present in any taxinomy. One passes from a level of the taxinomy to a higher level according to the specialization-generalization axis We have called this hierarchy a *conceptual hierarchy* which must not be mistaken for the *structural hierarchy* previously.described We use the key word *a kind of* classicaly used in knowledge basis. For instance, we will say that a dense forest is a *kind of* forest. We can see here that in order to express more sophisticated taxinomies and construct systems producing intelligent legends (§2.1), it will be necessary to call for syntactic and semantic analysis [COULON 86] of the language used by the thematician to describe the landscape he has to represent with a map.

3.3.2. The description of thematic entities

We have just seen that the thematician lists and classifies the entities contained in the scene. He may also describe them by their intrinsic characteristics, whether iconic or radiometric. Then, they must be associated with the iconic entities known at the current state. Otherwise, they involve the search for new iconic entities satisfying the constraints implied by the iconic characteristics. Thus, the thematic entity clear forest may be described by means of its iconic and radiometric characteristics, as shown in the example of table 2.

thematic entity :	clear_forest		
iconic entities :	regions		
	surface	large	value>400
	texture	heterogeneous	variance>50
	red_band	low	mean_value<20

Table 2: Iconic and radiometric characterization of a thematic entity

It is possible as well to describe the thematic entities through the relationships existing between these entities. These relationships may be structural or spatial.

We call structural relationships those which allow to go from the parts to the whole in the structural organization of the entities, by composition or decomposition. They apply both to thematic and iconic entities. However the structural decomposition of a thematic entity does not allow to deduce the corresponding iconic entity other than by the composition of already interpreted iconic entities, as in the following example :

thematic entity:	settlement	composed of :	houses
			roads
			gardens

Spatial relationships between two thematic entities directly refer to the spatial organization of the corresponding iconic entities. They may be relationships of *proximity, adjacency* or *overlapping,* as in the following example :

thematic entity: forest roads
in spatial relationship with forest
type of relationship overlapping

3.4. Image processing

The dynamic transformation of the image is performed by means of analysis tools which we consider as basic facts relating to the system. They consist of numerical procedures of image processing. Here, we consider that these procedures are known and used according to the set goal, that is the interpretation of image fragments according to the model provided by the thematician. There exist several types of image processing that may be classified according to different criteria : If the criterion is the kind of action performed on the image, we may distinguish, for example, the following operations :

- geometric correction
- image enhancement (change of dynamics, smoothing and convolution, Fourier transform)
- operations with several images (multispectral classifications, linear or non-linear combinations of several images)
- edge or line detection

The processes may also be classified with respect to the type of result which is obtained. For example, we might distinguish the following processes :

preprocessing (compression, geometric and radiometric corrections)
segmentation
classification

As we have seen, several principles may be applied and none of them has been able yet to serve as a universal reference for image processing systems As a matter of fact, this hierarchical representation of processes is guided by the application. In our case, we will use a hierarchy which corresponds to the two classification criteria mentioned above, as shown in table 3

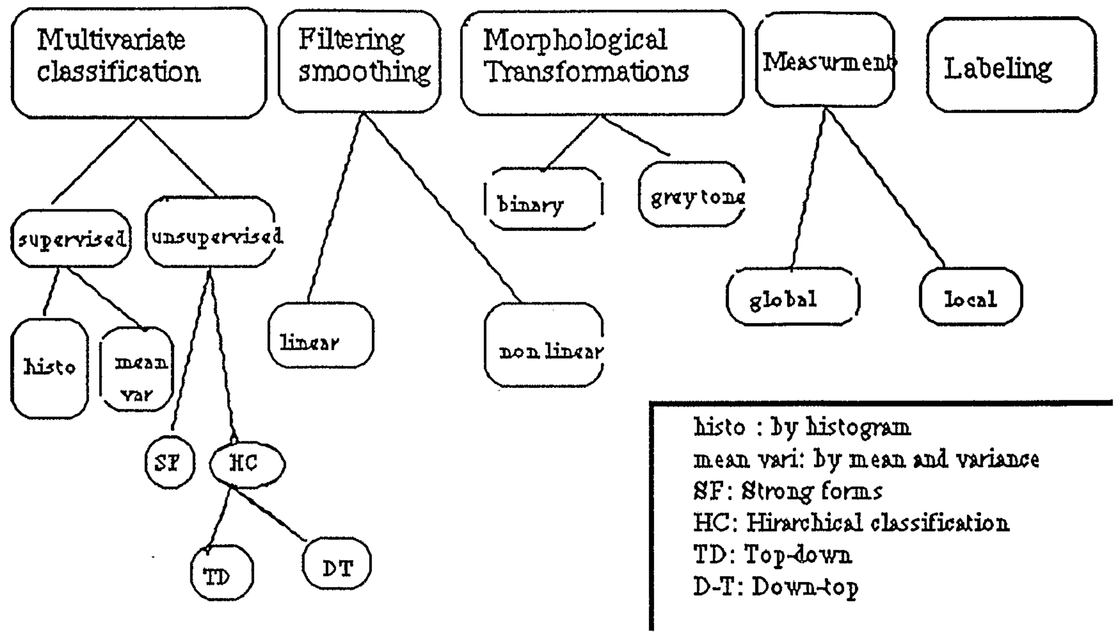


Table 3 : Hierarchical classification of image processing

The specialist classifies a given process within this hierarchy. The merit of a hierarchical representation, in this case, is that it allows to use inheritance mechanisms : a particular method will inherit of the properties (in terms of attributes) of the class to which it belongs. For example, a supervised classification method implies to have training plots. Thus, the particular method called NPD (Non Parametric Discrimination) will inherit this characteristic, as well as the SEBEST method (SEBESTYEN method). In constructing this hierarchy, the specialist may guide the user towards one or several particular methods while helping him to formulate his requests. For example, we could imagine the following dialogue between the system and the user :

S : Do you wish to apply a multivariate classification ?
U : Yes.
S : Do you want to supervise the classification ?
U : Yes.
S : Give the name of your training plot :
U : P1.
S : Do you wish to select the discrimination mode ?
U : No.
S : Two methods are available : NPD and SEBEST.
.
.
etc...

The methods selected by the system are activated by data processing procedures as soon as all the parameters required for their execution are specified. For instance, in the case of multivariate classification, the number of images, their nature, the number of output classes, the name of the output medium will be specified. These parameters are partly provided by the user and partly imposed by the system according to the current context. Indeed, to achieve a certain aim, a chain (or sequence) of processes has to be built, in which the process to be selected at a given instant only constitutes one step of the processing. However, the relative place the process occupies in the chain imposes certain constraints, in particular those implied by output nature of the previous result. The consistency between two successive processes is defined by the following relation:

T2 may succeed to T1 if I(T2) < O(T1)
(I and O respectively represent the description of the set of processing inputs and outputs).

This condition is necessary but not sufficient For instance, if at step (n-1), the process produces a classified image, it is not consistent to apply a filtering or grey-tone morphological transformation at step n. Consequently, the control of validity and consistency must be performed by the system according to the current context (base of facts at time t).

The activation of a processing procedure may be described as shown in the diagram of table 4:

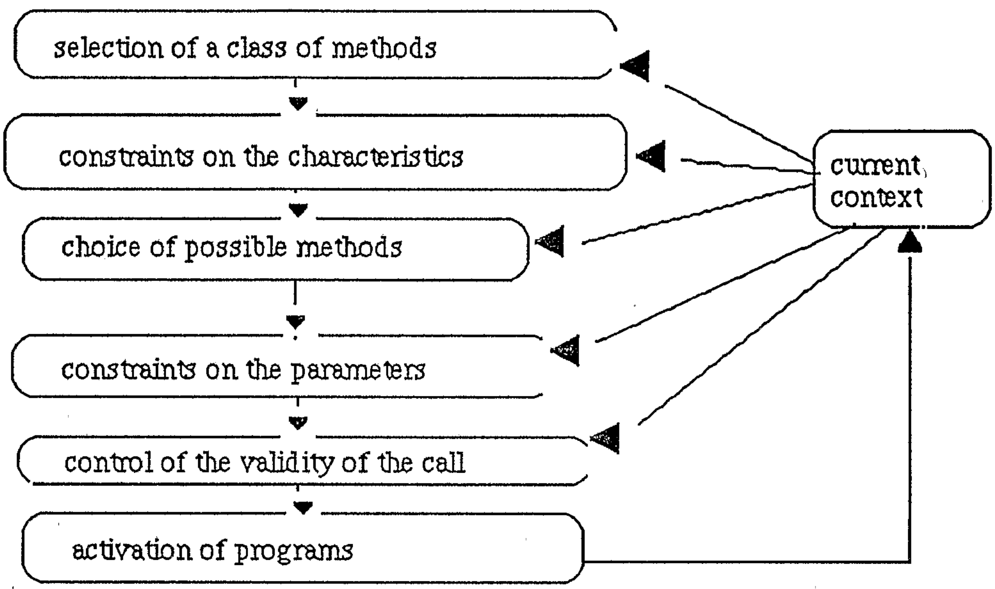


Table 4: Activation of a processing procedure

The application of this principle allows the user to formulate, if he wants to, the elements which lead to the choice of a method or of a class of methods without having to know the programs enabling its implementation. However, the weaker the formulated constraints, the more the concurrent methods. Therefore, through the rules, the expert has to predict and control the implementation of several concurrent methods, at whatever step. In order to help him handle the choice between methods, without having to formulate every possible combinations of methods and parameters, we chose to use a "hypothesis handler" algorithm named CH (for "Choice of Hypotheses") which allows to perform automatically the choices of methods and arguments according to the data contained in a specific base, the control knowledge base, which describes the methods and related arguments, and control rules present in the base of rules [

The selection of the method m1 to be applied to the data at step n of the chain is performed according to the diagram of table 5.

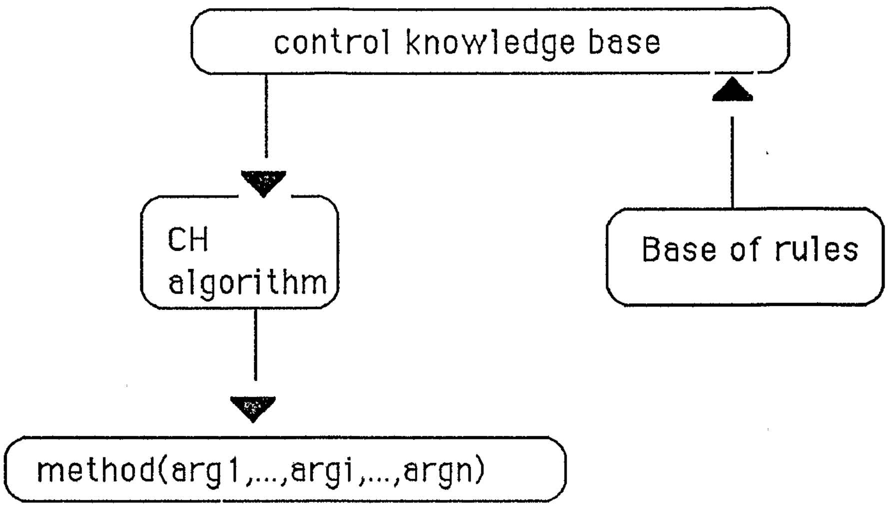
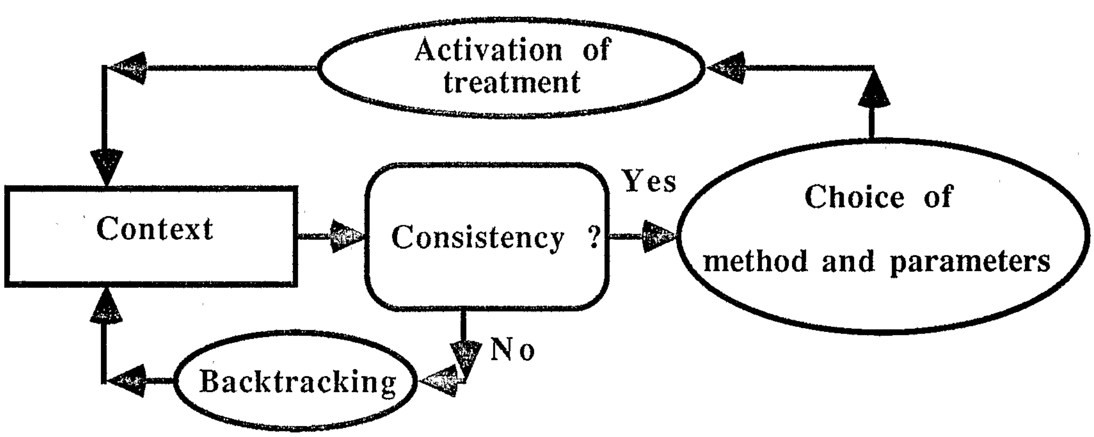
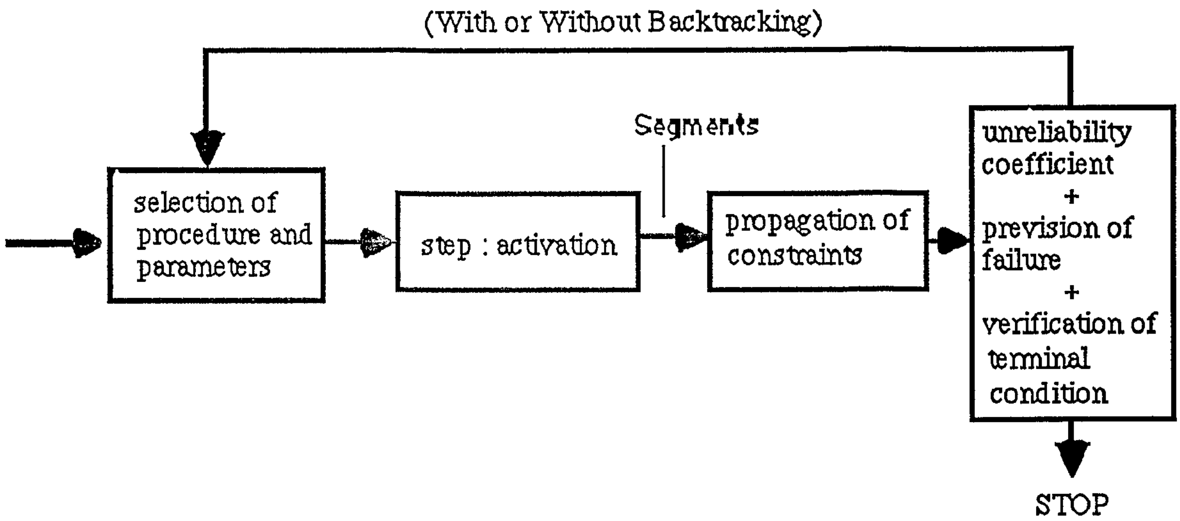


Table 5 : Choice of a method

The specialist will construct as many control knowledge bases as the choices of processing he will have to make to solve a given problem (classify pixels, assess a region texture, etc...)

More precisely, using the certainty factor Cv (Cf. ???), we get a valuation for each chain of treatment which has been applied to the test pixels. This valuation correspond to the quality of the treatment, i.e. to the number of well classified pixels. Then, if this valuation is lower than some fixed threshold, we say that the chain is inconsistent with the data which provocates a backtracking on the different choices. In order to get an efficient implementation of the backtracking mechanism, we established a parallel between a chain of treatment and a sequence of hypothesis, each treatment, i.e. each instanciated method which is applied to the data, being viewed as an hypothesis. Therefore, hypothetical reasoning can be applied to model the ellaboration of a consistent chain of treatment. This is done in CIME2 by the use of a Truth Maintenance System (TMS) which is described in the section 5.4. For the sake of clarity, the figure 6 gives a schema of this mechanism:





4. GENERAL CHARACTERISTICS OF THE ADOPTED FORMALISM

According to what we have just seen, very different elements enter the composition of the Systems as we view them :To represent these elements, we have to adopt a formalism meeting clarity requirements so that the thematician can manipulate them directly without needing the use of a programming language and robustness requirements as well as the operationality expected from any software program.

Remind that an expert system associates a software package, the inference engine, with an expertise, the knowledge base. The inference engine is a very general program, independent of the knowledge, it is directed both by the rules and by the facts. Those we have used [MONJANEL 87], [ETIFIER 88] were designed to enable the interpretation of the knowledge bases that we are currently developing. We will only consider here the part of the system concerned with the knowledge bases.

4.1. The syntax of facts

In CIME the facts are represented by the classical triple:

(object,attribute,value) (I)

where:

object corresponds to the object name
attribute corresponds to the name of one of the attributes that characterize the object
value corresponds to the value or the range of possible values taken by the attribute of the described object

In CIME2 [ETIFIER 88] the syntax has been enriched by expressing each fact under the form of a quadruple :

(type,attribute,value,list) (II)

where:

type denotes the nature of the described object
list denotes either the value of the attribute or the other objects with which the considered object has a hierarchic relationship.

4.2. The syntax of rules

As we have seen, we are concerned with production rules of the kind :

If conditions Then conclusions

In the conditions, may be expressed the relationships concerning the facts such as described above

If type,attribute,object,comparator,value (III)

where
comparator is a logic comparator: "=" and "<>"
or an arithmetic comparator: "<", ">", "<=", ">=",

It is also possible to compare the value of an attribute with that of the attribute of another (or the same) object by writing :

If attribute1(object1),comparator,attribute2(object2)

The objects can be parameterized by variables as follows :

If type ?x = pixel
altitude ?x < a

If several variables are used, the comparison between attributes may be written :

If attribute_x ?x,comparator,attribute_y ?y

The conclusions part can only include assignments (assignment of an attribute value for the corresponding objects) or the names of internal or external Actions.

A rule may be triggered if the conditions are met. The assignments and the actions contained in the conclusions may then be executed. The base of facts is modified accordingly.

5. KNOWLEDGE REPRESENTATION

We should now examine more precisely how the different categories of knowledge mentioned above may be represented by means of the selected syntax. This syntax is similar to all those which are commonly used in the expression of production systems [. We shall see, however, that it has been necessary to add elements in order to enrich the expression of the knowledge implemented in the interpretation of remote sensing images.

5.1. Representation of iconic entities

In order to represent iconic entities as factual data of the system, we will use the formalism mentioned in (II) as shown in the examples of table 6.

type : pixel	name : P_i	attributes :	radiometry: r1,r2,r3,r4
type : region	name R_k	attributes :	texture : heterogeneous
			mean : 50
			variance : 20
			surface : 100

Table 6 : representation of iconic entities

Here, the attributes allow to characterize the entity in an intrinsic way by first- or second-level descriptors. But, according to what we saw in section 3.2., this type of characterization is not sufficient. We must be able to describe the topographic relationships existing between the iconic entities : *proximity ,adjacency,* and *overlapping*.These relationships are assessed by functions specific to the system (boolean functions) introduced by key-words listed in a lexicon. These functions most of the time correspond to the application of an algorithm which allows to compute the corresponding relationships . Thus, these key-words may be used as comparators as a rule condition in this way :

If adjacent ?x ?y

The premise will be true or false depending on the result returned by the function.

The structural relationships between iconic entities are described by means of a list attached to an object according to the formalism described in (II). The list either corresponds to a list of properties P_i or to a list of hierarchic relations H_i .

In the list (P_1,P_2 , ...P_n), the P_i are the properties that must be satisfied by the object components. Each P_i has the following structure :

(type,attribute,comparator,value)

For instance, the following fact:

(region,22,components,((pixel,altitude, < , 3000),(pixel,slope,>, 0.4)))

is read : "the region 22 is composed of pixels whose altitude is lower than 3000 meters and the slope higher than 40%".

In the list (H_1,H_2 , ...H_n), the H_i have the following specific structure :
(T_p ,N_p)
where :
T_p is the type of hierarchic parent, that is the element of which the object is a component.
N_p the name of the parent

For example, the following fact:

(pixel,4,parent,region,1)

is read : "the pixel number 4 is a component of the region number 1".

5.2. The representation of thematic knowledge

Contrary to iconic entities, thematic entities are designated as values of a particular attribute which we have called classes, since the concepts used in our system serve to classify iconic entities. The word classes is in the plural because it is a multivalued attribute, insofar as, at any step of the process, several possible thematic entities may be retained to interpret the same iconic entity.

In Table7, we took again the example of Table 2, to which we adjoined the representation of the thematic content of a particular iconic entity using the formalism described in (II).

type : region	name : R_k	attributes:	texture :	heterogeneous
			mean :	50
			variance :	20
			surface :	100
			classes :	forest, settlement

Table 7: Thematic description of an iconic entity

The interpretation may be achieved by means of rules. So, we use the formalism of production rules described in (III) in order to express the iconic and radiometric characterization of a geographic entity. Thus, in the example of Table 8, the knowledge is represented by means of a production rule where the attribute classes appears in the conclusions part, and where the related iconic entities appear in the conditions part.

```
If
    type ?x = region
    size ?x = large
    texture ?x = heterogeneous
    red_band ?x = low
Then
    classes ?x = clear_forest
```

Table 8: Thematic interpretation of an iconic entity by the mean of a production rule

We have seen (§3.3) that the expression of thematic knowledge required a taxinomy of thematic entities which may be described as a hierarchic relationship between entities according to the specialization-generalization axis. It also implies the description of spatial and structural relationships. In order to represent these relationships as relationships between objects, we have chosen to consider that the attribute classes is an object of the attribute type and that the values taken by this attribute are objects of the value type. (For instance, forest is an object of the value type). In this way, we may describe relationships between these objects, and in particular, the taxinomy of the thematic entities by means of the key-word kind_of. For example, we express that clear_forest is a kind of forest in the following manner :

```
type = value
name = clear_forest
attributes = kind_of : forest
```

The advantage of representing the hierarchic relationship between thematic entities in order to describe the interpretation process is illustrated by the following example :

```
If      type ?x =      region
        size ?x =      large
        texture ?x =   heterogeneous
        classes ?x =   kind_of forest
Then
        classes ?x =   clear_forest
```

The spatial and structural relationships between thematic entities are represented in the same way as the relationships between iconic entities.

5.3. The representation of the processes

The different processes are represented as object of the process type. They are described by a series of attributes allowing to define the conditions required for their application to iconic entities. These attributes may be :

Inputs
Input Parameters
Outputs
Output Parameters
Control

Inputs and Outputs are necessarily iconic data, contrary to Input parameters which represent numeric or symbolic information enabling the processing, or to Output parameters which correspond to the results of the processes which are not iconic entities. The Control represents the constraints allowing to validate the consistency of the results.

The category of the described process is also specified. This attribute, by analogy with the attribute classes (cf §5.2) allows to describe the hierarchy of the processes shown in Table 3, by means of the key-word *a_kind_of.* Thus, a process that belongs to the supervised classification category, consequently belongs to the kind_of multivalued classification category. It will then inherits all the properties of the processes included in the latter category. This allows to specify certain descriptors of a process according to its category, as indicated in the following rule :

If

type ?x =	process
category ?x =	a_kind_of supervised classification

Then

Inputs ?x =	training_pixels

In the example of Table 9, you will find a general description of the NPD process. As all the other processes, it can be activated only when all the valuable attributes (i.e. different from ()) are valued.

type :	process	
name :	npd	
attributes :		
	category :	supervised segmentation
	Inputs :	training_pixels
	Outputs :	()
	Input Parameters :	()
	Output Parameters :	segments
	Control :	number_of_segments

Table 9 : Description of a process

5.4. HYPOTHESIS MANAGEMENT

As we previously saw, the construction of a chain of treatments is assimilated to an hypothetical reasoning. Then it is possible to use tools designed to model hypothetical reasoning. One of the main problem artificial intelligence faces while modeling hypothetical reasoning is to maitain the consistency of a set of fact whithout having to recompute everything each time an hypothesis is retracted. In order to do that we classicaly use a justification network. As we shall see in the following the justification network can be refined by the use of a TMS (Truth Maintenance System) which improve the efficiency.

5.4.1. Justification network

It is to associate to each fact the list of fact which are derived from this fact through the rules. For instance, been given the two following rules R1 and R2:

```
(defrule R1 (a ?x) -> (assert (c ?x)))
(defrule R2 (b ?x) (d ?x) -> (assert (c ?x)))
```

Let us assume that those two rules be triggered. If J1 and J2 are the two instances of R1 and R2 which are trigered, than justification associated to the facts (a 0), (b 0), (d 0) et (c 0) are computed as follows:

(a 0) *Log*(... J1 (c 0) ...)

(b 0) *Log*(... J2 (c 0) ...)   (c 0) *Inst*(... J1... J2...)

(d 0) *Log*(... J2 (c 0) ...)

J1 being the instance of R1 which comes from (a 0) to (c 0), when (a 0) is retracted then J1 has to be supressed from the list Inst. When this list is empty, (c 0) has to be retracted.

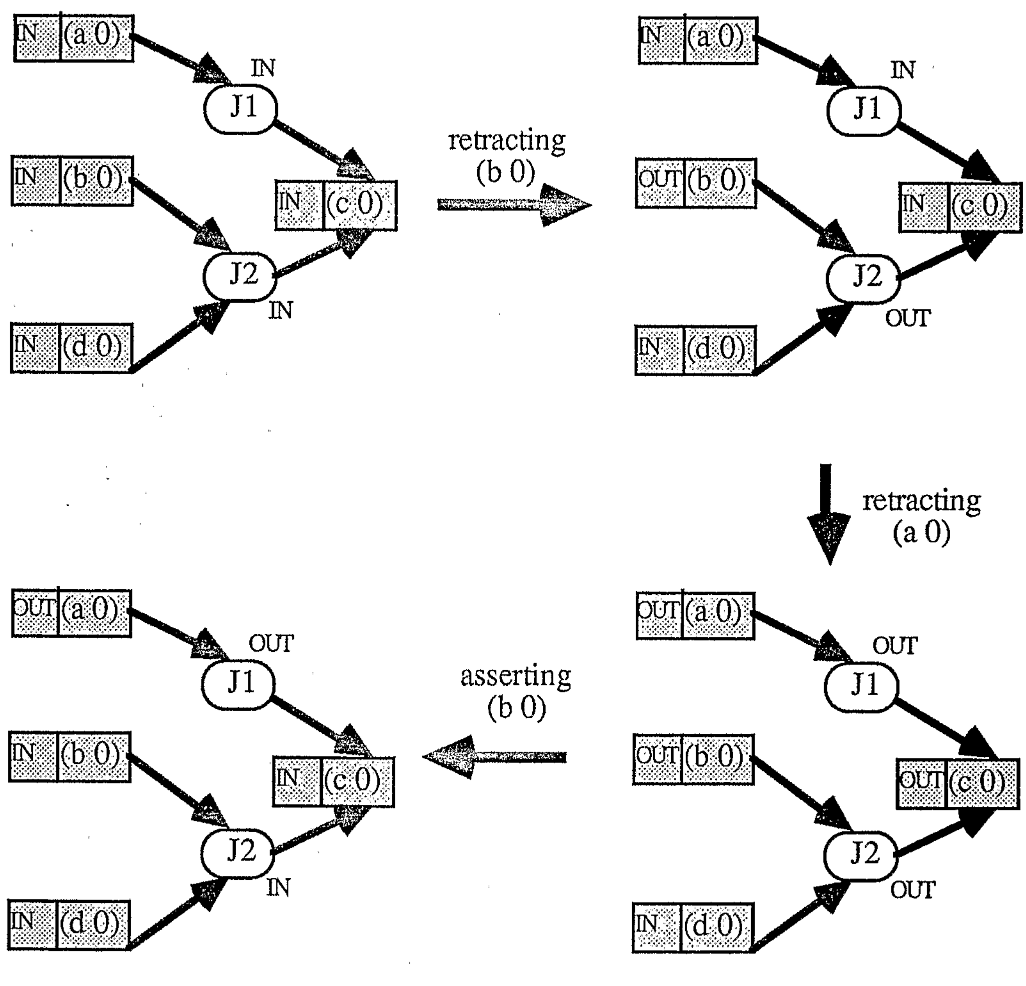
This mechanism is easy to implement, however, it is very costly to maintain, especially when the number of facts is high which is the case when a picture is represented as a set of pixels.

5.4.2. Using a Truth Maintenance System

In order to decrease the number of activated rules, it is needed to keep in memory every computed facts and their justifications, even when they are retracted. For instance, let us assume that R1 been trigered for ?x = 0:

(defrule R1 (a ?x) -> (assert (c ?x))))

Therefore, (c 0) will be generated by the instance J1 of R1. If, now (a 0) is retracted, then (c 0) has to be retracted. But, when we add again (a 0), we have to trigger again the instance J1 of R1 and to add again (c 0). Such sequences of assertion and retraction are very costly when it is necessary to manage hypothesis. It is why we introduce a token to each fact. Those token can be IN or OUT, which means that the corresponding fact is considered as present or absent. As soon as a fact is retracted or asserted, its token is modified. Then the effect of a modification if propagated on the justification network using the token. For instance our example can be simulated on the following graph:



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