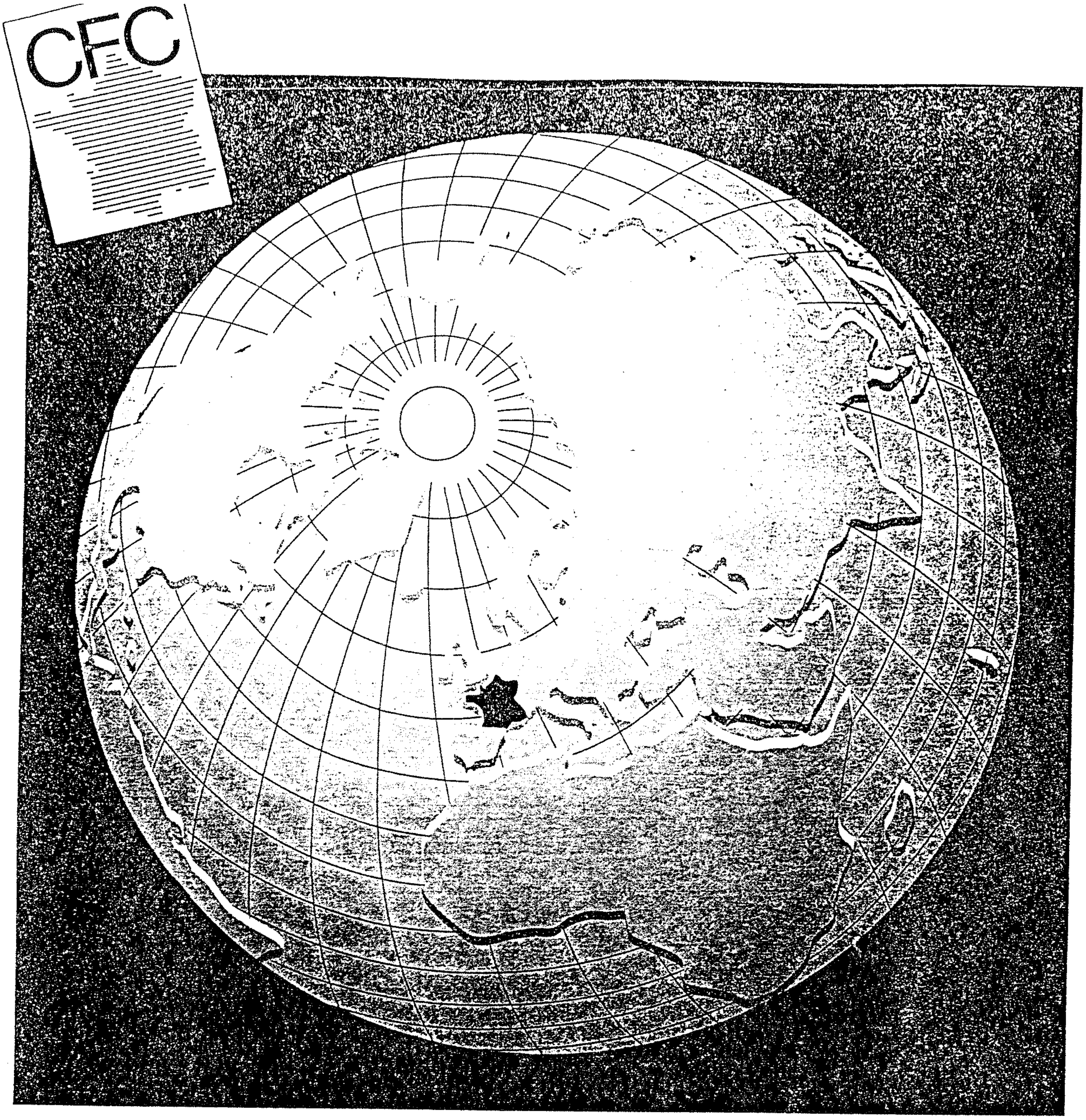


SYMPOSIUM INTERNATIONAL DE CARTOGRAPHIE THÉMATIQUE DÉRIVÉE DES IMAGES SATELLITAIRES

(Saint-Mandé, 2-4 octobre 1990)

***

COMITÉ FRANÇAIS DE CARTOGRAPHIE

Bulletin N° 127-128 120 F Mars-Juin 1991

◆ Conclusion

The method described has been successfully applied at Remote Sensing Centre of Geodetic and Cartographic Enterprise in Prague. Several photomaps sheet from North Bohemia and neighbourhood of Prague have been produced in this way.

References

CHARVÁT K., CERVENKA V. and HYLMAR F. - Production of 1: 50 000 Pseudocolor Photomaps from Thematic Mapper data. Symposium ICA, Budapest, 1989.

APPLICATION OF ARTIFICIAL INTELLIGENCE IN LAND USE MAPPING FROM SATELLITE IMAGERY

par G.G. WILKINSON and C. KONTOES

Commission of the European Communities
Joint Research Centre
Institute for Remote Sensing Applications
Varese, Italy.

Abstract

An expert system has been developed for land use mapping from SPOT imagery. The system combines multiple sources of evidence using the Dempster-Shafer theory of reasoning and allows evidence to be propagated a multiple levels in a land cover classification tree. A spatial context rule base has been implemented allowing pixel classifications to be refined and generalised to yield improved thematic map products.

◆ Introduction : satellite mapping and expert systems

The production of useful thematic maps of the Earth's surface from satellite imagery is currently one of the main challenges faced by the remote sensing community. Despite a steady growth in the sophistication of satellite sensors over a period of two decades, traditional analysis techniques still do not permit us to extract convincing map-like products from images. There are many reasons for this, foremost among which is that satellite images are normally classified using a parametric or statistical model of the distribution of classes in feature space – these models are directed towards classifying single pixels (or sometimes segments) and do not necessarily yield products which correspond to thematic maps in a cartographic or spatial sense. Furthermore these models necessarily involve approximations to reality and many pixels from an image can be "impure" (i.e. of mixed classes) and are therefore difficult to put into unique classes. A second major reason for the inadequacy of current satellite products is that it is difficult to match classes which are statistically separable in satellite imagery to land cover classes mapped by a cartographer. This "thematic matching" problem continues to be a serious problem in remote sensing.

We believe that the answer to some of these difficulties lies in making more use of ancillary geographic information and also additional relevant human common-sense knowledge in processing satellite imagery. This, more holistic approach, is sometimes regarded as image understanding. Background knowledge can be used as an aid both in refining pixel or segment classifications by helping to overcome some of the errors encountered in applying a strictly numerical or statistical analysis to pixel radiances, and also in spatially simplifying the array of satellite image information to make it conform more closely to the expectations of a cartographer.

In general we foresee the widespread use of expert systems in thematic mapping applications. Essentially these systems contain knowledge encoded as "rules" which can be used to generate improved thematic products. Three different kinds of rules can be envisaged in remotely-sensed image analysis:

- **Geographic context rules** to help refine pixel/segment classificatiosn on the basis of background geographic parameters: e.g. soil type present; land surface slope, height, aspect; predominant vegetation types expected etc..

- **Spectral rules** particularly to help with the interpretation of multitemporal spectral signatures for classification purposes.

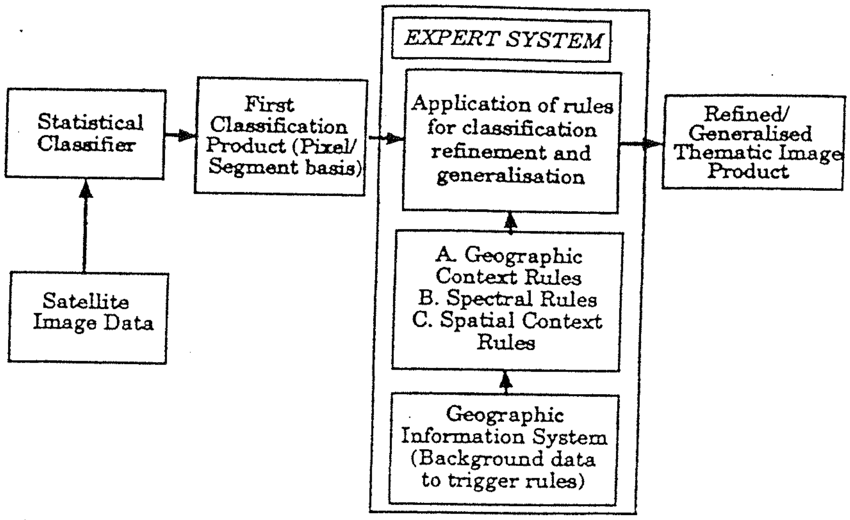


Fig. 1 : Expert system for image analysis

• **Spatial context rules** (to refine pixel classes on the basis of their neighbourhood/location in an image and to assist in the generalisation of a pixel-based product to a more cartographically-acceptable structure).

It is therefore possible to conceive of image analysis systems as shown below in figure 1 comprising statistical classifiers, expert system rule bases and a geographic information system holding data which can be used to "trigger" the application of certain rules.

We have recently conducted experiments on improving thematic mapping using the third category of rules above (spatial context rules). In the remainder of this paper we shall demonstrate the method and the results achievable by this approach.

◆ Handling uncertainty : use of belief functions

It is conventional practice in treating and analysing remotely-sensed satellite imagery to apply classification methods which assign unique class labels to each pixel or semgent. For example a classification based on the commonly-used maximum-likelihood classifier would select the class of maximum probability based on the multivariate distributions of pixel radiances in feature space. One of the drawbacks of this approach is that pixels are forced to take a single class label even though in some cases the likelihood values for two different classes may be very close and the maximum likelihood class may not necessarily be the correct one. Some method of handling uncertainty is therefore required in order not to commit pixels to class assignments which are only vaguely supportable. Since land cover classification is normally done with a hierarchical nomenclature it may in some cases be appropriate to classifiy pixels at a high-level in the hierarchy rather than at the bottom level. Figure 2 illustrates this concept. A super-class label (e.g. "permanent crop") may be more appropriate than an individual class label (such as "vines") when there is some degree of doubt. A **correct** super-class is arguably thematically more useful than an **incorrect** low-level class.

Since our aim has been to combine traditional statistical classification methods and expert system reasoning we have had to adopt an appropriate method for combining the various pieces of evidence and to assign suitable classes or super-classes depending on the degrees of support available for them. The numerical reasoning scheme that we have adopted is based on the "belief function" method of the Dempster-Shafer theory of evidence (Shafer 1976). A description of how this method can be used in remote sensing is provided in Wilkinson and Mégier (1990). In essence individual expert system rules as well as classifiers may provide "degrees of support" (range 0->1) either confirming or disconfirming classes or super-classes in the classification tree. These degrees of support may then be combined into "belief" figures for classes and super-classes in the tree.

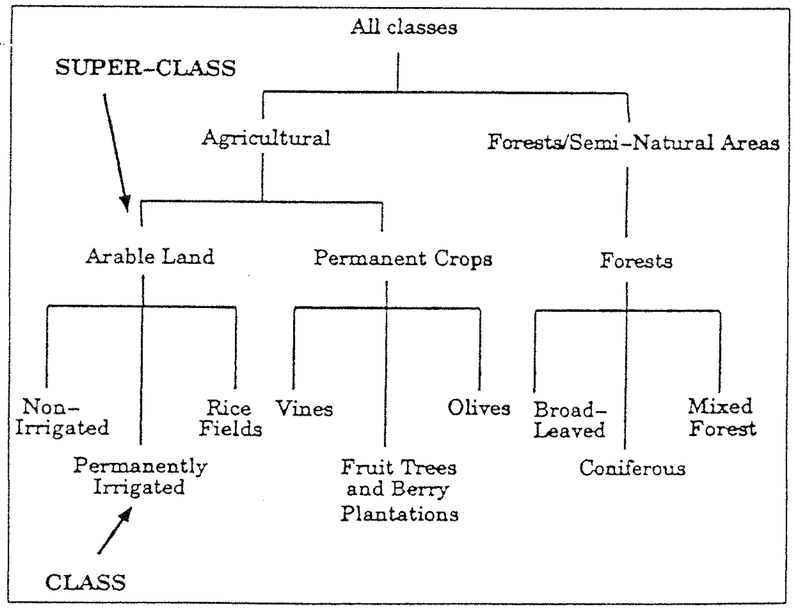


Fig. 2 : Typical land cover hierarchy

There are several algorithms for doing this; a suitable one (for strict tree hierarchies) is the algorithm of Gordon and Shortliffe (1985). Once belief figures have been calculated using all available evidence for an image pixel or segment of interest the class or super-class with the maximum belief value is assigned to it. It is possible that this will be a super-class high in the tree when there is much doubt the precise classification of this pixel or segment. In this way we can take full account of uncertainty. An important aspect of the Dempster-Shafer methodology is that lack of evidence for a particular class is not taken as evidence to be shared between all the **other** classes as is done in the traditional Bayesian approach. In fact in such a situation the evidence is applied as a support figure to the super-class at the very top of the tree -i.e. it is taken as null evidence which can only be sensibly assigned to the super-class encompassing all classes in the tree.

◆ Use of spatial context rules in satellite mapping

We have developed an image analysis expert system based on the method described above to enable us to produce useful thematic maps of the main land use classes (primarily agricultural) in the Département Loir-et-Cher, France, using SPOT imagery. This system uses a classification hierarchy with 15 land cover classes at the bottom level (see figure 3) and the Dempster-Shafer method is utilized to weigh-up all relevant evidence in classifying pixels. We thus find the class or super-class label with the highest belief value and assign it to the pixel.

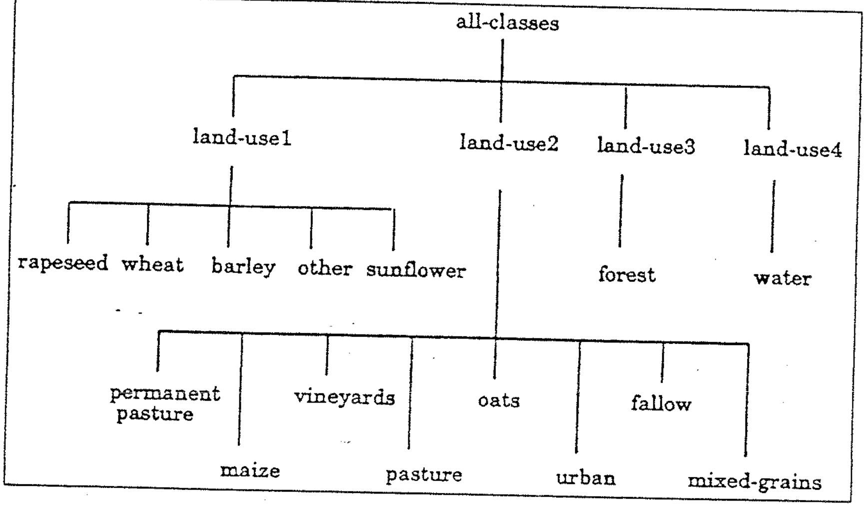


Fig. 3 : Land cover classification hierarchy for experiments in Loir-et-Cher

The evidence which we use comes from three sources:

- a maximum-likelihood classification of imagery into individual classes using spectral signatures,
- a maximum-likelihood classification of imagery into land use super-classes based on a local image variance texture feature (see Haralick et al. 1973) and,
- an expert system rule base of 38 rules which concern the spatial context of pixels (only a subset of the rules will be triggered for a given pixel).

Each source of evidence (classifier results and triggered expert system rules) provide support figures which are all weighed-up in deriving belief values for the classes and super-classes of the tree for a specific pixel. The class/super class of maximum belief is then finally assigned to the pixel. A typical spatial contexte rule is shown in figure 4.

INPUTS TO TRIGGER RULES FOR PIXEL P :

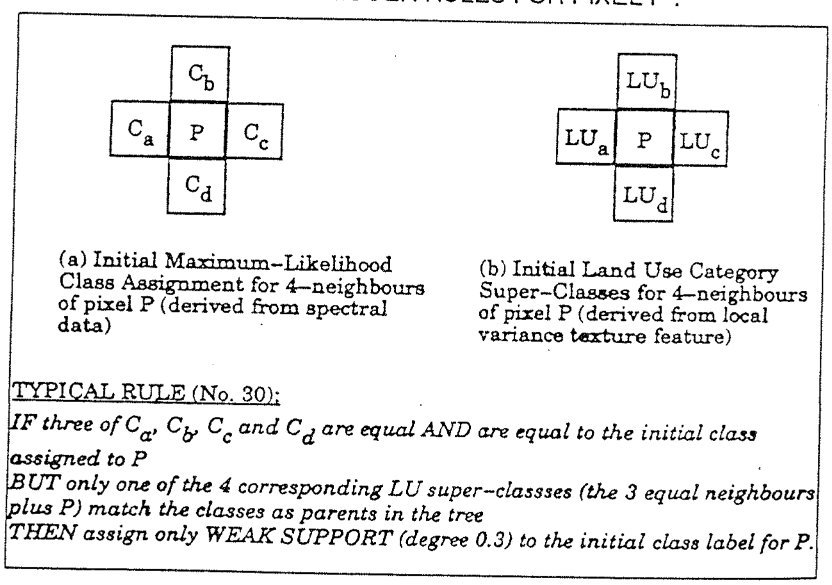


Fig. 4 : Example of spatial context rules

◆ Results

Results from our experiments with the expert system method for producing thematic maps of land use in the Département Loir-et-Cher are shown in figure 5. Figure 5(a) shows a photo-interpretation map of the test area. Figure 5(b) shows an initial pixel-by-pixel classification of the single date SPOT imagery using the spectral information alone. This "classification map" is very noisy with many isolated pixels. Also a nomber of classification errors are apparent

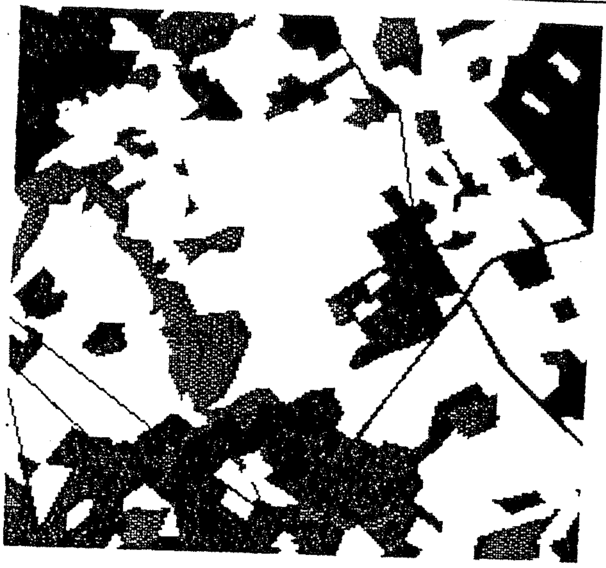
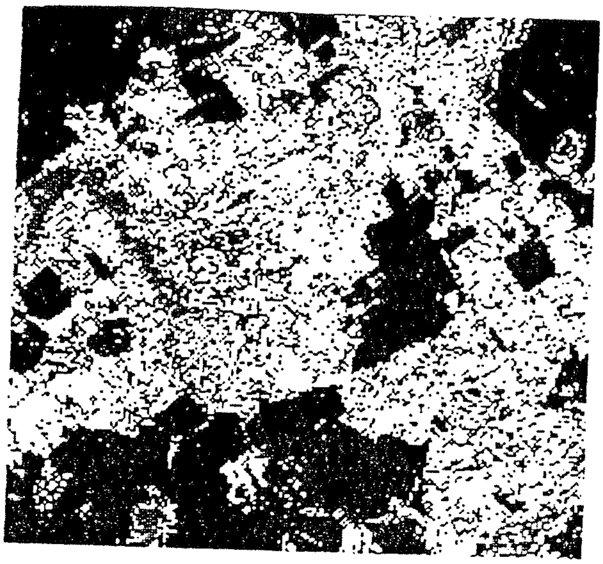


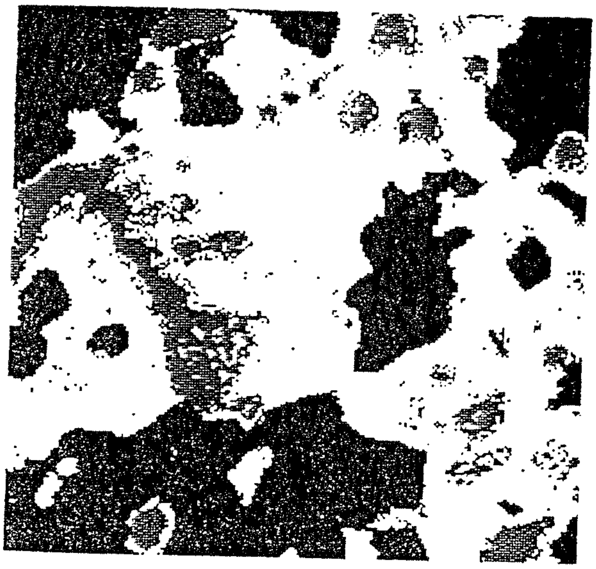
PHOTO-INTERPRETATION MAP

FIGURE 5(a)



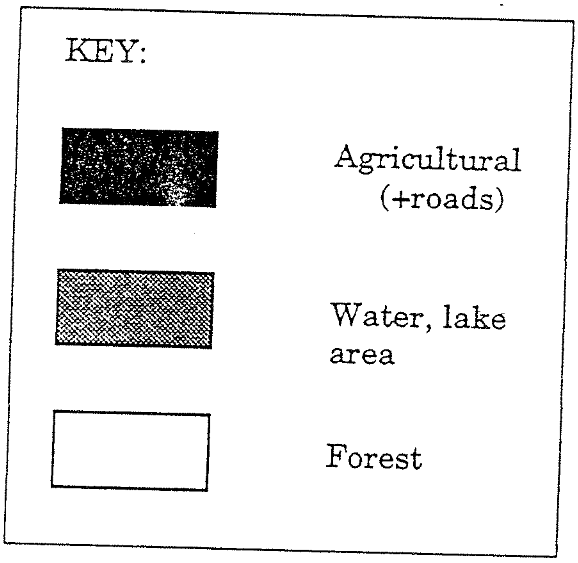
FIRST CLASSIFICATION PRODUCT

FIGURE 5(b)



FINAL CLASSIFICATION PRODUCT

FIGURE 5(c)



NOTE: The figures above show the results obtained in the experiments in the Loir-et-Cher region of France. Each image is a 220x220 pixel subscene extracted from the SPOT imagery. The figures show only the classification at the super-class level because of the restriction on use of grey-scales for reproduction. The images were in fact classified using the hierarchical scheme described in the text with 15 classes at the bottom level.The two agricultural super-classes have been merged in the figures. Note that the road features are unavoidably removed in the spatial generalisation process.

such as erroneous "forest" pixels inside a lake area. Figure 5(c) on the other hand shows the final classification map after application of the expert system. The classification map is now much less noisy and contains significantly fewer errors. In situations where the evidence is not strong enough to classify at the bottom level the pixel is only assigned a super-class (according to the belief values computed). This final product is much closer in appearance to the photo-interpretation map -i.e. much of the variability in the satellite data is removed by our procedure which effectively performs generalisation besides post-classification refinement.

By using ground truth segments with percentage areal coverage figures for different classes we have established that our results initially gave an average error of +/- 28.7% at the land-use super-class level. After application of the expert system this was reduced to 18.3%. The full analysis of the error at the individual class level has yet to be performed, but the results so far appear encouraging.

◆ Discussion

In this paper we have presented an expert system method for thematic mapping which allows us to combine multiple sources of evidence in reasoning about pixels and to weigh-up evidence at various levels of a classification hierarchy. By developing a set of spatial context rules we have been able to substantially improve the cartographic quality of a classified image yielding both more accurate pixel classifications and moreover a more convincing and usable generalised product. There still remains much work to be done on this technique such as the addition of spectral signature rules and background geographic rules which could add significantly to the power of the technique.

Also it will be important to address the issue of accuracy assessment and the interpretation of a mixed-level thematic product. Our purpose in producing a mixed-level product has been to avoid assigning classes at a low-level where there is insufficient evidence for doing so. In areas where the image pixels or segments can only be allocated super-classes we can deduce that extra information is required in order to resolve the individual classes concerned. This may indicate the need for direct human intervention in the processing and the acquisition of extra information sources (e.g. air-photos). Our approach therefore enables us to define more precisely the limitations of the satellite information.

At this early stage of the developement we feel there is much future potential in this method for bridging the gap between pure statistical image classification and the generatioin of useful thematic maps. We hope to experiment further with these ideas in the context of the European Commission's CORINE Land Cover mapping programme.

References

GORDON J. and SHORTLIFFE E. H. - A Method for Managing Evidential Reasoning in a Hierarchical Hypothesis Space", Artifical Intelligence, 26, 1985, pp. 323-357.

HARALICK R.M., SHANMUGAM K. and DINSTEIN Its'Hak - Textural Features for Image Classification, IEEE Trans. on Systems, Man and Cybernetics, SMC-3, 6, 1973, pp. 610-621.

SHAFER G. - A Mathematical Theory of Evidence, Princeton University Press, Princeton, NJ, 1976.

WILKINSON G. G. and MÉGIER J. - Evidential Reasoning in a Pixel Classification Hierarchy – A Potential Method for Integrating Image Classifiers and Expert System Rules Based on Geographic Context", Int. J. Remote Sensing 1990.