A FRAMEWORK FOR THE ASSESSMENT OF LOCAL SPATIAL UNCERTAINTY USING A POLYGON APPROACH

R.C. Allan & G.P. Ellis

RMIT Centre for Remote Sensing & GIS
RMIT University
124 Latrobe Street, Melbourne, Victoria, Australia 3000
E-mail: rod.allan@rmit.edu.au

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ABSTRACT:

For remotely sensed data to be effectively used in a GIS the user needs to know the reliability of the product. Typically, in the production of a thematic layer in a land resource data base, an overall accuracy assessment of the product is undertaken in which the user determines its fitness for use. However neither the magnitude of source errors at each stage of data handling nor the within spatial variability is known from this assessment.

This paper proposes a methodology to elicit relative measures of error in the various stages of the data processing flow and the extent of local spatial variability in the input data layer by identifying and then measuring the error source in an iterative scheme. The process utilises overlays of independent realisations by image interpreters of the same scene to create polygons in disagreement between the interpreters. Geometric characteristics of these polygons are investigated to establish as to whether any changes in geometry are attributable to a particular source. Preliminary results from a case study are discussed.

1. INTRODUCTION

An important but complex issue, when using Geographic Information Systems (GIS) to integrate, analyse and display spatial data, is the definition and quantification of errors. With increasing emphasis placed on spatial information processing, data are being used for purposes they were never intended (Goodchild 1993). The resultant products often have no indication as to their suitability for use in the decision making process.

With the integration of disparate data sources required for a GIS, error propagation and control throughout the processes are not readily understood nor easily imposed.

1.1 Spatial Data Bases - A User's Perspective

For many applications, the effective use of spatial data bases is dependent upon the data user who determines its fitness for use (Chrisman 1994). A data user's own perception of its worth for an application is based on some *a priori* knowledge of the user about GIS and about the data bases themselves (Coward & Heywood 1991). Spatial data bases can represent multiple versions of reality and the operation of a basic GIS function such as generalisation for example, creates a less representative version of reality. Indeed, for many users, these operations on the data base are necessary to achieve the required product.

The lack of any detailed knowledge of the extent to which error is introduced and its magnitude, particularly at its source, is one of the impediments in understanding error propagation. Source errors enter in the data processing flow at various stages and, importantly, not solely at the data acquisition stage. With land resource data bases, for example, the classification phase which includes the operator's interpretative skills and bias can be a significant source of error.

1.2 Local and Boundary Errors

The production of thematic maps through spatial data processing is primarily based upon the nominal categorisation of discrete classes with boundaries and, by implication, is representative of what exists in reality. In fact, the representation of contiguous classes (polygons) is "nothing more than a construct of cartographic convenience" (Trotter 1991). The interpretive techniques employed to delineate classes in the production of a thematic map are subjective. The degree of subjectivity is largely dependent on the heterogeneity of the image pixels, the scale of representation and the number of allocated classes. Cherrill and McClean (1995) found that, in interpreting land cover change, smaller class areas yielded less precise results. They also suggest that classification (attribute) error is more significant than positional error with land cover types.

The present problems in using maps with fixed categorical attributes results in a binary (yes/no) response to a spatial query rather than a measure of the likelihood of a certain characteristic being at that location (Lowell 1992). Boundary representation between the classes, in this instance, would not be a cartographic line but rather a transition zone of width dependent on the spectral similarity of contiguous classes. However, Goodchild (1994) asserts that the 'blurring' of a boundary may give the user a false impression of the extent of geographic detail present as this zone is less distorted than the original boundary.

Gong and Chen (1992) deal with methods that may be used to determine, represent and display boundary uncertainties in categorical (area-class) maps. They state that it is impossible to tell the most accurate realisation and they suggest ways in which the most probable boundary could be determined using curve-fitting techniques and blending functions. They generated a number of realisations of land use categories from classification and subsequently manually digitised the map. Other authors (Maffini *et al* 1989; Dutton 1992) have investigated the positional uncertainty of boundaries resulting from the manual digitising of land cover maps.

The problem that arises in these cases is the introduction of an additional interpretational process within data processing, i.e. classification and digitisation. This paper suggests that a framework for determining both local and boundary errors resulting from multiple realisations of the same phenomenon be resolved prior to raster to vector conversion within the spatial database. In this case, the operators are responsible for determining the classes without the need to digitise each determination. Using the GIS overlay function, the level of agreement can be assessed, most probable class boundary positions derived and then a once only vectorisation of the polygons for entry into the GIS data base carried out.

1.3 Accuracy Assessment Used in Remote Sensing

Present problems with accuracy assessment of thematic maps are that there is no indication of the variation of land use / land cover from the sampled data within each class. Each location on the ground has been allocated to a particular class and the assignment of the appropriate map label for some locations is ambiguous (Gopal and Woodcock 1993).

The importance of accuracy assessment for remotely sensed data is well recognised particularly when the data may be used in a GIS (Congalton & Green 1993). Allan *et al* (1996) detail previous literature concerning the methods employed in assessing the accuracy of remotely sensed data. In summary, the error (confusion) matrix (Aronoff 1982), determination of producer's and consumer's risk (errors of commission and omission) using row and column marginals of the matrix (Story & Congalton 1986) and compensation for chance agreement in the classes - Kappa coefficient of agreement (Rosenfield & Fitzpatrick-Lins 1986) have been used. Sampling designs have been investigated by a number of authors (Congalton 1988; Stehman 1992).

2. ERROR SOURCES IN REMOTELY SENSED DATA

In the production of a thematic map the user needs to have a knowledge of the error in the position and labelling of the derived classes. As this product (map) may be only one layer used in the GIS, quantitative measures of error are necessary at its source before progressing to error propagation in the GIS processing flow. Until these source errors are thoroughly examined and measured the utility of remotely sensed data as an appropriate and valuable information source within GIS is restricted. Goodchild *et al* (1994) suggest that consistency, or replicability, of processes and realisations have rarely been executed in practice.

An accuracy assessment of errors in a thematic map should provide details concerning their nature, frequency, magnitude and source (Gopal & Woodcock 1993). A conceptual framework has been described by Veregin (1989) in which he sets out 'a hierarchy of needs for modeling error in GIS operations'. In a five level hierarchy, level 1 is concerned with the identification of error sources, level 2: error detection and measurement, level 3: error propagation modelling, level 4: strategies for error management, and level 5: strategies for error reduction. A number of authors have set out the various stages in the spatial data 'life-cycle' in which error may be introduced (Aronoff 1989; Lunetta et al 1991; Collins & Smith 1994). They are summarised as follows:

- Data acquisition: geometric aspects, sensor systems, platforms, ground control.
- Data input (processing): geometric registration and resampling.
- Data analysis: classification systems, data generalisation.
- Data conversion: raster to vector.
- Data output: positional and attribute errors.
- Data usage and interpretation: insufficient understanding and incorrect use of data.

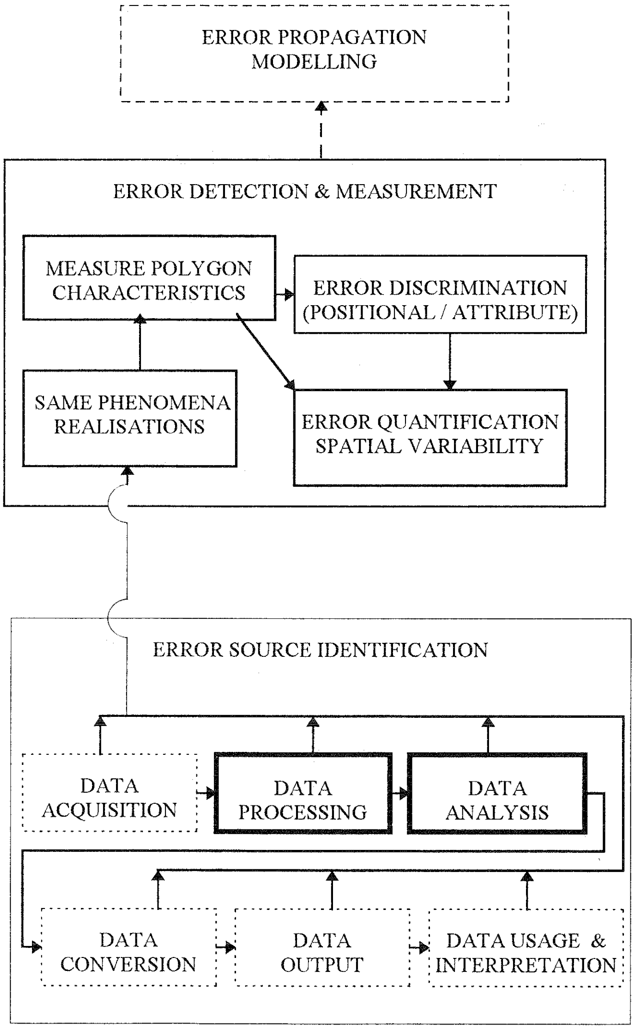
Lunetta *et al* (1991) identify source errors (Veregin's Level 1) for each stage. They point out that error accumulates for each successive stage but also may be introduced within any stage.

The proposed framework, shown in Figure 1, describes an approach to determine the degree to which stages in the GIS information processing flow contribute to the overall error in the data layer. It integrates the hierarchical approach proposed by Veregin (1989) within the framework of GIS processing with the potential error sources suggested by Lunetta *et al* (1991).

Specifically, the approach is to detect and measure the uncertainties in two stages of the processing flow: *data processing* and *data analysis* after having identified the source errors. At the source level in the framework, it acknowledges that error may accumulate from one stage to the next but may also contribute separately at each stage. Two stages in the data processing flow are selected to examine their respective contributions to the determination of class accuracy assessment.

At the next level in the framework, the detection and measurement of error phase, operational constraints are imposed on the interpreters to elicit quantitative estimates of error and its spatial variability. These constraints may be the adoption of the same image classification technique and the division of the same image into a predetermined number of classes. Polygons in disagreement are formed based on the realisations from each image interpreter. The polygon characteristics can be measured and aggregated based on a threshold established for areas, perimeters, shapes or a combination of these characteristics. Further examination of these polygons may reveal that the error is positional (data acquisition or data input stage), attribute (data analysis stage) or no discrimination is possible. Progression through to the error quantification/spatial variability stage is then possible to determine overall class accuracy estimates.

For this particular case study, each polygon in disagreement is created from an overlay of multiple independent realisations of the same classified image using remote sensing analysts. The size, shape, perimeter and spatial distribution of these polygons indicates whether the classes are positionally misaligned, the variations in class specification are due to different interpretation of pixel values (classification) or the interpreters are unable to differentiate mixed pixel effects. Polygons (clumps) in disagreement are those aggregated pixels that have been assigned different classes by independent interpreters.



Adapted from Lunetta et al (1991) & Veregin (1989)

Figure 1

3. CASE STUDY

The study area is situated south west of Melbourne, Australia on the western shore of Port Phillip Bay. No public access to the site is allowed which minimises the degree of disturbance to ground cover vegetation. This is important when considering the time lag between data capture, integration and validation (Race 1994).

Landsat TM imagery was used to spatially differentiate land cover into seven classes. For image rectification twelve ground control points were established over an area of 9km by 9km. In the **first stage** three interpreters classified the image using the same classification technique (supervised using maximum likelihood in this instance). The image was rectified prior to the classification. These realisations provided the basis for determining the degree to which the classified areas from each interpreter were in agreement. Of particular interest for this study were those areas classified differently between interpreters to enable some quantitative measures of these disagreements to be computed. Using the GIS overlay function the classified pixels not in agreement were clumped to form polygons and provide quantitative estimates of error in the respective classes.

Using the ground control points, acquired by field survey using GPS, the **second stage** of this study investigates the accumulation of source errors between the *data processing* to *data analysis* stages. Each image interpreter rectified and classified the image independently based upon three conditions: same classification technique (supervised using maximum likelihood classifier), resampling (using nearest neighbour and cubic convolution) and all pixels to be classified into one of the seven classes. The change in the geometrical characteristics of the polygons in disagreement, in some instances, detects the source of uncertainty either from the rectification (positional) or from the classification (attribute). Whether the positional and attribute uncertainties are separable or not, progression through to the detection and measurement of local spatial variability can then be undertaken.

4. RESULTS AND DISCUSSION

Using interpreter 1 as control, *Table 1* indicates the disagreement in pixel classification for interpreters 2 and 3. Whilst these differences appear to be significant, any further analysis requires a knowledge of the spatial distribution of error for each class. Over 900 polygons in disagreement were formed for this class with some polygons as small as one pixel. Based on the polygon characteristics and visual display, it is then possible to determine which polygons indicate a significant level of error. Threshold limits based on area and shape can be set and the location of uncertainty in the class can be examined. Allan & Ellis (1996) expand on this approach with tests for other classes.

Preliminary results from the first stage indicate that, as expected, the class boundaries are less certain but the detection of variability within these boundaries is able to be determined. However, this local spatial variability is less able to be detected with elongated class shapes, as sections of the same class boundary are too close to determine differences between uncertainties in the 'boundary' polygons and 'local' polygons. As the interpreters are using the same image the uncertainties for each class fall within the *data analysis stage* in the proposed framework.

	Interpreter 1 (Control) Pixels in Class (Irrigated Pasture)	
	Interpreter 2	Interpreter 3
Irrigated Pasture	44768	51582
Bare Ground	98	4552
Saltmarsh	0	0
Other	11698	430
Total	56564	56564

Extracted from Allan & Ellis (1996)

Table 1 - First Stage (classification)

Results shown in Tables 2 (a) & (b) represent a subset of the image used in the first stage of the case study. Only one class is shown in the tables as control although seven classes in all were classified. As previously mentioned, three interpreters rectified the same image from which they independently obtained a RMS of between 0.2 and 0.8 pixels. Resampling this image using nearest neighbour and cubic convolution respectively yielded consistent results. The same training data, independently determined by each interpreter, are used in both resampled images to classify the image into the seven classes as required. It appears from these results, and other classes used as control, that the magnitude and spatial distribution of error is less susceptible to differences obtained by interpreters in the rectification/resampling process. The degree to which this data processing stage contributes to overall class error is yet to be fully investigated.

	Interpreter 1 (Control) Pixels in Class (Irrigated Pasture)	
	Interpreter 2	Interpreter 3
Irrigated Pasture	45746	45205
Bare Ground	58	29
Saltmarsh	0	902
Other	1364	1032
Total	47168	47168

Table 2 (a) - Second Stage (resampliing using nearest neighbour then classification)

	Interpreter 1 (Control) Pixels in Class (Irrigated Pasture)	
	Interpreter 2	Interpreter 3
Irrigated Pasture	46212	45407
Bare Ground	125	60
Saltmarsh	3	821
Other	828	880
Total	47168	47168

Table 2 (b) - Second Stage (resampliing using cubic convolution then classification)

5. CONCLUSIONS

This paper has attempted to present a framework to test error characteristics in a remote sensing environment. The utility of this approach is the spatial representation of error which enables quantitative error estimates to be determined. Future work will investigate the possibility of characterising error and uncertainty differently and the the differentiation of polygons in disagreement for inclusion in the error measurement process.

Note: For this paper the terms error and uncertainty are considered to have the same meaning.

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