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REGIONAL ANALYSIS USING GEOGRAPHIC INFORMATION SYSTEMS BASED ON LINEAR QUADTREES

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Abstract

A pilot project to develop and evaluate a computerised geographic information system (GIS) for regional analysis of land resources is described. The concept and operation of linear quadtrees is outlined and results from operations on a small data base are presented and discussed. The GIS based on linear quadtrees is shown to provide a flexible tool for integration of geographic data from various sources and for interactive analysis of regional land resources.

Introduction

There has been growing interest in geographical information systems (GIS) for evaluation of regional land resources. Over the past few years, advances in technology have lead to the automated generation of massive volumes of geographic or spatial data in digital form. Satellite remote sensing provides land use and land cover maps which are up to date and increasingly accurate. Raster-scan and video digitising of archival maps, together with improved methods of digital photogrammetry have accelerated production of digital maps and digital terrain data. Other major sources of geographic data in digital form include geophysical surveys, meteorological and socio-economic data. Given the variety and volume of geographic data in digital form that is now available, it is hardly surprising that interest has recently focused on how best to manage and analyse geographic data in computers. This has become a crucial issue not merely for research in universities but for government agencies and private companies where such data is used routinely. Computerised GIS have special relevance to the needs of developing countries where economic development depends to a large extent on successful and continuing exploitation of natural resources.

Most existing GIS have been developed to store, manipulate, manage and display digital cartographic data for automated mapping (Tomlinson, 1984). Based upon vector or raster types of data model, they are typically capable of performing efficiently a range of cartographic functions for particular projects. They are rarely designed however for sophisticated analysis of geographic data. Their capacity to answer complex queries involving dynamic computation of textual or geometric properties is quite limited. Peuquet(1984b) attributed this to two major shortcomings:(1) the rigidity and narrowness in the range of applications and types of geographic data which can be accommodated;(2) the unacceptibly low levels of efficiency for storage and retrieval of current massive volumes of geographic data. Dangermond (1984) noted that there is a trend away from short-term, project-oriented GIS towards general GIS for extended use. This has involved the search for a suitable data model for storing geographic information and a data base approach to the development of sophisticated intelligent GIS which users can query interactively for geographic research. One approach that shows considerable promise is based upon the use of linear quadtrees (Samet et al. 1984a).

The aim of this paper is to provide a brief account of current research in the University of Leeds into the development of a GIS based on linear quadtrees for regional analysis of land resources. A brief review of quadtrees is presented, in which the nature and operations on quadtrees are explained. A description of functions that have been implemented and a demonstration of their use for regional evaluation of land resources is presented and discussed.

Research on quadtrees

Quadtrees have been the subject of intensive research over recent years. Systematic studies of the properties of quadtrees have been carried out by many computer scientists. An extensive review of the theory and application of quadtrees and related hierarchical structures has been prepared by Samet (1984b). He explained that a quadtree describes a class of hierarchical data models which are based on the principle of recursive decomposition of space. The term quadtree has assumed more than one meaning: there are many different types of quadtree such as point, line and regional quadtrees. In this paper we will concentrate on the regional quadtree.

Quadtree encoding

A quadtree is constructed from a square binary array of pixels which represent an image(Fig 1). The set of black pixels in the image is referred to as a region, such as an area of forest. If we assume that an image is comprised of a 2^nx 2^n binary array of pixels, then a quadtree encoding represents this image by recursively sub-dividing it into four quadrants until no further sub-division is necessary. This occurs when we obtain square blocks (possibly single pixels) which are homogeneous in value (i.e. either all black or all white) or when we reach the level of resolution that we require. This process is represented by a tree of "out degree four" in which the root node corresponds to the entire image, the four sons of the root node correspond to the four quadrants, which in our case are labelled North West, North East, South West and South East. The leaf nodes of the quadtree correspond to the homogeneous blocks for which no further sub-division is necessary. The nodes at level n (if any) represent square blocks of size 2^nx 2^n. Thus, a node at level 0 corresponds to a single pixel in the image, whereas a node at level n is the root node of the quadtree. An illustration of these concepts is presented in Figure 1 where the region in 1a is represented by the binary array in 1b, the square blocks which result from image decomposition of 1b are shown in 1c and the quadtree in 1d with black nodes shown by solid circles.

Early work on regional quadtrees was carried out using pointers to represent the tree structure. Each node was represented by a record which comprised five pointers: four to sons, one to an ancestor and a field for the colour of the node. (Rosenfield et al. 1982). Although image compaction and quick search times were achieved by using pointer-based structures, a large amount of storage is taken up by the pointers themselves. According to Stewart (1986), assuming that each pointer uses 16 bits of memory and the node descriptor 8 bits, then pointers take up nearly 90% of the memory space used.

Linear quadtrees

Gargantini(1982) proposed a data structure to represent quadtrees which was more economical in its requirements for memory space. Known as a linear quadtree, it is in the form of a linear list consisting of the quadtree nodes in some order of traversal of the tree. A number of different forms of keys is available to map a set of ancestors to a numeric key (Morton, 1966; Gargantini 1982; Abel and Smith 1983). In our case, we modify the form proposed by Gargantini (1982) by numbering the quadtrants 1, 2, 3 and 4. This avoids the use of zero numbers in linear keys, except as fillers, and so the list of keys appears in strict numerical order. Nodes are arranged so that the quadrants are in order 1,2,3,4 corresponding to the NW, NE, SW, SE quadrants of an image. Only black nodes are recorded since the position of all white nodes can be deduced from a list of the black nodes. Thus a block in an image which is homogeneous in respect to attributes (all black or all white) is represented by a unique key derived from its ordered list of ancestors. The digits of that key encode from left to right the successive quadrant subdivisions by labels 1, 2, 3 or 4.

A linear key may be described for a pixel in a $2^3 \times 2^3$ image (Fig 2). Consider the pixel with coordinates x=3 and y=5. At level 3, the block consists of the whole image. At level 2, the block is divided into four sub-quadrants and, as the pixel falls in SW sub-quadrant, it is identified by 3. At level 1, the pixel falls in the NE sub-quadrant, so it is identified by 32, and at level 0 the pixel falls in the SE sub-quadrant, so it is identified by 324. Note that the level determines the length of side of the block or scaling factor. Thus the whole image consists of a block with side 2^3, the first sub-quadrants have side 2^2, the next 2^1 and the leaf nodes or pixels 2^0.

The size and position of any block in a region can be computed by decoding the linear key in a bitwise fashion (Peuquet, 1984):

```
decimal  binary          Gargantini(1982)      Leeds Key

y=5      101
         | \ \
         10 01 11  ------------>  213              324
         / / /                         (i.e. 1 added to each digit)
x=3      011
```

The quadtree address for block 213 represents a bit interleaving of the Cartesian x and y coordinates (in base 2) to produce the address in base 4. Reversing the process allows coordinates of any block to be computed, the size of the block being determined by the number of digits in the linear key. Address computations may be readily performed using bitwise-interlaced arithmetic for neighbour finding, geometric computations and so on.

Oliver and Wiseman (1983) observed that at first sight quadtree encoding appears to be just a compression trick which saves storage space. As such, the savings are modest to good, depending on the properties of an image. They stress however that there are other aspects of quadtree encoding which are of interest and where differences from other methods of encoding are dramatic. These include ease of manipulation of images, keeping images in a form which can readily be displayed and ease of displaying images at variable levels of resolution. Gargantini (1982,1983) demonstrated how arithmetic operations on the key of the node can be evaluated to determine various properties such as finding the relative coordinates of a block, adjacency, ancestor or descendent relationships, colour of a node, translation, rotation and superimposition of two images. She stressed that linear quadtrees have a number of advantages over pointer-based quadtrees, especially in terms of time and space required for various operations. Bauer (1985) provided algorithms for efficient set logic operations on linear quadtrees. These algorithms offered the potential for a very efficient means of image processing. Where disk resident quadtrees must be considered, the linear quadtree can be readily indexed to a B-tree memory management system to provide efficient access to nodes when a straight-forward sequential search through the file would be too time-comsuming (Abel 1984).

The performance of GIS based on linear quadtrees for evaluation of land resources is being investigated by several different groups. One group in the Department of Computer Science at the University of Maryland has conducted extensive research into the development and efficiency of algorithms for GIS using linear quadtrees and have built a prototype system with a knowledge-based component for representing point, line and regional geographic data (Rosenfeld et al. 1982, 1983; Samet et al. 1984,1985). Another pilot GIS with a Knowldge-based component has been built in the Department of Geography at the University of California, Santa Barbara (Smith and Pazner 1984; Peuquet 1984; Chen 1984; Smith and Peuquet 1985; Chen and Peuquet 1985). Its novelty is that it possess functions for both query-answering and learning about spatial objects. It represents an attempt to integrate the concepts and techniques which were developed in the field of artificial intelligence for constructing knowledge-based GIS(KBGIS). The first KBGIS has been overhauled and upgraded to a system which uses a strategy of making recursive calls in a three level structure that involves high-level procedures for constraint satisfaction, medium-level "blackboard" procedures and low-level procedures for quadtree search.

Others working in the field of GIS using linear quadtrees include a group at NERC Thematic Information Systems in U.K.(Jackson and Mason, 1986), a group at the Department of Geography, State University of New York (Mark and Lauzon 1984) and groups within CSIRO in Australia (Abel 1985). Much of the algorithm development is being done by computer scientists, though it appears that geographers and other earth scientists are increasingly involved in evaluation of applications.

Implementation of GIS using linear quadtrees

As a part of a one year pilot study, we have developed a GIS based on linear quadtrees to determine its potential for geographical research in a range of different applications. The programs have been written in the C programming language on a VAX 11/750 computer running Berkeley UNIX 4.2. We are continuing to develop and expand the range of functions that are available to the user, but currently have functions for basic operations including input, manipulation, analysis and display of images and other geographic data.

The interface to the user is by a query language. For example, if we wish to find the intersection of grit, gley and heights, we enter the query:

grit I gley I N(height91_122 U height122_152)

The results can be formed into a new quadtree file or sent directly to the printer. Alternatively, there is a menu driven interface which allows the detailed study of one quadtree. This can be used to find the colour of a node, traverse a line across the image or find a neighbour to a node. The menu provides a choice of different functions. These include formation of linear quadtrees from binary images, storage and retrieval of linear quadtrees, various operations upon them such a determine the geometrical properties of a region, (its size, nearest neighbour, etc) and to provide graphical output of maps. The operations on linear quadtrees fall generally into 2 distinct categories: (1) find what is at a specified location;(2) find all occurrences of a specified or subset of features. To answer these queries, a range of functions can be invoked. These include set logic operations on images such as union (logical OR i.e. map overlay), intersection (logical AND i.e. regions common to both) and complement(logical NOT i.e. inverse of an image). Other functions include labelling separate components in an image, creating a window into a sub-region of interest, finding the perimeter of regions, generation of statistics about regions and analysis of geometric properties of regions, such as size, shape and orientation.

Work is now being done to integrate the GIS into a relational data base management system for storing regions and objects. A B-tree memory management system is being developed to store very large quadtrees (Abel, 1984).

Land evaluation in Peak District, Derbyshire

To illustrate the potential of the GIS based on linear quadtrees for regional evaluation of land resources, a data base was created by digitising selected features from maps and aerial photographs. Landsat MSS imagery was classified to provide land cover and is being included.

A study area was selected close to Matlock, Derbyshire. This was chosen because of the variety of geology, relief, soils and land use in a relatively small area. An area of 25 sq km was chosen for compatibility with existing mapsheets, and so that resolution after digitising would be sufficient for the type of queries being asked. The square region selected corresponds to Ordnance Survey mapsheet SK 26 SE at 1:10560 scale. This showed heights represented by contours at 8.25 m intervals but only selected contours at 33 m intervals were used in this study. The resulting raster grid of 256x256 pixels leads to a ground resolution of about 20 m while the Landsat MSS data was resampled to give 80 m ground resolution. A description of the methods of data capture, the study area and details of the separate images which were used is provided in Hogg et al(1986).

Results of operations on the GIS

The data base of the GIS consists of a set of some 20 binary array images, each 256 x 256 pixels in size but held as a linear quadtree. Many more quadtrees are formed during operations on the GIS. To illustrate some of the possible operations that may be conducted on quadtrees, a series of plots are shown in figures 3 to 9.

One of the common requirements for geographic analysis of a scene is to find all land above, below or between specified heights. Figure 3 shows all land below 274 m. Note how maximal blocks are formed at different levels and how isolated holes above 274 m are shown as white.

The linear quadtree lends itself to set operations. Figure 4 shows land not below 91 m (i.e. land above 91 m), which covers the whole scene except for the river bed in the SE quadrant. Note that the NW, NE and SW quadrants are represented as single maximal blocks. Even in the SE quadrant, maximal blocks at lower levels are formed and decomposition of the image is restricted to the vicinity of the 91 m contour. One unusual feature of the linear quadtree is that the size of the quadtree file depends generally on the complexity of the border of the regions rather than the size of the area encoded.

Each contour in the study area is represented by a linear quadtree in the GIS. By applying the function to find the perimeter of each contour and combining the results into one file, the conventional contoured plot is produced (Fig 5). The lowest contour in Figure 5 is represented in Figure 4 to illstrate how each contour is held in the GIS.

A user can choose the set operations and the sequence in which they are carried out to produce the desired results. Figure 6 shows the areas of gley soils within the study area, while Figure 7 shows all areas with heights less than 152 m. The intersection of gley soils and heights less than 152 m produces the area shown in Figure 8. Visual comparison shows some correlation between these heights and gley soils. To evaluate this correlation, the user can instruct the GIS to count nodes and compute areas which are common to both images:

	Gley soils	Heights below 152 m	Intersection Gley/Heights
nodes	2331	1328	1985
area	20979	30920	14363

Area refers to the total number of 20 x 20 m pixels. Another important feature of the GIS is the automatic labelling of components within an study area, so they may be linked to a relational data base containing ownership, population or other details. Figure 9 shows automated labelling of areas of forest and woodland within the study area.

An impressive feature of the GIS is its speed of operation. While this cannot be evaluated easily on a multi-user computing system such as we are using, the response times for set operations on the images described are of the order of 3 seconds.

Discussion

As quadtree encoding of a square binary image is based on the principle of recursive decomposition, it represents a "divide and conquer" approach. This focuses on the detail in an image but retains information about larger homogeneous parts as well. It follows that the more complex an image, the greater the amount of sub-division that is required to represent it and the greater the number of levels in the resulting quadtree. The number of levels in a quadtree image is therefore a measure of the complexity in the image and provides a useful measure for geographic analysis. The use of quadtree spatial spectrum analysis for improving search efficiency in large-scale GIS is based on analysis of black nodes at each level in a quadtree encoded image(Chen 1984; Chen and Peuquet 1985).

Quadtree encoding may not always be the most efficient way to store an image but quadtrees are usually efficient for regional, geographical data. As a worst case example, consider a binary image containing a ´chess board´ pattern. The resulting quadtree would be complex and relatively inefficient as a means of storage. If an image of a typical area of the earth´s surface is considered however geographic phenomena tend to occur in associated groups even in the most complex areas. Quadtree encoding exploits the spatial coherence that generally exists in the landscape where there are areas of relative homogeneity mixed with areas of complexity. It allows operations on geographic data which is inexact or fuzzy, multi-dimensional and in massive volumes. It also allows viewing of images at different levels of resolution or generalisation, which represents a major advantage for browsing and geographic analysis. Moreover, quadtrees are readily handled in computers as set operations are carried out by processing two sequential files together: only one node from each quadtree is required in memory and each node is read once only.

The representation of heights in a GIS based on linear quadtrees is generally based on digitising contours to produce relief as illustrated in figure 6. This is the method adopted by Samet et al.(1984). An alternative method of storing heights has been reported by Cebrian et al.(1985). Digital elevation models (DEM´s) are integrated into the linear keys of the GIS, so the every height point is tied to a locational key. The main advantage of this is that different users can derive height, slope, aspect and hill shading maps with categories of values that they require. There is of course a price to pay for using DEM´s in that they require considerably more storage than contours but Cebrian et al.(1985) argue that their method gives greater flexibility and analytical capabilities to the GIS.

Conclusions

The need for GIS as a tool for geographic research is accepted, but there is less agreement in the literature about how geographic data should be represented in computers. As this determines to a large extent the type of function that can be performed efficiently, this is a crucial issue. A pilot GIS based on linear quadtrees for regional analysis has been described and shown to have special features for integration and interactive analysis of geographic data from various sources. While further work is required to develop the GIS, it shows considerable promise as a research tool.

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References

Abel, D.J.& Smith, J.G. 1983 A data structure and algorithm-based on a linear key for a rectangular retrieval problem.
Computer Vision,Graphics and Image Processing,Vol.24,pp1-13

Abel, D.J. 1984 A B-tree structure for large quadtrees. Computer Vision, Graphics & Image Processing, Vol 27, pp 19-31.

Abel, D.J. 1985 Some Elemental Operations on Linear Quadtrees for Geographic Info Systems. Computer Journal, vol 28 ,No1 pp73-77.

Bauer, M.A. 1985 Set operations on linear quadtrees. Computer Vision, Graphics & Image Processing. Vol 29, pp 248-258.

Cebrian, J.A. Mower,J.E. & Mark, D.M. 1985 Analysis and display of digital elevation models within a quadtree-based geographic information system. Proc. Auto-Carto 7, Washington D.C. pp55-64.

Chen, Z.T. 1984 Quadtree spatial spectrum : Generation & application. Proc. Int. Symp. Spatial Data Handling,1984, Zurich, pp 218-236.

Chen, Z.T. & Peuquet, D. 1985 Quad tree spatial spectrum: a fast spatial heuristic search in a large GIS. Proc. Auto-Carto 7,ASP,pp 75-82.

Dangermond, J 1984 Geographic data base systems. Tech. Paper in ASP-ACSM Fall Convention, San Antonio, Texas, ASP. pp201-211.

Gargantini, I. 1982 An Effective Way to represent Quadtrees. Communications of A.C.M. vol 25 No. 12 pp905-910.

Gargantini, I. 1983 Translation, rotation and superposition of Linear Quadtrees. Int. Journal of Man-Machine Studies, (18), pp 253-263.

Hogg, J. Gahegan, M. & Stuart,N. 1986 Evaluation of regional land resources using geographic information systems based on linear quadtrees. ISPRS Commission VII, Enschede, Holland, 25-29th August,1986. 9 pages.

Jackson, M.J. & Mason, D.C. 1985 The development of integrated geo-information systems.NERC Thematic Information Systems,Reading,UK.pp24.

Mark, D.M. & Abel, D.J. 1985 Linear Quadtrees from Vector representation of polygons. IEEE Trans. on Pattern Analysis & Machine Intelligence, vol PAMI-7 No 3, pp343-349.

Mark, D.M. & Lauzon,J.P. 1984 Linear quadtrees for geographic information systems. Proc. Int. Symp. on Spatial Data Handling, Zurich, Switzerland, August 1984, vol. 2, pp. 412-430.

Morton,G. 1966 A computer oriented geodetic data base and a new technique in file sequencing. IBM Canada Ltd, unpublished report.

Oliver, M.A.& Wiseman,N.E. 1983 Operations on quadtree encoded images.The Computer Journal, Vol.26, No 1, pp 83-91.

Peuquet, D.J. 1984a Data structures for a knowledge - based GIS. Proc. Int. Symp. Spatial Data Handling, Zurich, Switzerland, Vol.2,pp372-391.

Peuquet, D.J. 1984b A conceptual framework and comparison of spatial data models. Workshop W2, International Symposium on Spatial Data Handling, 1984, Zurich, pp.80.

Rosenfeld, A. Samet, H Shaffer, C. Webber, R.E. 1982 Application of hierarchical data structures to geographical information systems TR-1197 Computer Vision Laboratory, University of Maryland.pp 160

Rosenfeld, A. Samet, H. Shaffer, C.A. Webber R.E. 1983 Application of heirarchical data structures to geographical information systems: Phase II. TR-1327 Computer Vision Laboratory, University of Maryland,pp76

Samet, H. 1984 A Geographic Information System using Quadtrees. Pattern Recognition, vol 17, No 6, pp647-656

Samet, H. 1984 The quadtree and related hierarchical data structures. ACM Computing Survyes 16, 2:187-260.

Samet,H. Rosenfeld, A. Shaffer, C.A Nelson, R.C. Huang, Y.G. 1984 Application of hierarchical data structures to geographical information systems: Phase III CS-TR-1457 Center For Automation Research,University of Maryland.

Samet H. Rosenfeld A. Shaffer,C.A. Nelson,R.C. Huang,Y.G. Fujimura, K. 1985 Application of hierarchical data structures to geographical information systems: Phase IV CS-TR-1578 Computer Science Department, University of Maryland,pp 61.

Smith, T.R.& Pazner, M.I. 1984 Knowledge - Based control of Search & Learning in a large scale GIS. Proc. Int. Symp. on Spatial Data Handling, 1984, Zurich, Switzerland, pp498-519..

Smith,T.R. & Pazner,M.I. 1984 A knowledge based system for answering queries about geographical objects. William T. Pecora Memorial symposium on spatial information technologies for remote sensing today and tomorrow. proc..9th pp 286-289.

Smith, T.R. & Peuquet, D.J. 1985 Control of spatial search for complex queries in a knowledge-based geographic information system. Proc. Int. Remote Sensing Society/CERMA Conf. on Advanced Technology for Monitoring and Processing Global Environmental Data, London, 1985, p439-453.

Stewart,I.P. 1986 Quadtrees: storage and scan conversion. The Computer Journal Vol 29, No 1, 60-75

Tomlinson, D.J. 1984 Geographical Information Systems - A New Frontier. Proc. Int. Symp. Spatial Data Handling, 1984, Zurich.

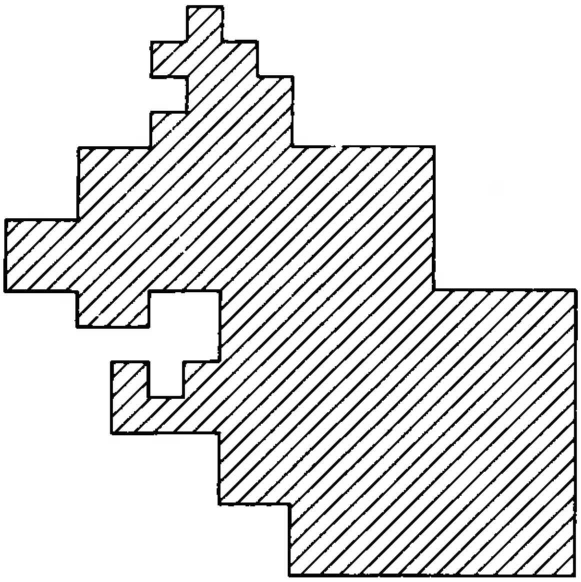

Fig 1a A region such as a forest

0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0
0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0
0	0	0	0	1	1	1	1	0	0	0	0	0	0	0	0
0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0
0	0	1	1	1	1	1	1	1	1	1	1	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
0	0	1	1	0	0	1	1	1	1	1	1	1	1	1	1
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0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1
0	0	0	0	0	0	0	0	1	1	1	1	1	1	1	1

Fig 1b Binary image of 1a

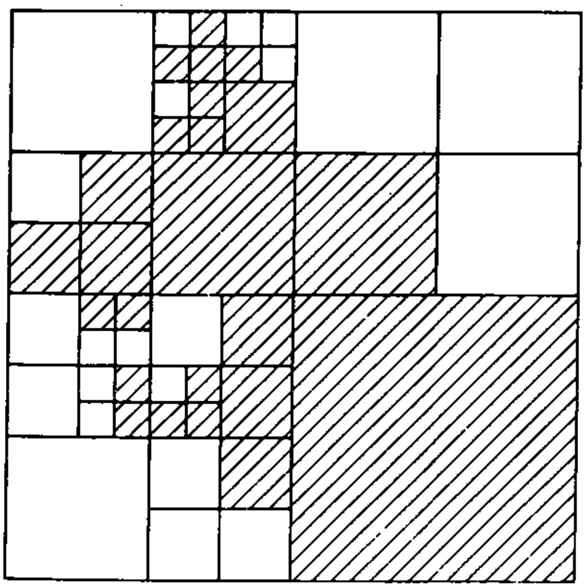

Fig 1c Block decomposition of the region in 1a showing the maximal blocks

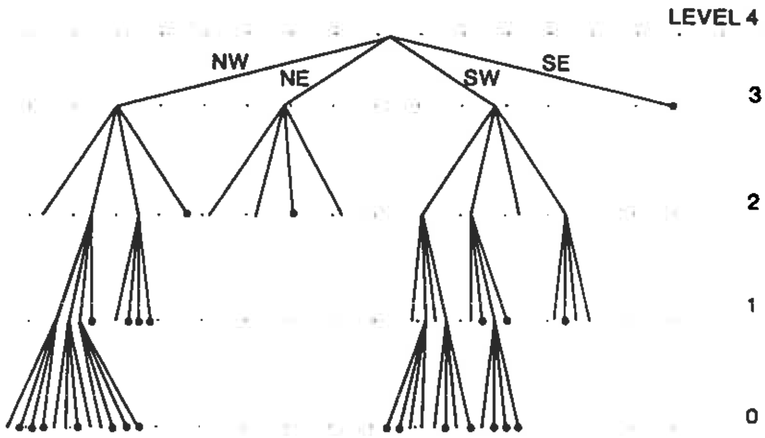

Fig 1d Quadtree representation of the blocks in 1c with black nodes shown by solid dot

NW	0	1	2	3	4	5	6	7	NE
0	111	112	121	122	211	212	221	222	
1	113	114	123	124	213	214	223	224	
2	131	132	141	142	231	232	241	242	
3	133	134	143	144	233	234	243	244	
4	313	314	321	322	411	412	421	422	
5	315	316	323	324	413	414	423	424	
6	331	332	341	342	431	432	441	442	
7	333	334	343	344	433	434	443	444	
SW									SE

x-axis; y-axis

Fig 2 Addressing scheme for locational keys.

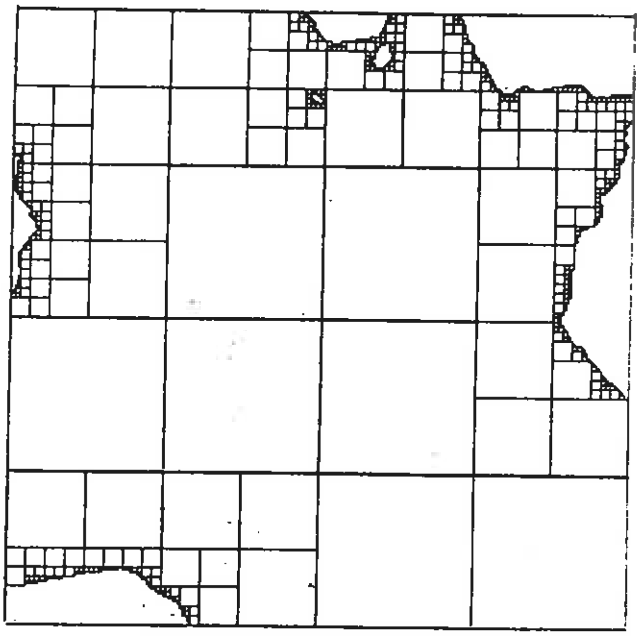

Fig 3 All land below 274 m.

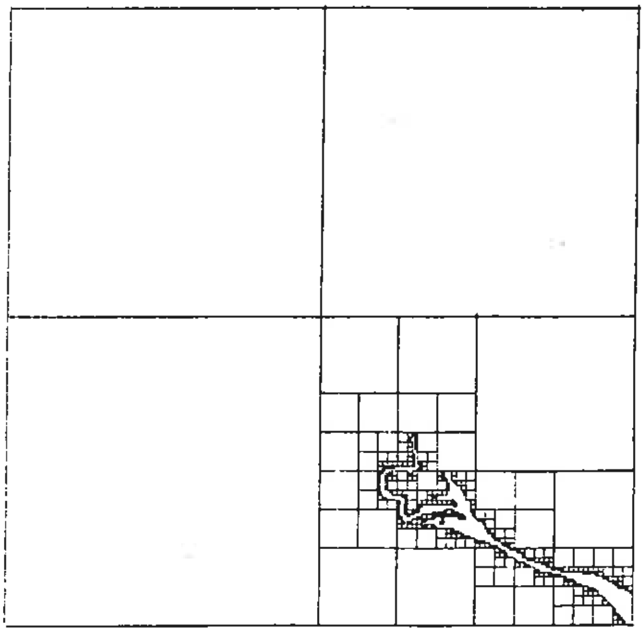

Fig 4 All land above 91 m.

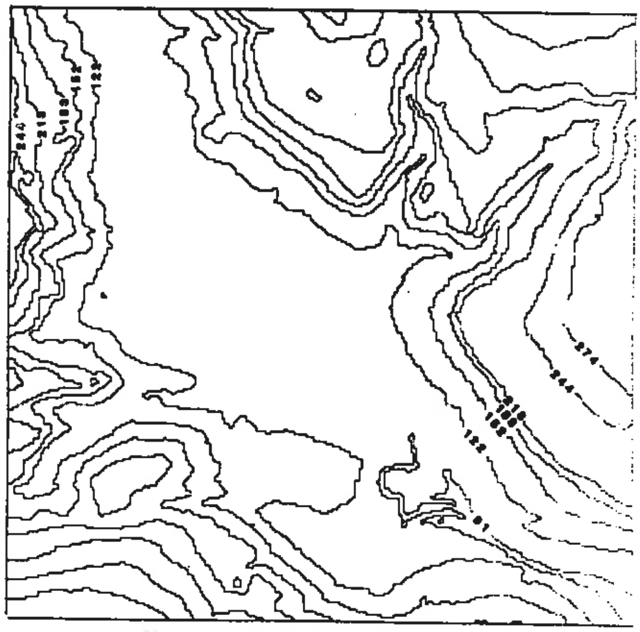

Fig 5 Conventional plot of all contours held as linear quadtrees.

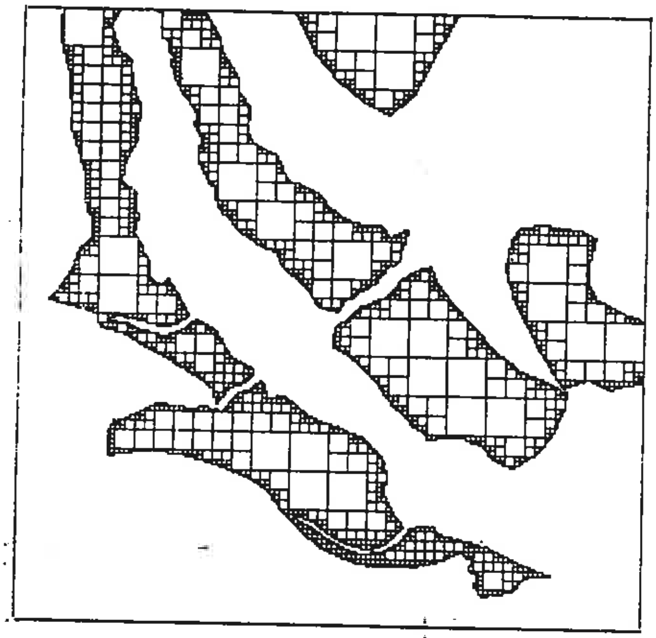

Fig 6 Areas of Gley soil

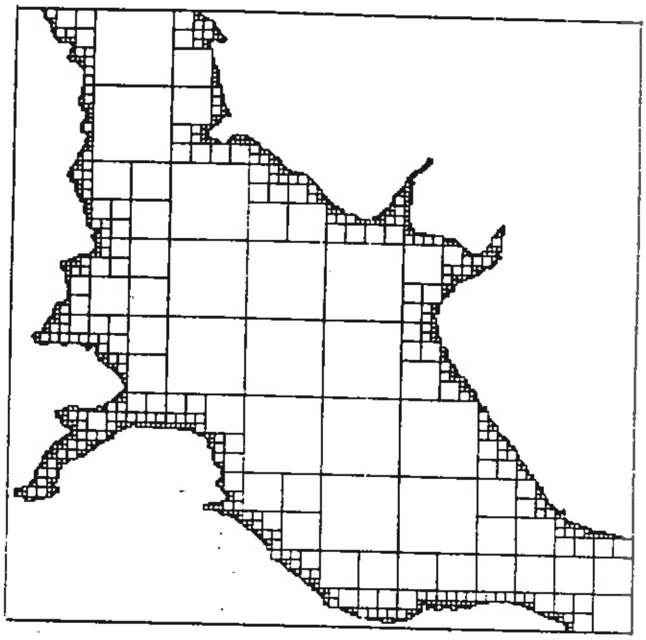

Fig 7 All land below 152 m.

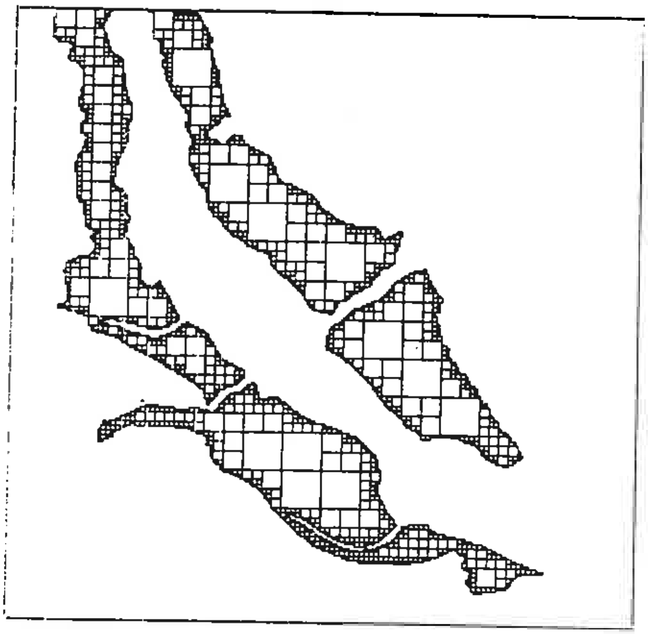

Fig 8 Intersection of Gley soil and land below 152 m.

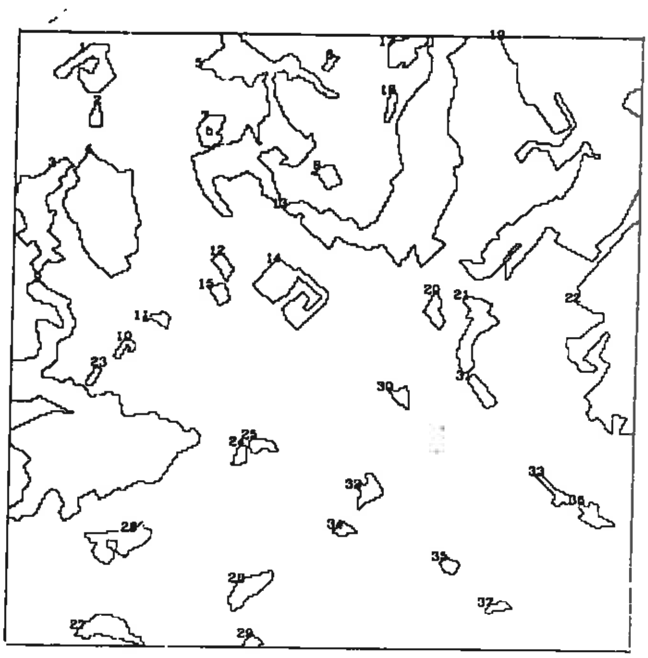

Fig 9 Automatic labelling of areas of forest.