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THE INTEGRATION OF GIS, REMOTE SENSING, EXPERT SYSTEMS AND ADAPTIVE CO-KRIGING FOR ENVIRONMENTAL HABITAT MODELING OF THE HIGHLAND HAGGIS USING OBJECT-ORIENTED, FUZZY-LOGIC AND NEURAL-NETWORK TECHNIQUES

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Abstract—A report is given on several major breakthroughs in geomatics‡, and their application is demonstrated on a particularly difficult habitat modeling exercise. Results show conclusively that these techniques, when applied to GIS related problems, improve the analytical capability in absolute quantitative terms by quite a bit really. Copyright © 1996 Elsevier Science Ltd

Key Words: Right, Grid-reference, Wrong, Planet.

INTRODUCTION

The Highland Haggis (*Podus Non-symmetricus*) is now on the WWF§ list of endangered species following excessive harvesting prior to the Burn's Night celebrations in 1994. The Haggis exists only in the highlands of Scotland¶ and sightings by humans in recent times are becoming rare.

The Highland Haggis is unique amongst all mammals in that it has a pair of legs (either left or right) that are shorter (longer) than the other pair. This evolutionary adaptation allows it to walk with ease around the very steep mountainous regions that compose its natural habitat. A Haggis feeds on native vegetation (wet grass, wet heather) as it walks around a mountain in either a clockwise or anticlockwise direction, depending on its legs. Haggis have a natural aversion to any other plane of movement, preferring areas where the angle of slope is within a certain tolerance (θ) of the difference in height between opposite pairs of legs. Hence, from birth, each Haggis will find a niche, that is, a traversal around a mountain, with a favorable gradient and free from any other Haggis. It is a sad consequence that each year, many fledgling Haggis die whilst attempting to move upslope or downslope to find such a niche, only to topple helplessly sideways and roll down the hill. The path taken by a falling Haggis is analogous to that of surface water runoff, and a full discussion of this effect is given later in the "theory" section.

Since each Haggis walks the same path around a hill for the duration of its life,* an effect similar to a contour line (Scott, 1967) becomes etched into the side of the hill, partly due to soil compaction, and partly to the reduction in vegetation cover. The effect is highly localized, but fortunately some evidence is apparent in the Digital Chart of the World (DCW) land cover layer.

A NEW SPATIAL UNCERTAINTY CALCULUS

Traditional fuzzy logic does not cope well with the image data used here, because of the nonlinear distortion effect caused by "Scotch Mist"; a local weather condition that has a direct, but complex relationship with altitude.** A new form of uncertainty calculus, "misty logic," is introduced. This allows all noise related to atmospheric distortion and scale effects to be removed from the raw data, enabling us to make out detail hitherto unobservable, to extract complete road and stream networks from satellite images, and to determine fully 3D geological structure from geophysical data. Several forms of remote sensing data were assessed for their usefulness for the problem outlined above. A comparison of satellite and radar images is given in Figure 1.

†email oleg@bullshit.no.never
‡No, I do not know what it means either.
§WWF: Wild and Wacky Furball.
¶Scotland is (contrary to the desires of many Scots) part of the U.K. It is distinguished easily from England, because it is not full completely of people. It is distinguished less easily from the surrounding seas, because it is marginally less wet.
*The only exception is to breed. This is an extremely delicate matter.
**Or was it alcohol?

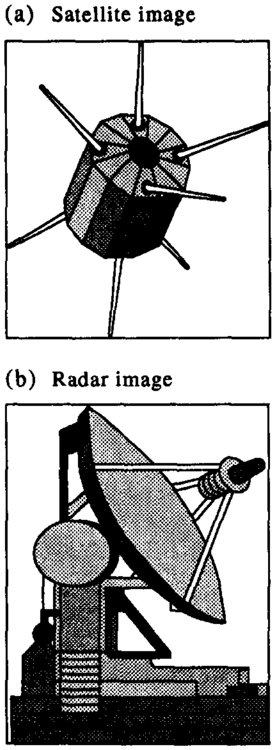

Figure 1. Comparison of alternative images.

A NEW APPROACH TO DATA INTEGRATION

Because of the stochastic nature of the problem, and the "mixed bag" of data required, a neural network approach to evidence combination is indicated. However, such networks traditionally are expensive on resources and difficult to configure. A variant has been constructed therefore where the network is specialized to a directed graph containing only two items (input node and output node). This *list*, whilst usually producing the same outcome as a neural network, executes in linear time and does not require any of that messy fiddling about with the hidden layer (McNoleg, 1995).

A NEW HIERARCHICAL DATA STRUCTURE

The huge volumes of data required for this exercise have led to the development of a new form of hierarchical data structure, the Polymorphic Euclidean Adaptive Region tree (PEARtree). The PEARtree can store all the 200 Gb of data used here in less than 640 k, allowing the software to run on all PC-type computers. For example, *ridges* are extracted from the Digital Elevation Model (DEM), hierarchically decomposed, and inserted into the PEARtree as a series of fragments (generically known as *parts*). Figure 2 shows a part (*ridge*) in a PEARtree (Oxford, 1903).

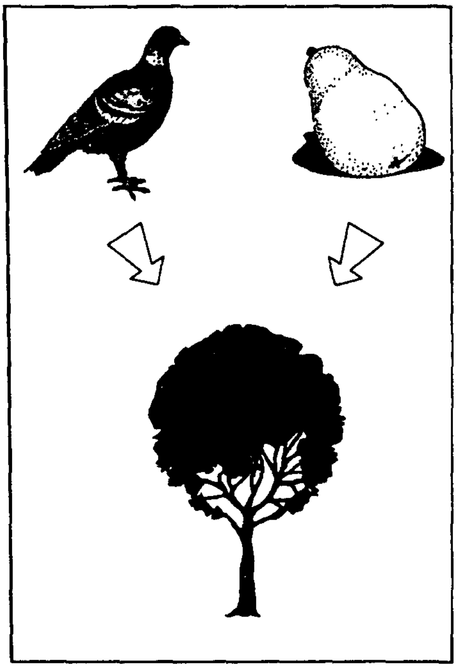

Figure 2. "... and a partridge† in a pear tree."

METHOD

Using the techniques outlined above, the path for each Haggis is modeled as a combination of environmental, spectral, spatial, economic, temporal, taxonomic, and astrologic data species in the following way.

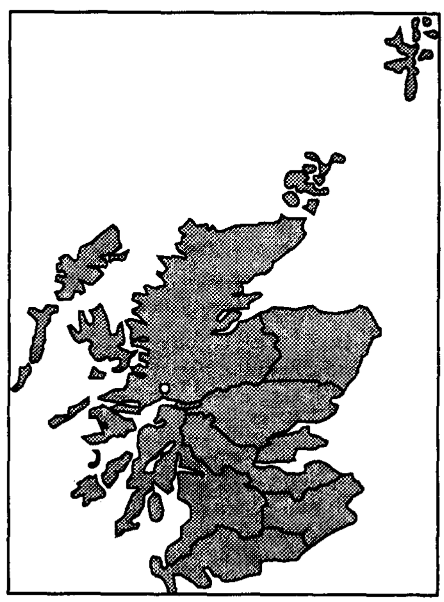

Figure 3. Scotland—coastal outline (and administrative boundaries).

†This early prototype actually shows a pigeon, with an aspect ratio of 4*3 and a deftly edited tail. It is hoped that future versions will be completely generalizable to all birds beginning with the letter "p."

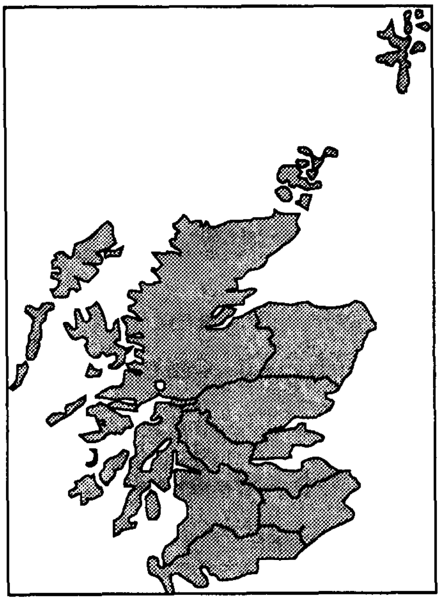

Figure 4. Remaining areas of Scotland, after application of rainfall constraint.

Firstly, it is known that Haggis can survive only in extremely wet conditions, requiring substantial rainfall on at least 350 days in a year. A rainfall map was formed for Scotland, then areas meeting the rainfall criteria were selected. A map of Scotland is shown in Figure 3. The resulting map of the same area after overlaying the rainfall constraint is shown in Figure 4.

Secondly, the elevation data is processed by the application of *adaptive co-kriging*, since this sounds incredibly impressive in the title of the paper and has been shown to have a subtle positive influence on the reviewer.†

Thirdly, regions of suitable gradient are combined using a set of expert rules with candidate Haggis tracks, extracted from the DCW land cover data, using misty logic at a scale of 1:1,000,000. The expert system is used here to bolster up the number of current *buzzwords* in the title of the paper.‡ Like most expert systems, it contains about half a dozen rules that could easily have been coded with a *case* statement in a PASCAL program, but the title would look a good deal less impressive as a result.

†Though not as subtle and positive as favorably referencing their work.

‡The greater the number of buzzwords in the title, the greater the chances of paper acceptance; as shown by McNoleg's Postulate:

$$\sum_n^1 Bi * Ti \propto Pr(A),$$

where Bi is the ith buzzword, and Ti represents a measure of its trendiness and $Pr(A)$ is the probability of acceptance. Care must be taken if any of the keywords are in fact now considered passé. Appendix 1 contains a selected list of keywords and their current trendiness.

§About one map every 0.5 sec on a grid size of 10 m^2 gives a sufficient sampling.

The object-oriented approach (King, 1989) has been chosen since it has been shown to have a 65% rate of success for paper acceptance when the words are included in the title. It has the added advantage of allowing the author to add a significant number of references very easily (John, 1991; Paul, 1992; George, 1993; Ringo, 1994.

THEORY

It has become customary for papers to contain copious quantities of gratuitous mathematics (Heckbert, 1987 Well and Du, 1993; Rull, 1993); the rationale being that even the most straightforward or outrageous of ideas can look credible if expressed using enough complex symbology.

In addition to searching for Haggis grazing "contours," it is possible also to locate Haggis habitats from geophysical data sources. As mentioned earlier, Haggis may lose their footing. When rolling down a hillside of length s, the steepness of the slope combined with the heavy weight (m_0) of a well-fed, sodden Haggis at rest, can lead to a (rotational) velocity approaching *relativistic* speeds. The beast acquires a total kinetic energy (T), approaching infinity, given, after Beiser (1963), by:

$$T = \int_0^s \mathrm{d}\frac{\mathrm{d}(mv)}{\mathrm{d}t}\,\mathrm{d}s$$

$$= \int_0^v v d\left(\frac{m_0 v}{\sqrt{1 - v^2/c^2}}\right).$$

Integrating by parts: ($\int x\, \mathrm{d}y = xy - \int y\, \mathrm{d}x$)

$$T = \frac{m_0 v^2}{\sqrt{1 - v^2/c^2}} - m_0 \int_0^v \frac{v\, \mathrm{d}v}{\sqrt{1 - v^2/c^2}}$$

$$= \frac{m_0 v^2}{\sqrt{1 - v^2/c^2}} + m_0 c^2 \sqrt{1 - v^2/c^2}\Big|_0^v$$

$$= mc^2 - m_0 c^2.$$

Now, since $m = m_0/\sqrt{(1 - v^2/c^2)}$, then as v approaches c, so $m \Rightarrow$ infinity.

The resulting increase in mass ($m - m_0$) causes the path taken by the Haggis to be visible as an *extremely* bright localized streak in perhaps one or two gravitational anomaly maps,§ and can be identified easily using image differencing.

RESULTS

Despite all the sophisticated analyses applied, no Haggis tracks were detected at all! Clearly, the Haggis is more endangered than was first thought!

FUTURE WORK

It is hoped that the author will secure a large research grant to allow a full ground survey to be carried out. This will enable an assessment of the quality of the model described here. The fact that there is a high correlation between whisky distilleries and known Haggis sightings suggests some likely centers from which to base the fieldwork.

The author intends to adapt these techniques and, with the addition of qualitative spatial reasoning (see Appendix 1), to apply them to further habitat models for the Yeti, the Loch Ness Monster, and the Australian Bunyip.

AUTHOR'S NOTE

No insult or slight is intended by the author towards any particular persons (especially Scots). This paper was inspired by a memorable, if somewhat damp, trip to Scotland for the Spatial Data Handling Conference in 1994.

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APPPENDIX 1

GIS keywords and their trendiness

Keyword	Trendiness
Object oriented approach	+0.6
Kriging	+0.5
FORTRAN	−0.3
Qualitative spatial reasoning	+0.9
Digital elevation model	0
Quadtree	−0.2
Nonspatial (conventional) statistics	−0.8
Spatial uncertainty	+0.7