

Representing forested regions at small scales: automatic derivation from very large scale data

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ABSTRACT

As with any class of feature, it is important to be able to view woodland or forest at multiple levels of detail. At the detailed level, a map can show clusters of trees, tree types, tracks and paths; at the small scale, say 1:250 000 scale, we can discern broad patterns of forests and other land use, which can inform planners and act as input to land resource models. Rather than store such information in separate databases (requiring multiple points of maintenance), the vision is that the information has a single point of storage and maintenance, and that from this detailed level various, more generalised forms can be automatically derived. This paper presents a methodology and algorithm for automatically deriving forest patches suitable for representation at 1:250 000 scale directly from a detailed dataset. In addition to evaluation of the output, the paper demonstrates how such algorithms can be shared and utilised via 'generalisation web services', arguing that the sharing of such algorithms can help accelerate developments in map generalisation, and increase the uptake of research solutions within commercial systems.

CONTEXT

Being able to view geographic phenomena at multiple levels of detail is essential to geographic inquiry (Sheppard and McMaster, 2004). It affords meaning through the identification of pattern and interpretation of a multitude of processes that operate at various scales (in both time and space). One class of feature commonly found on topographic maps is forest which at the finest scale involves representation of individual or small groups of trees and at a very coarse scale (e.g. 1:250 000), can show the general extent of forested regions across the landscape enabling broad classifications of land cover. Being able to demarcate such regions is useful to cartography, but is also relevant in spatial analysis and modelling, for example in resource modelling or carbon trading at the global scale.

Rather than endure redundant storage among multiple databases (each database representing forests at different conceptual scales), surely it is more efficient to maintain a single, highly detailed database that acts as a single point of update? The assumption would be that we then apply generalisation algorithms to that source data, aggregating clusters of trees, in order to convey forest? Any changes made at the fine detail, can then be automatically propagated to the smaller scales. The creation of such a system would support integration/conflation of data at different scales (Weibel, 1995); 'intelligent zoom' (Frank and Timpf, 1994) in interactive environments (seeing more detail as you zoom into the map); scale dependent spatial analysis (analysis of data at a scale appropriate to the task) (Mackaness, 2007); and exploratory data analysis (Dykes *et al.*, 2004).

This paper presents a technique that automatically creates forested regions for visualisation at a scale of 1:250 000 from very detailed vector. In the implementation section the paper explores ideas

of interoperability and the idea of sharing such algorithms via web services. A series of case studies together with their evaluation are presented.

Generalisation Techniques

The idea of creating automated generalisation solutions is premised on the creation and maintenance of a single, fine scale, detailed database from which multi scale products are derived using various generalisation techniques. The advantages of deriving multi-scaled products from a single database are: 1) a single point of maintenance and update from which multi-scale products can be produced, 2) a framework for the integration of data collected at disparate scales, and 3) a method of ensuring consistency between cartographic products covering the same area but at different scales (Mackness, 2007). Cartographic generalisation includes techniques such as selection, classification, simplification, exaggeration, elimination and displacement. Generalisation research has tended to focus on the development of techniques for generalising topographic data, typically provided via national mapping agencies. Research effort has focused on specific classes of features such as buildings, along with natural and anthropogenic networks (as summarised by Li, 2007; Regnauld and McMaster, 2007). A valid generalisation method should produce predictable and repeatable results; should minimize deviations of the resulting model from the original model; should maximize data volume reduction; should preserve topological consistency; should use as few control parameters as possible; and should be efficient (Weibel, 1995).

This research focuses upon the generalisation of forest regions with the aim of developing and evaluating an algorithm that simplifies the representation of forest regions for display at a notional scale of 1:250 000 derived directly from a detailed dataset. Forest or woodland generalisation has tended not to receive much attention (notable exceptions being Gold (1998) and Revell (2005)). Gold developed a digitizing technique for rapid capture of forest polygons based on digitizing around the interiors of each polygon and creating a Voronoi diagram, and extracting the Voronoi boundaries between points (Gold *et al.*, 1996; Gold, 1998). More recently, Revell (2005) outlined a technique for generalisation of forest polygons for representation at 1: 50 000 scale, which involved clustering of tree polygons into autonomous groups, amalgamation of these clusters into single areas of woodland and simplification of the woodland boundaries.

METHODOLOGY

This research sought to develop a fully automated solution for creating a forest layer for visualisation at 1:250 000 scale, which was evaluated by professional cartographers and by comparison with manually generalised 1:250 000 scale data (Ordnance Survey's Strategi dataset).

Data input

The source dataset was OS MasterMap[®] Topography Layer data which forms a complete coverage of Great Britain (GB) at a high level of detail, maintained as a seamless database (Ordnance Survey, 2007). MasterMap data was captured at a scale of 1:1250 in urban area, 1:2500 in rural areas and 1:10,000 in mountain and moreland areas (Ordnance Survey, 2007). The study area selected was the region surrounding the town of Peebles in the Scottish borders (Figure 1) – a region chosen because it contains dense regions of forestry with considerable variation in the size and shape of forests. Part of the region was used to parameterise the algorithms (making the algorithm produce output approximating that of the Strategi[®] data), whilst other regions were used to assess how generalisable the solution was. In the source dataset, each polygon represents a collection of trees. Each feature has a descriptive term that defines its land use category. A single feature can have multiple values for the descriptive term (coniferous, mixed, non-coniferous). In this research we focused on 'Coniferous Trees' and 'Non-Coniferous Trees' (accounting for a great majority of the woodland features in Ordnance Survey products). Figure 2 shows the typical detail of one of the sub-regions of the study area shown in Figure 1.



Figure 1 The Study Area. (Ordnance Survey 1:250,000 colour scale raster. ©Crown Copyright/database right 2007. An Ordnance Survey/EDINA supplied service)

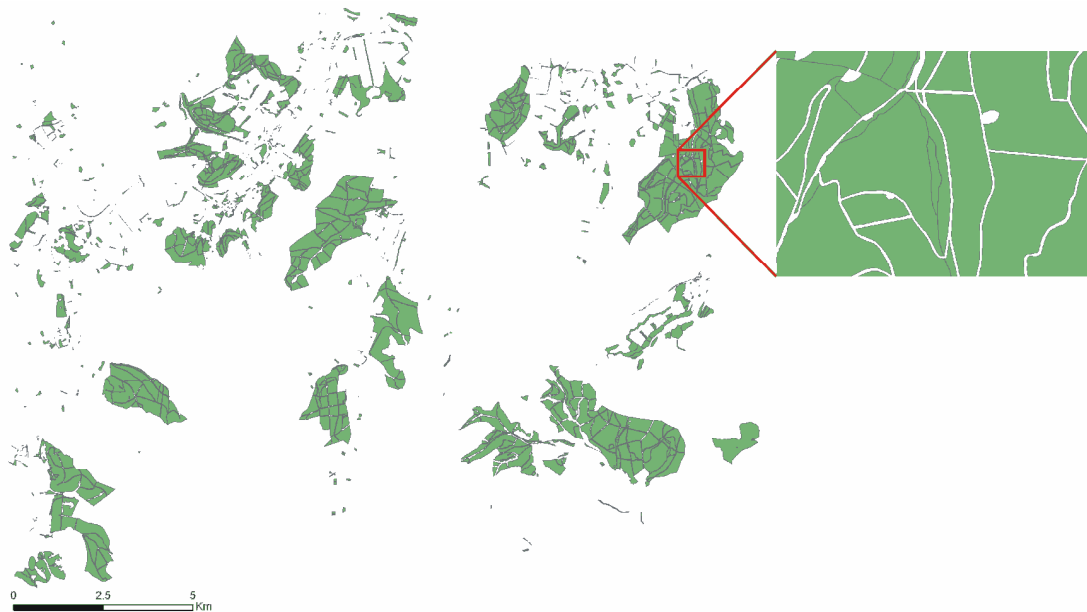


Figure 2: Example of input data (tree patches) from OS MasterMap showing the detail of forest patches (Ordnance Survey ©Crown Copyright. All rights reserved)

Area-Patch methodology

Initial work drew upon the work of Müller & Wang (1992) who developed an algorithm to generalise groups of lakes, and suggested that it would be suitable for other classes of polygonal features (such as forestry). The essence of their methodology was to rank the lakes in order of size and define a midpoint in the ranking. Those lakes greater than a certain area were enlarged (by buffering), and those beneath the midpoint were proportionally reduced in size. Then any lakes falling beneath some prescribed visual tolerance (the size at which they were no longer discernable to the human eye for a given scale) were removed. They argued that this mirrored the tendency for the eye to be drawn towards larger features, assuming them to have greater significance in terms of ‘lake-ness’. Their ‘area-patch’ methodology is analogous to the idea that ‘the rich get richer, and the poor get poorer’. Their algorithm was re-implemented and applied to forest patches but produced disappointing results when visually compared both with MasterMap (Figure 3a) and with Strategi data (Figure 3c). This was because of the variability in size, and pattern of distribution of tree patches which were often very small because they were ‘broken’ by network features (tracks, paths and roads) that criss-crossed a region (Figure 2) – something that is not true among groups of lakes. Though the new algorithm presented here retains the idea that “the rich get richer and the poor get poorer” it was extended to take into account the fragmented nature of forests.

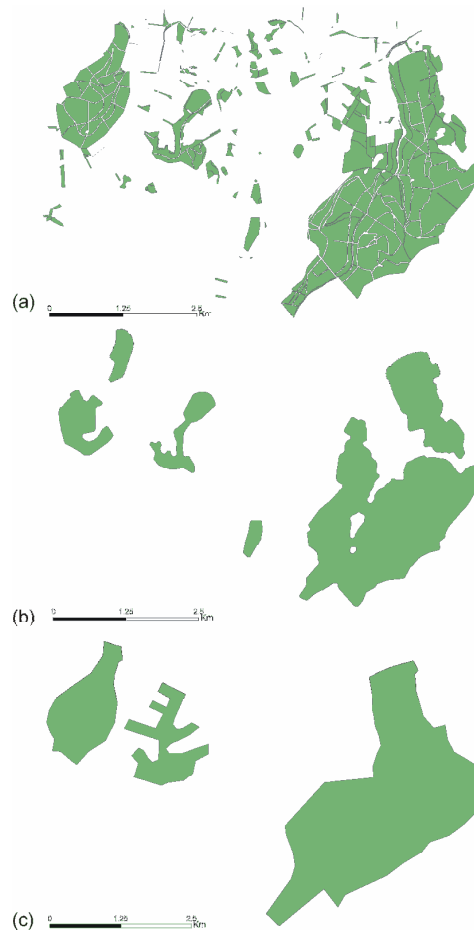


Figure 3: (a) Input tree patches from the source dataset. (b) Output forest patches produced using Muller and Wang’s ‘area-patch’ methodology. (c) Output from Strategi for the equivalent area (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved)

In essence, the proposed methodology works by buffering (either enlarging or contracting) according to the size of tree patches. The overlapping patches are aggregated into forest patches and small holes (e.g. scrubs, glades) are filled. Where there is a sufficient density of small patches, these

too are expanded. As a final step, the boundary of the resultant forest patches is simplified. The selection of various tolerances (how much to enlarge by, what size of hole is deemed to be too small, and what is the ‘tipping point’ at which some grow larger while some grow smaller), was determined through empirical analysis. In other words, various outputs were examined using different tolerances until the desired output was consistently produced. A ‘correct’ result was considered to be one that closely mirrored hand-drawn solutions reflected in Ordnance Survey Strategi data. Figure 4 illustrates the results of each of the three phases (selection/ resizing, hole filling, simplification of the boundary).

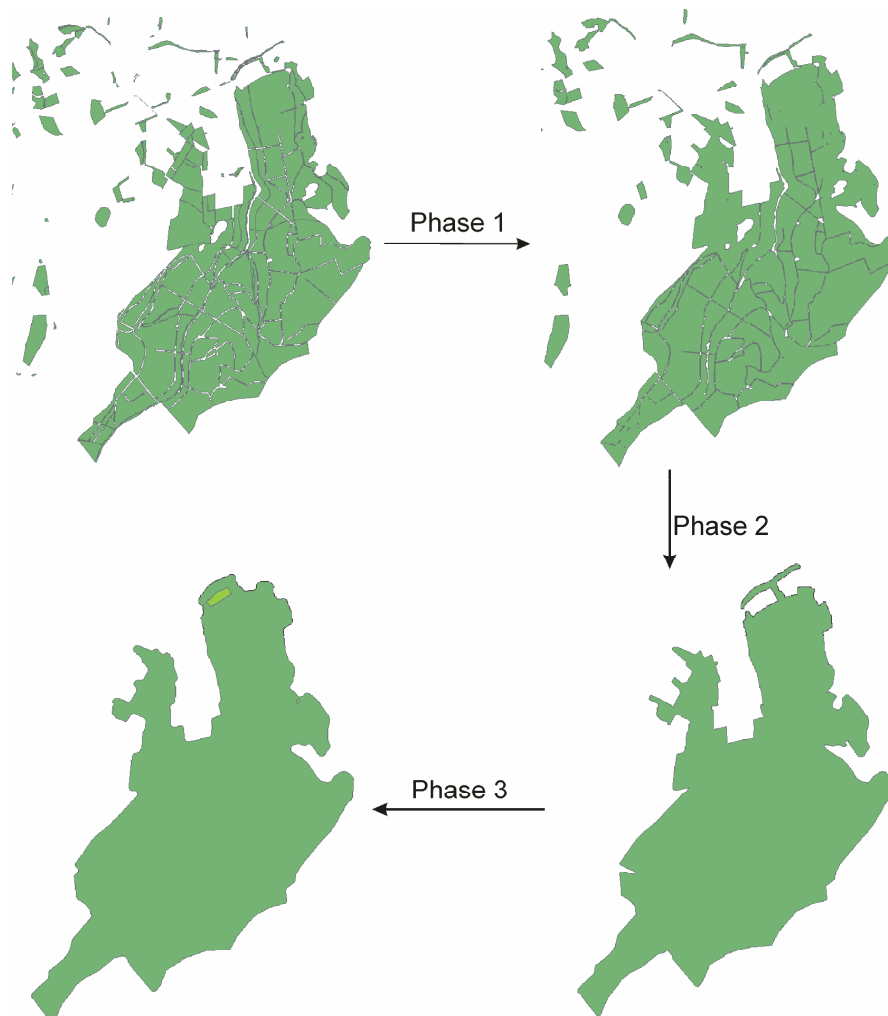


Figure 4: The three phases of the Methodology (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved)

Defining the thresholds

The thresholds were empirically derived after numerous tests with small test data sets. Inspection of the dataset revealed that there were many patches with an area less than 5000 m² (T1) a size that is practically invisible to the human eye at 1:250 000 scale. The buffering threshold (T2) (used in the first phase) was derived by inspection of dense collections of small areas and was set roughly to half the width of the network features that delineated and separated the tree patches. The purpose of setting this threshold was to merge patches separated by narrow roads, railways or river features in the source dataset. The most important threshold T3 was the size above which patches were expanded. The value for T3 was determined by overlaying the tree patches from the source dataset with the forest patches in Strategi data and identifying the point at which patches began to be eliminated. Finally the area threshold below which patches were eliminated, Ws, was set to 0.25 km². This value was determined from the Ordnance Survey 1:250 000 scale specifications for forest objects (Ordnance Survey, 2005). The threshold for removing or retaining holes, T4, was also

determined from empirical observation. Figure 5 presents the sub-stages involved in each of these three phases of the proposed methodology along with the threshold used in each step.

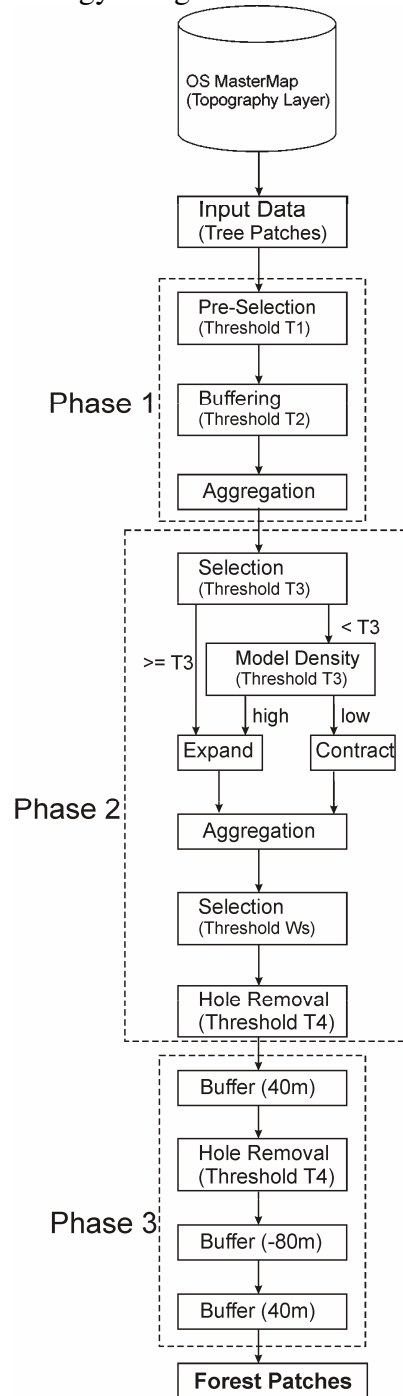


Figure 5: Different stages of the proposed approach for generation of forest patches from tree patches in the source dataset

Phase 1 - Pre selection and union

We sought to make the problem scalable since a pragmatic solution was required that was capable of handling large number of polygons. Original tree patches in the source dataset included a large number of very small patches, which were deemed not useful to a generalized solution and created high processing overheads. Therefore those patches below threshold T1 were eliminated. Next, patches within a certain distance threshold were aggregated together. To achieve as much aggregation as possible, all patches were buffered by a small threshold (T2) and the resulting overlapping patches were aggregated. This data pre-processing reduced the total number of patches

entering the second and main phase of the algorithm by up to 90% (depending on the amount of fragmentation and the density of patches). The result of this first phase is illustrated in Figure 6.



Figure 6: Output generated from phase 1 (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved)

Phase 2 - Forest-Patch generalisation

Phase 2 represents the most important phase, in which any patch larger than $T3$ is expanded by a blanket width defined by Equation 1 (Müller and Wang, 1992).

$$\text{Blanket Width: } t_i = (c_i)(K)/\sqrt{|a_i - T3|} \quad \text{Equation 1}$$

where K is the constant for scaling the blanket width

$$K = t' / \sqrt{(Max - T3)} \quad \text{Equation 2}$$

t' = Constant (the larger the scale reduction, the larger the constant should be)

Max = Maximum patch area of the input data

$T3$ = Threshold area determining expansion or contraction

c_i = Compactness of tree patch a_i , where

$$c_i = a_i / (p_i / 4\pi) \quad \text{Equation 3}$$

a_i = Area of patch i

p_i = Perimeter of area a_i

π = Mathematical pi

The objective of the next step was to ‘promote’ small tree patches if they are part of a dense region. This was done by subjecting any patch that was below an area threshold, T3, to a ‘density check’. For each such tree patch the summation of area of all tree patches that were within a given distance (set to 50m) of that patch is calculated. This summation area indicates whether the patch is part of a collection of other small patches. If the summation is greater than T3, the patch is considered part of a dense neighbourhood and is therefore expanded using Equation 1. On the other hand if the summation area is below the threshold then the object is contracted by a blanket size, again calculated using Equation 1. This intermediate step ensures that clusters of small patches are retained.

The next step within this phase was to aggregate all the overlapping patches which resulted from the process of expansion or contraction. Any aggregated patch with an area less than Ws was removed. Finally, those forest patches that are retained are checked for ‘holes’ either created by eliminating very small patches in phase 1 or pre-existing holes within dense areas. Holes smaller than (T4) are filled. What remains at the end of this second phase is a set of large patches with small holes removed. The idea of elimination of small holes (below T4) and small forest patches (below Ws) is based on the idea that the generalisation process should lead to the elimination rather than addition of detail. Figure 7 illustrates the effect of phase 2.



Figure 7: The sub-stages of phase 2 (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved)

Phase 3: Simplification

The resulting forest patches tend to have sharp edges and may contain unwanted cavities that need to be simplified. A variety of line simplification algorithms exist (Douglas and Peucker, 1973; Visvalingam and Whyatt, 1993) though many do not guarantee topological integrity (two exceptions being the solution by Edwardes *et al* (1998) and Boffet (2000)). A simple but effective form of simplification that does not change the topology of the forest patches was one that involved large buffering operations (both positive and negative). It had the effect of cutting and smoothing sharp edges, as well as removing cavities. Firstly a large positive buffer of 40m was applied to eliminate unwanted cavities. Then, a large negative buffer of 80m was applied. This removed all sharp and thin protuberances. The final step was a second positive buffer of 40m to bring the patches back to their correct size. Figure 8 summaries the effect of this final third stage.

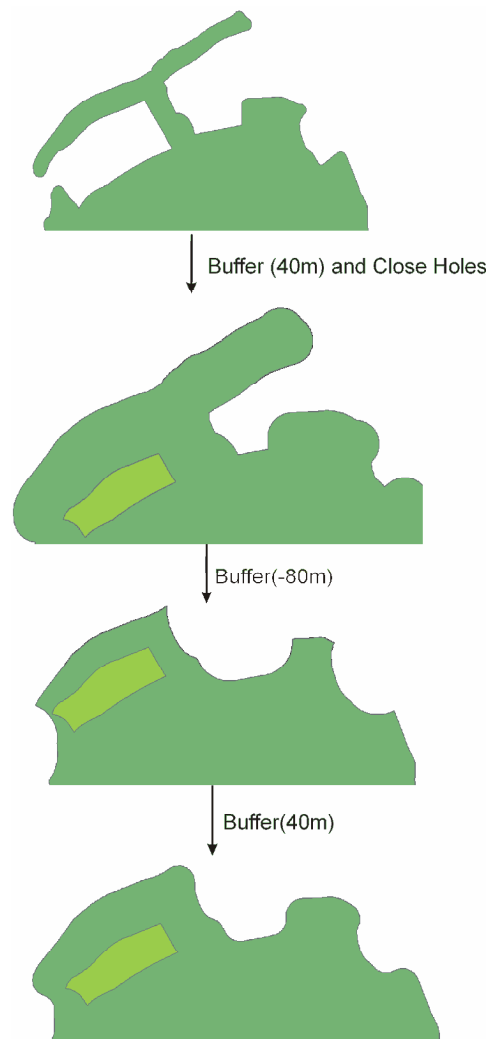


Figure 8: The sub-stages of phase 3 (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved)

MODEL IMPLEMENTATION

The entire model was implemented using the Eclipse Java development environment and the Java programming language. The Java Topology Suite's (JTS) libraries provided important methods such as the buffering, calculating distance between patches and aggregation of overlapping patches. JUMP (Java Unified Mapping Platform) is an open source workbench that provides a graphical user interface (GUI) used to visualise and manipulate spatial datasets (<http://www.jump-project.org/>). JUMP libraries were used to retrieve specific methods and classes. ESRI ArcGIS and MapManager version 8 were used for initial data processing of OS supplied data and for creation of the output.

Web Generalisation Services

Several researchers in recent years, have highlighted the value of making generalisation algorithms available via web generalisation services (Burghardt *et al.*, 2005; Neun and Burghardt, 2005; Foerster and Stoter, 2006; Edwards *et al.*, 2007). The idea is that these services provide generalisation functionality via a web-accessible interface in a platform and programming-language independent way. These services allow for the sharing of generalisation algorithms not only within the generalisation research community but to GIS developers and to those involved in other areas of research in GIS such as web mapping, geo-visualisation and location based services (Edwards *et al.*, 2007). These services allow comparison of results from different generalisation algorithms. Such a comparison is considered to be more appropriate as compared to comparison with manually generalised products (Harrie, 2001).

‘WebGen’ is one such example of a framework developed to access and provide generalisation services over the internet (Neun and Burghardt, 2005). It has been developed by Moritz Neun and Dirk Burghardt at Zurich University. It uses HTTP and XML (SOAP) for the data-exchange. The geometry of the input features is encoded in GML format and non-geometrical attributes are encoded as text in XML format. The client does not need to download the algorithm but needs to select the appropriate algorithm from the available list, provide necessary parameter values and the input data. The algorithm runs on the server side and transfers the results back to the client. The algorithms currently available include line and polygon smoothing, simplification, displacement, triangulation and a few evaluation algorithms. For the latest list of available algorithms see http://www.ixserve.de/pub_whatismwebgen.php. The algorithms developed in this research is now available as part of the WebGen service. The relevant algorithms are PatchesGeneralization and PatchesGeneralizationZH. Information on how to install the WebGen plugin in JUMP is given at <http://www.geo.unizh.ch/~neun/webgen/>. In order to utilise these algorithm, the client uses the provided client interface to transfers the input data (tree patches in this case) across the web to the server together with their own threshold values. The server will then run the algorithm and transfer the result of the generalisation back to the client.

CASE STUDIES

The test region was divided into two case studies. Figure 9 shows output from the algorithm for the data shown in Figure 2 (the two are overlaid in order to facilitate comparison). The algorithm was applied to a second geographic region (completely independent of the first) without any adjustment being made to the parameters. Though the shapes and densities varied from the first case, the results were very encouraging (Figure 10), with sensible grouping, retention of large regions, and removal of small forest patches.



Figure 9: Input (Figure 2) and output forest patches from the forest patch algorithm (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved)

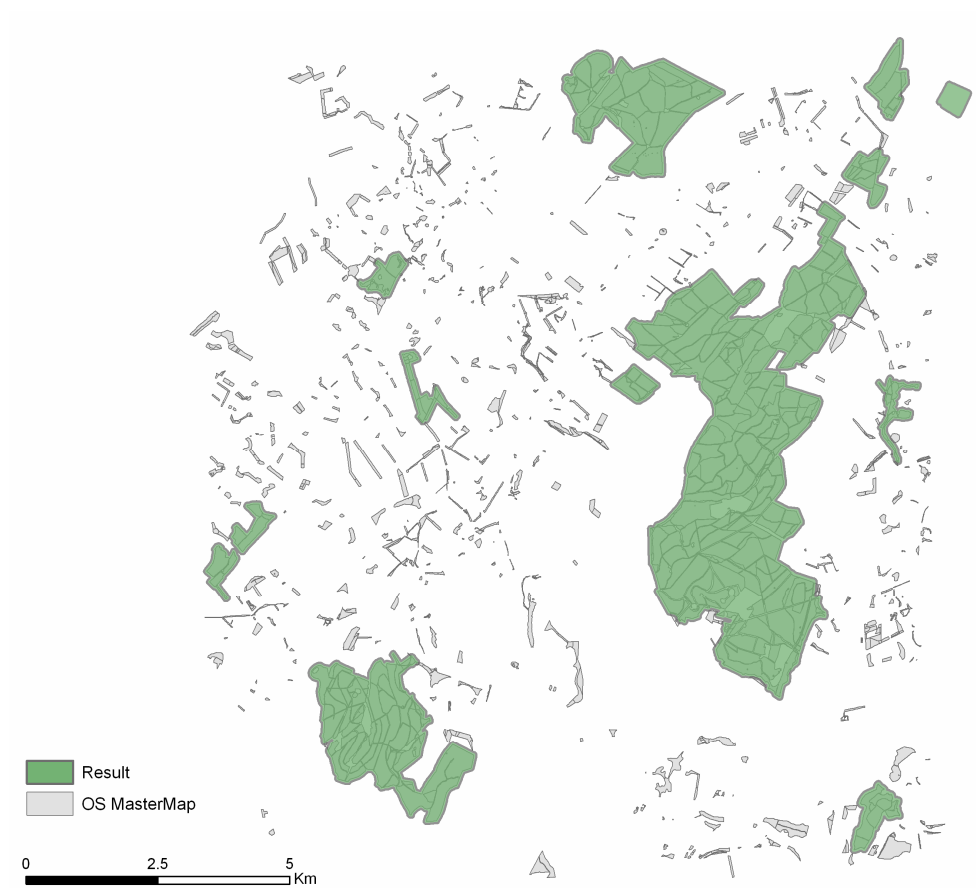


Figure 10: Output overlaid on the original input data (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved)

EVALUATION OF THE SOLUTION

Evaluation was achieved firstly by a direct visual comparison between the output and the Strategi data (Figure 11 and Figure 12 show the results overlaid with Strategi data). As observed, the proposed approach produces similar results as those achieved by manual generalisation, and was successful in selecting all the important tree patches, and creating large unified forest polygons from them. The slight mis-registration between the two arises from the relatively poor locational precision of Strategi data which has arisen from small amounts of displacement made by cartographers in order to improve the clarity of the map. Quite independent of the results from the algorithm, it is interesting to note the difference between the source dataset and Strategi data (Figure 13), which highlights the difference in the currency of the data (forest growth and clearance since Strategi was created).

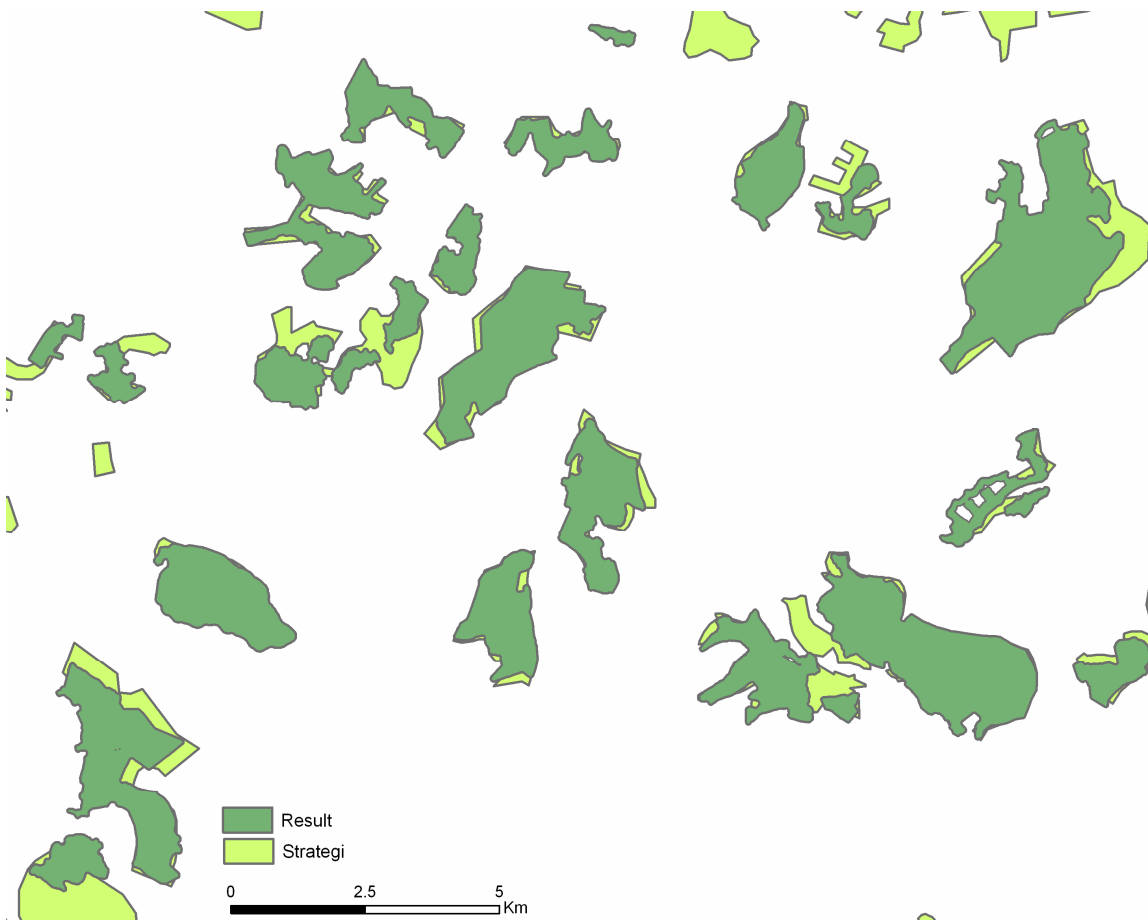


Figure 11: Output from the algorithm overlaid with Strategi data for case study 1 (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved)

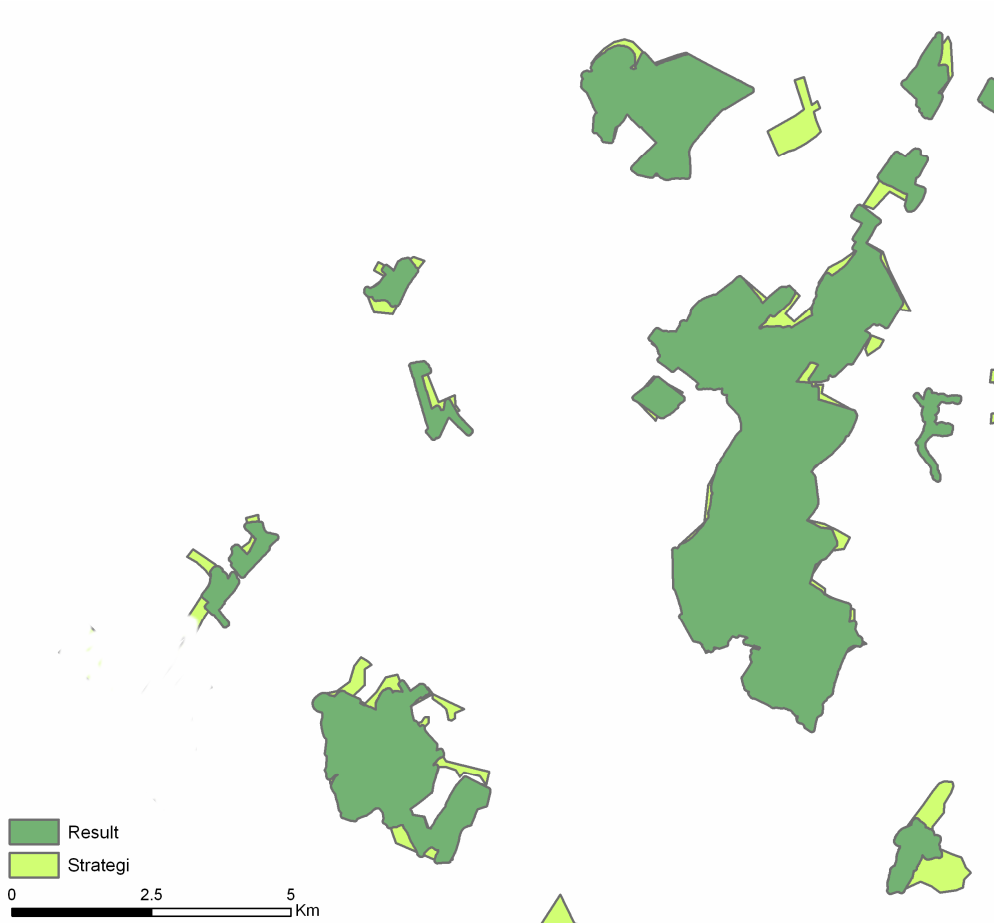


Figure 12: Comparison of output with Strategi data for case study 2 (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved)



Figure 13: Significant differences between the Strategi and the source data because of displacement, classification error, and change of landuse between updates (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved)

Table 1 illustrates the quantitative evaluation in terms of ‘global reduction’ (Richardson, 1993). It presents the total number of tree patches in the source data, for case study 1 and 2, and the total number of forest patches in the resultant data. This is compared against the number of forest patches in the Strategi dataset.

Table 1: For each of the two case studies the table shows: the number of tree/forest patches in the source dataset, in the results and in the Strategi dataset

Total Patches	Case Study1	Case Study 2
OS MasterMap Topography Layer	1488	3020
Total forest patches in the results	25	13
Total forest patches in Strategi	23	14

Expert’s view

The results were also examined by cartographers and the generalisation team manager at Ordnance Survey. In response to a set of questions, they commented that “whilst the algorithm has performed well, there are slight question marks concerning the minimum size threshold” and that “although the granularity obtained was adequate, the outlines could be simplified slightly more”. Some comments related to specific cases: “I’ve noticed a particular case on the left edge of the figure, the patch in the middle has been ‘filled’. The filled area is actually much larger than the two narrow strips of forest that surround it. So I prefer the way it’s done in Strategi.” Some comments acknowledged deficiencies in Strategi: “Apart from these two points, the results are very good. I would not worry about the differences with Strategi. Strategi is a generalised product, and there is not one right generalised representation, there is a wide range of acceptable ones. It’s more important to compare it with the source data, and see how it fits with the other generalised features.”

When comparing output (as part of the evaluation process) it is easy to be drawn into the detail and to identify some forest patches that have sharp or rather jagged boundaries that warrant further smoothing, as well as further removal of cavities. But it is always important to remember that these results are intended for display at 1: 250 000 scale (Figure 14). At this scale the discrepancies identified at the fine scale are no longer discernible. It is important to remember that the algorithm is attempting to characterise a region by creating a more generalised form. The layer becomes but one component, combined with other classes of objects (such as in Figure 1). In this regard, precision constraints become more relaxed at smaller scales. It is therefore argued that evaluation of any form needs to be considered in anticipation of the intended scale and the context of use, rather than slavish comparison with the detailed input data.

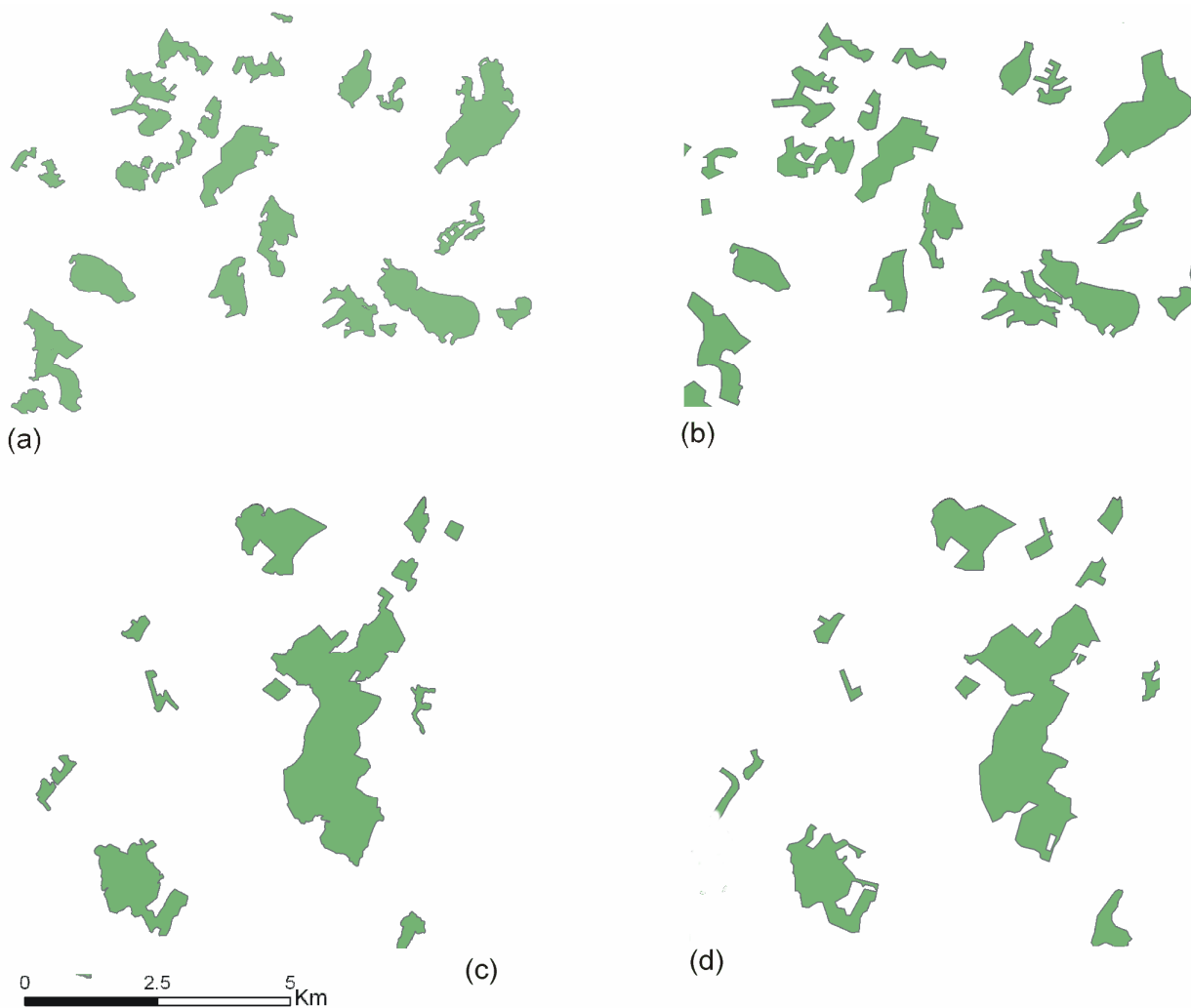


Figure 14: Spot the difference: Outputs (a and c) from the proposed methodology and from Strategi (b and d) (Mapping is Ordnance Survey ©Crown Copyright. All rights reserved)

Processing time, data volumes and further work

A pragmatic solution is one that can handle large datasets in a timely manner. Though the initial steps in the methodology (merging of very small polygons) led to a huge reduction in processing time, the algorithm could not be used in real-time principally because processing of such large data volumes required large amounts of memory. For the computer used (Pentium 4, 2GHz CPU and 1 GB RAM) it took between 1 and 2 minutes to process 300 tree patches. Memory management problems meant that no more than 2000 patches could be processed at any one time. It is proposed that this algorithm should be implemented using a spatial database management system (DBMS) such as Oracle Spatial 10g. Such a DBMS offer spatial indexing routines that enhance the performance of various spatial functions (Kothuri *et al.*, 2002).

It is argued that the general principles of this algorithm could be used as a framework for the generalisation of other land use types. Improvement to the simplification and smoothing of patches is one of the priorities for any future work. In addition scalability issues have to be explored since the performance of the algorithm is not satisfactory for large datasets. This effort would include development of methods for partitioning the datasets, possibly by clustering or by compartmentalizing the dataset using the road network (OS ITN dataset), and then processing the resultant patches on a regional basis. It would also be interesting to assess the suitability of this approach in order to create forest patches at other levels of detail such as 1:50 000 and 1:100 000 scale.

CONCLUSION

The research is part of the long term research in pursuit of systems capable of generating multi scaled maps from a single detailed database with minimum human intervention in the map compilation process. This paper has proposed an automated solution for forest patch generalisation based on an algorithm involving selection, aggregation, elimination and buffering of forest patches. The two case studies confirm the general applicability of the algorithm and point to future work. By making this algorithm available via the WebGen service, it is hoped that other researchers can make further improvements to the algorithm and that by sharing code in this manner, further evaluation can take place, hopefully by comparison with alternative solutions.

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