This month’s topic: Generalisation of Spatial Information

Last month, I discussed the concept of a “Generalised Repository”, containing spatial information at a wide range of scales.

This month’s topic goes deeper into the process of generalisation. This can be loosely defined as the art of reducing the scale of spatial data.

The reason for this further discussion is that there was a “Dagstuhl Seminar” on the subject this year, and I have been scanning the materials presented there. They can be found at http://www.dagstuhl.de/Materials/index.en.phtml?09161. Some additional materials from a seminar in 2006 have been useful. See also: http://www.dagstuhl.de/Materials/index.en.phtml?06101.

Scale

To recap, the scale of a map is the ratio of distances on paper to the distances of the real world objects being mapped. For example: a scale of one to 250,000 indicates that 1 cm on the page is equivalent to 250,000 cm (or 2.5 km) on the ground. The term “small scale” is used for cases where a small amount of paper is required to represent a region. Large scale requires a larger sheet of paper. Thus 1:250,000 is small scale, 1:2500 is large scale.

It might be thought that the concept of scale does not apply to spatial data in a computer representation, but this is far from the case. There is a maximum amount of magnification that can be allowed on a screen presentation before the result is meaningless, or even worse - wrong.

Figure 1 A useless map - zoomed in too far

1 Dagstuhl Castle is the home of the Leibniz Centre for Informatics. It is funded by the German government, and hosts a continuous series of seminars designed to allow researchers in IT related topics to meet and discuss. The seminars focus on current research rather than being “show and tells” for completed projects.
It is less obvious that there is a minimum level of magnification that can be applied to spatial data to view it on a screen. For example, zooming out on a keymap can result in a hopelessly cluttered screen with no useful information being

![Figure 2 Another useless map - this time too much information (badly misused Google Earth)](image)

**Why Do It?**

It is probably too late to ask this questions – we have been doing generalisation since Mercator was a lad. When Cook sailed around New Zealand, he produced highly detailed charts of the coast, giving information about how to enter the harbours, where to collect water, depths of anchorages and very accurate shapes of the capes and bays. He also was able to picture for the first time what we now instantly recognise as the shape of New Zealand. This was what we now call “generalising”.

To be more specific, this topic is computational generalisation, or at least computer-assisted generalisation.
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What are the Issues?
As Andrew Frank describes the problem (Frank 2009):

Assuming we want two maps at different scales, (and assuming the classic air-photo approach), we could fly a high resolution series of photos, and identify the objects in these photos to produce a map (series) at this scale. We could repeat the whole process using lower resolution photos (e.g. flown at a higher altitude) to produce a small scale map (series).

To avoid the cost of flying a second series of air photos, we could simply down-sample the high-res ones. This is a well known procedure and produces good results. It could be expected that the resultant map M2 would be indistinguishable from the one produced in the direct approach of Figure 3.

It would be far more efficient if a computerised process could convert directly from M1 to M2, as depicted in Figure 4. This is the process of generalisation, and would have the advantage of saving the manual effort of converting from image to map.

Unfortunately, this has proved to be difficult, and is seen as an “artificial intelligence issue”.

This is not as bad as it seems, as Frank points out. The difficulty in generalisation is largely a result of thinking in terms of producing a “general purpose map”. The sort of
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thing we would go to a shop and purchase for hiking, air navigation, or deciding where we want to live, etc\(^2\).

If we include the end user in the picture (Figure 4), the problem does not seem so daunting.

![Diagram]

**Figure 5 The user included**

Provided that the action\(^3\) taken as a result of the decision based on the information presented to the user is the same, it does not matter which path the information has followed to get to the user. Neither does it matter if the “small scale presentation” that the user sees is the same in each case.

Getting the appropriate information to the end-user is the aim of the exercise, and it is likely that model and cartographic generalisation routines can be developed to assist with this.

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\(^2\) This sentence illustrates the issue well. It is hard to imagine using the same map for these particular purposes. In face, the whole concept of a “general purpose” map is losing currency. Note that the original purpose of “Ordnance Survey” maps in Great Britain is indicated by the name – they were designed for use in aiming cannons in time of war. All the other uses have followed incidently.

\(^3\) Such as “turn left here”, “build our house here”, “excavate 1000 tonnes of rock from here and put it there”.

Rod Thompson 4 May 2009
As can be seen in Figure 6, although the result of automatic generalisation is different in appearance and in the actual information portrayed, the map is quite useable. (Unless we wanted to find the school or cemetery).

Referring again to Figure 5, a question is raised here as to what should be stored. Do we store the models M₁ and M₂, the presentation details N₁ and N₂, or only some of these. This is a significant question in itself.

**Tools of the Trade**

Many techniques have been developed, and are being further refined. The following is a selection from the methods to illustrate the processes. It is probably not complete, and the list may grow in the future.

**Feature Simplification**

This is probably the most basic requirement in generalisation. Where a large scale feature is to be represented at a small scale, the amount of data used to define it can be reduced. For example, if a coastline is represented as a linestring, and is displayed at a much smaller scale than appropriate, it takes on a thick “blurred” appearance. By reducing the number of points, a better appearance is obtained, and the storage and bandwidth requirements are reduced.

The key to successful simplification is to remove points that are not significant. For this there are several well known algorithms – the Douglas-Peucker (Douglas and Peucker 1973), and the simpler (and faster, and not much less effective) “tunnel algorithm.”
Figure 7 Simplification of linear features

Briefly, the Douglas-Peucker algorithm starts from a straight line from A to B, determines which point is most significant (the one most distant from the straight line), and breaks the straight line there. It then repeats the process for the resultant lines until no point is further than \( w \) (the tolerance).

The tunnel algorithm starts from A, and continues along the line as far as it is possible to go such that if there was a tunnel of width \( 2w \), all the points would fit within it (the dotted rectangles in Figure 7). This algorithm is much faster, but does tend to move the features of a line slightly towards B.

For area features, there is an additional complication. It is possible to use either of the above algorithms to remove points from the boundary, but this can lead to “topology breakdowns”.

Figure 8 Introduction of topological errors through generalisation

Significant work has been done on this issue, detecting and removing the effects.

**Geometry Collapse**

The next major form of geometric conversion is the reduction of a geometry into a simpler form – e.g. an area feature into a line, or a point.
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Figure 9 collapsing a river and a town from area to line and point features

This is a relatively simple and well understood procedure, but requires some knowledge of the type of feature to produce a clean and useful result. (See below).

**Semantics and Ontology**

The techniques discussed so far have been simple geometry, with little or no meaning being assigned to the objects. In order to go further, it is necessary to know something about the features.

**Feature Suppression**

One specific case is in the simple suppression of features. This is far more effective if some semantics are available. For example, if we have a number of small buildings scattered around in a rural area, we can drop some of them. It would be far better to retain a rural fire headquarters even if it is a smaller building than some of the nearby houses.

**Hydrology**

1- Collapse and classify

2- Prune and smooth

**Figure 10 Pruning of river networks. Nicolas Regnauld (Dagstuhl 2006)**
As a second example, if we have a drainage pattern with major rivers, minor streams flowing into them, and smaller creeks and gullies at the headwaters, as we decrease the scale, the less important features can just be dropped. The same can be true of roads, with the minor roads being dropped first, then connecting roads, leaving major highways.

But the processing of roads and rivers is not the same. An issue arises in Figure 11 with the road network breaking up because a major road feeds into minor roads, and is thus left hanging. Different rules apply to different feature types, and so it is important to know as much as possible about the features. The name of a feature is useful in some cases (“… Road” is usually a more important feature than “… Street”), but sometimes other attributes are helpful (such as the population of a town).

**Combining Area Features**

Where a set of area features cover all or a large part of a region, there is often a need to combine features. This may be because the features simply are too small to be significant, or because at the smaller scale, they are not sufficiently different in nature to be interesting.
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Figure 12 Combining area features. In case on the left, small areas have been dropped. On the right, areas of similar type have been combined.

These cases are quite different in practice, and are strongly dependant on the feature types. For example, it may be in order to omit small clearings out of a forest, but if we are dealing with small regions of settlement in an otherwise featureless region, then it may be better to replace them with point symbols.

An example of the case on the right in Figure 12 might be regions of scrubland being dissolved into a forest region.

Figure 13 Aggregation of areas in practice Jan-Henrik Haunert (Dagstuhl 2009)

Grouping Features

It is often best to replace a set of features with a single representation. A good example of this is a set of buildings grouped to form an urban conglomeration. Here again, the semantics are important. If we know that the features are houses, then they group to form a suburban area, if factories, then an urban area. Conversely, the
location of the objects affects the form of the grouping. Houses within a town are better handled in a different way from houses in rural areas.

Also, the nature of the feature can have a major effect on the process. For example, a building which is an ambulance station should not just be dissolved into adjoining buildings, but should be symbolised to make it stand out.

This is an area which is being researched at present – in an attempt to define and satisfy its often contradictory requirements and constraints.

**Building generalisation in urban areas**

1. Identify clusters
2. Identify the shadow lines of the clusters on the roads
3. Buffer these shadow lines
4. Extend the buffers to include the remaining buildings

**Ontology**

The above examples have a common thread. They all require us to know about the features, and how those features are related to one another. For example:

- We can dissolve scrubland into forest because they are similar regions.
- We can group houses into suburban areas because we know that a suburban region is defined as an area of housing.
- We know that a small clearing in a forest is not particularly significant.
- We know that an ambulance station is a type of building, but also that it has a distinguishing factor that makes it important.

Indeed, it is argued that “Generalisation is an ontological problem” (Werner Kuhn, Dagstuhl 2009). It is certainly true that the more we know about the features, the better job we can do – either manually or automatically. The current research is into ways of capturing the necessary concepts in a machine processable form.
Generating Semantics from Geometry

This turns the problem around. We need to know what type of feature a mark on the map represents. As humans, we are quite good at doing this. For example, a wriggly blue line is a river. A black rectangular blob at the end of a long minor road is a house or a homestead.

Some research is going on in this area, where little apart from the shape is available in the data, and an attempt is being made to recognise what type of feature the shape represents. For example (unfortunately not a very useful example for Queensland), a series of buildings on small parcels of land that adjoin in rows (and fulfil certain other
criteria) are probably “terraced houses”. Note that here, knowing just that they are buildings (by the colour of the rendering) it is possible to infer from the shape and location that they probably represent houses, and that the region is a residential area.

Having decided a feature type, this can be used to guide the next phase of the generalisation process. In the case of the terraced houses, they could then be grouped into a single feature – “row of terraced houses”.

**Cartographic Generalisation**

In addition to the processes above, which transform the storage representation of objects, there are a number of cartographic actions that are used to present a map in a human readable form, so as to allow more information to be visible in a small space.

These include such techniques as:

- The moving of objects from their correct position to a nearby location, where they are more readable (e.g. where a road, phone line and a railway line run parallel, but are too close together to be separated).
- The careful placement of text to avoid “collisions” with other text, and to avoid obscuring the detail of the map;
- Widening linear features (such as roads) to allow text to be placed within them.

This subject is characterised by conflicting constraints and objectives. The facts that are being presented must be maintained, but the presentation should be readable.

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**Figure 17 Some of the techniques of cartographic generalisation (William Mackaness, Dagstuhl 2009)**

Cartographic generalisation is probably the most difficult part of the automatic production of maps from larger scale source data, so it is tempting to consider storing the enhanced “map” data – the re-positioned features in their enhanced form. This is argued against by Peter van Oosterom (Dagstuhl 2009), based on the experience of
building IMTOP (Stoter et al. 2008) the Netherlands Cadastre’s multiple scale topographic database.

Data Structures for Generalisation

Tin last month’s discussion of a “Generalised Repository”, where the features are represented at several scale levels, it was suggested that the representations be stored in separate relational tables. This is a very basic approach, containing partially redundant data.

There are more sophisticated approaches being investigated, which combine the storage and indexing methods to allow a single representation of each feature, while keeping the speed of access and retrieval. One of these is the tGAP structure, which, in effect, presents a coarse representation of the feature, and subsequently refines it until the required scale level is reached (van Oosterom 2005). By contrast with the generalised repository approach, each feature is stored in only one place in the database, so there is no storage redundancy.

3D Issues

Many of the above issues apply equally to 3D data, albeit with the usual increase in complexity.

The major difference is that in a 3D rendition, there are mixed scales – foreground to background in the one view of the data. In taking an oblique view of a region, (for example in viewing a 3D city model), there will need to be highly detailed rendering of objects in the foreground, but in the background, there may be thousands of objects visible. These background objects need to be rendered at a reduced level of detail.

I hope to return to this topic – 3D “city” models, and CityGML in the future.

Non Vector Data

So far we have been discussing vector data, but that is not the only way of storing spatial information. Field data can be used to represent the value of a function at points in space. Some examples are:

- The elevations of a land surface stored as a DEM (Digital Elevation Model).
- Elevations stored as a TIN (Triangulated Irregular Network).
- The percentage of a mineral in rock at each point in a 3D geological formation.
- The air temperature in the 3D space above a town.

The above are all scalar fields, meaning that they assign a single (“scalar”) value to each point in space, but vector fields can also be represented:

- The wind strength and direction above the town.

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4 The use of the term “city” is perhaps unfortunate. While initially, the major use of this technology was in representing high-rise buildings in urban areas, it has spread well beyond that use now.

5 “Raster” is only a storage mechanism based on storing a line of “pixels” or cells at a time. The more general term used here is “field data”, in the sense of a magnetic field.
The set of translation vectors used to go from AGD84 to GDA94.

Field data can be generalised, and work is proceeding on this topic, but it is outside the scope of this discussion. Some information can be found in the slides of De Floriani in Dagstuhl 2006 and 2009.

**Summary**

There is much research still going on in this field, and results can be expected to improve over the years, but the situation at present is that useful functionality is available to produce valuable representations of spatial information at scales that are appropriate to their intended use.

We cannot now, and perhaps never will be able to produce “cartographic quality” results that are indistinguishable from those produced by experts in the field, but, as has been proved by Ordnance Survey in the UK, and IMTOP in the Netherlands (amongst others), a product can be made available that has strong user acceptance.

The SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis by Robert Weibel (Dagstuhl 2009) provides an interesting view of the current state of play.

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Douglas DH, Peucker TK (1973) Algorithms for the Reduction of the Number of Points Required to Represent a Digitized Line or its Caricature. The Canadian Cartographer **10**, 2:

