FIRST ATTEMPTS TO AUTOMATIZE GENERALISATION OF ELECTRONIC NAVIGATIONAL CHARTS – SPECIFYING REQUIREMENTS AND METHODS

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ABSTRACT

Automatic generalisation has now a decent history, yet there are no attempts to apply its principles to marine application. This paper summarizes a project that was carried out to create Electronic Navigational Charts of one scale from ENCs of a more detailed scale by means of automatic generalisation.

1. INTRODUCTION

One of the major tasks of Hydrographic Offices is to produce Electronic Navigational Charts. ENCs are file based vector datasets based on the IHO S-57 Standard. Those charts are similar to paper charts and have a similar purpose but they can carry a lot more information. They can be displayed on Electronic Chart Display and Information Systems (ECDIS) to combine data from multiple sources: ENC, Radar, and Automatic Identification Systems (AIS). While National (Land) Mapping Agencies developed their own domestic rules for generalisation, Hydrographic Offices, united under the auspices of the International Hydrographic Organization, create products based on the international standard S-57 (to be replaced by S-100)[1]. In addition, rules, or at least guidelines for hydrographic offices, are centrally created by the IHO. This opens possibilities to create a uniform generalisation workflow for charts around the world.

The goal of the research presented in this paper was to define computer translatable rules that allow creation of smaller scale ENCs from a higher scale ENC / S-57 database with minimal human intervention.

To realise this, requirements of HOs in conjunction with the guidance already contained in S-4 [2] are combined with knowledge in model and cartographic generalisation of topographic maps. The problem was narrowed down to two usage bands. Approach band data (1:22000 – 1:89999 scale) was generalised to the destination usage band – Coastal (1:90000 – 1:349999 scale). The scope of the project was limited to Geo type of features. Generalisation of Meta objects was not considered. This is due to the fact that Meta objects either cover the entire area or large portions of the chart or are related to Geo objects. Collection objects do not have spatial component and are relations between Geo type of objects.

Also generalisation of bathymetry was not tackled. Bathymetry plays an important role on a chart, but it is a mathematical model of a bottom depth approximations managed separately before the final depth areas, contours and sounding selection can be used for production. The efforts to obtain

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[1] www.iho.int

[2] Special Publication no. 4 Regulations Of The IHO For International (INT) Charts. International Hydrographic Organisation, Monaco.

the highest level of safety should not be spoilt by performing hasty generalisation transformations.

This paper summarises the methodology, the case studies, the results, the conclusions and further research in respectively sections 2 till 6. More details can be found in Socha (2012).

2. METHODOLOGY

The methodology consisted of the following steps:

1. Data collection
2. Visual inspection
3. Survey no. 1 Qualitative Research
4. Synthesis of available information
5. Experiments – Multiple trials
6. Survey no. 2 Evaluation

These steps are detailed in the remainder of this section.

Data collection

Because this is one of the first times automated generalisation is considered for marine maps, the initial stakeholders' base was approached via an e-mail and in person during one of the IHO user group meetings. Collaboration was established with four hydrographic offices – Brazil, France, The Netherlands and New Zealand. Once the stakeholders confirmed their participation e-mail request was sent to provide one or more Coastal scale ENC produced by the organisation and one or more Approach ENC covering the same area.

Data specifications were downloaded from the official IHO webpage. Other materials consisted of manuals, textbooks published on the internet, navigation, hydrography and GIS course materials and private professional library.

Visual Inspection

Datasets were loaded into an S-57 compliant software and overlaid. Transparency and thematic layers were used to facilitate the inspection. Statistical information available in the software was used (feature count) to select classes of interest. Open mapping services were visually examined and encyclopaedic knowledge in geography used to understand chart content. Visual inspection was complemented with the study of technical documentation indicating safety relevant objects.

Survey no. 1 Qualitative Research

A questionnaire was created and sent out to the stakeholders to validate the visual inspection, to clarify ambiguous elements and to assess current production methods. The questionnaire was divided into four parts. General part contained questions about the producing agency (human-ware, software, charting responsibility). Chart Production section asked about current data production methods, data sources and production times. Questions in Data related section were derived from the previous step. This part contained an analysis of the data the organisations provided and these questions were customized for each participant separately. Last part – Automatic Generalisation (AG) was designed to confirm the current state of AG in the offices and examined if the organisations were interested in pursuing its implementation.

Synthesis of available information

To define the specifications reverse engineering was used. For this charts' structure and function were analysed. The function of charts was derived from literature, and their structure from the datasets themselves and from technical documentation. All this was collated with the findings from literature and returned questionnaires. Missing specifications were created by deduction. For this, ancillary documentation about navigation, radars, hydrography, cartography etc. served as important source.

Experiments – Multiple trials

Inspection of available generalisation methods and functions helped to match what needs to be done with how it can be done. Methods were tested on the datasets with the use of parameters derived from the specifications. Generalisation methods were cross-validated (if a method used worked on one dataset, remaining datasets were used to validate and calibrate the method). Effectiveness of a method was measured by visual and content comparison with the benchmark- original dataset. Where parameters in the specifications were derived from external official, documentation, results were accepted "as is", unless they greatly differed from the original dataset. Where hard values were deduced or results varied greatly, a sensitivity analysis aided to find settings best fitting the results to the original chart.

Survey no. 2 Evaluation

Resulting maps were visually inspected and initial evaluation performed by the authors focused mainly on similarities and differences between the resulting and original charts. The main differences or problems with generalisation were extracted with examples. They were put into the final evaluation questionnaire. The questionnaire consisted of three parts. Introduction part explained and justified the results. It provided a summary of generalisation methods and specifications used. Evaluation part started with an explanation of evaluation expected from the experts and rules of grading the results. Each class's evaluation was divided into four components: Safety of Navigation, Aesthetics, Usability and Efficiency versus effects. General comments concluded the questionnaire. Questionnaires were sent along with the resulting maps by e-mail.

Results of the questionnaires were collated, compared and summarized.

3. CASE STUDIES

The four datasets came from areas of a great topological and hydrographical variety. They show from the western coasts of the Atlantic (Brazil), via relatively closed and busy waters of the North Sea (The Netherlands), an island on the Indian Ocean (France) and finally the gates of the Pacific (New Zealand). All datasets were delivered in S-57 format.

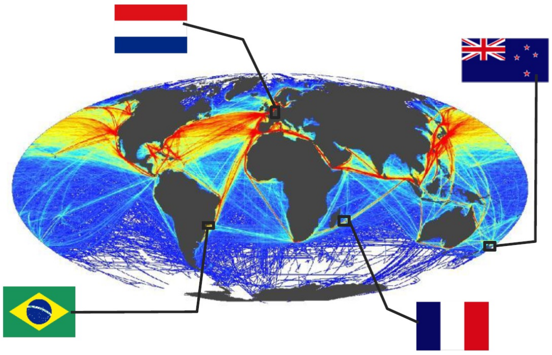


Figure 1 Locations of the provided datasets

The table below presents some of the particularities of the charts received. One should notice a variation in scale pairs and how charts focused on various themes or objects that were particular to their depicted area.

Country	Scale Coastal/ Approach	Location	Description
Brazil	1:180 000 1:45 000	Rio De Janeiro / Baía de Guanabara	Large near shore lagoons. Complex built-up area pattern.
France	1:180 000 1:60 000	Île de La Réunion	Volcanic topography. Concentration of fishing Aids to Navigation.
The Netherlands	1:90 000 1:45 000	Eurogeul / Maasgeul. Port of Rotterdam	Density of the traffic enforces creation of detailed, densely populated charts.
New Zealand	1:90 000 1:22 000	Approaches to Auckland via Hauraki Gulf	Concentration of underwater rocks and small islands.

Table 1 Source data description

4. RESULTS

The research identified patterns and presented an automatic generalisation solution for nine groups of objects: Aids to Navigation, Landmarks, Wrecks, Underwater Rocks, Land areas, Coastlines, built-up areas, Obstructions and Miscellaneous. Proposed generalisation solution comprised of specifications and rules, standardisation requirements, conditions and finally proposed and alternative generalisation methods. Specifications can be loosely grouped into those that focused around:

- selection methods,
- class transformations,
- geometry transformations.

Selection, De-clustering, Removing redundant objects, Aggregation, Simplification, Collapsing, Creating feature based on geometry, Buffers, Assignation of attributes and Enlargement were the main methods used.

Main problems were the need for further manual editing, lack of patterns, "safety" constrains not maintained or impossible to execute and discrepancies between charting practices.

Four Coastal ENCs were created based on the solution and the results were evaluated both internally and externally by the HO's experts. Most of the outputs scored positively (above 6, see Figure 2) with comments describing the results as "promising" and "encouraging".

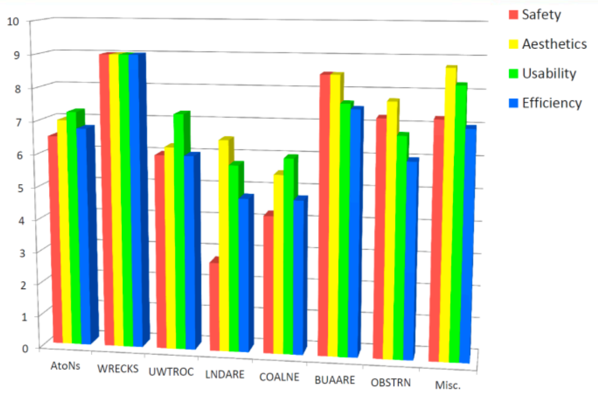


Figure 2 Column chart presenting averaged scores in four categories for each generalisation group

- Aids to Navigation

Generalisation was semi-manual due to lack of existing tools necessary to perform it automatically. It was based on sub-layers and attribute based selections. Generalised AtoNs are more accurate than their paper chart digitized equivalents due scale independence. Also the approach is more logical preventing various levels of detail due to subjective cartographic interpretation.

The algorithm was not perfect as it didn't recognize main land. The specifications state that AtoNs surrounded by land (like those in closed bays or lagoons) shouldn't be kept, but this constraint was difficult to model. Also, as generalisation approach was not interdependent when an island is collapsed into a point, an AtoN that is not positioned in the centre would be located on water and thus subject to different generalisation rules.

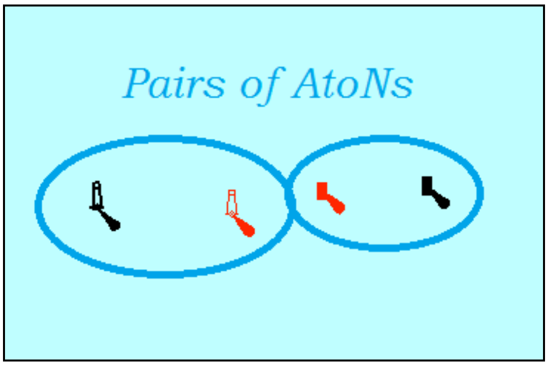
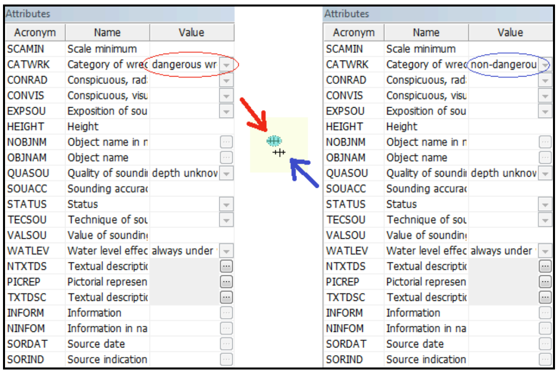


Figure 3 Generalised AtoNs are more accurate

- Wrecks

Generalisation was semi-automatic with the aid of attribute based selections and buffers. An automatic tool can replace human interaction. Similarly to AtoNS, generalised WRECKS benefit from a more accurate position and consistent attribution. Further testing is required to verify whether it performs equally well in other areas.



Attributes

Acronym	Name	Value
SCAMIN	Scale minimum	
CATWRK	Category of wrec	dangerous wr
CONRAD	Conspicuous, rad	
CONVIS	Conspicuous, visu	
EXPSOU	Exposition of sou	
HEIGHT	Height	
NOBJNM	Object name in n	
OBJNAM	Object name	
QUASOU	Quality of soundi	depth unknov
SOUACC	Sounding accura	
STATUS	Status	
TECSOU	Technique of sou	
VALSOU	Value of soundin	
WATLEV	Water level effec	always under
NTXTDS	Textual descripti	
PICREP	Pictorial represen	
TXTDSC	Textual descripti	
INFORM	Information	
NINFOM	Information in na	
SORDAT	Source date	
SORIND	Source indication	

Attributes

Acronym	Name	Value
SCAMIN	Scale minimum	
CATWRK	Category of wrec	non-dangerou
CONRAD	Conspicuous, rad	
CONVIS	Conspicuous, visu	
EXPSOU	Exposition of sou	
HEIGHT	Height	
NOBJNM	Object name in n	
OBJNAM	Object name	
QUASOU	Quality of soundi	depth unknov
SOUACC	Sounding accura	
STATUS	Status	
TECSOU	Technique of sou	
VALSOU	Value of soundin	
WATLEV	Water level effec	always under
NTXTDS	Textual descripti	
PICREP	Pictorial represen	
TXTDSC	Textual descripti	
INFORM	Information	
NINFOM	Information in na	
SORDAT	Source date	
SORIND	Source indication	

Figure 4 Inconsistent encoding between Approach (red)and Coastal (blue) cells

- UWTROC

Generalisation was done manually with the aid of filters and selection tools. No human interpretation was applied; specifications were executed as a computer would execute them. Objects were once again proven safer and more accurate, but this, occasionally led to clusters of UWTROCs in densely populated areas.

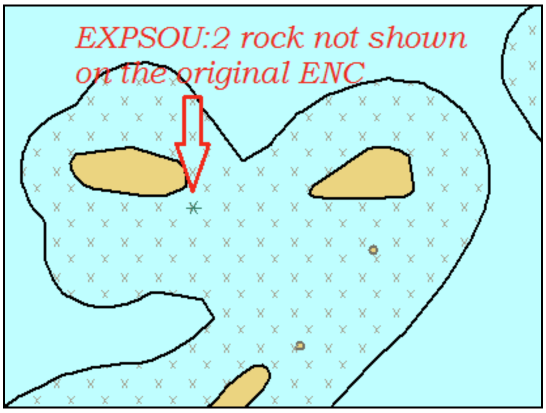


Figure 5 Example of UWTROC generalisation

- LNDARE

LNDARE was entirely generalised by means of a model created out of various cartographic and not only operators. Although the algorithm smoothed and collapsed land areas according to specifications found in literature, all producing agencies were unanimous- the generalisation should be only in one direction – seaward.

- COALNE

COALNE was created semi-automatically; the only manual operation was to assign attributes based on automatic selection, which could be automatized too. The lines are created as outlines of the generalised land areas and attributed based on buffers from the original datasets. Although the method is effective in most cases, it occasionally produces short edges that need to be manually merged (see figure 6).

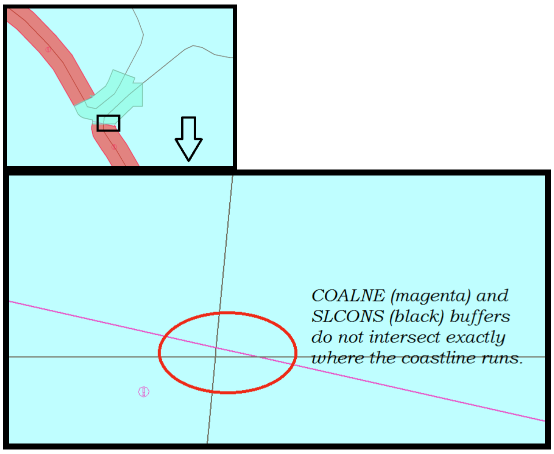


Figure 6 Short edges effect

- BUAARE

Built-up areas were entirely generalised by means of a model. This usually proved to work well and delivered satisfactory results, but where road network pattern was used to depict the extents of a city and a city itself was encoded as a point, the algorithm wouldn't work properly.

- OBSTRN

Generalisation was based on buffers which gave a good level of safety and also assured consistency between Approach and Coastal charts, however a truly safe approach should be more "intelligent". Instead of buffers , surrounding bathymetry and other conditions should be used as constraints . This was outside of the scope of the project.

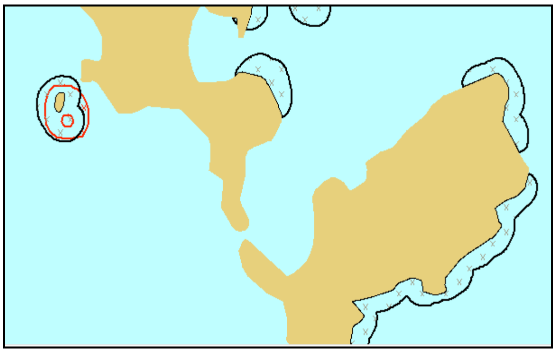


Figure 7 Example of many OBSTRN areas created in place of one on the original chart

- Miscellaneous

Miscellaneous object were compared between scales and simply copied to the target dataset where a pattern was found. This was a manual work imitating the use of scale-less layers.

It was possible to create satisfactory generalisation rules for eight out of nine chosen object groups. Rules created for one of the eight groups – Land areas did not meet the requirements (mainly Safety of Navigation) of the nautical experts and need to be revised. Evaluation of rules for creation of coastlines suffered due to a close link with Land areas. Experts evaluated the outputs based on the unsatisfactory land generalisation, not the method used to create them, which itself might give satisfactory results provided the associated land areas are generalised correctly.

This project could not produce full charts due to:

- Scope

Bathymetry and "insignificant" objects were not tackled due to lack of time and dedicated researches taking place in parallel.

- Lack of tools

Some possible automatic generalisation solutions were only modelled as automatic, but were in reality interactive due to lack of tools.

- Complicated to model chart transformations

Although only specific objects were generalised often it can be found that other objects should also be taken into account during generalisation.

5. CONCLUSIONS

The assumption that generalisation of topographic and nautical charts is different was correct. This was proven especially when generalising land area and subsequently coastline. Available tools and rules were often not sufficient.

Objects that do not require geometric transformations (points, simple lines and areas, like restricted areas, traffic separation schemes etc.) could be stored on a layer that is independent of scale. Conditional selection (based on location, topological relation and/or attribute(s) value) can be used to automatically assign representations to production (scale dependant) layers.

Objects that require geometrical transformations (other lines and areas) need to be aggregated, simplified/smoothed, collapsed etc. This can be achieved by applying generalisation operators to a base dataset. Either star or ladder approach can be used. This research did not differentiate between the two approaches, because there was only one pair of datasets, where one was considered as a source and the second as a target.

The current methods of generalisation, used in this research, did not prove to be suitable for ENC generalisation. None of them made use of “safety” constrains. Often, safety constrains had to be forced by allowing additional, artificial buffers. “Safe” methods should make use of more situational constrains. The key to the “safe” line and area generalisation in nautical applications is directional generalisation.

New tools need to be developed to promote and facilitate automatic generalisation. It is not clear who should take the initiative – software vendors may not know what their clients need, but hydrographic offices are also not always aware of what is possible. Without new tools it is not possible to generalise charts without human interference.

To standardise chart content one should use reverse engineering and focus on the main and emergency purpose of a chart usage. Available objects should be categorised and those that are considered critical for the chart purpose need to be selected.

For these objects rules need to be set-up regarding the way they should be depicted in various situations. Semantics need to be analysed and clear rules of the use of attributes created. Other objects, which are not critical, may be let to the discretion of producing agencies, but a maximum level of detail would help to assure that charts do not differ greatly from country to country.

In theory it is possible to achieve consistent charting practice by standardisation but the producing agencies may be reluctant to give up their own procedures and practices.

Scale ranges per usage are too broad to effectively apply the same standardisation. Specifications created in this research suffer shortcomings due to trying to cluster such a broad range of scales to produce uniform specifications. Smaller chart scale steps should be considered to define a chart’s purpose.

It is possible to achieve time savings with generalisation. Evan at this initial stage of research into ENC generalisation, the results are encouraging. The development of constrains and semi-manual work on 4 charts took less time than what Hydrographic Offices have indicated is required to compile one chart.

One should not assume that the charts created by means of automatic generalisation would be identical as their benchmarks. It was not possible to achieve the same results as the original charts. This is partially due to the shortcomings of the used generalisation methods, partially due to the lack of tools, but also because the original source charts are erroneous.

The quality of datasets affects the success rate of automatic generalisation. For example lack of or inconsistent attribute values make it impossible to make use of them as constrains for generalisation operators. Specifications may read "Important buildings should not be generalised" but it is not clear, how this importance could be measured. Experience in chart creation could hint making use of CONVIS attribute value (visually conspicuous), but this value is not always available or specifications may omit the necessity of populating it. Also topology is the key issue. If datasets are sourced from discrete paper charts and their corners do not match, it is very difficult to create a continuous smaller scale chart.

Charts produced with automatic generalisation tools will differ from current products, but their quality, if parameters and tools are appropriate will be better.

6. FURTHER RESEARCH

This project is the first step to link advancements in contemporary map production with the needs of hydrographic offices. As such it shows clearly that there is great potential in this niche. Further research is needed to continue the exploration.

Only a small percentage of objects that can appear on the Approach and Coastal charts was analysed. Remaining geo objects excluded from this research need to be described and rules for their generalisation formulated. They should be linked to the current rules that where needed may require modification.

The scope excluded a major component of all charts – Bathymetry. This field is very interesting for hydrographic offices, as they expect great time saving to be possible to achieve (see Peters at al, 2013). What is needed is the link between the approached by this research underwater rocks & wrecks generalisation and bathymetric generalisation. Bathymetric solution needs to be approached holistically.

The "safe", "seaward" or "deeper" side is mentioned often when results are evaluated. As mentioned by one of the stakeholders – not respecting this rule is the biggest problem of current hydrographic software.

Apart from Geo objects, partially analysed in this research, Meta objects remain an important part of every chart. M_QUAL object, for example, describes the quality of bathymetry based on a current survey reports. Every time bathymetry is recreated, those objects need to be updated as well. It would be worth considering creating Meta objects from the actual geo objects.

This research was based on a case study of two, consecutive usage bands. The same amount of work as for the Approach –

Coastal pair is also needed for other usage bands.

Paper charts should follow the advancements of Electronic Navigational charts. The platforms used for chart creation should be combined so that two products have data sourced from the same storage, however generalisation methods will slightly differ. Paper charts have a fixed scale, therefore operators belonging to the cartographic generalisation group, like Enhancement, Displacement, Elimination and Typification should be explored.

A very important research, partially related to automatic chart generalisation is about defining the perfect level of detail for charts and standardising its content. S-57 does not enforce any rules on the chart content per scale nor does any other publication. S-4 makes a distinction between best scale, medium scale and small scale charts. It is clear that an overview chart will not include single buildings, cranes etc. and it is clear that Berthing chart will include berth numbers, facilities etc. This knowledge however isn't very well formalised. Approach and Coastal charts that differ only by one scale step are very difficult to specify the proper content. The weakest point of this research was trying to standardise generalisation rules for all charts, regardless how different their original content was.

All those further developments should have the advent of S-100 Geospatial Standard for Marine Data in mind, however the research can go much further and consider the possible future of charting - 3D presentation. How could the current 2D hydrographic data repository be effectively and efficiently transformed into 3D? – is the question that still waits answering.

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