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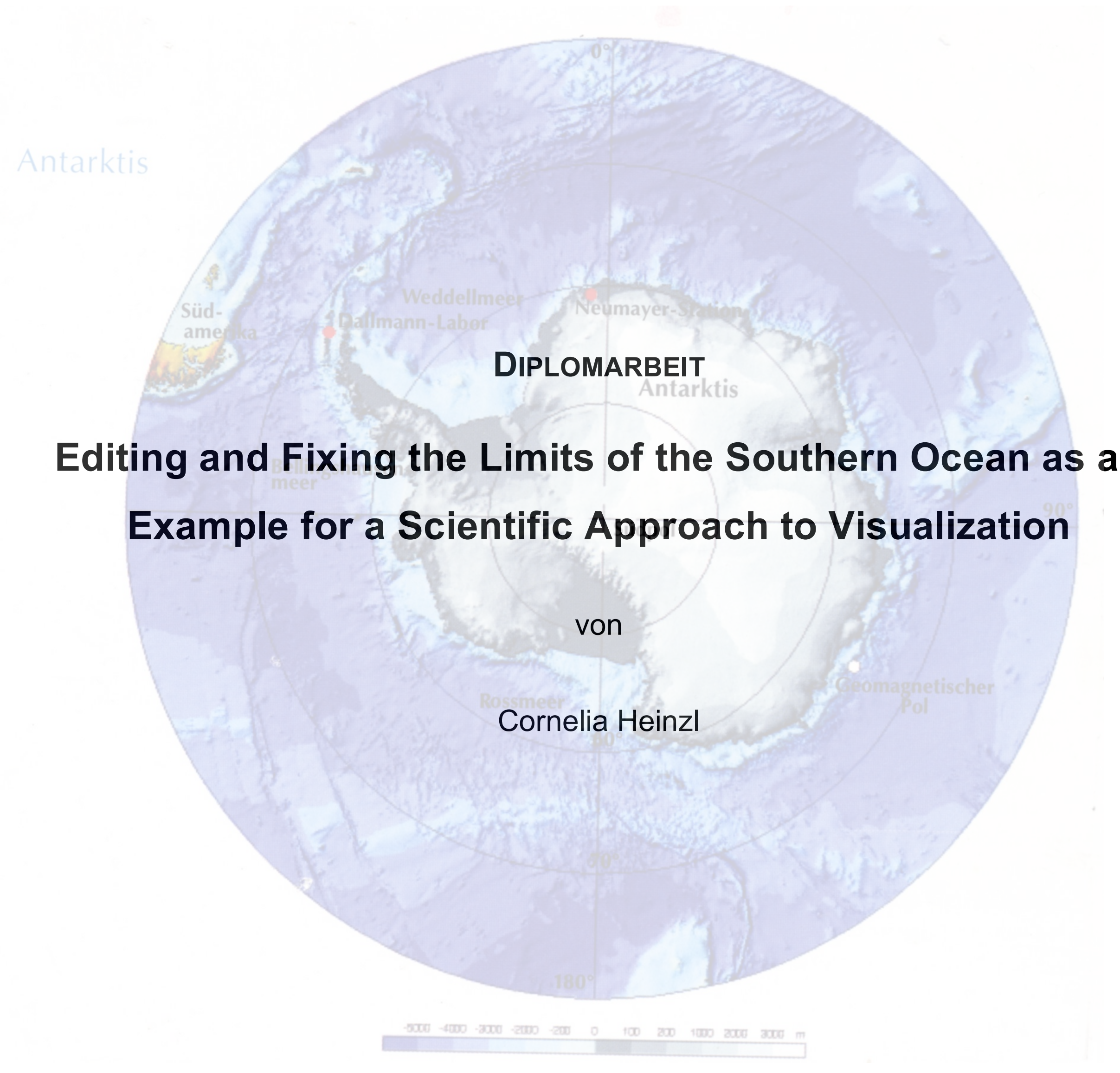

DIPLOMARBEIT

Editing and Fixing the Limits of the Southern Ocean as an Example for a Scientific Approach to Visualization

von

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Zusammenfassung der Diplomarbeit "Editing and Fixing the Limits of the Southern Ocean as an Example for a Scientific Approach to Visualization"

Kenntnisse über die Prozesse bei der Wahrnehmung und beim Verstehen sind für die Gestaltung von Kommunikationsmittel wie Karten unerlässlich – gerade wenn man den Kartennutzer nicht aus dem Blick verlieren will und die Kartengestaltung an dessen Bedürfnissen ausrichtet, um die Nutzbarkeit (usability) des kartographischen Produkts zu erhöhen.

Ein wissenschaftlicher Ansatz der Visualisierung kann dabei helfen, gut nutzbare Ergebnisse zu erzielen. Die so gewonnenen Erkenntnisse können hinsichtlich ihres Nutzens und ihrer Effektivität zu Visualisierungsarten führen, die denen, die sich scheinbar in der Praxis bewährt haben (so genannten „Best Practices"), überlegen sind.

Die vorliegende Diplomarbeit macht dies am Beispiel der Visualisierung von Seegrenzen im Antarktischen Ozean (Southern Ocean) deutlich.

Nach einigen einleitenden Ausführungen bzgl. der gewählten Methode der Problemlösung im ersten Kapitel, die gleichzeitig den Arbeitsfluss während der Bearbeitung des Problems illustrieren, werden im zweiten Kapitel die relevanten Informationen für das Problem der Grenzziehung im Antarktischen Ozean skizziert.

Davon losgelöst folgt im dritten Kapitel die Entwicklung eines multidisziplinären, wissenschaftlichen Ansatzes. Dieser beruht auf dem theoretischen Gerüst, das der amerikanische Kartograph MacEachren in seinem Werk „How Maps Work" (1995/2004) vorschlug. MacEachrens „scientific approach to visualization" wird in dieser Diplomarbeit, wo nötig, durch neuere Erkenntnisse aus den Humanwissenschaften ergänzt. Der vorgestellte Ansatz bildet so eine Synergie aus Psychologie, Soziologie, Semiotik, Linguistik, Kommunikationswissenschaften und Kartographie und steht so in der Tradition interdisziplinärer Wissenschaft, die die engen Grenzen einer speziellen Wissenschaftsdisziplin überwindet und so in einem ganzheitlichen Ansatz zu einer verbesserten Nutzbarkeit (usability) kartographischer Produkte beitragen kann.

Dieser ganzheitliche Ansatz umfasst einerseits Prozesse, die bei der Wahrnehmung und beim Erkennen von kartographischen Informationen eine Rolle spielen (Bottom-

Up-Prozesse). Er betrachtet aber auch die mit den Bottom-Up-Prozessen untrennbar verwobenen Top-Down-Prozesse, die ein Verstehen des Wahrgenommenen ermöglichen.

Da im gewählten Ansatz der Nutzer ein starkes Gewicht erhält, gewinnt auch die Kommunikation mittels der Karte einen höheren Stellenwert als MacEachren ihr in seinem kartenzentrierten Ansatz einräumt. Daher wird auf Grundlage des dargestellten theoretischen Gerüsts im vierten Kapitel ein ganzheitliches Kommunikationsmodell entwickelt, das klar macht, dass nur der Kartennutzer letztendlich die Nutzbarkeit (usability) eines kartographischen Produkts bewerten kann. Denn nur wenn er die für ihn relevanten Informationen aus der im kartographischen Produkt dargebotenen Informationen extrahieren kann, ist die Karte wirklich nützlich. Das Konzept Kommunikation ist gut geeignet, dies theoretisch zu fassen.

Die aus der wissenschaftlichen Analyse der ablaufenden Prozesse abgeleiteten Ergebnisse führen für den Fall der Visualisierung von Seegrenzen, der aufgrund seiner mangelnden Komplexität nicht alle Erkenntnisse darstellen kann, zu dem Vorschlag, die Seegrenzen als rote Linien zu visualisieren. Dieser Vorschlag weicht von der bisher praktizierten Art der Visualisierung ab.

So macht die Diplomarbeit deutlich, wie die Theorie die Praxis bereichern kann.

Das fünfte Kapitel führt nach dem theoretischen, wissenschaftlichen Exkurs wieder zu dem Beispiel der Seegrenzen im Antarktischen Ozean zurück.

Der Konvention der International Hydrographic Organization (IHO) folgend sollen die Seegrenzen anhand von Längengraden, Breitengraden, Loxodromen und bathymetrischen Daten festgelegt werden.

Auf Grundlage der für den Antarktischen Ozean vorliegenden bathymetrischen Daten werden mithilfe von ESRI ArcGIS ein Repräsentations- und ein Prozessmodell erstellt. Die Datenqualität und die daraus resultierende Qualität der beiden unterschiedlichen Modelle führen zu dem Ergebnis, dass lediglich das Repräsentationsmodell beim Ziehen der Seegrenzen dienlich ist.

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Erklärung

gemäß § 12 Abs. 8 ADPO

Hiermit erkläre ich, dass ich die Diplomarbeit selbständig verfasst, noch nicht anderweitig für Prüfungszwecke vorgelegt, keine anderen als die angegebenen Quellen oder Hilfsmittel benutzt und wörtliche sowie sinngemäße Zitate als solche gekennzeichnet habe.

(Cornelia Heinzl)

Abstract

The knowledge about processes concerning perception and understanding is of paramount importance for designing means of communication like maps and charts. This is especially the case, if one does not want to lose sight of the map-user and if map-design is to be orientated along the map-users needs and preferences in order to improve the cartographic product's usability.

A scientific approach to visualization can help to achieve useable results. The insights achieved by such an approach can lead to modes of visualization that are superior to those, which have seemingly proved their value in praxis – so-called "best-practices" –, concerning their utility and efficiency.

This thesis shows this by using the example of visualizing the limits of bodies of waters in the Southern Ocean.

After making some introductorily remarks on the chosen mode of problem-solution in chapter one, which simultaneously illustrate the flow of work while working on the problem, in chapter two the relevant information concerning the drawing of limits in the Southern Ocean is outlined.

Chapter 3 builds the theoretical framework, which is a multidisciplinary approach to representation. This theoretical framework is based on "How Maps Work" by the American Cartographer MacEachren (1995/2004). His "scientific approach to visualization" is amended and adjusted by the knowledge gained from recent findings of the social sciences where necessary.

So, the approach suggested in this thesis represents a synergy of psychology, sociology, semiotics, linguistics, communication theory and cartography. It follows the tradition of interdisciplinary research getting over the boundaries of a single scientific subject. The achieved holistic approach can help to improve the usability of cartographic products.

It illustrates on the one hand those processes taking place while perceiving and recognizing cartographic information – so-called bottom-up-processes. On the other hand it illuminates the processes which happen during understanding this information in so-called top-down-processes. Bottom-up- and top-down-processes are interdependent and inseparably interrelated and therefore cannot be understood without each other.

Regarding aspects of usability the approach suggested in this thesis strongly focuses on the map-user. This is the reason why the phenomenon of communication gains more weight than in MacEachren's map-centered approach.

Because of this, in chapter 4 a holistic approach to communication is developed. This approach makes clear that only the map-user can evaluate the usability of a cartographic product. Only if he can extract the information relevant for him from the cartographical product, it is really useable. The concept of communication is well suited to conceive that.

In case of the visualization of limits of bodies of water in the Southern Ocean, which is not complex enough to illustrate all results of the theoretical considerations, it is suggested to visualize the limits with red lines. This suggestion deviates from the commonly used mode of visualization.
So, this thesis shows how theory is able to ameliorate praxis.

Chapter 5 leads back to the task of fixing limits of the bodies of water in the area of concern. A convention by the International Hydrographic Organization (IHO) states that those limits should be drawn by using meridians, parallels, rhumb lines and bathymetric data.
Based on the available bathymetric data both a representation and a process model are calculated, which should support the drawing of the limits. The quality of both models, which depends on the quality of the bathymetric data at hand, leads to the decision that the representation model is better suited to support the drawing of limits.

Contents

1 Procedural Considerations

1.1 Object

This thesis uses a proposal of how to implement limits[1] into the International Bathymetric Chart of the Southern Ocean (IBCSO) and Southern Ocean Geographic Information System (SOGIS)[2], which is part of IBCSO, as an example for a scientific approach to visualization. The implementation of limits will help scientists to gain a common understanding of what name belongs to which body of water and contributes to gain a common definition.

Object and aim of the thesis is to suggest a possible mode of visualization of the limits of the bodies of water situated in the area south of 60° South latitude not only following "best practices". It has its main effort on the question of how to visualize on a scientific basis.

The limits proposed are not designed to have political relevance. They are for scientific use only.

1.2 IBCSO Mapping Project

The IBCSO Mapping Project is based on a decision of an ad-hoc working group during a meeting of the General Bathymetric Chart of the Oceans (GEBCO) in 2002. IBCSO should be an equivalent of the existing International Bathymetric Chart of the Arctic Ocean (IBCAO)[3], which deals with the Arctic region.

The whole IBCSO project is officially framed by the Geosciences Standing Group of the Scientific Committee on Arctic Research (SCAR)[4] and the Consultative Group on Ocean Mapping and Hydrographic Committee on Antarctica of the Intergovernmental Oceanographic Commission (IOC)[5].

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[1] For the differentiation of the terms "limit", "boundary" and "border" see 2.2, p. 12.

[2] For further details of International Bathymetric Chart of the Southern Ocean and the Southern Ocean Geographic Information System see http://ibcso.org/index.html, http://ibcso.org/sogis.html, last access 19.11.2010.

[3] For further details see Ott, Norbert and Schenke, Hans Werner: Southern Ocean Bathymetry. Return of the IBCSO Mapping Project, Hydro International, November 2007, pp. 1–3.

[4] For further information see http://www.scar.org, last access 19.11.2010.

[5] For further Information see http://www.ioc-unesco.org, last access 19.11.2010.

The aim of the IBCSO project is to produce a bathymetric map of the entire Southern Ocean[6]. This includes not only printed maps but since 2006 emphasizes the production of a geographic information system (GIS) based on digital data – the so-called Southern Ocean Geographic Information System (SOGIS). In this way the "IBCSO Expert Group may develop from a solely ocean mapping programme into an international and interdisciplinary forum for Antarctica and the Southern Ocean"[7].
Such a GIS has several scientific purposes and possible applications.
For example it enables "the generation of paleobathymetric maps with special emphasis on submarine gateways and barriers for updated plate tectonic reconstruction of the Southern Ocean"[8].
Additionally, it can help to predict the crustal behavior and therefore contribute to localizing potential earthquake hypocenters and in this way to tsunami early-warning systems.[9]
This thesis is a part of the production of SOGIS and represents a little contribution to the endeavor of creating this GIS.

1.3 Central Questions

Before starting the work there are several questions to be answered:

1. What are the national or international standards for fixing boundaries, limits and borders?
2. Are there any difficulties in fixing limits because of geological or regional particularities?
3. Which are the boards or institutions to be involved in the fixation of limits?
4. Which data, sea charts and topographic maps are available and needed?
5. How could the fixed boundaries be implemented comprehensibly and reasonably into a cartographical product according to the achieved guidelines ?
6. Which are the scientific guidelines to be taken into consideration for making a cartographical product [e.g. from psychology or communication theory] ?

[6] For the specification of the area described by the term "Southern Ocean" and the difficulties in using this term see 2.1.2, p. 10.
[7] Ott, Norbert and Schenke, Hans Werner: Southern Ocean Bathymetry. Return of the IBCSO Mapping Project, Hydro International, November 2007, p. 2.
[8] Ibid. pp. 2–3.
[9] For further possible applications see ibid. p. 3.

7. How could an attractive cartographic product be manufactured in a way that it visualizes the identified limits in a comprehensible and reasonable manner?

1.4 Procedure

During the thesis these questions will explicitly and implicitly be answered. The procedure itself can be divided into four steps.[10] This will be done according to the classical way to solve problems described by John Dewey.[11]
The procedure is graphically depicted in *figure 3.*

1.4.1 Anamnesis

The first step of the thesis is the collection of the information that might be useful to solve the scientific problem.

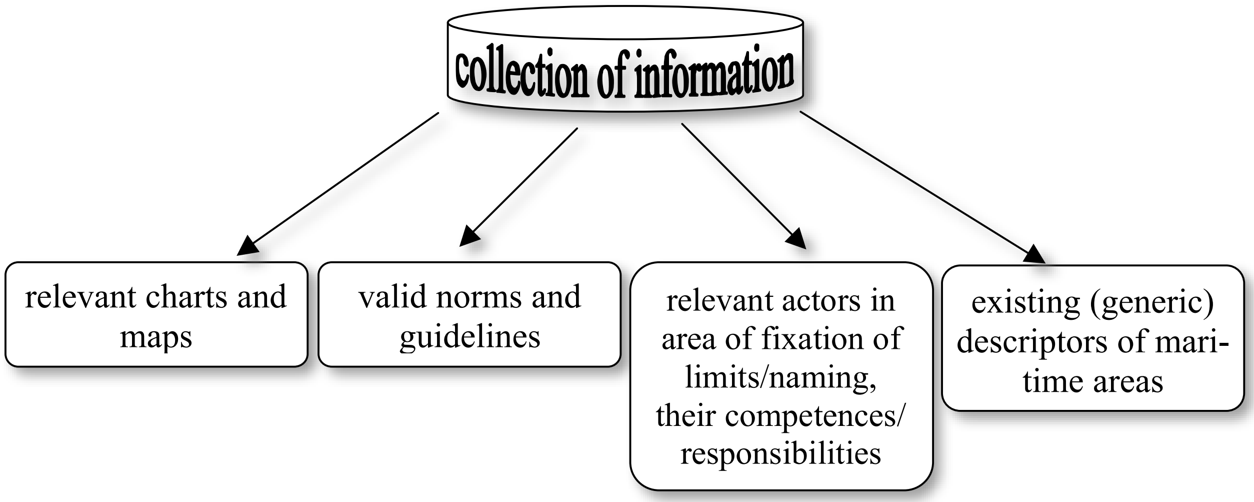

figure 1 *Collection of information.*

[10] For the procedure, the project being the basis for this thesis and its integration into SOGIS see: Schenke, Hans Werner and Heinzl, Cornelia: Definition of the Limits and Seas in the Southern Ocean, in: The Korean Cartographic Association: The Third International Symposium on Application of Marine Geophysical Data and Undersea Feature Names, 2008, pp. 99–103.

[11] See Dewey, John: Wie wir denken. Eine Untersuchung über die Beziehung des reflektiven Denkens zum Prozeß der Erziehung, Morgarten Verlag Conzett&Huber, 1951, pp. 88–163.

1.4.2 Analysis

During this step the collected information is to be checked with regard to its relevance for the further procedure and its coherence.

1.4.3 Diagnosis

Here there is to be found out, whether the collected information is consistent or not. Depending on the diagnosis there are two possibilities:

1. Information is consistent.
2. Information is not consistent.

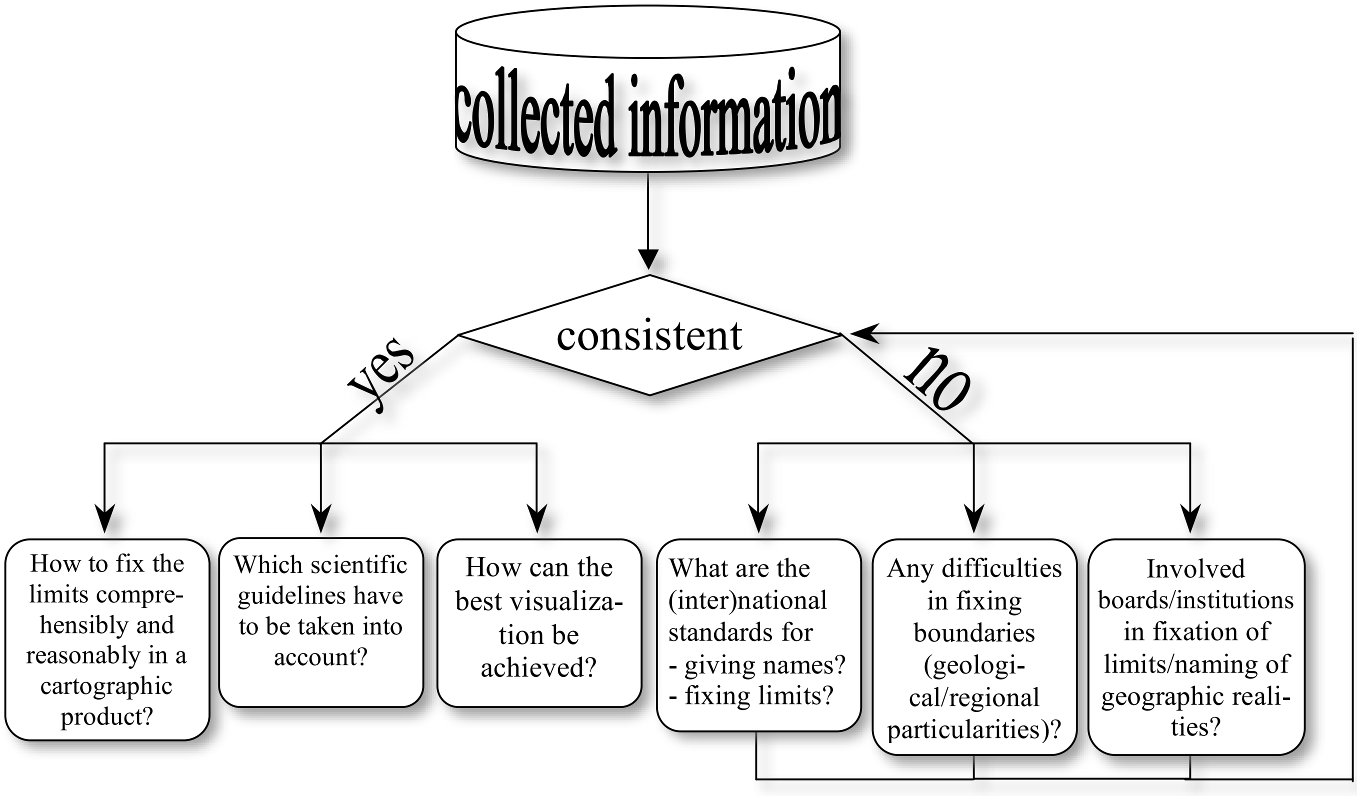

figure 2 *Course of action for the program.*

1.4.4 Solution – Consistence of Information

If the collected information is consistent, the question how the limits can be fixed comprehensibly and reasonably in a cartographical product is to be answered. Furthermore, there is to be answered, which scientific guidelines have to be taken into consideration and how the best visualization can be achieved (central questions 5–7).

The following decisions are to be made:

- Which kind of software is to be used and why?[12]
- Which and how many details have to be taken into the charts?

If the collected information is not consistent, central questions 1–3 are additionally to be answered before.

1.5 Summary

The thesis is characterized by an alternation of practical work and theoretical considerations. Both are to be joined in a scientifically based cartographical product best visualizing comprehensibly and reasonably the fixed limits in the Southern Ocean.

The procedure illustrated in *figure 3* does not represent the structure of the written part of the thesis, but outlines the workflow. The text itself is a collection of theoretical preconditions to be taken into consideration and a succession of relevant illustrations of the practical work and depicts the part "Visualization" at the bottom of the figure.

[12] The possibility of a paper map is to be discarded, because the cartographic product is part of a digitalized GIS. Ott, Norbert and Schenke, Hans Werner: Southern Ocean Bathymetry. Return of the IBCSO Mapping Project, Hydro International, November 2007, p. 3.

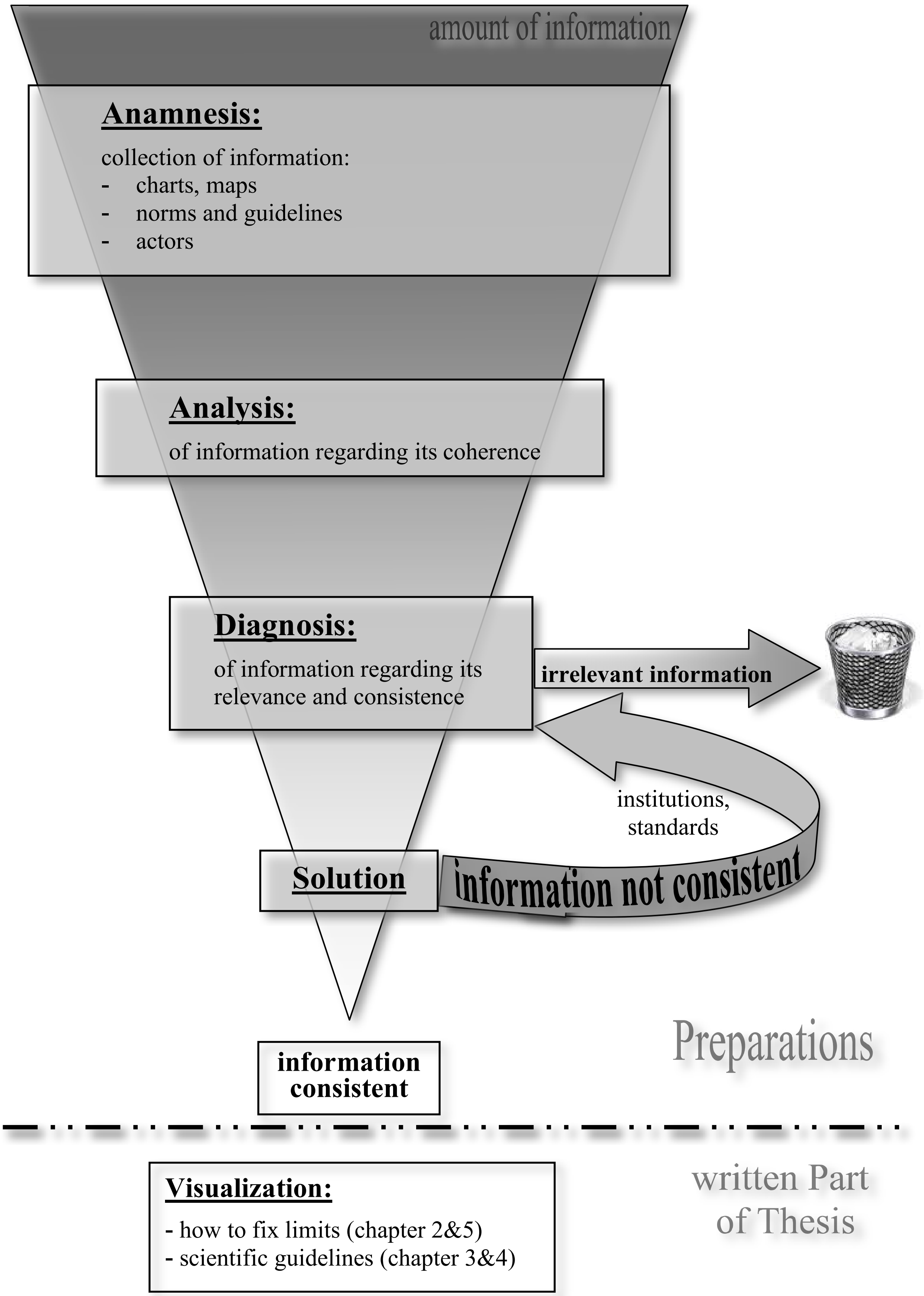

figure 3 Procedure of thesis.

1.6 Structure of the Thesis

The thesis is divided into four major parts.

Chapter 2 summarizes the information relevant for the solution of the practical problem of fixing limits of water bodies. In the course of this chapter the relevant actor in the process of fixing the limits of seas and oceans, which is the International Hydrographic Organization is briefly introduced.[13] Doing this a few words on standardization in international nautical charts will be spent. Then the area of concern, which is the so-called Southern Ocean, will be defined. After this, it will be sketched how boundaries, limits and borders can be fixed. This concludes the first general and illustrating part of the thesis.

Chapter 3 outlines the theoretical framework, which is a multidisciplinary approach[14] to representation. This theoretical framework is based on the work of the American cartographer MacEachren, who is highly relevant, because he was one of the first scientists in the field of cartography trying to implement new findings of social sciences in cartography. His "scientific approach to visualization" is amended by knowledge gained from recent findings of the social sciences where necessary. So, the approach suggested in this thesis represents a synergy of psychology, sociology, semiotics, linguistics, communication theory and cartography. Therefore, it follows the tradition of interdisciplinary research getting over the boundaries of a single scientific subject. The achieved holistic approach can help to improve the usability of cartographic products. It illustrates on the one hand those processes taking place

[13] Of course one further possibly relevant actor in the regard of limits of the oceans is the United Nations. The UN have published the United Nations Convention on the Law of the Sea (UNCLOS), which deals with boundaries in international waters and defines different legal terms. Although Antarctica is a legal subject, because it is subject of the Antarctic Treaty, it is not a national state itself. Therefore regulations from UNCLOS will not apply to it. Moreover, the definitions being found in UNCLOS define legal zones like the "territorial waters", "contiguous zone" or "exclusive economic zone". So they are not really relevant for this thesis stressing suitable limits of the different areas in the Southern Ocean.
For details see http://www.un.org/Depts/los/index.htm, last access 21.03.2010, http://www.un.org/Depts/los/clcs_new/continental_shelf_description.htm#definition, last access 21.03.2010.
For a brief overview over UNCLOS and several important definitions see http://en.wikipedia.org/wiki/United_Nations_Convention_on_the_Law_of_the_Sea, last access 21.03.2010.

[14] For the multidisciplinarity of today's cartography see Hake, Günter, Grünreich, Dietmar, Meng, Liqiu: Kartographie. Visualisierung raum-zeitlicher Informationen, deGruyter, 2001, pp. 5–13.

while perceiving and recognizing cartographic information – the so-called bottom-up-processes. On the other hand it illuminates the processes which happen during understanding this information in so-called top-down-processes. Bottom-up- and top-down processes are interdependent and inseparably interrelated and therefore cannot be understood without each other.

Regarding aspects of usability the approach suggested in this thesis focuses strongly on the map-user. This is the reason why the phenomenon of communication gains more weight than in MacEachren's map-centered approach. Because of this**, in chapter 4** a holistic approach to communication is developed, which is based on the theoretical framework outlined in chapter 3. From the insight that only the map-user can decide whether a cartographical product is sufficient or not, practical considerations concerning usability are made. The results from these considerations are compared with the common modes of visualization – the so-called "best practices".

Chapter 5 leads back to the task of fixing limits of the bodies of water in the area of concern. Based on the available bathymetric data both a representation and a process model are calculated, which should support the drawing of the limits. Both models are discussed regarding their utility for the task.

Chapter 5 closes with a suggestion of how to visualize the limits of bodies of water.

The thesis can be downloaded from file://localhost/lia77/bov7f3.

The cartographical product can be downloaded from http://homepage.mac.com/WebObjects/FileSharing.woa/wo/eBkbRhNSOwx12VwY.1/0.2.1.2.26.31.97.4.35.0.1.1.1?user=lia77&fpath=Uni&templatefn=FileSharing2.html[15]

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[15] In case your browser does not support this link, please click https://public.me.com/lia77/de/ and select folder "Uni".

2 Limits of the Oceans and Seas

2.1 International Hydrographical Organization, the Relevant Actor

2.1.1 Process and Aim of Standardization

The International Hydrographical Organization[16] (IHO) was formed in 1921 as an international intergovernmental organization. It is the result of the wish for greater standardization of nautical charts and associated publications. Its overall aim is to improve the safety of mariners.

Despite all efforts it was not until 1967 before the first really standardized charts – the so-called INT-series[17] – were proposed.

The countries joining the IHO felt the need that, instead of several different Hydrographic Offices each producing different charts of the same ocean area, often with different data, scales and limits, it would be more economic and safer, if one Hydrographical Office "would compile and produce an original chart to internationally agreed specifications"[18].

The first step towards standardization was the agreement on the standardization of the format and symbols to be used in international charts.[19] In the process of standardization several Hydrographical Conferences were held.[20]

By today there is no way around the constraints established by the IHO in regard to nautical charts.

Therefore, for the creation of a cartographic product illustrating the limits of the Southern Ocean the guidelines given by the IHO are mandatory.[21] In regard for the visualization of limits INT-1 does not offer a standard.

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[16] For further details see http://www.iho-ohi.net/english/home/, last access 19.11.2010.

[17] "INT" standing for international and meaning internationally agreed and standardized.

[18] See International Hydrographical Organization: Guidance for the preparation and maintenance of international chart schemes, S-11, 2010, p. V, http://www.iho-ohi.net/mtg_docs/com_wg/CSPCWG/CSPCWG_MISC/S-11/S-11.htm, last access 14.03.2010.

[19] See for the different formats mandatory for nautical charts S-11, pp. 4–5, and for standardized symbols INT-1. http://www.bsh.de/de/Produkte/Buecher/Sonstige_Publikationen/Karte-1/index.jsp, last access 26.10.2010.

[20] See S-11, 2010, p. V, http://www.iho-ohi.net/mtg_docs/com_wg/CSPCWG/CSPCWG_MISC/S-11/S-11.htm, last access 14.03.2010.

2.1.2 Southern Ocean – The Area of Concern

The area to be depicted in this thesis is the so-called Southern Ocean. The limits of oceans and seas are published by the IHO in its publication S-23 "Limits of the Oceans and Seas" published in 1953.[22]

Regarding the Southern Ocean this publication states:

> The Antarctic or Southern Ocean has been omitted from this publication as the majority of opinions received since the issue of the 2nd Edition in 1937 are to the effect that there exists no real justification for applying the term of Ocean to this body of water, the northern limits of which are difficult to lay down owning to their seasonal change. The limits of the Atlantic, Pacific and Indian Ocean have therefore been extended South to the Antarctic Continent.
> Hydrographic Offices who issue separate publications dealing with this area are therefore left to decide their own northern limits. (Great Britain uses the Latitude of 55° South)[23]

This statement makes clear that there is no international agreement of the area described by the term "Southern Ocean". In fact the limits are even recently a point of contentious issue.[24]

One possible definition of that water body is the British one mentioned in the quotation above. More appealing for this work could be to define the limits of the Southern Ocean according to "The Antarctic Treaty". It defines the area of Antarctica in Article VI:

> The Provision of the present Treaty shall apply to the area of 60° South latitude, including all ice shelves, but nothing in the present Treaty shall prejudice or in any way affect the rights, or the exercise of rights, of any State under international law with regard to the high seas within that area.[25]

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[21] For standards of electronic charts see IHO publications S-52, S-57, S-61 and S-63, http://www.iho-ohi.net/iho_pubs/IHO_Download.htm, last access 11.05.2010.

[22] See International Hydrographical Organization: Limits of Oceans and Seas, S-23, 1953, http://www.iho-ohi.net/iho_pubs/IHO_Download.htm, last access 14.03.2010.

[23] Ibid. p. 4.

[24] A hint at the quarrels concerning the Southern Ocean is for example the claim that this water body rises at 67° South latitude by the Australian government. See Darby, Andrew: Canberra all at sea over Position of Southern Ocean, 22.12.2003, http://www.theage.com.au/articles/2003/12/22/1071941610556.html, last access 10.03.2010.

[25] See „The Antarctic Treaty“ Article VI, http://www.nsf.gov/od/opp/antarct/anttrty.jsp, last access 12.03.2010.

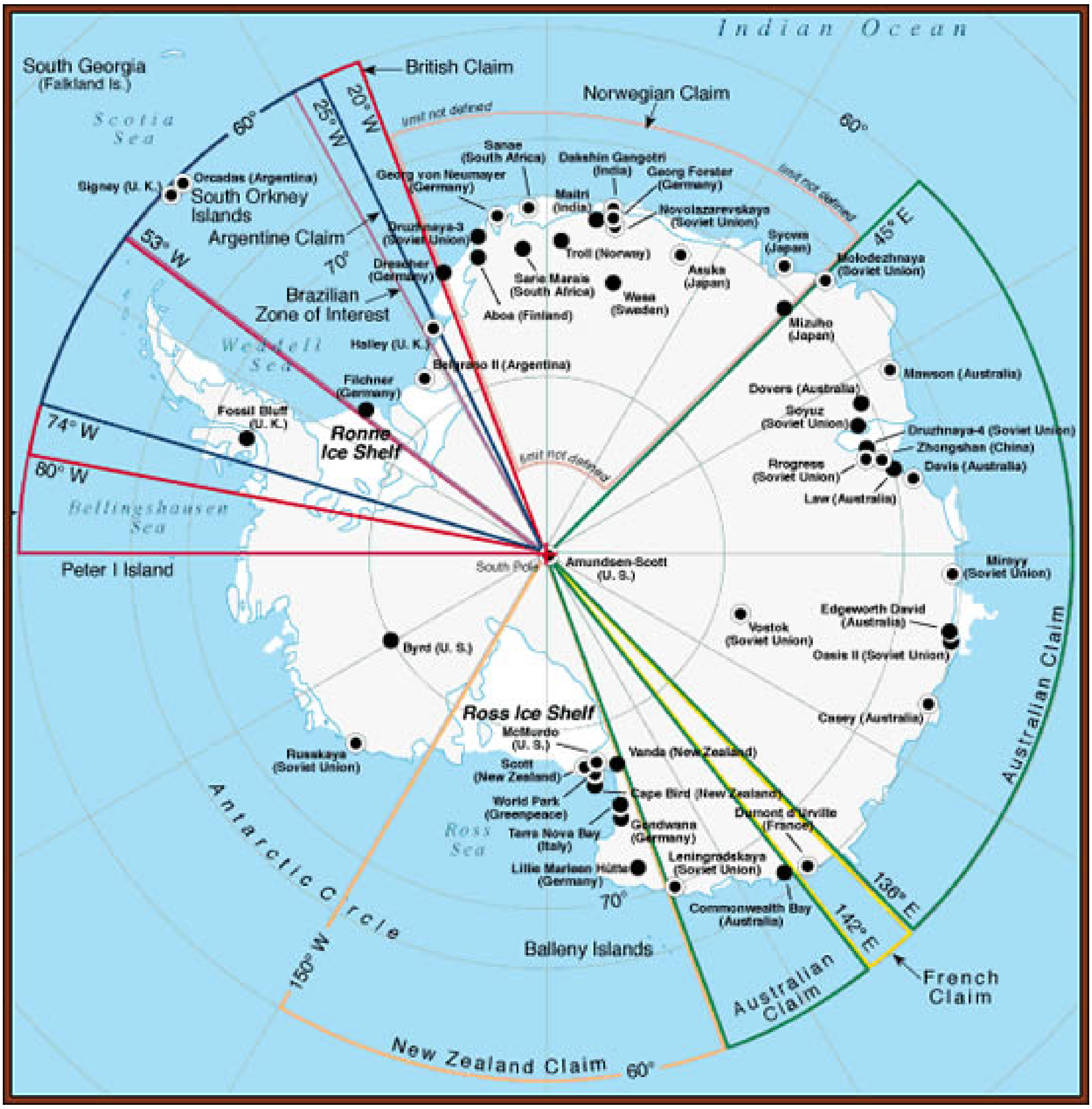

figure 4 *The area covered by the Antarctic Treaty.*
[http://www.landcareresearch.co.nz/research/ecosystems/penguins/images/mapshowingterritoriesetc.jpg, last access 26.10.2010.]

In favor of this definition – i.e. the area south of 60° South latitude – is also the fact that 46 treaty members have internationally agreed to the Antarctic Treaty system, which was called into existence by twelve members in 1961 and will expire in 2041.[26] Article VI also gives a hint that the definition of the Southern Ocean and its respective limits has no legally binding effect on any country with territorial claims. Therefore,

[26] Of course not only is it appealing to use this definition because of the Antarctic Treaty but also because SOGIS is concerned with the same area. However, in my opinion it would be very critical to only have this reason for choosing this approach.

there are no political consequences and implications to be expected from the results of this thesis.

Moreover – deduced from the statement quoted from S-23 by IHO – it is not likely that there is going to be an international nautical chart dealing with this area.[27]

2.2 Fixing Limits and Boundaries

For the further procedure the terms “border”, “boundary” and “limit” have to be differentiated. While “border” describes “the dividing line between two countries or the area near that line”[28], “limit” and “boundary” have the same meaning of a “point or line beyond which sth does not extend”[29].

So, technically boundaries and limits have to be distinguished from borders, because – as mentioned above – they are not politically relevant. Nevertheless, for their fixing it might be important to realize, how borders are drawn up. This might give some hints at possibilities of “best practice”.

The main purpose of borders has always been to outline the boundaries of political entities. Therefore, they have to clearly define, what lies inside this entity and what is outside of it. Furthermore, they help to gain a common understanding of what area belongs to which entity. This leads to fewer difficulties in identifying a certain area.

Traditionally, borders have been fixed by using more or less unambiguous features of the landscape. For example the border between Germany and France had been the river Rhine for centuries; the recent border between Germany and Poland is a line represented by the rivers Oder and Neisse. Besides rivers inaccessible mountain ranges etc. also have been used.

Generally, boundaries and limits have also the function to give clarity in regard of the outline of an area. But – as mentioned above – they are not politically relevant like borders.

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[27] For existing and planned nautical charts concerning this area see IHO publication No. S-11, Part B, Region ‘M’, Antarctica, http://www.iho-ohi.net/mtg_docs/com_wg/CSPCWG/CSPCWG_MISC/S-11/S11_PartB_RegionM_e2.003.pdf, last access 11.05.2010.

[28] See Oxford Advanced Learner’s Dictionary of current English, Oxford University Press, 1995, p. 121.

[29] Ibid. p. 653 for “limit” and p. 123 for “boundary”.

Nevertheless, the use of unambiguous features also applies for the fixing of boundaries und limits. Normally, in the case of limiting oceans and seas these unambiguous features are coastlines.

For example, the S-23 identifies as the limits of the Barentsz Sea *(figure 5)* the following features:

> On the West.
> The Northeastern limit of the Norwegian Sea (6).
>
> On the Northwest.
> East shore of West Spitzbergen, Henlopen Strait up to 80° lat. North; South and East coast of North-East Land to Cape Leigh Smith (80°05' N, 28°00' E).
>
> On the North.
> Cape Leigh Smith across the Islands Bolshoy Ostrov (Great Island), Gilles and Victoria; Cape Mary Harmsworth (Southwestern extremity of Alexandra Land) along the northern coast of Franz-Josef Land as far as Cape Kohlsaat (81°14' N, 65°10' E).
>
> On the East.
> Cape Kohlsaat to Cape Zhelaniya (Desire); West and Southwest coasts of Novaya Zemlya to Cape Kussov Noss and thence to Western entrance Cape, Dolgaya Bay (70°15' N, 58°25' E) on Vaigach Island.
> Through Vaigach Island to Cape Greben; thence to Cape Belyi Noss on the main land.
>
> On the South.
> The northern limit of the White Sea (8).[30]

[30] See International Hydrographical Organization: Limits of Oceans and Seas, S-23, 1953, pp. 7–8, http://www.iho-ohi.net/iho_pubs/IHO_Download.htm, last access 11.05.2010.

figure 5 Limits of Barentsz (Barents) Sea. [http://www.worldatlas.com/aatlas/infopage/barentssea.htm, last access 24.10.2010.]

Apart from coastlines parallels, meridians and rhumb lines have been used for limiting oceans and seas. The reason for this might have been the lack of sufficient bathymetric data. Nevertheless, there is still the effort to use unambiguous undersea features for the delineation of limits.[31]

All in all, for the task of fixing the limits of the Southern Ocean there are several possibilities.

The first one is to use the fault lines between the tectonic plates.

[31] See footnote 38.

A second possibility could be the use of the undersea topography to identify unambiguous features like sea mountains or trenches in the sea.

Derived from this topography, as a third option, one could use the analysis of the watersheds describing the drainage system located in the bodies of water.[32]

Last but not least one could stick to the common option of using parallels, meridians and rhumb lines[33].

The benefit of using bathymetric data for the delineation of specific bodies of water very much depends on the quality and quantity of the available data. This data is collected from different research institutes from all over the world, is received from different instruments with different accuracy and is from different dates.[34]

This is why Ott and Schenke identify as a main objective

> to collect and compile bathymetric data sets with additional seamless data derived from radar satellite images (…) , satellite altimetry and marine gravity that presently reside in numerous national and international databases and repositories.[35]

The quality and usefulness of the bathymetric data for fixing the limits of the bodies of water in the Southern Ocean will be discussed later on.[36]

The use of fault lines does not provide us with enough unambiguous features in the area of concern.[37] Therefore this possibility is discarded.

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[32] For the explanation of drainage systems see 5.6, p. 83.

[33] Although this possibility does not really meet the requirement of using unambiguous features in the landscape, it is still a common way of establishing borders in reality. The post-colonial political landscape in for example Africa is an example for this praxis.

[34] Ott, Norbert and Schenke, Hans Werner: Southern Ocean Bathymetry. Return of the IBCSO Mapping Project, Hydro International, November 2007, p. 2.

[35] Ibid. p. 2.

[36] See 5.3, p. 71.

[37] For further details about the fault lines in the area of the Southern Ocean see http://en.wikipedia.org/wiki/Plate_tectonics, last access 20.10.2010.

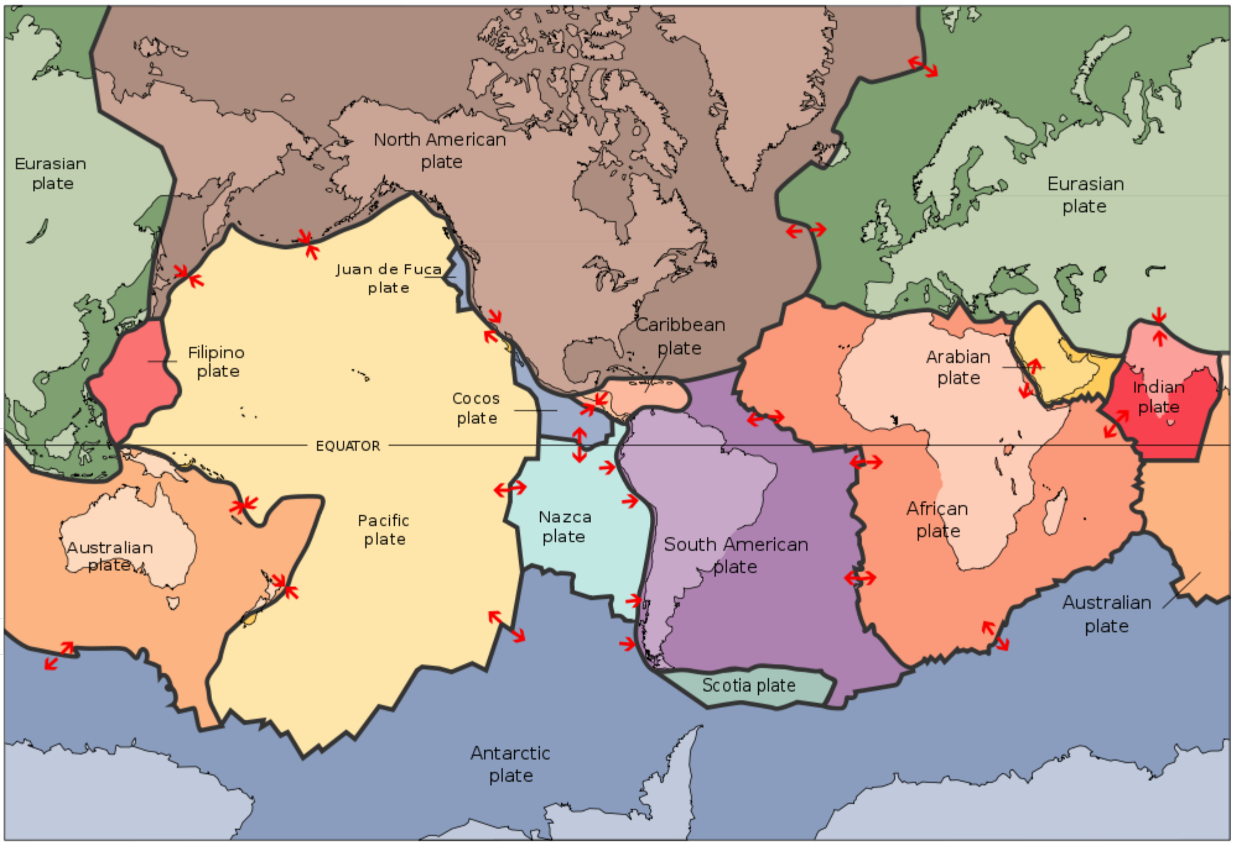

figure 6 *The tectonic plates of the world.* [http://en.wikipedia.org/wiki/Plate_tectonics, last access 20.10.2010.]

As a result of the described overall situation a suitable solution could be to use a combination of bathymetric data, parallels, meridians and rhumb lines. This method also seems to be a common procedure for the fixing of limits. This can be derived from the quotation of publication S-23 by the IHO below:

> The limits proposed … have been drawn up solely for the convenience of National Hydrographic Offices when compiling their Sailing Directions, Notices to Mariners, etc. so as to ensure that such publications headed with the name Ocean or Sea will deal with the same area, and they are not to be regarded as representing the result of full geographic study; the bathymetric results of various oceanographic expeditions have however been taken into consideration as far as possible, and it is therefore hoped that these delimitations will also prove acceptable to Oceanographers.
> These limits have no political significance whatsoever.
> …
> Meridians and Parallels or Rhumb Lines have been used as far as possible for limits.[38]

[38] See International Hydrographical Organization: Limits of Oceans and Seas, S-23, 1953, Preface to third Edition, http://www.iho-ohi.net/iho_pubs/IHO_Download.htm, last access 11.05.2010.

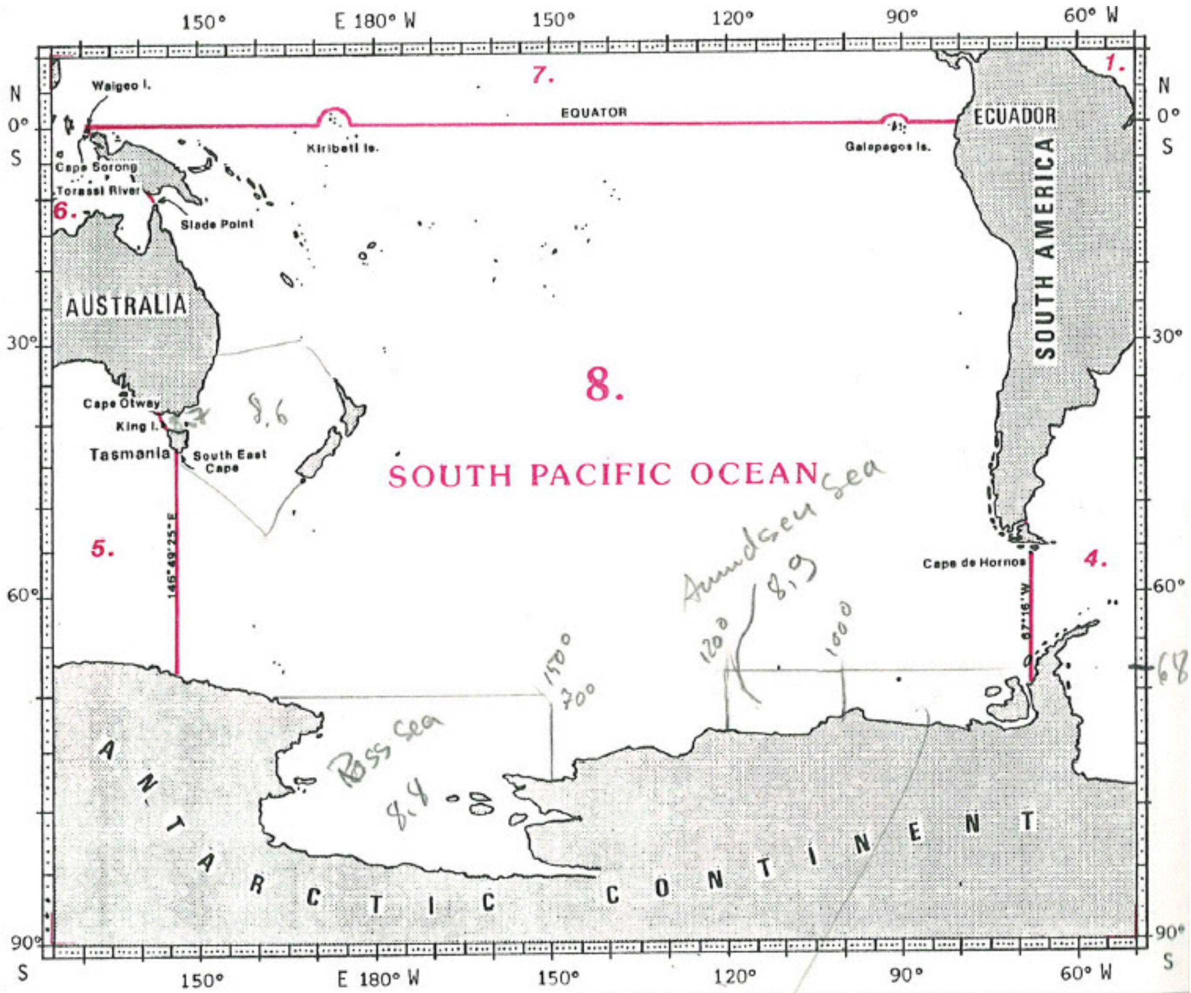

figure 7 *Limits of the South Pacific Ocean and adjacent seas* [International Hydrographic Bureau: Limits of Oceans and Seas, Special Publication 23, Draft 4th edition, 1986, p.174]

2.3 Conclusion and Summary

The map, which is to be produced, will have only a scientific purpose and no political significance. For the fixation of the limits within the Southern Ocean – not being a agreed term but as an assumption covering the area south of 60° South latitude – bathymetric data in conjunction with parallels, meridians and rhumb lines will be used.

2.4 Further Procedure

The next topic to deal with is the question of how to produce a scientifically based chart, which takes into consideration the latest scientific results and which is usable and suitable for researchers and other users of SOGIS.

The idea of critically scrutinizing methods of “best practice”, which mostly consist of the ways “we have been doing this for years and it has *somehow* turned out to be the best way”, reflects the traditional thinking that theory should support and ameliorate practice. Cartography itself seems to have been a science with a long tradition in using best practice but in a way neglecting findings of neighboring sciences like for example psychology or sociology. However, using the results of those scientific subjects helps to design more sufficient cartographic products, which consider and focus human needs.

This is the reason why in this thesis a high degree of emphasis lays on the theoretical foundation of the practical work.

Firstly, the map-centered “scientific approach to visualization” proposed by MacEachren will be outlined.

Because psychology and communication theory have kept on developing, it is important to keep an eye on these developments and to adjust the theoretical framework of MacEachren where necessary.

Additionally to the approach to visualization, communication theory seems to play a more important role, if the focus lies on the topic of usability, which centers more the map-user than the map.

Hence, communication theory and usability will be dealt with in the theoretical part – in chapter 4 – as well.

3 Theoretical Framework

The theoretical framework of this chapter is the “scientific approach” to maps introduced by MacEachren.[39] MacEachren understands maps as “dynamic interactive spatial information tools”[40] and points out that there is no “single correct scientific or nonscientific approach to how maps work”[41]. In his opinion, it is more useful to adopt a comprehensive approach, which’s foundation is the concept of representation.[42] Hence, he sees maps as one of many “potential representations of phenomena in space that a user may draw upon as a source of information or an aid to decision making and behavior in space”.[43] In his view emphasis lays on the topics of lexical, semiotic or functional and cognitive representation and on how human perception influences the viewer’s access to meaning.

This perspective leads to several conclusions.

The first is that both communication and visualization or in other words representation are vital for the use and therefore for the design of maps. For this reason it is important to comprehend the basics of two theories. One of them is communication theory[44] and the other is how our brain manages the processing of information and thus how perception works.

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[39] For details about this approach see MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, pp. 1–16.

[40] See MacEachren, Alan M. and Taylor, D.R. Fraser (Eds.): Visualization in Modern Cartography, Pergamon, 1994, p. 2.

[41] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 12.

[42] MacEachren defines representation as ”a general concept if we are to understand maps”. Ibid. p. 12.

[43] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 12.

[44] It is to be mentioned at this point that the understanding of communication theory, which MacEachren depicts in “How Maps Work” limits the process of communication very much. It depicts more or less what is true for information theory which deals with the improvement of the transmission of information and topics like “noise reduction”. Therefore, MacEachren`s rejection of communication theory is understandable. Nevertheless, it does not seem to be reasonable. For further details about communication theory and the difficulties in science to delineate this theory see Burkart, Roland: Kommunikationswissenschaft. Grundlagen und Problemfelder. Umrisse einer interdisziplinären Sozialwissenschaft, Böhlau Verlag, 1995, pp. 15–54.

Directly interrelated with these two aspects is the issue of man-map-(machine)-interaction[45]. In this realm fall the topics of who is the specific audience for a map and how the usability of the cartographical product can be improved.

In this chapter MacEachren's understanding of representation and visualization will briefly be outlined and amended by recent results from the social sciences where necessary.

3.1 Representation

According to MacEachren representation "happens" on *three levels* *(figure 8* and *figure 9)*, which he equates with *"approaches"* and which belong to different sciences or theories.[46] For him it is important to state that there is no single theory of representation. In fact he speaks of "the multiplicity of theories that become possible when we realize the scope of the concept of representation".[47]

In reference to Howard[48] he identifies the *lexical*, the *functional* and the *cognitive* approach to representation, which are not divided approaches, but interrelated and integrated ones.

The *lexical approach* deals with the question of how symbols achieve their meaning and how people learn to use forms of symbolization.

The *second approach* to representation is the *functional or semiotic* one. This approach deals with the relationship between the referent, the interpretant and the sign-vehicle as a mediator.[49]

These two approaches look primarily at cultural and scientific practices, social processes and so on[50], while the *third approach* – the *cognitive* one – emphasizes the individual with its preconditions and limitations regarding the processing of information *(figure 9)*.

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[45] This topic gets more and more relevant, if we take into account the quick development of internet maps and so on.

[46] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 12.

[47] Ibid. p. 12.

[48] See Howard, V.A.: Theory of representation: Three questions, in: Kolers, P.A., Wrolstad, M.E. and Bouma, H. (Eds.): Processing of Visible Language, Volume 2, Plenum Press, 1980, pp. 501–515.

[49] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 246.

[50] Ibid. p. 13.

In MacEachren's words the lexical and the semiotic approach "deal with the public realm of how maps are imbued with meaning".[51]

On the other hand the cognitive approach considers the question of how an individual sees and interprets the individual symbols and maps and therefore has its perspective on the private realm.[52]

In this way MacEachren introduces *two levels of analysis*.

The first is the *private/perceptual-cognitive level* with the focus on human information processing and the second is the *public/social level*.

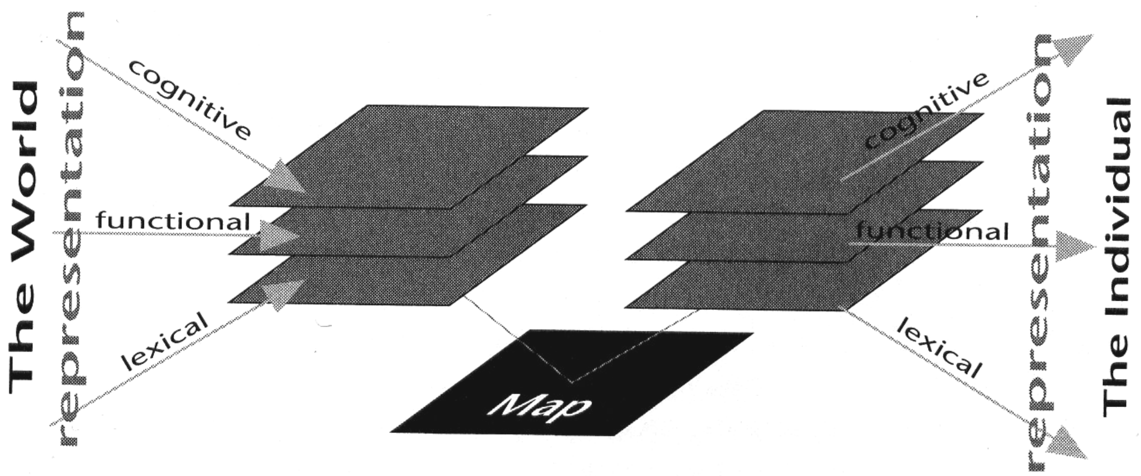

figure 8 *The multiple levels of map representation.* [MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, figure 1.3, p. 14]

[51] Ibid. p. 15. He identifies an epistemological-philosophical-sociological-historical perspective for the lexical approach and a logical-categorical perspective for the functional or semiotic approach.

[52] Ibid. p. 15.

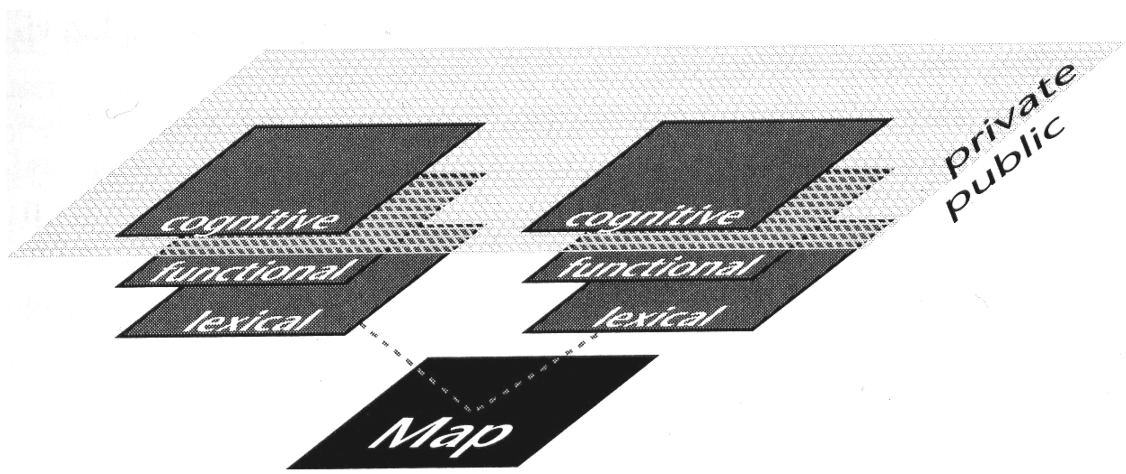

figure 9 *The public and private issues of maps representation.* [MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, figure 1.4, p. 15]

3.1.1 Private/Perceptual-Cognitive Level

3.1.1.1 Visual Perception and Information Processing

MacEachren criticizes cartography for having focused on specific low-level abilities[53] following an American trend in psychology – the behaviorism. In his opinion this trend was a dead end, because it emphasized too much the abstract laboratory test stimuli[54] and lost sight of the questions of how we see the real world and what perception is for.

A turning point in psychology regarding these questions was J.J. Gibson‘s ecological approach to visual perception.[55] In his approach Gibson denied that vision processes information. He argued that vision directly reacted to information.[56] The second notable approach of modern psychology to visual perception is Marr’s approach to vision[57], which MacEachren employs in his approach. Like Gibson Marr examines the question of *what vision is for in the real world*. This question helps to understand the processes taking place during visual perception. In contrast to Gibson he empha-

[53] Ibid. p. 25.
[54] An explanation for this might be, that the tested symbols and signs were much alike those used in cartographic products which at this time were mainly 2D.
[55] For extensive information about this approach see Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, pp. 301–314.
[56] For a discussion of the ecological approach: Ibid. pp. 407–408.
[57] Marr`s approach is founded in the artificial intelligence tradition. See ibid. p. 80.

sizes the *active role of the individual*. MacEachren points out that Marr's approach had a dramatic impact on understanding vision and the processing of information at *various levels of analysis*.[58]

All in all Marr identifies *three levels*:

First, most important and most fundamental in Marr's understanding is the level of *computational theory*. This level is concerned with the description of what a process must do and why it has to do it. Additionally, it deals with logical theory of how the defined needs might be carried out.

The *second level* is hierarchically lower and examines how the implications found on the level above can be implemented. This is the level of *representation and algorithms*[59].

The *third level* is the most practical one. It is the level that deals with *processing devices* and *hardware implementation*. It considers how a particular representation might be implemented in the available device.

Marr states that *some phenomena* only *fall in one level* and *some* might concern *all*. Therefore it is *critical* for him to consider the appropriate *level of analysis* during evaluating evidence about different process functions.

From the importance of the computational level we can deduce that the question we have to answer first is the question of *what vision is for in the real world*.

Because we live in a *three-dimensional* world our representations and algorithms are made for those conditions. This is the reason why *problems with* interpreting *two-dimensional* displays might occur. This means that it is not only important how information is processed but also how it is represented.[60] Or to say it with MacEachren's words:

> With vision it is, after all, a representation of the world formed on the retina that must be processed; and if Marr is correct, this retina representation is transformed in a series of subsequent representations that lead from the two-dimensional retinal representation to a three-dimensional object-centered representation of the structure and organization of the viewed object or scene.[61]

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[58] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, pp. 27–33.

[59] In this context algorithm is defined as "a specific logical or mathematical procedure operating on an imput to yield an output". See Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, 2006, p. 81.

[60] This question leads us to the issue of representation and visualization which will be dealt with later on.

[61] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 28.

In other words the *visual processing is modular* – meaning that it can be divided into a number of *sub-processes* in each of which one representation is transformed into another *(figure 10)*.

The first module creates a "*primal sketch*"[62] representing the changes in light intensity that occur over space in the image. It also organizes these local descriptions of intensity change into a two-dimensional representation of image regions and boundaries between them.[63]

The next module specifies the visible object surfaces in relation to the perceiver in the "*2.5 D sketch*".

Finally this information is used to create the "*3 D model representation*" specifying the solid shapes of objects. This representation is used to identify the objects with representations of objects held in our memory.[64]

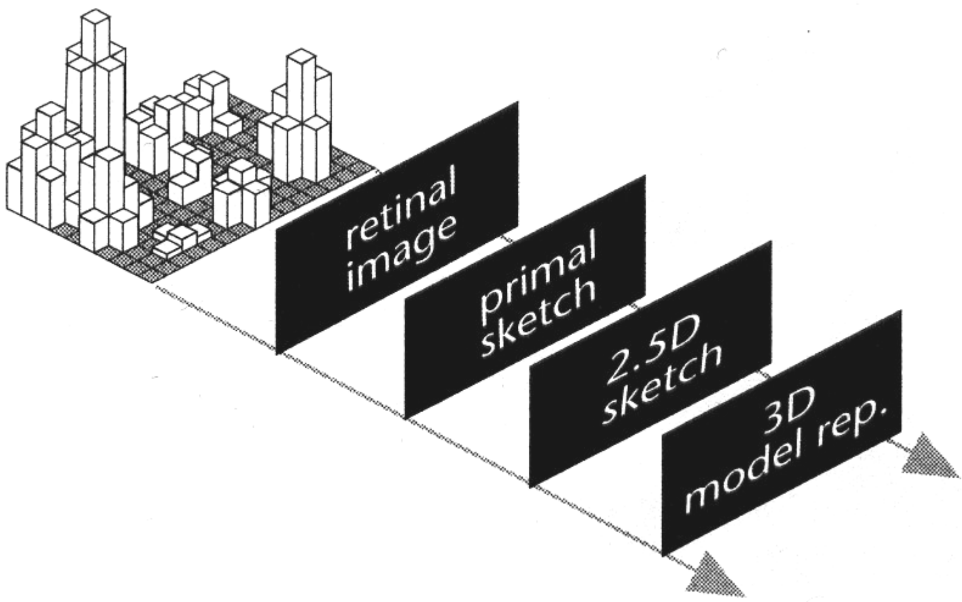

figure 10 *Marr's stages of vision. Derived from Marr (1982)* [MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, figure 2.1, p. 29]

[62] The primal sketch is a description of edge and line segments, terminations and other key features.

[63] See Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, p. 80.

[64] For a more detailed description see MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, pp. 29–33.

A *crucial assumption* for this theory is that features or component parts symbolized in the primal sketch are extracted separately for various scales. Those *major features* can be distinguished from other details. This leads to a hierarchical model for storage of shape categories in our memory against which information from visual scenes is compared.[65]

Using such a theory of representation two major conclusions can be drawn:

The *first* is that *contrast* among map features *plays an important role* in recognition.[66]

The *second* is that the *shape and* the *relation* between single objects are also of huge *importance*.[67]

Both conclusions show a link to the so-called "*Gestalt principles*" or "*Gestalt laws*"[68], which have to be considered as well. *If it is possible to use Gestalt groupings that link map elements in a logical way and that are applicable for everyone, it will be much easier to convey information from the cartographer to the map-user.*

As a result the *quality* of a map could for example be evaluated by the extent to which there is a *matching of map representation and memory representation*.[69]

As stated above it is important to answer the question of what vision is for in the real world. This helps to understand how vision works and to learn how one can produce better and more usable cartographical charts.

The answer to this question can be used as a summary of the last paragraphs:

> Vision should, on evolutionary grounds, be good at extracting object shape from visual scenes, assessing depth and relative size, and noticing movement. It must perform these functions from information about contrast on roughly pixel-by-pixel basis on retinal level, using neurological hardware to process the retinal image.[70]

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[65] Ibid. p. 29. For further explanation also see Peterson, Michael P.: Cognitive Issues in Cartographic Visualization, in: MacEachren, Alan M. and Taylor, D.R. Fraser (Eds.): Visualization in Modern Cartography, Pergamon, 1994, pp. 29–30. There the role of patterns during the process of recognition is depicted in detail. Peterson identifies at least three different models of visual pattern recognition (template matching, feature detection and symbolic description). Furthermore he deals with visualization and defines it (pp. 28–29) as "internal and external creation of images".

[66] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, 2004, pp. 51–52.

[67] Ibid. p. 52.

[68] Following the psychological usage I will use "Gestalt laws" although MacEachren tends to use „Gestalt principles", because their adaptability in cartography is controversial. For the discussion: ibid. pp. 77–80.

[69] Ibid. p. 49.

[70] Ibid. p. 52.

The description of this neurological hardware processing the retinal image will be skipped[71]. More emphasis will be put on the "Gestalt laws", which are the first step to an explanation of how perception is organized by the individual. The main statements of this theory will be outlined in the following paragraphs.

3.1.1.2 Perceptual Organization

3.1.1.2.1 Grouping and Figure-Ground Segregation

When we perceive our surrounding we do not see a "collection of edges and blobs … but we see instead an organized world of surfaces and objects"[72]. Therefore, it is *important* from an information-processing point of view to further examine how the phenomena of *grouping* and *figure-ground segregation* work.

If one follows MacEachren's assumption, the phenomenon of grouping happens logically before the individual can distinguish between figure and background.[73] The Gestalt psychologists found out several principles of perceptual organization describing how certain perceptions were more likely to appear than others. As pointed out above some of those principles or "Gestalt laws" deal with the grouping of figures and other have to do with the segregation of figure from ground. The Gestalt psychologists formulated the following rules:[74]

1. **Proximity**: Objects that are close together are grouped together.
2. **Similarity**: Objects that look "similar" form groups. It is important to realize that similarity is no absolute category. There are several graduations of "being similar". It seems more or less to be a matter of individual experience.
3. **Common Fate**: Objects that appear to move together are grouped together. This law might even lead to a re-grouping of existing groups, if objects of different groups start to move together.

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[71] For a detailed description of the eye-brain-system: ibid. pp. 53–68 or Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, pp. 3–74.

[72] Ibid. p. 119.

[73] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 77.

[74] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004 pp. 71–76 or Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, pp. 123–127. The number of rules varies from 9 (MacEachren) to 7 (Bruce, Green, Georgeson).

4. **Prägnanz**: According to Gestalt psychology objects will be organized in the best, simplest and most stable shape – the so-called “gute Gestalt”.[75]
5. **Objective set**: If there is a change – e.g. objects drifting apart –, there is a tendency to maintain initially formed groups.
6. **Good continuation**: Objects that follow a constant direction are grouped. In a figure like *figure 11* the individual is rather likely to perceive two curves crossing at point X than seeing two V-shapes touching at point X. The law of good continuation can be considered the spatial analogue to the law of common fate.

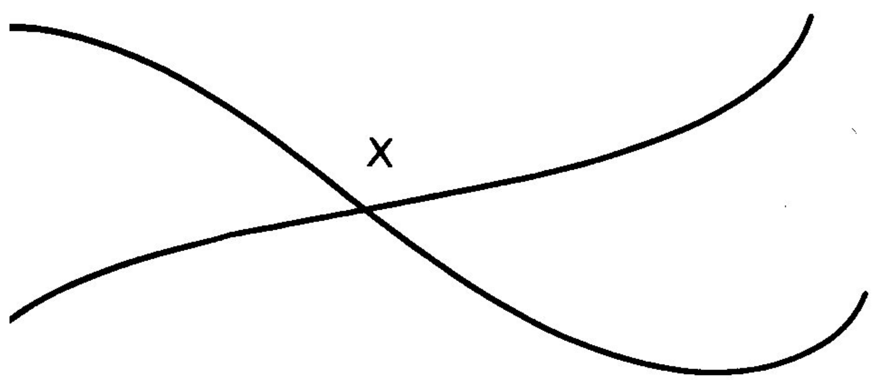

figure 11 *Example for good continuation* [Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, figure 6.10, p. 125]

7. **Closure**: Objects that form a close shape are organized as wholes.
8. **Simplicity**: Objects will – as pointed out in the explanation of the law of Prägnanz will organize in the simplest form or shape.
9. **Experience and Habit**: Familiar shapes or arrangements are grouped together.

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[75] Although the law of Prägnanz appears to be the essence of Gestalt psychology it is this law that is the hardest to be grasped and therefore object of ample critique. It can only be subjective what is the best, the simplest and the most stable Gestalt. For further discussion see Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, p. 127.

3.1.1.2.2 Ambiguity

An *additional phenomenon* concerning perceptual organization is *ambiguity*. It can occur *during* the process of *figure-ground segregation* and in the *internal organization* of an object.

The most famous example of ambiguity in figure-ground segregation is the face/vase picture *(figure 12)* used by the Gestalt psychologist Edgar Rubin.[76]

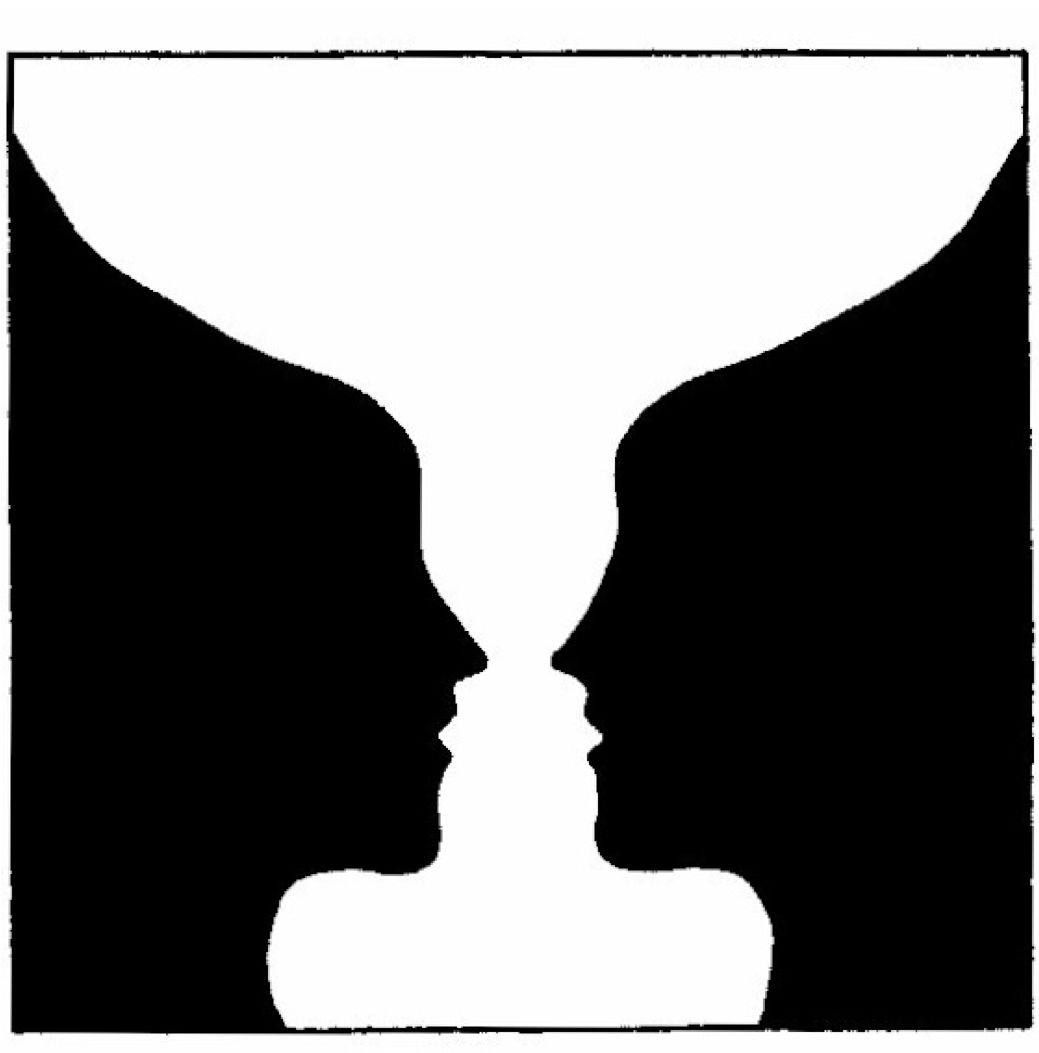

figure 12 *face/vase picture devised by E. Rubin in 1915* [Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, figure 6.2, p. 120]

[76] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 113.

Ambiguity in the internal organization is illustrated by the Jastrow's duck-rabbit picture *(figure 13)*.

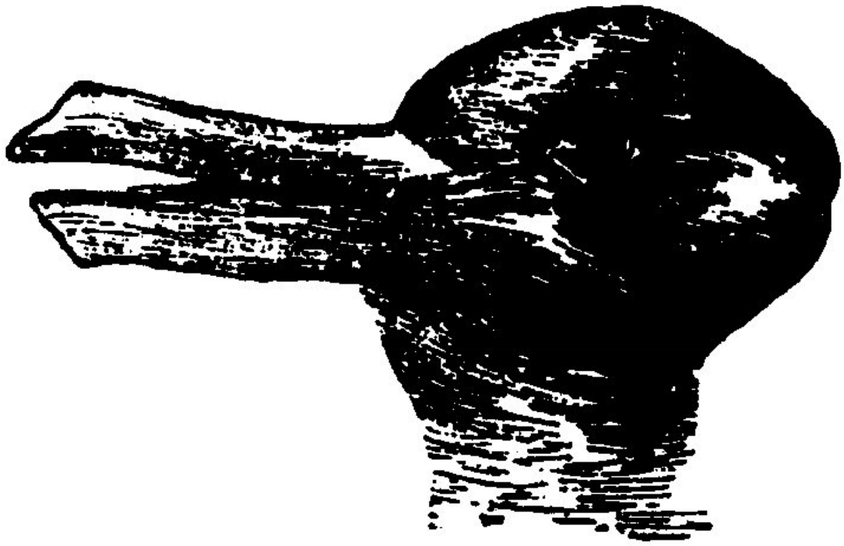

figure 13 *Duck-rabbit picture. This ambiguous picture was introduces to psychologists by J. Jastrow in 1900.* [Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, figure 6.4 (a), p. 122]

Ambiguity occurs when the interpretation of the same input data shifts. This is the reason why it is impossible to maintain both different interpretation – vase or faces in the first example or rabbit or duck in the second one – simultaneously.

This phenomenon *might not play an important role in the real world*[77], because perception takes place in a three-dimensional environment. In such an environment it is clear, what object is the figure and which one is the ground, or whether it is a rabbit or a duck. But it can have implications for two-dimensional maps and cartographic representation in terms of usability or misinterpretation of information.[78]

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[77] See Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, p. 122.

[78] One example might be those maps, where land is illustrated in blue and oceans are shown in white. Concerning usability in this case it can take the map-user several moments until he can distinguish between land and ocean. Or to say it more precisely: in this case it will be hard for the map-user to identify which figure is to represent "water" and which is to represent "land", because he has a concept of water being blue. This topic will be discussed later on in this chapter.

For an extensive discussion of the issue of ambiguity also see MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, pp. 113–117.

Unfortunately, Gestalt psychology only provides us with a “set of descriptive principles”[79] and not with a model of perceptual processing. Moreover – as pointed out above – the Gestalt laws of perceptual organization sound “vague” and “inadequate”[80] like the “gute Gestalt” – good shape – and the law of similarity. Recently psychologists have tried to experimentally provide evidence that Gestalt laws work.[81]
Moreover, the validity of some of the Gestalt laws can be demonstrated in natural settings for example in cases of natural camouflage of animals or artificial or man-made camouflage used by armed forces.[82]
But even with this proof Gestalt laws still remain a sole descriptive tool.
Despite all these restrictions Gestalt laws play at least implicitly a more or less important role in cartography.[83]

3.1.1.2.3 Attention

One further and important point regarding perceptual organization besides grouping is *visual* attention. *Attention and grouping interact in complex ways*.[84] Although some grouping works pre-attentively, visual *attention* is a *prerequisite for grouping*. MacEachren describes the interrelationship between grouping and visual attention as follows:

> Where our gaze is directed will limit what can be grouped (only global features of a scene in peripheral vision vs. details in central vision). The results of grouping will control what can be attended to and where our gaze might travel next. Where we direct our attention can, of course, also be consciously controlled.[85]

Talking about attention, selective attention is an important factor, which comes along with the Gestalt laws. *Selective attention is the ability to attend to one feature and ignore another*. This phenomenon can be explained with the principle of the “*gute Gestalt*”. The individual integrates fitting features and leaves out those, which do not

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[79] See Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, p. 127.
[80] Ibid. p. 127.
[81] In Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, pp. 127–134 can be found a description of how the „gute Gestalt“ and the law of similarity are demonstrated by scientific experiments.
[82] For the explanation of how camouflage works with the Gestalt laws: ibid. pp. 129–134.
[83] For details see MacEachren’s discussion of the impact of Gestalt laws on cartography in MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, pp. 77–80.
[84] Ibid. p. 80.
[85] Ibid. p. 80.

fit. Besides the Gestalt laws *personal experience* and the *cultural background*[86] of the individual plays an important role here, because it organizes information in a manner that avoids cognitive dissonance and ambiguities.[87]

Of further importance is the question of where we attend to. MacEachren describes the *significance of location and scale*[88] and of *eye movements*[89]. All those phenomena play an important role in the concept of figure-ground segregation.

This requires that perception organizes the visual input sufficiently for the elements of that input to group and attract attention to themselves. The distinction between significant and insignificant elements needs to happen at a "coarse holistic level"[90]. In the further information processing it guides attention to specific details. Significant figures attracting our attention are distinguished from the background and are often seen in front of it.

MacEachren identifies *six factors* being *relevant to establishing symbols and regions as figures on maps*.[91]

These are heterogeneity, contour, surroundedness, orientation, relative size and convexity.

Heterogeneity has been given the greatest attention. The other five factors are seen complementary to it.[92]

Brightness and *contrast* seem to be most important for figure-ground segregation. The higher the difference in brightness the higher is the experience of the "gute Gestalt".[93]

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[86] The topic of experience is extensively discussion ibid. pp. 117–120.

[87] For details about experiments on selective attention and its interrelationship with Gestalt laws see ibid. pp. 81–87 and for divided attention and variable conjunctions ibid. pp. 87–94.

[88] Ibid. pp. 94–101.

[89] Ibid. pp. 101–107. For an ample illustration of recent research results in the field of eye movement also see Swienty, Oliver: Attention-Guiding Geovisualisation. A cognitive approach of designing relevant geographic information, PhD Thesis, Technische Universität München (TUM), München, 2008, pp. 21–24.

[90] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 107.

[91] Ibid. pp. 108–110.

[92] Ibid. p. 110.

[93] Ibid. p. 111.

3.1.1.2.4 Conclusions

Summarizing this brief outline on the question of how we see maps one could state:

1. Gestalt laws help us to understand how we perceive our surrounding.
2. It is vital to keep in mind that the contrast between different map features and the shape of objects and their relationship is crucial for a "successful" perception. Most important are the process of figure-ground segregation and the related phenomenon of ambiguity.
3. Heterogeneity of figure and background is crucial in this process.
4. To efficiently create maps one must consider manners of detection and discrimination.
5. Therefore, attention and drawing of attention to the relevant objects is an important issue as well.

3.1.1.3 Organization of Knowledge

The *next facet* in the *private/perceptual-cognitive* level is the question of *how maps are understood*. To examine this stage of human-map-interaction the following questions are important to be considered:

1. How does what we perceive interact with our existing knowledge?
2. How is knowledge organized?

MacEachren takes the perspective that

> existing knowledge, in form of propositional, analog and procedural representations, is brought to bear on the interpretation of visual scenes through knowledge schemata that serve as an interface between visual descriptions and knowledge representations. These schemata act to structure what we know about objects, concepts, relationships, and processes in the world. As a result, they also structure what we see by making certain groupings, categorizations, patterns, and so on, more likely than others. In a complementary fashion what we see … provides input to generalized schemata. These complementary processes allow us to make sense out of the visual scene.[94]

MacEachren brings into discussion *three probable knowledge schemata*. These are *propositional, image and event schemata*.

[94] Ibid. p. 150.

Additionally, he points out that the *prerequisite* of using any form of knowledge scheme is the "human propensity to categorize"[95]. The process of *categorizing* determines the design of knowledge schemata.

Therefore, it is important to have a glance on *mental categories* – especially when it is correct that maps would not work without categorization. The knowledge of categorization helps to understand how maps are interpreted. A consequence of this is the answer to the question how good maps should be created.

3.1.1.3.1 Mental Categories

There are *two different kinds of theories* about categories. In this context a category can be defined as something in which things having something in common can be gathered.[96]

The *first* one is the older one, which is based on Aristotle's work on logic. It states that there are *natural categories* being true for everybody and which are in the world *a priori*. [97]

The *second* theory argues that there are no natural categories but that *cultures* provide us with categories through the *process of socialization*.[98]

The latter theory seems to be the one, which is more probable, and it represents a more flexible view allowing multiple representations of individual concepts. *This brings about the need for cartographers to abandon the view that there is only one way to categorize any data set*.

> There is a need to explore the possibility of varying levels of categorization for different goals, application, and perspectives, and to explore how our maps might incorporate some of the less precisely defined (but none the less truthful) ways of categorizing the world.[99]

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[95] Ibid. p. 151.

[96] Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, pp. 266–267 illustrates this with the example of the three-spined stickleback which discriminates rival male fish by the key stimulus of a red marking. All objects having the effective stimulus are organized in the category "rival male".

[97] To gain a quick overview about Aristotle's theory of universals see http://en.wikipedia.org/wiki/Aristotle%27s_theory_of_universals, last access 31.10.2010.

[98] See for the discussion and the several representatives MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, pp. 151–167, or Mead, George Herbert: Geist, Identität und Gesellschaft aus Sicht des Sozialbehaviorismus, Suhrkamp, 1991, pp. 81–166 [Engl.: Mind, Self an Society. From the standpoint of a social behaviorist] for the process of socialization.

[99] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 169.

This leads to the question of how to design useable maps and the need to define relevant audiences for maps. These topics will be dealt with in chapter 4.2 (Usability). Under the conditions described above MacEachren suggests the use of “fuzzy representations of well defined domains”[100], because they allow fast judgments. They use the human propensity to identify patterns quickly and to categorize them. These patterns will be identified for example by “using” the Gestalt laws.

Categories are crucial for the individual for coping with its complex surrounding. Without the ability to categorize elements humans would suffer from information overload and would loose their ability to act.

So, on the one hand they allow the individual to organize its environment. But on the other hand they are the prerequisite for prejudices, which make humans less flexible and tolerant.

So the ability to categorize is both a blessing and a curse.

3.1.1.3.2 Representation of Knowledge

All in all categories are the precondition for the organization and representation of knowledge.

MacEachren suggests dividing knowledge representation into *three types*: *procedural, propositional and analogical*.[101]

These three types interact very complexly. While *procedural knowledge* is the knowledge “of how to do something”[102], *propositional knowledge* is declarative knowledge and *analog representations* can be described as “configurational knowledge about space”[103]. The two last types are *cognitive representations*. MacEachren found out that *map reading relies* on knowledge structures that deal with declarative and *configurational knowledge*. Hence, map reading can generate or change both propositional and analogical knowledge representations.[104]

It is vital to identify in advance what the purpose of a map should be and then address the right kind of knowledge representation. The linkage between procedural and propositional knowledge seems to be stronger than the linkage between proce-

[100] Ibid. p. 170.
[101] Ibid. p. 171.
[102] Ibid. p. 172.
[103] Ibid. p. 172.
[104] Ibid. p. 172.

dural and analog knowledge. Because of different problem-solving strategies of individuals MacEachren comes to the following result:

> My research on the role of maps in environmental knowledge acquisition supports the hypothesis that individuals differ in the tendency to organize map-derived knowledge in an analog versus a propositional (and/or maybe a procedural) form (or in the tendency to retrieve knowledge in that form).[105]

3.1.1.3.3 Object Recognition

But how is the visual array or the scene we "see" processed until it can be in a way "compared" with our knowledge? This question leads to a topic, which psychologists call "object recognition".[106] *Object recognition* is based on structural descriptions that for example describe the relationship between objects, their orientation or their relative position. These relationships can be simple like for the example of letter "T" shown in *figure 14*.

The letter "T" consists of two lines, which are orientated in a specific way *(figure 14 (a)* and *(b)*). The structural description can lead to different ways to represent the letter "T". Depending on the flexibility of the mental category of an individual he or she can identify it or not.

[105] Ibid. p. 173.

[106] Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, pp. 265–298.

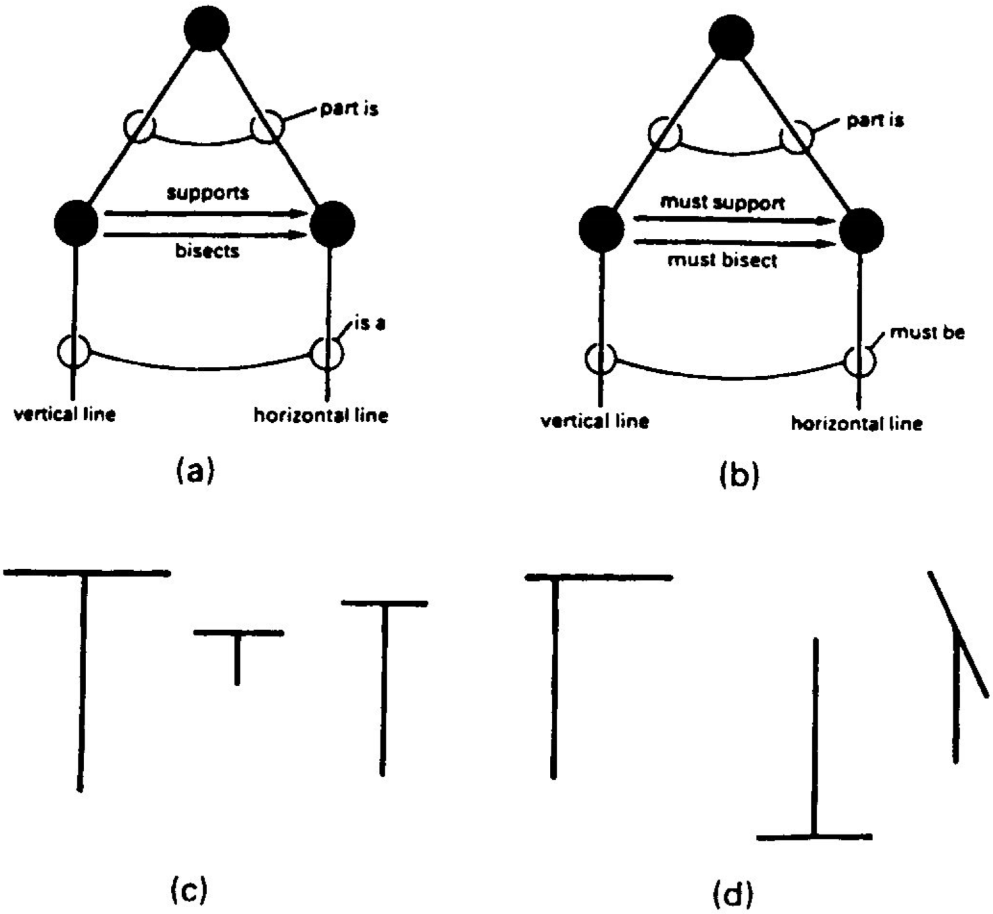

figure 14 *Two different structural descriptions of the letter "T"[(a) and (b)] and possible representations derived from these descriptions [(c) and (d)].* [Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, figure 9.10, p. 273]

However, the structural description of an object like the "National Park Service Point" symbol *(figure 15)* can be much more complex. The symbol itself consists of the frame and the interior. The whole symbol can only be interpreted correctly, if both parts and their relationship are interpreted in the same way as the creator of the symbol did it. If this attempt fails, the whole symbol is useless.

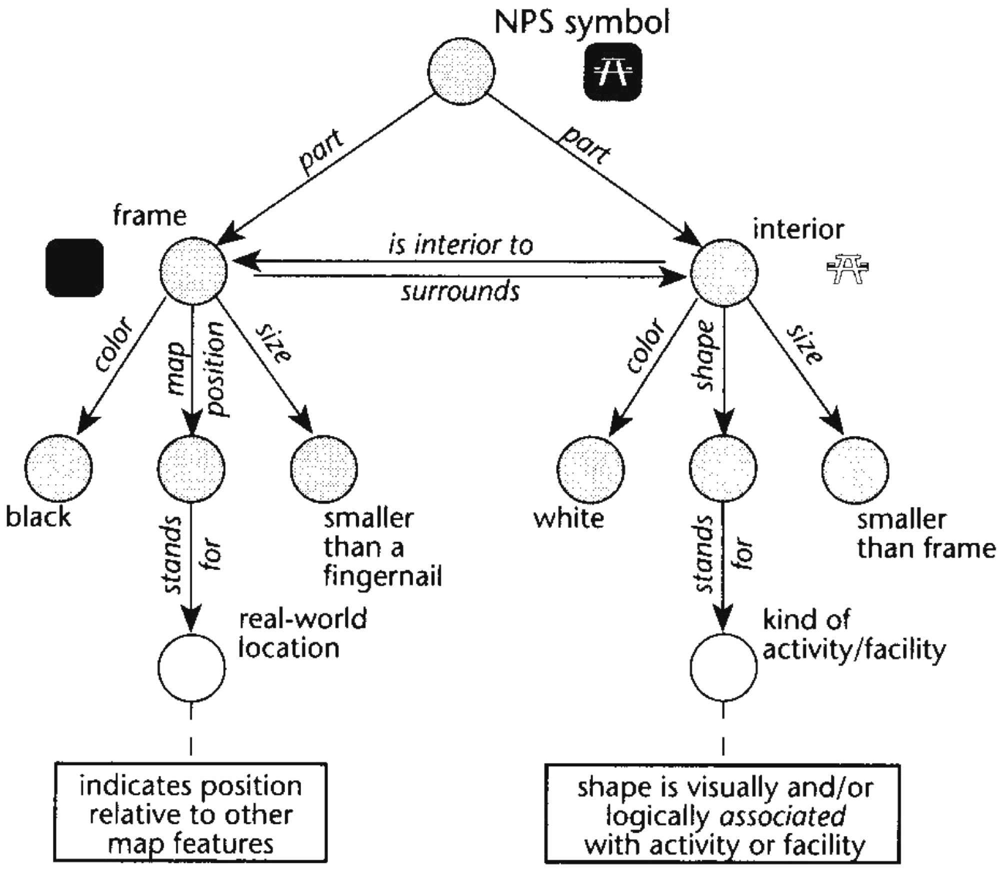

figure 15 *A possible schema diagram for interpretation of National Park Service (NPS) point symbols.*
[MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, figure 4.10, p. 178]

Bruce et al. identify the problem of the vantage point of the viewer, because these structural descriptions are made from a certain point of view. So the problem is to find a description of the object in its own coordinate system and without the usage of object-specific knowledge. Only this could resolve the paradox that relying on object-specific knowledge means knowing what an object is before recognizing it.

Still some knowledge is essential for parsing objects. The remaining question is, how specific it has to be.[107]

A possible first solution might be Marr and Nishihara's "speculative"[108] theory of object recognition.[109] Marr's theory of visual perception has already been outlined in

[107] Ibid. p. 276.
[108] Ibid. p. 281.
[109] Ibid. pp. 276–281. Or Peterson, Michael: Cognitive Issues in Cartographic Visualization, in MacEachren, Alan M. and Taylor, D.R. Fraser (Eds.): Visualization in Modern Cartography, Pergamon, 1994, pp. 27–43.

chapter 3.1.1.1 (Visual Perception and Information Processing). Obviously this theory is the foundation of his and Nishihara's theory of object recognition.

Any given object must be described within a frame of references based on its shape. Therefore a coordinate frame being determined by the shape itself[110] must be set up for the shape before the shape has been described.

The process of recognition can start with several basic elements or "primitives" which are for example edges and blobs. Furthermore however a modular organization of shape description is needed which describes the relative size of these primitives in relation to the object they belong to. Thus, fingers belonging to a human hand cannot be described in a system that uses primitives the size of human arms or legs.

A modular organization of shape description with different-sized elements at different levels of description allows a stable global description being independent of the variation of details and a detailed description at a differentiated level *(figure 16)*.

The first step towards recognition is the identification of an axis of the shape. This is relatively easy for elongated shapes or ones with natural axis of symmetry. Marr and Nishihara restrict their discussion to this class of objects that can be described as a set of one or more "generalized cones". A generalized cone is defined as „the surface created by moving a cross-section of constant shape but variable size along an axis… The cross-section can get fatter or thinner provided that its shape is preserved".[111]

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[110] This kind of coordinate frame is called "canonical coordinate frame".Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, p. 276.

[111] Ibid. p. 276. In this way a ball or a vase can be described as a generalized cone as well.

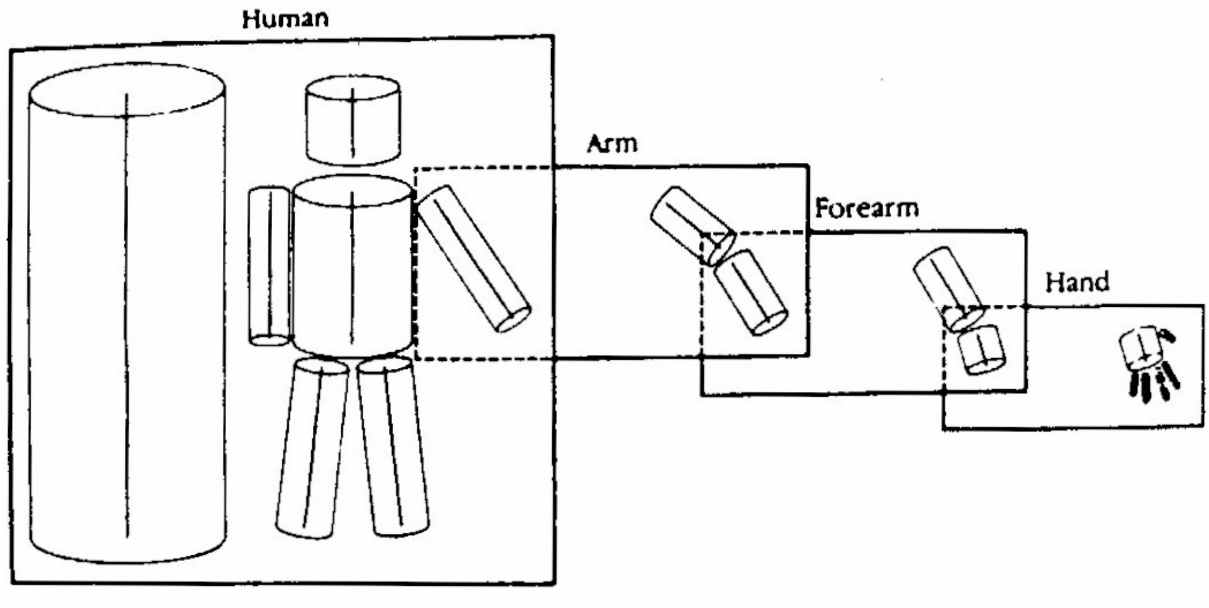

figure 16 A hierarchy of 3-D models. Each box shows the major axis for the figure of interest on the left, and its component axes to the right. From Marr and Nishihara (1978). [Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, figure 9.16, p. 277]

For example a human can be described using a set of generalized cones with the trunk, the head, arms and legs *(figure 16)*. All these cones have their own axis. Together these axes form the representation of a human looking like a stick figure capturing the relative length and disposition of the axes that form the components of the entire structure.

The stick figure is a quite useful description for recognition because it is inherently modular. A single stick or generalized cone can represent a whole leg. If more detail is required on a finer level, it can also be represented with a higher amount of sticks.

> At each level of description we can construct a 3-D model where each 3-D model specifies:
> 1. A single model axis. This provides coarse information about size and orientation of the overall shape described.
> 2. The arrangements and lengths of the major component axes.
> 3. Pointers to the 3-D models for the shape components associated with these component axes.[112]

The result is a hierarchy of 3-D models each with its own coordinate system.

In this 3-D model description recognition is achieved when there is a match between the model description derived from the visual array and one of the 3-D model de-

[112] Ibid. p. 277.

scriptions stored in the memory as “knowledge” which can be hierarchically organized.

For example a human figure can be matched to the general form or the category of a biped. In a more detailed description it can be discriminated from an ape by the relative length of the axes of its components.[113]

There has been some development of Marr and Nishihara’s theory. The concept of cones as primitives has been specified. So for example Biederman’s theory identifies 36 so-called “geons”.

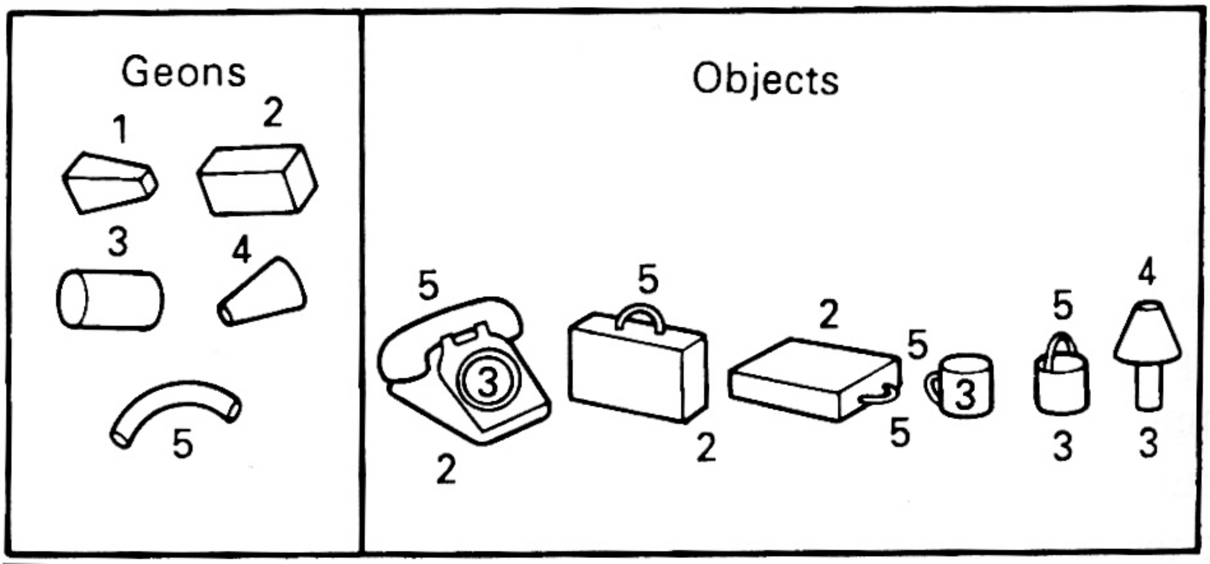

figure 17 A selection of volumetric primitives called “geons” (left-hand panel) are used to specify objects in the right-hand panel. [Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, figure 9.21, p. 282]

In this context “geon“ stands for “geometric icons”. Geons are basic shapes such as wedges, cylinders, pyramids, cubes and so forth *(figure 17)*.[114] Any object is a combination of geons and can be recognized in this way. This makes it possible to recognize objects one has never seen before as long as we know of which geons an object must consist.

Because of the Gestalt law of “good continuation” geons or objects can even be recognized when they are partly covered. Each geon has specific features that can be

113 For a critical discussion of this theory see Bruce, Vicki, Green, Patrick R., Georgeson, Mark A.: Visual Perception, physiology, psychology and ecology, Psychology Press, 2006, pp. 278–281.

114 Ibid. p. 282.

identified from most possible vantage points so there is an effective reduction of ambiguity.[115]

3.1.1.3.4 Conclusion

The findings about 3-D model description and object recognition can be useful for map design – which is 2-D in most cases – as well, because, no matter if we recognize a 3-D object in the “real world” or a artificial 2-D representation of it, the processes remain the same. This is the case, because our vision is made for a 3-D world. Problems that could occur with 2-D representations (i.e. “2-D objects”) like ambiguity have been described in chapter 3.1.1.2.2.

MacEachren points out:

> When dealing with a map or other graphical display, the human propensity to categorize and apply knowledge structures to sort out what is seen leads to both the great advantages and (often hidden or overlooked) disadvantages of visual tools as a prompt of thinking.[116]

Therefore it is quite important to adapt psychological theories to cartography. Using the findings of psychology helps to design maps or visual tools profiting from the human propensity of categorizing. So certain relationships can almost automatically be identified.

After outlining the information processing from perception to recognition the next topic to deal with is the question of “how maps are imbued with meaning”[117].

3.1.2 Public/Social Level

3.1.2.1 Semiotic Approach

According to MacEachen a *semiotic approach* to map representation gives us a frame for scrutinizing *how maps can structure knowledge*. The *assumption* leading to this statement is that *maps gain their meaning from semiotic relationships*.

In this context “semiotics” are defined as the “science of signs”, at which a “sign” can be “considered to be a relationship between expression (the sign-vehicle) and its referent (content)”.[118] This relationship determines how one thing represents another.

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[115] For an outline of Biederman’s theory see: ibid. pp. 282–287.

[116] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 209.

[117] Ibid. pp. 213–353.

[118] Ibid. p. 213.

MacEachren points out that *cartography can profit from semiotics in two ways*.
Firstly, it helps to *develop a "cartographic representation logic"* profiting from the knowledge about cognitive representation, mental categories and knowledge organization, which have been outlined in the paragraphs above (3.1.1 Private/Perceptual-Cognitive Level).
Secondly, *different approaches* of map representation can be *integrated*. In this way one can profit from the diversity of views on the function of maps in societies. This avoids being captured in arguments about map "objectivity".[119]
Taking into consideration the function of maps in societies it gets clear that the discussion of schemata in semiotics is lead from a philosophical, logical and sociological point of view.
This is the reason why it belongs to the social/public level of representation.
MacEachren states that the use of terms concerning semiotics is quite confusing.[120]
This is the reason why the first step towards an understanding of semiotics is definition work.
Semiotic models can be divided into so-called dyadic and triadic models.
Dyadic models state a clear relationship between the sign and its referent. If one follows such a model, the consequence is that every for example map-user would interpret the same sign in the same way. Cultural differences or such differences rooted in experience would not count. This is the reason why in recent theories those dyadic models are evaluated as not useful. Therefore, in this thesis a triadic model will be used.[121]
For the further discussion "sign" will be used as the entity "encompassing an expression, the concept stands for, and the object of reference".[122]
The "carrier of meaning" is defined as a sign-vehicle. The "meaning" (or concept) to which the sign-vehicle refers is labeled the interpretant. This term suggests an act of interpretation that is quite useful for the further discussion.
The object of reference to which the sign-vehicle is linked via the sign is defined as the referent.[123]

[119] Ibid. p. 214.
[120] Ibid. p. 218.
[121] For an extensive discussion regarding both types of models see: ibid. pp. 219–220.
[122] Ibid. p. 218.
[123] For the definitions see ibid. pp. 218–219.

3.1.2.1.1 The Semiotic Triangle

The relationship between these terms can be visualized in the so-called "semiotic triangle". This triangle has the interpretant as a mediator between the sign-vehicle and the referent.[124]

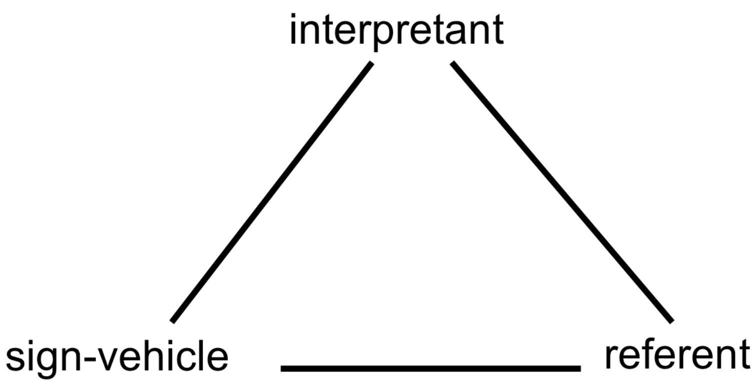

figure 18 *A depiction of the semiotic triangle with the interpretant (rather than the sign-vehicle) as mediator.*
[Derived from Odgen, C.K., and Richards, I.A.: The Meaning of Meaning: A Study of the Influence of Language upon Thought and of the Science of Symbolism, Harcourt, Brace & Co., 1989, p.11]

For cartography this triangle has the advantage that it emphasizes the nature of the interpretant as a link between map symbols and the referent. So it is possible to direct attention to *alternative interpretation* of the relationship between the sign-vehicle and referent.

Such interpretation can be seen as "knowledge schemata as the mediator between what is seen and what is known".[125] This explains why there have to be alternative interpretations. Not everybody has the same knowledge. And knowledge depends on culture and experience.

In everyday life signs can be used in *five different modes* of signifying and *four dimensions*.

The *modes* of signifying can be *designative, appraisive, prescriptive, identificative or formative*.

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[124] Ibid. p. 221. This model was offered by Odgen and Richards. Odgen, C.K., and Richards, I.A.: The Meaning of Meaning: A Study of the Influence of Language upon Thought and of the Science of Symbolism, Harcourt, Brace & Co., 1989, p. 11.

[125] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 221.

The *dimensions* of sign use can be *informative, valuative, incitive or systemic*. Although the modes of signifying and the dimensions of sign use are not necessarily linked, there are some combinations that are most likely.
So designative signs are often used informatively or appraisive signs valuatively.[126]
According to MacEachren *seven categories of signs* can be identified. These categories in a way represent the chance of the correct interpretation of a sign. They are:

1. **Singular sign:** The interpretant permits only one referent.
2. **General sign:** The interpretant permits any number of individual referents (e.g. “river”).
3. **Interpersonal sign:** several interpreters share the same signification (e.g. experts who have special terms).
4. **Comsign:** Has the same signification for the producing organism and the interpreter.
5. **Vague sign:** There is no determination allowed of whether a particular entity is or is not a referent of the sign.
6. **Unambiguous sign-vehicle:** Has one interpretant.
7. **Ambiguous sign-vehicle:** Has several interpretants.[127]

3.1.2.1.2 Denotation and Connotation

Semiotics also deals with questions of denotation and connotation. While denotation is the primary, conscious and explicit meaning of a sign, connotation is a possibly added secondary, implicit and sometimes unconscious meaning of the sign. MacEachren illustrates this phenomenon by using the example of the military uniform.
“A uniform denotes rank and function; it connotes the prestige and the authority attached to rank and function.”[128]

3.1.2.1.3 Comprehension of Signs

It is of further importance to understand how signs are comprehended. This seems to be one key to the question of how maps work.

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[126] Ibid. pp. 226–227. The modes and dimensions of the use of signs are referred to Morris’s typology of discourse.
[127] Ibid. pp. 228–229.
[128] Ibid. p. 229.

To explain the process of comprehension MacEachren refers to Prieto's theory of semiotic acts.[129]

> Fundamental principle of his theory is that for a sign to function, a person comprehending it must recognize that the perceptible sign-vehicle belongs to a particular class and infer from it that some other indicated entity (the interpretant) belongs to a specific class … Both the sign-vehicle and the interpretant exist in a separate "Universe of Discourse" … The sign-vehicle occupies a Universe of Discourse termed a "semantic field" consisting of all the alternatives with which it significantly contrasts … The interpretant's Universe of Discourse is termed the "noetic field" … Comprehension involves comparing these two fields (or Universes of Discourse).[130]

In other words the sign-vehicle is embedded in its semantic context, which has a place in the semantic field. When a person recognizes the sign-vehicle, he or she intuitively tries to find a corresponding object in his or her knowledge – the noetic field[131], which builds up from his or her experiences and the cultural background like different sign-systems in languages (e.g. Arabic script, Cyrillic script, Chinese script, Hebrew script etc.). So the matching of the noetic fields (interpretant) of the creator of the sign and the one of the reader of the sign is mediated by the sign-vehicle. In the case of a text written in Cyrillic script a Japanese not knowing this script at all will have no success in understanding the text. He has no matching noetic classes in his noetic field. In the best case he will recognize the sign-vehicle as a Cyrillic letter. Then one could evaluate the comprehension as a partial failure (see point 2. below).

If the level of matching semantic and noetic classes can describe comprehension, there can be delineated four comprehension possibilities:[132]

1. **Complete success:** The interpreter has reduced the noetic field down to one class exactly corresponding to the class of the sign-vehicle. For the example above the Japanese can read and understand the Cyrillic letter or word.
2. **Partial failure:** A level of uncertainty in the sign-vehicle – interpretant match, because it was not possible for the interpreter to reduce the noetic field to only one class. In the example of the Japanese reading a Cyrillic text might recognize the sign-vehicles as a letter. But he does not know of which script.

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129 He gains his insights using an outline of this theory by Hervey, Sandor: Semiotic Perspectives, HarperCollins Publishers, 1982.

130 See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 232.

131 Noetic is the adjective derived from Noesis (Greek for "insight", "intellection" or "intelligence"). See http://en.wikipedia.org/wiki/Noesis, last access 25.09.2010.

132 See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 233.

3. **Total failure:** The interpreter has reduced the noetic field to one class, but the choice is wrong meaning that sign-vehicle and interpretant do not correspond. The Japanese will not recognize the sign-vehicle as a letter and will interpret it as something else e.g. the scribbling of a child.
4. **Failure due to situational factors:** Either the originator of the sign-vehicle is not as precise as the situation allows the percipient to be, or there are more interpretants than expected meaning that the own definition of an object is not a common definition (e.g. "middle"). The Japanese of the example knows Cyrillic but the writer has an awful handwriting. So the Japanese cannot decipher it. The reason for this might lay in different structural descriptions.[133]

3.1.2.1.4 Semantics, Pragmatics and Syntactics

Mental categories of the noetic field and categories indicated by sign-vehicles in the semantic field need to correspond in some logical way, if maps work under those conditions. Furthermore map schemata must be linked to sign systems developed by cartographers.

This can be achieved by the *dimensions semiosis*, *semantics, pragmatics* and *syntactics* adapted to understanding map representation *(figure 19)*.[134]

While *semantics* studies the relationship between sign-vehicles and their referents, *pragmatics* deals with the relations between sign-vehicle and the interpretant[135]. This means that both are focusing on individual signs.

MacEachren identifies the third dimension "syntactics" as the probably most important dimension for cartography. *Syntactics* scrutinizes the relationship between a given sign-vehicle and other sign-vehicles.

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[133] For structural descriptions see 3.1.1.3.3, p. 35.

[134] For details on this issue MacEachren outlines Morris's considerations. See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, pp. 234–242.

[135] Morris himself distinguishes the interpreter from the interpretant. In the original text by Morris "pragmatics" describes the relationship between sign-vehicle and interpreter. See Morris, Charles W.: Writings on the General Theory of Signs, The Hague: Mouton, 1971, p. 417.

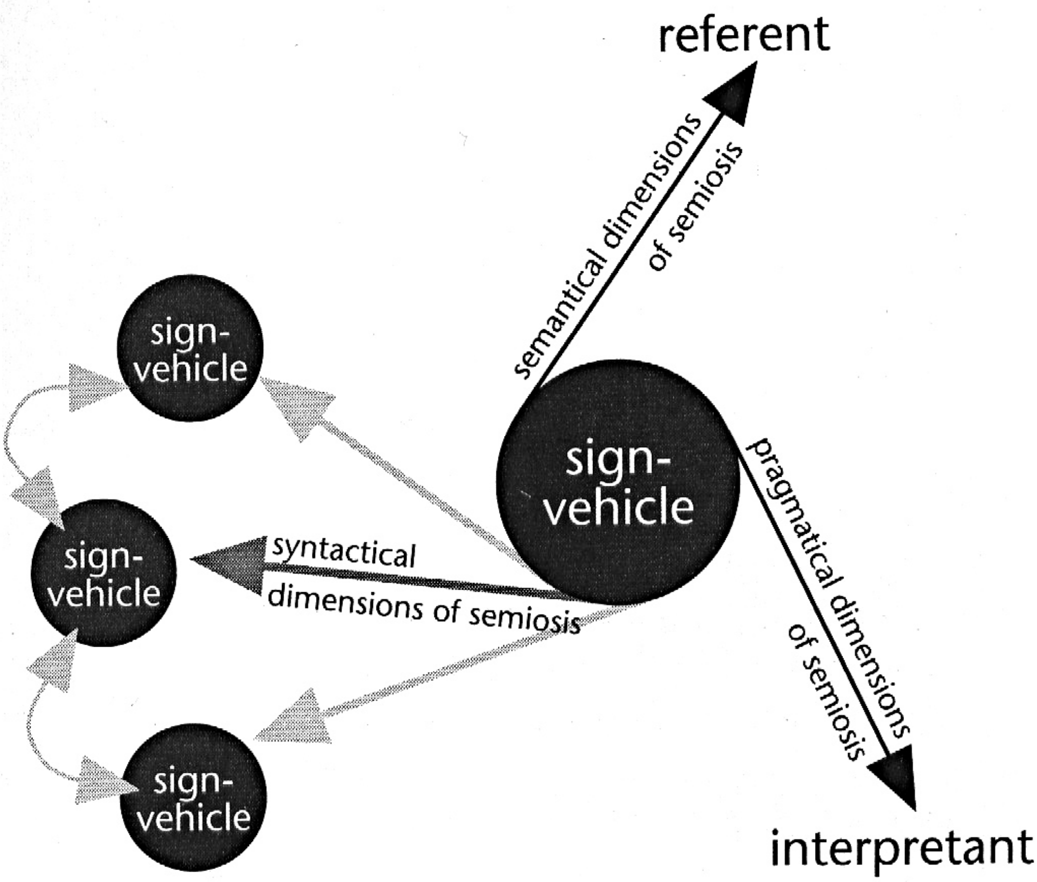

figure 19 *A depiction of a sign as an entity linking its three components via the relations of syntactics, semantics, and pragmatics.* [Derived from Morris, Charles W.: Writings on the General Theory of Signs, The Hague: Mouton, 1971, p. 417]

MacEachren states that the nature of signs can be considered from various points of view. Those depend on the interpretation of the semiotic triangle and the definition of which element is seen as the mediator. Each perspective on this relationship emphasizes particular cartographic issues.[136]

MacEachren identifies visual, dynamic and auditory variables[137] that can be grouped in various combinations to produce sets of map sign-vehicles. With sets of sign-vehicles syntactic relations become relevant.

At the highest syntactic level all possible systems share one universal "rule":

"Similar referents should be depicted by similar sign-vehicles and different referents by different sign-vehicles."[138] This means that this relation should be at least in some

[136] For the ample discussion of the respective issues see MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, pp. 246–269.

[137] For the different variables see: ibid. pp. 269–290.

way iconic. If cartographers abide by this "rule", they allow map percipients to apply the Gestalt law of similarity to visually group similar objects.

MacEachren points out referring to Schlichtmann that interpretants and sign-vehicles should be organized in hierarchies and paradigms.[139]

Each paradigm should be distinguished by keeping one visual variable constant. So on a population map cities might be depicted as circles with varying sizes according to the population of the respective city.

> The choice of which graphic variable(s) to hold constant at each level of a hierarchy should be made on basis of principles of perceptual organization together with syntactic principles related to appropriate matches between specific visual variables and levels of measurement.[140]

It is important that matching sign-vehicle-sets to a particular object or phenomenon not only requires a classification of the sign-vehicle but also of the phenomenon itself. A good and comprehensible set of sign-vehicles therefore will be one in which logical relations within the "noetic field" (in which the respective interpretants are located) are matched to corresponding logical relations within a semantic field (with the relevant sign-vehicles).[141] Additionally, syntactics should be based on cultural agreements and/or psychophysical processes. Regarding hierarchical organization "the simplest and most abstract sign-vehicles should be assigned to the highest level of classification while the lowest level should be assigned the most iconic sign-vehicles"[142]. This implicates that very abstract objects like "climate" are hard to be represented by iconic sign-vehicles and the lower the level of abstraction the higher the probability to find iconic sign-vehicles (e.g. for a tree).

3.1.2.2 Social Aspects – the Lexical Approach

However, map representation should not only be seen in a functional way. The functional approach to map representation offers a method to logically structure information. But it more or less leaves out the aspect of the social milieu in which the interpretation takes place. This facet is the topic of the so-called *lexical approach* to map

[138] Ibid. p. 290.
[139] Ibid. p. 290.
[140] Ibid. p. 290. MacEachren mentions in this context Ratajski's attempt to standardize sign-vehicles for economic maps and discusses it critically. In spite of all critique he states that Ratajski is one of the first to apply systematically semiotics to sign-vehicle sets.
[141] This can be understood as "complete success" in comprehending. See 3.1.2.1.3, p. 45.
[142] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 291.

representation.[143] Following this approach "objective" correctness of a sign-vehicle becomes secondary, because the emphasis lays on the exploration of the various perspectives from which map sign-vehicles might be understood.

From this point of view *meaning* and map *representation* can be discussed from *two perspectives*:

1. the meaning in maps[144] and
2. the meaning of maps[145].

The *meanings in maps* can be interpreted as the primary or *denotative meanings* that are either specified precisely in for example a map legend or can be assumed to be part of a reader's general knowledge of map signs (e.g. water is visualized in blue color). So, for example, the meaning in a roadmap is to describe several roads connecting several places. From this one can find the shortest or quickest way from one place to another.

The *meaning of maps* can be seen as the secondary or connotative meanings given to map signs "as a consequence of a denotative interpretant becoming a referent in its own right"[146]. In the case of the roadmap this secondary meaning is subtler. The roadmap may give an impression of accuracy and impartiality. In this way it could convey "objectiveness" as a connotation. [147]

3.1.2.2.1 Meaning in Maps

MacEachren depicts maps as "powerful tools"[148]. They use five different kinds of intrasignifical codes. These are "tectonic" or related to space, "temporal" or related to time, "iconic" regarding the attribute taxonomy of denotative meanings in maps, and "linguistic" and "presentational". The last two codes "are used primarily to make denotative meaning in space, time, and attributes possible and to limit the map-user's options when determining the intended denotation of particular space, time, attribute

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[143] Ibid. pp. 310–353.
[144] See for more details 3.1.2.2.1, p. 49.
[145] See for more details 3.1.2.2.2, p. 52.
[146] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 312.
[147] See for Denotation and Connotation chapter 3.1.2.1.2, p. 44.
[148] Ibid. p. 312.

map signs”[149]. Linguistic and presentational codes serve to link time, space an attributive denotations with propositional and analog knowledge structures.[150]

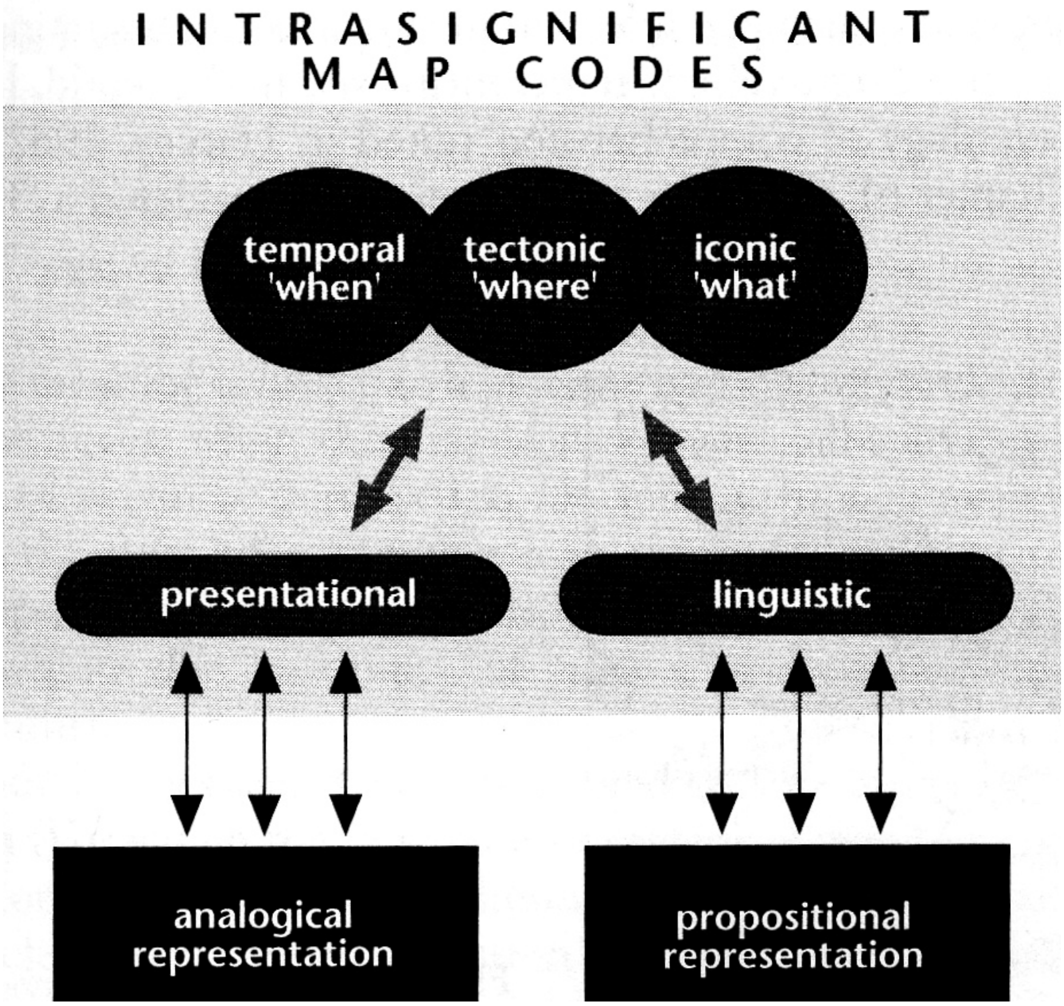

figure 20 *An interpretation of Wood and Fels's (1986) "intrasignificant"codes as they relate to image and propositional representations. Direct denotation of where, when, or what links through presentational and linguistic codes to the broader context of knowledge (in the form of propositional or analogical representations).*
[MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, figure 7.1, p. 313]

Concerning space maps denote relative proximity of entities along with their size, relative direction, shape and so on.[151] A source for misinterpretation of maps is that not all interpretation from map space signs or their relations are to be found in reality, because the map representation might be biased due to its purpose. MacEachren

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149 Ibid. pp. 312–313.
150 For the different forms of knowledge representation see 3.1.1.3.2, p. 34.
151 See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 313.

shows two different maps representing the 1990 mean temperatures relative to long-term temperature as an illustration for this *(figure 21)*. On the left is a Mercator projection, which distorts area widely. On the right is a Goode's projection retaining area correctly. Although the Mercator projection is the common representation of the world it can bias the described phenomenon in a way that leads to severe misinterpretations. Regarding the temperature the Mercator projection implies that a huge area of the world has gotten warmer. The Goode's projection, which retains area correctly, in contrast shows that the warmer area is not that huge.

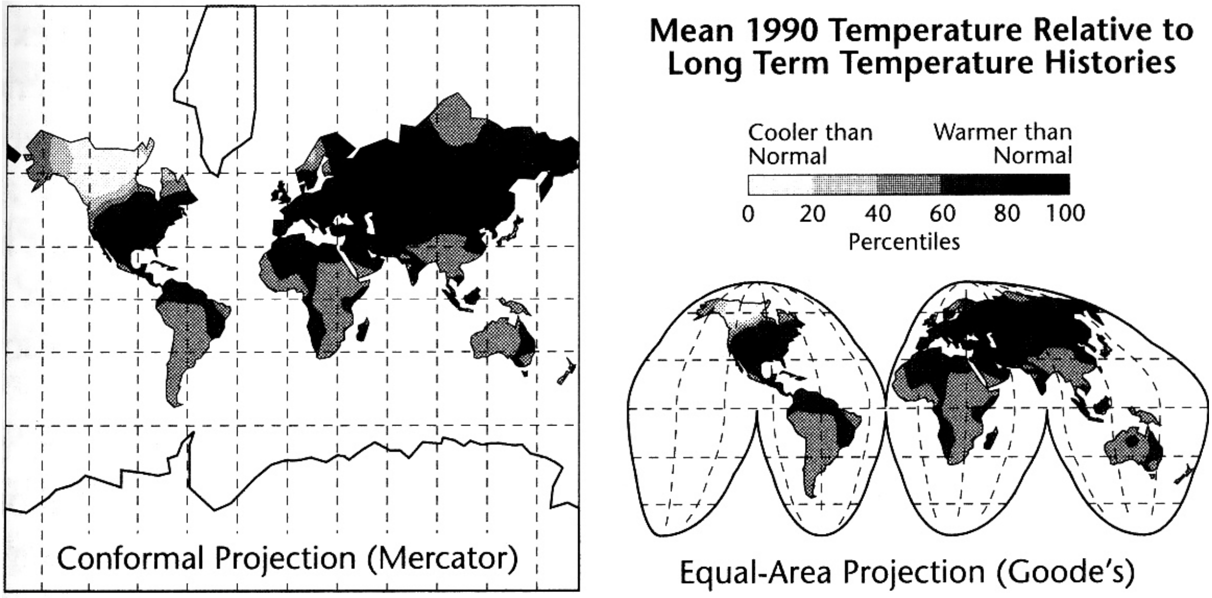

figure 21 *Mean 1990 temperatures relative to long-term temperature. The map as the left uses a Mercator projection (retaining angular relations, but distorting area wildly), while the map at the right uses Goode's projection (retaining correct area, while interrupting the oceans and presenting each pole as a multiple set of points).* [MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, figure 7.3, p. 315]

MacEachren calls this kind of misinterpretation "failure due to situational factors"[152]

> "If a person's general map scheme includes the assumption that relative size on map corresponds to relative size in the world, she is likely to (mis)interpret the sign-vehicles to mean something that they do not."[153]

Even harder to deal with in map representation are the aspects of time and attribute sign meaning.[154]

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[152] Ibid. pp. 314–315 and 3.1.2.1.3, p. 46.
[153] See MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, p. 315.
[154] For details: ibid. pp. 315–330.

3.1.2.2.2 Meaning of Maps

Maps are always produced in a sociocultural context putting "constraints on the potential categories that are considered appropriate to represent and on how the geography to be represented on map is divided into categories"[155]. Being captured in a sociocultural context may be the reason why cartographers often take the features that belong to maps as given and forget to critically ask themselves whether this is the case or not. MacEachren points out that they also "tend to ignore broader issues of how the map as a whole functions as a symbol"[156].

To understand this it is crucial to recall the *difference between denotative and connotative meanings*. While the denotative meaning is the explicit meaning of what things really are, the connotative meaning deals with what the things implicitly stand for (see chapter 3.1.2.1.2 Denotation and Connotation).

Connotations can be seen as indirect signs. They are more likely to differ from individual to individual or from cartographer to cartographer.[157]

Similar to intrasignificant codes in the context of meanings in maps for the meaning of maps five extrasignificant codes can be identified. These delineate the possibilities of connotative meanings of map signs.

[155] Ibid. pp. 330–331.
[156] Ibid. p. 331.
[157] For the discussion whether connotations can be "innocent" or not see: ibid. pp. 331–332.

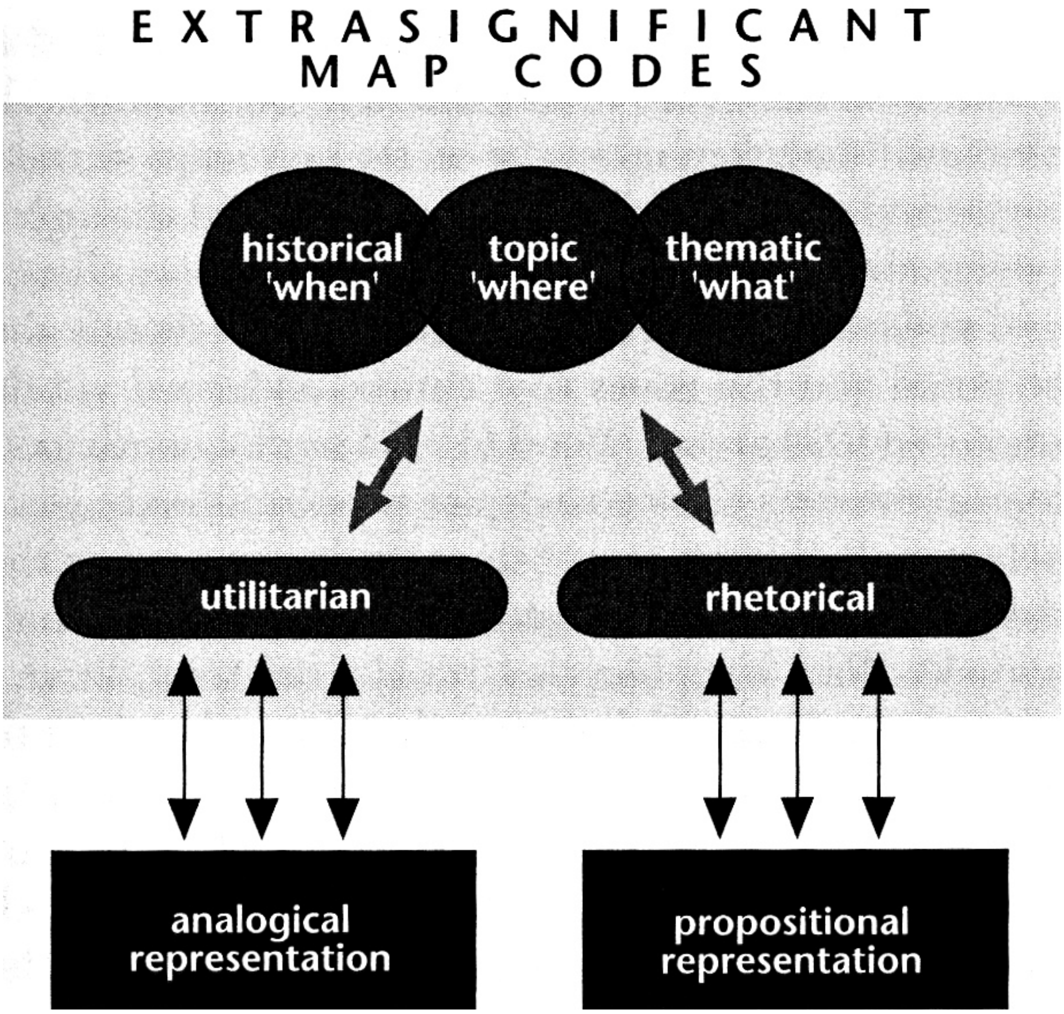

figure 22 *An interpretation of Wood and Fels's (1986) "extrasignificant" codes with their links outward to the society within which they are defined (in contrast to intersignificant codes that link inward to the individual)* [MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, figure 7.13, p. 333]

> *Topic:* Turns space established by tectonic codes into place.
> *Historical:* Turns abstract time into "eras" (which they refer to as "sequacious causal schemata" for organizing conceptions of time).
> *Thematic:* Establishes the subject of discourse (e.g., "automobility," "nature subdues," etc.).
> *Rhetorical:* Sets the tone – "The rhetorical code appropriates to its map the style most advantageous to the myth it intends to propagate" ...
> Utilitarian: Affords the "real" uses of maps (e.g., state possession, monetary control, etc.).[158]

The cartographer's or his client's choices about what to denote and what to leave out decide on the connotative meaning.[159]

[158] Ibid. p. 333. The quotation is taken from Wood, D., and Fels, J.: Designs on signs: Myth and meaning in maps, Cartographica, 23 (3), 1986, pp. 54–103.

Due to social conventions connotations can gradually acquire the status of a denotative sign. In this context it is to be mentioned that those convention differ from culture to culture. This is the reason why – given the trend of globalization – intercultural researches in this area could be so important.
Moreover, the purpose of a map or its role (the utilitarian code) dictates the rhetorical code. MacEachren illustrates this assumption with the design of U.S. Geological Survey maps that connotes accuracy, impartiality and authority. More implicitly the map design connotes that those maps have "no point of view" or are objectively "true".[160]
Connotations convey implicitly concepts of truth and reality, of values and of power.[161] Therefore they are really powerful tools.
This is the reason why it is so important to consider semiotics while thinking of producing maps and to reflexively scrutinize the own concepts and connotation and the question of truth and reality.

3.2 Visualization and Map-Use-Cube

MacEachren states for his map-centered approach that communication and visualization – and thus representation – cannot be divided.[162] So it is important to shortly outline his concept of geographic visualization because it combines all relevant aspects discussed above.
MacEachren has chosen the use of maps as a starting point. This is important to mention because for scientific research it could also have been possible to start from the cartographer's side or from the side of the map-user. The latter perspective will be chosen later on, because it is better suited for usability issues than MacEachren's approach.
The choice to focus on the map is nevertheless comprehensible because when discussing the psychological aspects of perception and information processing the first question was what vision was for. If one is asking the same question concerning maps – i.e. what maps are for –, the answer is clearly that they are for being used.

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159 Ibid. pp. 334–336. MacEachren gives several examples of possible aspects represented in maps and of those left out. Moreover he identifies some possible connotations regarding the color "green".
160 Ibid. p. 335. For the discussion about the connotation of truth and reality see ibid. pp. 338–340.
161 Ibid. pp. 338–351.
162 MacEachren, Alan M. and Taylor, D.R. Fraser (Eds.): Visualization in Modern Cartography, Pergamon, 1994, pp. 2–8.

Consequently, he developed a concept to explain the use of maps. Its basis is the common understanding of "all authors … that visualization includes both an analytic/visual thinking component and a communication/presentation component and suggest (or at least imply) that communication is a subcomponent of visualization".[163] This concept is visualized with the so-called "Map-Use-Cube" *(figure 23)*.[164]

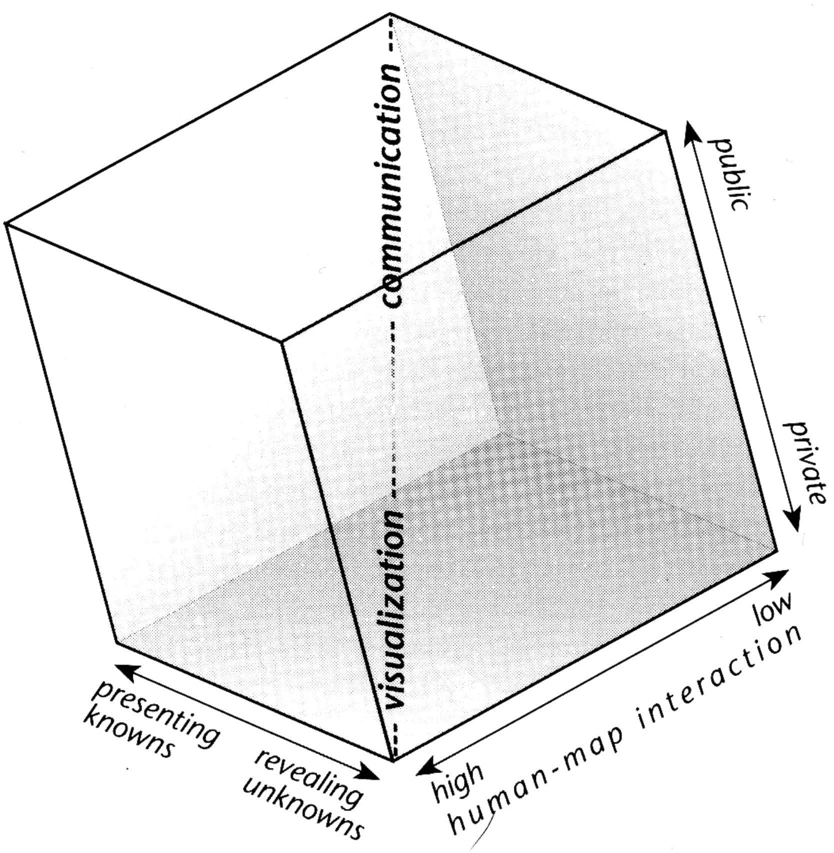

figure 23 *Map-Use-Cube.* [MacEachren, Alan M. and Taylor, D.R. Fraser (Eds.): Visualization in Modern Cartography, Pergamon, 1994, figure 1.3, p. 6]

The three dimensions of the cube are defined by three continua.

The first continuum represents the dimension of map-use. It reaches from the private map-use, in which an individual produces a map for his own use – e.g. a sketch to find from one point to another – to public map-use, in which produced maps are made available to a wider audience – e.g. tourism maps or road maps.

[163] Ibid. p. 5. For the discussion of how to distinguish then visualization from cartography itself see ibid. p. 5.
[164] Ibid. p. 6.

The second continuum represents the purpose of the map. It reaches from the use directed towards revealing unknowns to presenting knowns.

Last but not least the third continuum reflects the level of human-map-interaction reaching from low interaction – where the user only has very limited means to change the representation like on paper maps – to high interaction where he can manipulate the maps in substantial ways like in very interactive internet maps.

Although there are no clear boundaries in the described space, clearly identifiable extremes exist.

The continua of private, revealing unknowns and high interaction meet in one corner. In the opposite corner the ends of the continua public, representing knowns and low interaction meet.

The first corner exemplifies the approach of geographic visualization as proposed by MacEachren.

The second one represents the concept of cartographic communication.

MacEachren states that it is not one single continuum that distinguishes his concept of visualization from other possible concepts but it is their combination or interaction.[165]

He emphasizes this statement by stressing that research on cartographic communication is not irrelevant and that there is no sharp dividing line between communication and visualization.

"Communication is a component of all map-use, even when visualization is the main object."[166] From this perspective even a roadmap having the purpose of communicating information to a broad audience can serve as an inspiration for mental visualization. MacEachren's definitions help to emphasize the different goals – and therefore principles for the design – of maps varying from the primary function of transferring information from a few people to a broader audience to the primary purpose of helping a small audience to think spatially.

So it is important for the further proceeding to identify the relevant audience for the representation on the one hand and to further investigate the aspect of map-use and usability.

[165] Ibid. p. 7.
[166] Ibid. p. 7.

The cartographical product produced in the course of this thesis can be positioned in the concept of the Map-Use-Cube as follows:

The map-use is more private than public, because the map is designed for a specific and rather small audience.

The map is more or less presenting something, which the audience knows. Nevertheless, it reveals some new information or specifies the information about the bodies of water in the Southern Ocean.

On the third dimension the map provides the map-user only with limited possibilities to interact with it.

In the Map-Use-Cube the cartographic product can be positioned as shown in *figure 24*.

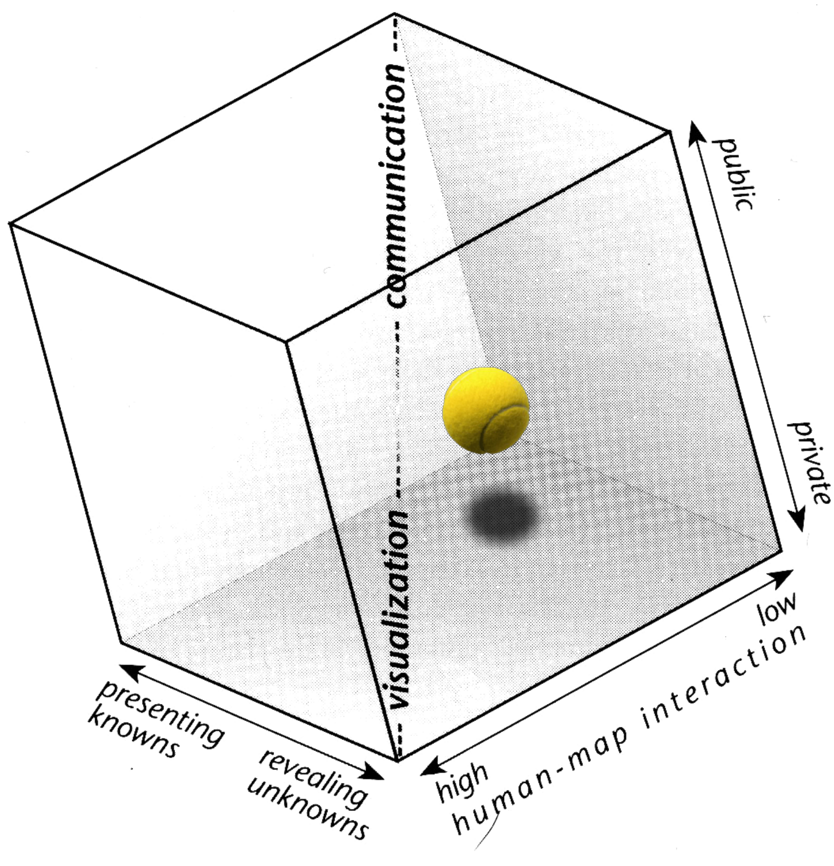

figure 24 *Cartographic product positioned in the Map-Use-Cube.* [Based on MacEachren, Alan M. and Taylor, D.R. Fraser (Eds.): Visualization in Modern Cartography, Pergamon, 1994, figure 1.3, p. 6]

4 Communication

4.1.1 Importance of Communication Theory

As shown in chapter 3.2, MacEachren focuses on the use of maps. From this perspective he develops his concept of visualization, which is map-centered. This point of view puts less emphasis on the map-user and therefore is not so much focusing on issues of usability.

Additionally, MacEachren disregards many aspects of communication theory because he has a limited understanding of communication aspects. This can be derived from his statement that communication theory is mainly concerned about the "elimination of possibilities for multiple connotations"[167] and to reduce in this way possible mismatches.

This is true for the reductionalist and simplistic approaches to communication theory, which has much in common with the tradition of behaviourism[168]. Such reductionalist communication theories propose a dyadic model of communication with a sender and a receiver communicating via channels. One special branch of these theories is information theory, which deals with noise reduction during the transmission of information.[169] Taking into consideration MacEachren's statements in regard to communication theory it becomes clear that he has in mind such a reductionalist theory. In this case his rejection is understandable for both reductionalist approaches to communication theory and behaviourism try to achieve "objectivity" by using what they call scientific methods.[170] In those traditions all sciences have to operate like the "natural" sciences. This point of view does in no way fit MacEachren's statements in regard to representation.

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[167] Ibid. p. 229.

[168] For criticism on behaviorism see 3.1.1, p. 22.

[169] For an overview over the variety of different approaches to communication theory see Burkart, Roland: Kommunikationswissenschaft. Grundlagen und Problemfelder. Umrisse einer interdisziplinären Sozialwissenschaft, Böhlau Verlag, 1995, pp. 15–19. He points out the real complexity of communication only comes into perspective, because so many different branches deal with the "object of investigation". "And none of the different sciences can claim to master the process of communication in all its dimensions." [Transl. C. H.].

[170] For the discussion of different approaches to communication theory and the attempt to adapt information theory to cartography see Keates, J.S.: Understanding Maps, Addison Wesley Longman Limited, 1996, pp. 112–118.

In "human" sciences like psychology and sociology there is no such objectivity.[171] This means that "truth" is not a category. What matters is whether an explanation seems to be reasonable or not. And: What might seem reasonable today might be overthrown by scientific findings tomorrow.[172] An example for this is the turning away from behaviorism towards more comprehensive theories in psychology like those of J. J. Gibson or Marr.[173]

For complex "objects of investigation" only holistic approaches are suitable. The processes described in chapter 3 are very complex. The same is true for the map-user himself, who should be the center of all considerations concerning usability. The use of a holistic approach to communication theory can be assumed as suitable for dealing with this complexity.

Communication theory is relevant for cartography because cartography uses sign-vehicles and depends on the understanding of these sign-vehicles. Several branches of communication theory deal with the same topic.

One objection against applying communication theory is that communication is always an intentional process taking place between at least two persons. The objectors of communication theory in cartography claim that this does not always happen in cartography, because charts may have an artistic dimension as well, in which the cartographer simply expresses himself and does not think about potential map-users.[174]

Nevertheless, in the perspective of this thesis a cartographical product is designed to convey information from the cartographer and/or his client to a map-user.

This is an intentional action. One facet of action theory, which is the basis of such an understanding, is that intentional action is connected with subjective meaning.[175]

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171 For a critique on "objective" communication theory see Habermas, Jürgen: Theorie des kommunikativen Handelns. Band 1. Handlungsrationalität und gesellschaftliche Rationalisierung, Suhrkamp, 1995, pp. 372–373.

172 Elias, Norbert: Was ist Soziologie?, Juventa Verlag, 1996, p. 54.

173 See 3.1.1, pp. 22–32.

174 MacEachren, Alan M.: How Maps Work Presentation, Visualization, and Design, The Guilford Press, 2004, pp. 8–9.

175 See for action theory Weber, Max: Wirtschaft und Gesellschaft, Wunderkammer Verlag GmbH, 2008, p. 3 and for its use in communication theory Burkart, Roland: Kommunikationswissenschaft. Grundlagen und Problemfelder. Umrisse einer interdisziplinären Sozialwissenschaft, Böhlau Verlag, 1995, p. 23.

Jürgen Habermas stresses that the aim of communication is a mutual understanding or at least the attempt to make clear one's point of view.[176]

Both characteristics – intentionality and the attempt to reach a mutual understanding – are true for cartography as well. The cartographer and/or his client want to convey some pieces of information to a map-user and not only to express himself/their selves like an artist, who paints a picture.

Cartography may contain aspects of arts and aesthetics. But those are in most cases not the main purpose of maps.

The great advantage of the perspective on the interaction is that the map-user can be taken into focus. This is very sufficient, if topics of usability are to play a role in the consideration of map-design. Whether a map is useable or not can only be judged by its user and not by the producer.

Therefore, it is important to keep in mind the processes taking place during the perception, recognition and understanding of cartographic information. This can sufficiently be achieved by a user-centered approach to communication.

In 4.1.2 a holistic approach to communication will be introduced.

4.1.2 A Holistic Approach to Communication Theory

A holistic approach to communication theory must meet the requirements of the complexity of the processes of perception and understanding. This complexity has been described on the public/social (chapter 3.1.2) and the private/perceptual-cognitive level (chapter 3.1.1). It is not suitable to divide the whole process of communication into too little pieces. The better way seems to be an integration of the two levels, because they are strongly interrelated.

It is important to keep in mind that communication "happens" between at least two individuals. Those individuals use different sign-vehicles and mean to communicate via different channels. In mass communication – to which the use of maps belong – the used channels vary from visual (e.g. in newspapers, books or printed maps) to audio-visual (e.g. in internet or television) and may use the whole spectrum of senses in the future.

In case of cartography – map design – or in a broader sense in case of map-use the means of communication are the sign-vehicles used in the map.

[176] See Habermas, Jürgen: Theorie des kommunikativen Handelns. Band 1. Handlungsrationalität und gesellschaftliche Rationalisierung, Suhrkamp, 1995, p. 385.

For the understanding of the information represented by the map it is important that the specific sign-vehicles can be detected and recognized (private/perceptual-cognitive level) and that they are understood (public/social level) in the context of the map (semantics and syntactics). If it is the aim to achieve a mutual understanding of cartographer and map-user, the sign-vehicles and the map as an amount of coherent sign-vehicles must be designed in a manner that the user can understand them.

The processes taking place during the use of a map-representation can be described as follows *(figure 25)*:

On the "sender"-side the following processes can be identified:

After the cartographer is sure what the *purpose* of his map should be and what the *relevant audience* is – the purpose has perhaps to be negotiated with one or more clients – he has to try to *find a fitting representation* of the *relevant objects* of "his" reality. If *more individuals* (for example a client or more cartographers) than the one cartographer are involved, *different perceptions and valuations* of *different realities* have to be adapted.

The *result* of these processes is the identification of a *suitable sign-vehicle* used for *map-representation*.

During this process some kind of hidden agendas, socio-cultural aspects and hidden objectives influence the result.[177]

The user of the map is on the side of the "receiver". He has chosen the map because he needs special information about a specific topic. Maybe he is a hiker and plans his next hiking-trip in the mountains. Or in terms of this thesis he is a scientist, who wants to have special information about the limits in the Southern Ocean.

The map-user is also embedded in a socio-cultural environment that could but not necessarily has to be the same as the one of the cartographer and his client.

Taking the map-representation he may detect the sign-vehicles used by the cartographer. He then interprets them along his own concepts and categories. Comparing his semantic and noetic fields he understands what he thinks the cartographer wanted to convey. If the matching of the semantic and noetic fields of both cartographer and map-user is successful, they share the same reality. This reality has been successfully conveyed by a map-representation.

[177] For further details see 3.1.2.2.2, p. 52.

Only maps in which cartographic information is successfully conveyed can be seen as really usable.

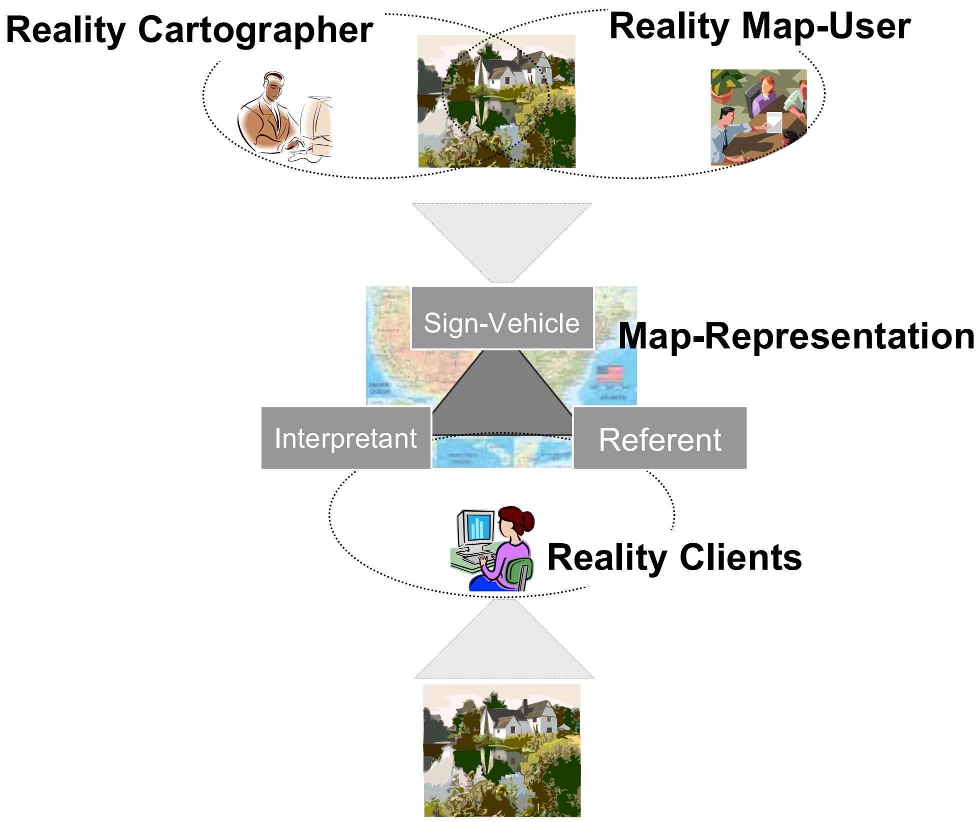

figure 25 *Holistic approach to communication.*

The approach suggested here is a hermeneutic[178] approach. It describes and interprets the processes and derives conclusions that help to improve the map-design. The next step in this theory chapter is the topic of usability.

[178] Hermeneutics is a tradition in social sciences. It deals with the understanding of processes by interpreting them. Its emphasis lays not so much on predictions of future actions but more on the question how and why a decision or an action takes place. For details about the etymology of the word see http://en.wikipedia.org/wiki/Hermeneutic, last access 26.09.2010.

4.2 Usability

4.2.1 Conceptual Considerations

In the widest sense the concept of usability is dealing with the interaction of the map-user with the map. If the map is provided for example via Internet, additionally the topic of man-machine-interface has to be taken into consideration.

Therefore, it is vital to keep in mind the psychological processes described in chapter 3.1.

Recognition can be divided into *two processes* taking place more or less at the same time.

There is the *information processing*, which can be described as a *"bottom-up-process"* resulting from a sensory stimulation and the *"top-down-process"* of *recognition* itself, where the retinal images are recognized by being compared with mental categories.

Therefore, the aim of a suitable cartographic product, which should meet the standards of usability, should be a cognitively adequate visualization.

To meet this criterion it also has to distinguish relevant from irrelevant information. This sounds easier than it is, because the relevance of information differs from audience to audience.

Certain interests and activities identify these audiences. But unfortunately, even specific audiences cannot easily be generalized, because they consist of individuals with different dispositions and preferences.

An example for this is the target audience for a cartographic chart representing the limits of the bodies of water in the Southern Ocean.

At the first glance the audience "scientists with an interest in the Antarctic region" seems to be quite homogeneous. But after further investigation it becomes clear that it is not. The scientists come from different countries with different cultures. Although all these persons can be counted to the same audience with one special interest, they have different dispositions and preferences. The phenomenon of heterogeneity within a target audience is very much supported by the trend of globalization. The quick availability of information concerning a special interest via internet is a fact that has to be taken into consideration. Therefore, one cannot assume the audience – although being very small – to be homogeneous.

Along with interests comes the aspect of attention. As a matter of fact our attention is guided by our interest and it is supported by the design of the sign-vehicle (e.g. closure, contrast and figure-ground-segregation in chapter 3.1.1.2.1).

A usable cartographic chart should make it easy for the map-user to more or less “automatically” identify the information he seeks.

Hence, the data has to be provided in a manner that supports explorative processes.

Nevertheless, it must not be forgotten that the use of a map still remains to be an individual activity.

In chapter 3.1.1 the psychological bases of perception and information processing have been discussed. The socio-cultural dimensions of the map-use have been outlined in chapter 3.1.2.

The socio-cultural environment influences the preferences and the evaluations of the individual and most importantly directs the attention of the map-user to certain features.

From this one can derive at least four topics that are important for producing a useable map.

Firstly, the chosen representation has to meet the limitation and the functioning of human perception and information processing.

Secondly, the map must be tailored to the task it will be used for.

Thirdly, the whole concept of the map must incorporate the technology being used. One must consider the “man-map-interface”. Modern technology can facilitate man-map-interaction a lot.

Last but not least, the map-designer must take into consideration the social and organizational environment of the potential map-user. This topic becomes very important when designing special-purpose cartographic products like the one to be designed in the practical part of this thesis. It deals with topics like the question, which kinds of computer hard- and software are been used by the target audience.

4.2.2 Practical Considerations

As pointed out during the introduction of this thesis the map is and can only be for a purely scientific purpose. The limits that are drawn will in no way have a legal effect on any party of the Antarctic Treaty. *They only will be a suggestion* of how to visualize potential limits in the Southern Ocean for scientific needs.

In contrast to a common international nautical chart the audience in the first place will not be mariners but scientists.

The cartographic product will – according to its purpose – emphasize the limits of the different bodies of water resulting from the bathymetric data, parallels, meridians and rhumb lines.

The limits will be visualized as red lines. This choice can be deduced from the processes that happen during the map-user's perception and interpretation of the cartographic product.

These processes are described in chapter 3.1.

On the private/perceptual level (chapter 3.1.1), which describes what is perceived, the following processes can be identified.

Red as a signal color guides the viewer's attention directly to the relevant topic of the map. He is not distracted by less important features like the outline of Antarctica or the available information about the bathymetry of the seafloor.

The lines are identified as figures, because of their closure. The huge contrast between blue as the background color and red supports the discrimination of figure and ground – the figure-ground-segregation (chapter 3.1.1.2.1). So, the recognized object is classified as an area.

This point represents the interface between the private/perceptual and the public/social level.

The public/social level deals (chapter 3.1.2) with the question of how the perceived object is interpreted. The socio-cultural background of the viewer plays a very important role here. This is the reason why there has to be an analysis of the relevant target audience.

If it is known how this audience normally visualizes certain objects, one could use these known concepts to support the understanding. This procedure is part of a concept that enhances usability.

Familiar visualizations help to avoid misinterpretations. Following the holistic approach to communication proposed in chapter 4.1.2 one could say that in such a case the reality of the cartographer and the reality of the map-user are nearly congruent with each other.

The process beginning with the perception of the sign-vehicle, which is the figure outlined by the red lines, and ending with the interpretation that this figure represents a certain body of water in the Southern Ocean as the referent can be depicted by a semiotic triangle.

This triangle visualizes the relationship between the sign-vehicle, how it is interpreted (interpretant) and what it refers to (referent).

Unfortunately, in case of nautical charts the relevant audience is not used to visualize limits as red lines. It is common but not conventional to visualize limits as dotted black lines, if they are represented at all.

But in the context of a nautical chart, names of certain areas in conjunction with red lines outlining these areas, misinterpretations are not likely to occur.

So using red lines instead of black dotted ones – which would be “best practice” – is a result of scientific analysis and research. This decision is based on a theoretical foundation having its roots in psychology, sociology, semiotics and communication theory. This means that it results from an interdisciplinary scientific approach.

5 Practical Procedure

5.1 Introduction

This part of the thesis summarizes the practical work visualizing the limits of the bodies of water in the Southern Ocean[179] and discusses the results.

The solution of the scientific problem consists of two successive steps. The first step is the analysis of datasets to create a model that is able to support the visualization. The second step is the visualization itself.

Consequently, the first topic to be dealt with is the question, which kinds of different spatial models exist.
The second question is, which kind of model can be created by which dataset.
The third question to be answered is, with which software the models are to be created and which software is to be used for the visualization.

Thereafter, it has to be decided, which model is best suited for supporting the visualization.

Last but not least, the limits of the bodies of water of the Southern Ocean have to be visualized.

Finally, the practical work conducted in the thesis is discussed and some prospects are given.

The practical part illustrated in this chapter is located in the part "Visualization" of the workflow depicted in *figure 3*.

[179] For the region described by the term Southern Ocean see 2.1.2, p. 10.

How to fix Limits

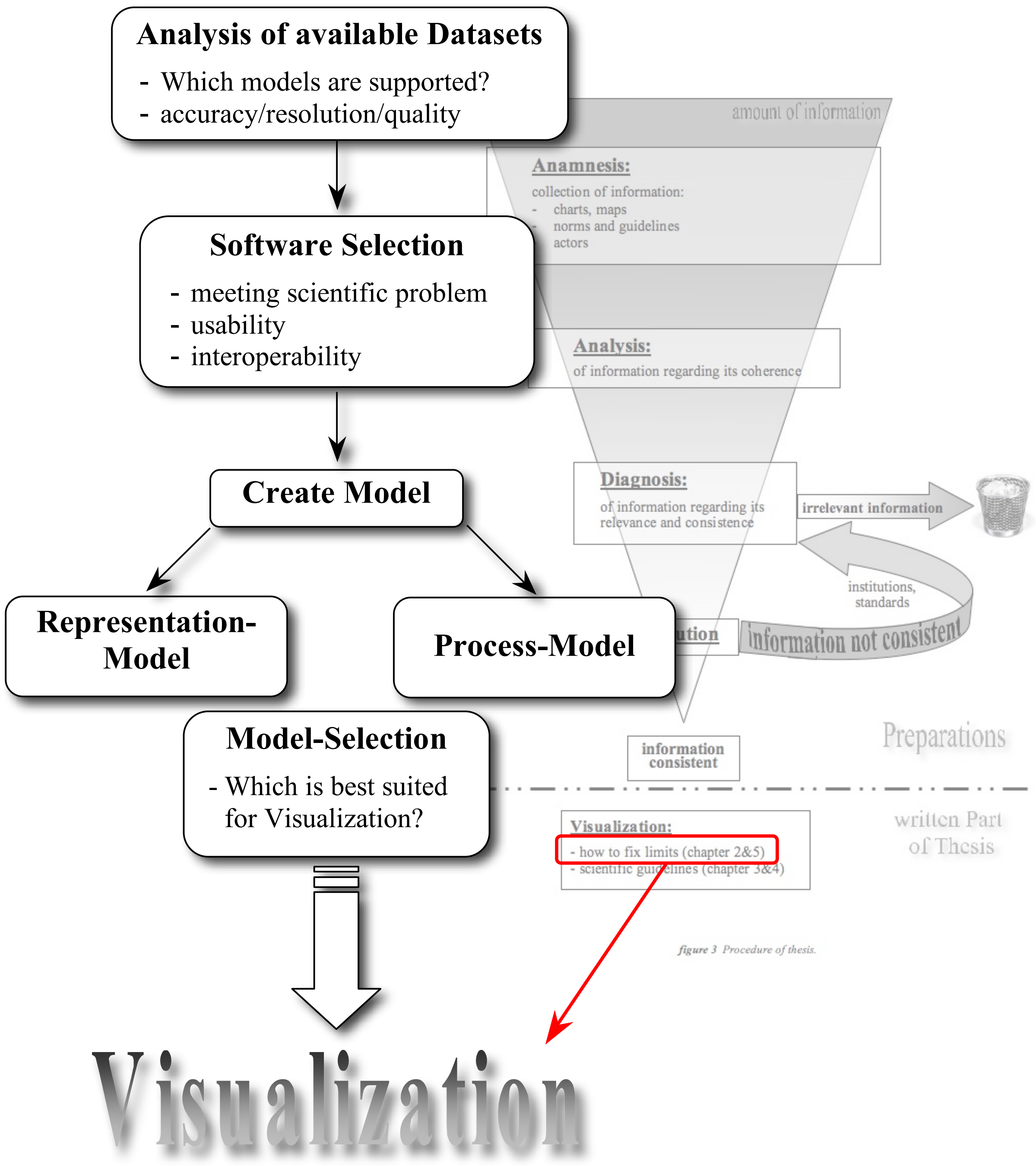

figure 26 *Practical procedure.*

5.2 Data Analysis and Spatial Modeling

Software analysis tools are able to help creating two different kinds of spatial models from the available bathymetric data.[180]
These main types of models are:

1. Representation models, which represent objects and features of the landscape.
2. Process models, which simulate processes in the landscape.

As pointed out in the Practical Considerations[181] the limits of the bodies of water in the Southern Ocean will be fixed using major features of the seabed where possible in conjunction with parallels, meridians and rhumb lines where necessary.
The major features have to be modeled from the available datasets[182]. This can either be conducted "directly" by an elevation model representing sea mountains, etc. (representation model) or "indirectly" by identifying drainage systems in the Southern Ocean (process model).
So both of these possible spatial models are potentially suitable for this thesis. The decision in favor or against one specific model can only reasonably be made after examining the available datasets, if they are sufficient to create both kinds of models. If this is the case, the results of both models have to be compared. The decision then depends on how useful the models are for fixing the limits.

5.3 Discussion of available Datasets

There are two different datasets available, which deal with the area of concern. The first is a dataset taken from the "GEBCO One Minute Grid"[183]. The second is the BEDMAP/BEDELEV dataset provided by the British Antarctic Survey[184].

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[180] See http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Modeling_spatial_problems, last access 11.09.2010.
[181] See chapter 4.2.2, p. 65.
[182] The available datasets are the GEBCO-dataset and the BEDELEV-dataset. Both are of different accuracy and are achieved from different sources. The quality and the usefulness of the respective datasets will be discussed in 5.3, p. 71.
[183] See http://www.gebco.net/data_and_products/gridded_bathymetry_data/, last access 10.09.2010.
[184] See http://www.antarctica.ac.uk//bas_research/data/access/bedmap, last access 10.09.2010.

The bathymetric data of both datasets are collected with different instruments and accuracy. The most common techniques are echosounding and satellite altimetry.

5.3.1 Techniques to collect Bathymetric Data

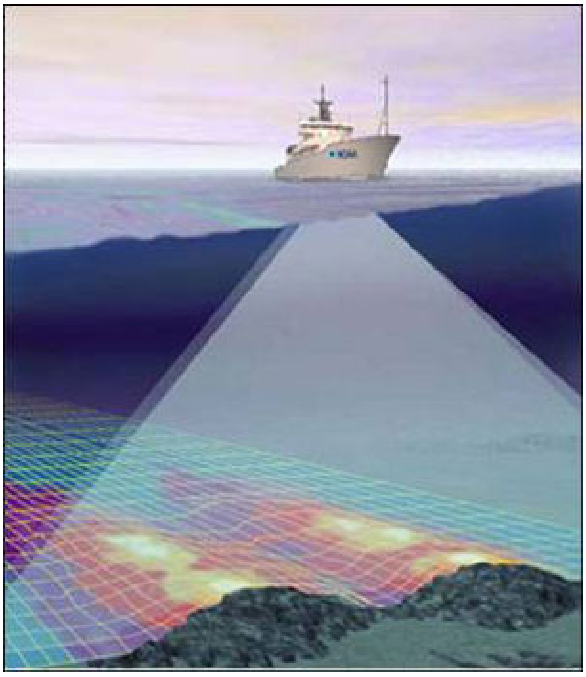

figure 27 *Procedure of echosounding using multibeam echosounder.*
[http://www.hawaiianatolls.org/research/June2006/painting_seafloor.php, last access 25.10.2010.]

Bathymetry is the study of underwater depth of lake or ocean floors.

Bathymetric charts support the safety of surface or sub-surface navigation, and usually provide information about the topography of the seafloor by using contour lines (depth contours or isobaths) and selected depths (soundings).

“Bathymetric map” is a more general term, which encompasses also those cartographic products in which navigational safety is not a concern. These cartographic products may also use Digital Elevation or Terrain Models (DEM or DTM) and artificial illumination techniques like “shading”.

There are several techniques to collect bathymetric data. The most common ones are echosounding and satellite altimetry.

The echosounder or sonar is typically mounted beneath or over the side of a ship. It sends a beam of sound downward to the seafloor. The time it takes the sound to travel through the water, be reflected by the seafloor and return to the sounder is the basis for the calculation of the depth of the sea at one specific point. The commonly used multibeam echosounders send out hundreds of very narrow adjacent beams arranged in a fan-like swath of 90° to 170°. This technique provides a high angular resolution and accuracy and allows a ship to map more of the seafloor in less time than a singlebeam echosounder. Attitude sensors allow for the correction of the ship's roll, pitch and yaw on the ocean floor. A gyrocompass provides accurate heading information to correct for the ships yaw. The Global Positioning System (GPS) is used to position the soundings with respect to the surface of the earth. A computer system processes the collected data, correcting for all of the biases mentioned and for factors of non-uniform water column characteristics like temperature, conductivity and pressure.

The accuracy and density of the collected dataset for a specific area depend very much on the ship tracks *(figure 28)*.

Nowadays, satellites are also used to measure bathymetry. The radar mounted on the satellite detects subtle variations in the sea level, which are caused by the gravitational pull of undersea mountains, ridges and other masses. On average, the sea level is higher over mountains and ridges than over abyssal plains and trenches. These phenomena are used to create DEMs or DTMs and bathymetric maps.

5.3.2 GEBCO One Minute Grid

The GEBCO One Minute Grid is a computer-based representation of a 3D dataset. The z-value represents the depth of the seafloor and is given at evenly spaced increments of longitude (x) and latitude (y).[185] Its resolution is a 1 arc minute grid spacing. The raw data of this vector-dataset comes from the digitization of contours from the GEBCO Digital Atlas (GDA), track lines of ships performing echosoundings and satellite altimetry and coastline data.[186]

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185 See Goodwille, Andrew M.: Concepts behind the GEBCO global bathymetric grid, 2004, https://www.bodc.ac.uk/data/online_delivery/gebco/gebco_one_minute_grid/#version, p. 2, last access 10.09.2010.

186 See User Guide to the GEBCO one Minute Grid, http://www.gebco.net/data_and_products/gridded_bathymetry_data/, pp. 2–4, last access 10.09.10. For further information regarding the gridding method see ibid. pp. 7–11 or

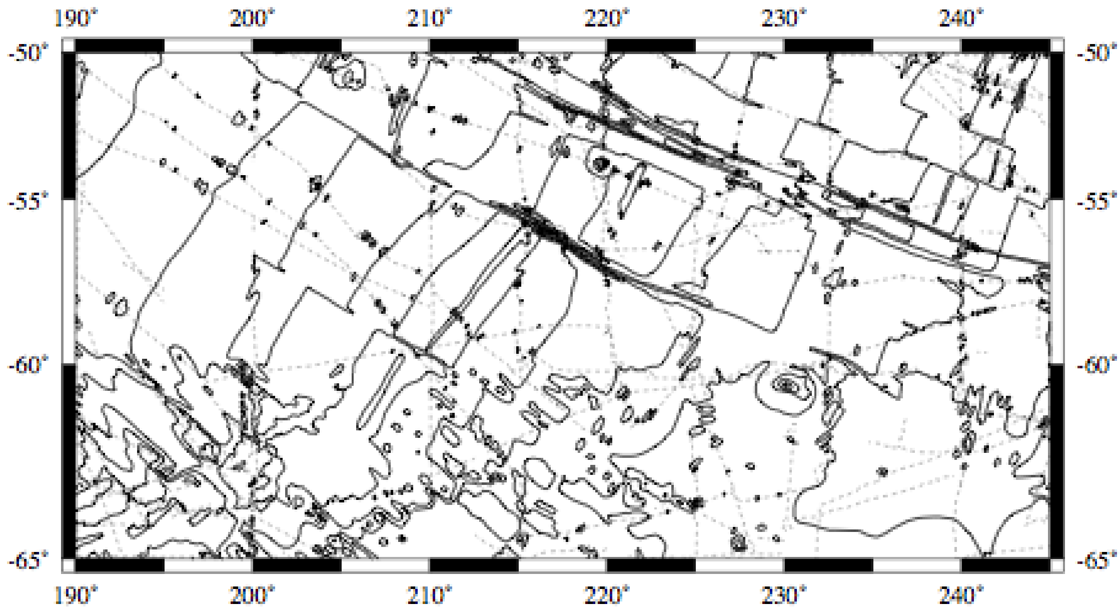

figure 28 *The GEBCO contours (__) and ship track control (...) in an area along the Pacific-Antarctic Ridge show the use of geological interpretation to assist contouring.* [User Guide to the GEBCO One Minute Grid, figure 4.1, p. 31]

The quality of the grid is not easily to be assessed. As pointed out in the User Guide to the GEBCO Minute Grid:

> Assessing grid quality simply as a difference between grid and input depths fails to take into account the wealth of data and expert geological knowledge that were used be the bathymetrists to painstakingly construct the GDA contours… Thus, some measure of the quality of the contouring is perhaps more useful than a statistic determined from the grid depths.[187]

The grid has further limitations, which are relevant for the use of the dataset in this thesis:[188]

1. GEBCO's traditional concern has been the interpretation of bathymetry in deep waters. Therefore, for decades standard contours have been fixed at intervals of 500m. Although significant quantities of data contoured at intervals of 200m and 100m have been incorporated recently, the standard 500m contours comprise the bulk of the dataset.
2. It is possible that a bathymetric feature with a height less than 500m could be excluded from the GDA contours if its base and peak fall inside the same

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https://www.bodc.ac.uk/data/online_delivery/gebco/gebco_one_minute_grid/#version, last access 10.09.2010.
[187] Ibid. p. 12.
[188] Ibid. pp. 14–15.

500m-level contour. For this reason it is not likely that the GEBCO dataset is suitable for creating a sufficient process model, because these features could have a large impact on flow directions.[189]

3. The 1x1-minute bin size used in the grid does not imply that the input data were this densely distributed.

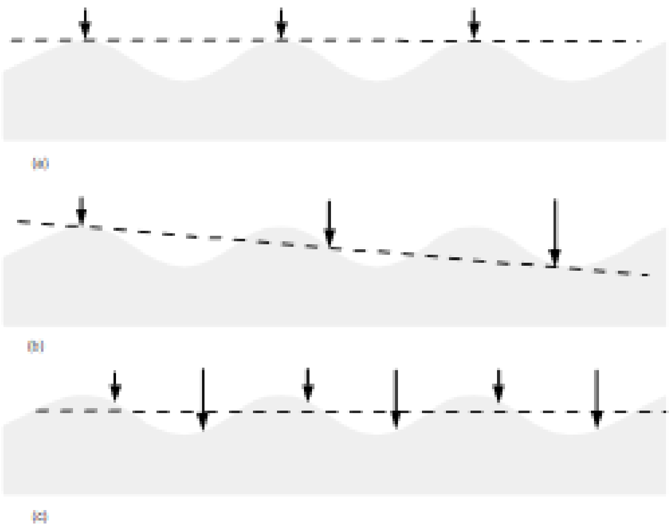

figure 29 *Sampling an undulating surface at different frequencies. The dashed line is a linear least-squares fit through the samples.* [User Guide to the GEBCO One Minute Grid, figure 3.1, p. 28]

Furthermore, concerning computer visualization it has to be pointed out that the GEBCO dataset will not sufficiently support perspective views or "shading". These visualization techniques will only be successful if the first differences of the gridded data – meaning the numeral approximation of the first derivatives of the data in the grid directions – are reliable. The reason for this is that these techniques involve calculating the angle of the local perpendicular to the gridded surface.[190]

Concerning the GEBCO dataset the User Guide states: "Most of the gridding algorithms which are specified to grid contour data yield a grid with poor quality derivatives, unfortunately."[191] This means that this dataset will not support the creation of perspective views to visualize the undersea features in the Southern Ocean.

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[189] For further information see 5.6, p. 83.

[190] Ibid. p. 22.

[191] Ibid. p. 22.

Furthermore, for the same reason the dataset is not suited for performing analysis as the basis of a process model representing flow directions and drainage systems.[192] Still it is well suited for generating a representation model with contour lines. Best results are likely to be achieved in a model with 500m-intervals.

5.3.3 The BEDMAP/BEDELEV dataset

The BEDMAP project was designed as an attempt to rationalize the coverage of ice thickness measurements over Antarctica, compile the data and produce a new topographical model of the bed of the Antarctic Ice Sheet, to provide a new basis for all aspects of Antarctic geosciences.[193] Therefore, its main focus lies on the Antarctic continent. Nevertheless, the whole Antarctic region south of 60° South Latitude is covered by the dataset.

The BEDMAP project used a consistent projection (Polar Stereographic projection with 71°S as the latitude of true scale and 0°E as central meridian), geoid model and a geographic framework.[194] Coordinates are expressed in meters with the origin at the South Pole. As the vertical reference system for the integration of all source data a geopotential model (OSU91A) was chosen. The introduction of this model has become necessary to facilitate the integration of bathymetric data with terrestrial data.

To delimit the continent boundary and its physiographic elements like ice sheet, ice shelf or ice-free ground the 1:1,000,000 scale dataset from the Antarctic Digital Database (ADD), which is the best resolution data with complete coverage over the continent and provides important descriptions of rock outcrop polygons, grounding lines, ice shelves and ice rises.

The datasets have a nominal grid spacing of 5 km. The BEDELEV grid is a 1334x1334 data array with a total elevation range of approximately 11,000m. Additionally to the orthometric digital elevation model (DEM), which is referenced to the OSU91A geopotential model, an ellipsoidal height DEM relative to the WGS84 ellipsoid has been constructed.

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[192] For the exact mathematical explanation why the GEBCO dataset is not suitable for such calculation although contour data theoretically could be, see ibid. pp. 24–30.

[193] See http://www.antarctica.ac.uk//bas_research/data/access/bedmap/information/introduction.html, last access 10.09.2010.

[194] See http://www.antarctica.ac.uk//bas_research/data/access/bedmap/download/information.html, last access 10.09.2010.

A DEM is the prerequisite for performing process analysis with the analysis software. It is defined as a raster representation of a continuous surface, usually referencing the surface of the earth. The data accuracy is determined by the resolution (distance between sample points), the data type (integer or floating point) and the actual sampling of the surface when creating the original DEM.[195]

So, the BEDELEV dataset is suitable for creating a process model.

5.3.4 Conclusions

The available datasets GEBCO One Minute Grid and BEDELEV have been designed for different purposes and with different techniques. As a consequence, they are tailored for generating different models.

The GEBCO dataset with its focus on the contours of the seafloor has the potential to generate a representation model of the seafloor of the Southern Ocean. But it will fail in generating a process model because of the type of data used to create the dataset.

Therefore, this dataset will be used for a representation model.

The DEM of the region south of 60° South Latitude created by the BEDELEV dataset – although having a lower resolution than the GEBCO dataset – provides the opportunity to create a process model of the flow directions and the drainage system of the bodies of water in the Southern Ocean.

The overarching question whether both datasets are accurate enough to support the fixing and visualizing of the limits of the bodies of water in the Southern Ocean still remains unanswered.

Only performing the respective analysis using the datasets to create the specific models – representation model with the GEBCO dataset and process model with the BEDELEV dataset – and comparing the results regarding their usefulness for the visualization can finally give an answer to this question.

5.4 Software Selection

The next question in regard of the practical procedure is what software should be used to analyze the bathymetric data and to visualize the limits of the bodies of water

[195] See http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Exploring_Digital_Elevation_Models_(DEM), last access 10.09.2010.

in the Southern Ocean. Furthermore, it is to be decided whether one computer program is to be used for both steps or if it is more useful to use specific software for each step.

The first criterion for the software selection is that it should be able to solve the scientific problem.

Taking into account the conclusions from the theoretical part of this thesis, as the second criterion the chosen software should be known and used by the relevant audience (usability).

As a third criterion the software should support GIS-applications because the cartographic product does not stand alone but is part of the IBCSO-Project, which includes the creation of a GIS for the region of the Southern Ocean.

Derived from the need to integrate the cartographic product into SOGIS the used software must be interoperable.

In this thesis ESRI ArcGIS is used for both the analysis and the visualization of the limits of the bodies of water in the Southern Ocean for several reasons.

Firstly, ESRI ArcGIS is well suited for performing analysis of spatial data with its "Spatial Analyst"-tools.[196]

Using these specific tools ESRI ArcGIS helps to create spatial models[197] – both representation models and process models – out of the bathymetric data. These models can help to use the data to support the fixing of suitable limits of the bodies of water in the Southern Ocean.

Moreover, ESRI ArcGIS provides proper tools for a suitable visualization.

For ESRI ArcGIS can support both analysis and visualization there is no need to use separate software for both tasks. Thus it is possible to avoid interoperability problems, which could occur otherwise.

Secondly, ESRI ArcGIS is the state-of-the-art software for GIS applications and it is widely used by the specific audience. Therefore, the use of this software will contribute to enhance the usability of the cartographic product.

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[196] See http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Solving_spatial_problems, last access 09.09.2010.

[197] In the context of this thesis the term "model" describes a simplified, manageable representation of reality.

Additionally, it is possible for scientist not having ESRI ArcGIS installed on their computers to download ESRI ArcGIS-Explorer[198]. In this way they can easily participate in the information provided by the GIS.

Finally, the IBCSO-Project uses ESRI ArcGIS as a software platform. With a visualization of the limits of the bodies of water in the Southern Ocean conducted with the help of ESRI ArcGIS for the use in an ESRI ArcGIS-based GIS there will be no interoperability problems.

5.5 Representation Model – The Surface of the Seafloor

Generally, representation models describe the objects of a landscape. In the case of the area of concern these are undersea features like sea mountains, the contours of the seafloor, trenches in the sea, etc.. Representation models in a GIS are created through a set of data layers.

Using ESRI ArcGIS these data layers will be raster data.[199] Raster layers are represented by a grid with each location being represented by a grid cell, which has a value. Cells from various layers stack on top of each other. In this way, they describe many attributes of each location *(figure 30)*.

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[198] Source for ESRI ArcGIS-Explorer:
http://www.esri.com/software/arcgis/explorer/arcexplorer.html, last access 11.11.10.

[199] See
http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Modeling_spatial_problems, last access 11.09.2010.

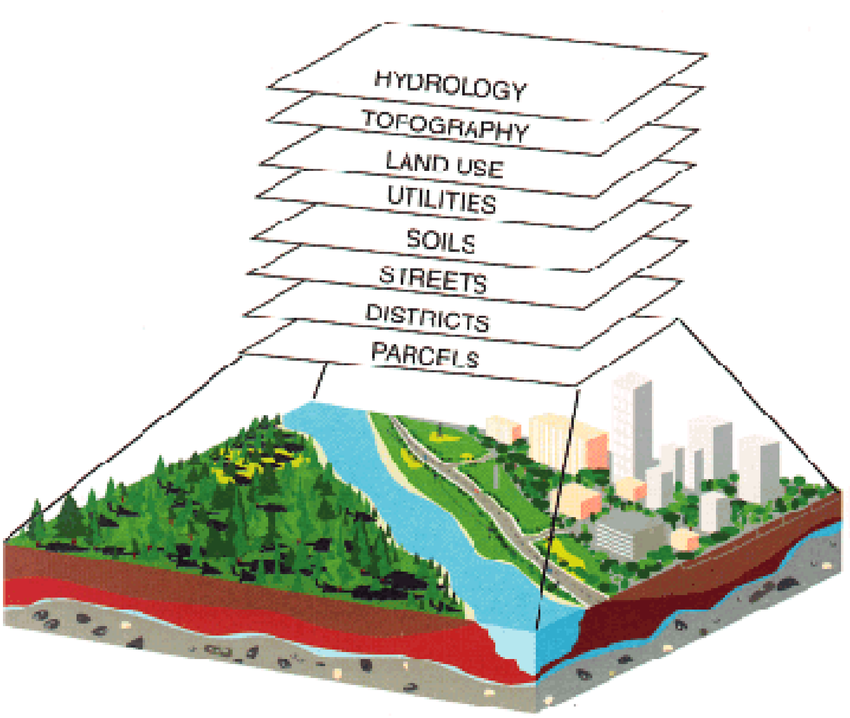

figure 30 *Example of a representation model with various layers describing different attributes.* [ESRI ArcGIS 9.2. Desktop Help, http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Modeling_spatial_problems, last access 11.09.2010]

A representation model tries to capture the spatial relationships within an object – e.g. the shape of an undersea feature – and between the other objects in the landscape – e.g. the distribution of sea mountains and trenches in the sea in a specific area.

In this thesis the representation model of the seafloor of the Southern Ocean will be created using the GEBCO dataset.

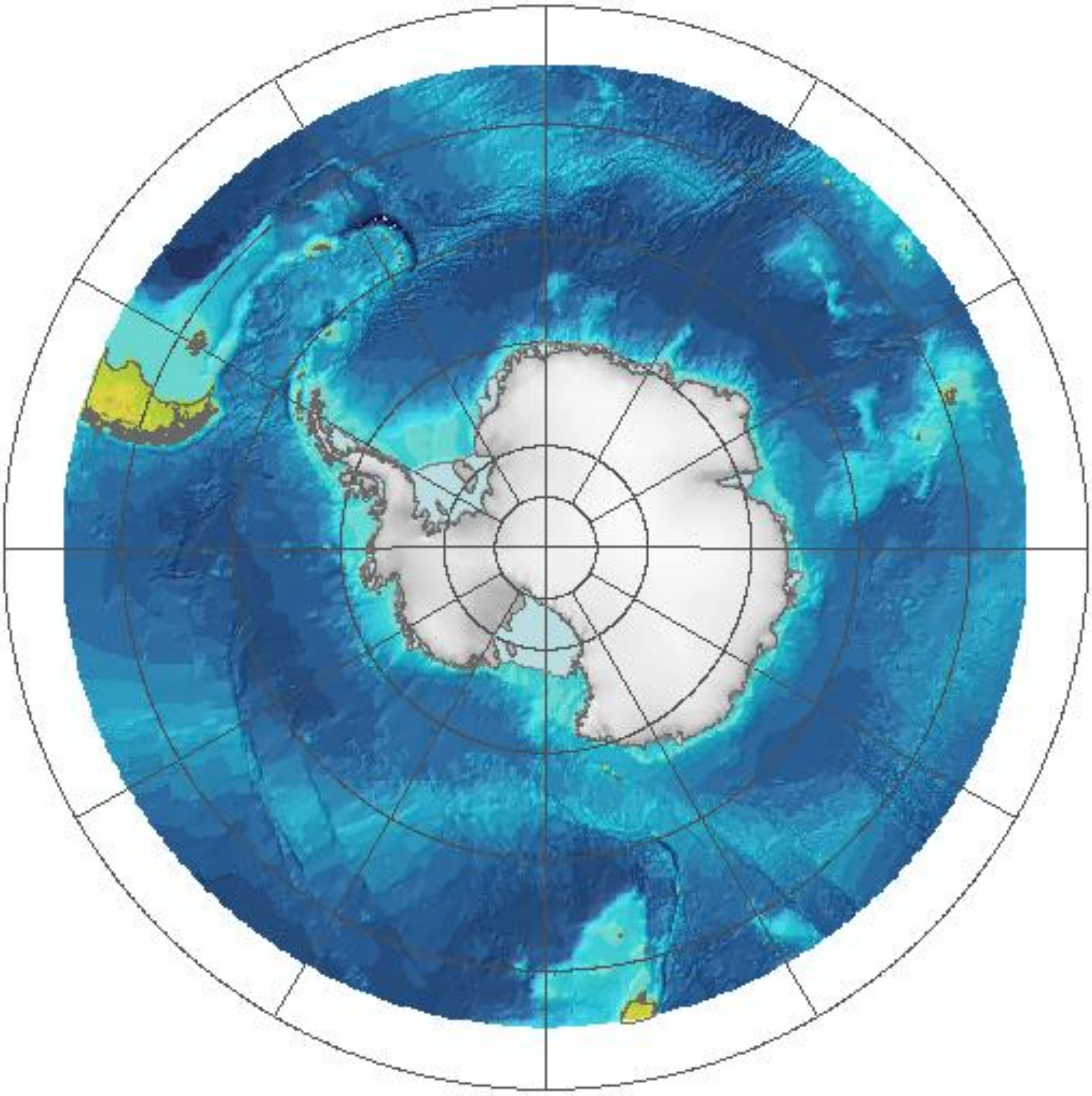

figure 31 GEBCO dataset created with ESRI ArcGIS.

Using the “Surface”-tool of ESRI ArcGIS a layer is created, which provides information about the elevation of the terrain. The “Contour”-tool represents this information with the help of isobaths in adjustable intervals.

The interval chosen for the representation model below is 500m. The reason for this lie in the data quality of the GEBCO dataset[200] and in the fact that only major undersea features are reasonably used for fixing the limits of the bodies of water in the Southern Ocean.

[200] See 5.3.2, p. 73.

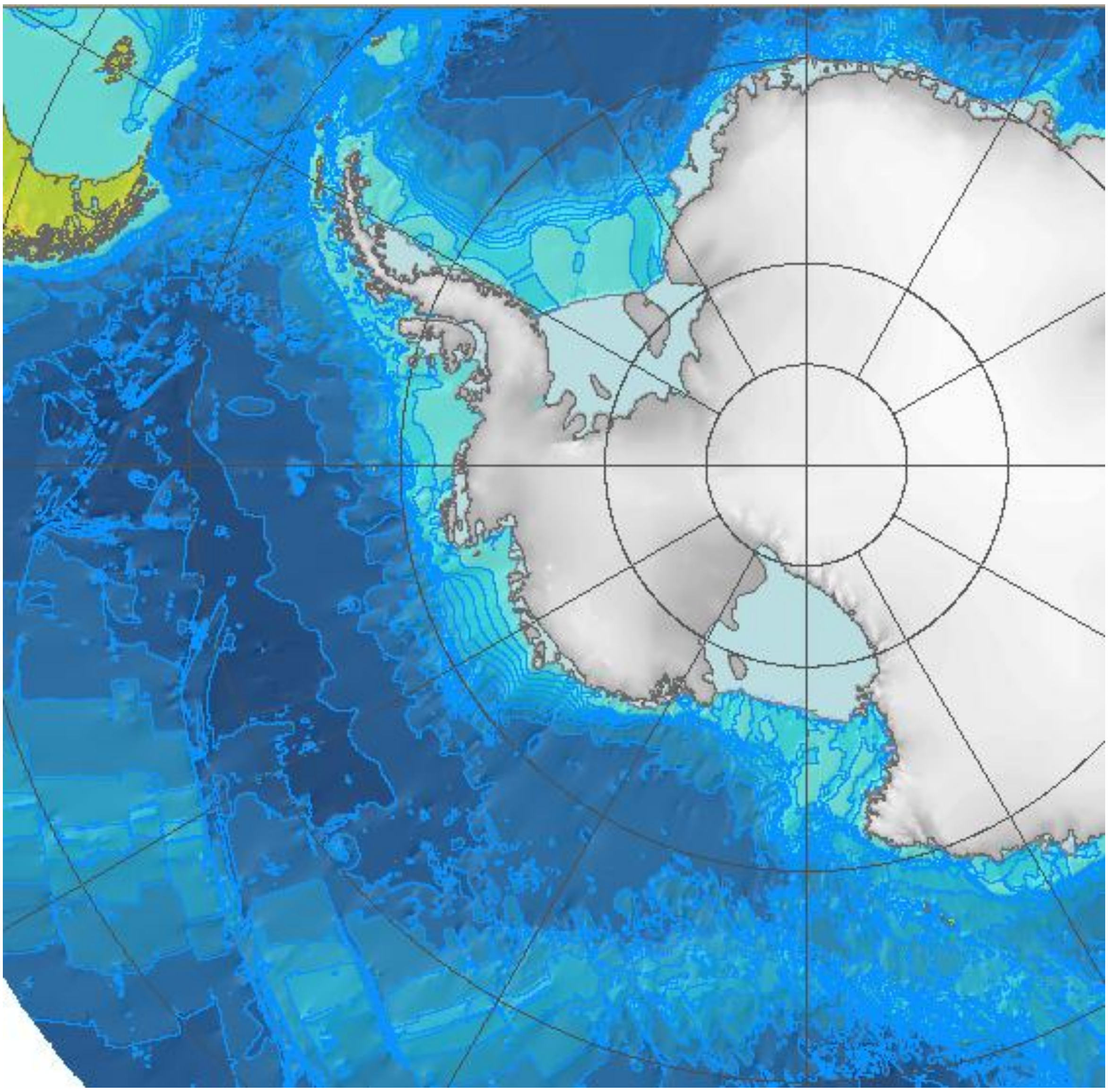

figure 32 Representation model: result of using the ESRI ArcGIS "Surface"-tool for creating isobaths in 500m-intervals with GEBCO dataset.

Unfortunately, the use of the "Hillshade"-tool does not improve the representation. The reason for this – again – lies in the quality of the data set and the technique the data has been produced with.[201]

Nevertheless, the analysis of the GEBCO dataset performed by ESRI ArcGIS provides a useable representation. This representation is suitable to support the visualization of the limits of the bodies of water in the Southern Ocean.

[201] See 5.3.2, p. 73.

5.6 Process Model – The Drainage System of the Southern Ocean

Process models describe the interaction of the objects being modeled in a representation model. The respective relationships are modeled by the use of spatial analysis tools. In this way, they describe process like flow directions or what a drainage system in a specific area looks like.

5.6.1 Using a DEM to model a Drainage System

A "drainage system" can be defined as an "area upon which water falls and the network trough which it travels to an outlet".[202] The focus of a model of the drainage system in a specific area is the movement of water across the surface. Important terms used to describe a drainage system are:[203]

1. **Basin:** A basin, drainage basin or watershed is an area that drains water to a common outlet.
2. **Pour point:** A pour point is the common outlet of a basin. It is the lowest point of a given basin.
3. **Watershed boundary:** The watershed boundary is the boundary between two adjacent basins.

[202] See http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Understanding_drainage_systems, last access 11.09.2010.
[203] See http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Understanding_drainage_systems, last access 11.09.2010.

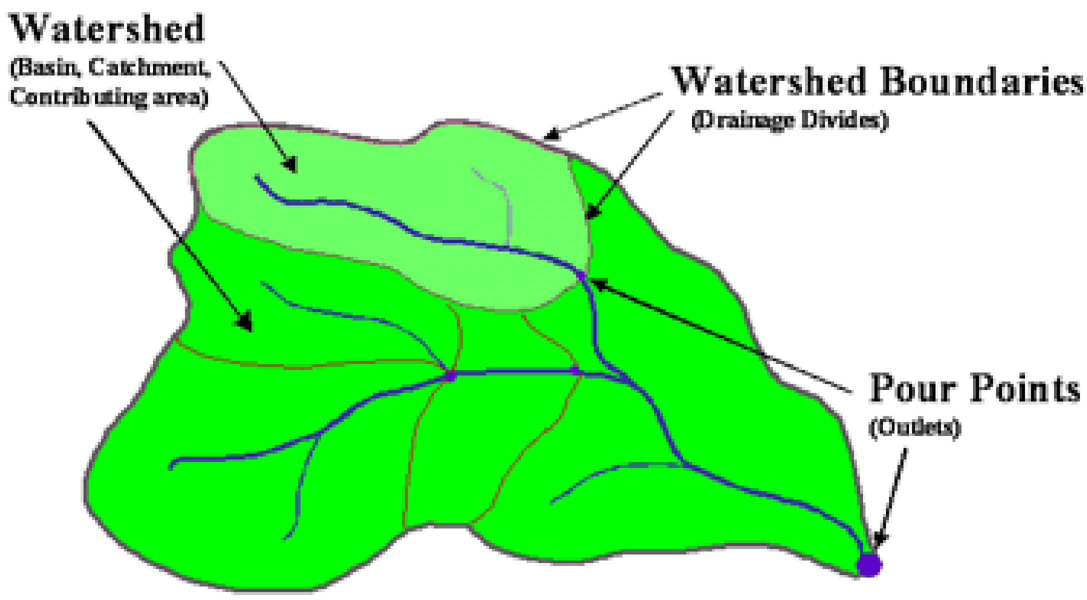

figure 33 *Schematic example of a drainage system.* [ESRI ArcGIS 9.2. Desktop Help, http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Understanding_drainage_systems, last access 11.09.2010]

Process models describing the movement of water are recently used in physical oceanography and hydrology. Computer models simulating the flow of water solve the hydrological equations at a network of points. These points are described as a set of fixed depths at each point of a horizontal grid. This setting and strategy is supported by the fact that the respective flows are dominantly horizontal. So the stratification of the model gains a computational simplification. The stratification of the different layers results in the need for the modelers to determine at what grid location or cell a given horizontal layer is connected or isolated. In terms of the topography of the seafloor this means which grid points are parts of a basin which is closed below a given layer depth and where there are troughs which allow deep water flow between basins.[204]

As pointed out above[205] the prerequisite for such a model is a DEM as a raster representation of a continuous surface.

Depending on the quality of data and the density of the grid the DEM will have more or less errors, which can be classified as sinks or peaks.

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[204] See User Guide to the GEBCO one Minute Grid, http://www.gebco.net/data_and_products/gridded_bathymetry_data/, p. 22, last access 10.09.2010.

[205] See 5.3.3, p. 76.

Sinks are areas surrounded by higher elevation values. Some of the sinks may be natural, but many of them can be regarded as imperfections in the DEM.
Peaks are areas surrounded by cells of lower value. These are often natural features. Additionally, they have a lesser effect on calculation of the flow direction.
Especially sinks should be removed or filled before creating process model.
Using the ESRI ArcGIS “Sink”-function requires a direction raster, which is created by the “Flow Direction”-function.

5.6.2 Creating a Direction Raster by using the “Flow Direction”-Tool

The “Flow Direction”-function creates a direction raster representing the flow direction from each cell to its steepest downslope neighbor.
Starting point of this process are the z-values of each cell representing their elevation. The z-value of each cell is compared with that if its eight neighboring cell. Depending on the direction of the steepest drop in elevation the cell is assigned a specific value.
The values for each direction from the center are:

32	64	128
16		1
8	4	2

figure 34 *Values for different directions from the center.* [ESRI ArcGIS 9.2. Desktop Help, http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Flow_Direction, last access 14.11.2010]

For example, if the direction of the steepest drop was to the left from the current processing cell, its flow direction would be coded as 16.

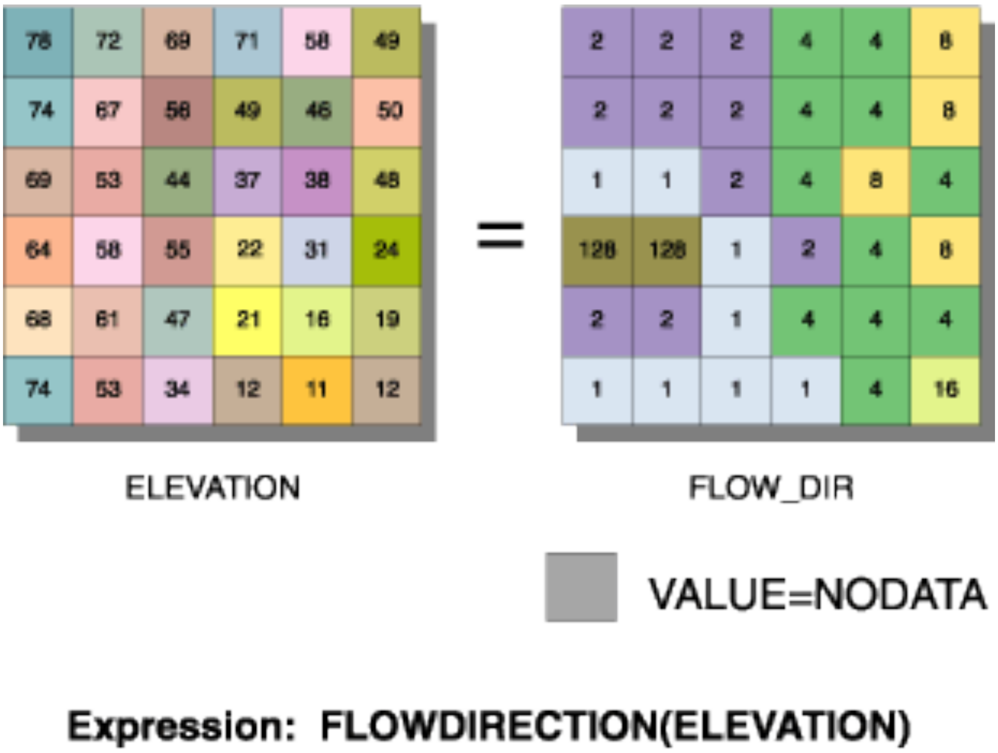

figure 35*Result from using flow direction tool on elevation model.* [ESRI ArcGIS 9.2. Desktop Help, http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Flow_Direction, last access 14.11.2010]

If a cell is lower than the eight adjacent cells, that cell is given the value of its lowest neighbor and flow is defined towards this cell. If multiple neighbors have the lowest value, the cell is still given this value, but its flow is defined either by using the most likely flow direction or by calculation the overall percentage of the slope in the watershed system[206]. In this way one-cell sinks, which are considered as noise are filtered out.

If a cell has the same change in z-value in more than one direction and the cell is part of a sink, the flow direction is undefined. Then the value for this cell in the output raster will be the sum of those directions. For example, the value of a cell will be 5, if the change in z-value is highest both to the downward cell (4) and the right cell (1). A cell with undefined flow direction can be flagged as sinks by using the “Sink”-function.

[206] The percent slope between the cells is calculated as the difference in z-value divided by the path length between the cell centers. See http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName=Flow_Direction, last access 14.11.2010.

If a cell has the same change in z-value in multiple directions and is not part of a sink, the flow direction is assigned with a lookup table, which defines the most likely direction.
The output of using the “Flow Direction”-tool is an integer direction raster whose values range from 1 to 255.
As pointed out above, using the “Fill”-tool on this direction raster can now eliminate little imperfections. The result is a more continuous DEM.
This DEM represented by the direction raster can be used to identify basins using the “Basin”-tool.

5.6.3 Modeling Basins to support the Fixing of Limits

The delineation of basins or watersheds can help to visualize the limits of bodies of water in the Southern Ocean, because the watershed boundaries as unambiguous features of the seafloor represent potential limits.

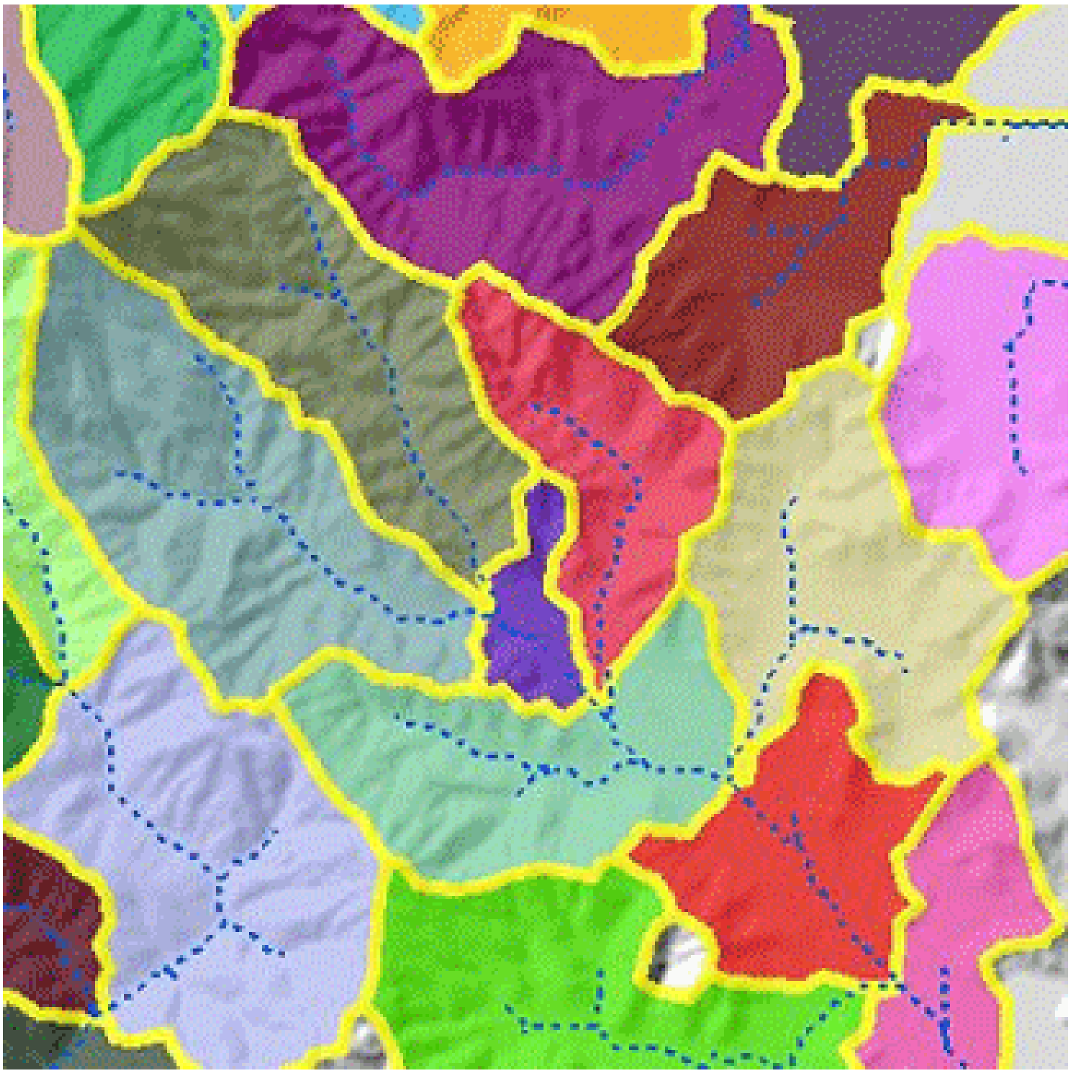

figure 36 Example of watershed boundaries as potential limits. [ESRI ArcGIS 9.2. Desktop Help, http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?TopicName==Delineating_watersheds, last access 11.09.2010]

Using the “Basin”-tool basins are identified using the direction raster performed by the “Flow Direction”-tool. The “Basin”-tool provides the opportunity to identify main basins and additional “subbasins”. These “subbasins” are part of a larger basin and stand hierarchically lower.

It is possible to identify up to 32 basins each representing a so-called “class”.

For the area of concern being very large, it is sufficient to choose the highest amount of basins. This is, because the more watershed boundaries to choose from the more potential limits for the bodies of water are available.

The result from the DEM created by the BEDELEV dataset using the ESRI ArcGIS-tools as described above is the following:

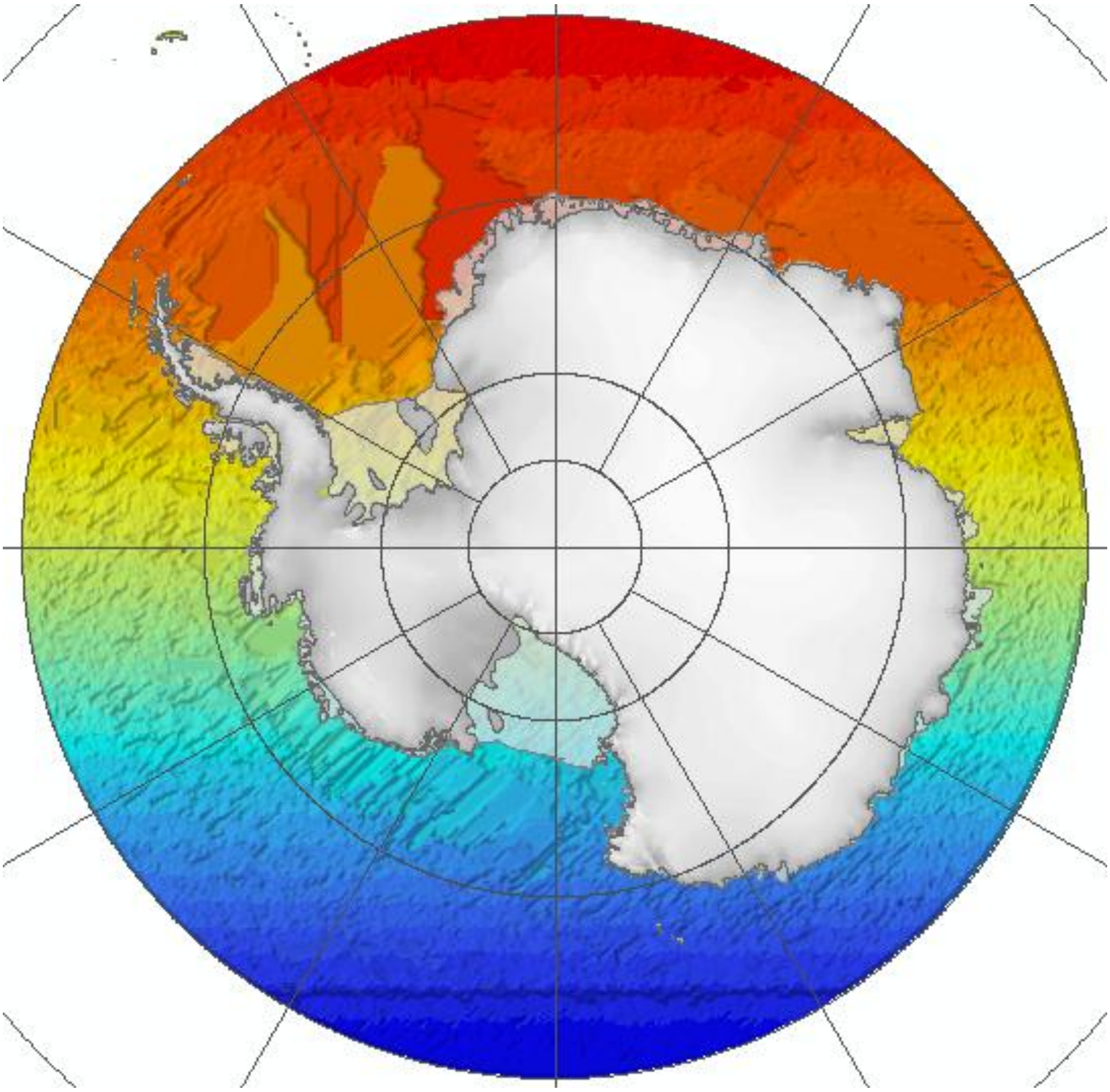

figure 37 *Process model: result of DEM by BEDELEV dataset representing 32 basins in the Southern Ocean.*

Figure 37 shows that the BEDELEV dataset only provides sufficient information about the flow directions and basins for the upper part, which is illustrated in orange and red color. In this area the Weddell Sea and adjacent bodies of water are located. The reason for the sufficiency of the bathymetric data in this area is the high amount of surveying and research missions there.

In contrast, in the blue area of *figure 37* it is impossible to discriminate different basins.

Thus, the process model provided by the BEDELEV dataset could support the drawing of limits in a very limited area – the orange-red one. But it is unsuitable for the drawing of limits in the whole Southern Ocean.

5.7 Representation Model or Process Model to support Visualization

Generally, both models theoretically could be suitable to support the visualization of bodies of water in the Southern Ocean.

However, the decision in favor of one model depends on more than just "taste".

The area of concern is no "terra incognita". This means that over years the relevant audience – the scientific community concerned with Antarctica – has named areas in a specific way. These names may not be politically binding, but in terms of usability they should not be radically changed. So, a Southern Ocean without an "Amundsen Sea" or a "Ross Sea" is hardly imaginable. The vanishing of long-used names could strongly disturb the communication inside the scientific community with one scientist still using the traditional name and others the new one. Furthermore, the decision against one name itself could become a political issue, because most of the bodies of water in the Southern Ocean are named after famous explorers of different countries and therefore contribute to their countries' pride.

This fact speaks against the use of basins for fixing the limits, because this method only makes sense, if the basin is used as a whole to identify a body of water.

So this method – as useful as it might be in smaller areas and areas with no historically grown names for several locations – has a huge disadvantage in comparison to the traditional method of using isobaths representing major features in the representation model.

Moreover, the process model does not provide enough differentiation concerning the drainage systems. The reason for this appears to be the inaccuracy and low density of the available bathymetric data. *Figure 37* shows that only in the Weddell Sea and the adjacent areas the bathymetric data is sufficient to create a significant process model.

For these two reasons – the Southern Ocean is no terra incognita and the process model is not providing significant drainage systems – the process model has to be discarded and the representation model is being used for the further procedure.

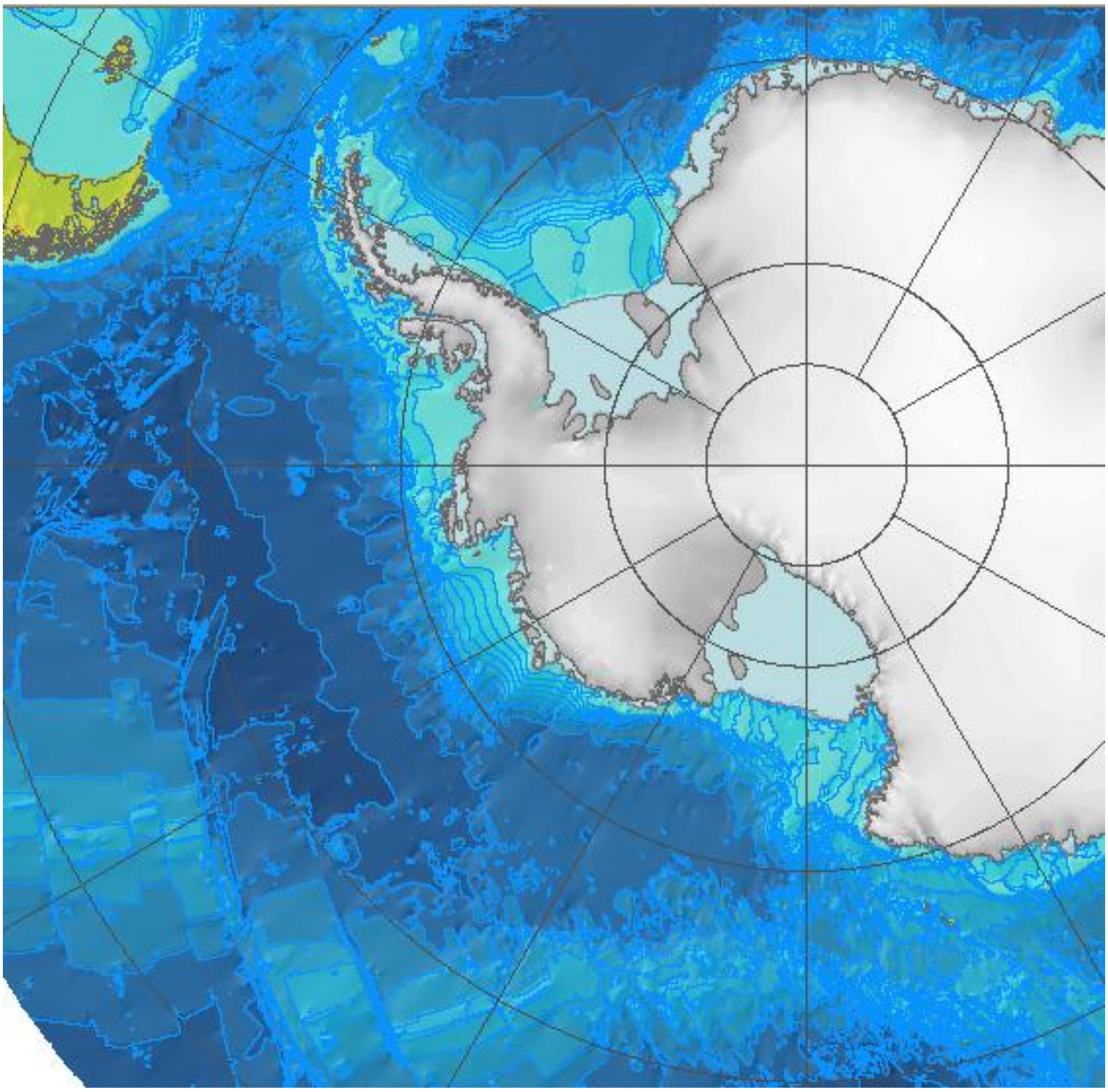

figure 38 Representation Model of the seafloor of Southern Ocean.

5.8 Drawing the Limits

As pointed out (chapter 5.4 Software Selection) ESRI ArcGIS will be used for both the analysis of the bathymetric data and the visualization of the limits. The reasons for this decision were the general suitability of this software to solve the scientific problem and interoperability and usability issues.

There are at least three potential possibilities to draw the limits.

The *first* is analog to the general procedure of digitizing bitmaps. Firstly, the bitmap – in this case the bathymetric map as shown in *figure 38* – is to be loaded.

In a second step the map has to be georeferenced. After this is accomplished, the limits could be semi-automatically digitized by using specific properties – in this case different isobaths, meridians, parallels or rhumb lines.
Unfortunately, this method does not work here. It is not possible to digitize the limits on a separate layer, because the GEBCO One Minute Grid dataset consists of vector data (see chapter 5.3.2). So this method has to be discarded although it could have lead to an accurate result.

The *second* possibility is to manually digitize the limits. To conduct this it would be necessary to visually identify suitable points that define the limits of the water bodies. These points could be put on a separate layer and be connected with each other. Apparently, this method would lead to an inaccurate visualization of the limits, which could have been conducted even without the creation of a model from the available GEBCO or BEDELEV datasets. Furthermore, to create an appealing result, it would be necessary to set a huge amount of single points. The most accurate visualization would result from points following the respective isobaths one besides the other. Due to the manual setting of the respective points the result itself would still be inaccurate. So this method is to be discarded in favor of a more accurate one. A possible out-come of this method is illustrated in *figure 39.*

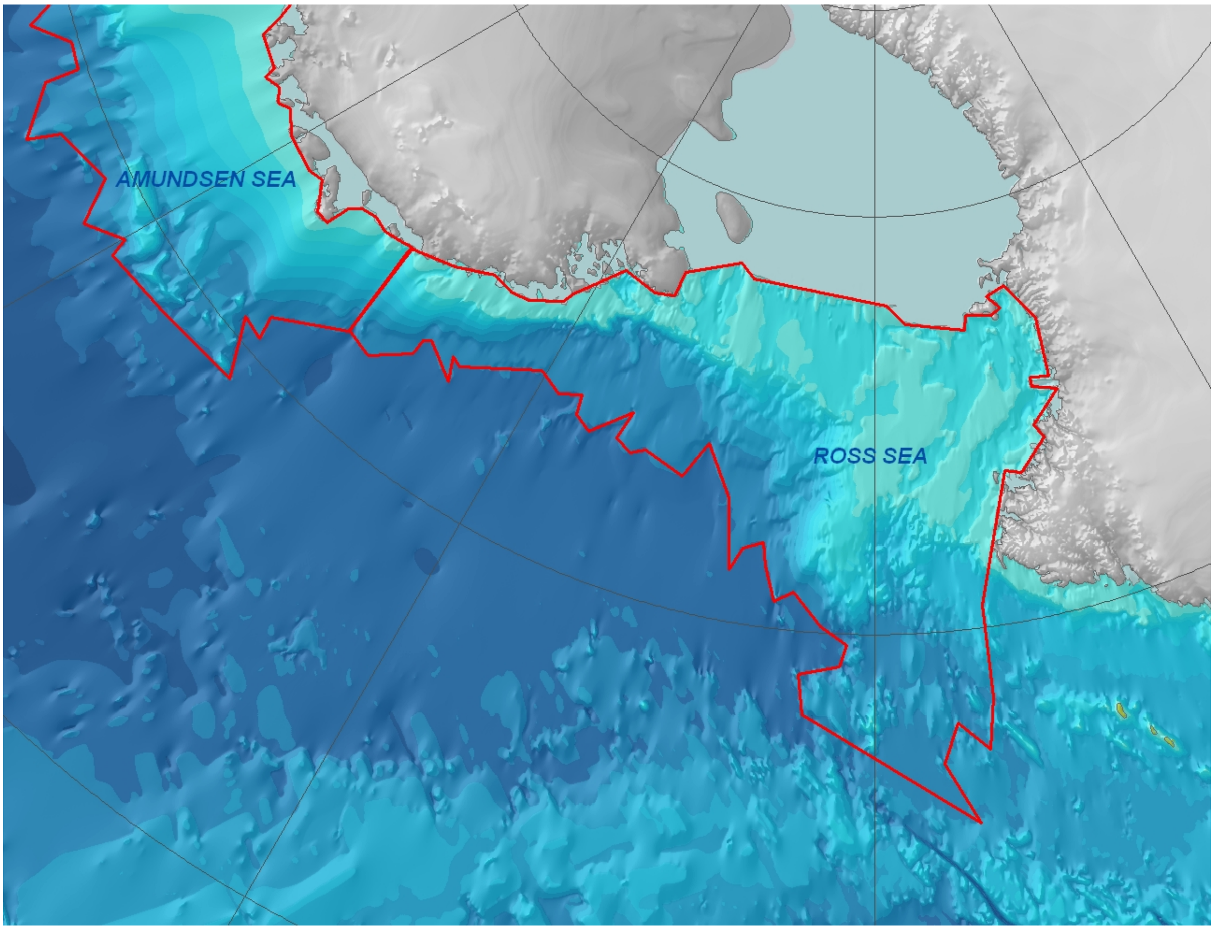

figure 39 *Detail screenshot of representation model of the seafloor of Southern Ocean with limits of the bodies of water visualized with red lines. The visualization has been conducted by manually setting points and by connecting them.*

The *third* method is to merge all available layers containing isobaths and information about the coastline into one layer. The continent of Antarctica is cut out, because it is irrelevant for the limits of the bodies of water.

The resulting layer contains all available isobaths of the representation model. Now the irrelevant isobaths are deleted. Where necessary the isobaths defining the water bodies are connected with rhumb lines, meridians or parallels. This method, although being time-consuming, is much more accurate than to manually digitize the limits. Moreover, it is the method, which extracts most information from the used representation model (*figure 40*).

Therefore, it is applied in this thesis.

To support the drawing of the limits in the Southern Ocean the following bathymetric maps are used.

- Antarctica, 1:10000000, Division of national Mapping, Commonwealth of Australia, 1986;
- AWI Bathymetric Chart of the Weddell Sea, Antarctica, 1:3000000 at 71° S, Alfred Wegener Institute for Polar and Marine Research, 1997;
- AWI Bathymetric Chart of the Weddell Sea, Antarctica, 1:1000000 at 76° S, Alfred Wegener Institute for Polar and Marine Research, 1996;
- Bathymetric Chart of Bransfield Strait, 1:500000, Institute of Cartography, University of Gdansk, 1991;
- Bathymetry of the Ross Dependency and adjacent Southern Ocean, 1:5000000, Institute of geological and nuclear Sciences limited, New Zealand, 2004;
- General Bathymetric Chart of the Oceans (GEBCO), No. 5.18, 1:6000000, Canadian Hydrographic Service, 1983;
- General Bathymetric Chart of the Oceans (GEBCO), No. 5.13, 1:10000000, Canadian Hydrographic Service, 1983;
- General Bathymetric Chart of the Oceans (GEBCO), World Ocean Bathymetry, 1:35000000, GEBCO World Map Cartographic Editorial Board, 2004.

The achieved limits of the Southern Ocean are saved as a separate layer in ESRI ArcGIS. The result be downloaded from http://homepage.mac.com/WebObjects/FileSharing.woa/wo/eBkbRhNSOwx12VwY.1/0.2.1.2.26.31.97.4.35.0.1.1.1?user=lia77&fpath=Uni&templatefn=FileSharing2.html [207].

[207] In case your browser does not support this link, please click https://public.me.com/lia77/de/ and select folder "Uni".

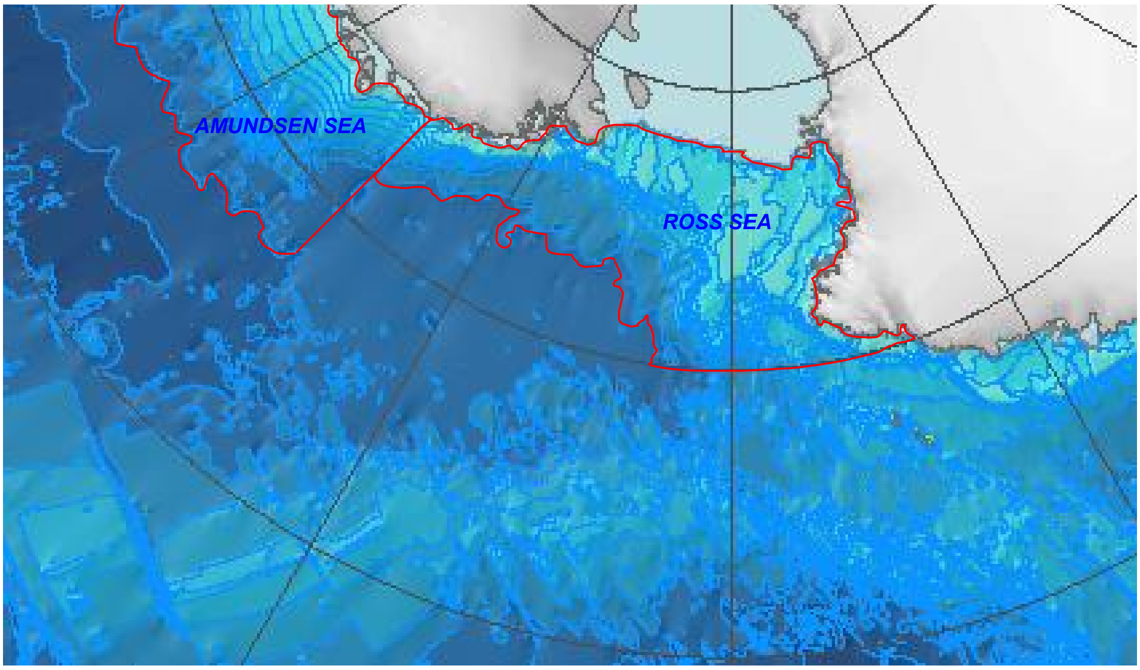

figure 40 *Detail screenshot of representation model of the seafloor of Southern Ocean with limits of the bodies of water visualized with red lines.*

5.9 Discussion and Prospects

The decision to visualize the limits of the bodies of water with red lines is discussed extensively in chapter 4.2.2. It is directly deduced from the scientific, map-user centered approach, which has been developed for this thesis. As can be seen in *figure 40*, it leads to a suitable visualization of the suggested limits in the Southern Ocean.

The realization and the quality of the visualization – meaning its accuracy – itself depends on two things.

The *first* is the quality of the model used to support the drawing of the limits, which is dictated by the quality of the used dataset.

The *second* is the usability of the used software.

As discussed in the chapters 5.3 and 5.7 the two possible models – the representation model and the process model – suffer from the quality of the respective datasets used to design them.

Although potentially useful, innovative and appealing on the first sight the process model representing flow directions and basins in the Southern Ocean had to be discarded, because of its insignificance in wide areas and, therefore, its inability to support the visualization of the limits in the whole area of concern. Moreover, it was discussed (see chapter 5.7) that this model, even if it had been based on a more sufficient dataset, would have had to be ruled out, because the Southern Ocean cannot be seen as "terra incognita". The potential need to delete some existing names for specific areas could have lead to irritations.

Thus, the more conventional representation model has been selected. Although it was suitable to support the visualization of the limits of the water bodies in the whole Southern Ocean, the used data format – i.e. vector data –, made it impossible to semi-automatically digitize the limits.

So it was necessary to use a more complicated way to define the limits, which was more time-consuming. Moreover, it was not possible to use the full spectrum of utilities of the selected software.

The visualization of the limits can be evaluated as sufficient. The red lines, which represent the limits, can be segregated from the blue ground very well (see chapter 4.2.2). The definition of the limits could be improved by enhancing the quality of the models, which support the identification of unambiguous undersea features and thus help to define the bodies of water – either by simply representing them or by deducing processes caused by these features in for example drainage systems.

So the quality of the bathymetric data is of huge importance in this context. If the objectives of the IBCSO-project are to create a significant GIS and to achieve a suitable model of the Southern Ocean and its topography, the endeavors of compiling sufficient bathymetric data is of paramount importance.

To create more useful models there are several demands for the consistence and quality of the datasets strived for. It has turned out in the course of this thesis that creating useful models with the help of analysis software like ESRI ArcGIS requires datasets with specific properties.

First of all, the data format, which is best suited for analysis software, is gridded data.

The ideal grid should be a faithful and reliable representation of the depth in the ocean or in other words of the topography of the seafloor. Such a grid would help to create helpful representation and/or process models.

A grid with such a potential should be continuous with no gaps on land or on the seafloor and should have no points of discontinuity.

Furthermore, a grid designed in this fashion would enable analysis tools to calculate first derivatives. As pointed out in chapter 5.3.2 these first derivatives are the prerequisite for visualization techniques like “shading” in the case of representation models or for the calculation of process models like drainage systems.

Interrelated with the last two points is the demand that a suitable grid should be free of statistical anomalies and other biases like terraces or discontinuities.

To create such a grid would need much more efforts in collecting and compiling bathymetric data and therefore a higher amount of surveying missions.

In recent years there has been a large increase in polar research in connection with researches on the climate change. So it can be hoped for an increase in quality and density of available bathymetric data.

Nevertheless, for this thesis the quality of the available data was satisfactory. As pointed out earlier the selected software would have provided more applications, if the datasets had met the some of the demands on an ideal grid.

Not meeting these demands leads to the consequence that the mode of visualizing the limits was conventional using a representation model. Moreover, it was very time-consuming compared to semi-automatically digitizing the limits.

However, the result itself appears to be suitable and useable for SOGIS.

6 Table of figures

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